CHAPTER 103E

DRAINAGE

GENERAL PROVISIONS

103E.005 DEFINITIONS.

Subdivision 1. **Applicability.** The definitions in this section apply to this chapter.

Subd. 2. **Affected.** "Affected" means benefited or damaged by a drainage system or project.

Subd. 3. **Auditor.** "Auditor" means the auditor of the county where the petition for a drainage project was properly filed.

Subd. 4. **Board.** "Board" means the board of commissioners of the county, a joint county board, the board of managers of the watershed district, or a metropolitan watershed management organization that serves as the drainage authority where the drainage system or project is located.

Subd. 5. **Commissioner.** "Commissioner" means the commissioner of natural resources.

Subd. 6. **Director.** "Director" means the director of the Division of Ecological and Water Resources in the Department of Natural Resources.

Subd. 7. **Dismissal of proceedings.** "Dismissal of proceedings" means that the petition and proceedings related to the petition are dismissed.

Subd. 8. **Ditch.** "Ditch" means an open channel to conduct the flow of water.

Subd. 9. **Drainage authority.** "Drainage authority" means the board or joint county drainage authority having jurisdiction over a drainage system or project.

Subd. 10. **Drainage lien.** "Drainage lien" means a lien recorded on property for the costs of drainage proceedings and construction and interest on the lien, as provided under this chapter.

Subd. 11. **Drainage project.** "Drainage project" means a new drainage system, an improvement of a drainage system, an improvement of an outlet, or a lateral.

Subd. 12. **Drainage system.** "Drainage system" means a system of ditch or tile, or both, to drain property, including laterals, improvements, and improvements of outlets, established and constructed by a drainage authority. "Drainage system" includes the improvement of a natural waterway used in the construction of a drainage system and any part of a flood control plan proposed by the United States or its agencies in the drainage system.

Subd. 13. **Engineer.** "Engineer" means the engineer for a drainage project appointed by the drainage authority under section 103E.241, subdivision 1.

Subd. 14. **Established.** "Established" means the drainage authority has made the order to construct the drainage project.

Subd. 15. **Lateral.** "Lateral" means any drainage construction by branch or extension, or a system of branches and extensions, or a drain that connects or provides an outlet to property with an established drainage system.

Subd. 16. **Municipality.** "Municipality" means a statutory or home rule charter city or a town having urban powers under section 368.01, subdivision 1 or 1a. For purposes of sections 103E.315, 103E.611, and 103E.615, municipality includes a water management authority to which a portion of a drainage system is transferred under section 103E.812.

Subd. 17. **Notice by mail.** "Notice by mail" means a notice mailed and addressed to each person entitled to receive the notice, if the address is known to the auditor or can be determined by the county treasurer of the county where the affected property is located.

Subd. 18. **Owner.** "Owner" means an owner of property or a buyer of property under a contract for deed.

Subd. 19. **Passes over.** "Passes over" means in reference to property that has a drainage project or system, the 40-acre tracts or government lots or property that is bordered by, touched by, or underneath the path of the proposed drainage project.

Subd. 20. **Person.** "Person" means an individual, firm, partnership, association, or private corporation.

Subd. 21. **Political subdivisions.** "Political subdivisions" means statutory and home rule charter cities, counties, towns, school districts, and other political subdivisions.

Subd. 22. **Proceeding.** "Proceeding" means a procedure under this chapter for or related to drainage that begins with filing a petition and ends by dismissal or establishment of a drainage project.

Subd. 23. **Property.** "Property" means real property.

Subd. 24. **Publication.** "Publication" means a notice published at least once a week for three successive weeks in a legal newspaper in general circulation in each county affected by the notice.

Subd. 25. **Public health.** "Public health" includes an act or thing that tends to improve the general sanitary condition of the community by drainage, relieving low wetland or stagnant and unhealthful conditions, or preventing the overflow of any property that produces or tends to produce unhealthful conditions.

Subd. 26. **Public waters.** "Public waters" has the meaning given in section 103G.005, subdivision 15.

Subd. 27. **Public welfare or public benefit.** "Public welfare" or "public benefit" includes an act or thing that tends to improve or benefit the general public, either as a whole or as to any particular community or part, including works contemplated by this chapter, that drain or protect roads from overflow, protect property from overflow, or reclaim and render property suitable for cultivation that is normally wet and needing drainage or subject to overflow.

Subd. 28. **Road.** "Road" means any road used by the public for transportation purposes.

Subd. 28a. **Secretary.** "Secretary" means the secretary of the watershed district that serves as the drainage authority for the applicable drainage system.

Subd. 29. **Water management authority.** "Water management authority" means a county or municipality, watershed district, watershed management organization, storm water management district, lake improvement district, subordinate service district, joint powers organization or other special district organized and formed according to law for the purpose of managing storm, surface, and flood waters, or with the authority to manage storm, surface, and flood waters.

History: *1990 c 391 art 5 s 1; 2002 c 327 s 1,2; 2013 c 4 s 1-3*

103E.011 DRAINAGE AUTHORITY POWERS.

Subdivision 1. **Generally.** The drainage authority may make orders to:

(1) construct and maintain drainage systems;

(2) deepen, widen, straighten, or change the channel or bed of a natural waterway that is part of the drainage system or is located at the outlet of a drainage system;

(3) extend a drainage system into or through a municipality for a suitable outlet; and

(4) construct necessary dikes, dams, and control structures and power appliances, pumps, and pumping machinery as provided by law.

Subd. 2. **Drainage of water basins and watercourses.** A drainage authority may not drain a water body or begin work or activity regulated by the public waters work permit requirement under section 103G.245 in a watercourse until the commissioner determines that the water body or watercourse is not public waters. If a water body or watercourse is determined to be public waters, the drainage proceedings are subject to section 103G.215 relating to replacing public waters and the water bank program.

Subd. 3. **Permission of commissioner for work in public waters; application.** (a) The drainage authority must receive permission from the commissioner to:

(1) remove, construct, or alter a dam affecting public waters;

(2) establish, raise, or lower the level of public waters; or

(3) drain any portion of a public water.

(b) The petitioners for a proposed drainage project or the drainage authority may apply to the commissioner for permission to do work in public waters or for the determination of public waters status of a water body or watercourse.

Subd. 4. **Flood control.** The drainage authority may construct necessary dams, structures, and improvements and maintain them to impound and release flood water to prevent damage. The dams, structures, and improvements may be constructed with or without a drainage project. For a water body or watercourse that is not public waters the drainage authority may:

(1) lower or establish the level of water in the water body or watercourse to control flood waters;

(2) build structures and improvements to maintain a water body or watercourse for flood control or other public purposes; and

(3) construct dikes or dams in a water body to maintain water at the level designated by the drainage authority and to drain part of the water body.

Subd. 5. **Use of external sources of funding.** Notwithstanding other provisions of this chapter, a drainage authority may accept and use funds from sources other than, or in addition to, those derived from assessments based on the benefits of the drainage system for the purposes of wetland preservation or restoration or creation of water quality improvements or flood control. The sources of funding authorized under this subdivision may also be used outside the benefited area but must be within the watershed of the drainage system.

History: *1990 c 391 art 5 s 2; 2000 c 488 art 3 s 27*

103E.015 CONSIDERATIONS BEFORE DRAINAGE WORK IS DONE.

Subdivision 1. **Environmental, land use, and multipurpose water management criteria.** Before establishing a drainage project, the drainage authority must consider each of the following criteria:

(1) private and public benefits and costs of the proposed drainage project;

(2) alternative measures, including measures identified in applicable state-approved and locally adopted water management plans, to:

(i) conserve, allocate, and use drainage waters for agriculture, stream flow augmentation, or other beneficial uses;

(ii) reduce downstream peak flows and flooding;

(iii) provide adequate drainage system capacity;

(iv) reduce erosion and sedimentation; and

(v) protect or improve water quality;

(3) the present and anticipated land use within the drainage project or system, including compatibility of the project with local land use plans;

(4) current and potential flooding characteristics of property in the drainage project or system and downstream for 5-, 10-, 25-, and 50-year flood events, including adequacy of the outlet for the drainage project;

(5) the effects of the proposed drainage project on wetlands;

(6) the effects of the proposed drainage project on water quality;

(7) the effects of the proposed drainage project on fish and wildlife resources;

(8) the effects of the proposed drainage project on shallow groundwater availability, distribution, and use; and

(9) the overall environmental impact of all the above criteria.

Subd. 1a. **Investigating potential use of external sources of funding and technical assistance.** When planning a drainage project or a repair under section 103E.715, and prior to making an order on the engineer's preliminary survey report for a drainage project or the engineer's report for a repair, the drainage authority shall investigate the potential use of external sources of funding to facilitate the purposes indicated in section 103E.011, subdivision 5, and alternative measures in subdivision 1, clause (2). This investigation shall include early coordination with applicable soil and water conservation district and county and watershed district water planning authorities about potential external sources of funding and technical assistance for these purposes and alternative measures. The drainage authority may request additional information about potential funding or technical assistance for these purposes and alternative measures from the executive director of the Board of Water and Soil Resources.

Subd. 2. **Determining public utility, benefit, or welfare.** In any proceeding to establish a drainage project, or in the construction or repair of or other work affecting a public drainage system under any law, the drainage authority or other authority having jurisdiction over the proceeding must give proper consideration to conservation of soil, water, wetlands, forests, wild animals, and related natural resources, and to other public interests affected, together with other material matters as provided by law in determining whether the project will be of public utility, benefit, or welfare.

History: *1990 c 391 art 5 s 3; 2014 c 164 s 1-3*

103E.021 DITCHES MUST BE PLANTED WITH PERENNIAL VEGETATION.

Subdivision 1. **Spoil banks must be spread and permanent vegetation established.** In any proceeding to establish, construct, improve, or do any work affecting a public drainage system under any law that appoints viewers to assess benefits and damages, the authority having jurisdiction over the proceeding shall order spoil banks to be spread consistent with the plan and function of the drainage system. The authority shall order that permanent grass, other than a noxious weed, be planted on the ditch side slopes and that a permanent strip of perennial vegetation approved by the drainage authority be established on each side of the ditch. Preference should be given to planting native species of a local ecotype. The approved perennial vegetation shall not impede future maintenance of the ditch. The permanent strips of perennial vegetation shall be 16-1/2 feet in width measured outward from the top edge of the constructed channel resulting from the proceeding, or to the crown of the leveled spoil bank, whichever is the greater, except for an action by a drainage authority that results only in a redetermination of benefits and damages, for which the required width shall be 16-1/2 feet. Drainage system rights-of-way for the acreage and additional property required for the permanent strips must be acquired by the authority having jurisdiction.

Subd. 2. **Reseeding and harvesting perennial vegetation.** The authority having jurisdiction over the repair and maintenance of the drainage system shall supervise all necessary reseeding. The permanent strips of perennial vegetation must be maintained in the same manner as other drainage system repairs. Harvest of the vegetation from the permanent strip in a manner not harmful to the vegetation or the drainage system is the privilege of the fee owner or assigns. The drainage inspector shall establish rules for the fee owner and assigns to harvest the vegetation.

Subd. 3. **Agricultural practices prohibited.** Agricultural practices, other than those required for the maintenance of a permanent growth of perennial vegetation, are not permitted on any portion of the property acquired for perennial vegetation.

Subd. 4. **Compliance work by drainage authority.** If a property owner does not bring an area into compliance with this section as provided in the compliance notice, the inspection committee or drainage inspector must notify the drainage authority. If a property owner does not bring an area into compliance after being notified under section 103E.705, subdivision 2, the drainage authority must issue an order to have the work performed to bring the property into compliance. After the work is completed, the drainage authority must send a statement of the expenses incurred to bring the property into compliance to the auditor of the county where the property is located and to the property owner.

Subd. 5. **Collection of compliance expenses.** (a) The amount of the expenses to bring an area into compliance with this section is a lien in favor of the drainage authority against the property where the expenses were incurred. The auditor must certify the expenses and enter the amount in the same manner as other drainage liens on the tax list for the following year. The amount must be collected in the same manner as real estate taxes for the property. The provisions of law relating to the collection of real estate taxes shall be used to enforce payment of amounts due under this section. The auditor must include a notice of collection of compliance expenses with the tax statement.

(b) The amounts collected under this subdivision must be deposited in the drainage system account.

Subd. 6. **Incremental implementation of vegetated ditch buffer strips and side inlet controls.** (a) Notwithstanding other provisions of this chapter requiring appointment of viewers and redetermination of benefits and damages, a drainage authority may implement permanent buffer strips of perennial vegetation approved by the drainage authority or side inlet controls, or both, adjacent to a public drainage ditch, where necessary to control erosion and sedimentation, improve water quality, or maintain the efficiency of the drainage system. Preference should be given to planting native species of a local ecotype. The approved perennial vegetation shall not impede future maintenance of the ditch. The permanent strips of perennial vegetation shall be 16-1/2 feet in width measured outward from the top edge of the existing constructed channel. Drainage system rights-of-way for the acreage and additional property required for the permanent strips must be acquired by the authority having jurisdiction.

(b) A project under this subdivision shall be implemented as a repair according to section 103E.705, except that the drainage authority may appoint an engineer to examine the drainage system and prepare an engineer's repair report for the project.

(c) Damages shall be determined by the drainage authority, or viewers, appointed by the drainage authority, according to section 103E.315, subdivision 8. A damages statement shall be prepared, including an explanation of how the damages were determined for each property affected by the project, and filed with the auditor or watershed district. Within 30 days after the damages statement is filed, the auditor or watershed district shall prepare property owners' reports according to section 103E.323, subdivision 1, clauses (1), (2), (6), (7), and (8), and mail a copy of the property owner's report and damages statement to each owner of property affected by the proposed project.

(d) After a damages statement is filed, the drainage authority shall set a time, by order, not more than 30 days after the date of the order, for a hearing on the project. At least ten days before the hearing, the auditor or watershed district shall give notice by mail of the time and location of the hearing to the owners of property and political subdivisions likely to be affected by the project.

(e) The drainage authority shall make findings and order the repairs to be made if the drainage authority determines from the evidence presented at the hearing and by the viewers and engineer, if appointed, that the repairs are necessary for the drainage system and the costs of the repairs are within the limitations of section 103E.705.

History: *1990 c 391 art 5 s 4; 2007 c 57 art 1 s 107-110*

103E.025 PROCEDURE FOR DRAINAGE PROJECT THAT AFFECTS STATE LAND OR WATER AREA USED FOR CONSERVATION.

Subdivision 1. **Applicability.** If a land or water area owned by the state and held or used to protect or propagate wild animals, provide hunting or fishing for the public, or for any other purpose relating to the conservation, development, or use of soil, water, forests, wild animals, or related natural resources will be affected by any public project or proceeding for drainage under any law, all procedures relating to the project or proceeding are subject to this section, if applicable.

Subd. 2. **Conditions to take or damage state land and water areas.** (a) Any part of the state land or water area may be taken or damaged for a public project after payment of just compensation as provided by law and under the provisions of this subdivision.

(b) The authority having jurisdiction of the drainage project or proceeding shall first find and determine that there is public necessity for the taking or damage that is greater than the public interest in the purposes for which the affected land and water areas are held or used by the state.

(c) In determining the compensation to be paid for the taking or damage, the authority must give proper consideration to the value of the land and water area for the purposes it is held or used by the state and other material elements of value.

(d) Public waters may not be taken, damaged, or impaired except as otherwise expressly authorized by law, and a provision of any other law for the protection or conservation of public waters may not be abridged or superseded by this subdivision.

Subd. 3. **Considerations in determining benefits.** In determining benefits to the state land or water area in any proceeding to levy assessments or offset benefits against damages, proper consideration must be given to the value of the area for the purpose it is held or used by the state, with other material elements of value.

Subd. 4. **Amounts paid to state.** Any amounts paid to the state for taking or damaging the state land or water area in a proceeding must be credited to the proper account for acquisition, development, or maintenance of the areas, and the amount is appropriated to the commissioner for those purposes to remain available until expended.

Subd. 5. **Money to pay assessments.** Assessments for benefits made against the state land or water area in a proceeding must be paid out of money appropriated and available to pay assessments as provided by law.

History: *1990 c 391 art 5 s 5*

103E.031 CONNECTION WITH DRAINS IN ADJOINING STATES.

Subdivision 1. **Procedure.** If it is necessary to construct a drainage project at or near the boundary between this state and another state or country and the work cannot be done in a proper manner without extending the drainage project into the adjoining state or country, the drainage authority may join with the board or tribunal of the adjoining state or country having jurisdiction to plan and construct public drainage systems. The drainage authority in this state may enter into contracts or arrangements with the board or tribunal of the adjoining state or country to construct the drainage project. The proceeding and construction related to property in this state and, as applicable, the drainage authority in relation to the joint drainage work, are governed by this chapter.

Subd. 2. **Payment of costs.** The adjoining county or district in another state or country must pay its proper share of the necessary costs of the construction of any drainage work including damages. If the benefits to property in the adjoining state or country are not sufficient to pay all the costs of construction of the drainage project in that state or country, including damages, the drainage authority may authorize or direct the affected counties to contribute sufficient funds to complete the construction of the drainage project in the adjoining state or country, if the construction will be of sufficient benefit to the affected property in this state to warrant the contribution.

History: *1990 c 391 art 5 s 6*

103E.035 DEFECTIVE NOTICE.

If notice is required under this chapter and proper notice has been given to some parties but the notice is defective or not given to other parties, the drainage authority has jurisdiction of all parties that received proper notice. The proceedings may be continued by order of the drainage authority for the time necessary to publish, post, or mail a new notice. The new notice needs only be given to those not properly notified by the first notice.

History: *1990 c 391 art 5 s 7*

103E.041 PERSONAL SERVICE IN LIEU OF OTHER METHODS OF NOTICE.

If notice is to be given under this chapter, personal service at least ten days before the date of hearing may be given in lieu of the manner provided. The notice must be served in the manner provided for the service of summons in a civil action in district court.

History: *1990 c 391 art 5 s 8*

103E.043 INFORMAL MEETINGS.

A drainage authority may hold informal meetings in addition to the meetings and hearings required in this chapter to inform persons affected by the drainage system about the drainage proceedings and provide a forum for informal discussions.

History: *1990 c 391 art 5 s 9*

103E.045 FAILURE OF DRAINAGE AUTHORITY TO ATTEND HEARINGS.

If an order has been made and notice for a hearing given under this chapter, and the drainage authority does not appear at the time and place specified for any reason, the auditor shall continue the hearing to a date set by the auditor. The auditor shall notify the drainage authority of the continuance and the date of hearing. The jurisdiction is continued until the date set by the auditor.

History: *1990 c 391 art 5 s 10*

103E.051 DEFECTIVE PROCEEDINGS.

(a) A party may not take advantage of an error in a drainage proceeding or an informality, error, or defect appearing in the record of the proceeding or construction, unless the party complaining is directly affected. The modification of the benefits or damages to any property, or the enjoining of collection of any assessment, does not affect any other property or the collection of any assessment on other property.

(b) If a drainage project has been established and a contract awarded in good faith, without collusion, and at a reasonable price:

(1) a defect or lack of notice in awarding, making, or executing the contract does not affect the enforcement of an assessment; and

(2) if the contract is performed in good faith in whole or in part, a defect does not invalidate the contract.

History: *1990 c 391 art 5 s 11*

103E.055 REIMBURSEMENT OF COST OF FORMER SURVEYS WHEN USED LATER.

If after a proceeding has begun a survey has been made and a proceeding to establish a drainage project has been dismissed or the drainage project has not been established, and if all or a part of the former survey is used by the engineer for a drainage proceeding in the same area, the amount saved in the subsequent proceedings must be paid to the proper parties according to this section. If the parties who paid the expense of the former survey make a petition, the drainage authority shall:

(1) determine the amount of benefit that was derived by the subsequent proceedings from the former survey;

(2) order the amount of the benefit to be paid to the proper parties; and

(3) charge the amount paid as a cost of the subsequent drainage proceeding.

History: *1990 c 391 art 5 s 12*

103E.061 RIGHT OF ENTRY.

In proceedings under this chapter, the engineer, the engineer's assistants, the viewers, and the viewers' assistants may enter any property to make a survey, locate a drain, examine the property, or estimate the benefits and damages.

History: *1990 c 391 art 5 s 13*

103E.065 DRAINAGE INSPECTORS.

In counties or watershed districts having drainage systems constructed in accordance with this chapter, the drainage authority shall appoint a competent person as drainage inspector. The inspector must not be a county commissioner. The inspector may be the county highway engineer. The inspector shall examine the drainage systems designated by the drainage authority. The drainage authority shall specify the appointment period and compensation.

History: *1990 c 391 art 5 s 14; 2010 c 298 s 2; 2014 c 289 s 50*

103E.067 DITCH BUFFER STRIP ANNUAL REPORTING.

The drainage authority shall annually submit a report to the Board of Water and Soil Resources for the calendar year including:

(1) the number and types of actions for which viewers were appointed;

(2) the number of miles of buffer strips established according to section 103E.021;

(3) the number of drainage system inspections conducted; and

(4) the number of violations of section 103E.021 identified and enforcement actions taken.

History: *2007 c 57 art 1 s 111*

103E.071 COUNTY ATTORNEY.

The county attorney shall represent the county in all drainage proceedings and related matters without special compensation. A county attorney, the county attorney's assistant, or any attorney associated with the county attorney in business, may not otherwise appear in any drainage proceeding for any interested person.

History: *1990 c 391 art 5 s 15*

103E.075 OBSTRUCTION OF DRAINAGE SYSTEM.

Subdivision 1. **Notification to responsible party.** If the board determines that a drainage system has been obstructed, including by the installation of bridges or culverts of insufficient hydraulic capacity, the board shall notify the person or public authority responsible for the obstruction as soon as possible and direct the responsible party to remove the obstruction or show the board why the obstruction should not be removed. The board must set a time and location in the notice for the responsible person to appear before the board.

Subd. 2. **Obstruction on private property.** If the obstruction is on private property, the owner is responsible for the obstruction unless the owner proves otherwise. The owner must be notified by certified mail at least ten days before the hearing.

Subd. 3. **Obstruction hearing.** The board shall hear all interested parties and if the board determines that the drainage system has been obstructed by a person or public authority, the board shall order the obstruction removed by the responsible party within a reasonable time set in the order. If the obstruction is not removed by the prescribed time, the board shall have the obstruction removed and the auditor shall make a statement of the removal cost. The statement must be filed in the county recorder's office as a lien on the property where the obstruction is located or against the responsible party. The lien must be enforced and collected as liens for drainage repairs under this chapter, except that a lien may not be filed against private property if the board determines that the owner of the property is not responsible for the obstruction. The lien may be enforced against the responsible party by civil action.

History: *1990 c 391 art 5 s 16*

103E.081 CRIMES RELATED TO DRAINAGE SYSTEMS; PENALTIES.

Subdivision 1. **Unauthorized drain outletting into drainage system.** A person may not cause or construct a drain that outlets into a lawfully constructed drainage system except as provided in this chapter.

Subd. 2. **Obstruction or damage of a drainage system.** A person may not willfully obstruct or damage a drainage project or system.

Subd. 2a. **Planting trees over public tile.** A person must not knowingly plant trees over a public drain tile, unless the person planting the trees receives permission from the drainage authority.

Subd. 2b. **Planting trees over private tile.** A person must not knowingly plant trees over a private drain tile that provides for the drainage of land owned or leased by another person, unless the person planting the trees receives permission from all persons who receive drainage benefits from the drain tile.

Subd. 3. **Altering engineer's marking of stakes.** A person may not willfully change the location or alter markings of stakes set by the engineer in a drainage project or system.

Subd. 4. **Penalty.** Violation of this section is a misdemeanor.

History: *1990 c 391 art 5 s 17; 1Sp2005 c 1 art 2 s 117,118*

103E.085 ENFORCEMENT.

Subdivision 1. **Warrants and arrests.** An enforcement officer, as defined in section 97A.015, subdivision 18, may execute and serve warrants, and arrest persons detected in actual violation of sections 103E.005 to 103E.811 as provided in sections 97A.205 and 97A.211.

Subd. 2. **Prosecution.** The county attorney shall prosecute all criminal actions arising under this chapter.

History: *1990 c 391 art 5 s 18*

103E.091 APPEALS.

Subdivision 1. **Grounds for appeal.** A party may appeal to the district court from a recorded order of a drainage authority made in a drainage proceeding that determines:

(1) the amount of benefits;

(2) the amount of damages;

(3) fees or expenses allowed; or

(4) whether the environmental, land use, and multipurpose water management requirements and criteria of section 103E.015, subdivision 1, are met.

Subd. 2. **Procedure for appeals related to benefits and damages.** (a) A person who appeals the amount of benefits or damages may include benefits and damages affecting property not owned by the appellant. Notice of the appeal must be served to the auditor and to the owner or occupant of property included in the appeal or to the attorney representing the property owner in the proceedings.

(b) The appellant must file a notice of appeal with the auditor within 30 days after the order to be appealed is filed. The notice must state the particular benefits or damages appealed and the basis for the appeal. Within 30 days after the notice is filed, the auditor must file the original notice with the court administrator of the district court.

Subd. 3. **Procedure for appeal related to allowance of fees or expenses.** An appeal related to the allowance of fees or expenses may be to the district court of any county where the affected property is located. The appeal must be made within 30 days after the order allowing or disallowing the claim and is governed as applicable by the provisions of subdivision 4.

Subd. 4. **Appeal trial.** (a) The issues in the appeal are entitled to a trial by a jury in the district court of the county where the drainage proceeding was pending.

(b) At the request of the appellant, the trial must be held at the district court of the county where the affected property is located. The court administrator of the district court where the appeal is first filed shall make, certify, and file with the court administrator of the district court of the county where the trial is transferred, a transcript of the papers and documents on file in the court administrator's office in the proceedings related to the matters of the appeal. After the final determination of the appeal, the court administrator of the district court that tried the appeal shall certify and return the verdict to the district court of the county where the drainage proceedings were filed.

(c) The appeal shall take precedence over all other civil court matters. If there is more than one appeal to be tried in one county, the court may, on its own motion or the motion of an interested party, consolidate two or more appeals and try them together, but the rights of the appellants must be determined separately. If the appellant does not prevail, the cost of the trial must be paid by the appellant.

(d) The court administrator of the district court where the appeal is filed shall file a certified copy of the final determination of the appeal with the auditor of the affected counties.

Subd. 5. **Effect of determination.** For all appeals, the amount awarded by the jury as a determination of the issue appealed shall replace the amount that was appealed.

History: *1990 c 391 art 5 s 19; 2014 c 164 s 4*

103E.095 APPEAL FROM ORDERS DISMISSING OR ESTABLISHING DRAINAGE SYSTEMS.

Subdivision 1. **Notice of appeal.** A party may appeal an order made by the board that dismisses drainage proceedings or establishes or refuses to establish a drainage project to the district court of the county where the drainage proceedings are pending. The appellant must serve notice of the appeal to the auditor within 30 days after the order is filed. After notice of the appeal is served, the appeal may be brought to trial by the appellant or the drainage authority after notifying the other party at least ten days before the trial date.

Subd. 2. **Trial.** The appeal must be tried by the court without a jury. The court shall examine the entire drainage proceeding and related matters and receive evidence to determine whether the findings made by the board can be sustained. At the trial the findings made by the board are prima facie evidence of the matters stated in the findings, and the board's order is prima facie reasonable. If the court finds that the order appealed is lawful and reasonable, it shall be affirmed. If the court finds that the order appealed is arbitrary, unlawful, or not supported by the evidence, it shall make an order, justified by the court record, to take the place of the appealed order, or remand the order to the board for further proceedings. After the appeal has been determined by the court, the board shall proceed in conformity with the court order.

Subd. 3. **Determination of benefits and damages after court order.** If the order establishing a drainage project is appealed, the trial of appeals related to benefits or damages in the drainage proceeding must be stayed until the establishment appeal is determined. If the order establishing the drainage project is affirmed, appeals related to benefits and damages must then be tried.

Subd. 4. **Procedure if appeal order establishes drainage project.** If an order refusing to establish a drainage project is appealed, and the court, by order, establishes the drainage project, the auditor shall give notice by publication of the filed order. The notice is sufficient if it refers to the drainage project or system by number or other descriptive designation, states the meaning of the order, and states the date the court order was filed. A person may appeal the establishment order to the district court as provided in this section.

Subd. 5. **Appeal of appellate order.** A party aggrieved by a final order or judgment rendered on appeal to the district court may appeal as in other civil cases. The appeal must be made and perfected within 30 days after the filing of the order or entry of judgment.

History: *1990 c 391 art 5 s 20*

103E.097 PAYMENT OF ATTORNEY FEES ON APPEAL.

If the commissioner of natural resources is a party making an appeal under section 103E.091 or 103E.095 and the commissioner does not prevail on the issues appealed, the court may award attorney fees to the party prevailing on the appeal. If more than one issue is appealed and the commissioner prevails on some issues and does not prevail on others, the court shall determine the amount of the attorney fee to be awarded.

History: *1990 c 391 art 5 s 21*

103E.101 DRAINAGE PROCEEDING AND CONSTRUCTION RECORDS.

Subdivision 1. **Public records.** All maps, plats, charts, drawings, plans, specifications, and other documents that have been filed, received in evidence, or used in connection with a drainage proceeding or construction are subject to the provisions on public records in section 15.17.

Subd. 2. **Record requirements.** All maps, plats, profiles, plans, and specifications prepared and used in relation to a proceeding must:

(1) be uniform;

(2) have each sheet marked to identify the proceeding by the drainage project and system number;

(3) show the name of the person preparing the sheet;

(4) show the date the sheet was prepared; and

(5) conform to rules and standards prescribed by the director.

Subd. 3. **Index of proceedings and records.** The auditor or secretary shall keep all orders, exhibits, maps, charts, profiles, plats, plans, specifications, and records of the proceedings. These records may not be removed except when the board makes a written order to remove them. The auditor or secretary shall keep an accurate index of the proceedings and related documents in a readily usable, resilient, and secure manner.

Subd. 4. **Engineer's documents.** All original plats, profiles, records, and field books made by the engineer during the proceedings or the construction of a drainage project are public records and the property of the drainage authority. These public records must be filed with the auditor or secretary under the direction of the drainage authority when construction is completed or when the engineer stops acting for the drainage project, whichever is earlier.

Subd. 4a. **Reestablishment of drainage system records.** (a) If, after thorough investigation of drainage system records, a drainage authority finds that records establishing the alignment, cross-section, profile, or right-of-way of a drainage system that it administers are lost, destroyed, or otherwise incomplete, it may, by order, reestablish records defining the alignment; cross-section; profile; hydraulic structure locations, materials, dimensions, and elevations; or right-of-way of the drainage system as originally constructed or subsequently improved in accordance with this chapter. The procedure for reestablishing drainage system records must involve, at a minimum, investigation and a report of findings by a professional engineer licensed in Minnesota supported by existing records and evidence, including, but not limited to, applicable aerial photographs, soil borings or test pits, culvert dimensions and invert elevations, and bridge design records. The existing and reestablished records together must define the alignment; cross-section; profile; hydraulic structure locations, materials, dimensions, and elevations; and right-of-way of the drainage system. Drainage system records reestablished under this subdivision do not interrupt prescriptive occupation.

(b) The description of a drainage system under this subdivision may be initiated by the drainage authority on its own motion or by any party affected by the drainage system filing a petition. If the system is under the jurisdiction of a county board, the petition must be filed with the auditor. If the system is under the jurisdiction of a joint county drainage authority, the petition must be filed with the auditor of the county with the largest area of property in the drainage system. If the system is under the jurisdiction of a watershed district board, the petition must be filed with the secretary.

(c) When a drainage authority directs by resolution or when a petition is filed under this subdivision, the drainage authority, in consultation with the auditor or secretary, shall set a time and location for a hearing after the engineer's report is complete. The auditor or secretary shall give notice of the hearing by mail to the commissioner of natural resources, the executive director of the Board of Water and Soil Resources, the petitioner or petitioners, and all property owners benefited or damaged by the drainage system and shall give notice to other interested parties either in a newspaper of general circulation in the drainage system area or by publication on a Web site of the drainage authority.

(d) Drainage system records reestablished under this subdivision constitute official drainage system records. A finding of drainage system right-of-way in the applicable order is a defense to a trespass claim and shall be given due weight in any subsequent court proceeding to establish the existence or nature of a property encumbrance.

Subd. 5. **Filing and storage facilities.** County boards shall provide the auditor, and watershed district boards shall provide the secretary, with necessary filing and storage facilities to protect the files and records of all proceedings under its jurisdiction. The county boards and watershed district boards may provide for the copying and filing of the documents and records of proceedings by photographic devices as provided for public records under section 15.17. In the event of loss of the originals, the photographic copies are originals after authentication by the auditor or secretary.

Subd. 5a. **Transfer of drainage system records.** (a) When a watershed district assumes authority for a drainage system according to section 103D.625, the county or joint county board transferring authority shall transfer all of the original records for the drainage system to the watershed district, except as provided in paragraph (b).

(b) Physical or electronic copies of drainage system records that are authenticated by the county auditor having the original records may be used in place of the originals by the watershed district until the watershed district has necessary records storage facilities to protect the original records or, in the case of a partial transfer of a drainage system, until the entire drainage system is transferred to the watershed district.

Subd. 6. **Records; prima facie evidence.** The record of proceedings under this chapter and of orders made by the drainage authority or the district court in the proceedings, or a certified copy of a record or order, is prima facie evidence of the facts stated in the record or order and of the regularity of all proceedings prior to the making of the order.

History: *1990 c 391 art 5 s 22; 2013 c 4 s 4-9*

103E.105 ADVICE ABOUT DRAINAGE QUESTIONS.

The director shall provide advice to a drainage authority or engineer, upon request, about engineering questions or problems in connection with a drainage project or drainage system.

History: *1990 c 391 art 5 s 23*

103E.111 FIELD SURVEYS AND INVESTIGATIONS BY DIRECTOR.

Subdivision 1. **Authorization.** If a field survey or investigation of a drainage project or drainage system is determined to be necessary by the director or is requested in writing by the drainage authority, the director may conduct the survey or investigation.

Subd. 2. **Costs if requested by drainage authority.** If the field survey or investigation is made at the request of a drainage authority, the cost must be reported to the drainage authority and paid by the drainage authority as a drainage project or drainage system expense.

History: *1990 c 391 art 5 s 24*

103E.115 HYDROLOGICAL AND DRAINAGE INFORMATION.

(a) The director may prepare and publish: (1) runoff data; (2) information about the capacity of drain tile and ditches; (3) specifications for drain tile, ditches, and ditch construction; and (4) standard procedural forms for public ditch proceedings.

(b) The director may furnish the information to engineers and drainage authorities for their advice and information.

History: *1990 c 391 art 5 s 25*

103E.121 DRAIN TILE MANUFACTURING STUDIES.

Subdivision 1. **Drain tile investigations.** The director may:

(1) investigate the methods used in the manufacture of drain tile;

(2) determine the causes of drain tile failure; and

(3) conduct research and experimentation to improve the quality of drain tile.

Subd. 2. **Manufacturing investigations and tests.** The director may make inspections and tests of manufacturing processes and materials used and the resultant product of a manufacturing plant in the state where drain tile is made and sold to drainage authorities or the general public. The director, or an authorized agent of the director, must have free access to manufacturing plants of drain tile sold in this state for inspections and tests.

Subd. 3. **Distribution of information.** The results of inspections and tests must be made public for drainage authorities, engineers, tile manufacturers, and others interested in the use of drain tile.

History: *1990 c 391 art 5 s 26*

PETITIONS FOR DRAINAGE PROJECTS

103E.202 PETITIONS.

Subdivision 1. **Applicability.** This section applies to a petition for a drainage project and a petition for repair.

Subd. 2. **Signatures on petition.** (a) A petition must be signed by a requisite number of owners of 40-acre tracts or government lots and property that the drainage project described in the petition passes over, or by the property owners of the required percentage of the property area determined by the total and percentage of area of 40-acre tracts or government lots that the proposed drainage project passes over, excluding areas in and holders of easements for utilities and roads. A petition may be signed by the commissioner of transportation or by a political subdivision if the property is in their jurisdiction and is passed over by the proposed drainage project.

(b) Each separate parcel of property counts as one signature but the petition must be signed by all owners of the parcel to count as a signature. The signature of each entity regardless of the number of parcels of property owned counts as one signature on the petition.

(c) Paragraph (a) does not apply to a petition for an improvement of an outlet.

Subd. 3. **Withdrawal of petitioner.** After a petition has been filed, a petitioner may not withdraw from the petition except with the written consent of all other petitioners on the filed petition.

Subd. 4. **Filing petition and bond.** A petition for a drainage project and a bond must be filed with the auditor. If a drainage system is within two or more counties, the petition must be filed with the auditor of the county with the greatest area of property that the proposed drainage project passes over.

Subd. 5. **Petitioners' bond.** One or more petitioners must file a bond with the petition for at least $10,000 that is payable to the county where the petition is filed, or for a petition for a proposed joint county drainage system or a petition for a drainage project affecting a joint county drainage system, the bond must be payable to all of the counties named in the petition. The bond must have adequate surety and be approved by the county attorney where the petition is filed. The bond must be conditioned to pay the costs incurred if the proceedings are dismissed or a contract is not awarded to construct the drainage system proposed in the petition.

Subd. 6. **Expenses not to exceed bond.** The costs incurred before the proposed drainage project is established may not exceed the amount of the petitioners' bond. A claim for expenses greater than the amount of the bond may not be paid unless an additional bond is filed. If the drainage authority determines that the cost of the proceeding will be greater than the petitioners' bond before the proposed drainage project is established, the drainage authority must require an additional bond to cover all costs to be filed within a prescribed time. The proceeding must be stopped until the additional bond prescribed by the drainage authority is filed. If the additional bond is not filed within the time prescribed, the proceeding must be dismissed.

History: *1990 c 391 art 5 s 27*

103E.212 NEW DRAINAGE SYSTEM PROJECTS.

Subdivision 1. **Procedure.** To establish a new drainage system under this chapter, the petitioners and drainage authority must proceed according to this section and the provisions applicable to establishment of drainage projects.

Subd. 2. **Signatures on petition.** The petition for a new drainage system must be signed by a majority of the owners of the property that the proposed drainage system described in the petition passes over, or by the property owners of at least 60 percent of the area that the proposed new drainage system passes over.

Subd. 3. **Petition requirements.** The petition must:

(1) describe the 40-acre tracts or government lots and property where the proposed new drainage system passes over, including names and addresses of the property owners from records in the county assessor's office;

(2) describe the starting point, the general course, and the terminus of the proposed drainage system;

(3) state why the proposed drainage system is necessary;

(4) state that the proposed drainage system will benefit and be useful to the public and will promote public health; and

(5) state that the petitioners will pay all costs of the proceedings if the proceedings are dismissed or the contract for the construction of the proposed drainage system is not awarded.

History: *1990 c 391 art 5 s 28*

103E.215 IMPROVEMENT OF DRAINAGE SYSTEM.

Subdivision 1. **Procedure.** The procedure in this section must be used to improve an established and constructed drainage system.

Subd. 2. **Definition.** In this section "improvement" means the tiling, enlarging, extending, straightening, or deepening of an established and constructed drainage system including construction of ditches to reline or replace tile and construction of tile to replace a ditch.

Subd. 3. **Limit of extension.** An improvement may only extend a drainage system downstream to a more adequate outlet and the extension may not exceed one mile.

Subd. 4. **Petition.** (a) A petition must be signed by:

(1) at least 26 percent of the owners of the property affected by the proposed improvement;

(2) at least 26 percent of the owners of property that the proposed improvement passes over;

(3) the owners of at least 26 percent of the property area affected by the proposed improvement; or

(4) the owners of at least 26 percent of the property area that the proposed improvement passes over.

(b) The petition must be filed with the auditor or, for a drainage system in more than one county, with the auditor of the county having the largest area of property the improvement would be located on.

(c) The petition must:

(1) designate the drainage system proposed to be improved by number or another description that identifies the drainage system;

(2) state that the drainage system has insufficient capacity or needs enlarging or extending to furnish sufficient capacity or a better outlet;

(3) describe the starting point, general course, and terminus of any extension;

(4) describe the improvement, including the names and addresses of owners of the 40-acre tracts or government lots and property that the improvement passes over;

(5) state that the proposed improvement will be of public utility and promote the public health; and

(6) contain an agreement by the petitioners that they will pay all costs and expenses that may be incurred if the improvement proceedings are dismissed.

Subd. 5. **Subsequent proceedings.** When a petition and the bond required by section 103E.202 are filed, the auditor shall present the petition to the board at its next meeting or, for a joint county drainage system, to the joint county drainage authority within ten days after the petition is filed. The drainage authority shall appoint an engineer to examine the drainage system and make an improvement report. The improvement proceedings must be conducted under this chapter as provided for the original proceedings for the establishment of a drainage project. The benefits and damages determined must be as a result of the proposed improvement. Assessments for the repair of the improvement must be based on the benefits determined for the improvement.

Subd. 6. **Petition for separable part of drainage system needing repair.** (a) If the existing drainage system needs repair and the petition for the improvement is for a separable part only of the existing drainage system, the engineer may include in the detailed survey report a statement showing the proportionate estimated cost of the proposed improvement required to repair the separable part of the existing system and the estimated proportionate cost of the added work required for the improvement. The notice of hearing on the detailed survey report must be given by publication and mailing to all persons owning property affected by the existing drainage system. The hearing may be held at the same time and location as the establishment hearing for the improvement.

(b) At the hearing, if the drainage authority determines that only a separable portion of the existing drainage system will be improved and that the portion needs repair, the drainage authority shall determine and assess, by order, the proportionate cost of the improvement that would be required to repair the separable portion of the drainage system to be improved. The order must direct that:

(1) the repair portion is allocated as repairs and assessed against all property benefited by the entire drainage system, as provided by section 103E.731; and

(2) the balance of the cost of the improvement is assessed in addition to the repair assessment against the property benefited by the improvement.

History: *1990 c 391 art 5 s 29*

103E.221 IMPROVEMENT OF OUTLETS.

Subdivision 1. **Conditions for improvement of outlets.** If a public or private proposed drainage project or existing drainage system has waters draining into an existing drainage system, watercourse, or body of water, and the construction or proposed construction of the drainage project causes an overflow of the existing drainage system, watercourse, or body of water on adjoining property, an affected county or the owners of the overflowed property may start outlet improvement proceedings under this section.

Subd. 2. **Petition.** (a) A petition must be signed by the board of an affected county, by at least 26 percent of the owners of adjoining overflowed property, or by the owners of at least 26 percent of the area of the overflowed property. The petition must:

(1) describe the property that has been or is likely to be overflowed including the names and addresses of the property owners from records in the county assessor's office;

(2) state in general terms by number or otherwise the drainage systems that have caused or are likely to cause the overflow;

(3) describe the location of the overflowed drainage system, watercourse, or body of water and the outlet;

(4) show the necessity of the improvement by enlarging the system or controlling the waters by off-take ditches, additional outlets, or otherwise;

(5) show that the outlet improvement will protect the adjoining property from overflow;

(6) state that the improvement will be of public benefit and utility and improve the public health; and

(7) state that the petitioners will pay all costs incurred if the proceedings are dismissed or a contract for construction of the outlet improvement is not awarded.

(b) The petitioners, except for a petition made by the board, shall give the required bond.

Subd. 3. **Filing of petition.** The petition shall be filed with the county auditor. If the board makes the petition, it must be addressed to the drainage authority and filed with the auditor. If part of the improvement or the overflowed property is located in more than one county, the petition must be filed with the auditor of the county with the greatest affected area.

Subd. 4. **Jurisdiction of drainage authority.** After the petition is filed, the board or joint county drainage authority where the petition is filed has jurisdiction of the petition, the improvement, the affected property, and all proceedings for the establishment and construction of the outlet improvement and the assessment of property benefited by the outlet improvement, as provided for establishment and construction of a drainage project under this chapter.

Subd. 5. **Preliminary survey report requirements.** In the preliminary survey report, the engineer shall show the existing or proposed drainage projects or systems that cause the overflow, the property drained or to be drained by the drainage project, and the names of affected property owners.

Subd. 6. **Benefited property to be determined by viewers.** If, after the preliminary survey report hearing, a detailed survey is ordered and viewers are appointed, the viewers shall determine and report the benefits to all property from the outlet improvement including property drained or to be drained by the existing drainage system and proposed drainage project.

History: *1990 c 391 art 5 s 30*

103E.225 LATERALS.

Subdivision 1. **Petition.** (a) Persons that own property in the vicinity of an existing drainage system may petition for a lateral that connects their property with the drainage system. The petition must be signed by at least 26 percent of the owners of the property or by the owners of at least 26 percent of the area of the property that the lateral passes over. The petition must be filed with the auditor, or for property in more than one county, the petition must be filed with the auditor of the county with the largest property area to be passed over by the lateral. The petition must:

(1) describe in general terms the starting point, general course, and terminus of the proposed lateral;

(2) describe the property traversed by the lateral including the names and addresses of the property owners from records in the county assessor's office;

(3) state the necessity to construct the lateral;

(4) state that, if constructed, the lateral will be of public benefit and utility and promote the public health;

(5) request that the lateral be constructed and connected with the drainage system; and

(6) provide that the petitioners will pay all costs incurred if the proceedings are dismissed or if a contract for the construction of the lateral is not awarded.

(b) The petitioners shall give the bond required by section 103E.202, subdivision 5.

Subd. 2. **Establishment procedure.** After the petition is filed, the procedure to establish and construct the lateral is the same as that provided in this chapter to establish a drainage project.

Subd. 3. **Authority necessary for property not assessed.** A lateral may not be constructed to drain property that is not assessed benefits for the existing drainage system until express authority for the use of the existing drainage system as an outlet for the lateral has been obtained under section 103E.401.

History: *1990 c 391 art 5 s 31*

103E.227 IMPOUNDING, REROUTING, AND DIVERTING DRAINAGE SYSTEM WATERS.

Subdivision 1. **Petition.** (a) To conserve and make more adequate use of our water resources or to incorporate wetland or water quality enhancing elements as authorized by section 103E.011, subdivision 5, a person, public or municipal corporation, governmental subdivision, the state or a department or agency of the state, the commissioner of natural resources, and the United States or any of its agencies, may petition to impound, reroute, or divert drainage system waters for beneficial use.

(b) If the drainage system is under the jurisdiction of a county drainage authority, the petition must be filed with the auditor of the county. If the drainage system is under the jurisdiction of a joint county drainage authority, the petition must be filed with the county having the largest area of property in the drainage system, where the primary drainage system records are kept, and a copy of the petition must be submitted to the auditor of each of the other counties participating in the joint county drainage authority. If the system is under the jurisdiction of a watershed district, the petition must be filed with the secretary of the district. The auditor of an affected county or the secretary of a watershed district must make a copy of the petition available to the public.

(c) The petition must contain the location of the installation, concept plans for the proposed project, and a map that identifies the areas likely to be affected by the project.

(d) The petition shall identify the sources of funds to be used to secure the necessary land rights and to construct the project and the amount and rationale for any drainage system funds requested.

(e) The petitioner or drainage authority must also acquire a public waters work permit or a water use permit from the commissioner of natural resources if required under chapter 103G.

Subd. 2. **Bond.** (a) Upon filing the petition, the petitioners shall file a bond as provided in section 103E.202.

(b) A bond is not required if the petition is filed by the state, a state agency or department, the commissioner of natural resources, the United States or any of its agencies, a soil and water conservation district, a watershed district, or a municipality.

Subd. 3. **Procedure to establish project.** (a) After receiving the petition and bond, if required, the drainage authority must appoint an engineer to investigate the effect of the proposed installation and file a report of findings.

(b) After filing of the engineer's report, notice must be given and a public hearing held as provided in section 103E.261.

(c) If at the hearing it appears from the engineer's report and other evidence presented that the project will be of a public or private benefit and that it will not impair the utility of the drainage system or deprive affected land owners of its benefit, the drainage authority shall make an order modifying the drainage system, to include the amount, if any, of drainage system funds approved for the project at the discretion of the drainage authority, and issue an order authorizing the project.

Subd. 4. **Permits and flowage easements required.** Before installing or constructing the project, the petitioner or drainage authority shall obtain all required permits and all necessary rights-of-way and flowage easements from owners of land to be affected by it.

Subd. 5. **Construction, operation, maintenance, and repair responsibilities.** The order of the drainage authority modifying the drainage system must identify the parties responsible for construction, operation, and maintenance of the drainage system modification and the amount, if any, of drainage system funds for the project. If the part of the drainage system located within the project boundaries is in need of repairs, the petitioner's engineer shall estimate the cost at the time of petition of these separable repairs. The drainage authority shall consider the separable repair costs that will be avoided as a result of the petitioned project, as well as any other benefits of the project to the drainage system, when determining whether or how much to contribute to the petitioned project.

History: *1990 c 391 art 5 s 32; 2010 c 298 s 3; 2013 c 4 s 10*

103E.231 DISMISSAL OR DELAY OF PROCEEDINGS BY PETITIONERS.

Subdivision 1. **Dismissal.** (a) A proceeding under this chapter may be dismissed by a majority of the petitioners if they own at least 60 percent of the area owned by all of the petitioners as described in the petition.

(b) The proceeding may be dismissed at any time before the proposed drainage project is established after payment of the cost of the proceeding. If the costs cannot be collected, each and all petitioners are liable for unpaid assessments. The drainage authority shall determine and assess the cost of the proceeding against the persons liable. After the proceeding is dismissed any other action on the proposed drainage project must begin with a new petition.

Subd. 2. **Delay.** The drainage authority may delay drainage proceedings and drainage project construction under this chapter if a majority of the petitioners petition for a delay and the drainage authority holds a hearing on the petition. The delay may be for a period determined by the drainage authority. The drainage authority shall determine the cost of the proceedings up to the time the proceedings are delayed and when the costs are to be paid. The costs may include interest on the costs due.

History: *1990 c 391 art 5 s 33*

103E.235 DRAINAGE SYSTEM IN TWO OR MORE COUNTIES.

Subdivision 1. **Designation.** A petition for a proposed drainage project in two or more counties must be designated as a joint county drainage system with a number assigned by the auditor of the county with the largest area of property in the drainage system.

Subd. 2. **Joint county drainage authority.** The board where a petition for a proposed joint county drainage project is filed shall notify the board of each county where property is affected by the drainage system and request the boards to meet jointly and consider the petition. The boards shall select five of their members at the meeting to be the drainage authority. At least one member must be from each board. The drainage authority shall be known as the joint county drainage authority with a joint county drainage project or system number. A vacancy in the membership of the joint county drainage authority must be filled by joint action of the boards.

Subd. 3. **Transfer of drainage systems to watershed districts not affected.** This section does not affect the transfer of a drainage system to the board of managers of a watershed district under chapter 103D.

History: *1990 c 391 art 5 s 34*

103E.238 COUNTY ATTORNEY REVIEW OF PETITION AND BOND.

The county attorney must review each petition and bond filed with the county to determine if it meets the requirement of the proceedings for which it is intended. The county attorney must review the petition and bond within 30 days after it is filed. The county attorney must:

(1) refer the petition and bond back to the petitioners if it does not meet the requirements, with the county attorney's opinion describing the deficiencies of the petition; or

(2) refer the petition to the drainage authority.

History: *1990 c 391 art 5 s 35*

PRELIMINARY SURVEY AND HEARING

103E.241 ENGINEER.

Subdivision 1. **Appointment.** Within 30 days after receiving a petition and bond from the county attorney, the drainage authority shall, by order, appoint an engineer to make a preliminary survey within a prescribed time. The engineer must be the county highway engineer of a county where the affected property is located or a professional engineer registered under state law. The engineer is the engineer for the drainage project throughout the proceeding and construction unless otherwise ordered. Each appointed engineer must file an oath and bond. The engineer may be removed by the drainage authority at any time. If the engineer position is vacant, the drainage authority shall appoint another engineer as soon as possible.

Subd. 2. **Oath; bond.** An appointed engineer must subscribe to an oath to faithfully perform the assigned duties in the best manner possible and file a bond with the auditor. Within ten days after being appointed, the drainage authority shall set an amount of at least $5,000 for the bond. The bond must have adequate surety and be payable to the county where the petition is filed, or for a proposed joint county drainage project to all counties in the petition. The bond must be conditioned to pay any person or the drainage authority for damages and injuries resulting from negligence of the engineer while the engineer is acting in the proceedings or construction and provide that the engineer will diligently and honestly perform the engineer's duties. The bond is subject to approval by the auditor. The aggregate liability of the surety for all damages may not exceed the amount of the bond.

Subd. 3. **Assistants; compensation.** The engineer may appoint assistant engineers and hire help necessary to complete the engineer's duties. The engineer is responsible for the assistant engineers and may remove them. The compensation of the engineer, assistant engineers, and other employees is provided by section 103E.645.

Subd. 4. **Engineer's reports.** The engineer shall make an expense report every two weeks after the beginning of the engineer's work until the construction contract is awarded. The report must show costs incurred by the engineer and expenses incurred under the engineer's direction relating to the proceeding, and include the names of the engineer, engineer assistants, and employees and the time each was employed, and every item of expense incurred by the engineer. The engineer must file this report with the auditor as soon as possible and may not incur expenses for the proceeding greater than the petitioners' bond.

Subd. 5. **Consulting engineer.** After the engineer is appointed and before construction of the drainage project is finished, the drainage authority may employ an engineer as a consulting engineer for the proceeding and construction. A consulting engineer shall advise the engineer and drainage authority on engineering matters and problems that may arise related to the proceeding and construction of the drainage project. The drainage authority shall determine the compensation for the consulting engineer.

History: *1990 c 391 art 5 s 36*

103E.245 PRELIMINARY SURVEY AND PRELIMINARY SURVEY REPORT.

Subdivision 1. **Survey.** The engineer shall proceed promptly to:

(1) examine the petition and order;

(2) make a preliminary survey of the area likely to be affected by the proposed drainage project to enable the engineer to determine whether the proposed drainage project is necessary and feasible with reference to the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1;

(3) examine and gather information related to determining whether the proposed drainage project substantially affects areas that are public waters; and

(4) if the proposed drainage project requires construction of an open channel, examine the nature and capacity of the outlet and any necessary extension.

Subd. 2. **Limitation of survey.** The engineer shall restrict the preliminary survey to the drainage area described in the petition, except that to secure an outlet the engineer may run levels necessary to determine the distance for the proper fall of the water. The preliminary survey must consider the impact of the proposed drainage project on the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1. The drainage authority may have other areas surveyed after:

(1) giving notice by mail of a hearing to survey additional areas, to be held at least ten days after the notice is mailed, to the petitioners and persons liable on the petitioners' bond;

(2) holding the hearing;

(3) obtaining consent of the persons liable on the petitioners' bond; and

(4) ordering the additional area surveyed by the engineer.

Subd. 3. **Adoption of federal project.** The engineer may approve and include as a part of the report, a project of the United States relating to drainage or flood control that is within the proposed drainage project area, and may accept data, plats, plans, or information relating to the project furnished by United States engineers. The engineer does not need to make the preliminary survey if the material furnished by the United States is sufficient for the engineer to make the preliminary survey report.

Subd. 4. **Preliminary survey report.** The engineer shall report the proposed drainage project plan or recommend a different practical plan. The report must give sufficient information, in detail, to inform the drainage authority on issues related to feasibility, and show changes necessary to make the proposed plan practicable and feasible including extensions, laterals, and other work. If the engineer finds the proposed drainage project in the petition is feasible and complies with the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1, the engineer shall include in the preliminary survey report a preliminary plan of the drainage project showing the proposed ditches, tile, laterals, and other improvements, the outlet of the project, the watershed of the drainage project or system, and the property likely to be affected and its known owners. The plan must show:

(1) the elevation of the outlet and the controlling elevations of the property likely to be affected referenced to standard sea level datum, if practical;

(2) the probable size and character of the ditches and laterals necessary to make the plan practicable and feasible;

(3) the character of the outlet and whether it is sufficient;

(4) the probable cost of the drains and improvements shown on the plan;

(5) all other information and data necessary to disclose the practicability, necessity, and feasibility of the proposed drainage project;

(6) consideration of the drainage project under the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1; and

(7) other information as ordered by the drainage authority.

History: *1990 c 391 art 5 s 37; 2014 c 164 s 5-7*

103E.251 FILING PRELIMINARY SURVEY REPORT.

The engineer shall file the completed preliminary survey report in duplicate with the auditor. The auditor shall send one copy of the report to the director. If the proposed drainage project involves a joint county drainage project or system, a copy of the report must be filed with the auditor of each affected county.

History: *1990 c 391 art 5 s 38*

103E.255 COMMISSIONER'S PRELIMINARY ADVISORY REPORT.

The commissioner shall make a preliminary advisory report to the drainage authority with an opinion about the adequacy of the preliminary survey report. The commissioner shall state any additional investigation and evaluation that should be done relating to public waters that may be affected and environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1, and cite specific portions of the preliminary survey report that are determined inadequate. The commissioner shall file an initial preliminary advisory report with the auditor before the date of the preliminary hearing. The commissioner may request additional time for review and evaluation of the preliminary survey report if additional time is necessary for proper evaluation. A request for additional time for filing the commissioner's preliminary advisory report may not be made more than five days after the date of the notice by the auditor that a date is to be set for the preliminary hearing. An extension of time may not exceed two weeks after the date of the request.

History: *1990 c 391 art 5 s 39; 2014 c 164 s 8*

103E.261 PRELIMINARY HEARING.

Subdivision 1. **Notice.** When the preliminary survey report is filed, the auditor shall promptly notify the drainage authority. The drainage authority in consultation with the auditor shall set a time, by order, not more than 30 days after the date of the order, for a hearing on the preliminary survey report. At least ten days before the hearing, the drainage authority after consulting with the auditor shall give notice by mail of the time and location of the hearing to the petitioners, owners of property, and political subdivisions likely to be affected by the proposed drainage project in the preliminary survey report.

Subd. 2. **Hearing.** The engineer shall attend the preliminary hearing and provide necessary information. The petitioners and all other interested parties may appear and be heard. The commissioner's advisory report on the preliminary plan must be publicly read and included in the record of proceedings.

Subd. 3. **Sufficiency of petition.** (a) The drainage authority shall first examine the petition and determine if it meets the legal requirements.

(b) If the petition does not meet the legal requirements of this chapter, the hearing shall be adjourned until a specified date by which the petitioners must resubmit the petition. The petition must be referred back to the petitioners who, by unanimous action, may amend the petition. The petitioners may obtain signatures of additional property owners as added petitioners.

(c) When the hearing is reconvened, if the petition is not resubmitted or does not meet the legal requirements, the proceedings must be dismissed.

Subd. 4. **Dismissal.** (a) The drainage authority shall dismiss the proceedings if it determines that:

(1) the proposed drainage project is not feasible;

(2) the adverse environmental impact is greater than the public benefit and utility after considering the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1, and the engineer has not reported a plan to make the proposed drainage project feasible and acceptable;

(3) the proposed drainage project is not of public benefit or utility; or

(4) the outlet is not adequate.

(b) If the proceedings are dismissed, any other action on the proposed drainage project must begin with a new petition.

Subd. 5. **Findings and order.** (a) The drainage authority shall state, by order, its findings and any changes that must be made in the proposed drainage project from those outlined in the petition, including changes necessary to minimize or mitigate adverse impact on the environment, if it determines that:

(1) the proposed drainage project outlined in the petition, or modified and recommended by the engineer, is feasible;

(2) there is necessity for the proposed drainage project;

(3) the proposed drainage project will be of public benefit and promote the public health, after considering the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1; and

(4) the outlet is adequate.

(b) Changes may be stated by describing them in general terms or filing a map that outlines the changes in the proposed drainage project with the order. The order and accompanying documents must be filed with the auditor.

Subd. 6. **Outlet is existing drainage system.** If the outlet is an existing drainage system, the drainage authority may determine that the outlet is adequate and obtain permission to use the existing drainage system as an outlet. The drainage authority shall assign a number to the proposed drainage project and proceed under section 103E.401 to act in behalf of the proposed drainage project.

Subd. 7. **Effect of findings.** (a) For all further proceedings, the order modifies the petition and the order must be considered with the petition.

(b) The findings and order of the drainage authority at the preliminary hearing are conclusive only for the signatures and legal requirements of the petition, the nature and extent of the proposed plan, and the need for a detailed survey, and only for the persons or parties shown by the preliminary survey report as likely to be affected by the proposed drainage project. All questions related to the practicability and necessity of the proposed drainage project are subject to additional investigation and consideration at the final hearing.

History: *1990 c 391 art 5 s 40; 2014 c 164 s 9,10*

DETAILED SURVEY AND VIEWING

103E.265 ORDER FOR DETAILED SURVEY AND DETAILED SURVEY REPORT.

Subdivision 1. **Order.** When the preliminary hearing order is filed with the auditor, the drainage authority shall order the engineer to make a detailed survey with plans and specifications for the proposed drainage project and submit a detailed survey report to the drainage authority as soon as possible.

Subd. 2. **Waiver.** The drainage authority may waive the detailed survey order and the detailed survey if it determines that adequate data, plans, and specifications have been furnished by a United States engineer.

History: *1990 c 391 art 5 s 41*

103E.271 DETAILED SURVEY.

Subdivision 1. **Survey and examination.** When an order for a detailed survey is filed, the engineer shall proceed to survey the lines of the proposed drainage project in the preliminary hearing order, and survey and examine affected property.

Subd. 2. **Survey requirements.** All drainage lines must be surveyed in 100-foot stations and elevations must be based on standard sea level datum, if practical. Bench marks must be established on permanent objects along the drainage line, not more than one mile apart. Field notes made by the engineer must be entered in bound field books and preserved by the engineer until they are filed with the auditor.

History: *1990 c 391 art 5 s 42*

103E.275 ENGINEER'S VARIANCE FROM DRAINAGE AUTHORITY ORDER.

(a) In planning a proposed drainage project, the engineer may vary from the starting point and the line and plan described by the preliminary hearing order if necessary to drain the property likely to be assessed in the proposed drainage project.

(b) The engineer may:

(1) survey and recommend the location of additional necessary ditches and tile;

(2) where better results will be accomplished and more desirable outlets secured, provide for the extension of the outlet; and

(3) provide for different parts of the drainage to flow in different directions with more than one outlet.

(c) The open ditches do not have to connect if they drain the area to be affected in the petition. The variance must be reported with similar information in the detailed survey report.

History: *1990 c 391 art 5 s 43*

103E.281 SOIL SURVEY.

The engineer shall make a soil survey if: (1) the drainage authority orders a soil survey; (2) the commissioner requests a soil survey; or (3) the engineer determines a soil survey is necessary. The soil survey must show the nature and character of the soil in the proposed drainage project area and include the engineer's findings from the soil survey. The report on the soil survey must be included in the detailed survey report or reported and filed separately before the final hearing.

History: *1990 c 391 art 5 s 44*

103E.285 DETAILED SURVEY REPORT.

Subdivision 1. **Report and information required.** The engineer shall prepare a detailed survey report that includes the data and information in this section.

Subd. 2. **Map.** A complete map of the proposed drainage project and drainage system must be drawn to scale, showing:

(1) the terminus and course of each drain and whether it is ditch or tile, and the location of other proposed drainage works;

(2) the location and situation of the outlet;

(3) the watershed of the proposed drainage project and the subwatershed of main branches, if any, with the location of existing highway bridges and culverts;

(4) all property affected, with the names of the known owners;

(5) public roads and railways affected;

(6) the outline of any lake basin, wetland, or public water body affected;

(7) other physical characteristics of the watershed necessary to understand the proposed drainage project and the affected drainage system; and

(8) the area to be acquired to maintain a grass strip under section 103E.021.

Subd. 3. **Profile of drainage lines.** A profile of all proposed drainage lines must be presented showing, graphically, the elevation of the ground and gradient at each 100-foot station, and the station number at each section line and at each property line. The profile must show information necessary to understand it, including, in the case of an open ditch, the bottom width and side slope and, in the case of a tiled ditch, the size of tile.

Subd. 4. **Bridge and culvert plans.** Plans for private bridges and culverts to be constructed by and as a part of the proposed drainage project and plans for other works to be constructed for the proposed drainage project must be presented. A list must be made that shows the required minimum hydraulic capacity of bridges and culverts at railways and highways that cross ditches, and at other prospective ditch crossings where bridges and culverts are not specified to be constructed as part of the proposed drainage project. Plans and estimates of the cost of highway bridges and culverts must be prepared for the viewers to determine benefits and damages.

Subd. 5. **Tabular statement of excavation, construction, and cost.** A tabular statement must be prepared showing:

(1) the number of cubic yards of excavation, linear feet of tile, and average depth on each tile line;

(2) the bridges, culverts, and works to be constructed under the plans for the drainage project; and

(3) the estimated unit cost of each item, a summary of the total cost, and an estimate of the total cost of completing the proposed drainage project that includes supervision and other costs.

Subd. 6. **Right-of-way acreage.** The acreage must be shown that will be taken for ditch right-of-way on each government lot, 40-acre tract, or fraction of a lot or tract under separate ownership. The ditch right-of-way must include the area to be taken to maintain a grass strip under section 103E.021.

Subd. 7. **Drain tile specifications.** Specifications for drain tile must be given that comply with the requirements of the American Society for Testing Materials standard specifications for drain tile, except where the engineer requires tile of a special, higher quality for certain tile depths or soil conditions.

Subd. 8. **Soil survey report.** If required under section 103E.281, the report on the soil survey must be included in the detailed survey report or submitted and filed separately before the final hearing.

Subd. 9. **Recommendation for division of work.** If construction of the proposed drainage project would be more economical, the engineer may recommend:

(1) that the work be divided into sections and contracted separately;

(2) that the ditch and tile work or tile and labor on the project be contracted separately; or

(3) the time and manner for the work to be completed.

Subd. 10. **Other information on practicability and necessity of drainage project.** Other data and information to inform the drainage authority of the practicability and necessity of the proposed drainage project must be made available including a comprehensive examination and the recommendation by the engineer regarding the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1.

Subd. 11. **Outlet in another state.** If an outlet is only practical in an adjoining state, the engineer shall describe the right-of-way needed and the cost of obtaining the right-of-way and constructing the outlet.

Subd. 12. **Completion.** The engineer shall prepare the detailed survey and complete the detailed survey report, in duplicate, as specified in this section.

History: *1990 c 391 art 5 s 45; 2014 c 164 s 11*

103E.291 FILING DETAILED SURVEY REPORT.

The engineer must file the detailed survey report with the auditor where the proceedings are pending and the auditor must deliver a copy of the detailed survey report to the commissioner. The engineer must also file copies of the detailed survey report with the auditors of any affected counties.

History: *1990 c 391 art 5 s 46*

103E.295 REVISION OF ENGINEER'S DETAILED SURVEY REPORT AFTER ACCEPTANCE.

After the final acceptance of the proposed drainage project, the engineer shall revise the plan, profiles, and designs of structures to show the drainage project as actually constructed on the original tracings. The engineer shall file the revised detailed survey report with the auditor. The auditor shall forward the original or a copy to the director as a permanent record.

History: *1990 c 391 art 5 s 47*

103E.301 COMMISSIONER'S FINAL ADVISORY REPORT.

(a) The commissioner shall examine the detailed survey report and within 30 days of receipt make a final advisory report to the drainage authority. The final advisory report must state whether the commissioner:

(1) finds the detailed survey report is incomplete and not in accordance with the provisions of this chapter, specifying the incomplete or nonconforming provisions;

(2) approves the detailed survey report as an acceptable plan to drain the property affected;

(3) does not approve the plan and recommendations for changes;

(4) finds the proposed drainage project is not of public benefit or utility under the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1, specifying the facts and evidence supporting the findings; or

(5) finds a soil survey is needed, and, if it is, makes a request to the engineer to make a soil survey.

(b) The commissioner shall direct the final advisory report to the drainage authority and file it with the auditor.

History: *1990 c 391 art 5 s 48; 2014 c 164 s 12*

103E.305 VIEWERS' APPOINTMENT AND QUALIFICATION.

Subdivision 1. **Appointment.** When the order for a detailed survey is made, the drainage authority shall, by order, appoint viewers consisting of three disinterested residents of the state qualified to assess benefits and damages. The drainage authority may establish qualifications for viewers.

Subd. 2. **Auditor's order for first meeting.** Within five days after the detailed survey report is filed, the auditor shall, by order, designate the time and location for the first meeting of the viewers and issue a copy to the viewers of the auditor's order and a certified copy of the order appointing the viewers.

Subd. 3. **First meeting.** At the first meeting and before beginning their duties, the viewers shall subscribe to an oath to faithfully perform their duties. If an appointed viewer does not qualify for any reason, the auditor shall designate another qualified person to take the disqualified viewer's place.

History: *1990 c 391 art 5 s 49*

103E.311 VIEWERS' DUTIES.

The viewers, with or without the engineer, shall determine the benefits and damages to all property affected by the proposed drainage project and make a viewers' report.

History: *1990 c 391 art 5 s 50*

103E.315 ASSESSMENT OF DRAINAGE BENEFITS AND DAMAGES.

Subdivision 1. **State land.** Property owned by the state must have benefits and damages reported in the same manner as taxable lands subject to the provisions relating to conservation areas in section 103E.025.

Subd. 2. **Government property.** The viewers shall report the benefits and damages to the state, counties, and municipalities from the proposed drainage project. The property within the jurisdiction of a municipality, whether owned by the municipality or by private parties, may be assessed as benefits and damages to the municipality.

Subd. 3. **Public roads.** If a public road or street is benefited or damaged, the state, county, or political subdivision that is the governmental unit with the legal duty of maintaining the road or street, must be assessed benefits or damages to the road or street, except that benefits and damages for bridges and culverts must be assessed to the governmental unit that has the legal duty to construct and maintain the bridge or culvert under section 103E.525.

Subd. 4. **Railway and other utilities.** The viewers shall report the benefits and damages to railways and other utilities, including benefits and damages to property used for railway or other utility purposes.

Subd. 5. **Extent and basis of benefits.** (a) The viewers shall determine the amount of benefits to all property within the watershed, whether the property is benefited immediately by the construction of the proposed drainage project or the proposed drainage project can become an outlet for drainage, makes an outlet more accessible, or otherwise directly benefits the property. The benefits may be based on:

(1) an increase in the current market value of property as a result of constructing the project;

(2) an increase in the potential for agricultural production as a result of constructing the project; or

(3) an increased value of the property as a result of a potential different land use.

(b) Benefits and damages may be assessed only against the property benefited or damaged or an easement interest in property for the exclusive use of the surface of the property.

Subd. 6. **Benefits for proposed drainage project as outlet.** (a) If the proposed drainage project furnishes an outlet to an existing drainage system and benefits the property drained by the existing system, the viewers shall equitably determine and assess:

(1) the benefits of the proposed drainage project to each tract or lot drained by the existing drainage system;

(2) a single amount as an outlet benefit to the existing drainage system; or

(3) benefits on a watershed acre basis.

(b) Assessments that conform with the provisions in this subdivision are valid. If a single sum is assessed as an outlet benefit, the lien for the assessment must be prorated on all property benefited by the existing drainage system in proportion to the benefits determined for the existing drainage system.

(c) Within the watershed that drains to the area where a project is located, the viewers may assess outlet benefits on:

(1) property that is responsible for increased sedimentation in downstream areas of the watershed; and

(2) property that is responsible for increased drainage system maintenance or increased drainage system capacity because the natural drainage on the property has been altered or modified to accelerate the drainage of water from the property.

Subd. 7. **Benefits for project that increases drainage capacity.** If part of a drainage project increases drainage capacity and the increased capacity is necessary due to increased drainage in the project watershed rather than increased drainage in a specific area, the viewers may assess benefits on property in the project watershed on a pro rata basis.

Subd. 8. **Extent of damages.** Damages to be paid may include:

(1) the fair market value of the property required for the channel of an open ditch and the permanent strip of perennial vegetation under section 103E.021;

(2) the diminished value of a farm due to severing a field by an open ditch;

(3) loss of crop production during drainage project construction;

(4) the diminished productivity or land value from increased overflow; and

(5) costs to restore a perennial vegetative cover or structural practice existing under a federal or state conservation program adjacent to the permanent drainage system right-of-way and damaged by the drainage project.

History: *1990 c 391 art 5 s 51; 2007 c 57 art 1 s 112*

103E.321 VIEWERS' REPORT.

Subdivision 1. **Requirements.** The viewers' report must show, in tabular form, for each lot, 40-acre tract, and fraction of a lot or tract under separate ownership that is benefited or damaged:

(1) a description of the lot or tract, under separate ownership, that is benefited or damaged;

(2) the names of the owners as they appear on the current tax records of the county and their addresses;

(3) the number of acres in each tract or lot;

(4) the number and value of acres added to a tract or lot by the proposed drainage of public waters;

(5) the damage, if any, to riparian rights;

(6) the damages paid for the permanent strip of perennial vegetation under section 103E.021;

(7) the total number and value of acres added to a tract or lot by the proposed drainage of public waters, wetlands, and other areas not currently being cultivated;

(8) the number of acres and amount of benefits being assessed for drainage of areas which before the drainage benefits could be realized would require a public waters work permit to work in public waters under section 103G.245 to excavate or fill a navigable water body under United States Code, title 33, section 403, or a permit to discharge into waters of the United States under United States Code, title 33, section 1344;

(9) the number of acres and amount of benefits being assessed for drainage of areas that would be considered conversion of a wetland under United States Code, title 16, section 3821, if the area was placed in agricultural production;

(10) the amount of right-of-way acreage required; and

(11) the amount that each tract or lot will be benefited or damaged.

Subd. 2. **Benefits and damages statement.** (a) The viewers' report must include a benefits and damages statement that shows for each property owner how the benefits or damages for similar tracts or lots were determined. For similar tracts or lots the report must describe:

(1) the existing land use, property value, and economic productivity;

(2) the potential land use, property value, and economic productivity after the drainage project is constructed; and

(3) the benefits or damages from the proposed drainage project.

(b) The soil and water conservation districts and county assessors shall cooperate with viewers to provide information required under paragraph (a).

Subd. 3. **Disagreement of viewers.** If the viewers are unable to agree, each viewer shall separately state findings on the disputed issue. A majority of the viewers may perform the required duties under this chapter.

Subd. 4. **Filing.** When the viewers complete their duties, they shall file the viewers' report with the auditor of each affected county. A detailed statement must be filed with the viewers' report showing the actual time the viewers were engaged and the costs incurred. The viewers shall perform their duties and complete the viewers' report as soon as possible after their first meeting.

History: *1990 c 391 art 5 s 52; 2007 c 57 art 1 s 113*

103E.323 PROPERTY OWNERS' REPORT.

Subdivision 1. **Report.** Within 30 days after the viewers' report is filed, the auditor must make a property owners' report from the information in the viewers' report showing for each property owner benefited or damaged by the proposed drainage project:

(1) the name and address of the property owner;

(2) each lot or tract and its area that is benefited or damaged;

(3) the total number and value of acres added to a tract or lot by the proposed drainage of public waters, wetlands, and other areas not currently being cultivated;

(4) the number of acres and amount of benefits being assessed for drainage of areas which before the drainage benefits could be realized would require a public waters work permit to work in public waters under section 103G.245 to excavate or fill a navigable water body under United States Code, title 33, section 403, or a permit to discharge into waters of the United States under United States Code, title 33, section 1344;

(5) the number of acres and amount of benefits being assessed for drainage of areas that would be considered conversion of a wetland under United States Code, title 16, section 3821, if the area was placed in agricultural production;

(6) the damage, if any, to riparian rights;

(7) the amount of right-of-way acreage required;

(8) the amount that each tract or lot will be benefited or damaged;

(9) the net damages or benefits to each property owner;

(10) the estimated cost to be assessed to the property owner based on the cost of the drainage project in the engineer's detailed survey report; and

(11) a copy of the benefits and damages statement under section 103E.321, subdivision 2, paragraph (a), relating to the property owner.

Subd. 2. **Mailing.** The auditor must mail a copy of the property owners' report to each owner of property affected by the proposed drainage project, and may prepare and file an affidavit of mailing.

History: *1990 c 391 art 5 s 53*

FINAL HEARING

103E.325 FINAL HEARING NOTICE.

Subdivision 1. **Time.** Promptly after the filing of the viewers' report and the commissioner's final advisory report, the drainage authority after consulting with the auditor shall set a time and location for the final hearing on the petition, the detailed survey report, and the viewers' report. The hearing must be set 25 to 50 days after the date of the final hearing notice.

Subd. 2. **Notice.** (a) The final hearing notice must state:

(1) that the petition is pending;

(2) that the detailed survey report is filed;

(3) that the viewers' report is filed;

(4) the time and place set for the final hearing;

(5) a brief description of the proposed drainage project and affected drainage system, giving in general terms the starting point, terminus, and general course of the main ditch and branches;

(6) a description of property benefited and damaged, and the names of the owners of the property; and

(7) the municipal and other corporations affected by the proposed drainage project as shown by the detailed survey report and viewers' report.

(b) Names may be listed in a narrative form and property affected may be separately listed in narrative form by governmental sections or otherwise.

(c) For a joint county proceeding, separate notice may be prepared for each county affected, showing the portion of the proposed drainage project and the names and descriptions of affected property in the county.

Subd. 3. **Method of notice.** The auditor shall notify the drainage authority, auditors of affected counties, and all interested persons of the time and location of the final hearing by publication, posting, and mail. A printed copy of the final hearing notice for each affected county must be posted at least three weeks before the date of the final hearing at the front door of the courthouse in each county. Within one week after the first publication of the notice, the auditor shall give notice by mail of the time and location of the final hearing to the commissioner, all property owners, and others affected by the proposed drainage project and listed in the detailed survey report and the viewers' report.

Subd. 4. **Defective notice.** If the final hearing notice is not given or is not legally given, the auditor shall properly publish, post, and mail the notice or provide the notice under the provisions to cure defective notice in section 103E.035.

History: *1990 c 391 art 5 s 54*

103E.331 JURISDICTION OF PROPERTY BY DRAINAGE AUTHORITY.

After the final hearing notice is given, the drainage authority has jurisdiction of all property described in the detailed survey report and viewers' report, of the persons and municipalities named in the reports, and of persons having an interest in a mortgage, lien, or encumbrance against property described in the reports.

History: *1990 c 391 art 5 s 55*

103E.335 PROCEEDINGS AT THE FINAL HEARING.

Subdivision 1. **Consideration of petition and reports.** At the time and location for the final hearing specified in the notice, or after the hearing adjourns, the drainage authority shall consider the petition for the drainage project, with all matters pertaining to the detailed survey report, the viewers' report, and the commissioner's final advisory report. The drainage authority shall hear and consider the testimony presented by all interested parties. The engineer or the engineer's assistant and at least one viewer shall be present. The director may appear and be heard. If the director does not appear personally, the final advisory report shall be read during the hearing. The final hearing may be adjourned and reconvened as is necessary.

Subd. 2. **Changes in drainage plan.** If the drainage authority determines that the general plan reported by the engineer may be improved by changes, or that the viewers have made an inequitable assessment of benefits or damages to any property, the drainage authority may amend the detailed survey report or the viewers' report, and make necessary and proper findings in relation to the reports. The drainage authority may resubmit matters to the engineer or to the viewers for immediate consideration. The engineer or viewers shall proceed promptly to reconsider the resubmitted matters and shall make and file the amended findings and reports. The amended reports are a part of the original reports.

Subd. 3. **Reexamination.** If the drainage authority determines that property not included in the notice should be included and assessed or that the engineer or viewers, or both, should reexamine the proposed drainage project or the property benefited or damaged by the system, the drainage authority may resubmit the reports to the engineer and viewers. If a report is resubmitted, the final hearing may be continued as is necessary to make the reexamination and reexamination report. If the reexamination report includes property not included in the original report, the drainage authority may, by order, adjourn the hearing and direct the auditor to serve or publish, post, and mail a final hearing notice with reference to all property not included in the previous notice. The jurisdiction of the drainage authority continues in the property given proper notice, and new or additional notice is not required for that property.

History: *1990 c 391 art 5 s 56*

103E.341 DRAINAGE AUTHORITY FINAL ORDER.

Subdivision 1. **Dismissal of proceedings.** The drainage authority must dismiss the proceedings and petition, by order, if it determines that:

(1) the benefits of the proposed drainage project are less than the total cost, including damages awarded;

(2) the proposed drainage project will not be of public benefit and utility; or

(3) the proposed drainage project is not practicable after considering the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1.

Subd. 2. **Establishment of proposed drainage project.** (a) The drainage authority shall establish, by order, a proposed drainage project if it determines that:

(1) the detailed survey report and viewers' report have been made and other proceedings have been completed under this chapter;

(2) the reports made or amended are complete and correct;

(3) the damages and benefits have been properly determined;

(4) the estimated benefits are greater than the total estimated cost, including damages;

(5) the proposed drainage project will be of public utility and benefit, and will promote the public health; and

(6) the proposed drainage project is practicable.

(b) The order must contain the drainage authority's findings, adopt and confirm the viewers' report as made or amended, and establish the proposed drainage project as reported and amended.

History: *1990 c 391 art 5 s 57; 2014 c 164 s 13*

103E.345 APPORTIONMENT OF COST FOR JOINT COUNTY DRAINAGE SYSTEMS.

For joint county proceedings, the auditor where the petition is filed shall file a certified copy of the viewers' report with the auditor of each affected county within 20 days after the date of the final order establishing the system. When the final order to establish the drainage project is made, the drainage authority shall determine and order the percentage of the cost of the drainage project to be paid by each affected county. The cost shall be in proportion to the benefits received, unless there is a contrary reason. An auditor of an affected county may petition the drainage authority after the final order is made to determine and order the percentage of costs to be paid by the affected counties. The drainage authority shall hold a hearing five days after giving written notice to the auditor of each affected county. After giving the notice to the auditors of the affected counties, the drainage authority may, at any time that it is necessary, modify an order or make an additional order to allocate the cost among the affected counties.

History: *1990 c 391 art 5 s 58*

REDETERMINATION OF BENEFITS

103E.351 REDETERMINATION OF BENEFITS AND DAMAGES.

Subdivision 1. **Conditions to redetermine benefits and damages; appointment of viewers.** If the drainage authority determines that the original benefits or damages determined in a drainage proceeding do not reflect reasonable present day land values or that the benefited or damaged areas have changed, or if more than 50 percent of the owners of property benefited or damaged by a drainage system petition for correction of an error that was made at the time of the proceedings that established the drainage system, the drainage authority may appoint three viewers to redetermine and report the benefits and damages and the benefited and damaged areas.

Subd. 2. **Hearing and procedure.** (a) The redetermination of benefits and damages shall proceed as provided for viewers and the viewers' report in sections 103E.311 to 103E.321.

(b) The auditor must prepare a property owners' report from the viewers' report. A copy of the property owners' report must be mailed to each owner of property affected by the drainage system.

(c) The drainage authority shall hold a final hearing on the report and confirm the benefits and damages and benefited and damaged areas. The final hearing shall proceed as provided under sections 103E.325, 103E.335, and 103E.341, except that the hearing shall be held within 30 days after the property owners' report is mailed.

Subd. 3. **Redetermined benefits and damages replace original benefits and damages.** The redetermined benefits and damages and benefited and damaged areas must be used in place of the original benefits and damages and benefited and damaged areas in all subsequent proceedings relating to the drainage system.

Subd. 4. **Appeal.** A person aggrieved by the redetermination of benefits and damages and benefited and damaged areas may appeal from the order confirming the benefits and damages and benefited and damaged areas under section 103E.091.

History: *1990 c 391 art 5 s 59*

OUTLETS FOR DRAINAGE SYSTEMS

103E.401 USE OF DRAINAGE SYSTEM AS OUTLET.

Subdivision 1. **Commissioner must recognize drainage outlet proceedings when purchasing wetlands.** If the commissioner purchases wetlands under section 97A.145, the commissioner must recognize that when a majority of landowners or owners of a majority of the land in the watershed petition for a drainage outlet, the state should not interfere with or unnecessarily delay the drainage proceedings if the proceedings are conducted according to this chapter.

Subd. 2. **Express authority necessary.** After the construction of a drainage project, a public or private drainage system that drains property not assessed for benefits for the established drainage system may not be constructed to use the established drainage system as an outlet without obtaining express authority from the drainage authority having jurisdiction over the drainage system proposed to be used as the outlet. This section is applicable to the construction of a public or private drainage system that outlets water into an established drainage system regardless of the actual physical connection.

Subd. 3. **Petition.** A person seeking authority to use an established drainage system as an outlet must petition the drainage authority. When the petition is filed, the drainage authority in consultation with the auditor shall set a time and location for a hearing on the petition and shall give notice by mail and notice by publication of the hearing. The auditor must be paid the actual costs for the hearing notices by the petitioner.

Subd. 4. **Hearing.** At the hearing the drainage authority shall consider the capacity of the outlet drainage system. If express authority is given to use the drainage system as an outlet, the drainage authority shall state, by order, the terms and conditions for use of the established drainage system as an outlet and shall set the amount to be paid as an outlet fee. The order must describe the property to be benefited by the drainage system and must state the amount of benefits to the property for the outlet. The property benefited is liable for assessments levied after that time in the drainage system, on the basis of the benefits as if the benefits had been determined in the order establishing the drainage system.

Subd. 5. **Private drainage system; outlet fee required.** A private drainage system may not be constructed to use the established drainage system as an outlet until the outlet fee, set by order, is paid by the petitioner to the county treasurer where the petitioner's property is located.

Subd. 6. **Payment of outlet fee.** The outlet fee for a proposed drainage project is a part of the cost of the proposed drainage project and is to be paid by assessment against the property benefited by the proposed drainage project, under section 103E.601, and credited to the established drainage system account.

Subd. 7. **Unauthorized outlet into drainage system.** (a) The drainage authority must notify an owner of property where an unauthorized outlet into a drainage system is located and direct the property owner to block the outlet or otherwise make the outlet ineffective by a specified time. The outlet must be blocked and remain ineffective until:

(1) an outlet fee is paid, which is determined by the drainage authority based on the benefits received by the property for the period the unauthorized outlet was operational; and

(2) the drainage authority approves a petition for the outlet and establishes the outlet fee.

(b) If a property owner does not block or make the outlet ineffective after being notified, the drainage authority must issue an order to have the work performed to bring the outlet into compliance. After the work is completed, the drainage authority must send a statement to the auditor of the county where the property is located and to the property owner where the unauthorized outlet is located, containing the expenses incurred to bring the outlet into compliance and the outlet fee based on the benefits received by the property during the period the unauthorized outlet was operational.

Subd. 8. **Collection of unauthorized outlet compliance expenses.** (a) The amount of the expenses and outlet fee is a lien in favor of the drainage authority against the property where the unauthorized outlet is located. The auditor must certify the expenses and outlet fee and enter the amount in the same manner as other drainage liens on the tax list for the following year. The amount must be collected in the same manner as real estate taxes for the property. The provisions of law relating to the collection of real estate taxes shall be used to enforce payment of amounts due under this section. The auditor must include a notice of collection of unauthorized outlet compliance expenses with the tax statement.

(b) The amounts collected under this subdivision must be deposited in the drainage system account.

History: *1990 c 391 art 5 s 60; 2010 c 298 s 4*

103E.405 OUTLETS IN ADJOINING STATES.

In any drainage proceeding, at the hearing on the detailed survey report and viewers' report, if the drainage authority determines that a proper outlet for the drainage system does not exist except through property in an adjoining state, the drainage authority may adjourn the hearing. If the hearing is adjourned the drainage authority shall require the auditor or, for a joint county drainage system, the auditors of affected counties to procure an option to acquire the needed right-of-way at an expense not exceeding the estimated cost specified in the detailed survey report. The order establishing the drainage project may not be made until the option is procured. If the option is procured and the drainage project established, the option shall be exercised and the cost of the right-of-way shall be paid as a part of the cost of the drainage project.

History: *1990 c 391 art 5 s 61*

103E.411 DRAINAGE SYSTEM AS OUTLET FOR MUNICIPALITY.

Subdivision 1. **Petition.** A municipality may use a drainage system as an outlet for its municipal drainage system or the overflow from the system under the provisions of this section. The municipality must petition to the drainage authority to use the drainage system. The petition must:

(1) show the necessity for the use of the drainage system as an outlet;

(2) show that the use of the drainage system will be of public benefit and utility and promote the public health;

(3) be accompanied by a plat showing the location of the drainage system and the location of the municipal drainage system; and

(4) be accompanied by specifications showing the plan of connection from the municipal drainage system to the drainage system.

Subd. 2. **Approval by Pollution Control Agency.** The plan for connecting the municipal drainage system to the drainage system must be approved by the Pollution Control Agency.

Subd. 3. **Filing; notice.** (a) If proceedings to establish the drainage project to be used as an outlet are pending, the petition must be filed with the auditor. The municipal drainage system petition must be presented to the drainage authority at the final hearing to consider the detailed survey report and viewers' report. Notice of the municipal drainage system petition must be included in the final hearing notice.

(b) If the drainage system to be used as an outlet is established, the municipal drainage system petition must be filed with the auditor. When the petition is filed, the drainage authority in consultation with the auditor shall, by order, set a time and place for hearing on the petition. Notice of the hearing must be given by publication and by mailed notice to the auditor of each affected county.

Subd. 4. **Hearing and order.** (a) At the hearing the drainage authority may receive all evidence of interested parties for or against the granting of the petition. The drainage authority, by order, may authorize the municipality to use the drainage system as an outlet, subject to the conditions that are necessary and proper to protect the rights of the parties and safeguard the interests of the general public, if the drainage authority determines:

(1) that a necessity exists for the use of the drainage system as an outlet for the municipal drainage system or the overflow from the system;

(2) that use of the drainage system will be of public utility and promote the public health; and

(3) that the proposed connection conforms to the requirements of the Pollution Control Agency and provides for the construction and use of proper disposal works.

(b) The drainage authority must, by order, make the municipality a party to the drainage proceedings and determine the benefits from using the drainage project or system as an outlet.

Subd. 5. **Benefits and assessments if drainage system established.** If the drainage system is established, the drainage authority must determine the amount the municipality must pay for the privilege of using the drainage system as an outlet. The amount must be paid to the affected counties and credited to the account of the drainage system used as an outlet. The municipality is liable for all subsequent liens and assessments for the repair and maintenance of the drainage system in proportion to the benefits, as though the benefits were determined in the order establishing the drainage system.

History: *1990 c 391 art 5 s 62*

CONSTRUCTION OF DRAINAGE PROJECT

103E.501 CONTRACT AND BOND.

Subdivision 1. **Preparation.** The county attorney, the engineer, and the attorney for the petitioners shall prepare the contract and bond. The contract and bond must include the provisions required by this chapter and section 574.26 for bonds given by contractors for public works and must be conditioned as provided by section 574.26 for the better security of the contracting counties and parties performing labor and furnishing material in performance of the contract. The prepared contract and bond must be attached and provided to the contractor for execution.

Subd. 2. **Contractor's bond.** The contractor shall file a bond with the auditor for an amount not less than 75 percent of the contract price of the work. The bond must have adequate surety and be approved by the auditor. The bond must provide that the surety for the bond is liable for all damages resulting from a failure to perform work under the contract, whether the work is resold or not, and that any person or political subdivision showing damages from the failure to perform work under the contract may maintain an action against the bond in their own names. Actions may be successive in favor of all persons injured, but the aggregate liability of the surety for all the damages may not exceed the amount of the bond. The surety is liable for the tile work guaranteed by the contractor. The contractor is considered a public officer and the bond an official bond within the meaning of section 574.24 construing the official bonds of public officers as security to all persons and providing for actions on the bonds by a party that is damaged.

Subd. 3. **Contract.** The contract must contain a specific description of the work to be done, either expressly or by reference to the plans and specifications, and must provide that the work must be done and completed as provided in the plans and specifications and subject to the inspection and approval of the engineer. The contract must provide that time is of the essence of the contract, and that if there is a failure to perform the work according to the terms of the contract within the time given in the original contract or as extended, the contractors shall forfeit and pay the affected counties an amount stated in the contract as liquidated damages. The amount must be fixed by the auditor for each day that the failure of performance continues.

Subd. 4. **Contract provisions for changes during construction.** The contract must give the engineer the right, with the consent of the drainage authority, to modify the detailed survey report, plans, and specifications as the work proceeds and as circumstances require. The contract must provide that the increased cost resulting from the changes will be paid by the drainage authority to the contractor at a rate not greater than the amount for similar work in the contract. A change may not be made that will substantially impair the usefulness of any part of the drainage project or system, substantially alter its original character, or increase its total cost by more than ten percent of the total original contract price. A change may not be made that will cause the cost to exceed the total estimated benefits found by the drainage authority or that will cause any detrimental effects to the public interest under the environmental, land use, and multipurpose water management criteria in section 103E.015, subdivision 1.

Subd. 5. **Contract with federal unit.** If any portion of the work is to be done by the United States or an agency of the United States, a bond or contract is not necessary for that portion of the work, except that a contract must be made if the United States or its agencies require a contract with the local governmental units. The contract must contain the terms, conditions, provisions, and guaranties required by the United States or its agencies to proceed with the work.

Subd. 6. **Guaranty of tile work.** If tile is used to construct any part of the drainage project, a majority of the persons affected may file a written request with the auditor to contract the tile work separately. The request must be filed before advertising for the sale of the work has begun. If the request is properly made, the tile work must be contracted separately. The contractor must guarantee the tile work under the contract for three years after its completion against any fault or negligence on the part of the contractor. The advertisement for bids must include this requirement.

Subd. 7. **Modification of contract by agreement.** This chapter does not prevent the persons with property affected by the construction of a drainage project from uniting in a written agreement with the contractor and the surety of the contractor's bond to modify the contract as to the manner or time when any portion of the drainage project is constructed, if the modification is recommended, in writing, by the engineer and approved by the drainage authority.

History: *1990 c 391 art 5 s 63; 2014 c 164 s 14*

103E.505 AWARDING CONSTRUCTION CONTRACT.

Subdivision 1. **Auditors and drainage authority to proceed.** Thirty days after the order establishing a drainage project is filed, the auditor and the drainage authority or, for a joint county drainage project, a majority of the auditors of the affected counties shall proceed to award the contract to construct the drainage project.

Subd. 2. **Pending appeal of benefits and damages.** If an appeal regarding the determination of benefits and damages is made within 30 days after the order establishing the drainage project has been filed, a contract may not be awarded until the appeal has been determined, unless the drainage authority orders the contract awarded. The auditor of an affected county or an interested person may request the drainage authority to make the order. If the request is not made by an affected auditor, the auditors of affected counties must be given notice five days before the hearing on the request.

Subd. 3. **Notice of contract awarding.** The auditor of an affected county shall give notice of the awarding of the contract by publication in a newspaper in the county. The notice must state the time and location for awarding the contract. For a joint county drainage project the auditors shall award the contract at the office of the auditor where the proceedings are pending. If the estimated cost of construction is more than $25,000, the auditor must also place a notice in a drainage construction trade newspaper. The trade newspaper notice must state:

(1) the time and location for awarding the contract;

(2) the approximate amount of work and its estimated cost;

(3) that bids may be for the work as one job, or in sections, or separately, for bridges, ditches and open work, tile, or tile construction work, if required or advisable;

(4) that each bid must be accompanied by a certified check or a bond furnished by an approved surety corporation payable to the auditors of affected counties for ten percent of the bid, as security that the bidder will enter into a contract and give a bond as required by section 103E.501; and

(5) that the drainage authority reserves the right to reject any and all bids.

Subd. 4. **Engineer shall attend awarding of contract.** The engineer shall attend the meeting to award the contract. A bid may not be accepted without the engineer's approval of the bidder's compliance with plans and specifications.

Subd. 5. **How contract may be awarded.** The contract may be awarded in one job, in sections, or separately for labor and material and may be let to the lowest responsible bidder. Alternatively, the contract may be awarded to the vendor or contractor offering the best value under a request for proposals as described in section 16C.28, subdivision 1, paragraph (a), clause (2), and paragraph (c).

Subd. 6. **Bids exceeding 130 percent of estimated cost not accepted.** Bids that in the aggregate exceed the total estimated cost of construction by more than 30 percent may not be accepted.

Subd. 7. **Affected counties contract through auditor.** The chair of the drainage authority and the auditor of each affected county shall contract, in the names of their respective counties, to construct the drainage project in the time and manner and according to the plans and specifications and the contract provisions in this chapter.

Subd. 8. **Work done by federal government.** If any of the drainage work is to be done by the United States or its agencies, a notice of awarding that contract does not need to be published and a contract for that construction is not necessary. Affected municipalities may contract or arrange with the United States or its agencies for cooperation or assistance in constructing, maintaining, and operating the drainage project and system, for control of waters in the district, or for making a survey and investigation or reports on the drainage project or system. The municipalities may provide required guaranty and protection to the United States or its agencies.

History: *1990 c 391 art 5 s 64; 2007 c 148 art 3 s 10; 2010 c 298 s 5*

103E.511 PROCEDURE IF CONTRACT NOT AWARDED DUE TO BIDS OR COSTS.

Subdivision 1. **Applicability.** The procedure in this section may be used if, after a drainage system is established:

(1) the only bids received are for more than 30 percent in excess of the engineer's estimated cost, or in excess of the benefits, less damages and other costs; or

(2) a contract is awarded, but due to unavoidable delays not caused by the contractor, the contract cannot be completed for an amount equal to or less than the benefits, less damages and other costs.

Subd. 2. **Petition after cost estimate error or change to lower cost.** A person interested in the drainage project may petition the drainage authority if the person determines that the engineer made an error in the estimate of the drainage project cost or that the plans and specifications could be changed in a manner materially affecting the cost of the drainage system without interfering with efficiency. The petition must state the person's determinations and request that the detailed survey report and viewers' report be referred back to the engineer and to the viewers for additional consideration.

Subd. 3. **Petition after excessive cost due to inflation.** (a) A person interested in the drainage project may petition the drainage authority for an order to reconsider the detailed survey report and viewers' report if the person determines:

(1) that bids were received only for a price more than 30 percent in excess of the detailed survey report estimate because inflation increased the construction cost between the time of the detailed survey cost estimate and the time of awarding the contract; or

(2) that after the contract was awarded there was unavoidable delay not caused by the contractor, and between the time of awarding the contract and completion of construction inflation increased construction costs resulting in the contract not being completed for an amount equal to or less than the assessed benefits.

(b) The person may request in the petition that the drainage authority reconsider the original cost estimate in the detailed survey report and viewers' report and adjust the cost estimate consistent with the increased construction cost.

Subd. 4. **Hearing ordered after receipt of petition.** After receiving a petition, the drainage authority shall order a hearing. The order must designate the time and place of the hearing and direct the auditor to give notice by publication.

Subd. 5. **Hearing on cost petition.** (a) At the hearing the drainage authority shall consider the petition and hear all interested parties.

(b) The drainage authority may, by order, authorize the engineer to amend the detailed survey report, if the drainage authority determines that:

(1) the detailed survey report cost estimate was erroneous and should be corrected;

(2) the plans and specifications could be changed in a manner materially affecting the cost of the drainage project without interfering with efficiency; and

(3) with the correction or modification a contract could be awarded within the 30 percent limitation and equal to or less than benefits.

(c) If the drainage authority determines that the amended changes affect the amount of benefits or damages to any property or that the benefits should be reexamined because of inflated land values or inflated construction costs, it shall refer the viewers' report to the viewers to reexamine the benefits and damages.

(d) The drainage authority may, by order, direct the engineer and viewers to amend their detailed survey report and viewers' report to consider the inflationary cost increases if the drainage authority determines that:

(1) bids were not received; or

(2) because of inflationary construction cost increases, construction under the awarded contract cannot be completed for 30 percent or less over the detailed survey cost estimate or in excess of the benefits, less damages and other costs.

(e) The drainage authority may continue the hearing to give the engineer or viewers additional time to amend the reports. The jurisdiction of the drainage authority continues at the adjourned hearing.

(f) The drainage authority has full authority to consider the amended reports and make findings and orders. A party may appeal to the district court under section 103E.091, subdivision 1.

History: *1990 c 391 art 5 s 65*

103E.515 DAMAGES, PAYMENT.

The board of each county where the damaged property is located must order the awarded damages to be paid, less any assessment against the property, before the property is entered for construction of the drainage project. If a county or a municipality that is awarded damages requests it, the assessment may not be deducted. If there is an appeal, the damages may not be paid until the final determination. If it is not clear who is entitled to the damages, the board may pay the damages to the court administrator of the district court of the county. The court shall direct the court administrator, by order, to pay the parties entitled to the damages.

History: *1990 c 391 art 5 s 66*

103E.521 SUPERVISION OF CONSTRUCTION.

The drainage authority shall require the engineer to supervise and inspect the construction under contract. The drainage authority shall cause the contracts under this chapter to be performed properly.

History: *1990 c 391 art 5 s 67*

103E.525 CONSTRUCTION AND MAINTENANCE OF BRIDGES AND CULVERTS.

Subdivision 1. **Hydraulic capacity.** A public or private bridge or culvert may not be constructed or maintained across or in a drainage system with less hydraulic capacity than specified in the detailed survey report, except with the written approval of the director. If the detailed survey report does not specify the hydraulic capacity, a public or private bridge or culvert in or across a drainage system ditch may not be constructed without the director's approval of the hydraulic capacity.

Subd. 2. **Road authority responsible for construction.** Bridges and culverts on public roads required by the construction or improvement of a drainage project or system must be constructed and maintained by the road authority responsible for keeping the road in repair, except as provided in this section.

Subd. 3. **Notice; charging cost.** The auditor shall notify the state and each railroad company, corporation, or political subdivision that they are to construct a required bridge or culvert on a road or right-of-way under their jurisdiction, within a reasonable time as stated in the notice. If the work is not done within the prescribed time, the drainage authority may order the bridge or culvert constructed as part of the drainage project construction. The cost must be deducted from the damages awarded to the corporation or collected from it as an assessment for benefits. If the detailed survey report or viewers' report shows that the construction of the bridge or culvert is necessary, the drainage authority may, by order, retain an amount to secure the construction of the bridge or culvert from amounts to be paid to a railroad, corporation, or political subdivision.

Subd. 4. **Construction on line between two cities paid equally.** The costs of constructing a bridge or culvert that is required by construction of a drainage project on a public road that is not a state trunk highway on the line between two statutory or home rule charter cities, whether in the same county or not, must be paid jointly, in equal shares, by the cities. The cities shall pay jointly, in equal shares, for the cost of maintaining the bridge or culvert.

Subd. 5. **Construction on town and county lines.** The cost of constructing and maintaining bridges and culverts on a town or county road across a drainage system ditch constructed along the boundary line between towns or counties, with excavated material deposited on the boundary line or within 33 feet of the line, must be paid equally by the town or county where the bridge or culvert is located and the other town or county adjoining the boundary.

History: *1990 c 391 art 5 s 68; 2013 c 4 s 11*

103E.526 CONSTRUCTION OF ROAD INSTEAD OF BRIDGE OR CULVERT.

If the drainage authority finds that constructing a private road would be more cost-effective or practical than constructing a bridge or culvert, the drainage authority may order that a private road be constructed. The private road must be constructed and maintained in the same manner as a bridge or culvert. The private road must be constructed in a manner suitable for farm vehicles but may not have a right-of-way wider than 33 feet. The drainage authority has jurisdiction over the land required for the private road and the road is part of the drainage system.

History: *1990 c 391 art 5 s 69*

103E.53 RULES TO STANDARDIZE FORMS.

The director may adopt rules to standardize the forms and sizes of maps, plats, drawings, and specifications in drainage proceedings. The director must require the permanent grass strips acquired under section 103E.021 to be shown on the maps and maintain an inventory of all permanent grass strips acquired by drainage authorities.

History: *1990 c 391 art 5 s 70*

103E.531 INSPECTION OF DRAINAGE CONSTRUCTION AND PARTIAL PAYMENTS.

Subdivision 1. **Inspection and report.** The engineer shall inspect and require the work as it is being completed to be done in accordance with the plans, specifications, and contract for construction. Each month during the work, the engineer shall report to the drainage authority, in writing, showing the work completed since the previous report and all materials furnished under the contract.

Subd. 2. **Preliminary certificate.** The engineer shall issue with the monthly report a preliminary certificate for work done and approved or materials delivered. The certificate must contain the station numbers of the work covered by the certificate and the total value of all work done and the materials furnished according to the contract. For each ditch section, the certificate must show the actual volume, in cubic yards, of the excavation completed. For joint county drainage systems the certificate must also show the percentage of the total value to be paid by each county in the proportion fixed by the drainage authority order. Each certificate must show that a loss will not occur as a result of a partial payment. A duplicate of the certificate must be delivered to the auditor of each affected county.

Subd. 3. **Partial payment.** The affected counties must pay the contractor, based on the certificate, 90 percent of the total value of work done and approved and 90 percent of the total value of material furnished and delivered. The materials may only be delivered as required in the course of construction and authorized by the engineer.

History: *1990 c 391 art 5 s 71*

103E.535 PARTIAL PAYMENT OF RETAINED CONTRACT AMOUNTS.

Subdivision 1. **Petition for partial payment of retained value.** If a single contract exceeds $50,000, and the contract, exclusive of materials furnished and not installed, is one-half or more complete and the contractor is not in default, the contractor may file a verified petition with the auditor stating these facts and requesting that an order be made to pay 40 percent of the retained value of work and material.

Subd. 2. **Notice of hearing.** When the petition is filed, the auditor shall set a time and location for a hearing on the petition before the drainage authority. At least five days before the date of hearing, the auditor shall give notice by mail of the date and location of hearing to the engineer, the attorney for the petitioners, the surety of the contractor's bond, and auditors of the affected counties.

Subd. 3. **Hearing.** At the hearing the drainage authority shall hear all parties interested. If the drainage authority determines that the facts in the petition are correct, the work has been performed in a satisfactory manner, and a portion of the retained percentage may be released without endangering the interests of affected counties, the drainage authority shall state the findings and may order not more than 40 percent of the retained value of work and material to be paid.

History: *1990 c 391 art 5 s 72*

103E.541 EXTENSION OF TIME ON CONTRACTS.

The auditors of affected counties may extend the time for the performance of a contract as provided in this section. The contractor may apply, in writing, for an extension of the contract. Notice of the application must be given to: (1) the engineer and the attorney for the petitioners; and (2) for a joint county drainage project, to the auditors of the affected counties. The auditors may grant an extension if sufficient reasons are shown. The extension does not affect a claim for liquidated damages that may arise after the original time expires and before an extension or a claim that may arise after the time for the extension expires.

History: *1990 c 391 art 5 s 73*

103E.545 REDUCTION OF CONTRACTOR'S BOND.

Subdivision 1. **Application to drainage authority.** The contractor, at the end of each season's work and before the contract is completed, may make a verified application to the drainage authority to reduce the contractor's bond and file the application with the auditor. The application must state:

(1) the work certified as completed by the engineer;

(2) the value of the certified work;

(3) the amount of money received by the contractor and the amount retained by the drainage authority;

(4) the amount unpaid by the contractor for labor or material furnished on the contract; and

(5) a request for an order to reduce the amount of the contractor's bond.

The application must be filed with the auditor.

Subd. 2. **Notice of hearing.** When an application is filed, the auditor, by order, shall set the time and location for a hearing on the application. Ten days before the hearing, notice of the hearing must be published in each affected county and notice by mail given to the engineer, the attorney for the petitioners, and the auditor of each affected county. The contractor must pay the cost of publishing the hearing notice.

Subd. 3. **Hearing; reduction of bond.** The drainage authority may, by order, reduce the contractor's bond if it determines that the contractor is not in default and that a loss will not result from reducing the bond. The bond may be reduced to an amount sufficient to protect the affected counties from loss and damage, but the reduction:

(1) may not be more than 35 percent of the amount already paid to the contractor;

(2) may not affect the remaining amount of the bond;

(3) does not affect liability incurred on the bond before the reduction; and

(4) does not affect a provision for a three-year guaranty of tile work.

History: *1990 c 391 art 5 s 74*

103E.551 CONTRACTOR'S DEFAULT.

Subdivision 1. **Notice.** If a contractor defaults in the performance of the contract, the auditor shall mail a notice of the default to the contractor, the surety of the contractor's bond, the engineer, and the auditors of the affected counties. The notice must specify the default and state that if the default is not promptly removed and the contract completed, the unfinished portion of the contract will be awarded to another contractor.

Subd. 2. **Completion of contract by surety.** If the surety of the contractor's bond promptly proceeds with the completion of the contract, the affected auditors may grant an extension of time. If the contract is completed by the surety, the balance due on the contract must be paid to the surety, less damages incurred by the affected counties from the default.

Subd. 3. **Awarding of contract; recovery on bond.** If the surety of the contractor's bond does not undertake the completion of the contract or does not complete the contract within the time specified or extended, auditors of the affected counties shall advertise for bids to complete the contract in the manner provided in the original awarding of contracts. The drainage authority may recover the increased amounts paid to a subsequent contractor after reselling the work, and damages incurred by affected counties, from the first contractor's bond.

History: *1990 c 391 art 5 s 75*

103E.555 ACCEPTANCE OF CONTRACT.

Subdivision 1. **Engineer's report and notice.** When a contract is completed, the engineer shall make a report to the drainage authority showing the contract price, the amount paid on certificates, the unpaid balance, and the work that is completed under the contract. When the report is filed, the auditor shall set a time and location for a hearing on the report. The auditor shall give notice of the hearing by publication or notice by mail at least ten days before the hearing to the owners of affected property. The notice must state that the report is filed, the time and location for the hearing, and that a party objecting to the acceptance of the contract may appear and be heard.

Subd. 2. **Hearing.** At the hearing the drainage authority may, by order, direct payment of the balance due if it determines that the contract has been completed in accordance with the plans and specifications. If good cause is shown, the drainage authority may waive any part of the liquidated damages accruing under the contract. When the order is filed, the auditor shall draw a warrant on the treasurer of the county for the balance due on the contract. For a joint county drainage project or system the auditor shall make an order to the auditors of the affected counties to pay for their proportionate shares of the balance due on the contract. After receiving the order, the auditor of each affected county shall draw a warrant on the treasurer of the county for the amount specified in the order.

History: *1990 c 391 art 5 s 76*

FUNDING, COLLECTION, AND PAYMENT OF DRAINAGE SYSTEM COSTS

103E.601 DRAINAGE LIEN STATEMENT.

Subdivision 1. **Determination of property liability.** When the contract for the construction of a drainage project is awarded, the auditor of an affected county shall make a statement showing the total cost of the drainage project with the estimated cost of all items required to complete the work. The cost must be prorated to each tract of property affected in direct proportion to the benefits. The cost, less any damages, is the amount of liability for each tract for the drainage project. The property liability must be shown in the tabular statement as provided in subdivision 2, opposite the property owner's name and description of each tract of property. The amount of liability on a tract of property for establishment and construction of a drainage project may not exceed the benefits determined in the proceedings that accrue to the tract.

Subd. 2. **Drainage lien statement.** The auditor of each affected county shall make a lien statement in tabular form showing:

(1) the names of the property owners, corporate entities, or political subdivisions of the county benefited or damaged by the construction of the drainage project in the viewers' report as approved by the final order for establishment;

(2) the description of the property in the viewers' report, and the total number of acres in each tract according to the county tax lists;

(3) the number of acres benefited or damaged in each tract shown in the viewers' report;

(4) the amount of benefits and damages to each tract of property as stated in the viewers' report and confirmed by the final order that established the drainage project unless the order is appealed and a different amount is set; and

(5) the amount each tract of property will be liable for and must pay to the county for the establishment and construction of the drainage project.

Subd. 3. **Supplemental drainage lien statement.** If any items of the cost of the drainage project have been omitted from the original drainage lien statement, a supplemental drainage lien statement with the omitted items must be made and recorded in the same manner provided for a drainage lien statement. The total amount of the original drainage lien and any supplemental drainage liens may not exceed the benefits.

Subd. 4. **Recording drainage lien statement.** The lien against property in the drainage lien statement and supplemental drainage lien statements must be certified by the auditor and recorded on each tract by the county recorder of the county where the tract is located. The county recorder's fees for recording must be paid if allowed by the board. The drainage lien statement and any supplemental drainage lien statements, after recording, must be returned and preserved by the auditor.

History: *1990 c 391 art 5 s 77*

103E.605 EFFECT OF FILED DRAINAGE LIEN.

The amount recorded from the drainage lien statement and supplemental drainage lien statement that each tract of property will be liable for, and the interest allowed on that amount, is a drainage lien on the property. The drainage lien is a first and paramount lien until fully paid, and has priority over all mortgages, charges, encumbrances, and other liens, unless the board subordinates the drainage lien to liens of record. The recording of the drainage lien, drainage lien statement, or a supplemental drainage lien statement is notice to all parties of the existence of the drainage lien.

History: *1990 c 391 art 5 s 78*

103E.611 PAYMENT OF DRAINAGE LIENS AND INTEREST.

Subdivision 1. **Payment of drainage lien principal.** (a) Drainage liens against property benefited under this chapter are payable to the treasurer of the county in 20 or less equal annual installments. The first installment of the principal is due on or before November 1 after the drainage lien statement is recorded, and each subsequent installment is due on or before November 1 of each year afterwards until the principal is paid.

(b) The drainage authority may, by order, direct the drainage lien to be paid by 1/15 of the principal on or before five years from November 1 after the lien statement is recorded, and 1/15 on or before November 1 of each year afterwards until the principal is paid.

(c) The drainage authority may order that the drainage lien must be paid by one or two installments, notwithstanding paragraphs (a) and (b), if the principal amount of a lien against a lot or tract of property or against a county or municipality is less than $500.

Subd. 2. **Interest.** (a) Interest is an additional drainage lien on all property until paid. The interest rate on the drainage lien principal from the date the drainage lien statement is recorded must be set by the board but may not exceed the rate determined by the state court administrator for judgments under section 549.09.

(b) Before the tax lists for the year are given to the county treasurer, the auditor shall compute the interest on the unpaid balance of the drainage lien at the rate set by the board. The amount of interest must be computed on the entire unpaid principal from the date the drainage lien was recorded to August 15 of the next calendar year, and afterwards from August 15 to August 15 of each year.

(c) Interest is due and payable after November 1 of each year the drainage lien principal or interest is due and unpaid.

Subd. 3. **Collection of payments.** Interest and any installment due must be entered on the tax lists for the year. The installment and interest must be collected in the same manner as real estate taxes for that year by collecting one-half of the total of the installment and interest with and as a part of the real estate taxes.

Subd. 4. **Prepayment of interest.** Interest may be paid at any time, computed to the date of payment, except that after the interest is entered on the tax lists for the year, it is due as entered, without a reduction for prepayment.

Subd. 5. **Payment of drainage liens with bonds.** The board may direct the county treasurer to accept any outstanding bond that is a legal obligation of the county under this chapter issued on account of a drainage lien in payment of drainage liens under the provisions of this chapter. The bonds must be accepted at their par value plus accrued interest.

Subd. 6. **Drainage lien record.** The auditor shall keep a drainage lien record for each drainage project and system showing the amount of the drainage lien remaining unpaid against each tract of property.

Subd. 7. **Collection and enforcement of drainage liens.** The enforcement, collection, penalty, and interest provisions relating to real estate taxes apply to the payment of drainage liens.

History: *1990 c 391 art 5 s 79; 1996 c 471 art 3 s 1; 2010 c 298 s 6*

103E.615 ENFORCEMENT OF ASSESSMENTS.

Subdivision 1. **Municipalities.** Assessments filed for benefits to a municipality are a liability of the municipality and are due and payable with interest in installments on November 1 of each year as provided in section 103E.611. If the installments and interest are not paid on or before November 1, the amount due with interest added as provided in section 103E.611 must be extended by the county auditor against all property in the municipality that is liable to taxation. A levy must be made and the amount due must be paid and collected in the same manner and time as other taxes.

Subd. 2. **County or state-aid road.** If a public road benefited is a county or state-aid road, the assessment filed is against the county and must be paid out of the road and bridge fund of the county.

Subd. 3. **State trunk highway.** An assessment against the state for benefits to trunk highways is chargeable to and payable out of the trunk highway fund. The commissioner of transportation shall pay assessments from the trunk highway fund after receipt of a certified copy of the assessment against the state for benefits to a trunk highway.

Subd. 4. **Assessment for vacated town roads.** If a town is assessed for benefits to a town road in a drainage project proceeding under this chapter and the town road is later vacated by the town board under section 164.07, the town board may petition the drainage authority to cancel the assessment. The drainage authority may cancel the assessment if it finds that the town road for which benefits are assessed has been vacated under section 164.07.

Subd. 5. **State property.** State property, including rural credit property, is assessable for benefits received. The assessment must be paid by the state from funds appropriated and available for drainage assessments after the state officer having jurisdiction over the assessed property certifies the assessment to the commissioner of management and budget.

Subd. 6. [Repealed, 1994 c 561 s 28]

Subd. 7. **Railroad and utility property.** Property owned by a railroad or other utility corporation benefited by a drainage project is liable for the assessments of benefits on the property as other taxable property. From the date the drainage lien is recorded, the amount of the assessment with interest is a lien against all property of the corporation within the county. Upon default the assessment may be collected by civil action or the drainage lien may be foreclosed by action in the same manner as provided by law for the foreclosure of mortgage liens. The county where the drainage lien is filed has the right of action against the corporation to enforce and collect the assessment.

History: *1990 c 391 art 5 s 80; 2009 c 101 art 2 s 109*

103E.621 SATISFACTION OF LIENS.

When a drainage lien with the accumulated interest is fully paid, the auditor shall issue a certificate of payment with the auditor's official seal and record the certificate with the county recorder. The recorded certificate releases and discharges the drainage lien. The auditor may collect 25 cents for each description in the certificate. The auditor's fee and the fee of the county recorder must be paid from the account for the drainage system.

History: *1990 c 391 art 5 s 81*

103E.625 SUBDIVISION BY PLATTING MUST HAVE LIENS APPORTIONED.

A tract of property with a drainage lien that is subdivided by platting is not complete and the plat may not be recorded until the drainage liens against the tracts are apportioned and the apportionment is filed with the county recorder of the county where the tract is located.

History: *1990 c 391 art 5 s 82*

103E.631 APPORTIONMENT OF LIENS.

Subdivision 1. **Petition.** A person who has an interest in property that has a drainage lien attached to it may petition the drainage authority to apportion the lien among specified portions of the tract if the payments of principal and interest on the property are not in default.

Subd. 2. **Notice.** When the petition is filed, the drainage authority shall, by order, set a time and location for a hearing on the petition. The drainage authority shall give notice of the hearing by personal service to the auditor, the occupants of the tract, and all parties having an interest in the tract as shown by the records in the county recorder's office. The service must be made at least ten days before the hearing. If personal service cannot be made to all interested persons, notice may be given by publication. The petitioner shall pay the costs for service or publication.

Subd. 3. **Hearing.** The drainage authority shall hear all related evidence and, by order, apportion the lien. A certified copy of the order must be recorded in the county recorder's office and filed with the auditor.

History: *1990 c 391 art 5 s 83*

103E.635 DRAINAGE BOND ISSUES.

Subdivision 1. **Authority.** After the contract for the construction of a drainage project is awarded, the board of an affected county may issue the bonds of the county in an amount necessary to pay the cost of establishing and constructing the drainage project.

Subd. 2. **Single issue for two or more drainage systems.** The board may include two or more drainage systems in a single drainage bond issue. The total amount of the drainage bond issue may not exceed the total cost, including expenses, to be assessed to pay for the drainage systems. The total cost to be assessed must be determined or estimated by the board when the drainage bonds are issued.

Subd. 3. **Security and source of payment.** The drainage bonds must be issued in accordance with chapter 475 and must pledge the full faith, credit, and resources of the county for the prompt payment of the principal and interest of the drainage bonds. The drainage bonds are primarily payable from the funds of the drainage systems financed by the bonds or from the common drainage bond redemption fund of the county. The common drainage bond redemption fund may be created by resolution of the county board as a debt redemption fund for the payment of drainage bonds issued under this chapter.

Subd. 4. **Payment period and interest on drainage bonds.** (a) The board shall determine, by resolution:

(1) the time of payment for the drainage bonds, not to exceed 23 years from their date of issue;

(2) the rates of interest for the drainage bonds, with the net average rate of interest over the term of the bonds not to exceed the rate established under section 475.55; and

(3) whether the drainage bonds are payable annually or semiannually.

(b) The board shall determine the years and amounts of principal maturities that are necessary by the anticipated collections of the drainage systems assessments, without regard to any limitations on the maturities imposed by section 475.54.

Subd. 5. **Temporary drainage bonds maturing in two years or less.** The board may issue and sell temporary drainage bonds under this subdivision maturing not more than two years after their date of issue, instead of bonds as provided under subdivision 4. The county shall issue and sell definitive drainage bonds before the maturity of bonds issued under this subdivision and use the proceeds to pay for the temporary drainage bonds and interest to the extent that the temporary bonds are not paid for by assessments collected or other available funds. The holders of temporary drainage bonds and the taxpayers of the county have and may enforce by mandamus or other appropriate proceedings:

(1) all rights respecting the levy and collection of assessments sufficient to pay the cost of drainage proceedings and construction financed by the temporary drainage bonds that are granted by law to holders of other drainage bonds, except the right to require levies to be collected before the temporary drainage bonds mature; and

(2) the right to require the offering of definitive drainage bonds for sale, or to require the issuance of definitive drainage bonds in exchange for the temporary drainage bonds, on a par for par basis, bearing interest at the rate established under section 475.55 if the definitive drainage bonds have not been sold and delivered before the maturity of the temporary drainage bonds.

Subd. 6. **Definitive drainage bonds.** The definitive drainage bonds issued in exchange for an issue of temporary drainage bonds must be numbered and mature serially at times and in amounts to allow the principal and interest to be paid when due by the collection of assessments levied for the drainage systems financed by the temporary bond issue. The definitive bonds are subject to redemption and prepayment on any interest payment date when the county notifies the definitive bondholders who have registered their names and addresses with the county treasurer. The bondholders must be notified by mail 30 days before the interest payment date. The definitive bonds must be delivered in order of their serial numbers, lowest numbers first, to the holders of the temporary drainage bonds in order of the serial numbers of the bonds held by them.

Subd. 7. **Sale of definitive drainage bonds.** The board must sell and negotiate the definitive drainage bonds according to sections 475.56 and 475.60.

Subd. 8. **County investment, purchase, and selling of temporary drainage bonds.** (a) Funds of the issuing county may be invested in temporary drainage bonds under section 118A.04, except that the temporary drainage bonds may be:

(1) purchased by the county when the temporary drainage bonds are initially issued;

(2) purchased only out of funds that the board determines will not be required for other purposes before the temporary drainage bonds mature; and

(3) resold before the temporary drainage bonds mature only if there is an unforeseen emergency.

(b) If a temporary drainage bond purchase is made from money held in a sinking fund for other bonds of the county, the holders of the other bonds may enforce the county's obligation to sell definitive bonds at or before the maturity of the temporary drainage bonds, or exchange the other bonds, in the same manner as holders of the temporary drainage bonds.

Subd. 9. **Delivery of bonds as drainage work proceeds.** The board may provide in the contract for the sale of drainage bonds, temporary drainage bonds, and definitive drainage bonds, that the bonds are delivered as the drainage work proceeds and the money is needed, and that interest is paid only from the date of delivery.

Subd. 10. **Bond recital.** Each drainage bond, temporary drainage bond, and definitive drainage bond must contain a recital that it is issued by authority of and in strict accordance with this chapter. The recital is conclusive in favor of the holders of the bonds as against the county, that the drainage project has been properly established, that property within the county is subject to assessment for benefits in an amount not less than the amount of the bonds, and that all proceedings and construction relative to the drainage systems financed by the bonds have been or will be made according to law.

Subd. 11. **How bonds may be paid.** The board may pay drainage bonds, temporary drainage bonds, and definitive drainage bonds issued under this chapter from any available funds in the county treasury if the money in the common drainage bond redemption fund or in the drainage fund for the issued bonds is insufficient. The county treasury funds that money is transferred from must be reimbursed, with interest at a rate of seven percent per year for the time the money is actually needed, from assessments on the drainage systems or from the sale of drainage funding bonds.

History: *1990 c 391 art 5 s 84; 1996 c 399 art 2 s 1; 2006 c 259 art 9 s 1*

103E.641 DRAINAGE FUNDING BONDS.

Subdivision 1. **Authority.** The board may issue drainage funding bonds under the conditions and terms in this section.

Subd. 2. **Conditions for issuance.** Drainage funding bonds may be issued if:

(1) money in a drainage system account or in the common drainage bond redemption fund will not be sufficient to pay the principal and interest of the drainage bonds payable from the funds and becoming due within one year afterwards; or

(2) the county has paid any of the principal or interest on any of its drainage bonds from county funds other than the fund from which the bonds are payable, or by the issuance of county warrants issued and outstanding.

Subd. 3. **Auditor's certificate.** (a) Before drainage funding bonds are authorized or issued under this section, the county auditor shall first sign and seal a certificate and present the certificate to the board. The board shall enter the certificate in its records. The certificate must state in detail, for each of the several drainage systems:

(1) the amount that will be required to pay an existing shortage under subdivision 2; and

(2) the probable amount that will be required to pay the principal and interest of the county's outstanding drainage bonds that become due within one year afterwards.

(b) The certificate is conclusive evidence that the county has authority to issue bonds under the provisions of this section in an amount that does not exceed the aggregate amount specified in the auditor's certificate.

Subd. 4. **Issuance of bonds.** When the auditor's certificate is entered in the board's records, the board may issue and sell, from time to time, county drainage funding bonds for the same drainage purposes as the funds listed in the certificate were used. The bonds must be designated drainage funding bonds. The board shall authorize issuance of the drainage funding bonds by resolution. The drainage funding bonds must be sold, issued, bear interest, and obligate the county as provided in section 103E.635 for drainage bonds. The drainage funding bonds must mature serially in annual installments that are payable within 15 years.

Subd. 5. **Application of bond proceeds.** The proceeds of drainage funding bonds that are paid into the treasury must be applied to the purpose for which they are issued.

Subd. 6. **County bond obligation.** Drainage funding bonds are general obligations of the county but are not included in determining the county's net indebtedness under any law.

History: *1990 c 391 art 5 s 85*

103E.645 ALLOWANCE AND PAYMENT OF FEES AND EXPENSES.

Subdivision 1. **Fees and expenses.** The fees and expenses in this section are allowed and must be paid for services provided under this chapter.

Subd. 2. **Engineer, engineer's assistants, and other employees.** The compensation of the engineer, the engineer's assistants, and other employees is on a per diem basis and must be set by order of the drainage authority. The order setting compensation must provide for payment of the actual and necessary expenses of the engineer, the engineer's assistants, and other employees, including the cost of the engineer's bond.

Subd. 3. **Viewers.** Each viewer may be paid for every necessary day the viewer is engaged on a per diem basis and for the viewer's actual and necessary expenses. The compensation must be set by the drainage authority.

Subd. 4. **Board members.** Each member of the board may be paid a per diem under section 375.055, subdivision 1, and actual and necessary expenses incurred while actually employed in drainage proceedings or construction, or in the inspection of any drainage system if the board member is appointed to a committee for that purpose.

Subd. 5. **Auditor, attorney for petitioners, and other county officials.** The county auditor and the attorney for the petitioners must each be paid reasonable compensation for services actually provided as determined by the drainage authority. The fees and compensation of all county officials in drainage proceedings and construction are in addition to other fees and compensation allowed by law.

Subd. 6. **Petitioners' bond.** The cost of the petitioners' bond must be allowed and paid.

Subd. 7. **Payment.** The fees and expenses provided for in this chapter for a drainage project or system in one county must be audited, allowed, and paid by order of the board or for a drainage project or system in more than one county must be audited, allowed, and paid by order of the drainage authority after ten days' written notice to each affected county. The notice must be given by the auditor to the auditors of affected counties. The notice must state the time and location of the hearing and that all bills on file with the auditor at the date of the notice must be presented for hearing and allowance.

History: *1990 c 391 art 5 s 86*

103E.651 DRAINAGE SYSTEM ACCOUNT.

Subdivision 1. **Funds for drainage system costs.** The board shall provide funds to pay the costs of drainage projects and systems.

Subd. 2. **Drainage system account.** The auditor shall keep a separate account for each drainage system. The account must be credited with all money from the sale of bonds and bond premiums and all money received from interest, liens, assessments, and other sources for the drainage system. The account must be debited with every item of expense made for the drainage system.

Subd. 3. **Investment of surplus funds.** If a drainage system account or the common drainage bond redemption fund has a surplus over the amount required for payment of obligations presently due and payable from the account or fund, the board may invest any part of the surplus in bonds or certificates of indebtedness of the United States or of the state.

Subd. 4. **Dormant drainage system account transferred to general revenue fund.** If a surplus has existed in a drainage system account for a period of 20 years or more and there have not been any expenditures from the account during the period, the board, by a unanimous resolution, may transfer the surplus remaining in the drainage system account to the general revenue fund of the county.

History: *1990 c 391 art 5 s 87*

103E.655 PAYMENT OF DRAINAGE SYSTEM COSTS.

Subdivision 1. **Payment made from drainage system account.** The costs for a drainage project proceeding and construction must be paid from the drainage system account by drawing on the account.

Subd. 2. **Insufficient funds; transfer from other accounts.** If money is not available in the drainage system account on which the warrant is drawn, the board may, by unanimous resolution, transfer funds from any other drainage system account under its jurisdiction or from the county general revenue fund to the drainage system account. If the board transfers money from another account or fund to a drainage system account, the money plus interest must be reimbursed from the proceeds of the drainage system that received the transfer. The interest must be computed for the time the money is actually needed at the same rate per year charged on drainage liens and assessments.

Subd. 3. **Warrant on account with insufficient funds; interest on warrant.** If a warrant is issued by the auditor under this chapter and there is not enough money in the drainage system account to pay the warrant when it is presented, the county treasurer shall endorse the warrant "Not paid for want of funds" with the date and treasurer's signature. Interest on the warrant must be at the rate of six percent per year and paid annually from available funds until the warrant is called in and paid by the treasurer. Interest may not be paid on a warrant after money is available to the treasurer to pay the warrants. The warrant is a general obligation of the county issuing the warrant.

History: *1990 c 391 art 5 s 88*

103E.661 EXAMINATION AND ESTABLISHMENT OF DRAINAGE SYSTEM ACCOUNTS BY STATE AUDITOR.

Subdivision 1. **State auditor must examine accounts upon application.** A county may apply, by resolution, to the state auditor to examine the accounts and records of any or all drainage systems in the county.

Subd. 2. **Establishment of accounts.** The auditor must establish a system of accounts for each drainage system applied for in the county.

Subd. 3. **Payment of expenses.** The compensation and travel and hotel expenses of the examining accountant must be audited, allowed, and paid into the state treasury by the board. The money must be credited to the general fund. The county auditor shall apportion the expenses among the drainage systems in the county.

History: *1990 c 391 art 5 s 89*

PROCEDURE TO REPAIR DRAINAGE SYSTEMS

103E.701 REPAIRS.

Subdivision 1. **Definition.** The term "repair," as used in this section, means to restore all or a part of a drainage system as nearly as practicable to the same hydraulic capacity as originally constructed and subsequently improved, including resloping of ditches and leveling of spoil banks if necessary to prevent further deterioration, realignment to original construction if necessary to restore the effectiveness of the drainage system, and routine operations that may be required to remove obstructions and maintain the efficiency of the drainage system. "Repair" also includes:

(1) incidental straightening of a tile system resulting from the tile-laying technology used to replace tiles; and

(2) replacement of tiles with the next larger size that is readily available, if the original size is not readily available.

Subd. 2. **Repairs affecting public waters.** Before a repair is ordered, the drainage authority must notify the commissioner if the repair may affect public waters. If the commissioner disagrees with the repair depth, the engineer, a representative appointed by the director, and a soil and water conservation district technician must jointly determine the repair depth using soil borings, field surveys, and other available data or appropriate methods. Costs for determining the repair depth beyond the initial meeting must be shared equally by the drainage system and the commissioner. The determined repair depth must be recommended to the drainage authority. The drainage authority may accept the joint recommendation and proceed with the repair.

Subd. 3. **Repair of town ditches.** The town board has the power of a drainage authority to repair a town drainage system located within the town.

Subd. 4. **Bridges and culverts.** (a) Highway bridges and culverts constructed on a drainage system established on or after March 25, 1947, must be maintained by the road authority charged with the duty of maintenance under section 103E.525.

(b) Private bridges or culverts constructed as a part of a drainage system established by proceedings that began on or after March 25, 1947, must be maintained by the drainage authority as part of the drainage system. Private bridges or culverts constructed as a part of a drainage system established by proceedings that began before March 25, 1947, may be maintained, repaired, or rebuilt and any portion paid for as part of the drainage system by the drainage authority.

(c) For a repair of a drainage system that has had redetermination of benefits under section 103E.351, the drainage authority may repair or rebuild existing bridges or culverts on town and home rule charter and statutory city roads constructed as part of the drainage system and any portion of the cost may be paid by the drainage system.

Subd. 5. **Construction of road instead of bridge or culvert.** In a repair proceeding under sections 103E.701 to 103E.745, if the drainage authority finds that constructing a private road is more cost-effective or practical than constructing a bridge or culvert, a drainage authority may order a private road to be constructed under section 103E.526, instead of a bridge or culvert.

Subd. 5a. **Compensation to landowners instead of bridge or culvert repair.** In a repair proceeding under sections 103E.701 to 103E.745, if the drainage authority finds that repairs to a private bridge or culvert are more expensive than compensation to landowners for permanent removal of the bridge or culvert, the drainage authority may order an amount of compensation to be paid to all landowners directly benefiting from the bridge or culvert, provided that:

(1) all landowners directly benefiting from the bridge or culvert provide written consent for permanent removal of the bridge or culvert;

(2) all landowners directly benefiting from the bridge or culvert agree in writing to permanently waive any right to repair or reconstruction of the bridge or culvert; and

(3) the compensation and cost of removing the bridge or culvert is less than the cost of repair of the bridge or culvert.

Subd. 6. **Wetland restoration and replacement; water quality protection and improvement.** Repair of a drainage system may include the preservation, restoration, or enhancement of wetlands; wetland replacement under section 103G.222; the realignment of a drainage system to prevent drainage of a wetland; and the incorporation of measures to reduce channel erosion and otherwise protect or improve water quality.

Subd. 7. **Restoration; disturbance or destruction by repair.** If a drainage system repair disturbs or destroys a perennial vegetative cover or structural practice existing under a federal or state conservation program adjacent to the permanent drainage system right-of-way, the practice must be restored according to the applicable practice plan or as determined by the drainage authority, if a practice plan is not available. Restoration costs shall be paid by the drainage system.

History: *1990 c 391 art 5 s 90; 1991 c 354 art 10 s 2; 1993 c 175 s 1; 1996 c 462 s 4; 2003 c 84 s 1; 2007 c 57 art 1 s 114; 2013 c 4 s 12,13*

103E.705 REPAIR PROCEDURE.

Subdivision 1. **Inspection.** After the construction of a drainage system has been completed, the drainage authority shall maintain the drainage system that is located in its jurisdiction, including the permanent strips of perennial vegetation under section 103E.021, and provide the repairs necessary to make the drainage system efficient. The drainage authority shall have the drainage system inspected on a regular basis by an inspection committee of the drainage authority or a drainage inspector appointed by the drainage authority. Open drainage ditches shall be inspected at a minimum of every five years when no violation of section 103E.021 is found and annually when a violation of section 103E.021 is found, until one year after the violation is corrected.

Subd. 2. **Permanent strip of perennial vegetation inspection and compliance notice.** (a) The drainage authority having jurisdiction over a drainage system must inspect the drainage system for violations of section 103E.021. If an inspection committee of the drainage authority or a drainage inspector determines that permanent strips of perennial vegetation are not being maintained in compliance with section 103E.021, a compliance notice must be sent to the property owner.

(b) The notice must state:

(1) the date the ditch was inspected;

(2) the persons making the inspection;

(3) that spoil banks are to be spread in a manner consistent with the plan and function of the drainage system and that the drainage system has acquired a permanent strip of perennial vegetation, according to section 103E.021;

(4) the violations of section 103E.021;

(5) the measures that must be taken by the property owner to comply with section 103E.021 and the date when the property must be in compliance; and

(6) that if the property owner does not comply by the date specified, the drainage authority will perform the work necessary to bring the area into compliance with section 103E.021 and charge the cost of the work to the property owner.

(c) If a property owner does not bring an area into compliance with section 103E.021 as provided in the compliance notice, the inspection committee or drainage inspector must notify the drainage authority.

(d) This subdivision applies to property acquired under section 103E.021.

Subd. 3. **Drainage inspection report.** For each drainage system that the board designates and requires the drainage inspector to examine, the drainage inspector shall make a drainage inspection report in writing to the board after examining a drainage system, designating portions that need repair or maintenance of the permanent strips of perennial vegetation and the location and nature of the repair or maintenance. The board shall consider the drainage inspection report at its next meeting and may repair all or any part of the drainage system as provided under this chapter. The permanent strips of perennial vegetation must be maintained in compliance with section 103E.021.

Subd. 4. **Inspection report to drainage authority.** If the inspection committee or drainage inspector reports, in writing, to the drainage authority that maintenance of grass strips or repairs are necessary on a drainage system and the report is approved by the drainage authority, the maintenance or repairs must be made under this section.

Subd. 5. **Repairs not subject to bidding requirements.** If the drainage authority finds that the estimated cost of repairs and maintenance of one drainage system for one year will be less than the greater of the dollar amount requiring the solicitation of sealed bids under section 471.345, subdivision 3, or $1,000 per mile of open ditch in the ditch system, it may have the repair work done by hired labor and equipment without advertising for bids or entering into a contract for the repair work.

Subd. 6. **Annual repair assessment levy limits.** The drainage authority may give notice of and hold a hearing on the repair levy before ordering the levy of an assessment for repairs. In one calendar year the drainage authority may not levy an assessment for repairs or maintenance on one drainage system for more than 20 percent of the benefits of the drainage system, $1,000 per mile of open ditch in the ditch system, or the dollar amount requiring the solicitation of sealed bids under section 471.345, subdivision 3, whichever is greater, except for a repair made after a disaster as provided under subdivision 7 or under the petition procedure.

Subd. 7. **Repair and construction after disaster.** The drainage authority may repair and reconstruct the drainage system without advertising for bids and without regard to the $1,000 per mile of open ditch or the dollar amount requiring the solicitation of sealed bids under section 471.345, subdivision 3, limitation if:

(1) a drainage system is destroyed or impaired by floods, natural disaster, or unforeseen circumstances;

(2) the area where the drainage system is located has been declared a disaster area by the President of the United States and federal funds are available for repair or reconstruction; and

(3) the public interests would be damaged by repair or reconstruction being delayed.

History: *1990 c 391 art 5 s 91; 2007 c 57 art 1 s 115-117; 2008 c 207 s 1-3*

103E.711 COST APPORTIONMENT FOR JOINT COUNTY DRAINAGE SYSTEMS.

Subdivision 1. **Repair cost statement.** For a joint county drainage system the auditor of a county that has made repairs may present a repair cost statement at the end of each year, or other convenient period after completion, to each affected county. The repair cost statement must show the nature and cost of the repairs to the drainage system and must be based on the original apportionment of cost following the establishment of the drainage system. If a board approves the repair costs, the amount of the statement must be paid to the county submitting the statement.

Subd. 2. **Repair cost statement not paid.** (a) If a county does not pay the amount of the repair cost statement, the board of an affected county may petition the joint county drainage authority. The petition must:

(1) show the nature and necessity of the repairs made to the drainage system in the county during the period;

(2) show the cost of the repairs; and

(3) request the drainage authority to apportion the costs, by order, among the affected counties.

(b) When the petition is filed, the drainage authority shall, by order, set a time and location for a hearing to apportion the costs, and direct the auditor to give notice of the hearing to each affected county by publication and notice by mail to its auditor. At or before the hearing, the auditor of each affected county, except the petitioner, shall file with the drainage authority a statement showing:

(1) all repairs made to the drainage system in that county, not previously reimbursed;

(2) the nature and necessity of the repairs; and

(3) the cost of the repairs.

(c) The drainage authority has jurisdiction over the affected counties and shall hear all interested parties. The drainage authority shall determine which repairs were necessary and reasonable and proper costs. For the allowed repairs the drainage authority shall balance the accounts among the affected counties, by charging each county with its proportionate share of the cost of all repairs made and crediting each county with the amount paid for the repairs. The drainage authority shall order a just reimbursement among the affected counties. A certified copy of the order must be filed by the auditor with the auditors of affected counties, and the boards shall make the required reimbursement.

History: *1990 c 391 art 5 s 92*

103E.715 PROCEDURE FOR REPAIR BY PETITION.

Subdivision 1. **Repair petition.** An individual or an entity interested in or affected by a drainage system may file a petition to repair the drainage system. The petition must state that the drainage system needs repair. The auditor shall present the petition to the board at its next meeting or, for a joint county drainage system, to the drainage authority within ten days after the petition is filed.

Subd. 2. **Engineer's repair report.** If the drainage authority determines that the drainage system needs repair, the drainage authority shall appoint an engineer to examine the drainage system and make a repair report. The report must show the necessary repairs, the estimated cost of the repairs, and all details, plans, and specifications necessary to prepare and award a contract for the repairs. The drainage authority may give notice and order a hearing on the petition before appointing the engineer.

Subd. 3. **Notice of hearing.** When the repair report is filed, the auditor shall promptly notify the drainage authority. The drainage authority in consultation with the auditor shall set a time, by order, not more than

30 days after the date of the order for a hearing on the repair report. At least ten days before the hearing, the auditor shall give notice by mail of the time and location of the hearing to the petitioners, owners of property, and political subdivisions likely to be affected by the repair in the repair report.

Subd. 4. **Hearing on repair report.** (a) The drainage authority shall make findings and order the repair to be made if:

(1) the drainage authority determines from the repair report and the evidence presented that the repairs recommended are necessary for the best interests of the affected property owners; or

(2) the repair petition is signed by the owners of at least 26 percent of the property area affected by and assessed for the original construction of the drainage system, and the drainage authority determines that the drainage system is in need of repair so that it no longer serves its original purpose and the cost of the repair will not exceed the total benefits determined in the original drainage system proceeding.

(b) The order must direct the auditor and the chair of the board or, for a joint county drainage system, the auditors of the affected counties to proceed and prepare and award a contract for the repair of the drainage system. The contract must be for the repair described in the repair report and as determined necessary by the drainage authority, and be prepared in the manner provided in this chapter for the original drainage system construction.

Subd. 5. **Apportionment of repair cost for joint county drainage system.** For the repair of a joint county drainage system, the drainage authority shall, by order, apportion the repair cost among affected counties in the same manner required in the original construction of the drainage system.

Subd. 6. **Repair by resloping ditches, incorporating multistage ditch cross-section, leveling spoil banks, installing erosion control, or removing trees.** (a) For a drainage system that is to be repaired by resloping ditches, incorporating a multistage ditch cross-section, leveling spoil banks, installing erosion control measures, or removing trees, before ordering the repair, the drainage authority must appoint viewers to assess and report on damages and benefits if it determines that:

(1) the resloping, incorporation of a multistage ditch cross-section, spoil bank leveling, installation of erosion control measures, or tree removal will require the taking of any property not contemplated and included in the proceeding for the establishment or subsequent improvement of the drainage system; or

(2) any spoil bank leveling or tree removal will directly benefit property where the spoil bank leveling or tree removal is specified.

(b) The viewers shall assess and report damages and benefits as provided by sections 103E.315 and 103E.321. The drainage authority shall hear and determine the damages and benefits as provided in sections 103E.325, 103E.335, and 103E.341. The hearing shall be held within 30 days after the property owners' report is mailed. Damages must be paid as provided by section 103E.315 as a part of the cost of the repair, and benefits must be added to the benefits previously determined as the basis for the pro rata assessment for the repair of the drainage system for the repair proceeding only.

History: *1990 c 391 art 5 s 93; 2013 c 4 s 14*

103E.721 REPLACEMENT AND HYDRAULIC CAPACITY OF BRIDGES AND CULVERTS.

Subdivision 1. **Report on hydraulic capacity.** If the engineer determines in a drainage system repair proceeding that because of added property under section 103E.741 or otherwise, a bridge constructed or replaced or culvert installed or replaced as a part of a drainage system provides inadequate hydraulic capacity for the efficient operation of the drainage system to serve its original purpose, the engineer shall make a hydraulic capacity report to the drainage authority. The hydraulic capacity report must include plans and specifications for the recommended replacement of bridges and culverts, the necessary details to make and award a contract, and the estimated cost.

Subd. 2. **Notice.** When the hydraulic capacity report is filed, the auditor shall promptly notify the drainage authority. The drainage authority in consultation with the auditor shall, by order, set a time not more than 30 days after the date of the order, for a hearing on the report. At least ten days before the hearing, the auditor shall give notice by mail of the time and location of the hearing to the petitioners, owners of property, and political subdivisions likely to be affected by the repair proposed in the repair report. The notice may be given in conjunction with and as a part of the repair report notice, but the notice must specifically state that increasing the hydraulic capacity will be considered by the drainage authority at the hearing.

Subd. 3. **Report hearing.** At the hearing on the hydraulic capacity report, the drainage authority shall hear all interested parties. If the drainage authority finds that existing bridges and culverts provide insufficient hydraulic capacity for the efficient operation of the drainage system as originally constructed or subsequently improved, the drainage authority shall make findings accordingly, and may order that the hydraulic capacity be increased by constructing bridges or installing culverts of a sufficient capacity. The drainage authority shall determine and include in the order the type and plans for the replacement bridges or culverts. The order must direct the state, political subdivision, railroad company, or other entity to construct bridges or culverts required by the order for its road or right-of-way within a reasonable time stated in the order. The auditor shall notify the state, political subdivision, railroad company, or other entity to construct the bridges and culverts in accordance with the order.

Subd. 4. **Construction not completed within specified time.** If the work is not done within the time specified, the drainage authority may order the bridges and culverts built and the cost collected as an assessment for benefits.

Subd. 5. **Request for culvert or bridge to be installed as part of repair.** If a political subdivision, railroad company, or other entity, at the hearing or when notified to construct a bridge or install a culvert, requests that the bridge or culvert be installed as part of the repair of the drainage system, the drainage authority may, by order, direct the cost of the construction and installation be assessed and collected from the political subdivision, railroad company, or other entity in the manner provided by section 103E.731.

History: *1990 c 391 art 5 s 94*

103E.725 COST OF REPAIR.

All fees and costs incurred for proceedings relating to the repair of a drainage system, including inspections, engineering, viewing, and publications, are costs of the repair and must be assessed against the property and entities benefited.

History: *1990 c 391 art 5 s 95*

103E.728 APPORTIONMENT OF REPAIR COSTS.

Subdivision 1. **Generally.** The cost of repairing a drainage system shall be apportioned pro rata on all property and entities that have been assessed benefits for the drainage system except as provided in this section.

Subd. 2. **Additional assessment for agricultural practices on permanent strip of perennial vegetation.** (a) The drainage authority may, after notice and hearing, charge an additional assessment on property that has agricultural practices on or otherwise violates provisions related to the permanent strip of perennial vegetation acquired under section 103E.021.

(b) The drainage authority may determine the cost of the repair per mile of open ditch on the ditch system. Property that is in violation of the grass requirement shall be assessed a cost of 20 percent of the repair cost per open ditch mile multiplied by the length of open ditch in miles on the property in violation.

(c) After the amount of the additional assessment is determined and applied to the repair cost, the balance of the repair cost may be apportioned pro rata as provided in subdivision 1.

Subd. 3. **Soil loss violations.** The drainage authority after notice and hearing may make special assessments on property that is in violation of a county soil loss ordinance.

History: *1990 c 391 art 5 s 96; 2007 c 57 art 1 s 118*

103E.731 ASSESSMENT; BONDS.

Subdivision 1. **Repair cost of assessments.** If there is not enough money in the drainage system account to make a repair, the board shall assess the costs of the repairs on all property and entities that have been assessed benefits for the drainage system.

Subd. 2. **Number of installments.** The assessments may be paid in annual installments specified in the assessment order. If the assessments are not more than 50 percent of the original cost of the drainage system, the installments may not exceed ten. If the assessments are greater than 50 percent of the original cost of the drainage system, the board may order the assessments to be paid in 15 or less installments.

Subd. 3. **Interest on assessments.** If the order provides for payment in installments, interest on unpaid assessments from the date of the order for assessments must be set by the board in the order. The interest rate may not exceed seven percent per year and must be collected with each installment.

Subd. 4. **Collection of assessments.** If the assessment is not payable in installments, a lien does not need to be filed, and the assessment, plus interest from the date of the order to August 15 of the next calendar year, must be entered on the tax lists for the year. The assessment and interest are due and payable with and as a part of the real estate taxes for the year. If an assessment is levied and payable in installments, the auditor shall file for the record in the county recorder's office an additional tabular statement in substance as provided in section 103E.601, and all the provisions of sections 103E.605, 103E.611, and 103E.615 relating to collection and payment must apply to the assessment. Upon the filing of the tabular statement, the installment and interest are due and payable and must be entered on the tax lists and collected in the same manner as the original lien.

Subd. 5. **Conditions to sell bonds for repair.** If a contract for drainage system repair has been entered into under this chapter or the repair has been ordered to be constructed by hired labor and equipment, and the board has ordered the assessments to be paid in installments, the board may issue and sell bonds, as provided by section 103E.635.

Subd. 6. **Repair of state drainage system when no benefits assessed.** For the repair of a drainage system established by the state where benefits were not assessed to the property, the drainage authority shall proceed to appoint viewers to determine the benefits resulting from the repair and collect assessments for the repair as provided in this chapter.

History: *1990 c 391 art 5 s 97*

103E.735 DRAINAGE SYSTEM REPAIR FUND.

Subdivision 1. **Authority and limits of fund.** To create a repair fund for a drainage system to be used only for repairs, the drainage authority may apportion and assess an amount against all property and entities assessed for benefits in proceedings for establishment of the drainage system, including property not originally assessed and subsequently found to be benefited according to law. The fund may not exceed 20 percent of the assessed benefits of the drainage system or $100,000, whichever is greater. If the account in a fund for a drainage system exceeds the larger of 20 percent of the assessed benefits of the drainage system or $100,000, assessments for the fund may not be made until the account is less than the larger of 20 percent of the assessed benefits or $100,000. Assessments must be made pro rata according to the determined benefits. Assessments may be made payable, by order, in equal annual installments. The auditor shall file a tabular statement as provided in section 103E.731, subdivision 4, with the county recorder. Assessments must be collected as provided in section 103E.731.

Subd. 2. **Transfer of drainage system.** If a drainage system within the county has been taken over by a watershed district, or if responsibility for repair and maintenance of the drainage system has been assumed by any other governing body, the board may transfer any remaining surplus of the drainage system repair fund to the repair fund of the watershed district or to the appropriate fund of any existing governing body having responsibility for repair and maintenance of the drainage system.

History: *1990 c 391 art 5 s 98; 2010 c 298 s 7*

103E.741 INCLUSION OF PROPERTY THAT HAS NOT BEEN ASSESSED BENEFITS.

Subdivision 1. **Consideration by engineer.** In a proceeding to repair a drainage system, if the engineer determines or is made aware that property that was not assessed for benefits for construction of the drainage system has been drained into the drainage system or has otherwise benefited from the drainage system, the engineer shall submit a map with the repair report. The map must show all public and private main ditches and drains that drain into the drainage system, all property affected or otherwise benefited by the drainage system, and the names of the property owners to the extent practicable. The property owners must be notified of the hearing on the repair report at least ten days before the hearing. The auditor must give notice of the time and location of the hearing by mail.

Subd. 2. **Appointment of viewers.** At the hearing on the repair report, if the drainage authority determines that property not assessed for benefits for the construction of the drainage system has been benefited by the drainage system, the drainage authority shall appoint viewers as provided by section 103E.305 before the repair contract is awarded. The viewers shall determine the benefits to all property and entities benefited by the original construction of the drainage system and not assessed for benefits arising from its construction. The viewers shall make a viewers' repair report to the drainage authority as provided by section 103E.315. When the viewers' repair report is filed, the auditor shall give notice of a hearing as required by section 103E.325 and the drainage authority has jurisdiction of each tract of property described in the viewers' report as provided in section 103E.331.

Subd. 3. **Viewers' repair report hearing.** At the hearing on the viewers' repair report, the drainage authority shall hear all interested parties and determine the benefits to property and entities benefited by the original construction of the drainage system and not assessed for benefits.

Subd. 4. **Appeal of assessment order.** A person may appeal from the order determining the assessments as provided by section 103E.091.

Subd. 5. **Property benefited in hearing order included in future proceedings.** For the repair of the drainage system under this section that included the property that was not assessed and in all future proceedings relating to repairing, cleaning, improving, or altering the drainage system, the property benefited in the viewers' report hearing is part of the property benefited by the drainage system and must be assessed, in the same manner provided for the assessment of the property originally assessed for and included in the drainage system.

History: *1990 c 391 art 5 s 99*

103E.745 COST OF REPAIR EXCEEDING BENEFITS IN ANOKA COUNTY.

If the cost of the repair of a drainage system exceeds the benefits determined in the original proceedings for the establishment of the drainage system, the requirements of section 103E.215 for improvements of drainage systems apply if:

(1) the repair will result in the drainage of 100 or more acres of public waters in Anoka County;

(2) the public waters have existed for 15 or more years;

(3) the drainage system has not been substantially repaired for more than 25 years; and

(4) the physical repair was not started before July 1, 1980.

History: *1990 c 391 art 5 s 100*

CONSOLIDATION, DIVISION, AND ABANDONMENT OF DRAINAGE SYSTEMS

103E.801 CONSOLIDATION OR DIVISION OF DRAINAGE SYSTEMS.

Subdivision 1. **Authority to consolidate or divide.** After the benefited area of a drainage system has been redetermined by the drainage authority under section 103E.351 or in connection with drainage proceedings, the drainage authority may divide one system into two or more separate systems, consolidate two or more systems, transfer part of one system to another, or attach a part of a system that has been abandoned as provided in section 103E.805 or 103E.811 to another system to provide for the efficient administration of the system consistent with the redetermination of the benefited area.

Subd. 2. **Initiation of action.** The consolidation or division may be initiated by the drainage authority on its own motion or by any party interested in or affected by the drainage system filing a petition. If the system is under the jurisdiction of a drainage authority, the petition must be filed with the auditor. If the system is under the jurisdiction of a watershed board, the petition must be filed with the secretary of the board.

Subd. 3. **Hearing.** (a) When a drainage authority or watershed board directs by resolution or a petition is filed, the drainage authority in consultation with the auditor or secretary shall set a time and location for a hearing. The auditor or secretary shall give notice by publication to all persons interested in the drainage system. The drainage authority may consolidate or divide drainage systems, by order, if it determines that the division of one system into two or more separate systems, the consolidation of two or more systems, the transfer of part of one system to another, or the attachment of a previously abandoned part of a system to another system:

(1) is consistent with the redetermination of the benefited areas of the drainage system;

(2) would provide for the efficient administration of the drainage system; and

(3) would be fair and equitable.

(b) An order to consolidate or divide drainage systems does not release property from a drainage lien or assessment filed for costs incurred on account of a drainage system before the date of the order.

History: *1990 c 391 art 5 s 101*

103E.805 REMOVAL OF PROPERTY FROM A DRAINAGE SYSTEM.

Subdivision 1. **Petition.** After construction of a drainage system, an owner of benefited property may petition the drainage authority to remove property from the drainage system.

Subd. 2. **Filing.** If the drainage system is under the jurisdiction of a county drainage authority, the petition must be filed with the auditor of the county. If the drainage system is under the jurisdiction of a joint county drainage authority, the petition must be filed with the county having the largest area of property in the drainage system, where the primary drainage system records are kept. If the system is under the jurisdiction of a watershed district, the petition must be filed with the secretary of the district.

Subd. 3. **Hearing.** (a) When the petition is filed, the drainage authority in consultation with the auditor or the secretary shall set a time and location for a hearing on the petition and shall give notice of the hearing by mail to the owners of all property benefited by the drainage system, and either in a newspaper of general circulation within the affected drainage area or by publication on a Web site of the drainage authority.

(b) At the hearing, the drainage authority shall make findings and shall direct, by order, that the petitioners' property be removed from the drainage system if the drainage authority determines:

(1) that the waters from the petitioners' property have been diverted from the drainage system, or that the property cannot significantly or regularly use the drainage system;

(2) that the property is not benefited by the drainage system; and

(3) that removing the property from the drainage system will not prejudice the property owners and property remaining in the system.

Subd. 4. **Effect of removing property from drainage system.** The property that has been removed from the drainage system is not affected by the drainage system at any later proceeding for the repair or improvement of the drainage system and a drainage lien or assessment for repairs or improvements may not be made against the property that has been removed on or after the date of the order.

Subd. 5. **Liens and assessments on property removed from drainage system.** An order under this section does not release the property from a drainage lien filed on account of the drainage system before the date of the order. An order under this section does not release the property from any assessment or a drainage lien filed on or after the date of the order for costs incurred on account of the drainage system before the date of the order.

History: *1990 c 391 art 5 s 102; 2010 c 298 s 8*

103E.806 PARTIAL ABANDONMENT OF DRAINAGE SYSTEM.

Subdivision 1. **Petition.** After construction of a drainage system, an owner of benefited property may petition the drainage authority to abandon any part of the drainage system that is not of public benefit and utility and does not serve a substantial useful purpose to property remaining in the system.

Subd. 2. **Filing.** If the drainage system is under the jurisdiction of a county drainage authority, the petition must be filed with the auditor of the county. If the drainage system is under the jurisdiction of a joint county drainage authority, the petition must be filed with the county having the largest area of property in the drainage system, where the primary drainage system records are kept. If the system is under the jurisdiction of a watershed district, the petition must be filed with the secretary of the district.

Subd. 3. **Hearing.** (a) When the petition is filed, the drainage authority, in consultation with the auditor or the secretary, shall set a time and location for a hearing on the petition and shall give notice of the hearing by mail to the owners of all property benefited by the drainage system, and either in a newspaper of general circulation within the affected drainage area or by publication on a Web site of the drainage authority.

(b) At the hearing, the drainage authority shall make findings and direct, by order, that part of the drainage system be abandoned, if the drainage authority determines that part of the drainage system does not serve a substantial useful purpose as part of the drainage system to any property remaining in the system and is not of a substantial public benefit and utility.

Subd. 4. **Effect of partial abandonment.** After partial abandonment of a drainage system, a repair petition may not be accepted for the abandoned part of the drainage system and the responsibility of the drainage authority for that part of the drainage system ends.

Subd. 5. **Liens and assessments on property involved in partial abandonment.** An order under this section does not release the property from a drainage lien filed on account of the drainage system before the date of the order. An order under this section does not release the property from any assessment or a drainage lien filed on or after the date of the order for costs incurred on account of the drainage system before the date of the order.

History: *2010 c 298 s 9*

103E.811 ABANDONMENT OF DRAINAGE SYSTEM.

Subdivision 1. **Drainage lien payment period must expire.** After the period originally fixed or subsequently extended to pay the assessment of the drainage liens expires, a drainage system may be abandoned as provided in this section.

Subd. 2. **Petitioners.** A petition must be signed by at least 51 percent of the property owners assessed for the construction of the drainage system or by the owners of not less than 51 percent of the area of the property assessed for the drainage system. For the purpose of the petition, the county is the resident owner of all tax-forfeited property held by the state and assessed benefits for the drainage system, and the board may execute the petition for the county as an owner.

Subd. 3. **Petition.** The petition must designate the drainage system proposed to be abandoned and show that the drainage system is not of public benefit and utility because the agricultural property that used the drainage system has been generally abandoned or because the drainage system has ceased to function and its restoration is not practical.

Subd. 4. **Filing petition; jurisdiction.** If all property assessed for benefits in the drainage system is in one county, the petition must be filed with the auditor unless the petition is signed by the board, in which case the petition must be made to the district court of the county and filed with the court administrator. If property assessed for benefits is in two or more counties, the petition must be filed with the auditor. When the petition is filed, the drainage authority in consultation with the auditor, or the court administrator with the approval of the court, shall set a time and location for a hearing on the petition. The auditor or court administrator shall give notice by publication of the time and location of the abandonment hearing to all persons interested. The drainage authority or the district court where the petition is properly filed has jurisdiction of the petition.

Subd. 5. **Abandonment hearing.** (a) At the hearing, the drainage authority or court shall examine the petition and determine whether it is sufficient and shall hear all interested parties.

(b) If a property owner assessed benefits for the drainage system appears and makes a written objection to the abandonment of the drainage system, the drainage authority or court shall appoint three disinterested persons as viewers to examine the property and report to the drainage authority or court. The hearing must be adjourned to make the examination and report and a date must be set to reconvene. The viewers, if appointed, shall proceed to examine the property of the objecting owner and report as soon as possible to the drainage authority or court with the description and situation of the property and whether the drainage system drains or otherwise affects the property.

(c) When the hearing is reconvened, the drainage authority or court shall consider the viewers' report and all evidence offered, and:

(1) if the drainage authority determines that the drainage system serves any useful purpose to any property or the general public, the petition for abandonment must be denied; or

(2) if the drainage authority determines that the drainage system does not serve any useful purpose to any affected property and is not of public benefit and utility, the drainage authority or court shall make findings and shall, by order, abandon the drainage system.

Subd. 6. **Effect of abandonment.** After abandonment of a drainage system, a repair petition for the drainage system may not be accepted and the responsibility of the drainage authority for the maintenance of the drainage system ends.

History: *1990 c 391 art 5 s 103*

103E.812 TRANSFER OF ALL OR PART OF DRAINAGE SYSTEM.

Subdivision 1. **Drainage lien payment period must expire.** After the period originally fixed or subsequently extended to pay the assessment of the drainage lien expires, all or part of a drainage system may be transferred from the jurisdiction of the drainage authority to a water management authority as provided in this section.

Subd. 2. **Petitioners.** (a) For drainage systems outside of the seven-county metropolitan area, and outside of the municipal boundaries of a statutory or home rule charter city, a petition must be signed by at least 51 percent of the owners of property assessed for the construction of the drainage system, or portion of the drainage system proposed to be transferred, or by the owners of not less than 51 percent of the area of the property assessed for the drainage system, or portion of the drainage system sought to be transferred. The water management authority to which the drainage system is to be transferred must join the petition.

(b) For drainage systems wholly or partially within the municipal boundaries of a statutory or home rule charter city, the city may petition for transfer if the drainage system or portion of the drainage system proposed to be transferred lies within the boundaries of the city. The water management authority to which the drainage system is to be transferred must join the petition.

(c) For drainage systems within the seven-county metropolitan area and within the jurisdictional boundaries of an existing water management authority, the water management authority may petition for transfer if the drainage system or portion of the drainage system proposed to be transferred lies within the boundaries of the water management authority.

(d) For the purpose of the petition, the county is the resident owner of all tax-forfeited property held by the state, under chapter 282, and assessed benefits for the drainage system, and the board may execute the petition for the county as an owner. This paragraph does not apply to lands acquired by the state under chapter 84A.

Subd. 3. **Petition.** (a) The petition must designate the drainage system, or portion thereof, proposed to be transferred and show that the transfer is necessary for the orderly management of storm, surface, or flood waters, including management for water quality purposes.

(b) The petition must indicate the impact, if any, that the transfer will have on properties utilizing the drainage system for an outlet or otherwise benefiting from the existence of the drainage system.

(c) The petition must include an engineering report, prepared by the transferee water management authority, establishing, for the record, the nature and extent of the drainage easement occupied by the drainage system, and the as-constructed, or subsequently improved, depth, grade, and hydraulic capacity of the drainage system.

Subd. 4. **Filing petition; jurisdiction.** (a) If the drainage system is administered by a county or joint county drainage authority and if all property assessed for benefits in the drainage system is in one county, the petition must be filed with the auditor unless the petition is signed by the board, in which case the petition must be made to the district court of the county where the drainage system is located and filed with the court administrator. If the board, acting as the drainage authority, is also the petitioning water management authority, the petition must be made to the district court of the county where the drainage system is located and filed with the court administrator. If property assessed for benefits is in two or more counties, the petition must be filed with the auditor or court administrator of either (1) the county where the portion of the drainage system sought to be transferred exists; (2) the county not petitioning for the transfer; or (3) the county where the majority of the drainage system sought to be transferred exists.

(b) If the drainage system is administered by the board of managers of a watershed district, the petition must be filed with the secretary of the watershed district. If the watershed district is also the petitioning water management authority, the petition must be filed with the court administrator consistent with the criteria in paragraph (a), clauses (1) to (3).

(c) When the petition is filed, the drainage authority in consultation with the auditor or secretary, or the court administrator with the approval of the court, shall set a time and location for a hearing on the petition. The auditor, secretary, or court administrator shall give notice by mail and publication of the time and location of the transfer hearing to all persons interested. The notice shall include a description of the property owner's right to object under subdivision 5. The drainage authority or the district court where the petition is properly filed has jurisdiction of the petition.

Subd. 5. **Transfer hearing.** (a) At the hearing, the drainage authority or court shall examine the petition and determine whether it is sufficient and shall hear all interested parties.

(b) If a property owner assessed benefits for the drainage system appears and makes a written objection to the transfer of the drainage system, the drainage authority or court shall appoint a technical panel to examine the drainage system, the property, and the proposed transfer and report to the drainage authority or court. The hearing must be adjourned to make the examination and report and a date must be set to reconvene. The technical panel shall consist, at a minimum, of a representative of the drainage authority, a representative of the commissioner, a representative of the soil and water conservation district, a representative of the Board of Water and Soil Resources, and a viewer. The technical panel shall proceed to examine the drainage system, the property, and the property owner's objections to the proposed transfer of the system and report as soon as possible to the drainage authority or court with the merits of the objections. The technical panel shall also determine the extent to which the transfer of the drainage system will damage or take property. Nongovernment employee members of the technical panel must be compensated in the same manner as viewers under section 103E.645, subdivision 3.

(c) The Board of Water and Soil Resources and the commissioner, if requested by the drainage authority or court, shall provide any technical assistance, including engineering, surveys, hydrologic analyses, or water quality studies as requested by the drainage authority or court.

(d) When the hearing is reconvened, the drainage authority or court shall consider the technical panel's report and all evidence offered. If the drainage authority or court determines that storm, surface, or flood waters along the drainage system or within the benefited area of the drainage system, could be better managed by a water management authority, it shall authorize the transfer of the drainage system.

Subd. 6. **Costs related to transfer and transfer proceedings.** Costs, including engineering and attorney's fees, related to the proceedings to transfer a drainage system must be paid by the proposed transferee water management authority. If the drainage authority or court orders that the drainage authority should not be transferred, the drainage authority shall reimburse the water management authority from the drainage system account for the reasonable value of engineering work conducted as part of the transfer proceedings.

Subd. 7. **Guarantee of outlet; no compromise of existing rights.** (a) Any proceeding to transfer all or part of a drainage system to a water management authority must guarantee that all rights to an outlet are preserved for property assessed for benefits on the transferred drainage system of at least equal hydraulic efficiency as the rights to an outlet that existed on the date of transfer.

(b) The transfer of a drainage system to a water management authority is not a compromise of any property right held by an owner of assessed property on the transferred drainage system.

(c) A water management authority shall compensate any owner of property assessed for benefits on the transferred drainage system for the loss or impairment of any drainage rights occurring after transfer of the drainage system.

Subd. 8. **Effect of transfer.** (a) Except as provided in this section, after transfer of a drainage system, or any part thereof, to a water management authority, the drainage system ceases to be subject to regulation under this chapter except that if only a portion of a drainage system is transferred, the water management authority may be assessed for improvements under section 103E.215 or repairs under sections 103E.701 to 103E.711 in the manner provided under sections 103E.315 and 103E.601 to 103E.615. The water management authority may manage water within its jurisdictional boundaries according to whatever law controls the function of the water management authority. The transferred drainage system shall become a work and a responsibility of the transferee water management authority. All responsibility of the drainage authority for the transferred drainage system ends.

(b) Activities conducted in the transferred drainage system must continue to be eligible for all exemptions and exceptions available for activities conducted in public drainage systems under sections 103G.2241 and 103G.245.

Subd. 9. **Effect on other law.** This section does not amend, supersede, or repeal any existing law providing for the transfer of a drainage system under this chapter, chapter 103D, or other law, but is supplementary to those laws.

History: *2002 c 327 s 3*

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Agency

Office of Water
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Questions & Answers on: Antidegradation

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QUESTIONS AND ANSWERS ON ANTIDEGRADATION

INTRODUCTION

This document provides guidance on the antidegradation policy component of water quality standards and its application. The document begins with the text of the policy as stated in the water quality standards regulation, 40 CFR 131.12 (40 FR 51400, November 8, 1983), the portion of the Preamble discussing the antidegradation policy, and the response to comments generated during the public comment period on the regulation.

The document then uses a question and answer format to present information about the origin of the policy, the meaning of various terms, and its application in both general terms and in specific examples. A number of the questions and answers are closely related; the reader is advised to consider the document in its entirety, for a maximum understanding of the policy, rather than to focus on particular answers in isolation. While this document obviously does not address every question which could arise concerning the policy, we hope that the principles it sets out will aid the reader in applying the policy in other situations. Additional guidance will be developed concerning the application of the antidegradation policy as it affects pollution from nonpoint sources. Since Congress is actively considering amending the Clean Water Act to provide additional programs for the control of nonpoint sources, EPA will await the outcome of congressional action before proceeding further.

EPA also has available, for public information, a summary of each State's antidegradation policy. For historical interest, limited copies are available of a Compendium of Department of the Interior Statements on Non-Degradation of Interstate Waters, August, 1968. Information on any aspect of the water quality standards program and copies of these documents may be obtained from:

David Sabock, Chief
Standards Branch (WH-585)
Office of Water Regulations and Standards
Environmental Protection Agency
401 M. Street, S.W.
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This document is designated as Appendix A to Chapter 2 - General Program Guidance (antidegradation) of the Water Quality Standards Handbook, December 1983.

James M. Conlon, Acting Director
Office of Water Regulations
and Standards

§ 131.12 Antidegradation policy.

(a) The State shall develop and adopt a statewide antidegradation policy and identify the methods for implementing such policy pursuant to this subpart. The antidegradation policy and implementation methods shall, at a minimum, be consistent with the following:

(1) Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

(2) Where the quality of the waters exceed levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected unless the State finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the State's continuing planning process, that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the State shall assure water quality adequate to protect existing uses fully. Further, the State shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best management practices for nonpoint source control.

(3) Where high quality waters constitute an outstanding National resource, such as waters of National and State parks and wildlife refuges and waters of exceptional recreational or ecological significance, that water quality shall be maintained and protected.

(4) In those cases where potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy and implementing method shall be consistent with section 316 of the Act.

Antidegradation Policy

The preamble to the proposed rule discussed three options for changing the existing antidegradation policy. Option 1, the proposed option, provided simply that uses attained would be maintained. Option 2 stated that not only would uses attained be maintained but that high quality waters, i.e. waters with quality better than that needed to protect fish and wildlife, would be maintained (that is, the existing antidegradation policy minus the "outstanding natural resource waters" provision). Option 3 would have allowed changes in an existing use if maintaining that use would effectively prevent any future growth in the community or if the benefits of maintaining the use do not bear a reasonable relationship to the costs.

Although there was support for Option 2, there was greater support for retaining the full existing policy, including the provision on outstanding National resource waters. Therefore, EPA has retained the existing antidegradation policy (Section 131.12) because it more accurately reflects the degree of water quality protection desired by the public, and is consistent with the goals and purposes of the Act.

In retaining the policy EPA made four changes. First, the provisions on maintaining and protecting existing instream uses and high quality waters were retained, but the sentences stating that no further water quality degradation which would interfere with or become injurious to existing instream uses is allowed were deleted. The deletions were made because the terms "interfere" and "injurious" were subject to misinterpretation as precluding any activity which might even momentarily add pollutants to the water. Moreover, we believe the deleted sentence was intended merely as a restatement of the basic policy. Since the rewritten provision, with the addition of a phrase on water quality described in the next sentence, stands alone as expressing the basic thrust and intent of the antidegradation policy, we deleted the confusing phrases. Second, in § 131.12(a)(1) a phrase was added requiring that the level of water quality necessary to protect an existing use be maintained and protected. The previous policy required only that an existing use be maintained. In § 131.12(a)(2) a phrase was added that "In allowing such degradation or lower water quality, the State shall assure water quality adequate to protect existing uses fully". This means that the full use must continue to exist even if some change in water quality may be permitted. Third, in the first sentence of § 131.12(a)(2) the wording was changed from ". . . significant economic or social development. . ." to ". . . important economic or social development. . . ." In the context of the antidegradation policy the word "important" strengthens the intent of protecting higher quality waters. Although common usage of the words may imply otherwise, the correct definitions of the two terms indicate that the greater degree of environmental protection is afforded by the word "important."

Fourth, § 131.12(a)(3) ~~dealing~~ with the designation of outstanding National resource waters (ONRW) was changed to provide a limited exception to the absolute "no degradation" requirement. EPA was concerned that waters which properly could have been designated as ONRW were not being so designated because of the flat no degradation provision, and therefore were not being given special protection. The no degradation provision was sometimes interpreted as prohibiting *any* activity (including temporary or short-term) from being conducted. States may allow some limited activities which result in temporary and short-term changes in water quality. Such activities are considered to be consistent with the intent and purpose of an ONRW. Therefore, EPA has rewritten the provision to read ". . . that water quality shall be maintained and protected," and removed the phrase "No degradation shall be allowed. . . ."

In its entirety, the antidegradation policy represents a three-tiered approach to maintaining and protecting various levels of water quality and uses. At its base (Section 131.12(a)(1)), all existing uses and the level of water quality necessary to protect those uses must be maintained and protected. This provision establishes the absolute floor of water quality in all waters of the United States. The second level (Section 131.12(a)(2)) provides protection of actual water quality in areas where the quality of the waters exceed levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water ("fishable/swimmable"). There are provisions contained in this subsection to allow some limited water quality degradation after extensive public involvement, as long as the water quality remains adequate to be "fishable/swimmable." Finally § 131.23(a)(3) provides special protection of waters for which the ordinary use classifications and water quality criteria do not suffice, denoted "outstanding National resource water." Ordinarily most people view this subsection as protecting and maintaining the highest quality waters of the United States: that is clearly the thrust of the provision. It does, however, also offer special protection for waters of "ecological significance." These are water bodies which are important, unique, or sensitive ecologically, but whose water quality as measured by the traditional parameters (dissolved oxygen, pH, etc.) may not be particularly high or whose character cannot be adequately described by these parameters.

Antidegradation Policy

EPA's proposal, which would have limited the antidegradation policy to the maintenance of existing uses, plus three alternative policy statements described in the preamble to the proposal notice, generated extensive public comment. EPA's response is described in the Preamble to this final rule and includes a response to both the substantive and philosophical comments offered. Public comments overwhelmingly supported retention of the existing policy and EPA did so in the final rule.

EPA's response to several comments dealing with the antidegradation policy, which were not discussed in the Preamble are discussed below.

Option three contained in the Agency's proposal would have allowed the possibility of exceptions to maintaining existing uses. This option was either criticized for being illegal or was supported because it provided additional flexibility for economic growth. The latter commenters believed that allowances should be made for carefully defined exceptions to the absolute requirement that uses attained must be maintained. EPA rejects this contention as being totally inconsistent with the spirit and intent of both the Clean Water Act and the underlying philosophy of the antidegradation policy. Moreover, although the Agency specifically asked for examples of where the existing antidegradation policy had precluded growth, no examples were provided. Therefore, wholly apart from technical legal concerns, there appears to be no justification for adopting Option 3.

Most critics of the proposed antidegradation policy objected to removing the public's ability to affect decisions on high quality waters and outstanding national resource waters. In attempting to explain how the proposed antidegradation policy would be implemented, the Preamble to the proposed rule stated that no public participation would be necessary in certain instances because no change was being made in a State's water quality standard. Although that statement was technically accurate, it left the mistaken impression that all public participation was removed from the discussions on high quality waters and that is not correct. A NPDES permit would have to be issued or a 208 plan amended for any deterioration in water quality to be "allowed". Both actions require notice and an opportunity for public comment. However, EPA retained the existing policy so this issue is moot. Other changes in the policy affecting ONRW are discussed in the Preamble.

QUESTIONS AND ANSWERS ON ANTIDEGRADATION

1. WHAT IS THE ORIGIN OF THE ANTIDEGRADATION POLICY?

The basic policy was established on February 8, 1968, by the Secretary of the U.S. Department of the Interior. It was included in EPA's first water quality standards regulation 40 CFR 130.17, 40 FR 55340-41, November 28, 1975. It was slightly refined and repromulgated as part of the current program regulation published on November 8, 1983 (48 FR 51400, 40 CFR §131.12). An antidegradation policy is one of the minimum elements required to be included in a State's water quality standards.

2. WHERE IN THE CLEAN WATER ACT (CWA) IS THERE A REQUIREMENT FOR AN ANTIDEGRADATION POLICY OR SUCH A POLICY EXPRESSED?

There is no explicit requirement for such a policy in the Act. However, the policy is consistent with the spirit, intent, and goals of the Act, especially the clause "... restore and maintain the chemical, physical and biological integrity of the Nation's waters" (§101(a)) and arguably is covered by the provision of 303(a) which made water quality standard requirements under prior law the "starting point" for CWA water quality requirements.

3. CAN A STATE JUSTIFY NOT HAVING AN ANTIDEGRADATION POLICY IN ITS WATER QUALITY STANDARDS?

EPA's water quality standards regulation requires each State to adopt an antidegradation policy and specifies the minimum requirements for a policy. If not included in the standards regulation of a State, the policy must be specifically referenced in the water quality standards so that the functional relationship between the policy and the standards is clear. Regardless of the location of the policy, it must meet all applicable requirements.

4. WHAT HAPPENS IF A STATE'S ANTIDEGRADATION POLICY DOES NOT MEET THE REGULATORY REQUIREMENTS?

If this occurs either through State action to revise its policy or through revised Federal requirements, the State would be given an opportunity to make its policy consistent with the regulation. If this is not done, EPA has the authority to promulgate the policy for the State pursuant to Section 303(c)(4) of the Clean Water Act.

5. WHAT COULD HAPPEN IF A STATE FAILED TO IMPLEMENT ITS ANTI-DEGRADATION POLICY PROPERLY?

If a State issues an NPDES permit which violates the required antidegradation policy, it would be subject to a discretionary EPA veto under Section 402(d) or to a citizen challenge. In addition to actions on permits, any wasteload allocations and total maximum daily loads violating the antidegradation policy are subject to EPA disapproval and EPA promulgation of a new wasteload allocation/total maximum daily load under Section 303(d) of the Act. If a significant pattern of violation was evident, EPA could constrain the award of grants or possibly revoke any Federal permitting capability that had been delegated to the State. If the State issues a §401 certification (for an EPA-issued NPDES permit) which fails to reflect the requirements of the antidegradation policy, EPA will, on its own initiative, add any additional or more stringent effluent limitations required to ensure compliance with Section 301(b)(1)(C). If the faulty §401 certification related to permits issued by other Federal agencies (e.g. a Corp of Engineers Section 404 permit), EPA could comment unfavorably upon permit issuance. The public, of course, could bring pressure upon the permit issuing agency.

6. WILL THE APPLICATION OF THE ANTIDEGRADATION POLICY ADVERSELY IMPACT ECONOMIC DEVELOPMENT?

This concern has been raised since the inception of the antidegradation policy. The answer remains the same. The policy has been carefully structured to minimize adverse effects on economic development while protecting the water quality goals of the Act. As Secretary Udall put it in 1968, the policy serves "...the dual purpose of carrying out the letter and spirit of the Act without interfering unduly with further economic development" (Secretary Udall, February 8, 1968). Application of the policy could affect the levels and/or kinds of waste treatment necessary or result in the use of alternate sites where the environmental impact would be less damaging. These effects could have economic implications as do all other environmental controls.

7. WHAT IS THE PROPER INTERPRETATION OF THE TERM "AN EXISTING USE"?

An existing use can be established by demonstrating that fishing, swimming, or other uses have actually occurred since November 28, 1975, or that the water quality is suitable to allow such uses to occur (unless there are physical problems which prevent the use regardless of water quality). An example of the latter is an area where shellfish are propagating and surviving in a biologically suitable habitat and are available and suitable for harvesting. Such facts clearly establish that shellfish harvesting is an "existing" use, not one dependent on improvements in water quality. To argue otherwise would be to say that the only time an aquatic protection use "exists" is if someone succeeds in catching fish.

8. THE WATER QUALITY STANDARDS REGULATION STATES THAT "EXISTING USES AND THE LEVEL OF WATER QUALITY NECESSARY TO PROTECT THE EXISTING USES SHALL BE MAINTAINED AND PROTECTED." HOW FULLY AND AT WHAT LEVEL OF PROTECTION IS AN EXISTING USE TO BE PROTECTED IN ORDER TO SATISFY THE ABOVE REQUIREMENT?

No activity is allowable under the antidegradation policy which would partially or completely eliminate any existing use whether or not that use is designated in a State's water quality standards. The aquatic protection use is a broad category requiring further explanation. Species that are in the water body and which are consistent with the designated use (i.e., not aberrational) must be protected, even if not prevalent in number or importance. Nor can activity be allowed which would render the species unfit for maintaining the use. Water quality should be such that it results in no mortality and no significant growth or reproductive impairment of resident species. (See Question 16 for situation where an aberrant sensitive species may exist.) Any lowering of water quality below this full level of protection is not allowed. A State may develop subcategories of aquatic protection uses but cannot choose different levels of protection for like uses. The fact that sport or commercial fish are not present does not mean that the water may not be supporting an aquatic life protection function. An existing aquatic community composed entirely of invertebrates and plants, such as may be found in a pristine alpine tributary stream, should still be protected whether or not such a stream supports a fishery. Even though the shorthand expression "fishable/swimmable" is often used, the actual objective of the act is to "restore and maintain the chemical, physical, and biological integrity of our Nation's waters (section 101(a)).1/ The term "aquatic life" would more accurately reflect the protection of the aquatic community that was intended in Section 101(a)(2) of the Act.

9. IS THERE ANY SITUATION WHERE AN EXISTING USE CAN BE REMOVED?

In general, no. Water quality may sometimes be affected, but an existing use, and the level of water quality to protect it must be maintained (§131.12(a)(1) and (2) of the regulation). However, the State may limit or not designate such a use if the reason for such action is non-water quality related. For example, a State may wish to impose a temporary shellfishing ban to prevent overharvesting and ensure an abundant population over the long run, or may wish to restrict swimming from heavily trafficked areas. If the State chooses,

1/ Note: "Fishable/swimmable" is a term of convenience used in the standards program in lieu of constantly repeating the entire text of Section 101(a)(2) goal of the Clean Water Act. As a short-hand expression it is potentially misleading.

for non-water quality reasons, to limit use designations, it must still adopt criteria to protect the use if there is a reasonable likelihood it will actually occur (e.g. swimming in a prohibited water). However, if the State's action is based on a recognition that water quality is likely to be lowered to the point that it no longer is sufficient to protect and maintain an existing use, then such action is inconsistent with the antidegradation policy.

10. HOW DOES THE REQUIREMENT THAT THE LEVEL OF WATER QUALITY NECESSARY TO PROTECT THE EXISTING USE(S) BE MAINTAINED AND PROTECTED, WHICH APPEARS IN §131.12(a)(1),(2), AND (3) OF THE WATER QUALITY STANDARDS REGULATION, ACTUALLY WORK?

Section 131.12(a)(1), as described in the Preamble to the regulation, provides the absolute floor of water quality in all waters of the United States. This paragraph applies a minimum level of protection to all waters. However, it is most pertinent to waters having beneficial uses that are less than the Section 101(a)(2) goals of the Act. If it can be proven, in that situation, that water quality exceeds that necessary to fully protect the existing use(s) and exceeds water quality standards but is not of sufficient quality to cause a better use to be achieved, then that water quality may be lowered to the level required to fully protect the existing use as long as existing water quality standards and downstream water quality standards are not affected. If this does not involve a change in standards, no public hearing would be required under Section 303(c). However, public participation would still be provided in connection with the issuance of a NPDES permit or amendment of a 208 plan. If, however, analysis indicates that the higher water quality does result in a better use, even if not up to the Section 101(a)(2) goals, then the water quality standards must be upgraded to reflect the uses presently being attained (§131.10(i)).

Section 131.12(a)(2) applies to waters whose quality exceeds that necessary to protect the Section 101(a)(2) goals of the Act. In this case, water quality may not be lowered to less than the level necessary to fully protect the "fishable /swimmable" uses and other existing uses and may be lowered even to those levels only after following all the provisions described in §131.12(a)(2). This requirement applies to individual water quality parameters.

Section 131.12(a)(3) applies to so-called outstanding National Resource (ONRW) waters where the ordinary use classifications and supporting criteria are not appropriate. As described in the Preamble to the water quality standards regulation "States may allow some limited activities which result in temporary and short-term changes in water quality," but such changes in water quality should not alter the essential character or special use which makes the water an ONRW. (See also pages 2-14,-15 of the <u>Water Quality Standards Handbook</u>.)

Any one or a combination of several activities may trigger the antidegradation policy analysis as discussed above. Such activities include a scheduled water quality standards review, the establishment of new or revised wasteload allocations NPDES permits, the demonstration of need for advanced treatment or request by private or public agencies or individuals for a special study of the water body.

11. WILL AN ACTIVITY WHICH WILL DEGRADE WATER QUALITY, AND PRECLUDE AN EXISTING USE IN ONLY A PORTION OF A WATER BODY (BUT ALLOW IT TO REMAIN IN OTHER PARTS OF THE WATER BODY) SATISFY THE ANTIDEGRADATION REQUIREMENT THAT EXISTING USES SHALL BE MAINTAINED AND PROTECTED?

No. Existing uses must be maintained in all parts of the water body segment in question other than in restricted mixing zones. For example, an activity which lowers water quality such that a buffer zone must be established within a previous shellfish harvesting area is inconsistent with the antidegradation policy. (However, a slightly different approach is taken for fills in wetlands, as explained in Question 13.)

12. DOES ANTIDEGRADATION APPLY TO POTENTIAL USES?

No. The focus of the antidegradation policy is on protecting existing uses. Of course, insofar as existing uses and water quality are protected and maintained by the policy the eventual improvement of water quality and attainment of new uses may be facilitated. The use attainability requirements of §131.10 also help ensure that attainable potential uses are actually attained. (See also questions 7 and 10.)

13. FILL OPERATIONS IN WETLANDS AUTOMATICALLY ELIMINATE ANY EXISTING USE IN THE FILLED AREA. HOW IS THE ANTIDEGRADATION POLICY APPLIED IN THAT SITUATION?

Since a literal interpretation of the antidegradation policy could result in preventing the issuance of any wetland fill permit under Section 404 of the Clean Water Act, and it is logical to assume that Congress intended some such permits to be granted within the framework of the Act, EPA interprets §131.12 (a)(1) of the antidegradation policy to be satisfied with regard to fills in wetlands if the discharge did not result in "significant degradation" to the aquatic ecosystem as defined under Section 230.10(c) of the Section 404(b)(1) guidelines. If any wetlands were found to have better water quality than "fishable/ swimmable", the State would be allowed to lower water quality to the no significant degradation level as long as the requirements of Section 131.12(a)(2) were followed. As for the ONRW provision of antidegradation (131.(a)(2)(3)), there is no difference in the way it applies to wetlands and other water bodies.

14. IS POLLUTION RESULTING FROM NONPOINT SOURCE ACTIVITIES SUBJECT TO PROVISIONS OF THE ANTIDEGRADATION POLICY?

Nonpoint source activities are not exempt from the provisions of the antidegradation policy. The language of Section 131.12 (a)(2) of the regulation: "Further, the State shall assure that there shall be achieved the highest statutory and regulatory requirements for all new and existing point sources and all cost-effective and reasonable best mangement practices for nonpoint source control" reflects statutory provisions of the Clean Water Act. While it is true that the Act does not establish a regulatory program for nonpoint sources, it clearly intends that the BMPs developed and approved under sections 205(j), 208 and 303(e) be agressively implemented by the States. As indicated in the introduction, EPA will be developing additional guidance in this area.

15. IN HIGH QUALITY WATERS, ARE NEW DISCHARGERS OR EXPANSION OF EXISTING FACILITIES SUBJECT TO THE PROVISIONS OF ANTIDEGRADATION?

Yes. Since such activities would presumably lower water quality, they would not be permissible unless the State finds that it is necessary to accommodate important economic or social development (Section 131.12(a)(2). In addition the minimum technology based requirements must be met, including new source performance standards. This standard would be implemented through the waste-load and NPDES permit process for such new or expanded sources.

16. A STREAM, DESIGNATED AS A WARM WATER FISHERY, HAS BEEN FOUND TO CONTAIN A SMALL, APPARENTLY NATURALLY OCCURRING POPULATION OF A COLD-WATER GAME FISH. THESE FISH APPEAR TO HAVE ADAPTED TO THE NATURAL WARM WATER TEMPERATURES OF THE STREAM WHICH WOULD NOT NORMALLY ALLOW THEIR GROWTH AND REPRODUCTION. WHAT IS THE EXISTING USE WHICH MUST BE PROTECTED UNDER SECTION 131.12(a)(1)?

Section 131.12(a)(1) states that "Existing instream water uses and level of water quality necessary to protect the existing uses shall be maintained and protected." While sustaining a small cold-water fish population, the stream does not support an existing use of a "cold-water fishery." The existing stream temperatures are unsuitable for a thriving cold-water fishery. The small marginal population is an artifact and should not be employed to mandate a more stringent use (true cold-water fishery) where natural conditions are not suitable for that use.

A use attainability analysis or other scientific assessment should be used to determine whether the aquatic life population is in fact an artifact or is a stable population requiring water quality protection. Where species appear in areas not normally expected, some adaptation may have occurred and site-specific criteria may be appropriately developed. Should the cold-water fish population consist of a threatened or endangered species, it may require protection under the Endangered Species Act. Otherwise the stream need only be protected as a warm water fishery.

17. HOW DOES EPA'S ANTIDEGRADATION POLICY APPLY TO A WATERBODY WHERE A CHANGE IN MAN'S ACTIVITIES IN OR AROUND THAT WATERBODY WILL PRECLUDE AN EXISTING USE FROM BEING FULLY MAINTAINED?

If a planned activity will forseeably lower water quality to the extent that it no longer is sufficient to protect and maintain the existing uses in that waterbody, such an activity is inconsistent with EPA's antidegradation policy which requires that existing uses are to be maintained. In such a circumstance the planned activity must be avoided or adequate mitigation or preventive measures must be taken to ensure that the existing uses and the water quality to protect them will be maintained.

In addition, in "high quality waters", under §131.12(a)(2), before any lowering of water quality occurs, there must be: 1) a finding that it is necessary in order to accommodate important economical or social development in the area in which the waters are located, (2) full satisfaction of all intergovernmental coordination and public participation provisions and (3) assurance that the highest statutory and regulatory requirements and best management practices for pollutant controls are achieved. This provision can normally be satisfied by the completion of Water Quality Management Plan updates or by a similar process that allows for public participation and intergovernmental coordination. This provision is intended to provide relief only in a few extra-ordinary circumstances where the economic and social need for the activity clearly outweighs the benefit of maintaining water quality above that required for "fishable/swimmable" water, and the two cannot both be achieved. The burden of demonstration on the individual proposing such activity will be very high. In any case, moreover, the existing use must be maintained and the activity shall not preclude the maintenance of a "fishable/swimmable" level of water quality protection.

18. WHAT DOES EPA MEAN BY "...THE STATE SHALL ENSURE THAT THERE SHALL BE ACHIEVED THE HIGHEST STATUTORY AND REGULATORY REQUIREMENTS FOR ALL NEW AND EXISTING POINT SOURCES AND ALL COST EFFECTIVE AND REASONABLE BEST MANAGEMENT PRACTICES FOR NON-POINT SOURCE CONTROL" (§131.12(a)(2)?

This requirement ensures that the limited provision for lowering water quality of high quality waters down to "fish-able /swimmable" levels will not be used to undercut the Clean Water Act requirements for point source and non-point source pollution control. Furthermore, by ensuring compliance with such statutory and regulatory controls, there is less chance that a lowering of water quality will be sought in order to accommodate new economic and social development.

19. WHAT DOES EPA MEAN BY "...IMPORTANT ECONOMIC OR SOCIAL DEVELOPMENT IN THE AREA IN WHICH THE WATERS ARE LOCATED" IN 131.1 2(a)(2)?

This phrase is simply intended to convey a general concept regarding what level of social and economic development could be used to justify a change in high quality waters. Any more exact meaning will evolve through case-by-case application under the State's continuing planning process. Although EPA has issued suggestions on what might be considered in determining economic or social impacts, the Agency has no predetermined level of activity that is defined as "important".

20. IF A WATER BODY WITH A PUBLIC WATER SUPPLY DESIGNATED USE IS, FOR NON-WATER QUALITY REASONS, NO LONGER USED FOR DRINKING WATER MUST THE STATE RETAIN THE PUBLIC WATER SUPPLY USE AND CRITERIA IN ITS STANDARDS?

Under 40 CFR 131.10(h)(1), the State may delete the public water supply use designation and criteria if the State adds or retains other use designations for the waterbodies which have more stringent criteria. The State may also delete the use and criteria if the public water supply is not an "existing use" as defined in 131.3 (i.e., achieved on or after November 1975), as long as one of the §131.10(g) justifications for removal is met.

Otherwise, the State must maintain the criteria even if it restricts the actual use on non-water quality grounds, as long as there is any possibility the water could actually be used for drinking. (This is analogous to the swimming example in the preamble.)

21. WHAT IS THE RELATIONSHIP BETWEEN WASTELOAD ALLOCATIONS, TOTAL MAXIMUM DAILY LOADS, AND THE ANTIDEGRADATION POLICY?

Wasteload allocations distribute the allowable pollutant loadings to a stream between dischargers. Such allocations also consider the contribution to pollutant loadings from non-point sources. Wasteload allocations must reflect applicable State water quality standards including the antidegradation policy. No wasteload allocation can be develped or NPDES permit issued that would result in standard being violated, or, in the case of waters whose quality exceeds that necessary for the Section 101(a)(2) goals of the Act, can result a lowering of water quality unless the applicable public participation, intergovernmental review and baseline control requirements of the antidegradation policy have been met.

22. DO THE INTERGOVERNMENTAL COORDINATION AND PUBLIC PARTICIPATION REQUIREMENTS WHICH ESTABLISH THE PROCEDURES FOR DETERMINING THAT WATER QUALITY WHICH EXCEEDS THAT NECESSARY TO SUPPORT THE SECTION 101(a)(2) GOAL OF THE ACT MAY BE LOWERED APPLY TO CONSIDERING ADJUSTMENTS TO THE WASTELOAD ALLOCATIONS DEVELOPED FOR THE DISCHARGERS IN THE AREA?

Yes. Section 131.12(a)(2) of the water quality standards regulation is directed towards changes in water quality _per se_, not just towards changes in standards. The intent is to ensure that no activity which will cause water quality to decline in existing high quality waters is undertaken without adequate public review. Therefore, if a change in wasteload allocation could alter water quality in high quality waters, the public participation and coordination requirements apply.

23. IS THE ANSWER TO THE ABOVE QUESTION DIFFERENT IF THE WATER QUALITY IS LESS THAN THAT NEEDED TO SUPPORT "FISHABLE/SWIMMABLE" USES?

Yes. Nothing in either the water quality standards or the wasteload allocation regulations requires the same degree of public participation or intergovernmental coordination for such waters as is required for high quality waters. However, as discussed in question 10, public participation would still be provided in connection with the issuance of a NPDES permit or amendment of a 208 plan. Also, if the action which causes reconsideration of the existing wasteloads (such as dischargers withdrawing from the area) will result in an improvement in water quality which makes a better use attainable, even if not up to the "fishable/swimmable" goal, then the water quality standards must be upgraded and full public review is required for any action affecting changes in standards. Although not specifically required by the standards regulation between the triennial reviews, we recommend that the State conduct a use attainability analysis to determine if water quality improvement will result in attaining higher uses than currently designated in situations where significant changes in wasteloads are expected (see question 10).

24. SEVERAL FACILITIES ON A STREAM SEGMENT DISCHARGE PHOSPHORUS-CONTAINING WASTES. AMBIENT PHOSPHORUS CONCENTRATIONS MEET CLASS B STANDARDS, BUT BARELY. THREE DISCHARGERS ACHIEVE ELIMINATION OF DISCHARGE BY DEVELOPING A LAND TREATMENT SYSTEM. AS A RESULT, ACTUAL WATER QUALITY IMPROVES (I.E., PHOSPHORUS LEVELS DECLINE) BUT NOT QUITE TO THE LEVEL NEEDED TO MEET CLASS A (FISHABLE/SWIMMABLE) STANDARDS. CAN THE THREE REMAINING DISCHARGERS NOW INCREASE THEIR PHOSPHORUS DISCHARGE WITH THE RESULT THAT WATER QUALITY DECLINES (PHOSPHORUS LEVELS INCREASE) TO PREVIOUS LEVELS?

Nothing in the water quality standards regulation explicitly prohibits this (see answer to questions 10 and 23). Of course, changes in their NPDES permit limits may be subject to non-water quality constraints, such as BPT or BAT, which may restrict this.

25. SUPPOSE IN THE ABOVE SITUATION WATER QUALITY IMPROVES TO THE POINT THAT ACTUAL WATER QUALITY NOW MEETS CLASS A REQUIREMENTS. IS THE ANSWER DIFFERENT?

Yes. The standards must be upgraded (see answer to question 10).

26. AS AN ALTERNATIVE CASE, SUPPOSE PHOSPHORUS LOADINGS GO DOWN AND WATER QUALITY IMPROVES BECAUSE OF A CHANGE IN FARMING PRACTICES, E.G., INITIATION OF A SUCCESSFUL NON-POINT PROGRAM. ARE THE ABOVE ANSWERS THE SAME?

Yes. Whether the improvement results from a change in point or nonpoint source activity is immaterial to how any aspect of the standards regulation operates. Section 131.10(d) clearly indicates that uses are deemed attainable if they can be achieved by "... cost-effective and reasonable best management practices for nonpoint source control". Section 131.12(a)(2) of the anti-degradation policy contains essentially the same wording.

27. WHEN A POLLUTANT DISCHARGE CEASES FOR ANY REASON, MAY THE WASTELOAD ALLOCATIONS FOR THE OTHER DISCHARGES IN THE AREA BE ADJUSTED TO REFLECT THE ADDITIONAL LOADING AVAILABLE?

This may be done consistent with the antidegradation policy only under two circumstances: (1) In "high quality waters" where after the full satisfaction of all public participation and intergovernmental review requirements, such adjustments are considered necessary to accomodate important economic or social development, and the "threshold" level requirements are met; or (2) in less than "high quality waters", when the expected improvement in water quality will not cause a better use to be achieved, the adjusted loads still meet water quality standards, and the new wasteload allocations are at least as stringent as technology-based limitations. Of course, all applicable requirements of the Section 402 permit regulations would have to be satisfied before a permittee could increase its discharge.

28. HOW MAY THE PUBLIC PARTICIPATION REQUIREMENTS BE SATISFIED?

This requirement may be satisfied in several ways. The State may obviously hold a public hearing or hearings. The State may also satisfy the requirement by providing the opportunity for the public to request a hearing. Activities which may affect several water bodies in a river basin or sub-basin may be considered in a single hearing. To ease the resource burden on both the State and public, standards issues may be combined with hearings on environmental impact statements, water management plans, or permits. However, if this is done, the public must be clearly informed that possible changes in water quality standards are being considered along with other activities. In other words, it is inconsistent with the water quality standards regulation to "back-door" changes in standards through actions on EIS's, wasteload allocations, plans, or permits.

29. WHAT IS MEANT BY THE REQUIREMENT THAT, WHERE A THERMAL DISCHARGE IS INCLUDED, THE ANTIDEGRADATION POLICY SHALL BE CONSISTENT WITH SECTION 316 OF THE ACT?

This requirement is contained in Section 131.12 (a)(4) of the regulation and is intended to coordinate the requirements and procedures of the antidegadation policy with those established in the Act for setting thermal discharge limitations. Regulations implementing Section 316 may be found at 40 CFR 124.66. The statutory scheme and legislative history indicate that limitations developed under Section 316 take precedence over other requirements of the Act.

30. WHAT IS THE RELATIONSHIP BETWEEN THE ANTIDEGRADATION POLICY, STATE WATER RIGHTS USE LAWS AND SECTION 101(g) OF THE CLEAN WATER ACT WHICH DEALS WITH STATE AUTHORITY TO ALLOCATE WATER QUANTITIES?

The exact limitations imposed by section 101(g) are unclear; however, the legislative history and the courts interpreting it do indicate that it does not nullify water quality measures authorized by CWA (such as water quality standards and their upgrading, and NPDES and 402 permits) even if such measures incidentally affect individual water rights; those authorities also indicate that if there is a way to reconcile water quality needs and water quantity allocations, such accomodation should be be pursued. In other words, where there are alternate ways to meet the water quality requirements of the Act, the one with least disruption to water quantity allocations should be chosen. Where a planned diversion would lead to a violation of water quality standards (either the antidegradation policy or a criterion), a 404 permit associated with the diversion should be suitably conditioned if possible and/or additional nonpoint and/or point source controls should be imposed to compensate.

31. AFTER READING THE REGULATION, THE PREAMBLE, AND ALL THESE QUESTIONS AND ANSWERS, I STILL DON'T UNDERSTAND ANTIDEGRADATION. WHOM CAN I TALK TO?

Call the Standards Branch at: (202) 245-3042. You can also call the water quality standards coordinators in each of our EPA Regional offices.

Technical Guidance for Reviewing and Designating Tiered Aquatic Life Uses in Minnesota Streams and Rivers – Draft

Minnesota Pollution Control Agency

August 2015

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Acronyms/Abbreviations

2Ae – Exceptional Use Cold Water Habitat
2Ag – General Use Cold Water Habitat
2Bde – Exceptional Use Warm Water Habitat (also protected for drinking water)
2Bdg – General Use Warm Water Habitat (also protected for drinking water)
2Bdm– Modified Use Warm Water Habitat (also protected for drinking water)
2Be – Exceptional Use Warm Water Habitat
2Bg – General Use Warm Water Habitat
2Bm – Modified Use Warm Water Habitat
ALU – Aquatic Life Use
ANOVA – Analysis of Variance
AUID – Assessment Unit ID
AWC – Altered Watercourse
BCG – Biological Condition Gradient
BMP – Best Management Practice
CALM – Consolidated Assessment and Listing Methodology
CFR – Code of Federal Regulations
CWA – Clean Water Act
DNR – Minnesota Department of Natural Resources
DRG – Digital Raster Graphic
IBI – Index of Biological Integrity or Index of Biotic Integrity
GIS – Geographic Information System
GNIS – Geographic Names Information System
HUC – Hydrologic Unit Code
HUC8 – 8-digit Hydrologic Unit Code
MBI – Midwest Biodiversity Institute
Minn. Stat. – Minnesota Statute
MLE – Multiple Lines of Evidence
MPCA – Minnesota Pollution Control Agency
MSHA – Minnesota (or MPCA) Stream Habitat Assessment
NHD – National Hydrography Dataset
NWI – National Wetlands Inventory
PWI – Public Waters Inventory
QHEI – Qualitative Habitat Evaluation Index
TALU – Tiered Aquatic Life Uses
TMDL – Total Maximum Daily Load
UAA – Use Attainability Analysis
USEPA – United State Environmental Protection Agency
USGS – United States Geologic Survey
WID – Waterbody ID
WQS – Water Quality Standards
WRAPS – Watershed Restoration and Protection Strategy

1 Executive summary

This document was developed to guide the process for changing or confirming aquatic life use (ALU) designations to ensure that the designation of ALUs for Minnesota streams and rivers are done in an appropriate and consistent manner. This focuses on the process for designating Tiered Aquatic Life Uses or TALUs. This document does not cover the process for reviewing non-aquatic life uses (e.g., recreation, domestic consumption), cold water subclass reviews, development of site specific standards, or natural background reviews. The first step in assessing a water body is determining the correct use as defined by the Clean Water Act (CWA) and Minnesota Rule. If the wrong use is applied to a water body, the steps that follow may not be valid and can lead to errors in the assessment and management of that water body. In general, a multiple lines of evidence approach is used which requires biological, chemical, habitat, channel status, and other forms of evidence to understand the attainability of a use such that the appropriate use can be applied. This approach seeks to bring in all available current and historical information from a water body unit (identified as a WID) in order to build supporting evidence for the attainability of a beneficial use. In addition to describing the process for designating uses, this document also provides guidance for developing recommendations for splitting or merging WIDs.

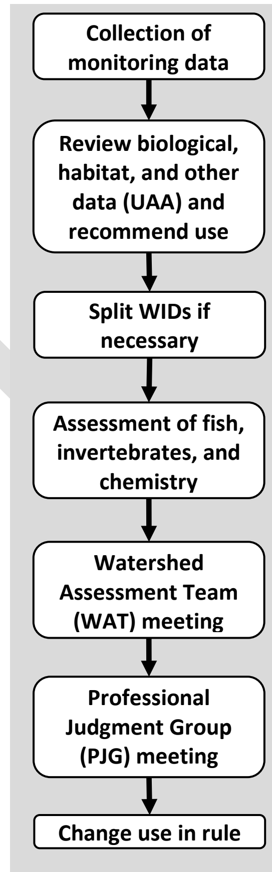

Figure 1. Steps for assessing aquatic life uses in Minnesota

2 Introduction

The Minnesota Pollution Control Agency (MPCA) is responsible for implementing the CWA in Minnesota. As such, the MPCA works to achieve the objective of the CWA which is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (U.S. Code title 33, section 1251 (a)). In addition to this objective, the CWA provides an interim goal for the Nations waters:

> ***"wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water" (U.S. Code title 33, section 1251 [a] [2])***

This sets a minimum goal for all waters that is often referred to as "fishable-swimmable". As a result, the MPCA protects most waters of the state (Minn. Stat. § 115.01, subd. 22) to at least this level. Some waters can be protected to a lower level, but this requires a Use Attainability Assessment (UAA) to determine if a lower use is appropriate. This assessment requires both a review of existing use (40 CFR § 131.3(e)) and a determination of whether or not a lower use is allowable because it cannot be feasibly attained (40 CFR § 131.10(g); see Table 1). This process is described in more detail in Section 3.

The use of biological indicators and the adoption of the TALU framework in Minnesota require methods to accurately and consistently determine the attainability of ALUs. Prior to the assessment of aquatic life, an accurate determination of a water body's designated use must occur, otherwise subsequent management actions (e.g., stressor identification, Total Maximum Daily Load [TMDL], and permitting) may be invalid or less effective. Sufficient biological data drives the decision to confirm or change an aquatic life use with additional data (e.g., habitat, chemistry, land cover, anthropogenic activity) providing further information on the attainability of that use. Once the ALU is confirmed and designated, then the assessment of that water body can proceed by comparing biological and chemical measures against the appropriate criteria. The major steps in this process are outlined in Figure 1. In practice, much of the work to redesignate or confirm a beneficial use will take place during a UAA. However, the recommended uses that are proposed from the UAA process will undergo internal MPCA reviews and external public reviews (e.g., Professional Judgment Group Meetings) to bring additional evidence and expertise that informs the attainability of the use. Finally the proposed use will undergo a formal rulemaking to establish the beneficial use in 7050.0470. This review process will ensure that the proposed use is appropriate.

3 Determination of tiered aquatic life uses for streams and rivers

A TALU-based monitoring program is designed and conducted to meet three principal objectives in the following order:

- Determine if use designations presently assigned to a given water body are appropriate and attainable
- Determine the extent to which use designations assigned in the state Water Quality Standards (WQS) are either attained or not attained
- Determine if any changes in key ambient biological, chemical, or physical indicators have taken place over time, particularly before and after the implementation of point source pollution controls or BMPs (i.e., effectiveness monitoring)

The review of the ALU designation determines the existing use of an assessment reach (see Table 1; 40 CFR § 131.3(e)). This states that the existing use is the beneficial use that was attained on or after November 28, 1975, so data outside of MPCA's 10-year assessment window is relevant to the determination of use. Biological data is central to use designation although several other forms of evidence are also required in determining aquatic life use for a water body. See MPCA (2014b, c) for descriptions of the Indices of Biological Integrity (IBI) and MPCA (2014a) for a description of the biological criteria. These other lines of evidence are especially important for waters where the General Use is not attained as it must then be determined if the General Use can and should be attained to be compliant with state and federal rules. The steps for determining a water body's beneficial use are detailed in Figure 3.

Although the final ALU recommendation is at the Waterbody ID or WID scale (i.e., a river or stream reach that is often delineated by major tributaries to the water course) and may include information from adjacent and nearby reaches, the review of the use is initially performed at the biological monitoring station level. The extent of the reach to which the beneficial use is applied is then determined by an assessment of the homogeneity uniformity of the reach. This involves an examination of channel condition throughout the WID and if there are any major geologic features, legacy anthropogenic impacts, tributaries, etc. present that could influence the attainability of the beneficial use. In cases where the WID is relatively homogenous and if the UAA of all monitoring stations within the reach results in the same recommended use, then the entire WID can be designated one use (Figure 2; Scenario 1). In cases where the monitoring stations indicate different uses are appropriate and/or the reach is not homogeneous, then a splitting of the reach can be recommended (Figure 2; Scenario 2). Similarly, if the WID is very long then a WID split may be recommended even if the entire reach is the same use. Splitting long WIDs is more likely to occur when the reach crosses through multiple aggregated 12-digit HUC watersheds. It should also be noted that the appropriate reach length is affected by the size of the river with longer reaches more appropriate on larger rivers. The determination of biological attainment for each WID is largely performed independently although the biological attainability of a reach may be informed by adjacent reaches.

Table 1. Clean Water Act rules relevant to designation of aquatic life uses.

40 CFR § 131.3(e) Existing uses are those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the Water Quality Standards.

40 CFR § 131.10(g) States may remove a designated use which is not an existing use, as defined in Section 131.3, or establish sub-categories of a use if the State can demonstrate that attaining the designated use is not feasible because:

1) Naturally occurring pollutant concentrations prevent the attainment of the use; or
2) Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met; or
3) Human caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or
4) Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or
5) Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses;
6) Controls more stringent than those required by sections 301(b) and 306 of the Act would result in substantial and widespread economic and social impact.

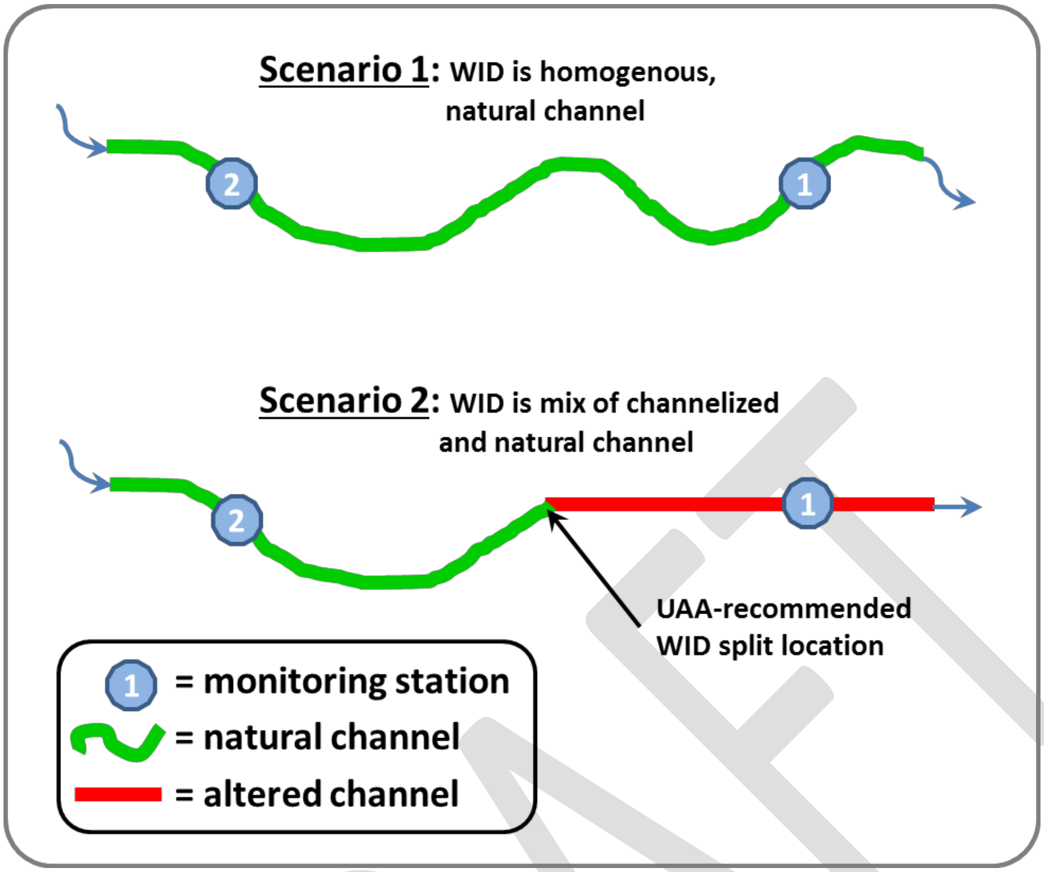

Figure 2. Examples of stream reaches (WIDs) with homogenous channel conditions and mixed channel conditions. The mixed channel reach would require a split to create two new homogenous reaches.

3.1 Use designation process

Prior to the adoption of the TALU framework, Minnesota largely used a one-size-fits-all approach to designate ALUs. A TALU framework changes this by introducing multiple tiers that better reflect the attainability of the use and which can be used to guide more effective management of the beneficial use. The introduction of additional tiers requires a detailed review of uses during the assessment of each 8-digit HUC (HUC8) watershed. In addition, changes to uses will need to be incorporated into the rule-making process (most likely on an annual basis). The process for performing TALU framework UAAs is described below with an overview of the process in Figure 3. The subsection numbers in Section 3.1 correspond to the step numbers in Figure 3. All of the appropriate steps in this process need to be followed and addressed before a change to a beneficial use is recommended.

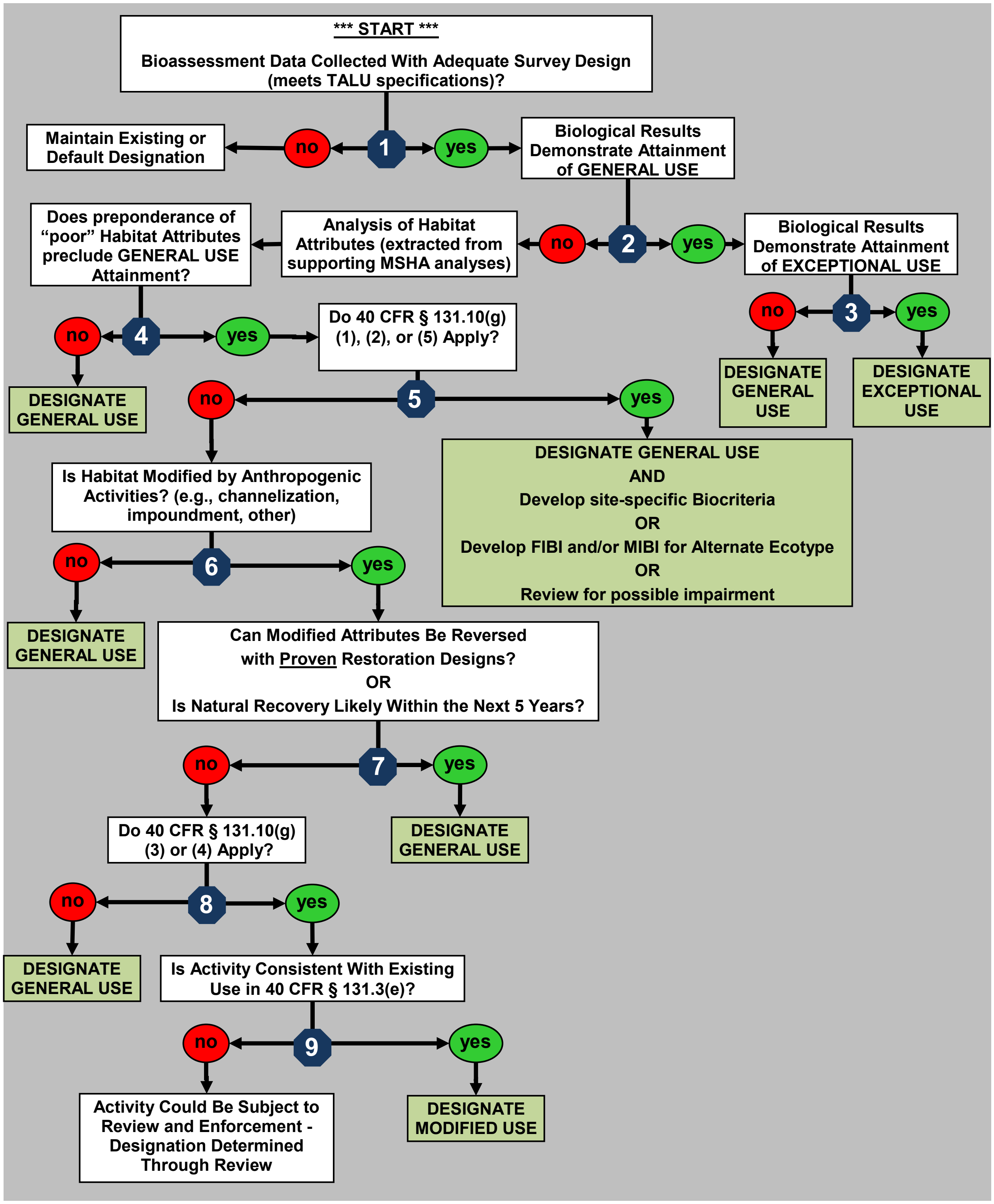

Figure 3. Process for using biological assessments to make use designation decisions within a TALU framework in Minnesota.

3.1.1 Data review

The first step in the use review is to compile the relevant biological, chemical, and habitat data from the WID. This differs from the data that is used for assessments as it can be older than 10 years. In fact, older data can be helpful when collecting evidence to determine the existing use for a water body. This data will need to include at least one reportable/assessable visit from either fish or macroinvertebrates, although it is preferable that data from both assemblages are present. It is preferable that habitat data (i.e., Minnesota Stream Habitat Assessment [MSHA]) collected at the same time as the biological sampling visit is used. However, habitat data collected on a different day (e.g., during the sampling of the other assemblage) or from a different year may be used. In fact multiple measurements of habitat can be useful in gauging habitat conditions at different flows. If the biological and habitat data were collected at different times, then this should be considered during the review process. These considerations could include whether samples were collected during periods of very different flows or if something meaningfully changed between habitat measurements (e.g., ditch clean out, flooding, etc.). It is also useful to review available chemical data to review how chemical stressors might be impacting the biological communities.

Once the relevant biological, habitat, and chemistry data has been compiled for the assessment reach (i.e., WID) it is useful to look at channel condition of the entire reach. To do this, review the WID in a Geographic Information System (GIS) application with the Altered Watercourse (AWC) layer. During this process it may also be useful to review LiDAR elevation data, historical and current aerial imagery, and drainage records if they are available. If discrepancies between the AWC layer and other information is identified it should be brought to the attention of the AWC manager for resolution. In most cases these issues will be resolved before this step through a comparison of the AWC layer and channel condition determinations during the biological sampling visit. The locations of the sample stations, the channel type(s) throughout the reach, and the length of the reach should be noted. The biological monitoring channel condition classification should be examined and compared to the AWC layer. Once a preliminary review of the locations of the biological stations and how they relate to the channel types in the whole WID is performed, proceed to Step 2 (Section 3.1.2).

3.1.2 Is the General Use attained?

Following a determination of sufficient monitoring data, an assessment of biological attainment of the General Use (i.e., Class 2Bg, 2Bdg, or 2Ag) is performed at each monitoring station using the biological data. This process is only needed for the nine stream classes for which Modified Uses are developed (i.e., **Fish:** Southern streams, Southern headwaters, Northern streams, Northern headwaters, Low gradient streams; **Macroinvertebrates:** Low gradient northern forest streams, High gradient southern streams, Low gradient southern forest streams, Low gradient prairie streams). For the remaining nine classes, the use review is limited to a review of the Exceptional Use (see Section 3.1.3). In cases where one biological assemblage is from a class that has a Modified Use and the other does not, the full use review can proceed for the assemblage with the Modified Use. The other assemblage would be limited to the Exceptional Use Review. The result may be that the WID will need to be split in order to accommodate multiple uses associated with different sections of the reach.

Each biological assemblage is initially assessed independently at the station level. This primarily involves a review of the IBI scores in relation to the relevant biological criteria although other lines of evidence may also be important. These data can include Biological Condition Gradient (BCG) scores, biological metric scores and raw biological data. If **both** biological assemblages have met General Use biocriteria on or after November 28, 1975, then at a minimum a recommendation of General Use can be made for the station. These data do not need to co-occur temporally as only a demonstration that both assemblages can meet the General Use is needed (see Figure 4). In cases where multiple biological visits are present this data will need to be examined together to determine the existing use. This includes scrutinizing the temporal relationships of the visits and the proximity of the IBI scores to the biocriteria.

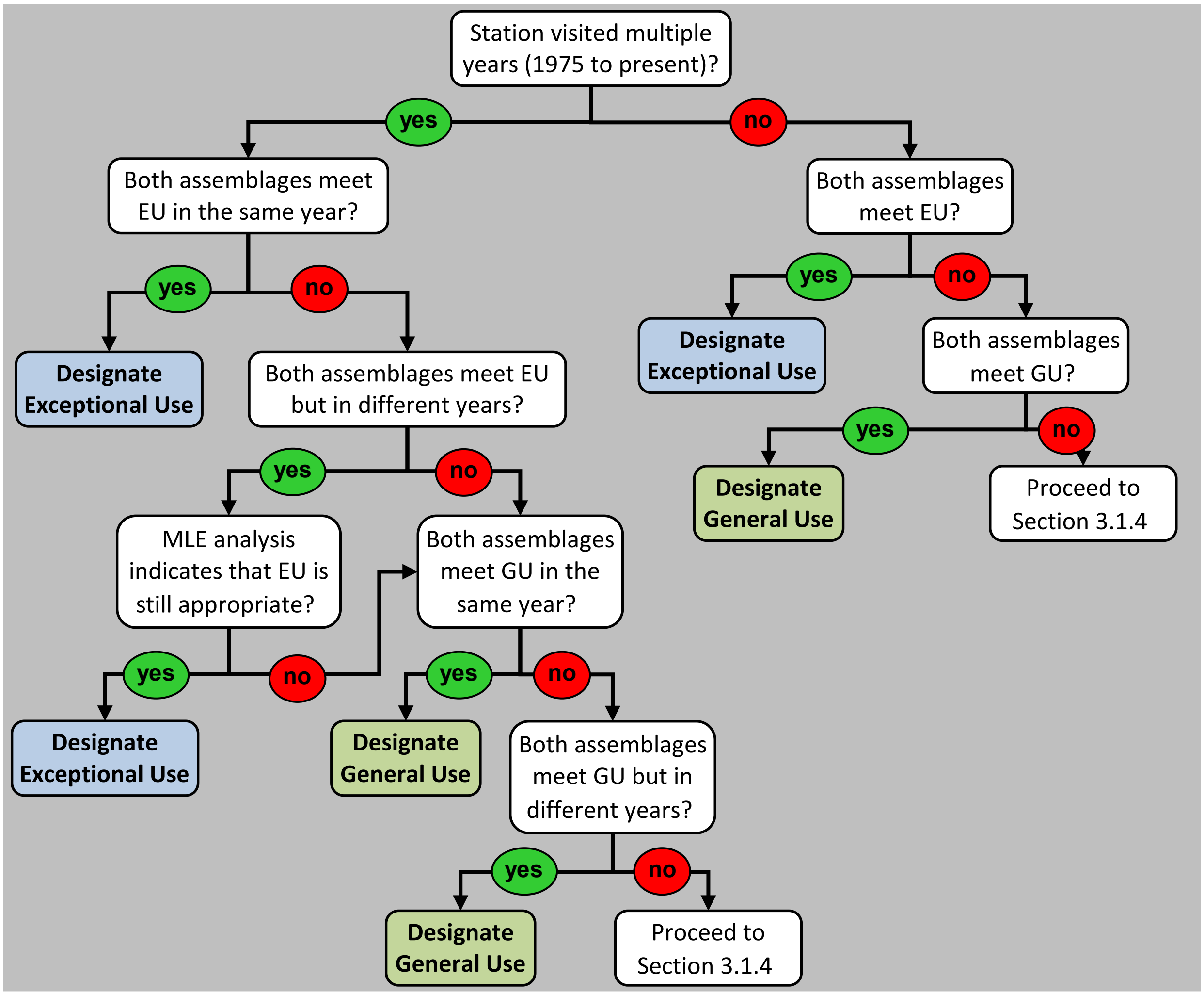

Figure 4. Process for making biological attainability decisions for single and multiple year sampling efforts.

For example, a single visit well above the biocriterion is probably sufficient to recommend General Use or higher unless there is evidence that the sample is atypical. If the biological data consists of several visits just above and/or below the biocriteria, then additional information should be considered. This can include a more detailed review of the biological data (e.g., metric by metric, species composition, BCG, etc.) to determine if the community is consistent with the General Use narrative (i.e., community structure and function largely maintained).

In cases where one assemblage does not meet the General Use while the other does, the review can proceed to the habitat assessment step (see Section 3.1.4). In other words, a Modified Use can be assigned based on the biological condition and habitat limitation of a single assemblage. Furthermore, when data is only available from a single assemblage, the review can still proceed to the habitat assessment step. In the case where the single assemblage strongly indicates a Modified Use is appropriate, the use designation is not likely to be altered by the collection of data for the other assemblage. However, if the only biological assemblage sampled meets or nearly meets the General Use biocriterion then the WID should be reviewed to determine channel condition (see Section 3.1.6). If the channel is anthropogenically modified then additional review should take place and a recommendation to collect data from the other assemblage may be warranted before the full use review can take place. In some cases the habitat data may be used without the biological data to determine if a Modified Use should be recommended.

Although a reach may be recommended for a Modified Use based on only one assemblage (i.e., one assemblage is limited by poor habitat while the other is not), the assemblages may inform each other in the review process. For example if one assemblage meets the Exceptional Use while the other nearly meets the General Use and/or is not strongly limited by habitat, it would most likely retain the General Use. In addition, the biological data from nearby sites can be reviewed whether they are within the same WID or not as long as the stations are located on similar reaches. Attainment of the biocriteria at nearby, similar stations may indicate that the General Use is attainable. To support the use decision, chemistry data, flow conditions, precipitation, and land use can also be considered.

If following the data review, there is still uncertainty regarding the attainment of the General Use, the station or WID can proceed to the next step of the UAA process (i.e., assessment of habitat condition; see Section 3.1.4). In many cases, the subsequent habitat review and other steps will help to resolve the use, but in others additional data may need to be collected.

If the biological assemblages meet at least the General Use biological criteria or through a Multiple Lines of Evidence (MLE) approach it appears that the General Use criteria can be met, proceed to Section 3.1.3. If one or both assemblages do not meet the General Use biological criteria, proceed to Section 3.1.4.

3.1.3 Is the Exceptional Use attained?

If the General Use is attained at the station level then the reach is further assessed to determine if it attains the Exceptional Use (i.e., Class 2Ae, 2Bde, or 2Be). As with the General Use, this primarily involves a review of the IBI scores in relation to the relevant biological criteria with other lines of evidence also considered (e.g., BCG scores, biological metric scores and raw biological data) when appropriate. If **both** biological assemblages meet the Exceptional Use biocriteria then the recommendation at the station level is Exceptional Use. This process is similar to that described for General Use assessment (see Section 3.1.2). Following this assessment, there are three scenarios:

1. A single station or multiple stations all meet the Exceptional Use biocriteria. In this case, all or part of the WID may be recommended for an Exceptional Use. To determine the extent of the reach to which the use can be extrapolated see Section 3.2.1.
2. There are multiple stations on the WID and not all stations meet the Exceptional Use biocriteria. In this case, some of the reach may be designated as Exceptional and some as General Use. See Section 3.2.2 for the process of reviewing the use designation in a WID with mixed biological results.
3. A single station or multiple stations all meet the General Use biocriteria, but not the Exceptional Use biocriteria. In this case, all or part of the WID should be recommended for a General Use. To determine the extent of the reach to which the use can be extrapolated see Section 3.2.1.

If there is a single station that attains the Exceptional Use for both assemblages, this station should be analyzed with consideration given to nearby stations and similar stations in the HUC8 watershed. For example, a single station that attains the Exceptional Use on a stream that otherwise only supports the General Use might not be designated Exceptional. However, if it is apparent that the stream reach that this single station is part of is different from adjacent reaches (e.g., different geology, gradient) it may still be designated Exceptional Use. In addition, if the single station that attains the Exceptional Use is in a watershed with little anthropogenic activity, that may also be used as evidence to support an Exceptional Use designation. If the biological data indicates that the Exceptional Use is nearly attained, additional monitoring may also be recommended for one or more stations to determine if the Exceptional Use is appropriate. In addition, most WIDs that nearly attain the Exceptional Use should be considered for protection strategies in the Watershed Restoration and Protection Strategy (WRAPS) report.

3.1.4 Habitat assessment

As part of Minnesota's TALU framework it is necessary to perform a review of the habitat when IBI scores are below the General Use biological criteria (Midwest Biodiversity Institute 2012). This is performed to determine if poor habitat is limiting attainment of aquatic life use goals in the station reach. If the habitat is deemed to be limiting the attainment of the biological criteria, then the reach could be considered for a Modified Use if other criteria are met.

When the General Use biocriteria are not met by one or both biological assemblages, a detailed analysis of the habitat is required (Figure 5). This analysis is driven by data collected for the Minnesota Stream Habitat Assessment tool or MSHA (MPCA 2014d; www.pca.state.mn.us/publications/wq-bsm3-02.pdf), although other lines of evidence can also be part of this analysis. An overview of this process is provided here but for a detailed description of this process see Appendix A: Habitat assessment tools. An analysis of the relationships between biological condition and habitat was performed which resulted in a suite of weighted habitat attributes that positively or negatively influence the ability of a stream to attain the applicable biocriteria (Midwest Biodiversity Institute 2015). The habitat attributes are specific to fish and invertebrate assemblages and to the nine different stream IBI classes with Modified Uses. Using these models, the number of poor or good habitat attributes as well as the probability of attainment given the scores for these attributes is calculated for each biological monitoring visit. Each biological assemblage (i.e., fish and macroinvertebrates) is reviewed separately to determine if habitat is limiting. This is done because these assemblages are sensitive to different habitat characteristics and separate models were developed to reflect these differences.

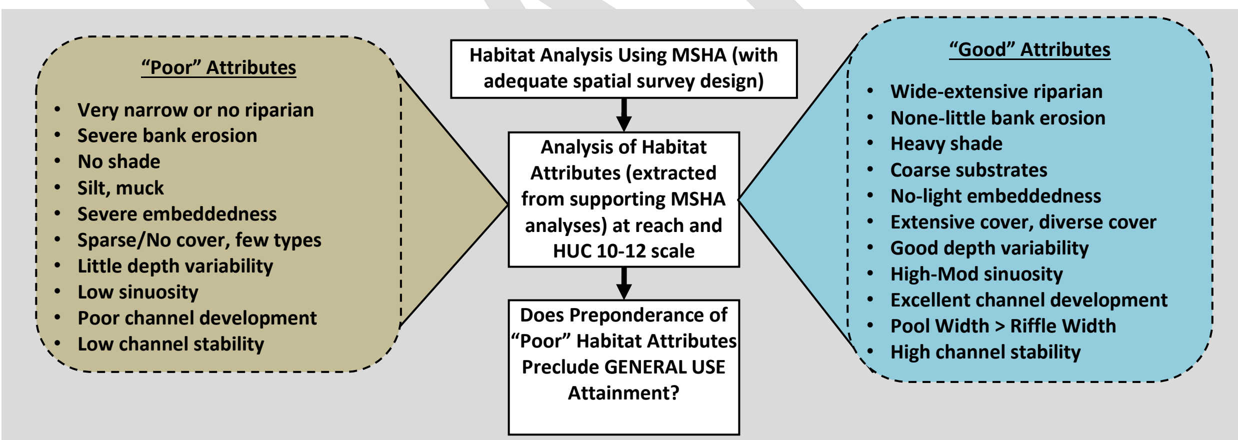

Figure 5. Habitat analysis conceptual diagram.

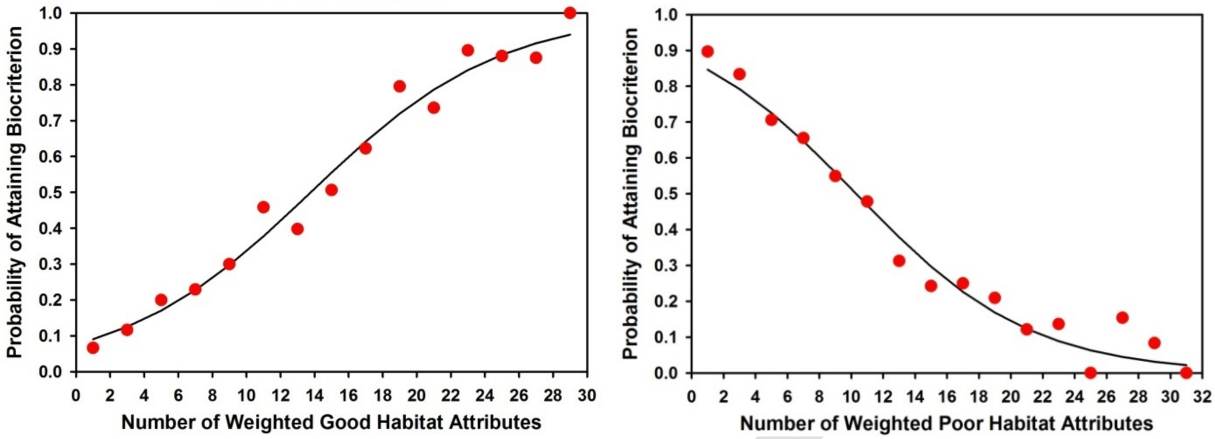

Figure 6. Probability of meeting the General Use biocriterion for fish against the number of good or poor habitat attributes in Northern headwaters (fit is a logistic regression).

Table 2. Decision matrix for determining habitat limitation based on probabilities of attaining the General Use. This assessment only occurs when the GU is not attained.

		MSHA		
	Attainment probability	**<25%**	**25-50%**	**>50%**
Habitat tool metrics	<25%	Yes	Probable	Possible
	25-50%	Probable	Possible	Unlikely
	>50%	Possible	Unlikely	No

The process for assessing habitat condition consists of a review of the outputs from logistic regression models (Figure 6; see Appendix A: Habitat assessment tools and Appendix C: Logistic Regression Plots) which are based on the four habitat measures (i.e., good, poor, ratio of poor to good, and MSHA). For a station that does not attain the General Use, the results of logistic regression models are used to interpolate the probability of attaining the biocriteria based on the habitat attributes at the biological sampling station. The three habitat tool outputs are considered jointly and the MSHA output is considered separately (Table 2). For example, if any one of the habitat tool metric models and the MSHA model predict a less than 25% probability of attaining the General Use criterion, the biological assemblage in the reach is considered to be limited by habitat. When probabilities are between 25 and 50% and/or the results are mixed between the metrics, additional information will need to be considered. This information includes biological performance (i.e., proximity of IBI score to biocriterion, BCG tier), performance of the other assemblage, chemical data, and the stream's physical characteristics (i.e., recovery status, atypical features). For example, a stream reach with habitat that falls into this gray area may not be recommended for a Modified Use if the biological assemblage is close to meeting the biocriterion and there are obvious chemical stressors. Biological metric data can also be informative. For example, a small number or proportion of clinger invertebrate taxa may confirm poor habitat. In Ohio, it was determined that sensitive species are also a good measure of habitat limitation (Midwest Biodiversity Institute 2015). Another consideration can be the flows at the time of sampling. Biological data is reviewed before this review to flag or remove samples that were collected during periods outside of normal flow conditions. However, through a review of the habitat it may be determined that the flows were such that the MSHA did not effectively characterize the habitat.

If it is determined that neither biological assemblage is limited by habitat conditions, then the General Use would be recommended for the reach. If one or both biological assemblages indicate that habitat is limiting, then the reach requires further review (proceed to Section 3.1.6).

3.1.5 Are limited or poor habitat conditions the result of natural conditions?

If the habitat is limiting the biological communities, then the reach can be reviewed to determine if 40 CFR § 131.10(g)(1), (2), or (5) applies (see Table 1). This is a review to determine if the poor biological performance is a result of natural factors such as natural pollutants, flow condition, or other conditions. If 40 CFR § 131.10(g) (1), (2), or (5) applies, then the reach may be eligible for site-specific biocriteria or may require the development of a new IBI for the ecotype (Figure 3). In all cases the reach should be recommended for a General Use or left as a default General Use and then reviewed by the appropriate group/panel (e.g., assessability, natural background, site-specific standard, etc.). In some cases the reach may be recommended for a Consolidated Assessment and Listing Methodology (CALM) category 4D (i.e., impaired or threatened but does not require a TMDL because impairment is solely a result of natural sources) or 4E (i.e., impaired or threatened but existing data strongly suggests that a TMDL is not required because impairment is solely a result of natural sources; a final determination of Category 4D will be made in the next assessment cycle pending confirmation from additional information).

Natural pollutants: "*Naturally occurring pollutant concentrations prevent the attainment of the use* (40 CFR § 131.10(g)(1))": At this stage in the UAA review it has already been determined that the habitat is a limiting factor for the biology. As a result, naturally occurring pollutants are not likely to be an issue or they are a separate issue contributing to nonattainment. In practice, unless the naturally occurring pollutants are obvious this factor may not be identified until the Stressor ID process. If there is evidence that the impairment is resulting from a natural pollutant then a site specific criterion will need to be considered. For example, in Minnesota there are streams that are influenced by wetlands which can naturally lower dissolved oxygen levels in the streams. These reaches would need to be referred to the Natural Background Review Team.

Natural low flow: "*Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met*" (40 CFR § 131.10(g)(2)): Notes and photos from the biomonitoring visits should be reviewed to determine if low flow conditions were present during biological sampling. If so it should to be determined if these flows were the result of normal conditions for this stream, drought conditions, or human alterations to the flow regime. If, for example, it is a small watershed or a more arid part of the state, it can be recommended that the default General Use be maintained. These streams may not be assessed until an IBI could be developed for this type of ephemeral or intermittent stream. If it is determined that the low flows are the result of atypical precipitation patterns then a default General Use would likely be recommended since the biological data collected during this period would likely be determined to be not assessable. If the low flows are the result of human alterations to the watershed (e.g., high percent of impervious surfaces) then it should be recommended for a General Use and this information should be noted for the assessment and stressor ID teams. In highly altered watersheds (e.g., watersheds with agriculture and/or urban land uses), reaches will often not be eligible for this consideration since the hydrology is often greatly modified by drainage. In the future, the incorporation of tools such as synthetic flows and reference flows might aid with the determination that a reach is naturally flow-limited or not. These reaches may need to be referred to the Natural Background Review Team.

Natural physical conditions: "*Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses* (40 CFR § 131.10(g)(5))." Natural physical conditions that result in nonattainment will likely need to be resolved by site-specific biocriteria or the development of IBIs for a new ecotype. If the physical issues are more common or widespread, then a new IBI model may be appropriate for that class of streams. The reach should be flagged so that it can be used in future work to develop this IBI. For example, some reaches are transitional between a stream and a wetland (i.e., defined channel but very low gradient) which may make the current IBIs unsuitable for assessment. In the case of unique features (e.g., natural impoundments) a recommendation of General Use or default General Use can be made, but a site-specific standard may need to be developed. These reaches may need to be referred to the Natural Background Review Team. If none of these three scenarios apply to the reach then a recommendation of General Use or default General Use is made. As a result of this review it may be determined that the poor habitat is the result of human activities and a recommendation of General Use is needed. For example, natural channel streams with unrestricted livestock access can often have poor habitat condition. Altered flow regimes, such as those found in watersheds with large amounts of impervious surfaces or tile drainage can also have poor habitat.

3.1.6 Origin of habitat modifications

In reaches where one or both biological assemblages do not attain the General Use and the habitat is determined to be limiting, it is then necessary to determine the origin of the habitat condition. In Minnesota the most common form of habitat modification is channelization. Another possible form of channel modification in Minnesota streams is bank armoring such as rip rap and concrete. Other modifications such as impoundments are also a possibility, but the MPCA's current biological sampling program typically avoids impounded reaches. If it is determined that habitat limitation is the result of a human-made impoundment, then this should be noted, but at this time the use should not be reviewed since the applicability of Minnesota's current biological tools have not been tested in impounded reaches. In some cases a WID will have a mix of altered and natural reaches, but the full review of the WID takes place after aquatic life uses are reviewed for all stations within a WID (see Section 3.2). However, it is often useful to review all of the data from the WID and from adjacent WIDs to help inform the monitoring reach level decision.

Determination of channelization should be based on several lines of evidence (e.g., AWC layer, aerial imagery, LiDAR, site visit records, site photos, and county records). For example, the channelization review should not be based solely on the AWC layer and requires at least a review of LiDAR and aerial imagery to determine the status of the channel. This is especially true of waters that are recommended for a Modified Use. This review determines if the habitat is modified. There are a number of lines of evidence than can be used to determine if a stream is altered (see Appendix A in Altered Watercourse Determination Methodology [Krumrie et al. 2013]). These can include:

- Watercourse does not exist on prior aerial photography
- Watercourse feature flows parallel to road or other artificial structure (e.g. levee)
- Watercourse's sinuosity is significantly decreased from connected watercourses
- Watercourse cuts across old oxbows and meanders
- Watercourse feature flows across or starts inside dried-up wetland, pond, or lake
- Uniform-colored halo of pixels on imagery is thin, of constant width and parallel to watercourse
- Watercourse does not follow Digital Raster Graphics (DRG) stream lines
- Watercourse crosses DRG contours unnaturally

- DRG elevation contours straight, close and parallel to watercourse
- LiDAR imagery shows watercourse as straight and narrow or otherwise unnatural shape
- Associated MPCA Bio Site shows stream as altered
- Associated DRG stream or Geographic Names Information System (GNIS) feature labeled County or Judicial Ditch
- Associated Minnesota Department of Natural Resources (DNR) 24k Stream feature's type is "Artificial" or nearby type is "Superseded Natural Channel"
- Associated GNIS of the United States Geologic Survey (USGS) indicates an artificial channel (FEATURE_CL = canal)
- Associated National Wetlands Inventory (NWI) feature's Special Modifier (SPEC_MOD) field is any type but blank or b (Beaver)
- Associated Public Waters Inventory (PWI) designates the stream as Public Ditch/Altered Natural Watercourse (PWI_Flag = 2)
- Watercourse connected or adjacent to artificial water body (e.g. sewage treatment pond)

In most cases this determination will be obvious; however, channelized streams that have naturally recovered or that have been restored may pose a challenge. In these cases, it will be important to determine if the habitat is limiting and to establish that at some point the channel was modified in order for the reach to be eligible for a Modified Use. If these requirements are met then it can be assumed that the legacy impacts of the channel modification are continuing to impact biological condition.

In addition to establishing that the reach is altered, the legality of that alteration should be determined. Since most alterations to stream channels are the result of drainage construction and maintenance, this review will commonly consist of a review of drainage records. However, in most cases these records are difficult to obtain and this review may be limited until electronic versions of these records are available.

If the evidence does not indicate that the reach has been legally altered, then proceed to Section 3.1.5. If the reach is legally altered then proceed to Section 3.1.7.

3.1.7 Can a physically altered stream be restored?

Following determination of non-attaining biology that is limited by anthropogenically altered habitat is a review of the restoration potential (Figure 3). This step determines if the habitat in the reach can be restored using proven designs or if the reach is likely to recover naturally in the next five years. At this time, the restorability of an altered reach may be limited to relatively short sections (<1 mile) where the natural channel meanders and some connectively to a floodplain can be restored. As channel restoration technology improves it will become feasible to restore larger sections and complexes of altered channels. Over time this will alter the threshold for this decision step. In regards to the natural recovery within five years, this step is in place for waters that are impacted by temporary modifications to the channel due to activities such as construction.

3.1.8 Do hydrological modifications or human-caused pollution preclude attainment of aquatic life uses?

Following determination of non-attaining biology that is limited by anthropogenically altered habitat is a review of the restoration potential (Figure 3). This includes review of compliance with 40 CFR § 131.10(g)(3) or (4). In this case, the modified condition of the channel needs to be considered as well as the possibility that irreversible human pollution limits attainment. These causes include 1) channelized for drainage, 2) modifications resulting from dams, diversions, and other hydrologic modifications, and

3) human-caused pollution that cannot be remedied or cannot be remedied without causing more environmental damage.

3.1.8.1 Hydrologic modifications

Channelized for drainage: Streams with modified habitat are most commonly drainage ways designed to move water quickly off the land to improve agriculture, to reduce flooding, or to make areas suitable for development. Under current technologies, the ability to construct multiuse drainage ways (i.e., channels that provide drainage and protect aquatic life) has not been fully demonstrated – especially on a large scale. As a result, most maintained drainage ways are not presently restorable without a huge investment with uncertain results. However, in some cases short reaches (e.g., <0.25 miles) that are part of a largely unmodified stream system may be considered restorable using current technologies (e.g., remeandering, 2-stage ditches). Road crossings are a common cause of short, channelized reaches that may be difficult to restore. These reaches tend to be short and not characteristic of the WID, and are usually avoided for biological sampling. In addition, because they are short and not characteristic of the WID a split would not be appropriate to redesignate these atypical reaches. In cases where biological data were collected from a short reach impacted by a road crossing, the reach could be designated General Use or a decision may be made to not assess those data and to retain the default General Use. Furthermore, resampling in the natural stretch of the reach could be considered. If it is likely that the reach can be restored or that it will recover on its own then the reach would be designated General Use. If based on a review of these considerations it is determined that the modifications cannot be feasibly reversed, then proceed to Section 3.1.9.

Dams and diversions: If the habitat in the reach is impacted by dams or diversions then it could be eligible for a Modified Use. To identify the influence of dams or diversions within a reach, the AWC layer, aerial photos, site visit notes and photos, and the DNR Dam GIS layer can be used. If it is determined that the reach is directly impacted by an impoundment a Modified Use may be appropriate. [Note: Reaches with fish communities that are impacted by dams which create fish barriers may be considered for CALM category 4C] However, at this time biological data from impounded reaches is not assessable because the IBIs have not been tested in reaches of this type. For dams it may be worthwhile to inquire with the DNR to determine if restoration is feasible. If based on a review of these considerations it is determined that the modifications cannot be feasibly reversed, then proceed to Section 3.1.9.

3.1.8.2 Human-caused pollution that cannot be remedied

If the cause of the impairment is the result of anthropogenic pollution that cannot be remedied or the act of remediation would cause more environmental damage, then the reach could be eligible for a lower use. This will not be common in Minnesota streams, but could include legacy impacts from acid mine drainage or heavy metal pollution. Generally such a finding will require an Environmental Review. Human-caused pollution that cannot be remedied does not include agricultural pollution. If based on a review of these considerations it is determined that the modifications cannot be feasibly reversed, then proceed to Section 3.1.9.

3.1.9 Existing use review

Following a determination that the reach cannot be restored, available information should be used to determine if the modifications occurred on or after November 28, 1975. This review will most likely be performed using historical aerial imagery. Presently, there are limited digital versions of these photos available, so this review may not be possible at this time. However, the USGS Historical Topographic Map Explorer does include many maps that can help to narrow down the modification date (http://historicalmaps.arcgis.com/usgs/). Other records such as ditch liens can also be used to determine the date of ditching; however, this information is largely available in hard copy from the county in which the ditch is located. If it is determined that the activity is not consistent with existing use the activity would need to be reviewed and the appropriate use would need to be determined. For example, a stream reach that was channelized after November 28, 1975, would not be eligible for a Modified Use and in most cases would be designated General Use.

If a review indicates that the channel was ditched before November 28, 1975, then the reach can be recommended for a Modified Use designation. If **both** biological assemblages meet the Modified Use biocriteria then the recommendation at the station level could be Modified Use. This process is similar to that described for General Use assessment (see Section 3.2).

3.2 Review of Aquatic Life Use for a WID

Following determination of the recommended use for each monitoring station within a WID, the full reach needs to be reviewed to determine the ALU for the WID and if splitting the WID is required. Although the focus is on the WID, it is also useful to make final use decisions using adjacent and nearby data to inform the decision. This WID-level process needs to take all of the steps in Figure 3 into consideration. This review is done to create WIDs that are homogeneous with a single TALU so that assessments in these stream segments are reflective of the entire reach. The existing WID framework is largely adequate for tiered uses. In this framework WID boundaries are primarily based on major tributaries, changes in use classification, or significant morphological features such as lakes and dams. It is also possible that WID merges could be recommended to improve management of these resources. The TALU framework will require some adjustment to the WID framework with most of these changes resulting from recommended use class changes within existing WIDs. However, reach characteristics (e.g., mid-reach lakes, changes in channel condition, major tributaries, etc.), landscape patterns (e.g., major changes in land use), or potential sources of legacy impacts (e.g., dams) can also be used to recommend a WID split. For reaches where sufficient biological data is not available (this can include data from November 28, 1975, to the present) the use typically cannot be confirmed. As a result these reaches will need to be delineated and left as default General Use waters. Most of the WID adjustments will be done during the first 10-years of the intensive watershed monitoring (IWM) cycle with some ongoing maintenance in subsequent cycles. Following the initial IWM cycle, additional use designation work will stem from data collected on previously unmonitored reaches, improvements in biological condition, and some corrections as more data is available.

Following the use review process at each monitoring station, the reviewer(s) should already be familiar with the WID. This step largely brings together the ALU information from the available stations and any other pertinent information at the WID level or from adjacent WIDs. As with the station-level reviews many forms of data are necessary to determine the appropriate ALU and the location of any WID splits (e.g., altered watercourse data, aerial imagery, site visit notes, etc.). This review should not result in many small (e.g., <0.25 miles) reaches with different uses. Instead the purpose of this review is to characterize and recommend the overall use for larger reaches. Below are descriptions of the possible options for recommending an ALU in a WID.

3.2.1 All stations within a WID have the same recommended use

If use recommendations for all of the stations within a WID are the same use, then that ALU would be applied to the full reach. However, if the site or sites are not adequate to provide an assessment of the entire WID, then the WID-level review would need to consider if there are unmonitored reaches that differ from the monitored reaches.The most common cases for this situation are as follows:

- **All stations are Modified Use:** In a WID with one or more stations that are recommended for Modified Use, there may also be unmonitored, meandering reaches within the WID. If the natural reach is relatively long (e.g., >0.5 miles) then it should be designated a default General Use and a WID split would be needed. Therefore it is only possible to include very short natural channel reaches that are associated with channelized reaches in a Modified Use WID. This review should also consider how far the Modified Use is extrapolated. Even in WIDs that are entirely altered, the Modified Use is typically only extrapolated approximately five miles from the biology station(s). This five mile guideline could be extended for reaches where there are a series of biological stations which all indicate similar uses.
- **All stations are General Use:** In a WID with one or more stations that are recommended for a General Use, there can be reaches that are channelized within the WID. In this situation the channelized reach could be retained within the WID as a General Use until there is data to recommend a different use for the channelized portion. However, if the channelized reach is very long or distant from the biomonitoring station (>5 miles), the unmonitored channelized portion should be designated a default General Use and a WID split would be required. In some cases where a resolution of the use is needed for an unmonitored reach, biological and habitat data (i.e., MSHA) should be collected to ascertain the appropriate use. In cases, where all or most of the channel is natural, but much of the reach is unmonitored, a General Use can be maintained. However, it should be noted in the UAA transparency form that the conformation of the use is based on limited information.
- **All stations are Exceptional Use:** The results of this review would be similar to the case when all of the stations are General Use. However, it is also possible that in a reach with only Exceptional Use stations that has natural channels, part of this reach could be considered General Use and a split could be recommended. This could occur on large reaches or reaches where landuse changes, a major tributary enters, channel condition changes, or some other landscape change occurs between the monitored and unmonitored reaches. In this case the unmonitored reach would be designated a default General Use and a WID spilt would be required. Typically the Exceptional Use is only extrapolated approximately five miles from the biology station(s) although the five mile guideline could be extended for reaches where there are a series of biological stations which all indicate Exceptional Use.

3.2.2 Different use recommendations for monitoring reaches within a WID

If there are different use recommendations among the stations within a WID, a review is needed to determine if the WID should be split and the location of such splits. As with the case where all stations have the same recommended use, a review of unmonitored reaches is also needed to determine if splits are needed for default General Use reaches. In some cases it may be determined that although recommended uses differ at the station level, the WID should be given a single use and not be split. Most commonly this would result from one Modified Use station among one or more General Use stations in a channelized WID. In this situation, the performance of the General Use station(s) may indicate that the General Use should also be attainable at the Modified Use station and therefore the entire reach designated General Use.

3.2.3 Splitting long WIDs

In all WIDs, the length of the WID should be considered. In many cases, especially on smaller streams, long reaches should be considered for a possible split unless the reach is homogenous and sufficient monitoring data is available throughout the reach. In most cases, if a large reach needs to be split this will be determined in the steps above. However, in cases where this does not occur it is worth reviewing the WID to determine if the reach is an appropriate assessment unit. A reason for splitting a long reach that is not the result of the designation of TALUs may include splitting a WID that crosses multiple aggregated 12-digit HUCs.

3.3 Summary of TALU use review process

The process of reviewing uses is intended to determine the appropriate and attainable use for Minnesota streams and rivers. It is important that these uses are properly reviewed and designated; otherwise the management activities that follow could be less efficient or erroneous. It is important that all of the steps are followed although the order of those steps may vary depending on the reach. Following a use recommendation, these waters will undergo an aquatic life use assessment and possibly stressor identification steps. These steps will include the incorporation of additional data and internal and external meetings. During this work, if evidence indicates that the initial use designation is incorrect, then the use can be reviewed further and changed if it is supported. Following the initial assessment of these reaches, a formal use designation process will occur. This formal rulemaking will incorporate these uses into Minn. R. 7050.0470 before any impairments on these reaches are added to the impaired waters list. Before the rule changes are adopted, the new designations are considered “recommended uses”.

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Appendix A: Habitat assessment tools

The implementation of Tiered Aquatic Life Uses (TALU) requires the development of several tools that make the management of the TALU framework feasible. One of these tools is a means to systematically and consistently measure the impacts of habitat on biological measures. This capability is necessary to support Use Attainability Analyses (UAAs) for Modified Use in the TALU framework. As part of routine biological monitoring, a qualitative habitat assessment called the Minnesota Stream Habitat Assessment or MSHA is performed (MPCA 2014d). This provides a measurement of the habitat condition as it relates to the biological assemblages. To further refine this information, an analysis was performed to determine which individual metrics are most strongly related to good or poor biological performance (Midwest Biodiversity Institute 2015). Building upon this work, this document describes how the habitat tool output is used to determine if habitat condition is limiting attainment of biological goals. Five fish and four macroinvertebrate classes are anticipated to have a Modified Use so the analyses in this document are limited to these nine classes.

Introduction

Some activities in Minnesota have resulted in legacy impacts to streams that currently have difficulty meeting Minnesota’s aquatic life General Use goals. These activities include stream channelization that was performed under Minnesota Drainage Law (Minn. Stat. ch. 103E). The relationships between aquatic life and reduced habitat condition have been well documented (Gorman and Karr 1978, Griswold et al. 1978, Schoof 1980, Karr and Dudley 1981, Karr et al. 1986, Schlosser 1987). The biological limitation and reduced function of these waters is imposed by poor habitat is caused by ditch maintenance activities (e.g., excavation, cleaning, snagging, repair of banks; Doyle and Bernhardt 2011, Yoder and Rankin 1995) The biological limitation of these streams is imposed by insufficient habitat to support aquatic life that meets Minnesota’s General Use goals. Despite these limitations, when these watersheds are managed appropriately (i.e., maintaining buffers, etc.) these systems should still be expected to meet some goal below General Use, and not be written off as waters that are incapable of supporting aquatic life or providing beneficial uses other than drainage. In fact, biological data collected by the MPCA demonstrates that some of these channelized waterways currently meet General Use goals for aquatic life. Under a TALU framework they will be held to a reasonable goal that accounts for the loss of habitat and is reflective of the biological potential of a properly managed channelized stream.

In accordance with the CWA, to determine when a Modified Use applies, a UAA will be performed to determine if the system cannot meet the General Use and that habitat is limiting this use. In cases where the habitat is deemed to be limiting, an evaluation is then required to determine if the habitat condition is the result of legal activities and that it cannot be restored (Midwest Biodiversity Institute 2012). If these criteria are met, the stream could be eligible for a Modified Use.

Minnesota Stream Habitat Assessment

As part of routine biological monitoring, field biologists perform a habitat assessment in the stream reach using the MPCA Stream Habitat Assessment (MSHA; MPCA 2014d). The MSHA is a qualitative measure of habitat condition modeled after Ohio’s Qualitative Habitat Evaluation Index (QHEI; Ohio EPA 2006). The MSHA measures four classes of habitat metrics: 1) Land Use, 2) Riparian Zone, 3) Instream Zone, and 4) Channel Morphology. The result of this assessment is a score from 0-100 with 0 indicating very poor habitat and 100 indicating excellent habitat. Details on the protocol for performing the MSHA can be found here: http://www.pca.state.mn.us/index.php/view-document.html?gid=6088.

Habitat tool

To improve the predictive ability of the habitat measures collected during biological visits, analyses were performed to identify specific habitat metrics that are associated with biological scores (i.e., indices of biotic integrity [IBIs]). The details of this work can be found in Midwest Biodiversity Institute (MBI) (2015). These analyses identified the habitat metrics associated with good or poor IBI scores using an Analysis of Variance (ANOVA) and a Tukey's Multiple Comparison test when significant differences were identified by the ANOVA. The result is a weighted score for those metrics identified as important (seeAppendix B: Habitat Tool Submetric Scores). Metric attributes that were highly significant ($p<0.001$) were given a score of 2 points. Metric attributes with a significance of $p>0.001$, but less than $p<0.05$ were given a score of 1 point. Those less significant $p>0.05$, but strongly trending or where a lack of significant was due to small samples size were give a weighting of 0.5 points. Metric attributes with no relationship did not receive a score. The individual metric attribute scores are provided in Appendix B: Habitat Tool Submetric Scores. Using these weighted scoring criteria, a count of the good and poor habitat attributes can be tallied for each stream reach.

Predicting biological potential using habitat measures

To determine the probability of attaining biological criteria, predictive models were developed using logistic regression. Logistic regression models (Eq. 1) were fit to binned data for the count of good attributes, the count of poor attributes, the ratio of good to poor attributes, and the raw MSHA score. This analysis was performed in the program R ver. 3.0.2 (R Development Core Team 2013) using a generalized linear model ("glm" function using the binomial family and the link function "logit"; R Development Core Team 2013). The equation for the logistic curve can be written as:

Eq. 1

$$P = \frac{e^{b_0+b_1X}}{1+e^{b_0+b_1X}}$$

The resulting logistic regression models for all five fish and four macroinvertebrate classes were significant ($p <0.05$) for the four habitat measures tested (Tables 3-6; see Appendix C: Logistic Regression Plots). Using these models, a probability of meeting the fish or macroinvertebrate biological criteria can be assigned to a station using the MSHA data collected during the biological visit (Table 7). For example, the model predicts that a stream in the Southern stream (2) class with a single good attribute has a 12% probability of meeting the biological criteria for fish.

Table 3: Logistic regression model equations for good habitat attributes.

Assemblage	Class name	#	b_0	b_1	P value
Fish	Southern streams	2	-2.2495464	0.1222406	<0.0001
Fish	Southern headwaters	3	-2.1678254	0.1777816	<0.0001
Fish	Northern streams	5	-1.5771966	0.1757848	<0.0001
Fish	Northern headwaters	6	-2.244949	0.1779056	<0.0001
Fish	Low gradient	7	-3.0092939	0.4130413	<0.0001

Assemblage	Class name	#	b_0	b_1	P value
Macroinvertebrates	Low gradient northern forest streams	4	-0.6347702	0.2872918	<0.0001
Macroinvertebrates	High gradient southern streams	5	-2.5834945	0.2779666	<0.0001
Macroinvertebrates	Low gradient southern forest streams	6	-2.9452517	0.3335281	<0.0001
Macroinvertebrates	Low gradient prairie streams	7	-3.772387	0.241916	<0.0001

Table 4: Logistic regression model equations for poor habitat attributes.

Assemblage	Class name	#	b_0	b_1	P value
Fish	Southern streams	2	0.3337835	-0.1641361	<0.0001
Fish	Southern headwaters	3	0.280476	-0.3067154	<0.0001
Fish	Northern streams	5	2.6819851	-0.2252628	<0.0001
Fish	Northern headwaters	6	2.082724	-0.2221071	<0.0001
Fish	Low gradient	7	1.8450675	-0.4164151	<0.0001
Macroinvertebrates	Low gradient northern forest streams	4	2.2536808	-0.2947712	<0.0001
Macroinvertebrates	High gradient southern streams	5	1.0973409	-0.2847617	<0.0001
Macroinvertebrates	Low gradient southern forest streams	6	0.8683169	-0.3114529	<0.0001
Macroinvertebrates	Low gradient prairie streams	7	1.0115956	-0.2701097	<0.0001

Table 5: Logistic regression model equations for the ratio of good to poor habitat attributes.

Assemblage	Class name	#	b_0	b_1	P value
Fish	Southern streams	2	-1.121281	-1.52768	<0.0001
Fish	Southern headwaters	3	-1.336723	-1.525376	<0.0001
Fish	Northern streams	5	0.3284526	-2.672028	<0.0001
Fish	Northern headwaters	6	-0.293191	-2.457475	<0.0001
Fish	Low gradient	7	-0.663735	-3.31253	<0.0001
Macroinvertebrates	Low gradient northern forest streams	4	0.8464985	-1.797965	<0.0001
Macroinvertebrates	High gradient southern streams	5	-0.741928	-2.312095	<0.0001
Macroinvertebrates	Low gradient southern forest streams	6	-1.043355	-2.241845	<0.0001
Macroinvertebrates	Low gradient prairie streams	7	-1.434873	-2.90616	<0.0001

Table 6: Logistic regression model equations for MSHA scores.

Assemblage	Class name	#	b_0	b_1	P value
Fish	Southern streams	2	-3.06590312	0.04268932	<0.0001
Fish	Southern headwaters	3	-2.95544088	0.04369541	<0.0001
Fish	Northern streams	5	-4.01841976	0.07078414	<0.0001
Fish	Northern headwaters	6	-4.11069995	0.06632642	<0.0001
Fish	Low gradient	7	-5.5288878	0.1010003	<0.0001
Macroinvertebrates	Low gradient northern forest streams	4	-3.12900681	0.06144438	<0.0001
Macroinvertebrates	High gradient southern streams	5	-3.59438404	0.04905375	<0.0001
Macroinvertebrates	Low gradient southern forest streams	6	-3.33722999	0.05473118	<0.0001
Macroinvertebrates	Low gradient prairie streams	7	-4.69133958	0.06545275	<0.0001

Table 7: Habitat assessment criteria based on logistic regression models. <25% and <50% equate to model predictions where there is a <25% or 50% probability of attaining the General Use biological criterion when the habitat metric threshold provided in the table is exceeded. Abbreviations: P/G = ratio of poor +1 attributes to good +1 attributes.

Assemblage	Class	Class #	Habitat metric	<25%	<50%
Fish	Southern streams	2	Good	≤9.0	≤18.0
Fish	Southern streams	2	Poor	≥8.5	≥2
Fish	Southern streams	2	P/G	≥0.97	≥0.19
Fish	Southern streams	2	MSHA	≤46.0	≤71.8
Fish	Southern headwaters	3	Good	≤6.0	≤12.0
Fish	Southern headwaters	3	Poor	≥4.5	≥1.0
Fish	Southern headwaters	3	P/G	≥0.70	≥0.14
Fish	Southern headwaters	3	MSHA	≤42.4	≤67.6
Fish	Northern streams	5	Good	≤2.5	≤9.0
Fish	Northern streams	5	Poor	≥17.0	≥12.0
Fish	Northern streams	5	P/G	≥3.42	≥1.33
Fish	Northern streams	5	MSHA	≤41.2	≤56.7
Fish	Northern headwaters	6	Good	≤6.0	≤12.5
Fish	Northern headwaters	6	Poor	≥14.5	≥9.5
Fish	Northern headwaters	6	P/G	≥2.13	≥0.76
Fish	Northern headwaters	6	MSHA	≤45.4	≤61.9
Fish	Low gradient streams	7	Good	≤4.5	≤7.0
Fish	Low gradient streams	7	Poor	≥7.5	≥4.5
Fish	Low gradient streams	7	P/G	≥1.36	≥0.63
Fish	Low gradient streams	7	MSHA	≤43.8	≤54.7
Macroinvertebrates	Low gradient northern forest streams	4	Good	-	≤2
Macroinvertebrates	Low gradient northern forest streams	4	Poor	≥11.5	≥8.0
Macroinvertebrates	Low gradient northern forest streams	4	P/G	≥12.08	≥2.96
Macroinvertebrates	Low gradient northern forest streams	4	MSHA	≤33.0	≤50.9
Macroinvertebrates	High gradient southern streams	5	Good	≤5.0	≤9.0
Macroinvertebrates	High gradient southern streams	5	Poor	≥8.0	≥4.0
Macroinvertebrates	High gradient southern streams	5	P/G	≥1.43	≥0.48
Macroinvertebrates	High gradient southern streams	5	MSHA	≤50.8	≤73.2
Macroinvertebrates	Low gradient southern forest streams	6	Good	≤5.5	≤8.5
Macroinvertebrates	Low gradient southern forest streams	6	Poor	≥6.5	≥3.0
Macroinvertebrates	Low gradient southern forest streams	6	P/G	≥1.06	≥0.35
Macroinvertebrates	Low gradient southern forest streams	6	MSHA	≤40.9	≤60.9
Macroinvertebrates	Low gradient prairie streams	7	Good	≤11.0	≤15.5
Macroinvertebrates	Low gradient prairie streams	7	Poor	≥8.0	≥4.0
Macroinvertebrates	Low gradient prairie streams	7	P/G	≥0.77	≥0.33
Macroinvertebrates	Low gradient prairie streams	7	MSHA	≤54.8	≤71.6

Appendix B: Habitat Tool Submetric Scores

Habitat tool scores for fish indices of biotic integrity (see MPCA [2014d] for descriptions of the metrics)

Metric	Attribute	Southern streams	Southern headwaters	Northern streams	Northern headwaters	Low gradient
Substrate	Boulder-pool		0.5	2	0.5	
Substrate	Cobble-pool	1	0.5	2	1	
Substrate	Gravel-pool			1	1	
Substrate	Sand-pool			-2		
Substrate	Clay-pool		-0.5	-1		
Substrate	Bedrock-pool					
Substrate	Silt-pool	-1		-2	-1	
Substrate	Muck-pool					
Substrate	Detritus-pool		-0.5	-2	-1	
Substrate	Boulder-riffle		0.5	2	1	
Substrate	Cobble-riffle	1	1	2		
Substrate	Gravel-riffle		1	-2	-1	
Substrate	Sand-riffle	-1	1	-2	-1	
Substrate	Clay-riffle					
Substrate	Bedrock-riffle					
Substrate	Silt-riffle	-0.5	-1		-1	
Substrate	Muck-riffle					
Substrate	Detritus-riffle					
Substrate	Boulder-run	0.5		2	2	
Substrate	Cobble-run	2	2	2	2	
Substrate	Gravel-run	2	1	-2	2	
Substrate	Sand-run	-1	1	-2	-2	
Substrate	Clay-run	-1	-1	-2	-2	
Substrate	Bedrock-run					
Substrate	Silt-run	-2	-1	-2	-2	
Substrate	Muck-run					
Substrate	Detritus-run		-2		-2	
Substrate	Boulder-glide					
Substrate	Cobble-glide					
Substrate	Gravel-glide					
Substrate	Sand-glide					
Substrate	Clay-glide					
Substrate	Bedrock-glide					
Substrate	Silt-glide					
Substrate	Muck-glide					
Substrate	Detritus-glide					
Embeddedness	No coarse	-1	-1	-2	-2	-0.5
Embeddedness	Severe	-1	-0.5	-2	-1	-1
Embeddedness	Moderate				-2	
Embeddedness	Light	1	1	1	2	1
Embeddedness	None			2	2	0.5

Metric	Attribute	Southern streams	Southern headwaters	Northern streams	Northern headwaters	Low gradient
# Substrate types	>4	0.5	0.5		2	1
# Substrate types	<4	-0.5	-0.5		-2	-1
Cover types	Undercut banks					
Cover types	Overhang vegetation					-0.5
Cover types	Deep pools	0.5	1			
Cover types	Logs and woody debris	1				
Cover types	Boulders				1	0.5
Cover types	Rootwads	1	1			
Cover types	Macrophytes					-0.5
Cover score	1	-1	-2	-0.5	-2	-2
Cover score	2	-1	-1	-0.5	-2	-2
Cover score	3	-0.5			-1	-1
Cover score	4		1		-1	
Cover score	5	0.5	1			1
Cover score	6	1	0.5		2	2
Cover score	7	1	2		1	
Cover amount	Choking vegetation		-0.5			
Cover amount	Absent	-2	-1	-1	-1	
Cover amount	Sparse	-0.5		-0.5		
Cover amount	Moderate	2	1	1	1	0.5
Cover amount	Extensive				1	
Pool/riffle width	Pw>rw	2	2		1	1
Pool/riffle width	Pw=rw	2				
Pool/riffle width	Pw<rw					
Pool/riffle width	No riffle	-2	-2		-1	-1
Pool/riffle width	No pool					
Pool/riffle width	Impounded					
Sinuosity	Excellent	1	1	2	2	2
Sinuosity	Good	2	2	2	2	1
Sinuosity	Fair	1	1	2	1	
Sinuosity	Poor	-2	-2	-2	-2	-2
Channel development	Excellent	2	0.5	2	2	0.5
Channel development	Good	2	2	1	1	2
Channel development	Fair	-1		-1	-1	
Channel development	Poor	-2	-2	-2	-2	-2
Channel stability	High			2	2	0.5
Channel stability	Moderate-high					
Channel stability	Moderate			-1	-2	
Channel stability	Low	-0.5		-2	-1	-0.5
Depth variability	4x var	2	2	2	2	2
Depth variability	2-4x var					
Depth variability	<2x var	-2	-2	-2	-2	-2

Metric	Attribute	Southern streams	Southern headwaters	Northern streams	Northern headwaters	Low gradient
Current velocity	Torrential					
Current velocity	Fast	1		0.5	0.5	0.5
Current velocity	Moderate					
Current velocity	Slow	-1				
Current velocity	Eddies	1	0.5	0.5	0.5	
Current velocity	Interstitial				1	
Current velocity	Intermittent					
Current score	-2					
Current score	-1					-0.5
Current score	0					-0.5
Current score	1	-2	-1	-1	-0.5	-1
Current score	2	-1		-1		
Current score	3	2	1	1		
Current score	4	2	1	1	0.5	
Riparian width	Extensive	0.5	0.5	1	2	2
Riparian width	Wide			1	2	2
Riparian width	Moderate				-2	-1
Riparian width	Narrow			-1	-2	-2
Riparian width	V. Narrow		-0.5	-1	-2	-2
Riparian width	None	-0.5	-0.5	-1	-2	-2
Erosion	Severe		-0.5			
Erosion	Heavy		-0.5			
Erosion	Moderate					
Erosion	Little					
Erosion	None	-0.5	-0.5	0.5		
Shading	None	-2	-0.5	-1	-0.5	-0.5
Shading	Light	-2			-0.5	
Shading	Moderate	2		1	0.5	
Shading	Substantial	1	0.5	1	1	
Shading	Heavy			1		0.5
Land use	Natural	1		2	2	2
Land use	Old field			1		1
Land use	Pasture			0.5		
Land use	No till				0.5	
Land use	Park			1		
Land use	Urban					
Land use	Row crop	-1		-2	-2	-2

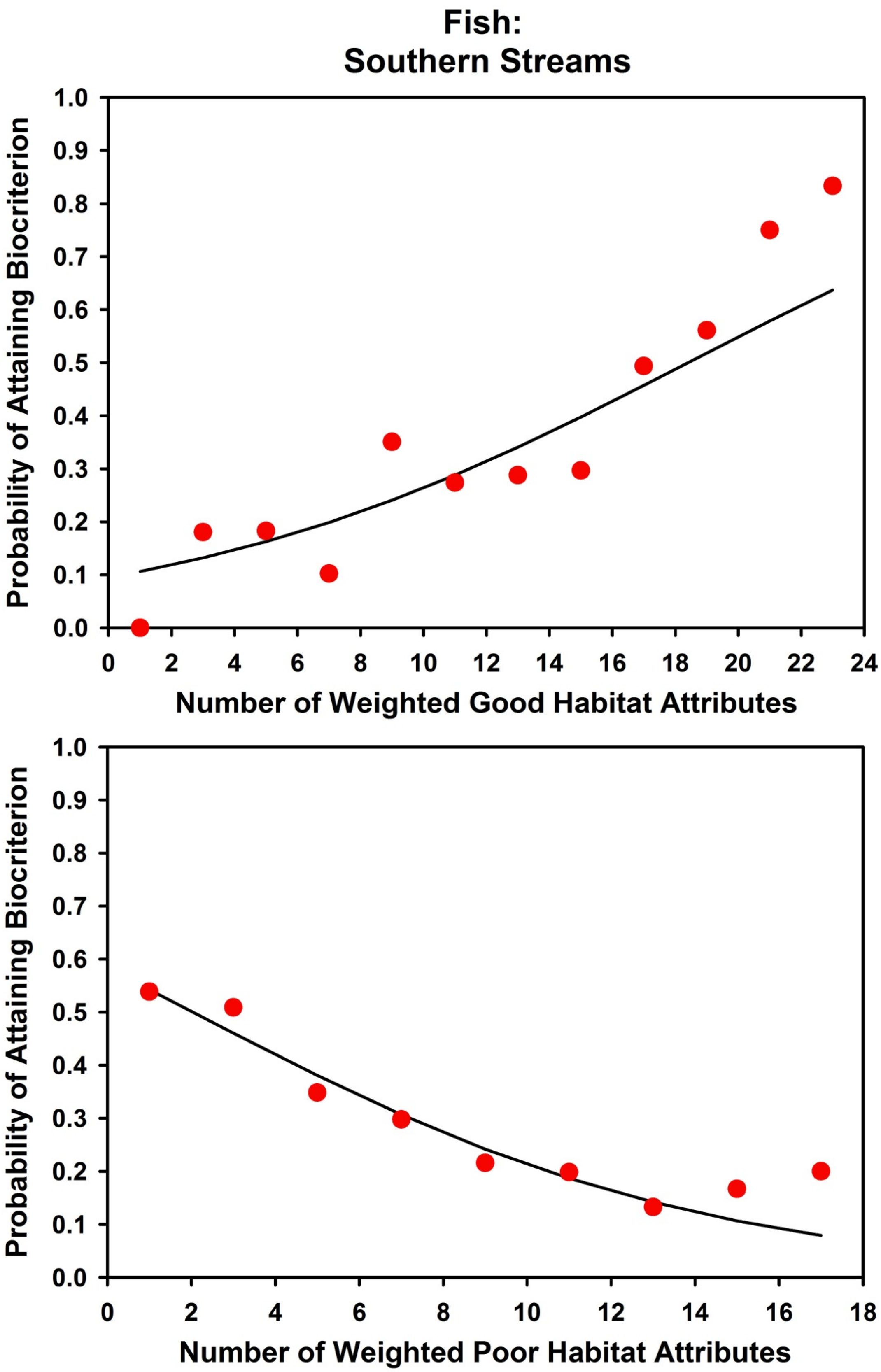
Habitat tool scores for macroinvertebrate indices of biotic integrity (see MPCA [2014d] for descriptions of the metrics)

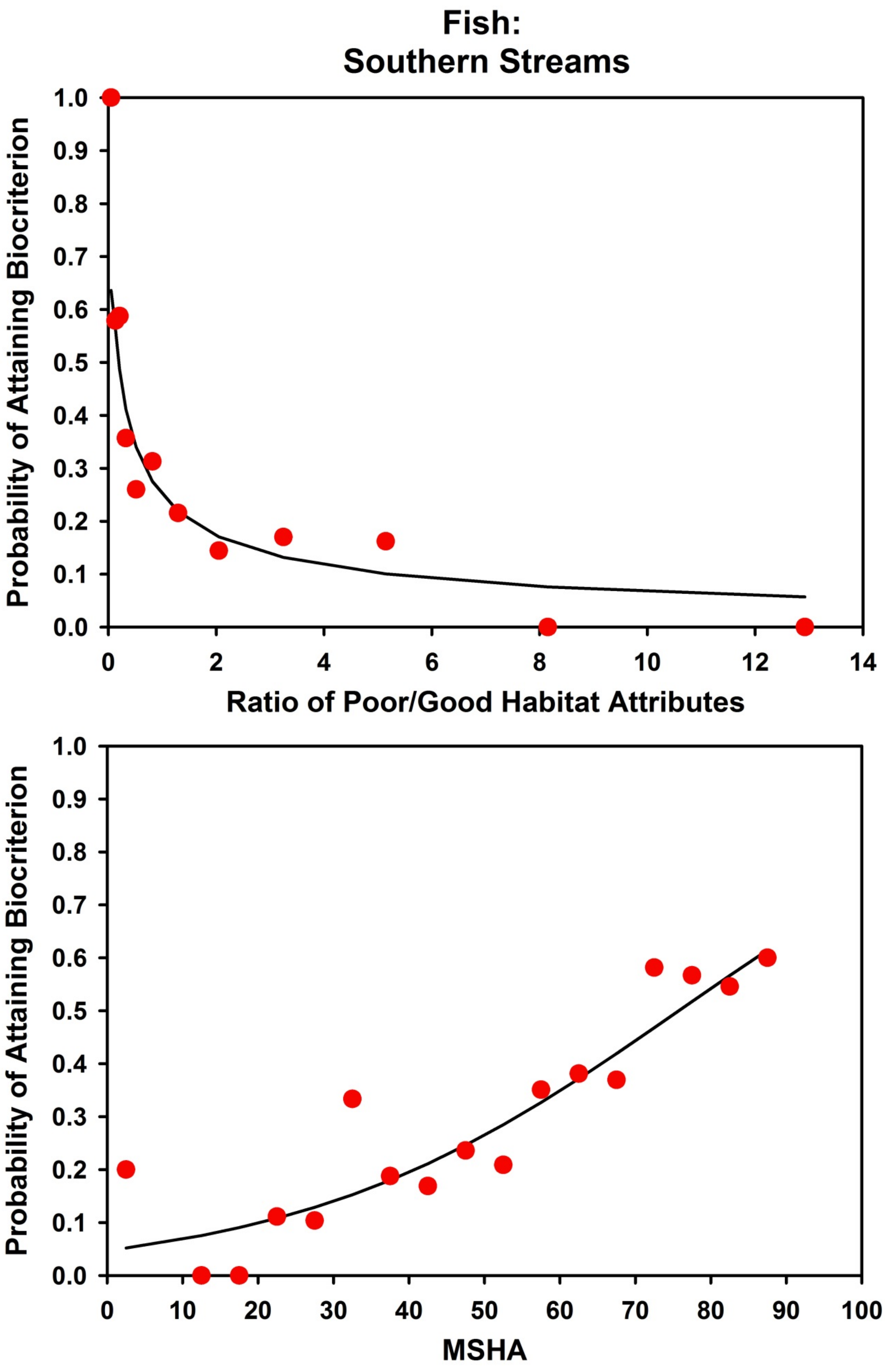
Metric	Attribute	Northern streams glide-pool	Southern streams riffle-run	Southern streams glide-pool	Prairie streams glide-pool
Substrate	Boulder-pool	0.5			
Substrate	Cobble-pool	0.5	2		
Substrate	Gravel-pool	0.5			
Substrate	Sand-pool				
Substrate	Clay-pool		-1		
Substrate	Bedrock-pool				
Substrate	Silt-pool	-0.5	-2		
Substrate	Muck-pool				
Substrate	Detritus-pool	-0.5			
Substrate	Boulder-riffle		0.5		
Substrate	Cobble-riffle				
Substrate	Gravel-riffle		-0.5		
Substrate	Sand-riffle		-0.5		
Substrate	Clay-riffle				
Substrate	Bedrock-riffle				
Substrate	Silt-riffle				
Substrate	Muck-riffle				
Substrate	Detritus-riffle				
Substrate	Boulder-run		1		0.5
Substrate	Cobble-run		1	0.5	0.5
Substrate	Gravel-run	2	-1	1	1
Substrate	Sand-run	-1	-1	1	1
Substrate	Clay-run		-1		-0.5
Substrate	Bedrock-run				
Substrate	Silt-run	-2	-1	-1	-1
Substrate	Muck-run				
Substrate	Detritus-run	-2		-1	-0.5
Substrate	Boulder-glide				
Substrate	Cobble-glide				
Substrate	Gravel-glide				
Substrate	Sand-glide				
Substrate	Clay-glide				
Substrate	Bedrock-glide				
Substrate	Silt-glide				
Substrate	Muck-glide				
Substrate	Detritus-glide				
Embeddedness	No coarse	-2			-2
Embeddedness	Severe	-0.5			
Embeddedness	Moderate				1
Embeddedness	Light	1			1
Embeddedness	None	1	1		

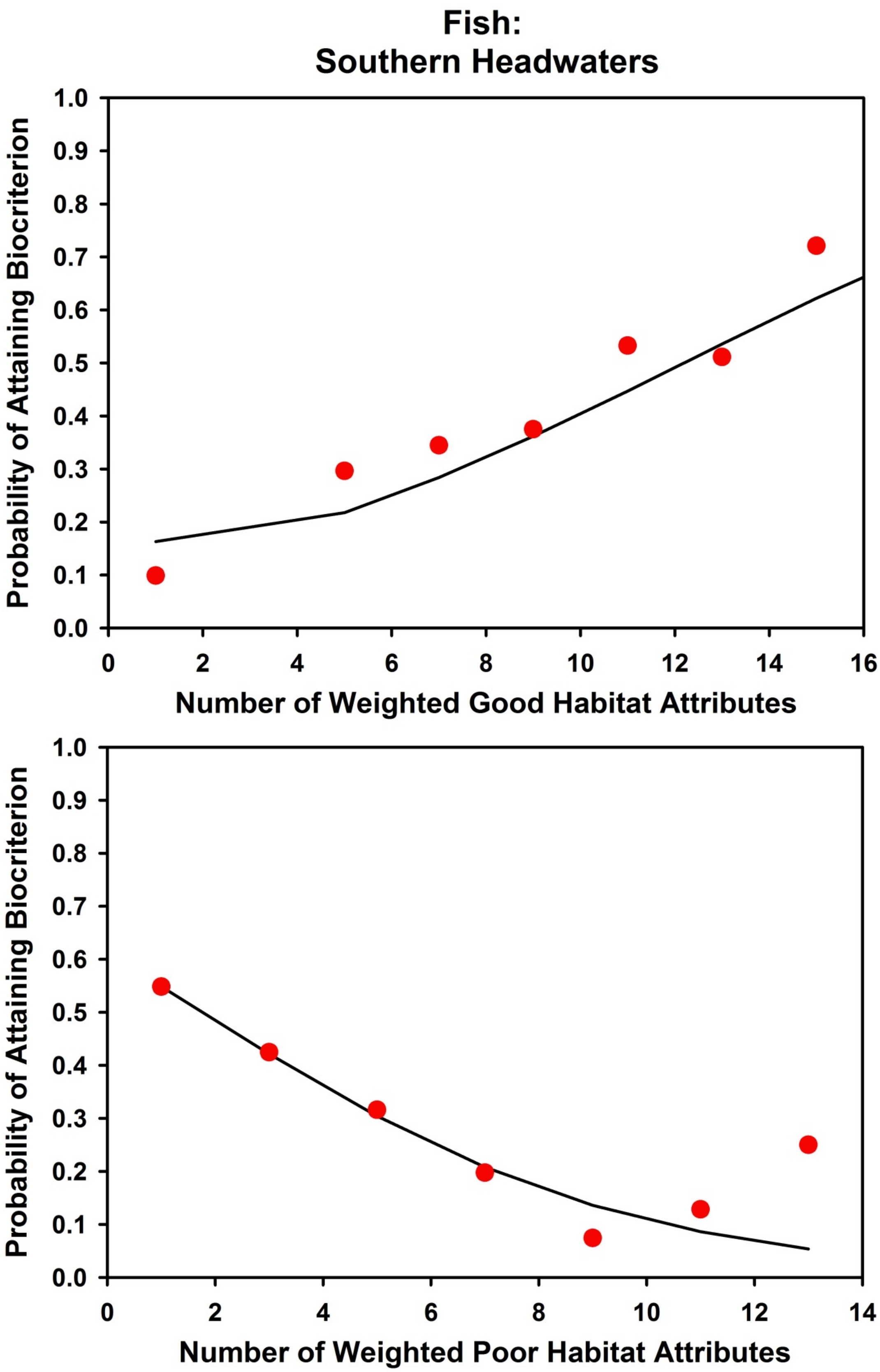
Metric	Attribute	Northern streams glide-pool	Southern streams riffle-run	Southern streams glide-pool	Prairie streams glide-pool
# Substrate types	>4	1			2
# Substrate types	<4	-1			-2
Cover types	Undercut banks				
Cover types	Overhang vegetation				
Cover types	Deep pools				1
Cover types	Logs and woody debris			0.5	1
Cover types	Boulders				1
Cover types	Rootwads				1
Cover types	Macrophytes				-1
Cover score	1				-1
Cover score	2				-1
Cover score	3		-1	-1	-2
Cover score	4				-1
Cover score	5				
Cover score	6	0.5	1	1	2
Cover score	7	0.5	0.5	1	2
Cover amount	Choking vegetation				
Cover amount	Absent				
Cover amount	Sparse				
Cover amount	Moderate				
Cover amount	Extensive				
Sinuosity	Excellent			-1	1
Sinuosity	Good			1	1
Sinuosity	Fair				
Sinuosity	Poor			-1	-1
Channel development	Excellent				
Channel development	Good				
Channel development	Fair	1	2	2	1
Channel development	Poor	1	2	1	2
Channel stability	High			1	-1
Channel stability	Moderate-high	-1	-2	-2	-2
Channel stability	Moderate	1	1	0.5	2
Channel stability	Low	1	1	1	2
Depth variability	4x var			1	
Depth variability	2-4x var	-1	-1	-2	-2
Depth variability	<2x var				
Current velocity	Torrential			1	
Current velocity	Fast				
Current velocity	Moderate				
Current velocity	Slow	1	2	2	2
Current velocity	Eddies	0.5	1	1	
Current velocity	Interstitial	-1	-2	-2	-2
Current velocity	Intermittent				
Current score	-2	1			2

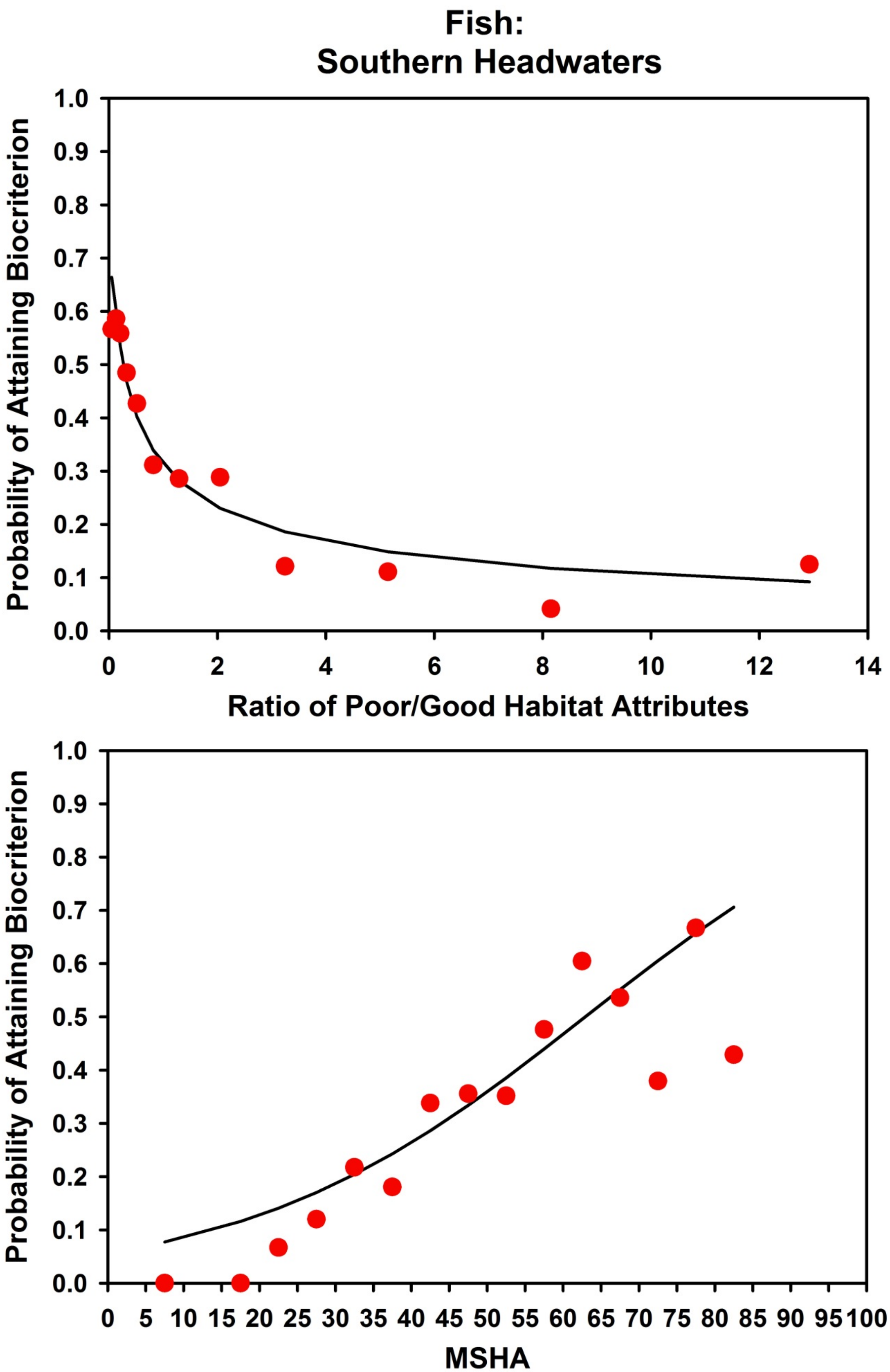
Metric	Attribute	Northern streams glide-pool	Southern streams riffle-run	Southern streams glide-pool	Prairie streams glide-pool
Current score	-1				
Current score	0	-1			-2
Current score	1	1		1	
Current score	2				
Current score	3				
Current score	4	-2	-1	-2	-2
Riparian width	Extensive	-2	-1	-2	-2
Riparian width	Wide	-2	-1	-2	-2
Riparian width	Moderate	-2	-1	-2	-2
Riparian width	Narrow				
Riparian width	Very narrow	2	1	2	2
Riparian width	None	1	1	2	1
Erosion	Severe		1	0.5	2
Erosion	Heavy			1	1
Erosion	Moderate				
Erosion	Little	-0.5	-1	-1	-1
Erosion	None	-0.5	-0.5	-1	-2
Shading	None	-0.5	-0.5	-0.5	-0.5
Shading	Light				
Shading	Moderate				
Shading	Substantial	2			
Shading	Heavy				
Land use	Natural				
Land use	Old field		-2	-2	-0.5
Land use	Pasture		-2	-1	-0.5
Land use	No till		1	1	
Land use	Park		1	1	0.5
Land use	Urban		1	1	0.5
Land use	Row crop		2	2	2

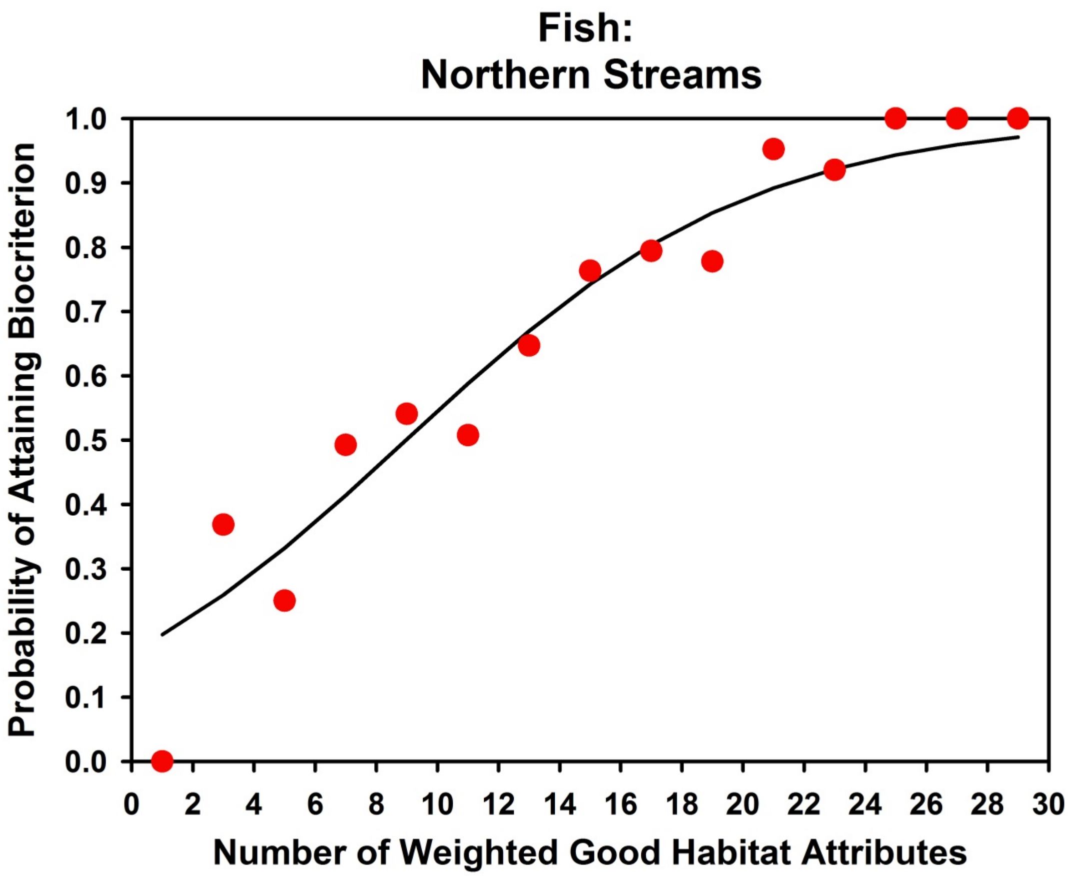
Appendix C: Logistic Regression Plots

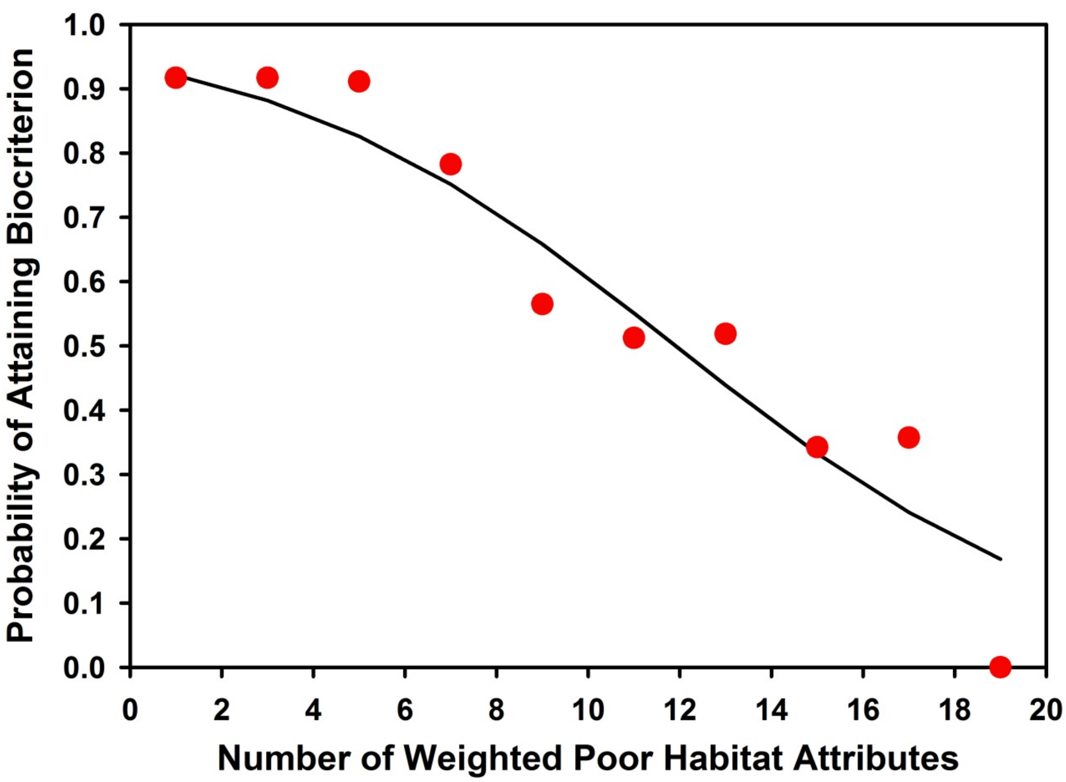


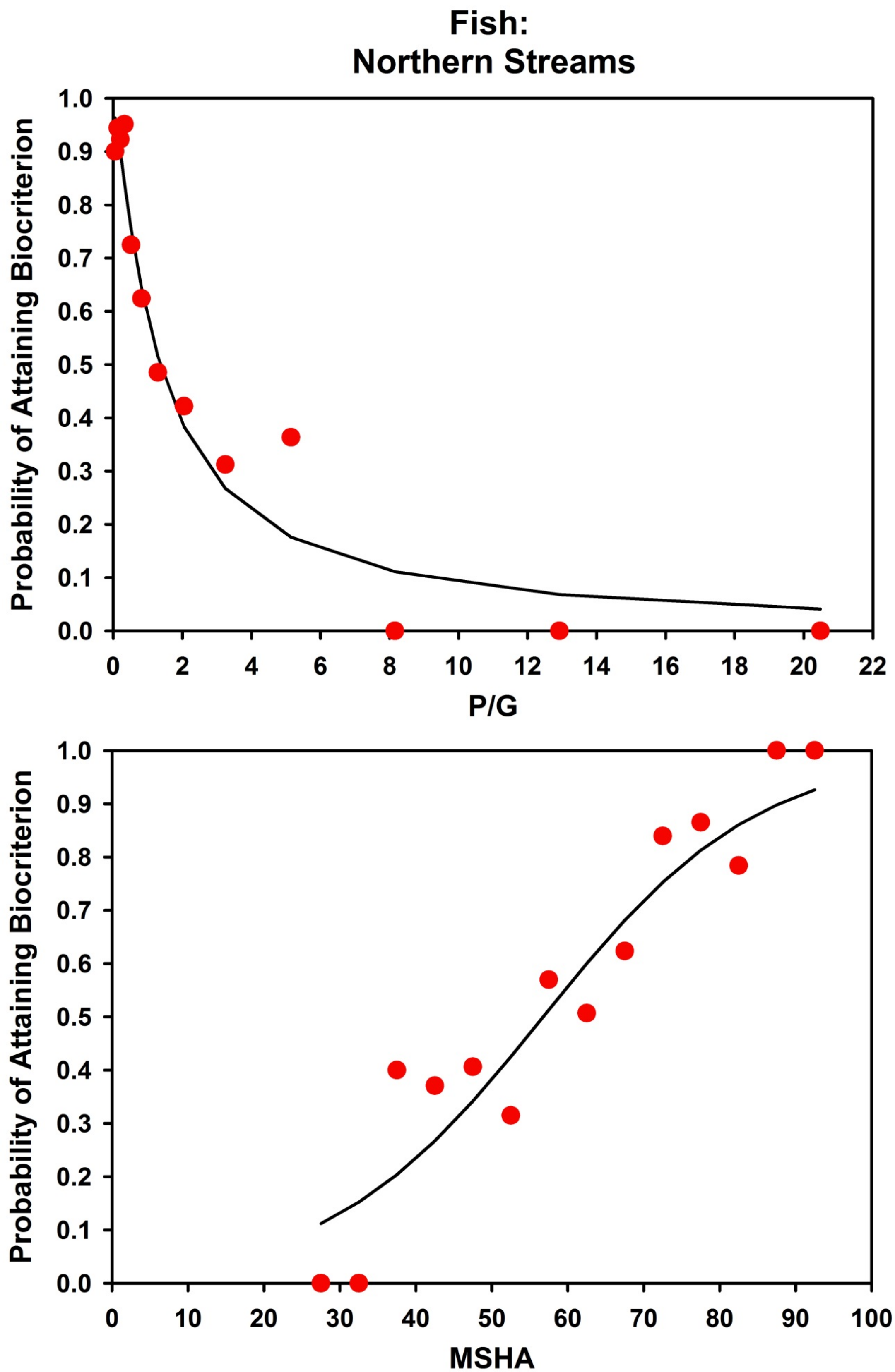

Fish:
Southern Streams
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
Ratio of Poor/Good Habitat Attributes
Probability of Attaining Biocriterion
0
10
20
30
40
50
60
70
80
90
100
MSHA


Fish:
Southern Headwaters
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
Number of Weighted Good Habitat Attributes
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
Number of Weighted Poor Habitat Attributes

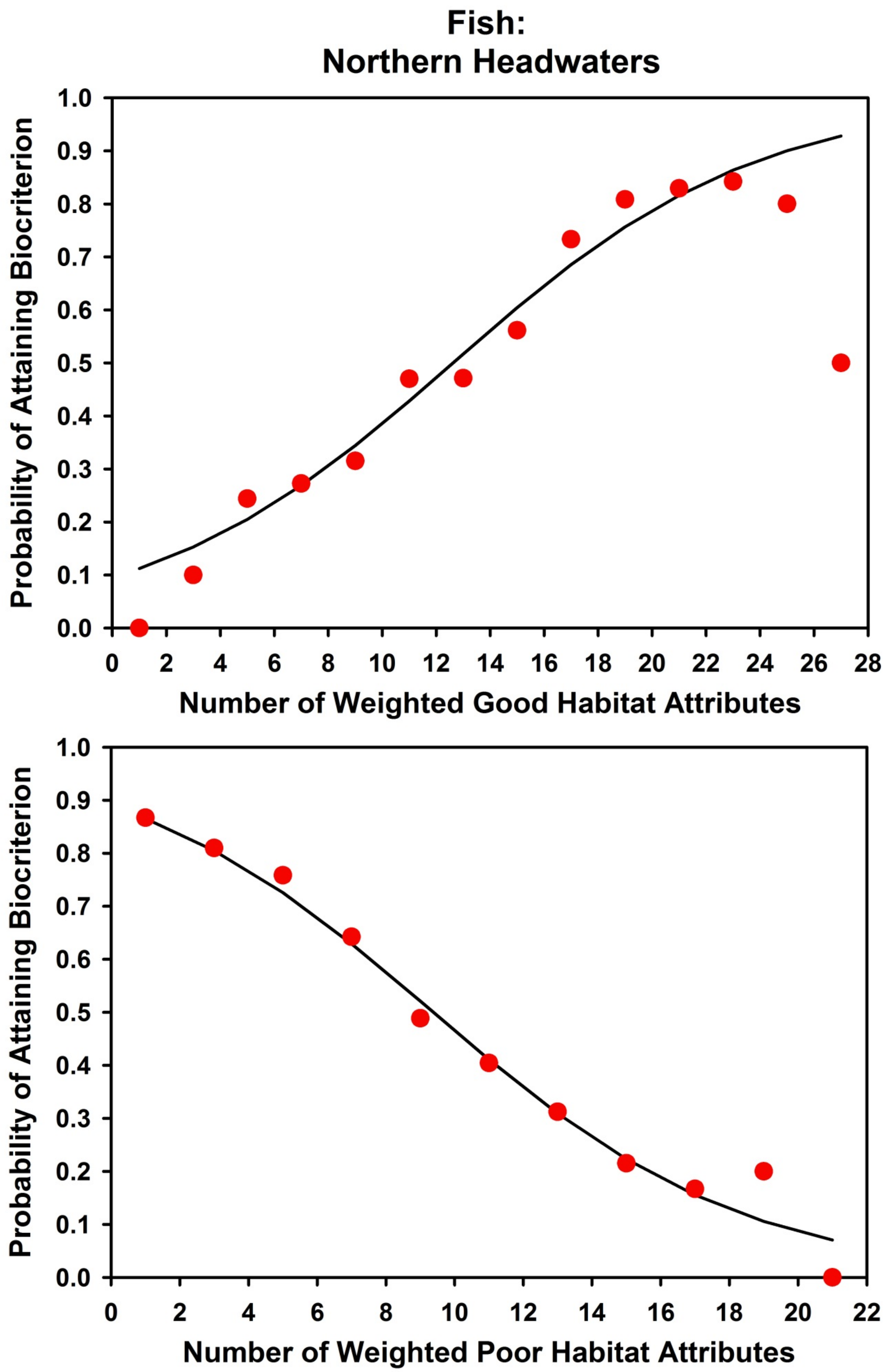

Fish:
Southern Headwaters
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
Ratio of Poor/Good Habitat Attributes
Probability of Attaining Biocriterion
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
MSHA

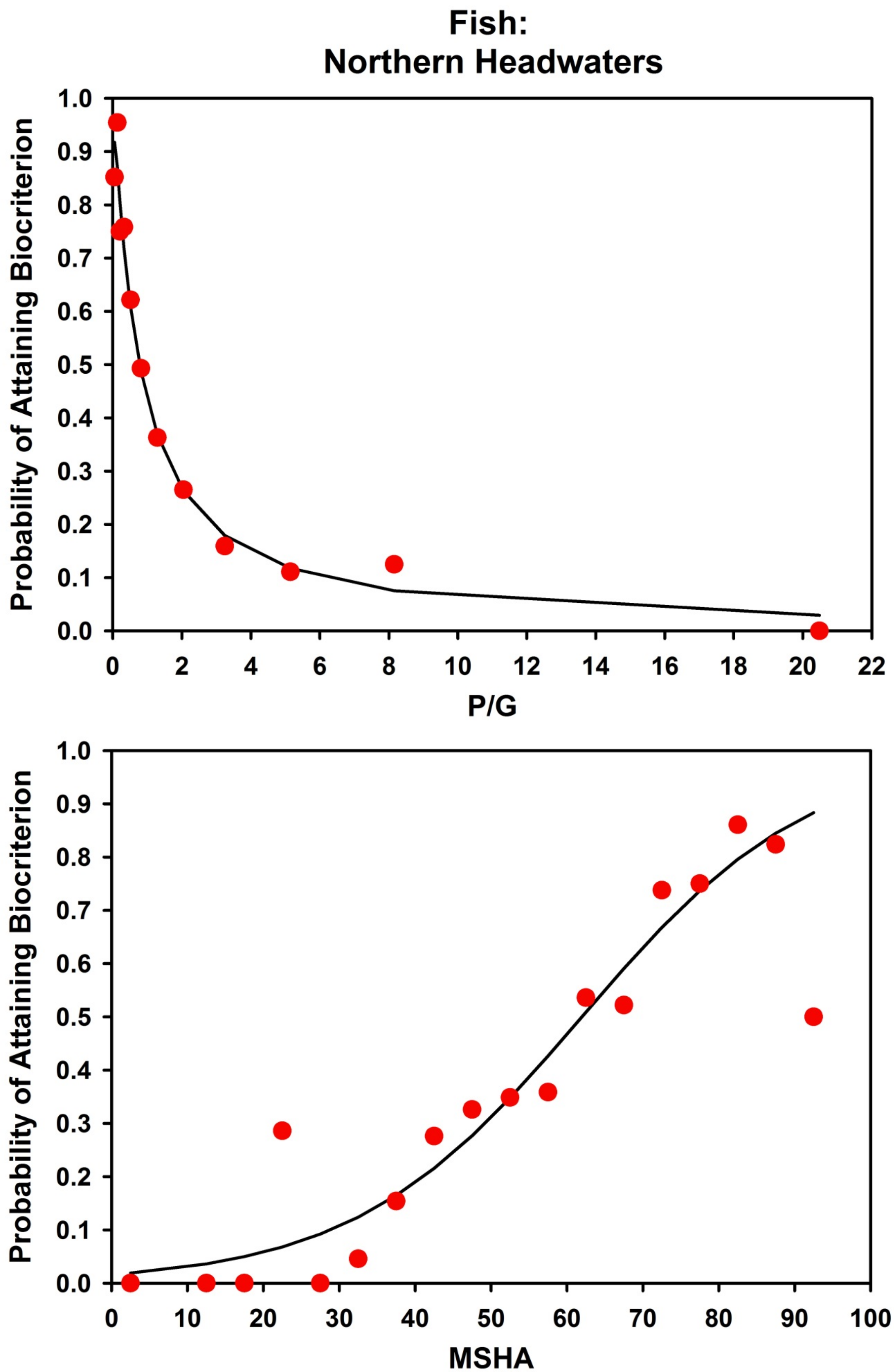

Fish:
Northern Streams
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Number of Weighted Good Habitat Attributes

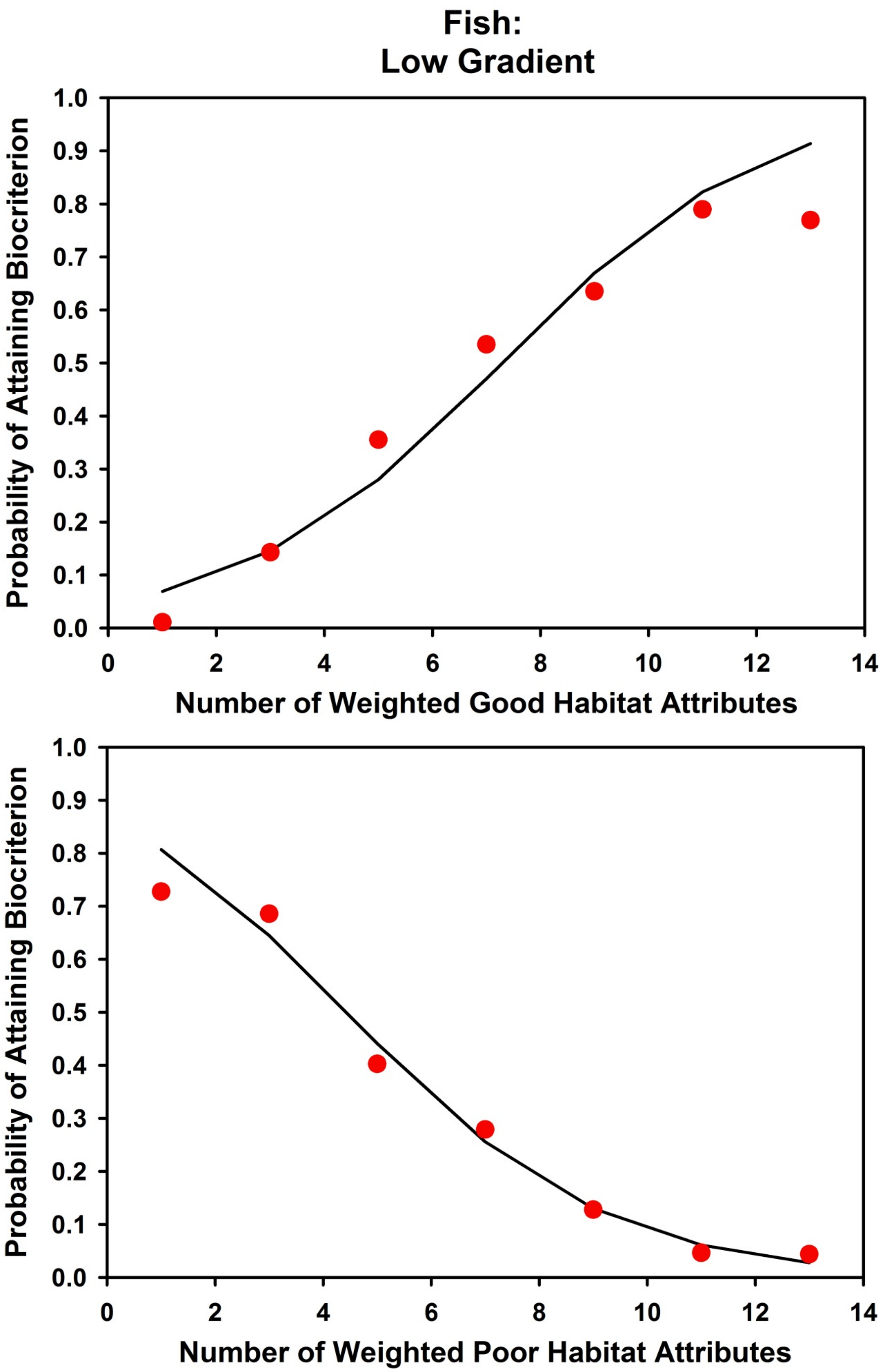

Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20
Number of Weighted Poor Habitat Attributes

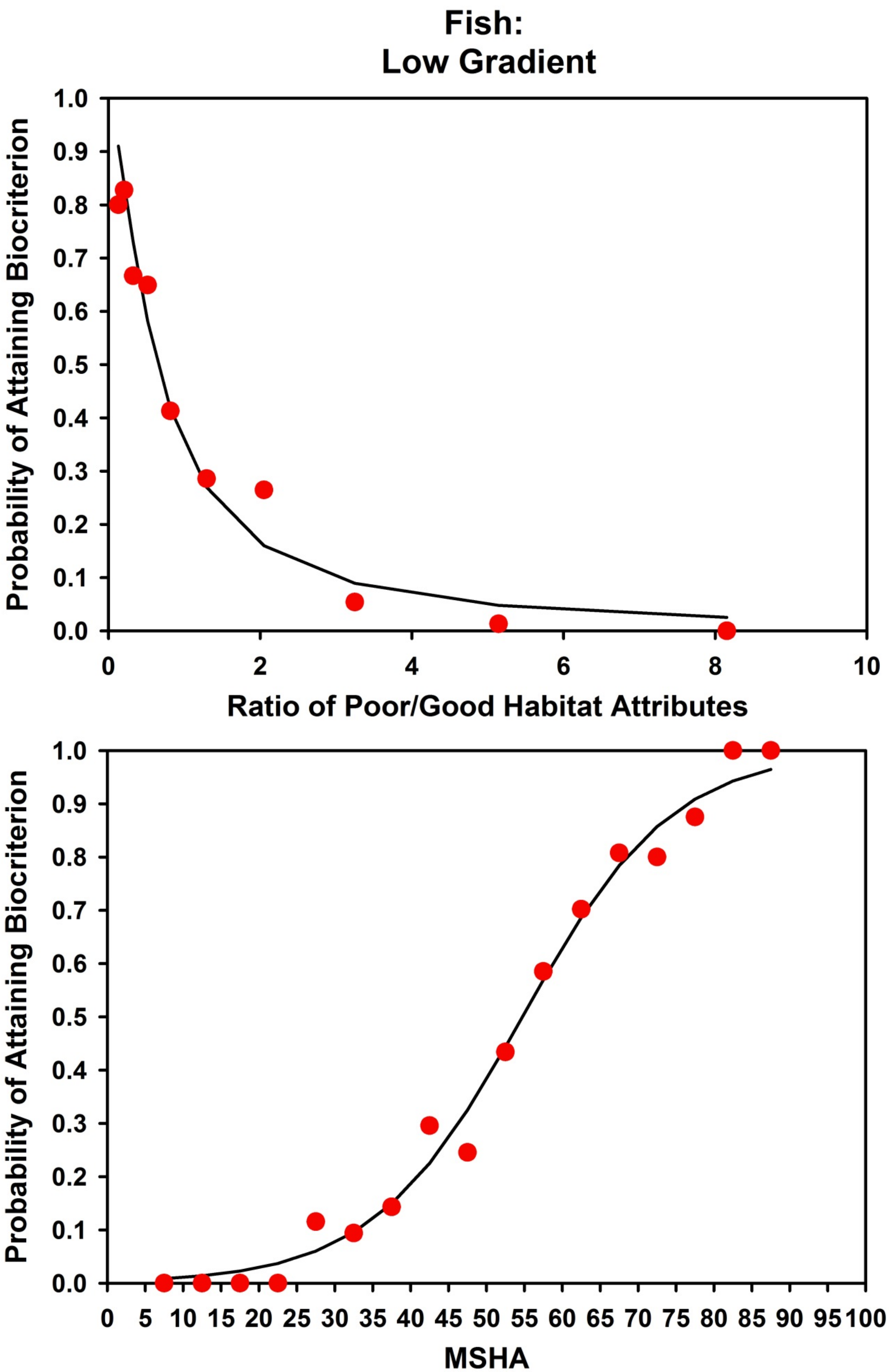


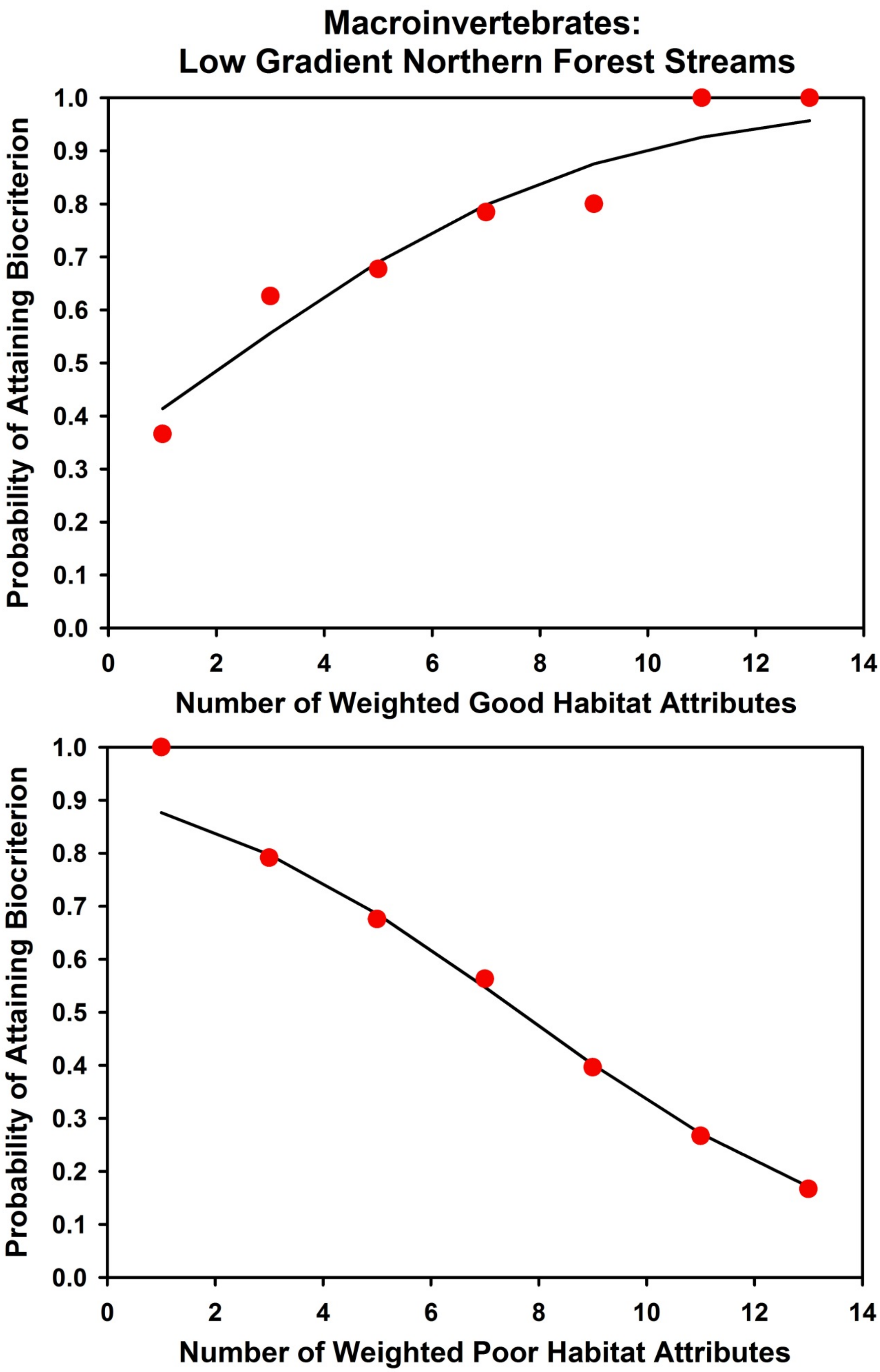
Fish:
Northern Streams
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22
P/G
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 10 20 30 40 50 60 70 80 90 100
MSHA

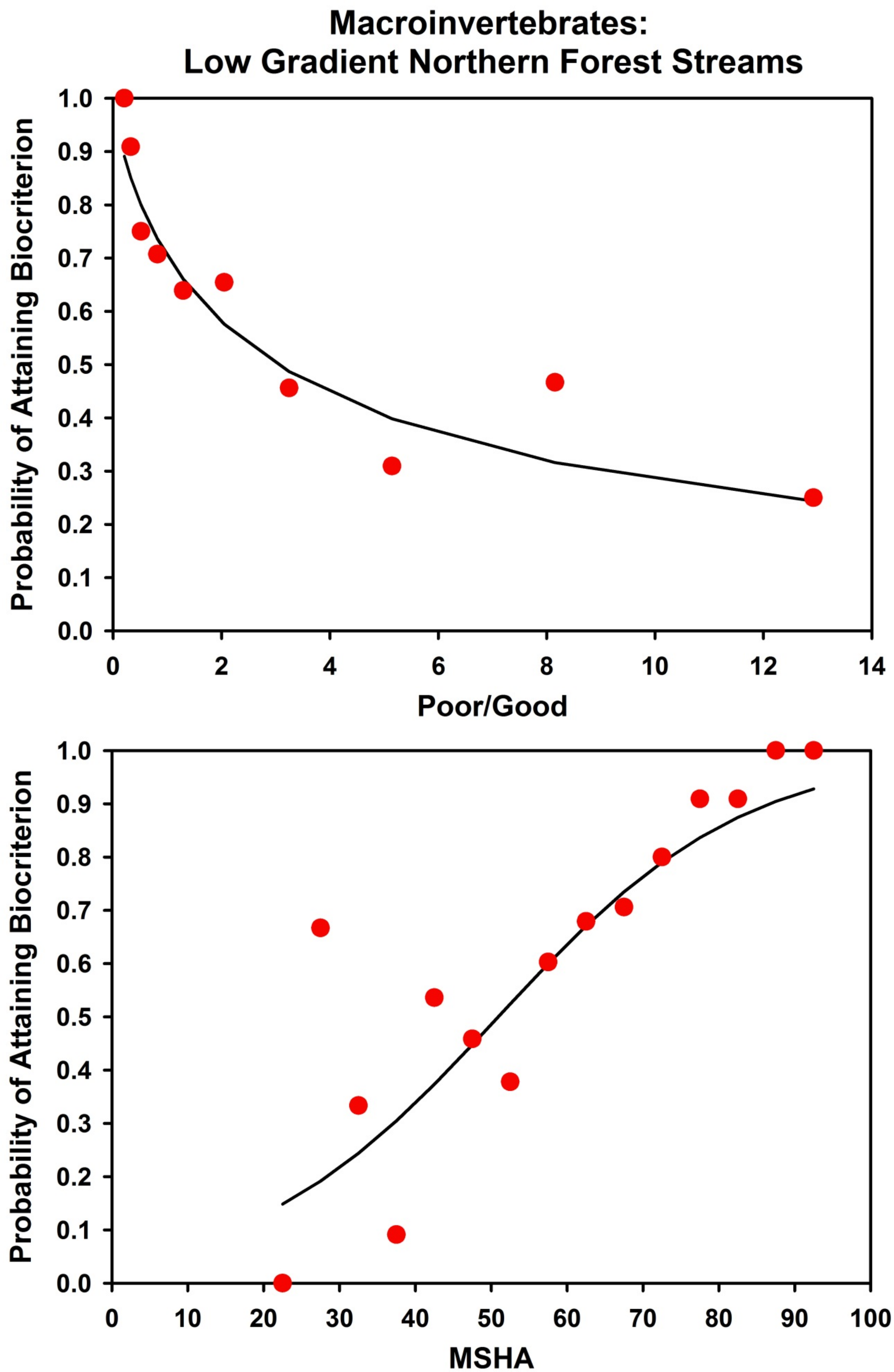

Fish:
Northern Headwaters
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
Number of Weighted Good Habitat Attributes
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 2 4 6 8 10 12 14 16 18 20 22
Number of Weighted Poor Habitat Attributes


Fish:
Northern Headwaters
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
18
20
22
P/G
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
80
90
100
MSHA


Fish:
Low Gradient
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
Number of Weighted Good Habitat Attributes
Probability of Attaining Biocriterion
Number of Weighted Poor Habitat Attributes


Fish:
Low Gradient
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
Ratio of Poor/Good Habitat Attributes
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
MSHA


Macroinvertebrates:
Low Gradient Northern Forest Streams
Probability of Attaining Biocriterion
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
2
4
6
8
10
12
14
Number of Weighted Good Habitat Attributes
Probability of Attaining Biocriterion
Number of Weighted Poor Habitat Attributes


Macroinvertebrates:
Low Gradient Northern Forest Streams
Probability of Attaining Biocriterion
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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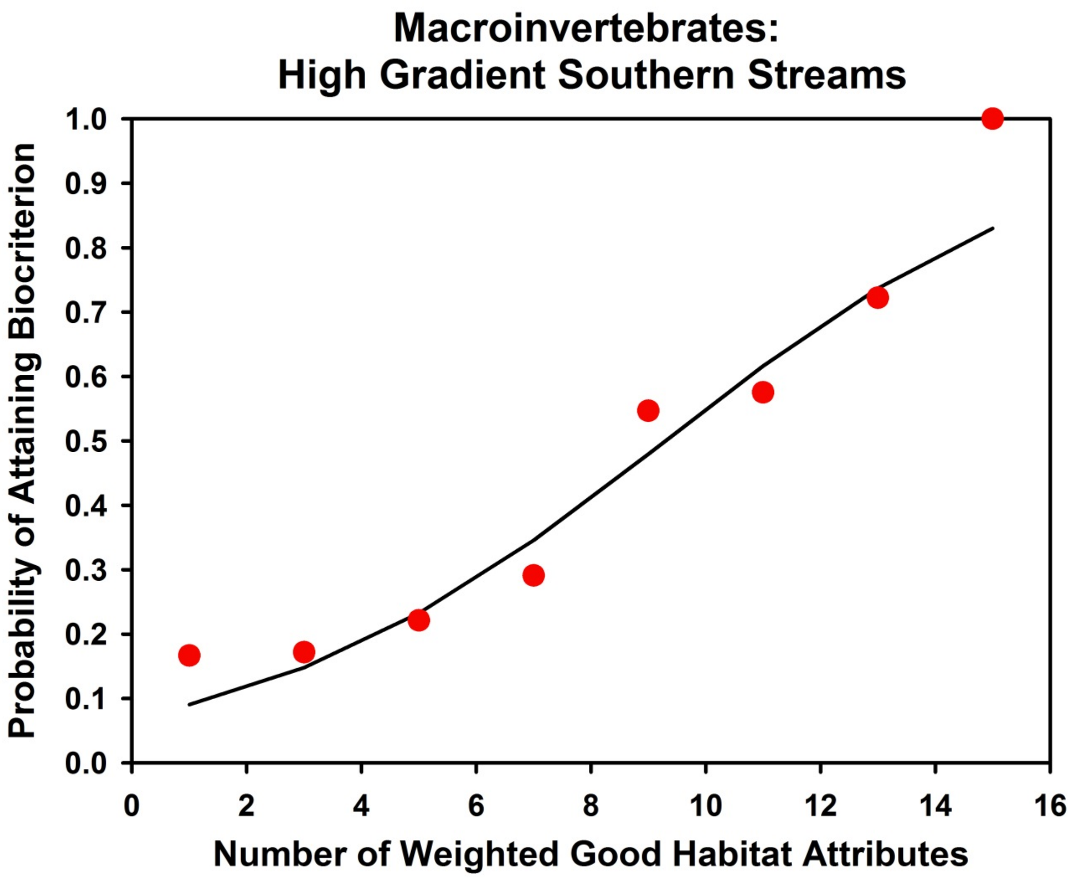
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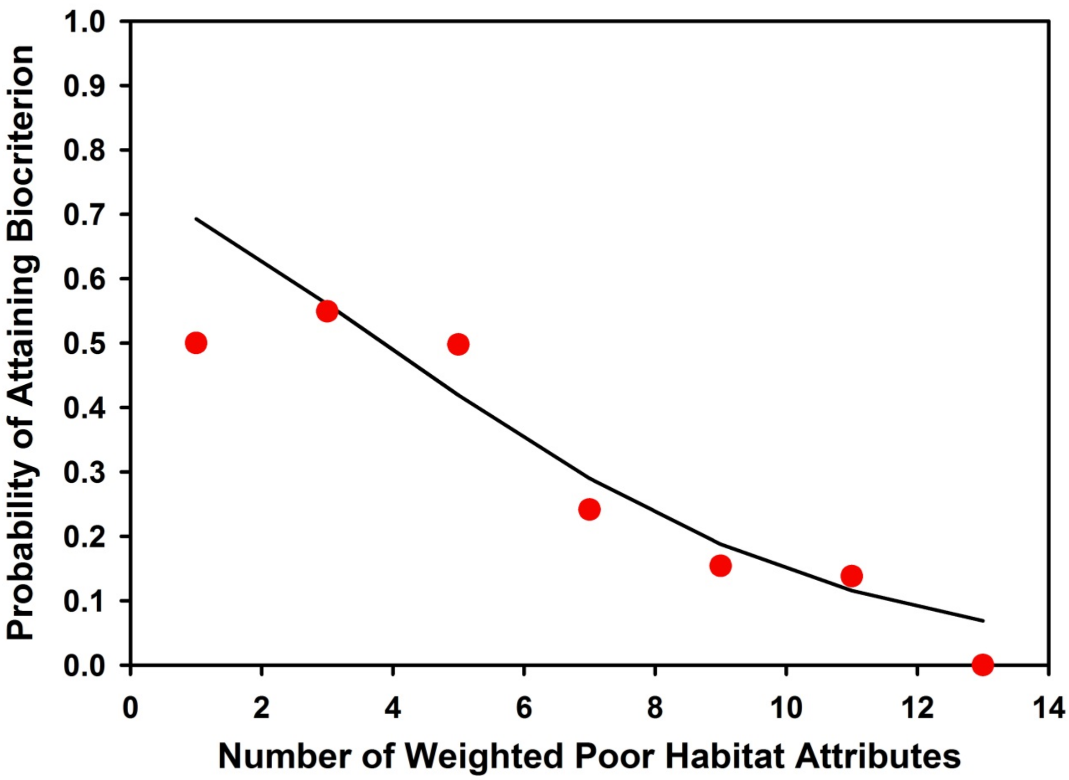
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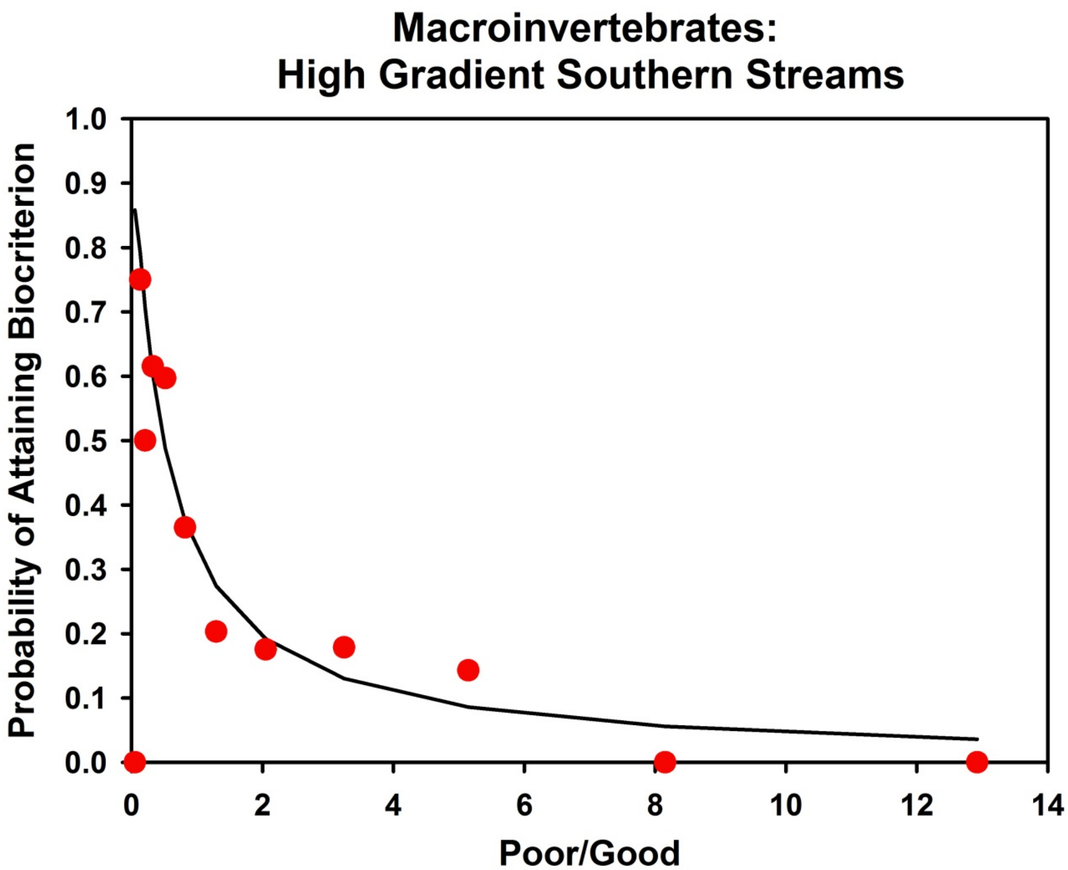
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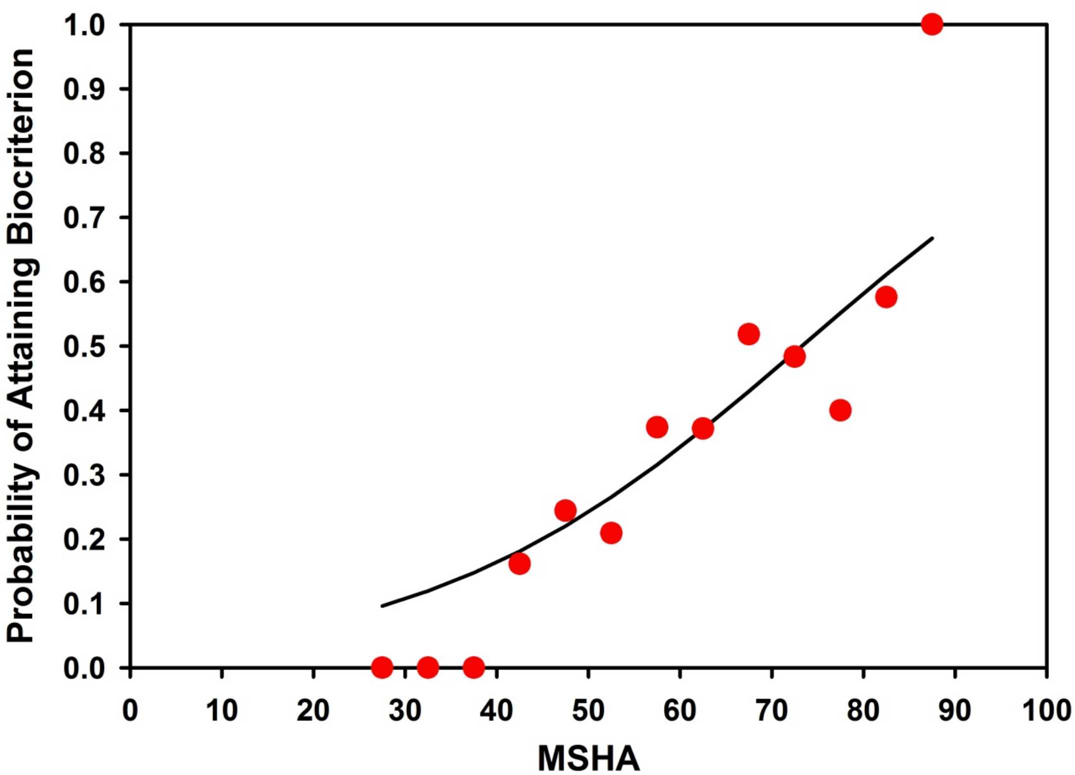
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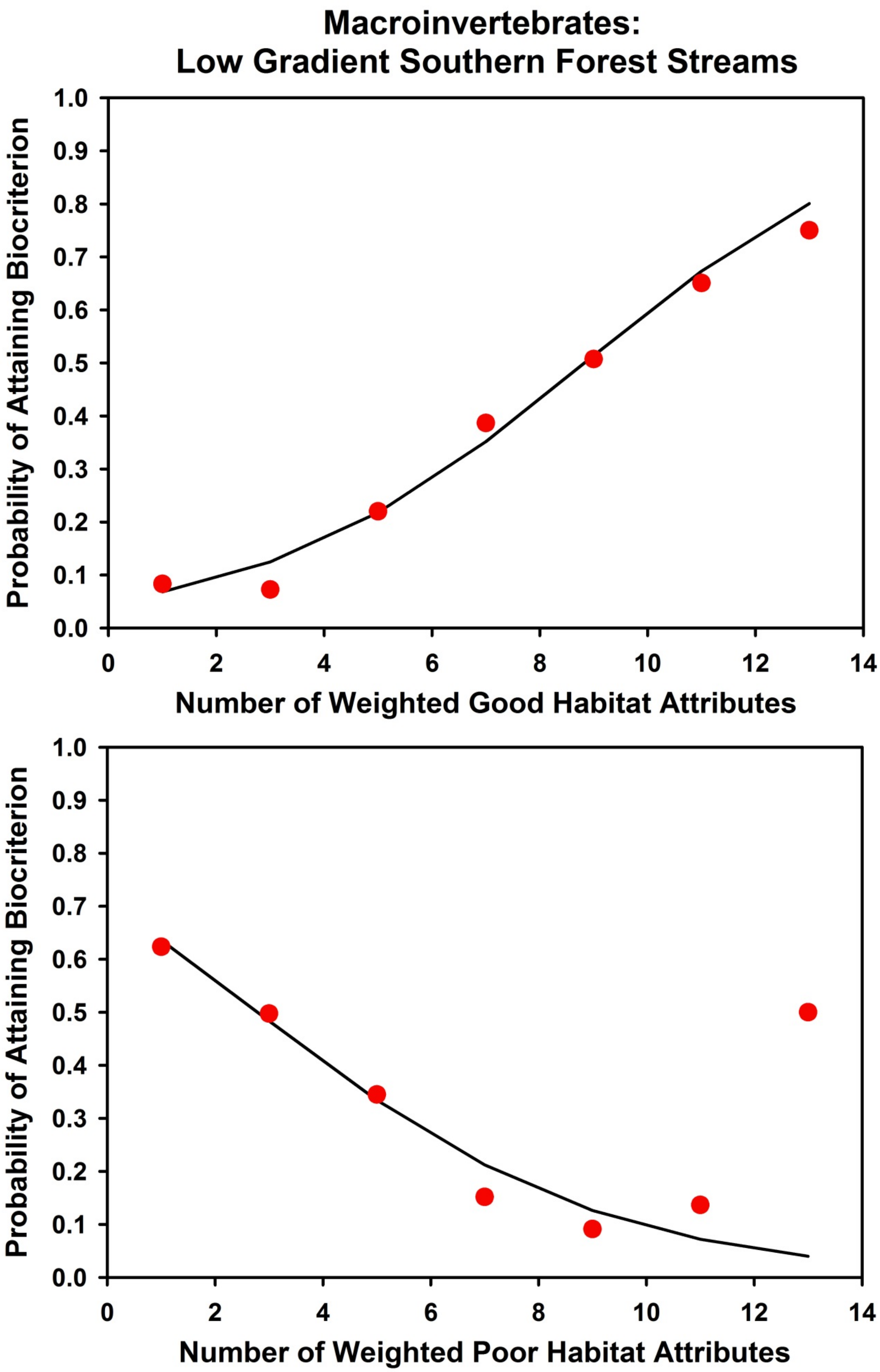
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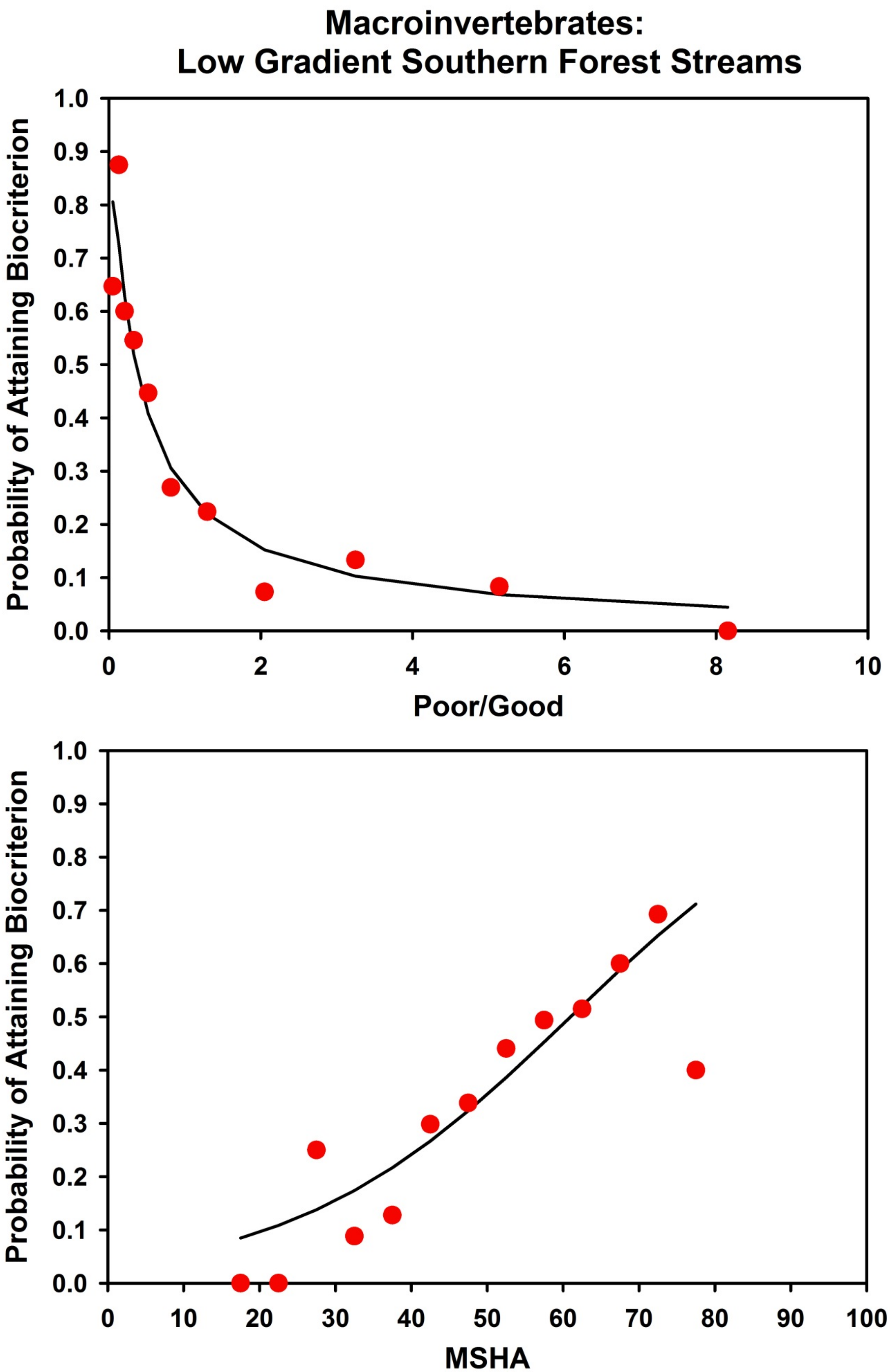
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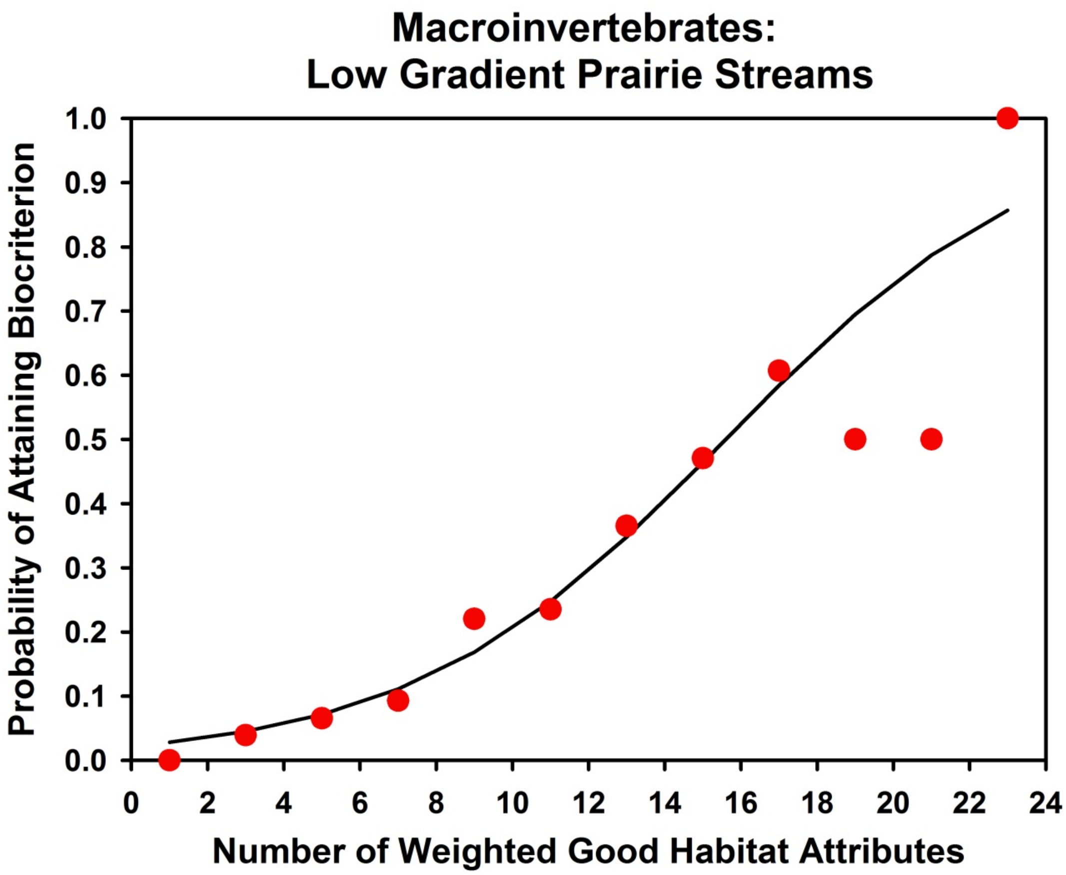
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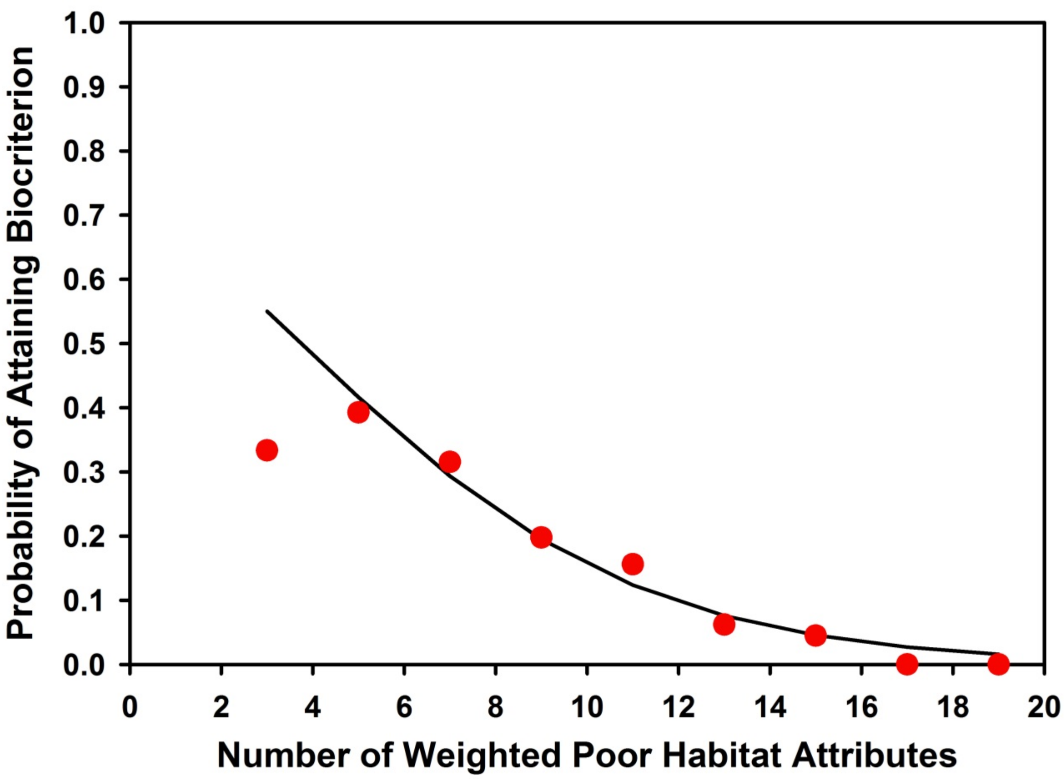
Number of Weighted Good Habitat Attributes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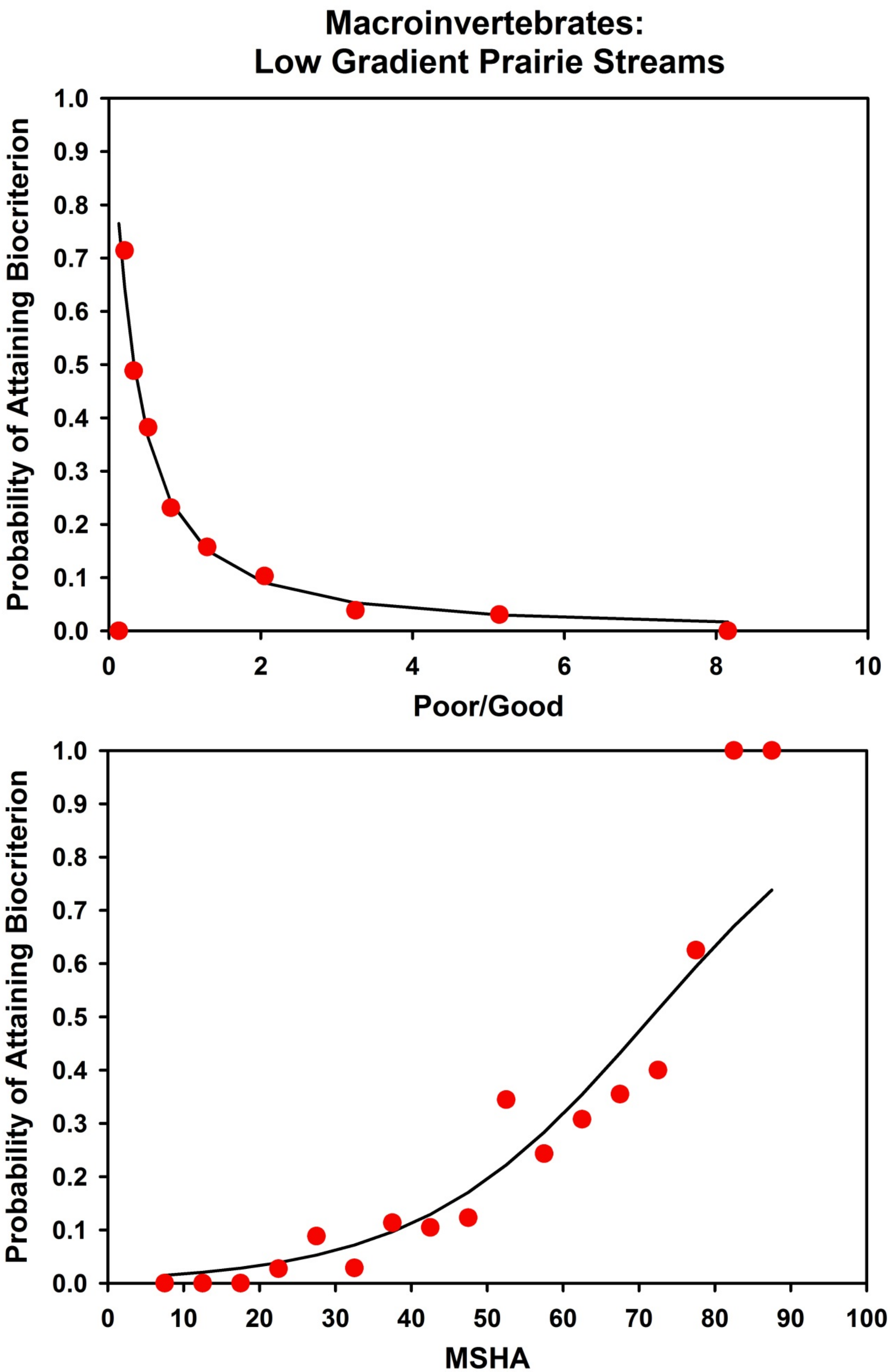
Number of Weighted Poor Habitat Attributes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Development of a Fish-Based Index of Biological Integrity for Minnesota's Rivers and Streams

Minnesota Pollution Control Agency

July 2014

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1. Overview

This report documents the development of a fish community-based Index of Biological Integrity (F-IBI) for Minnesota's streams and rivers. The primary intended use for this tool is the assessment of aquatic life use support by the Minnesota Pollution Control Agency (MPCA). More detailed descriptions of biomonitoring, bioassessments, biological assessment guidance, human disturbance score (HDS), and biological condition gradient (BCG) can be found in other documents.

Passage of Minnesota's Clean Water Legacy Act (CWLA) in 2006 provided a policy framework and resources to accelerate efforts to monitor, assess, and restore impaired waters, and to protect unimpaired waters. With passage of the Clean Water, Land and Legacy Amendment in 2008, additional funding was made available to the MPCA, Minnesota Department of Natural Resources (MnDNR), and partner agencies to continue and expand on efforts outlined in the CWLA.

In 2007, the MPCA initiated a 10-year, rotating watershed approach for comprehensive monitoring and assessment of Minnesota's waters. The MPCA has used indices of biological integrity and chemical measures to assess the integrity of streams since the mid-1990s. However, existing IBIs could not adequately support this statewide monitoring and assessment effort. For example, no biological assessment tools had been developed for the many miles of streams within the Rainy River and Lake Superior Basins, the Lower Mississippi River Basin, and the Red River Basin outside of the Lake Agassiz Plain Ecoregion. Furthermore, existing IBIs had not been developed concurrently, and varied in terms of their analytical approaches, classification frameworks, scoring systems, and taxa attributes. To support comprehensive monitoring and assessment of Minnesota's streams, it was necessary to develop new indicators applicable to the entire state of Minnesota, using a consistent, standardized approach.

Development of the statewide F-IBI utilized a protocol developed by researchers from the United States Environmental Protection Agency (USEPA) and elsewhere. Minnesota's streams and rivers were first partitioned into nine physiographic classes; a unique F-IBI was developed for each stream class. Within each stream class, biological metrics were evaluated using a series of tests. Metrics that passed these tests were ranked and a subset selected for inclusion in each IBI. The final indices included between seven and twelve metrics and demonstrated the ability to distinguish between levels of biological condition.

This document describes the process used in the development of F-IBI for Minnesota's rivers and streams, representing the state's first comprehensive, statewide tool for assessing biological integrity of riverine fish communities. These indices will be used during the first iteration of the 10-year watershed monitoring and assessment cycle, and periodically evaluated to ensure they remain robust and effective tools for assessing aquatic life.

2. Introduction

Waterbody monitoring and condition assessment provide resource managers with information needed to guide restoration and protection efforts. A wide variety of indicators are used in water monitoring and assessment programs, but among the most useful are those that integrate and reflect cumulative impacts to aquatic systems. Degradation of surface waters can be attributed to multiple sources including: chemical pollutants from municipal and industrial point source discharges; agricultural runoff of sediment, nutrients, and pesticides; hydrologic alteration in the form of ditching, drainage, dams, and diversions; and habitat alteration associated with agricultural, urban, and residential development. The timing and magnitude of these impacts may vary through time, and be difficult to detect and measure utilizing traditional chemical evaluations that focus on a single indicator or limited suite of parameters. However, biota reside in these waterbodies utilize the available aquatic habitats, and have life spans ranging from weeks to years. They experience the entire spectrum of environmental conditions, including stressors caused by human activities. Aquatic biota are known to be responsive to a wide variety of anthropogenic impacts and, at the community level, reflect the integrated result of physical, chemical, and biological processes through time (Barbour et al. 1999). In this manner, aquatic communities provide a direct, comprehensive perspective on water quality, and lend themselves well to tools that utilize community-level parameters, such as the Index of Biological Integrity (IBI).

The IBI was originally developed as a tool for assessing the condition of rivers and streams in the Midwestern United States (Karr 1981, Karr et al. 1986). The concept has since been expanded to a wide variety of geographic regions and ecological systems, and has demonstrated its effectiveness in several applications (e.g., condition monitoring, stressor identification). At its core, the IBI provides a framework for translating biological community data into information regarding ecological integrity ("the capability of supporting and maintaining a balanced, integrated, functional organization comparable to that of the natural habitat of the region," Frey 1977). It utilizes a variety of attributes ("metrics") of the biological community, each of which responds in a predictable way to anthropogenic disturbance. Metrics are based on ecological traits of species and represent different aspects of ecological structure and function. The metrics are scored numerically to quantify deviation from least-disturbed conditions, and summed together producing a composite IBI score that characterizes biological integrity (Karr et al.1986).

The composite IBI score is typically compared to a threshold to assess a waterbody's condition. However, it is also possible to deconstruct the index into its component metrics to determine which aspects of ecological structure and function are particularly robust or diminished. Relationships between specific stressors and the composite IBI or component metrics can be explored, and trait-environment linkages extended to diagnostic (i.e., stressor identification) applications (Culp et al. 2010). Stressor-response relationships are implicit in the IBI concept and may provide information relevant to watershed protection and restoration strategies.

Since the 1990s, the MPCA has utilized the IBI concept in its stream monitoring and assessment program. Narrative language within Minnesota Administrative Rule identifies an IBI calculation as the primary determinant for evaluating impairment of aquatic biota (Minn. R. 7050.0150, subp. 6, Impairment of biological community and aquatic habitat). Details regarding development and calibration of the IBI are included in an associated Statement of Need and Reasonableness, and use of this framework has been upheld in legal proceedings challenging its use.

Between 1993 and 2002, the MPCA developed Fish IBIs for streams in specific ecoregions and major basins of Minnesota, and used them conduct Aquatic Life Use assessments. Fish IBIs were developed for rivers and streams with the Minnesota River Basin (Bailey et al. 1993), the Lake Agassiz Plain Ecoregion of the Red River Basin (Niemela et al. 1999), the St. Croix River Basin (Niemela and Feist 2000), and the Upper Mississippi River Basin (Niemela and Feist 2002) (Figure 1). However, nearly half of Minnesota's streams and rivers were not covered by these existing IBIs (Table 1).

Index of Biotic Integrity	Stream Miles	Percentage
Lake Agassiz Plain	12057	11.9%
Minnesota River Basin	19264	19.0%
St. Croix River Basin	3775	3.7%
Upper Mississippi River Basin	19942	19.6%
No IBI	46461	45.8%

Table 1. Estimated sum of Minnesota stream miles previously covered by regional fish IBIs, and percentage of the state's total stream miles covered by each.

Figure 1. Map of Minnesota depicting regions previously encompassed by existing (1993-2002) Fish IBIs

Passage of Minnesota's Clean Water Legacy Act in 2006 and Clean Water, Land and Legacy Amendment in 2008 accelerated efforts to monitor, assess, restore, and protect the state's water resources. With this increased emphasis on water quality, it became evident that monitoring and assessment tools applicable on a statewide scale were needed, and that resources necessary to develop those tools were available. Our objective was to develop a series of IBIs for assessing the condition of fish communities in rivers and streams across the state of Minnesota.

In this document, we describe development and calibration of fish-based IBIs for streams and rivers across the State of Minnesota. Using a methodology developed by researchers at the United States Environmental Protection Agency (Whittier et al. 2007), metrics representing the structure and function of Minnesota's stream fish communities were systematically tested for inclusion in IBIs based on statistical criteria (e.g., responsiveness to disturbance, strong signal, low noise). These IBIs will be used in conjunction with numeric biocriteria to assess biological integrity of Minnesota's rivers and streams, and, in conjunction with water chemistry data and standards, to assess whether waterbodies are meeting designated Aquatic Life Uses as outlined in Minnesota Rules and the federal Clean Water Act.

3. Methods

3.1. Study area

The State of Minnesota lies in a water-rich region, at the headwaters of three major continental watersheds (Gulf of Mexico, Laurentian Great Lakes, Hudson Bay) and at the intersection of western prairies, eastern deciduous forests, and northern boreal forests (Figure 2). Much of the state lies in a transition zone between these ecotypes, and its watercourses reflect the diversity of their landscapes. A wide variety of rivers and streams are found within Minnesota's borders, including: short, steep bedrock-controlled cascades; broad, meandering prairie rivers; clear, cold spring-fed creeks; and tannic, low-gradient streams draining large bogs and swamps. The fish fauna is diverse (>140 native species) and dominated by cool- and warm-water taxa, though coldwater assemblages are found in some regions of the state. The distribution of individual fish species has been greatly shaped by glaciations, glacial refugia, and post-glacial barriers to dispersal (Underhill 1989), though several species have been introduced outside of their native range, both intentionally and inadvertently. Dams, pollution, channelization, and diversions have also artificially disrupted movements of migratory species into habitats they historically utilized.

Humans have substantially modified Minnesota's landscape. Most native prairies have been converted to agricultural land, with extensive systems of surface and subsurface drainage. Nearly all of the forested land has been logged at some point in the past 150 years. Urban areas have been steadily expanding in all regions of the state. Associated with this transformation, many of Minnesota's waterbodies have experienced historical and ongoing impacts, including stressors related to agricultural practices, urbanization, mining, logging, channel modification, and industrial discharges. However, substantial portions of the state have retained natural vegetative cover, relatively intact stream habitats, and connectivity within watersheds. The contemporary structure and function of Minnesota's stream ecosystems are shaped by these interacting factors of natural variability and human disturbance; the resulting level of biological integrity can be interpreted by tools such as the IBI.

3.2. Program details

Two Biological Monitoring Units within the MPCA's Environmental Analysis and Outcomes Division conduct ecological surveys on rivers and streams across the state. Since the early 1990s, an extensive dataset has been maintained, describing physical, chemical, and biological characteristics of rivers and streams. As of late 2012, more than 5,000 individual fish collection efforts are represented, from more than 4,500 monitoring sites across the state. The vast majority of surveys were conducted by MPCA staff, but the database also includes a limited number of surveys conducted by other agencies and organizations. These data are used to support annual waterbody condition assessments in concordance with state and federal requirements (MPCA 2012, MPCA 2014a, Figure 3).

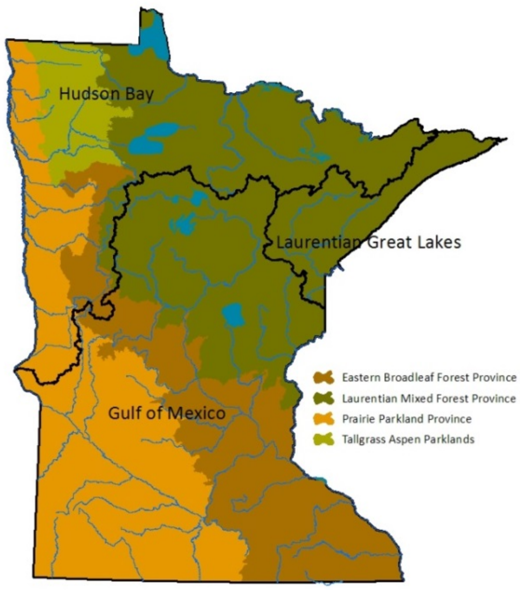

Figure 2. Map of Minnesota depicting major ecotypes (MnDNR Ecological Classification System Provinces), continental watersheds, major rivers and large lakes.

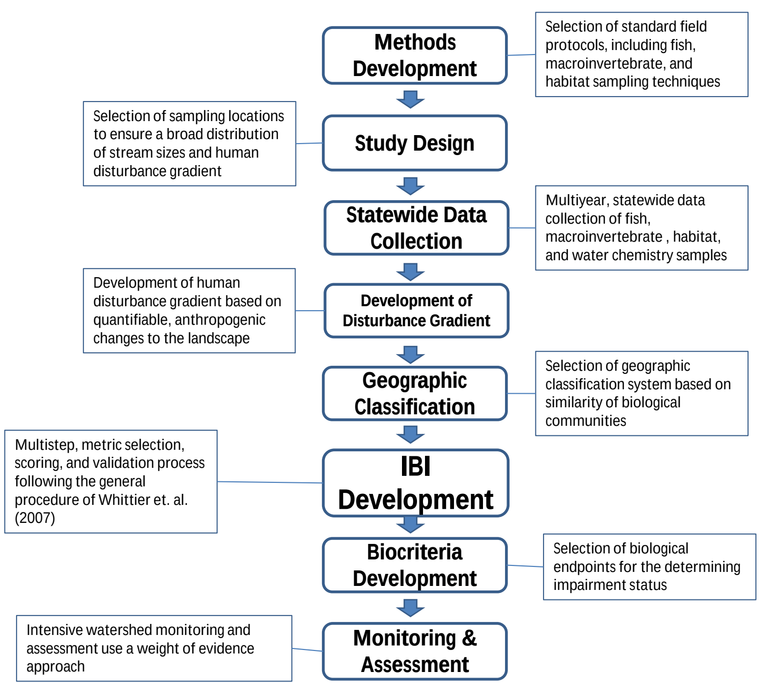

Figure 3. Overview of biological data use by Minnesota Pollution Control Agency.

3.3. Field methods

All fish community surveys were conducted using electrofishing techniques during daylight hours under base-flow conditions (generally early June to late September). Crews followed the MPCA's Fish Community Sampling Protocol for Stream Monitoring Sites (Feist 2011). Field methods of partnering agencies (e.g., MnDNR, United States Geological Survey) may have differed, but non-MPCA data was added to the database if methods were deemed similar. Electrofishing distance was typically 35 times mean stream width (at baseflow), with a minimum of 150m for sites less than 4m wide and a maximum of 500m for sites greater than 14m wide.

Fishes were collected using a variety of gear types, depending primarily upon stream width and depth. Backpack electrofishing units with a single anode and single netter were typically used in wadeable streams up to 8m wide. Larger wadeable streams were sampled using a two-anode/two-netter barge-type electrofishing platform ("stream shocker"). Non-wadeable sites were sampled using a boat electrofisher; a single-anode/single-netter jonboat platform ("mini-boom") was used for small or hard to access sites, while a larger two-anode/two-netter boat platform ("boom shocker") was used for large, accessible rivers. Single-pass upstream surveys were used at wadeable sites. Boat electrofishing proceeded in a downstream direction, either a single pass while weaving back and forth into different habitat types (mini-boom) or three separate runs (left bank, right bank, mid-channel) in larger rivers (boom shocker). Regardless of gear type, no physical barriers were deployed to prevent upstream or downstream movement of fishes during the course of the survey.

All fishes greater than 25mm total length were sorted and identified to the species level in the field, with a count, batch weight, and minimum/maximum total length recorded for each species. Small or difficult specimens were often preserved for later identification in a lab setting. Any deformities, eroded fins, lesions, or tumors were noted. Two voucher specimens of each species captured were confirmed and archived by the University of Minnesota's Bell Museum of Natural History. In cases where no small specimens of a species were captured, field identifications were later verified using photographs of distinguishing features (e.g., mouth, fins and caudal peduncle scales for *Moxostoma spp.*).

3.4. Human Disturbance Score

A composite Human Disturbance Score (HDS) was developed to represent potential cumulative anthropogenic disturbance experienced by stream environments, assessed at both a reach- and watershed-scale (MPCA 2014b). The disturbance metrics selected for inclusion in the HDS are grounded in the concept of a "Generalized Stressor Gradient" (USEPA 2005), and are evaluated on a site-by-site basis, using readily-available statistics on land use, feedlot and point source density and proximity, reach- and watershed-scale channelization, impervious surfaces, road density, and riparian conditions (Table 2). Eight primary metrics are individually scored on a 0 (highly disturbed) to 10 (minimally disturbed) scale and summed to derive a composite score. Metric scores represent rescaled (0-10) values for each stressor variable, after excluding values greater or less than three times the interquartile range. Up to seven additional "adjustment" metrics are then applied, each of which potentially deducts one point from the composite score. One of the adjustment metrics (watershed road density) may also result in the addition of a point. The final, composite Human Disturbance Score ranges from a minimum of 0 (highly disturbed) to a maximum of 81 (minimally disturbed). Negative composite scores are normalized to 0.

Table 2. Minnesota Pollution Control Agency Human Disturbance Score (HDS) metrics. Metrics are evaluated either at the scale of a site's contributing watershed, or the area immediately adjacent to the sampling location. Several categories of potential anthropogenic disturbance are included (e.g., land use, point sources, riparian condition, channelization). Eight "core metrics" are scored on a 0-10 scale, while six "adjustment" metrics may add or subtract a single point from the composite score.

HDS Metric Description	Scale	Category	Scoring Range
animal unit density	watershed	land use	0-10
percent agricultural land use	watershed	land use	0-10
percent impervious surface	watershed	land use	0-10
feedlot density	watershed	land use	-1
percent agricultural land use within 100m riparian buffer	watershed	land use	-1
road/stream intersection (road crossing) density	watershed	land use	-1 or +1
percent agricultural land use on ≥3% slope	watershed	land use	-1
urban land use proximity	local	land use	-1
point source density	watershed	point source	0-10
point source proximity[1]	local	point source	-1
feedlot proximity	local	point source	-1
percent disturbed riparian habitat	watershed	riparian	0-10
riparian condition rating	local	riparian	0-10
percent of stream distance modified by channelization	watershed	channelization	0-10
site channelization rating	local	channelization	0-10

[1] applies only to streams with watershed area <50 square miles

3.5. Stream classification

Recognizing that biological communities vary along natural gradients, an effort was undertaken to develop a stream classification framework for Minnesota's riverine fish communities. The goal was to identify natural variables that effectively separated sites into physiographic classes such that the fish community structure was similar among sites within each class, while at the same time distinct from sites in other classes. We considered natural classification variables unaffected by anthropogenic disturbance (e.g., watershed area, stream gradient) to ensure that sites would be classified according to their natural potential rather than by their current state. For example, stream nutrient levels were not considered as a classification variable, because nutrients may be derived from both natural and anthropogenic sources, and ambient levels may reflect anthropogenic disturbance as much or more than natural background. Candidate classification variables included both broad-scale and local variables to encompass the important natural drivers of stream fish community structure.

Stream classification was carried out separately for warm- and coldwater streams. Distinction between the two thermal classes was largely based on whether a site was located on an MnDNR Designated Trout Stream, but consideration was given to whether coldwater fish species (e.g., trout, sculpin) were present or known to have been present in the past. As a result, some sites on Designated Trout Streams were excluded from the Coldwater dataset, and vice-versa. Within each dataset (warmwater, coldwater), a set of least-disturbed sites was identified based on the 75th percentile threshold of the HDS distribution. Reach-scale habitat conditions were used to further refine the selection process in a limited number of cases. Classification analyses were carried out using both the least-disturbed dataset and the full dataset of all sites. While more emphasis was placed on patterns emerging from the least-disturbed dataset, the entire dataset was analyzed in a similar manner to provide supplementary information.

A variety of analytical techniques and statistical tools was used to partition variability in fish community structure into distinct stream classes and evaluate various candidate classification frameworks. For both the "All Sites" and "Least Disturbed" datasets, both presence-absence and relative abundance matrices of fish species observed at each site was analyzed using hierarchical cluster analysis (PC-Ord, Flexible β, β=-0.25). Hierarchical cluster analysis is a method for defining groups of objects such that objects within each group are more similar to each other and less similar to objects in other groups; results are often depicted as a dendrogram. Each dataset was clustered into as many as 15 and as few as 2 "species groups." Following the assignment of sites to species groups, sites were mapped using Geographic Information System software and color-coded by group membership. Sites were color-coded at each level of clustering (from 2 to 15 clusters) and the spatial arrangement of clusters was examined to detect obvious geographic patterns. Summary statistics, distribution plots and box plots were then used to examine the distribution of natural variables (e.g., watershed area, stream gradient, latitude, longitude) for sites comprising each cluster. Ordination (PC-Ord, Non-Metric Multidimensional Scaling) was used to visualize the relative similarity of different clusters, as well as the orientation of environmental gradients and existing regional classification frameworks (e.g., Omernik Ecoregions, MnDNR Ecological Classification System Provinces, HUC4 watersheds) among species clusters. Mean Similarity Analysis (MEANSIM, Van Sickle 1998) was used to evaluate effectiveness of various classification frameworks in partitioning fish community structure variability. This approach determines the classification strength of groupings, evaluated as a combination of both within-class and between-class dissimilarity. Selection and analysis of classification frameworks proceeded in an iterative manner, with candidate variables tested at different levels of partition and in combination with other variables.

While a large number of classes may produce a strong classification, a smaller number of classes might be preferable, given the intended use for the framework. Dozens of classes would likely result in identification of highly localized assemblages and be generally difficult to implement in a bioassessment setting. Fewer classes are preferable, assuming criteria can be identified to separate the dataset into sufficiently distinct and homogenous groups. To compare effectiveness of frameworks containing different numbers of classes, classification strength was calculated at each level of hierarchical clustering based on neutral model classifications (i.e., fish community structure alone) to represent a theoretical optimum to which environmental frameworks with an equivalent number of classes could be compared (Van Sickle and Hughes 2000). For example, classification strength for a 5-class environmental framework would be divided by the classification strength of a 5-cluster grouping of the fish community dataset, and expressed as a percentage of the "optimum." In this manner, marginal increases in classification strength achieved simply by adding classes could be objectively evaluated with respect to the increased complexity also introduced to the classification system.

Ultimately, a classification framework was developed that divides lotic sites into nine "fish classes," differentiated by region, drainage area, gradient, and thermal regime (Figure 4, Appendix A). An IBI was developed for each individual fish class, while keeping open the possibility of combining classes if obvious similarities emerged during the metric evaluation process.

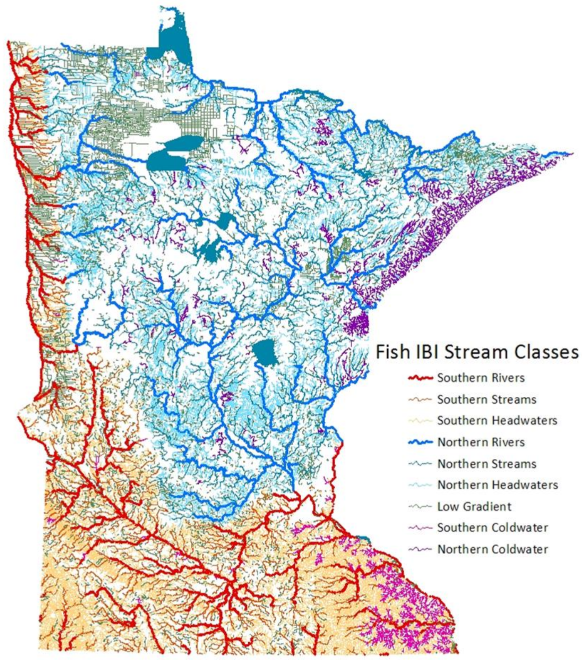

Figure 4. Generalized map of Fish IBI stream classes for the State of Minnesota. For display purposes, reach-specific fish class assignments were derived from the NHD+ spatial dataset. Map is for display purposes only; classification of individual sampling locations should utilize site-specific attributes as outlined in Appendix A.

3.6. IBI development dataset

Warmwater streams were prioritized for IBI development because they make up the vast majority (>90%) of Minnesota's stream miles and a sufficient dataset had been established by 2009. Coldwater streams make up less than 10% of Minnesota's stream miles, and preliminary evaluation of existing data in 2009 indicated that additional, targeted sampling was required to assemble a suitable IBI development dataset. The definition of "warmwater stream" used in this analysis encompassed all non-coldwater streams, including some that might be properly classified as "coolwater." Warmwater IBI development began in 2009 and was completed in early 2010; coldwater IBI development began following supplemental field sampling carried out in the summer of 2010, and was completed in early 2011.

The warmwater IBI development dataset consisted of 1,563 sites and 1,918 samples collected between 1990 and 2008 (Figure 5a). Fish sampling was conducted in the course of multiple projects, and included both randomly-located and targeted surveys. In cases where multiple samples were collected from the same site, the fish taxa abundance data were averaged. Sites with within-year repeat visits (n=146) were identified for use in evaluating metric precision.

The coldwater IBI development dataset consisted of 367 sites sampled between 1996 and 2010 (Figure 4b); in cases where multiple samples were collected from the same site, the most recent sample was used. Sites with within-year repeat visits (n=94) were identified for use in evaluating metric precision. Fish sampling was conducted in the course of multiple projects, and included both randomly-located and targeted surveys.

Two-thirds of the sites within each stream class were selected to serve as an IBI development dataset; the remaining one-third was reserved as a validation dataset. Within each dataset (development and validation), sites were sorted into disturbance categories defined by quartile boundaries of the Human Disturbance Score (HDS) for each class. "Least-disturbed" sites were defined as those with an HDS above the 75^{th} percentile for a particular class; "most-disturbed" sites were defined as those with an HDS below the 25^{th} percentile for a particular class.

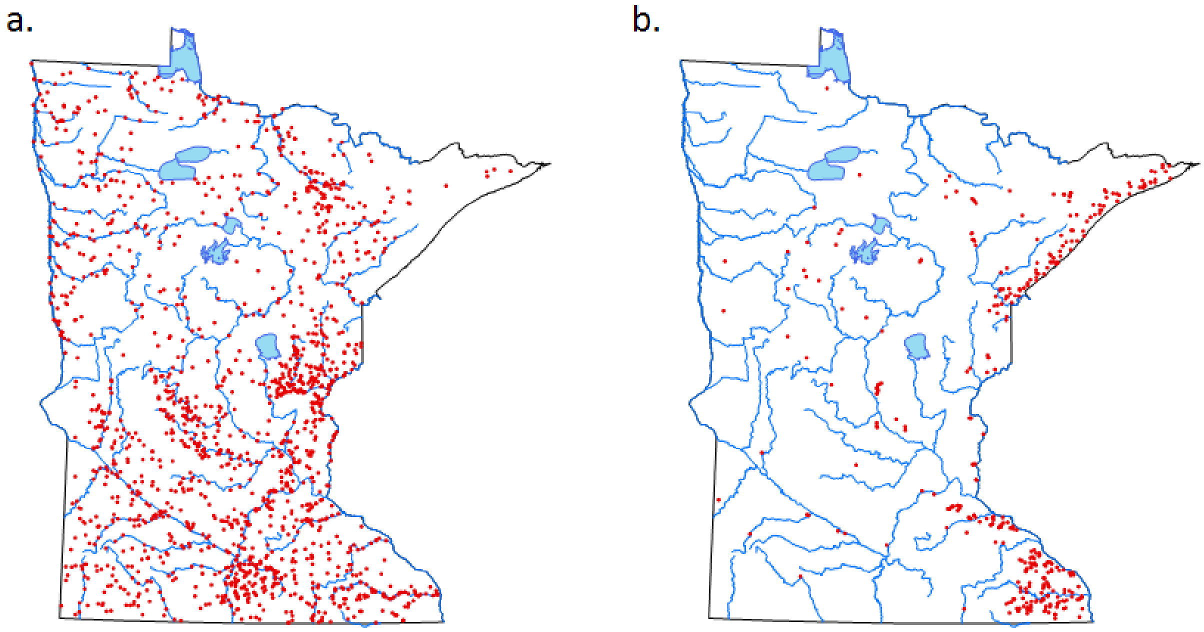

Figure 5. Maps of (a) warmwater and (b) coldwater stream monitoring sites used to develop F-IBI for the State of Minnesota. Large lakes and major rivers are also depicted.

3.7. Species characteristics

The IBI development process relies upon commonalities between fish species and combines them into groups related to their taxonomy, morphometry, behavior, habitat requirements, and life history traits. This type of trait-based approach groups species that experience their environment in a similar fashion, and emphasizes the functional structure of fish communities (Karr and Chu 1999). A variety of published and non-published sources were used to assign trophic, reproductive, habitat, tolerance, and life history traits to fish species known to inhabit Minnesota's rivers and streams (Balon 1975, Pflieger 1975, Becker 1983, Lyons 1992, Barbour et al. 1999, Etnier and Starnes 1999, Goldstein and Meador 2004, Frimpong and Angermeier 2009). We also used a weighted-averaging process (Meador and Carlisle 2007) to calculate species-specific tolerance values for both individual stressors (e.g., nutrients, turbidity, dissolved oxygen, habitat characteristics) and HDS. These data were used to refine existing tolerance attributes that were derived from the literature.

3.8. Metric evaluation

For warmwater streams, 240 candidate metrics were calculated from fish community data, utilizing the species characteristics database described above. The coldwater IBI development effort included an additional twelve metrics for a total of 252 (Appendix B). Metrics were summarized in three ways (taxa richness, relative taxa abundance, and relative taxa richness), and were assigned to one of seven metric classes (taxa richness, composition, tolerance, life history, habitat, reproductive, trophic), intended to represent different components of biotic integrity. Abundance of two schooling species (*Notropis atherinoides*, *Dorosoma cepedianum*) was excluded from relative taxa abundance metrics due to the tendency of these species to naturally occur in large numbers such that proportions of other taxa may be heavily skewed, depending on whether a school is encountered while sampling. While other species are known to occur in schools (e.g., *Cyprinella spiloptera*, *Luxilus cornutus*), catches of *N. atherinoides* and *D. cepedianum* were often two to three orders of magnitude larger than other taxa in the same assemblage, a unique situation which justified their exclusion from relative taxa abundance metrics.

To develop each stream-class IBI we evaluated metrics using a series of tests, following the general procedure of Whittier et al.(2007). Metrics were tested, eliminated or selected, and scored separately within each of the nine stream classes using the same methodology throughout. The IBI development dataset was used for each test unless otherwise noted.

3.8.1 Range test and metric transformation

Metrics with poor range are unlikely to differentiate disturbed and non-disturbed sites because the response gradient is highly compressed. We eliminated richness metrics if the range was less than three species and eliminated any metric if more than 75% of the values were identical.

In cases where the distribution of metric values within a class was highly skewed, transformation was used to normalize the data (or reduce skew). Several transformations were considered, including: log10, natural log, square root, and arcsine square root. Metrics were not automatically rejected if a normal distribution could not be achieved. In general, we attempted to reduce absolute skew values to less than 1 through transformation. The metric scoring process (described below) also reduced skewness in most cases.

3.8.2. Natural gradient metric correction

The classification of sites into nine different stream classes minimized the influence of natural gradients on metric response. However, we also evaluated each metric against natural gradients within each class to further ensure that metric response was not obscured or amplified. To minimize the potentially covarying effect of human disturbance, natural gradient relationships were evaluated using the subset of least-disturbed sites within each class. We used simple linear regression to evaluate the relationship between metric values, watershed area, and stream gradient, examined plots of the data points, and calculated correlation coefficients for the relationship. For metrics where a significant ($p \leq 0.05$) relationship existed and the correlation coefficient (R^2) was greater than 0.3 we derived a natural-gradient corrected metric by calculating the residual based on the regression equation. The residual then replaced the original metric value in the IBI development process (Figure 6). Calibration and validation datasets were combined to test whether natural gradient correction was necessary.

3.8.3. Responsiveness Test

To test metric responsiveness to human disturbance, we used the non-parametric Mann-Whitney U test to evaluate the difference between metric values at least- and most-disturbed sites. The magnitude of the Mann-Whitney p-value was used to gauge responsiveness, essentially the ability of a metric to distinguish least-disturbed sites from most-disturbed sites. Spearman rank correlation between metric values and HDS was also used to evaluate metric responsiveness, primarily by ranking metrics with similar p-values according to their Spearman r_s value. Finally, box plots of metric values within each disturbance quartile were also used to visually assess metric responsiveness. Non-responsive metrics (i.e., those with non-significant *U*-statistics at the p=0.05 level) were eliminated from the candidate metric pool. The validation dataset was used to confirm the responsiveness of metrics with significant Mann-Whitney p-values; if a metric's validation dataset produced a non-significant difference, it was eliminated. In a few cases, metrics at or near the responsiveness threshold were allowed to pass the test if a strong conceptual rationale existed for inclusion. IBI development and validation datasets were evaluated separately, and metrics were considered responsive if they passed this test for both datasets within a class.

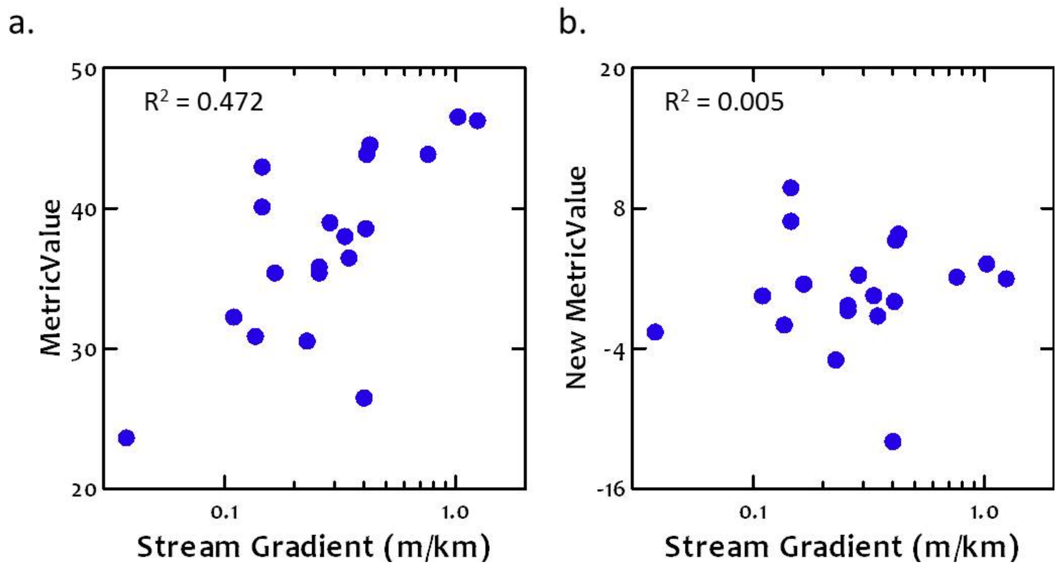

Figure 6. Example of metric value relationships with a natural gradient before and after correction. Metric value is Sensitive Taxa Percentage in the Northern Rivers F-IBI class. Raw metric values (a) demonstrate a positive relationship with stream gradient. Replacing metric values with the residual values from a simple linear regression (b) eliminates the natural gradient relationship.

3.8.4. Signal-to-Noise Test (S:N)

Precision of metric values can be evaluated by comparing variance among sites ("signal") to variance within sites ("noise") (Kaufmann et al. 1999). This statistic was calculated using the subset of sites that were sampled twice within the index period of the same year. This type of "repeat" sampling is a normal component of the MPCA's monitoring design; approximately 10% of monitoring sites are sampled twice each year, with an attempt made to distribute repeat sampling events evenly across the spatial extent and stream characteristics encompassed by a particular year's monitoring effort.

Low “signal-to-noise” ratios indicate low-precision metrics that are unable to distinguish well among sites (Kaufman et al. 1999, Whittier et al. 2007). While few well-established guidelines exist for evaluating S:N ratio, some researchers have suggested that signal-to-noise ratios greater than 3 characterize sufficiently precise data (Kaufmann et al. 1999). However, we used a conservative approach in evaluating metric precision, calculating S:N on a statewide basis rather than individually within each class. As a result, we utilized a slightly lower S:N threshold, where metrics with a ratio value less than 2 were eliminated from the candidate metric pool. In a few cases, metrics with S:N values slightly below 2 were allowed to “pass” this test if a strong conceptual basis existed for inclusion.

3.8.5. Metric redundancy

A correlation matrix of metric values was created to examine metric redundancy and avoid selecting IBI metrics that contained redundant information. We evaluated redundancy using the subset of least-disturbed sites within each class, to avoid rejecting metrics simply because their response to disturbance was similar. We also evaluated metric redundancy using all sites, regardless of disturbance level, but more emphasis was given to correlations in the least-disturbed dataset. In general, we considered metrics to be redundant when their Spearman correlation coefficients were greater than 0.7. However, “conceptual redundancy” was also considered in cases where the Spearman coefficient approached the threshold; metrics were sometimes included despite Spearman correlations greater than 0.7 if we considered them to represent distinct components of biological integrity, and sometimes rejected despite Spearman correlations less than 0.7 if we considered them to be conceptually redundant.

Within each class, metrics that passed the Range, Signal-to-Noise, and Responsiveness tests were ranked by their Responsiveness p-value (most responsive to least responsive). Metrics were selected for inclusion in the IBI in order of descending responsiveness, provided they were not redundant with more-responsive metrics. To obtain representation across the seven metric classes, a maximum of two non-redundant metrics from any single metric class was chosen until each class was represented by at least one metric. In some cases, it was not possible to select a metric from each metric class, due either to a lack of metrics passing earlier tests, or redundancy with highly-responsive metrics.

3.8.6. Range of metric scores

In cases where box plots and scatter plots indicated that a majority of sites within a class would receive the same metric score regardless of disturbance level, the metric was rejected. When metrics were eliminated by this test, we returned to the metric selection process described in the previous step and replaced it with the next most responsive metric.

3.8.7. Metric scoring

Each selected metric was scored on a continuous scale from 0 to 10 (with some exceptions, see below). Maximum and minimum values for each metric were defined as the 5^{th} and 95^{th}, or 10^{th} and 90^{th} percentile observed across all sites within each class. Southern Rivers, Southern Streams, Southern Headwaters, Southern Coldwater, and Northern Coldwater were scored using the $5^{th}/95^{th}$ threshold values. Northern Rivers, Northern Streams, and Northern Headwaters were scored using the $10^{th}/90^{th}$ threshold values. The two slightly different approaches resulted from an observation that few sites in the Northern Rivers, Northern Streams, and Northern Headwaters classes were achieving composite IBI scores near the theoretical minimum and maximum values. This may have occurred due to the generally high quality of sites in northern Minnesota, such that any given site was unlikely to achieve the maximum score for multiple metrics.

For positive metrics (those that decrease with disturbance), values less than the defined minimum were given a score of 0; those with values greater than the defined maximum were given a score of 10. Metric values between the minimum and maximum values were scored based on linear interpolation. Negative metrics (those than increase with disturbance) were scored in the same manner, with the minimum defined as the 95^{th} or 90^{th} percentile value and the maximum defined as the 5^{th} or 10^{th} percentile value. Metrics that passed all tests but still exhibited a skewed distribution of metric scores were scored discretely. These metrics typically received scores of 0, 5, or 10 depending on breakpoints in metric score distributions. Metric scores were summed within each class, and the resulting value re-scaled to a 0-100 range (multiplied by 10, divided by the number of metrics within each index).

Very low catch rates, either in terms of number of individuals or number of taxa, are generally indicators of severe degradation in permanent, warm- and coolwater Minnesota streams (Niemela and Feist 2000). In these special cases the presence of a few individuals may artificially inflate the IBI score and possibly mask a serious impairment. This is particularly concerning for proportional metrics (individual percentage and taxa percentage), where very low counts of “non-tolerant” individuals may result in extremely high metric scores for negative metrics. To address this issue, we implemented “Low End Scoring” criteria, under which individual percentage metrics in non-coldwater IBIs received a score of 0 when fewer than 25 individuals were captured, and taxa richness and taxa percentage received a score of 0 when fewer than 6 taxa were captured. Low End Scoring taxa richness and taxa percentage metric adjustments were applied to the Southern Rivers, Southern Streams, Northern Rivers and Northern Streams IBIs. Because fish assemblages of small, perennial headwaters may be relatively depauperate under natural conditions, the Low End Scoring threshold for taxa richness and taxa percentage metrics in Northern Headwaters, Southern Headwaters, and Low Gradient IBIs was reduced to fewer than 4 taxa. Low End Scoring criteria were not applied to Southern Coldwater and Northern Coldwater IBIs because these systems may exhibit extremely low taxa richness or number of individuals under natural, undisturbed conditions.

Each IBI was evaluated for overall responsiveness and correlation with natural gradients, using ANOVA and Pearson correlation. Sensitivity analysis was used to determine whether removal of individual metrics would dramatically improve overall responsiveness of the index or reduce correlation with natural gradients. If major improvement in these parameters was observed following temporary exclusion of one or more metrics, they were considered for permanent removal from the index.

4. Results

Within each class, a set of robust metrics was selected for inclusion in a final, class-specific IBI. The number of metrics in any given IBI ranged from seven to twelve (Table 3), but most included at least nine metrics. Each IBI included a combination of metrics that increase with disturbance (negative metrics) and metrics that decrease with disturbance (positive metrics), though some IBIs were more heavily weighted towards one or the other. Trophic and Tolerance metrics were utilized most frequently, Life History and Habitat metrics least frequently. The IBIs generally included greater proportions of Individual Percentage and Taxa Percentage metrics and fewer Taxa Richness metrics. Taxa Richness metrics were relatively uncommon; four of the nine IBIs featured only a single richness metric and the Northern Rivers IBI lacked richness metrics completely. A “total taxa count” metric (i.e., overall taxa richness) was not included in any class-specific IBI. In contrast, taxa percentage and individual percentage metrics demonstrated widespread effectiveness in distinguishing least- from most-disturbed sites. Four different IBIs each included four taxa percentage metrics, and each IBI included at least two. Individual percentage metrics were even more commonly-used, with each IBI including at least three and one IBI (Northern Rivers) included seven. A Catch-Per-Unit-Effort (CPUE) metric (number of individuals per meter, excluding Tolerant species) was included in both the Northern Headwaters and Low Gradient IBIs.

In most cases, a few effective metrics were excluded from the final IBI due to the earlier selection of more robust metrics from the same category, or quantitative/conceptual redundancy with more robust candidates. In addition, the “FishDELTPct” metric (see Appendix C for metric descriptions) was included in each IBI, and the “DomTwoPct” was included in the Southern Rivers, Southern Streams, Northern Rivers, and Northern Streams IBIs. These metrics failed to pass one or more tests, but were included due to their conceptual importance as indicators of severe environmental stress (Sanders et al.1999). The FishDELTPct metric was scored discretely based on the assumption that this metric is most responsive at the highly disturbed end of the spectrum. Two other metrics (Northern Rivers: ExoticPct, Southern Coldwater: HerbvPct) were scored discretely due to a highly skewed distribution of metric scores that could not be adequately corrected through transformation. Among all metrics included in the final class-specific IBIs, four required log transformation, and nine were adjusted for natural gradients (4 for watershed area, 5 for stream gradient).

Within each class, F-IBI scores differed between least- and most-disturbed sites (Table 4, Figure 7). Correlations between F-IBI scores and HDS were generally strong, while correlations between IBI scores and natural gradients (watershed area and stream gradient) were generally weak to moderately-strong (Table 5).

Table 3. Summary of metric count, trait category, metric type, and response type for each Fish IBI.

		Trait Category						Type				Response	
FishClass	number of metrics	Composition	Habitat	Life History	Reproductive	Tolerance	Trophic	CPUE	Individual Percent	Taxa Richness	Taxa Percent	Positive	Negative
Southern Rivers	12	2	1	1	2	2	4		6	2	4	4	8
Southern Streams	9	2		1	1	3	2		4	1	4	2	7
Southern Headwaters	7	1		1	1	2	2		3	1	3	1	6
Northern Rivers	11	3	1		3	2	2		7		4	4	7
Northern Streams	12	3			3	3	3		6	2	4	6	6
Northern Headwaters	11	4	1	1	1	2	2	1	3	4	3	8	3
Low Gradient	10	3	2	1	1	2	1	1	3	3	3	6	4
South Coldwater	8	1	2	1		2	2		5	1	2	3	5
North Coldwater	9	2	1	1	1	3	1		5	1	3	3	6
Grand Total		21	8	7	13	21	19	2	42	15	30	37	43

Table 4. Analysis of variance results testing for difference in F-IBI scores between least- and most-disturbed sites within each Fish IBI class.

FishClass	F-Ratio	Error df	R^2	p-Value
Southern Rivers	60.3	89	0.404	<0.001
Southern Streams	43.1	142	0.233	<0.001
Southern Headwaters	13.8	124	0.100	<0.001
Northern Rivers	75.2	53	0.587	<0.001
Northern Streams	92.1	118	0.438	<0.001
Northern Headwaters	180.8	148	0.550	<0.001
Low Gradient	106.7	84	0.560	<0.001
Southern Coldwater	43.6	92	0.321	<0.001
Northern Coldwater	76.9	136	0.361	<0.001

Table 5. Pearson correlation coefficients for F-IBI versus Human Disturbance Score (HDS), watershed area, and stream gradient within each Fish IBI class.

FishClass	HDS	watershed area	stream gradient
Southern Rivers	0.521	0.407	-0.075
Southern Streams	0.385	0.197	0.249
Southern Headwaters	0.238	0.140	0.142
Northern Rivers	0.731	0.346	0.089
Northern Streams	0.599	0.133	0.275
Northern Headwaters	0.649	0.252	-0.069
Low Gradient	0.665	0.150	0.074
Southern Coldwater	0.184	-0.164	0.344
Northern Coldwater	0.557	-0.038	0.561

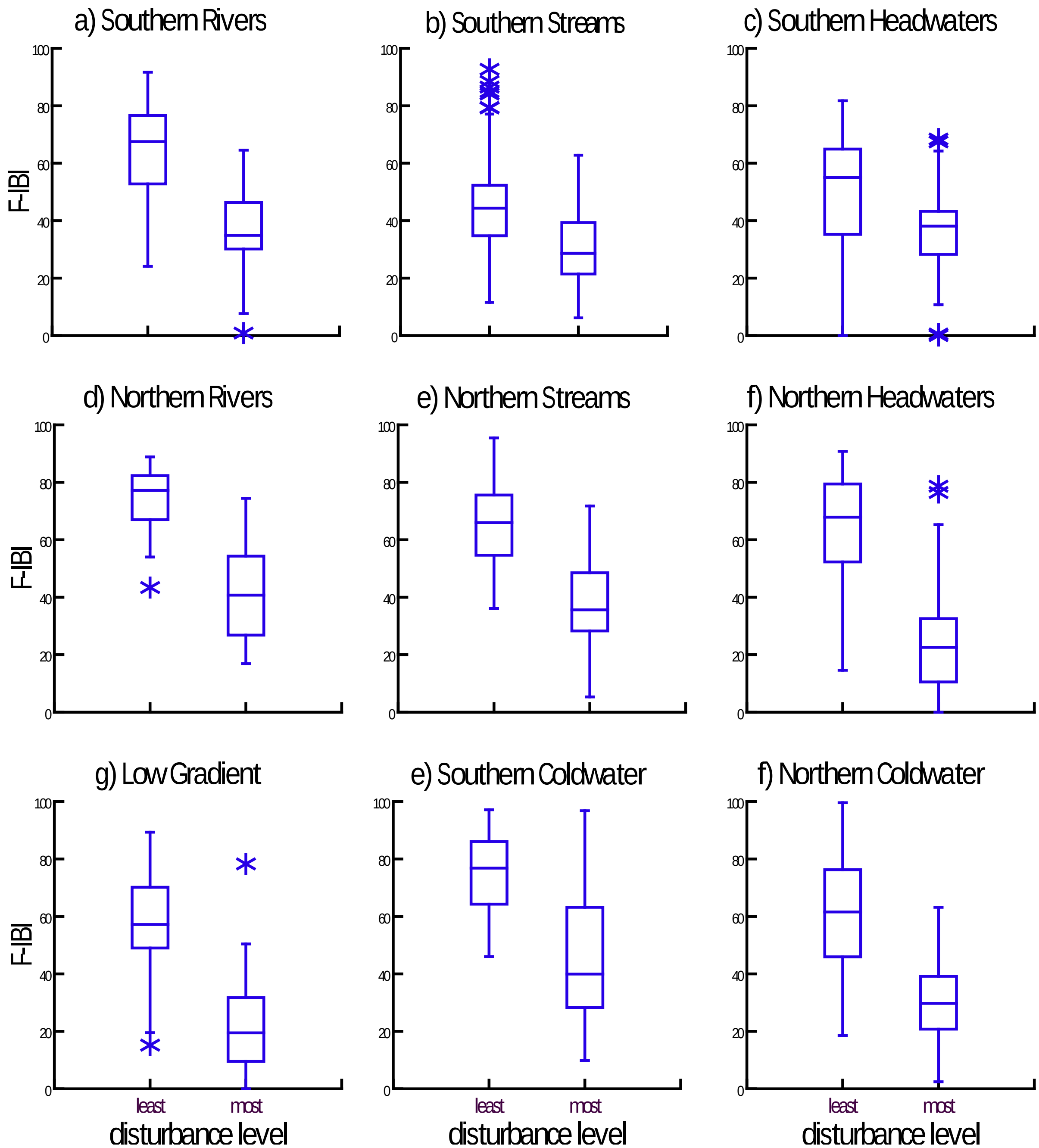

Figure 7. Boxplots of F-IBI scores among least- and most-disturbed sites within each fish class. Top edge, middle line, and bottom edge of boxes represent 75th, 50th, and 25th percentile values, respectively. Tails represent 1.5 times the interquartile range. Asterisks represent values between 1.5 and 3 times the interquartile range. All class-specific differences in F-IBI scores are significant (p<0.001).

4.1. Southern Rivers

Table 6. Metrics selected for the Southern Rivers F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Insectivore-Tol_Pct	IndPct	Percent insectivorous individuals (excludes tolerant species)	trophic	positive	<0.001	4.01	12.01	82.00
SimpleLithophil[1]	Richness	Simple lithophilic taxa	reproductive	positive	<0.001	7.84	-6.71	2.59
GeneralistFeeder_Pct	IndPct	Percent generalist feeder individuals	trophic	negative	<0.001	4.42	5.64	64.72
VeryTolerant_TxPct	TXPct	Percent very tolerant taxa	tolerance	negative	<0.001	2.11	5.04	33.33
SerialSpawner_TxPct	TXPct	Percent serial spawner taxa	reproductive	negative	<0.001	2.20	14.40	38.04
Tolerant_Pct	IndPct	Percent tolerant individuals	tolerance	negative	<0.001	9.23	5.38	82.30
ShortLived_Pct	IndPct	Percent short-lived individuals	life history	negative	0.001	3.43	0.83	60.10
Sensitive_TxPct[1]	TXPct	Percent sensitive taxa	tolerance	positive	0.002	6.58	-23.59	15.82
Detritivore_TxPct	TXPct	Percent detritivorous taxa	trophic	negative	0.002	2.66	15.38	41.62
Piscivore	Richness	Piscivorous taxa	trophic	positive	0.011	5.22	1.00	7.90
DominanceTwoTaxa_Pct[2]	IndPct	Combined relative abundance of the two most abundant taxa	composition	negative			30.39	75.00
FishDELT_Pct[3]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric scoring adjusted for stream gradient

[2] metric included based on conceptual importance

[3] metric included based on conceptual importance, scored discretely

A total of 60 metrics failed either the Range or Signal-to-Noise Test in the Southern Rivers class. Twenty-four metrics showed significant relationships with either watershed area or stream gradient and were replaced by natural gradient-corrected metrics. The Responsiveness Test eliminated an additional 91 non-responsive metrics, leaving a total of 86 metrics that met all testing criteria. Twelve metrics spanning five metric categories were selected for inclusion in the final Southern Rivers F-IBI (Table 5). Two F-IBI metrics were included based on their conceptual importance, and two required adjustment for stream gradient. We observed a strong correlation between F-IBI and HDS, a moderate correlation between F-IBI and watershed area, and a weak correlation between F-IBI and stream gradient (Table 4). “Low End Scoring” criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 6 taxa are captured.

4.2. Southern Streams

Table 7. Metrics selected for the Southern Streams F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
BenthicInsectivore-Tol_TxPct	TXPct	Percent benthic insectivore taxa (excludes tolerant species)	trophic	positive	<0.001	3.64	0.00	40.00
Sensitive_TxPct	TXPct	Percent sensitive taxa	tolerance	positive	<0.001	6.58	0.00	45.11
Detritivore_TxPct	TXPct	Percent detritivorous taxa	trophic	negative	<0.001	2.66	14.13	46.38
ShortLived	Richness	Short-lived taxa	life history	negative	<0.001	3.06	1.00	7.00
Tolerant_TxPct	TXPct	Percent tolerant taxa	tolerance	negative	<0.001	5.55	27.99	84.81
MatureAge<2_Pct	IndPct	Percent early-maturing individuals	reproductive	negative	<0.001	2.74	29.68	97.68
Tolerant_Pct	IndPct	Percent tolerant individuals	tolerance	negative	0.060	9.23	27.93	75.00
DominanceTwoTaxa_Pct[1]	IndPct	Combined relative abundance of the two most abundant taxa	composition	negative			34.00	75.00
FishDELT_Pct[2]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance

[2] metric included based on conceptual importance, scored discretely

A total of 76 metrics failed either the Range or Signal-to-Noise Test in the Southern Streams class. No metrics in this class required adjustment for natural gradients. The Responsiveness Test eliminated an additional 79 non-responsive metrics, leaving a total of 82 metrics that met all testing criteria. Nine metrics spanning five metric categories were selected for inclusion in the final Southern Streams IBI (Table 6). Two of these metrics were included based on their conceptual importance. The TolPct metric was included despite showing only moderately strong differences between least- and most-disturbed sites (Responsiveness p-value 0.06). The conceptual importance of the proportion of tolerant individuals, coupled with the high Signal-To-Noise ratio observed for this metric, justified its inclusion. We observed a moderate correlation between F-IBI and HDS, and weak correlations between F-IBI, watershed area, and stream gradient (Table4). "Low End Scoring" criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 6 taxa are captured.

4.3. Southern Headwaters

Table 8. Metrics selected for the Southern Headwaters F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Sensitive	Richness	Sensitive taxa	tolerance	positive	0.001	9.97	0.00	4.00
Detritivore_TxPct	TXPct	Percent detritivorous taxa	trophic	negative	0.002	2.66	0.00	50.00
GeneralistFeeder_TxPct	TXPct	Percent generalist feeder taxa	trophic	negative	0.010	3.79	31.92	76.53
SerialSpawner_Pct	IndPct	Percent serial spawner individuals	reproductive	negative	0.029	4.38	0.00	76.92
VeryTolerant_TxPct	TXPct	Percent very tolerant taxa	tolerance	negative	0.045	2.11	0.00	58.71
ShortLived_Pct	IndPct	Percent short-lived individuals	life history	negative	0.061	3.43	0.14	98.73
FishDELT_Pct[1]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance, scored discretely

A total of 63 metrics failed either the Range or Signal-to-Noise Test in the Southern Headwaters class. No metrics in the Southern Headwaters class required adjustment for natural gradients. The Responsiveness Test eliminated an additional 126 non-responsive metrics, leaving a total of 48 metrics that met all testing criteria. Seven metrics spanning four metric categories were selected for inclusion in the final Southern Headwaters IBI (Table 7). One of these metrics was included based on its conceptual importance. Southern Headwaters F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed weak correlations between F-IBI and HDS, watershed area, and stream gradient (Table 4). "Low End Scoring" criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 4 taxa are captured.

4.4. Northern Rivers

Table 9. Metrics selected for the Northern Rivers F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Sensitive_TxPct[1]	TXPct	Percent sensitive taxa	tolerance	positive	<0.001	6.58	-16.39	7.04
Sensitive_Pct[1]	IndPct	Percent sensitive individuals	tolerance	positive	<0.001	3.94	-33.70	17.75
Detritivore_Pct	IndPct	Percent detritivorous individuals	trophic	negative	<0.001	5.40	0.39	46.93
VeryTolerant_TxPct	TXPct	Percent very tolerant taxa	tolerance	negative	<0.001	2.11	0.00	20.00
Exotic_Pct[2]	IndPct	Percent exotic individuals	composition	negative	0.001	0.71		
SerialSpawner_TxPct	TXPct	Percent serial spawner taxa	reproductive	negative	0.001	2.20	8.70	29.22
Insectivore-Tol_Pct	IndPct	Percent insectivorous individuals (excludes tolerant species)	trophic	positive	0.006	4.01	28.94	74.99
NonLithophilicNester_Pct	IndPct	Percent non-lithophilic nest-building individuals	reproductive	negative	0.012	2.13	8.74	46.14
SimpleLithophil_TxPct	TXPct	Percent simple lithophilic taxa	reproductive	positive	0.015	1.67	26.28	48.32
DominanceTwoTaxa_Pct[3]	IndPct	Combined relative abundance of the two most abundant taxa	composition	negative	0.077	1.83	34.86	50.00
FishDELT_Pct[4]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric scoring adjusted for stream gradient

[2] metric scored discretely

[3] metric included based on conceptual importance

[4] metric included based on conceptual importance, scored discretely

A total of 54 metrics failed either the Range or Signal-to-Noise Test in the Northern Rivers class. Eighteen metrics showed significant relationships with either watershed area or stream gradient and were replaced by natural gradient-corrected metrics. The Responsiveness test eliminated an additional 134 non-responsive metrics, leaving a total of 52 metrics that met all testing criteria. Eleven metrics spanning five metric categories were selected for inclusion in the final Northern Rivers IBI (Table 8). Two metrics required adjustment for stream gradient, and two metrics were included based on their conceptual importance. Northern Rivers F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed a strong correlation between F-IBI and HDS, a moderate correlation between F-IBI and watershed area, and a weak correlation between F-IBI and stream gradient (Table 4). “Low End Scoring” criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 6 taxa are captured.

4.5. Northern Streams

Table 10. Metrics selected for the Northern Streams F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Sensitive_TxPct	TXPct	Percent sensitive taxa	tolerance	positive	<0.001	6.58	5.69	44.00
Intolerant_Pct	IndPct	Percent intolerant individuals	tolerance	positive	<0.001	3.51	0.00	41.98
Insectivore-Tol_TxPct	TXPct	Percent insectivorous taxa (excludes tolerant species)	trophic	positive	<0.001	3.36	26.12	50.50
MatureAge>3-Tol_Pct	IndPct	Percent late-maturing individuals (excludes tolerant species)	reproductive	positive	<0.001	6.25	0.00	34.09
GeneralistFeeder	Richness	Generalist taxa	trophic	negative	<0.001	3.50	2.20	7.00
SerialSpawner_TxPct	TXPct	Percent serial spawner taxa	reproductive	negative	<0.001	2.20	6.25	33.33
Detritivore_Pct	IndPct	Percent detritivorous individuals	trophic	negative	<0.001	5.40	1.01	38.98
VeryTolerant	Richness	Very tolerant taxa	tolerance	negative	<0.001	4.77	1.00	5.00
DarterSculpinSucker_TxPct	TXPct	Percent darter, sculpin, and sucker taxa	composition	positive	0.003	3.22	6.42	27.78
SimpleLithophil_Pct	IndPct	Percent simple lithophilic individuals	reproductive	positive	0.011	3.57	3.11	67.34
DominanceTwoTaxa_Pct[1]	IndPct	Combined relative abundance of the two most abundant taxa	composition	negative			37.64	50.00
FishDELT_Pct[2]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance

[2] metric included based on conceptual importance, scored discretely

A total of 70 metrics failed either the Range or Signal-to-Noise Test in the Northern Streams class. No metrics in this class required adjustment for natural gradients. The Responsiveness Test eliminated an additional 76 non-responsive metrics, leaving a total of 91 metrics that met all testing criteria. Twelve metrics spanning five metric categories were selected for inclusion in the final Northern Streams IBI (Table 9). Two of these metrics were included based on their conceptual importance. Northern Streams F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed a strong correlation between F-IBI and HDS, a weak correlation between F-IBI and watershed area, and a moderate correlation between F-IBI and stream gradient (Table 4). "Low End Scoring" criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 6 taxa are captured.

4.6. Northern Headwaters

Table 11. Metrics selected for the Northern Headwaters F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Sensitive	Richness	Sensitive taxa	tolerance	positive	<0.001	9.97	0.00	4.00
Minnow-Tol_Pct	IndPct	Percent cyprinid individuals (excludes tolerant species)	composition	positive	<0.001	2.50	0.00	51.48
Insectivore-Tol_TxPct	TXPct	Percent insectivorous taxa (excludes tolerant species)	trophic	positive	<0.001	3.36	0.00	42.87
NumPerMeter-Tol	CPUE	Number of fish per meter (excludes tolerant species)	composition	positive	<0.001	2.00	0.01	1.82
InsectivorousCyprinid_Pct	IndPct	Percent insectivorous cyprinid individuals	trophic	positive	<0.001	2.27	0.00	20.85
HeadwaterSpecialist-Tol	Richness	Headwater taxa (excludes tolerant taxa)	habitat	positive	<0.001	6.88	0.00	3.00
DarterSculpin	Richness	Darter and sculpin taxa	composition	positive	<0.001	3.57	0.00	2.00
SimpleLithophil	Richness	Simple lithophilic taxa	reproductive	positive	<0.001	7.84	0.00	4.28
Tolerant_TxPct	TXPct	Percent tolerant taxa	tolerance	negative	<0.001	5.55	33.33	80.00
Pioneer_TxPct	TXPct	Percent pioneer taxa	life history	negative	0.002	2.97	10.00	33.33
FishDELT_Pct[1]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance, scored discretely

A total of 73 metrics failed either the Range or Signal-to-Noise Test in the Northern Headwaters class. No metrics in the Northern Headwaters class required adjustment for natural gradients. The Responsiveness Test eliminated an additional 75 metrics, leaving a total of 89 metrics that met all testing criteria. Eleven metrics spanning seven metric categories were selected for inclusion in the final Northern Headwaters IBI (Table 10). One metric was included based on its conceptual importance. Northern Headwaters F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed a strong correlation between F-IBI and HDS, a moderate correlation between F-IBI and watershed area, and a weak correlation between F-IBI and stream gradient (Table 4). "Low End Scoring" criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 4 taxa are captured.

4.7. Low Gradient

Table 12. Metrics selected for the Low Gradient F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Minnow-Tol_Pct	IndPct	Percent cyprinid individuals (excludes tolerant species)	composition	positive	<0.001	2.50	0.00	52.29
Wetland-Tol	Richness	Wetland taxa (excludes tolerant species)	habitat	positive	<0.001	2.03	0.00	4.10
Sensitive	Richness	Sensitive taxa	tolerance	positive	<0.001	9.97	0.00	4.00
NumPerMeter-Tol	CPUE	Number of fish per meter (excludes tolerant species)	composition	positive	<0.001	2.00	0.00	1.89
HeadwaterSpecialist-Tol_Pct	IndPct	Percent headwater individuals (excludes tolerant species)	habitat	positive	<0.001	4.96	0.00	34.77
SimpleLithophil	Richness	Simple lithophilic taxa	reproductive	positive	<0.001	7.84	0.00	4.00
Ominivore_TxPct	TXPct	Percent omnivorous taxa	trophic	negative	<0.001	3.27	0.00	40.00
Tolerant_TxPct	TXPct	Percent tolerant taxa	tolerance	negative	<0.001	5.55	33.33	85.80
Pioneer_TxPct	TXPct	Percent pioneer taxa	life history	negative	0.005	2.97	0.00	35.71
FishDELT_Pct[1]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric included based on conceptual importance, scored discretely

A total of 81 metrics failed either the Range or Signal-to-Noise test in the Low Gradient class. No metrics required adjustment for natural gradients. The Responsiveness Test eliminated an additional 85 metrics, leaving a total of 71 metrics that met all testing criteria. Ten metrics spanning six metric categories were selected for inclusion in the final Low Gradient IBI (Table 11). One metric was included based on its conceptual importance. Low Gradient F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed a strong correlation between F-IBI and HDS, and weak correlations between F-IBI, watershed area, and stream gradient (Table 4). "Low End Scoring" criteria apply to this IBI, under which individual percentage metrics receive a score of 0 when fewer than 25 individuals are captured, and taxa richness and taxa percentage receive a score of 0 when fewer than 4 taxa are captured.

4.8. Southern Coldwater

Table 13. Metrics selected for the Southern Coldwater F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
ColdwaterNative_Pct[1]	IndPct	Percent native, coldwater individuals	habitat	positive	0.001	4.38	0.00	1.96
SensitiveColdwater_Pct[2]	IndPct	Percent sensitive individuals (specific to coldwater streams)	tolerance	positive	0.006	5.24	-76.14	17.59
DetritivoreMinor_TxPct[2]	TXPct	Percent detritivore (at least 5% of diet) taxa	trophic	negative	0.010	2.40	-14.35	28.09
TolerantColdwater[2]	Richness	Percent tolerant individuals (specific to coldwater streams)	tolerance	negative	0.011	3.80	-1.04	4.24
Pioneer_Pct	IndPct	Percent pioneer individuals	life history	negative	0.016	4.76	0.00	55.02
Herbivore_Pct[3]	IndPct	Percent herbivorous individuals	trophic	negative	0.018	1.91		
ColdwaterNative_TxPct[2]	TXPct	Percent native, coldwater taxa	habitat	positive	0.040	12.66	-32.45	28.48
FishDELT_Pct[4]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric value transformed ($\log_{10}$ +1)

[2] metric scoring adjusted for watershed area

[3] metric scored discretely

[4] metric included based on conceptual importance, scored discretely

Nine metrics failed the Range Test in the Southern Coldwater class. Of the remaining metrics, 118 showed a significant relationship with watershed area and required natural gradient correction before responsiveness testing. The Responsiveness Test eliminated an additional 173 non-responsive metrics, leaving a total of 70 metrics that met all testing criteria. Eight metrics spanning four metric categories were selected for inclusion in the final Southern Coldwater IBI (Table 12). Four metrics required adjustment for watershed area, and one metric was included based on its conceptual importance. Southern Coldwater F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed weak correlations between F-IBI, HDS, and watershed area, and a moderate correlation between F-IBI and stream gradient (Table 4).

4.9. Northern Coldwater

Table 14. Metrics selected for the Northern Coldwater F-IBI, listed in order of responsiveness. The p-values are from a one-way Mann-Whitney U test to distinguish between least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Type	Metric Description	Category	Response	p-value	S:N	floor	ceiling
Coldwater	Richness	Coldwater taxa	habitat	positive	<0.001	2.91	0.00	2.00
IntolerantColdwater_Pct	IndPct	Percent intolerant individuals (specific to coldwater streams)	tolerance	positive	<0.001	17.52	0.00	83.65
SensitiveColdwater_TxPct[1]	TXPct	Percent sensitive taxa (specific to coldwater streams)	tolerance	positive	<0.001	11.60	-27.66	25.90
TolerantColdwater_Pct[2]	IndPct	Percent tolerant individuals (specific to coldwater streams)	tolerance	negative	<0.001	11.45	0.00	1.49
NonLithophilicNester_Pct[2]	IndPct	Percent non-lithophilic nest-building individuals	reproductive	negative	<0.001	6.14	0.00	1.68
Ominivore_TxPct	TXPct	Percent omnivorous taxa	trophic	negative	<0.001	2.87	0.00	20.00
Pioneer_TxPct	TXPct	Percent pioneer taxa	life history	negative	<0.001	6.41	0.00	33.33
Perciformes_Pct[2]	IndPct	Percent of individuals belonging to Order Perciformes	composition	negative	0.002	3.78	0.00	1.52
FishDELT_Pct[3]	IndPct	Percent of individuals with Deformities, Eroded fins, Lesions, Tumors	composition	negative				

[1] metric scoring adjusted for stream gradient

[2] metric value transformed ($\log_{10}$ +1)

[3] metric included based on conceptual importance, scored discretely

Nine metrics failed the Range Test in the Northern Coldwater class. Of the remaining metrics, 62 showed a significant relationship with a natural gradient and required correction before responsiveness testing. The Responsiveness Test eliminated an additional 156 metrics, leaving a total of 93 metrics that met all testing criteria. Nine metrics spanning six metric categories were selected for inclusion in the final Northern Coldwater IBI (Table 13). One metric required adjustment for stream gradient, and one metric was included based on its conceptual importance. Northern Coldwater F-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 3, Figure 2). We observed strong correlations between F-IBI, HDS, and stream gradient, and a weak correlation between F-IBI and watershed area (Table 4).

5. Discussion

The class-specific indices described here represent the first comprehensive, statewide tool for assessing the biological integrity of riverine fish communities in the State of Minnesota. Our statewide approach encompassed the geographic extent and variety of lotic environments found across the state, including large rivers, moderate-sized streams, headwaters, low-gradient and coldwater streams. Some rare and/or transitional habitats (such as estuaries, impoundments, wetland flowages, and “Great Rivers”) fell beyond the scope of this project but future work may focus on development and application of fish community-based indicators for these systems.

Stream classification frameworks used to standardize IBIs have typically incorporated some aspect of regionalization (e.g., ecoregions, basins) along physical stream characteristics (e.g., water temperature, watershed area), under the assumption that the biological communities within each resulting class are relatively homogenous. This process of identifying discrete breakpoints across what are inherently continuous environmental gradients can be challenging, and requires that a balance be struck between precision and practical application of the tool. For example, a highly refined classification framework that identifies 100 different stream classes (and consequently, 100 different IBIs) would likely improve within-class precision of the IBI tool. However, the application of such a tool would be overly complex and burdensome for water managers and stakeholders alike. On the other hand, an overly simplified classification framework might be easily implemented, but provide an unacceptably low level of precision.

Our intent in this effort was to develop a framework that would work for most rivers and streams throughout the state but also offer precision at a management-relevant scale. The importance of recognizing issues of scale cannot be overemphasized when developing an indicator that will be used to detect often subtle changes in biological condition. IBIs used to detect broad patterns of change in biological condition across very large regions of the country, as was the objective of Whittier et al. (2007), might fail to detect more subtle changes in resource quality within a relatively undisturbed watershed in Northern Minnesota. Likewise, an IBI developed for low gradient headwater streams in Minnesota would not be an appropriate tool applied across broad regions of North America. In both cases the classification framework and metric selection process have been optimized to detect change at the most relevant scale to specific objectives and resource conditions.

Previous work related to biological indicators for Minnesota’s rivers and streams was primarily organized at the major basin scale (e.g., St. Croix Basin, Upper Mississippi Basin), though at least one ecoregion-specific IBI was developed (Niemela et al. 1999). Each of these IBIs typically identified a single set of metrics applicable to all streams, with unique scoring criteria identified for different stream types (typically differentiated by watershed area). Our approach differed in that we first identified a set of distinct stream types, and then evaluated metrics individually within each class. While we acknowledged the possibility of combining classes if the IBI development process revealed significant convergence between classes, we wanted to explore the possibility that certain metrics might be excellent indicators for one stream type, but not for others. This approach emphasized within-class metric precision, and likely improved the performance of each IBI, but added complexity to the resulting classification framework.

We evaluated several potential regional frameworks for use in IBI development. Existing regionalizations based on landscape features (e.g. ecoregions, ecological provinces) and large watersheds (e.g., HUC4) showed some utility in partitioning variability in stream fish community structure, but neither was ideal.

While ecoregions have a long history associated with biomonitoring applications in the United States, their use may have more to do with convenience than effectiveness (Hawkins et al. 2000). Minnesota's location at a transition zone between several distinct ecoregions, coupled with the commonplace occurrence of river networks crossing (and sometimes re-crossing) ecoregion boundaries may partially explain why existing regionalizations demonstrated weaker classification strength. Ecoregions also fail to account for certain landscape features relevant to fish community structure across the state. For example, within the St. Croix Basin, several species of fish are native to rivers and streams below Taylors Falls but are absent upstream; as a result, distinct differences exist between the fish assemblages above and below this barrier (Fago and Hatch 1993). Alternatively, frameworks based on major basins failed to adequately account for certain abrupt transitions between ecotypes, such as between the forested, higher-gradient headwaters of Red River tributaries and the low-gradient (former) prairie region surrounding the lower reaches of these same rivers.

We ultimately decided on a customized regional framework that (for the most part) utilizes watershed lines corresponding to post-glacial barriers to fish movement. For example, the importance of St. Anthony Falls as a fish migration barrier is well documented in the literature and is reflected in a much smaller number of native fish species above the falls (n=64) compared to below (n=123) (Eddy et al. 1963). We established a regional classification line at St. Anthony Falls which separates streams of the Upper Mississippi Basin from those of the Lower Mississippi, Minnesota, and Lower St. Croix basins. In a similar fashion, we established a regional line at Taylors Falls in the St. Croix Basin, also the location of a historic barrier to fish migration.

The importance of watershed area in structuring stream fish communities has been well-documented (Hugueny et al. 2010). Our framework partitions streams into three general size classes ("headwaters," "streams," and "rivers") based on watershed area – this approach is intuitive, given widespread understanding that the fish communities of large rivers differ greatly from those of small streams. However, the specific watershed area thresholds used to segregate each class required careful scrutiny of the distribution of different fish assemblages across a wide gradient of watershed area. We were able to identify watershed area thresholds that effectively partition natural variability in fish community structure, with the caveat that sites near a particular watershed area threshold value should be evaluated on a case-by-case basis to determine the most appropriate class. In a small number of cases, classification by watershed area was either not feasible or insufficient to completely account for its influence on metric values, requiring derivation of watershed area "corrected" metrics (e.g., *Percentage of sensitive coldwater individuals* metric in the Southern Coldwater IBI).

In a similar manner, stream gradient proved to be a useful variable in segregating the fish communities of headwater streams. In small watersheds, a unique "low gradient" fish assemblage was typically observed when stream gradient was less than 0.5 m/km. However, the method used to calculate stream gradient was somewhat imprecise. Essentially, the change in elevation between the two topographic lines that bracket a particular site was divided by the length of stream channel between them. Imprecision in the gradient value may result from errors in the location of topographic lines or landscape features that are not accurately depicted. In a similar manner to classification by watershed area, sites with gradient values at or near this threshold should be evaluated on a case-by-case basis to determine the most appropriate class. Secondary characteristics of sites with stream gradient >0.5 m/km may be evaluated for application of the Low Gradient IBI, including features such as substrate composition, flow velocity, and the nature of in-channel and riparian vegetation. In a small number of cases, classification by stream gradient area was either not feasible or insufficient to completely account for its influence on metric values, requiring derivation of stream gradient "corrected" metrics (e.g., *Taxa richness of simple lithophilic spawners* metric in the Southern Rivers IBI). Ongoing work by the MPCA is exploring the use of high-resolution digital topographic data (i.e., LIDAR) to estimate stream gradient, which may offer increased accuracy and precision for the purposes of IBI classification and scoring.

Our chosen method of correcting for natural gradient relationships was consistent with the method used by Whittier et al. (2007). This method regressed metric values from least-disturbed sites against natural gradients; where strong relationships existed, we replaced the original metric values with natural-gradient corrected metric values equal to the offset (plus or minus) from the regression. This method appeared to be effective in reducing the potential for covariance between disturbance and natural gradients to confound or obscure "true" metric relationships with disturbance. Corrected metric values demonstrated minimal correlation with natural gradients, and inspection of scatterplots indicated that the range of corrected metric values was not biased towards either end of the natural gradient. Alternative approaches to define and correct for natural gradient relationships might be explored in future IBI development efforts, including quantile regression and/or expression of corrected metric values as a percentile of the regression rather than a raw offset value.

Our initial decision to identify distinct stream classes and proceed through metric selection within each class likely aided us in developing effective IBIs for certain types of streams. In particular, low-gradient, wetland-influenced streams have presented bioassessment challenges in Minnesota and other states. These streams are common in Minnesota and are often dominated by fish species tolerant of natural conditions that, in higher-gradient systems, could be considered signals of degradation (e.g., low dissolved oxygen, dominance of fine-grained substrates, limited habitat complexity). Both taxa richness and number of individuals tends to be lower in these systems than in higher-gradient streams, and using the metrics and scoring criteria of most traditional IBIs, even the fish assemblages of Minnesota's minimally-impacted low-gradient streams would probably score poorly. We were aware of these circumstances going into the stream classification and metric selection processes, and anticipated challenges in constructing an effective IBI for low gradient and/or wetland-influenced streams. However, a distinct "low gradient" stream type was identified by the classification analysis, and a relatively large number (n=71) of metrics passed all metric selection tests; nine highly responsive metrics were identified for inclusion in the Low Gradient IBI. We observed excellent separation in IBI scores between least- and most-disturbed sites, and the correlation between Low Gradient IBI and HDS was among the highest across all fish classes. While the Low Gradient IBI included some non-conventional metrics (e.g., *Taxa richness of wetland species, excluding tolerants*), it also included several that were used in other IBIs and could be considered "traditional" metrics (e.g., *Taxa richness of Sensitive species*, *Percentage of tolerant taxa*). It is possible that a broader metric selection approach, conducted independently of stream class, would have identified metrics applicable across a wide variety of streams. However, we feel that our class-specific approach was largely successful in encapsulating natural variability in stream fish communities, and likely will improve the accuracy of bioassessment in systems such as low gradient headwaters.

The classification of streams into either "warmwater" or "coldwater" systems may have obscured a substantial amount of natural thermal variability, but was necessitated by an absence of better alternatives. The thermal regime of rivers and streams is complex, spatially and temporally dynamic, and can be dramatically altered by anthropogenic impacts. While ambient thermal conditions can be used to classify the current thermal regime, it may be difficult to distinguish impacted coldwater systems from non-impacted cool- and warmwater systems. For example, disturbances such as water appropriation and the clearing of riparian vegetation may artificially warm streams. The Designated Trout Stream framework established and maintained by MnDNR is typically based on historical records of stream conditions and several years of thermal monitoring. While the MnDNR classifications may not precisely describe the thermal conditions of all streams and rivers, in general this framework effectively separates coldwater streams from cool- and warmwater systems. We acknowledge that, in some cases, this classification may not adequately represent the natural thermal potential of a particular stream; these special cases may be identified and dealt with on an individual basis, and the most appropriate IBI determined following interagency review of available historic and contemporary data. Future work should explore whether a more accurate thermal classification system can be developed, but any such system will largely depend on the ability to isolate the natural thermal potential of streams from changes due to anthropogenic influence.

The approach outlined by Whittier et al. (2007) provided an objective methodological template for metric evaluation. Using a series of standardized metric tests, we developed sensitive, robust, community-based indices that provide reliable information about biological integrity. This method differed from a traditional, often-utilized approach, which is to essentially employ the original Karr (1981) IBI as a template and substitute individual metrics when deemed appropriate. While Minnesota lies in relatively close proximity to the geographic region where the original IBI was developed, we realized that some "unconventional" metrics might show potential as biological indicators, due to unique aspects of the state's ichthyofauna, river networks, and lotic habitats.

Our approach maintained the conceptual foundation of the IBI – a trait-based, multi-metric index demonstrably sensitive to anthropogenic disturbance – but assumed little regarding the *a priori* utility of specific metrics and considered a wider variety of candidates. However, while the metric selection tests were designed with objective criteria for removing candidates from the pool, those with test values slightly over the threshold for a particular test were sometimes allowed to "pass" if a sound conceptual basis for doing so could be identified. While few of these "borderline" metrics made it into the final indices, this interplay between a conceptual and quantitative approach strengthened our understanding of how fish communities respond to anthropogenic disturbance and ensured the resulting indices were well-balanced and representative of biological integrity.

In general, this approach worked well – most of the fish classes spanned a suitable range of disturbance, and we were able to identify a number of robust, responsive, non-redundant metrics within each class. Highly significant differences in IBI score were observed between least- and most-disturbed sites, and correlations with HDS were generally strong. While certain metrics included in the final IBIs might be considered relatively novel (e.g., *Percentage of serial spawning individuals*) and other "traditional" metrics were not included (e.g., *Total taxa richness*), a legitimate conceptual rationale could be identified for each metric that was included. In many cases, "traditional" metrics were excluded not because they failed a particular test, but instead because they were demonstrably less responsive than and/or redundant with other, more responsive metrics. It is also conceivable that the prevalence of non-traditional metrics reflects a shift in the dominant ecological stressors in streams and rivers since the initial development of the IBI concept in the late 1970s. For example, widespread improvements have been made in the areas of wastewater treatment and reductions of toxic effluents. At the same time, stressors related to hydrologic alteration, geomorphic destabilization, and habitat modification have possibly increased in relative importance. While any IBI should be responsive to a wide variety of stressors, the most important stressors affecting aquatic systems may change over time, and these changes will be manifested in terms of biological community response.

We used a composite human disturbance gradient (HDS) to select least- and most-disturbed sites and evaluate metric responsiveness. Our disturbance gradient included only variables that were unaffected by natural factors, excluding others where ambient conditions reflect both natural and anthropogenic contributions (e.g., nutrient levels, sediment characteristics). By focusing on variables unaffected by natural variability, this approach offers a greater degree of confidence that the observed metric and index responses are truly attributable to human influence rather than natural variability.

Other anthropogenic disturbances proved too difficult to quantify for inclusion in the HDS. For example, hydrologic alteration through water appropriation or diversion often varies from year to year, and manifests both chronic and acute effects on stream biota. This type of anthropogenic disturbance is also difficult to quantify, since even minimally-impacted hydrologic regimes are inherently dynamic. Furthermore, the data necessary to accurately estimate degree of hydrologic alteration (e.g., reference hydrographs, estimates of streamflow reduction or increase) are notably lacking for most of Minnesota's riverine habitats. As a result, the degree to which a stream's hydrologic regime has been altered was impossible to explicitly incorporate into the HDS. Disruptions to stream network connectivity (e.g., dams, perched culverts) are also difficult to quantify in an accurate manner at the scale required for this analysis, and were likewise not included. However, some HDS metrics, such as those related to road density and impervious surface, may provide surrogate representation for these types of stressors. While our HDS approach likely does not quantify all relevant anthropogenic disturbances, we feel confident that it provides a reasonable estimate of human-induced stress across the state.

The Southern Headwaters class lacked a large number of responsive metrics, despite featuring a relatively broad range of disturbance (HDS interquartile range = 20.7). Only 48 metrics passed all tests in the Southern Headwaters class, with more than half of the candidates (126 of 240) failing the Responsiveness Test. Of the metrics that passed all tests and were identified as candidates for inclusion in the final Southern Headwaters IBI, few demonstrated the highly significant Responsiveness p-values (<0.01) that were common among metrics in other classes. While the composite Southern Headwaters IBI scores were significantly different between least- and most-disturbed sites, the F-Ratio for this comparison was the lowest across all fish classes (Table 3) and the correlation between IBI score and HDS was relatively weak. The Southern Headwaters IBI was also heavily weighted towards "negative" metrics, with six of seven metrics increasing with human disturbance.

Streams in the Southern Headwaters class are relatively small (watershed area <30 square miles), and may be disproportionately impacted by poorly-quantified anthropogenic disturbances (e.g., hydrologic alteration, loss of network connectivity). At the same time, the effects of human disturbance on these streams may be partially mitigated by natural features providing resilience (e.g., localized groundwater inputs, small-scale habitat features). Some of these factors may be more relevant to the biological communities of small streams than to larger systems. For example, the fish communities of small headwater streams may be dependent on uninterrupted stream network connectivity due to the need for downstream refugia during periods of natural stress (e.g., periodic drying, winter freezing). A disturbance gradient that better accounts for some of these factors could possibly reveal obscured stress-response relationships for Southern Headwaters.

By any reasonable measure, few examples of minimally-impacted Southern Headwater stream communities exist in Minnesota. While the interquartile range of HDS was relatively broad, the median HDS score for Southern Headwaters (37) was the lowest of any F-IBI class. The generally degraded condition of streams in this class may partially explain why few positive metrics were selected, as well as relatively week correlation between HDS and F-IBI score. Future approaches to metric selection in this class might consider either including high-quality sites from other classes (e.g., Northern Headwaters, Southern Streams), or "hindcasting" hypothetical minimally-impacted communities (Kilgour and Stanfield 2006) for comparison.

The Southern Coldwater class also demonstrated a relatively weak correspondence between the disturbance gradient and IBI. Due to consistent patterns of land use within this class, upper- and lower-quartile HDS values were separated by a relatively narrow range of scores (HDS interquartile range = 11.9). While reach-scale variables are included in the HDS, it was necessary to utilize habitat scores and site photographs as secondary criteria for sorting sites into the least- and most-disturbed categories. As a result, some sites with “good” HDS scores were excluded from the least-disturbed dataset, and vice-versa. While this method diverged slightly from the quartile method used for all other fish classes, and resulted in a lower correlation between IBI score and HDS, it likely provided a better overall assessment of anthropogenic disturbance for the Southern Coldwater class. Localized groundwater features (e.g., springs, seeps) may also contribute resilience at some sites, and could possibly confound the influence of subtle differences in human disturbance within this class.

The influence of fish management also may have contributed to the relatively weak correspondence between HDS and IBI in the Southern Coldwater class. Between 2002 and 2009, MnDNR was responsible for the stocking of nearly 6 million trout in these streams (MnDNR, unpublished data). Trout are generally considered to be a positive indicator in aquatic systems, as they are sensitive to anthropogenic disturbances such as warming, siltation, and habitat degradation, though some researchers have indicated that stocking of non-native trout may lower biological integrity (Mundahl and Simon 1999). While significant natural reproduction of trout does occur in many Southern Coldwater streams, and a large proportion of these streams are not regularly stocked, it is difficult to account for the influence of stocking and other management practices (e.g., addition of in-stream habitat structures, harvest regulations) in the IBI development process. For example, it is possible that the large numbers of trout in some “disturbed” streams may be the result of stocking, while lower numbers of trout in non-stocked “least-disturbed” streams may be due to a management emphasis on natural reproduction in higher-quality habitats. In either case, it was impossible to distinguish “stocked” from “wild” trout in our datasets, which has been an important component of other coldwater IBIs (Lyons et al. 1996). Although the Southern Coldwater IBI was demonstrably effective in separating least- from most-disturbed sites, corresponded well with an independent assessment of biological condition (Gerritsen et al. 2012), and has proved to be an effective tool for waterbody assessment in Minnesota, index scores may be confounded in the cases of heavily-stocked and/or managed trout streams. Management practices may also influence fish community structure and function in other stream classes, though the exact nature of the resulting effects (if any) on IBI is largely unknown. Future efforts to identify and account for these effects should be pursued.

The MPCA has committed extensive time and effort towards the development of biological indicators and a framework for their use in its surface water monitoring and assessment process (Anderson et al. 2012). The stream classification system and fish-based Indices of Biological Integrity described in this document have been utilized (in concert with other indicators) since 2010 to annually assess the condition of aquatic life in Minnesota’s rivers and streams. Continuing work may attempt to expand the IBI concept to waterbodies not covered here, including lakes, reservoirs, and large rivers. Diagnostic applications of the IBI and its component metrics will also be explored. Large-scale changes in environmental condition across Minnesota, or advances in the science of biological indicators may require periodic evaluation of these indices to ensure their relevancy as assessment tools.

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7. Appendices

Appendix A. Classification criteria for Minnesota river and stream Fish IBI

1a. Northern…………..5
1b. Southern…………..2

Southern
- 2a. coldwater…………………Southern Coldwater
- 2b. warmwater……………..3
  - 3a. Drainage area >300 sq mi…………………..Southern Rivers
  - 3b. Drainage area <300 sq mi…………………..4
    - 4a. Drainage area >30 sq mi…………... Southern Streams
    - 4b. Drainage area <30 sq mi……………5
      - 5a. Gradient >0.50 m/km…………Southern Headwaters
      - 5b. Gradient <0.50 m/km…………Low-Gradient

Northern
- 5a. coldwater………………Northern Coldwater
- 5b. warmwater……………6
  - 6a. Basin = Red…………..7
  - 6b. Basin = other………….8
    - 7a. Drainage area >350 sq mi………………………Northern Rivers
    - 7b. Drainage area <350 sq mi………………………9
      - 8a. Drainage area >500 sq mi………………Northern Rivers
      - 8b. Drainage area <500 sq mi………………9
        - 9a. Drainage area >50………………Northern Streams
        - 9b. Drainage area <50………………10
          - 10a. Gradient >0.50 m/km…...Northern Headwaters
          - 10b. Gradient <0.50 m/km…...Low-Gradient

Appendix B. Metrics evaluated for F-IBI. (+) - metric satisfied all testing criteria. (IBI metric) - metric was included in F-IBI. (NT) - metric was not tested. See Appendix C for metric descriptions, Appendix D for trait assignments

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
BenthicFeeder			+			+			
BenthicFeeder_Pct									
BenthicFeeder_TxPct									
BenthicInsectivore	+					+			
BenthicInsectivore_Pct						+			
BenthicInsectivore_TxPct		+			+	+			
BenthicInsectivore-Tol	+	+			+	+	+		
BenthicInsectivore-Tol_Pct	+				+	+	+		
BenthicInsectivore-Tol_TxPct		IBI metric			+	+			
BenthicMinnowDarter	+					+			
BenthicMinnowDarter_Pct						+			
BenthicMinnowDarter_TxPct		+				+			
Carnivore							+		
Carnivore_Pct	+								+
Carnivore_TxPct									+
Centrarchid									
Centrarchid_Pct									
Centrarchid_TxPct		+							
Centrarchid-Tol									
Centrarchid-Tol_Pct	+								
Centrarchid-Tol_TxPct									
Coldwater								+	IBI metric
Coldwater_Pct								+	+
Coldwater_TxPct								+	+
ColdwaterCoolwater					+	+	+		
ColdwaterCoolwater_Pct								+	+
ColdwaterCoolwater_TxPct					+	+		+	+
ColdwaterCoolwaterNative					+	+	+		
ColdwaterCoolwaterNative_Pct		+							+
ColdwaterCoolwaterNative_TxPct		+			+	+			

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
ColdwaterNative								+	+
ColdwaterNative_Pct								IBI metric	+
ColdwaterNative_TxPct								IBI metric	+
ComplexLithophil						+	+		
ComplexLithophil_Pct					+		+		+
ComplexLithophil_TxPct									+
Coolwater						+	+		
Coolwater_Pct		+							
Coolwater_TxPct		+							
CoolwaterNative						+	+		
CoolwaterNative_Pct		+							
CoolwaterNative_TxPct		+							
CountofTaxa			+			+	+		
Darter		+				+			+
Darter_Pct									+
Darter_TxPct									+
DarterSculpin		+			+	IBI metric			
DarterSculpin_Pct									
DarterSculpin_TxPct									
DarterSculpinNoturus		+			+	+			
DarterSculpinNoturus_Pct									
DarterSculpinNoturus_TxPct									
DarterSculpinSucker		+			+	+	+		+
DarterSculpinSucker_Pct									+
DarterSculpinSucker_TxPct		+			IBI metric	+			
Detritivore		+	+	+	+			+	+
Detritivore_Pct	+			IBI metric	IBI metric				+
Detritivore_TxPct	IBI metric	IBI metric	IBI metric	+	+	+	+		+
DetritivoreMinor	+	+	+	+	+			+	
DetritivoreMinor_TxPct	+	+	+	+	+			IBI metric	+
DetritivoreMinorI_Pct	+			+	+				
DetritivorePlanktivore		+	+	+	+			+	
DetritivorePlanktivore_Pct	+			+	+				

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
DetritivorePlanktivore_TxPct		+	+	+	+				
DominanceOneTaxa_Pct									
DominanceThreeTaxa_Pct			+						
DominanceTwoTaxa_Pct	IBI metric	IBI metric	+	IBI metric	IBI metric				
Exotic									
Exotic_Pct				IBI metric				+	
Exotic_TxPct				+					
FilterFeeder									
FilterFeeder_Pct									
FilterFeeder_TxPct				+					
FishDELT_Pct	IBI metric	IBI metric	IBI metric	IBI metric	IBI metric	IBI metric	IBI metric	IBI metric	IBI metric
GeneralistFeeder	+		+	+	IBI metric				
GeneralistFeeder_Pct	IBI metric				+			+	
GeneralistFeeder_TxPct	+		IBI metric	+	+				
GeneralistFeederFrim					+	+		+	
GeneralistFeederFrim_Pct		+			+	+			+
GeneralistFeederFrim_TxPct								+	
HeadwaterSpecialist						+	+		
HeadwaterSpecialist_Pct									
HeadwaterSpecialist_TxPct									
HeadwaterSpecialist-Tol					+	IBI metric	+		
HeadwaterSpecialist-Tol_Pct					+	+	IBI metric		
HeadwaterSpecialist-Tol_TxPct					+	+	+		
Herbivore	+					+		+	+
Herbivore_Pct	+	+				+	+	IBI metric	
Herbivore_TxPct	+	+						+	+
HerbivorousNWQ						+	+	+	
HerbivorousNWQ_Pct									
HerbivorousNWQ_TxPct									
Insectivore	+					+	+		
Insectivore_Pct					+				+
Insectivore_TxPct	+								
Insectivore-Tol	+	+			+	+	+		

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
Insectivore-Tol_Pct	IBI metric			IBI metric	+	+	+		
Insectivore-Tol_TxPct	+	+			IBI metric	IBI metric	+		
InsectivorousCyprinid						+	+		
InsectivorousCyprinid_Pct			+			IBI metric	+		
InsectivorousCyprinid_TxPct					+	+	+		
Intolerant	+	+		+	+	+	+	+	+
Intolerant_Pct	+	+			IBI metric	+	+	+	+
Intolerant_TxPct	+	+		+	+	+	+	+	+
IntolerantColdwater	NT	NT	NT	NT	NT	NT	NT	+	+
IntolerantColdwater_Pct	NT	NT	NT	NT	NT	NT	NT	+	IBI metric
IntolerantColdwater_TxPct	NT	NT	NT	NT	NT	NT	NT	+	+
InvertivoreNWQ	+					+	+		
InvertivoreNWQ_Pct									
InvertivoreNWQ_TxPct									
LargeRiver	+								
LargeRiver_Pct	+								
LargeRiver_TxPct									
Lithophil	+					+	+		
Lithophil_Pct		+				+	+		+
Lithophil_TxPct		+		+		+	+		+
LongLived	+								
LongLived_Pct		+							+
LongLived_TxPct									+
MatureAge<1									
MatureAge<1_Pct	+	+				+		+	
MatureAge<1_TxPct									+
MatureAge<2			+		+	+	+		
MatureAge<2_Pct	+	IBI metric			+			+	
MatureAge<2_TxPct	+							+	+
MatureAge<2Vtol	+	+	+	+	+			+	+
MatureAge<2Vtol_Pct	+	+	+	+	+	+		+	+
MatureAge<2Vtol_TxPct			+	+				+	+
MatureAge>3	+				+	+	+		+

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
MatureAge>3_Pct	+	+			+			+	+
MatureAge>3_TxPct	+	+			+		+	+	+
MatureAge>3-Tol	+				+	+	+	+	+
MatureAge>3-Tol_Pct		+			IBI metric	+	+	+	
MatureAge>3-Tol_TxPct	+	+			+		+	+	
MatureAge>4	+								
MatureAge>4_Pct	+								
MatureAge>4_TxPct									
MeagerSpawner						+	+		
MeagerSpawner_Pct									+
MeagerSpawner_TxPct									
Migratory						+	+		
Migratory_Pct		+				+	+		+
Migratory_TxPct									+
Minnow		+	+		+	+	+		
Minnow_Pct	+	+	+			+			
Minnow_TxPct	+	+	+	+	+				
Minnow-Tol					+	+	+		
Minnow-Tol_Pct					+	IBI metric	IBI metric		
Minnow-Tol_TxPct					+	+	+		
Native			+			+	+		
Native_Pct				+				+	
Native_TxPct				+					
NonBenthicGeneralist	+	+	+	+	+				
NonBenthicGeneralist_Pct	+	+	+		+			+	
NonBenthicGeneralist_TxPct	+	+	+	+	+			+	
NonBenthicGeneralistTol	+	+	+	+	+				
NonBenthicGeneralistTol_Pct	+	+	+	+	+		+	+	
NonBenthicGeneralistTol_TxPct	+	+	+	+	+	+	+		
NonLithophilicNester			+		+				
NonLithophilicNester_Pct		+		IBI metric	+		+	+	IBI metric
NonLithophilicNester_TxPct	+			+	+	+	+		+
NumPerMeter									

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
NumPerMeter-Tol						IBI metric	IBI metric	+	
NumPerMin			+						
NumPerMin-Tol						+	+		
Ominivore	+	+	+	+	+			+	+
Ominivore_Pct	+			+	+		+		+
Ominivore_TxPct				+	+	+	IBI metric		IBI metric
OmnivorousCyprinid							+	+	
OmnivorousCyprinid_Pct		+		+	+	+	+	+	
OmnivorousCyprinid_TxPct		+		+	+	+	+	+	
Parasitic									
Parasitic_Pct									
Parasitic_TxPct									
Perciformes									+
Perciformes_Pct	+								IBI metric
Perciformes_TxPct		+							
Perciformes-Tol									+
Perciformes-Tol_Pct	+								+
Perciformes-Tol_TxPct				+					
Pioneer	+		+	+	+				+
Pioneer_Pct	+	+		+	+			IBI metric	+
Pioneer_TxPct	+			+	+	IBI metric	IBI metric		IBI metric
Piscivore	IBI metric								
Piscivore_Pct								+	+
Piscivore_TxPct									+
Planktivore	+		+						
Planktivore_Pct		+							
Planktivore_TxPct	+	+							
ProlificSpawner									
ProlificSpawner_Pct									+
ProlificSpawner_TxPct									
Rhinichthys									
Rhinichthys_Pct			+			+			
Rhinichthys_TxPct									

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
RiffleSpecialist						+			
RiffleSpecialist_Pct		+					+		
RiffleSpecialist_TxPct	+					+	+		
RoundBodiedSucker									
RoundBodiedSucker_Pct		+							
RoundBodiedSucker_TxPct									
Salmonid									+
Salmonid_Pct								+	+
Salmonid_TxPct								+	+
Sensitive		+	IBI metric	+	+	IBI metric	IBI metric		
Sensitive_Pct	+	+	+	IBI metric	+	+	+	+	+
Sensitive_TxPct	IBI metric	IBI metric	+	IBI metric	IBI metric	+	+	+	+
SensitiveColdwater	NT	NT	NT	NT	NT	NT	NT	+	+
SensitiveColdwater_Pct	NT	NT	NT	NT	NT	NT	NT	IBI metric	+
SensitiveColdwater_TxPct	NT	NT	NT	NT	NT	NT	NT	+	IBI metric
SerialSpawner			+	+	+				
SerialSpawner_Pct	+	+	IBI metric		+				
SerialSpawner_TxPct	IBI metric	+	+	IBI metric	IBI metric				
ShortLived		IBI metric	+		+			+	+
ShortLived_Pct	IBI metric	+	IBI metric		+			+	
ShortLived_TxPct	+	+			+				+
SimpleLithophil	IBI metric					IBI metric	IBI metric		
SimpleLithophil_Pct	+	+			IBI metric	+	+		
SimpleLithophil_TxPct				IBI metric					
SimpleLithophilFrim	+				+	+	+		
SimpleLithophilFrim_Pct	+	+				+	+		
SimpleLithophilFrim_TxPct									
StickebackMudminnow									
StickebackMudminnow_Pct		+							+
StickebackMudminnow_TxPct									+
SubterminalMouth	+	+	+		+				
SubterminalMouth_Pct	+	+	+						
SubterminalMouth_TxPct	+	+	+						

Appendix B (continued)

Metric Name	Southern Rivers	Southern Streams	Southern Headwaters	Northern Rivers	Northern Streams	Northern Headwaters	Low Gradient	Southern Coldwater	Northern Coldwater
Sucker						+			+
Sucker_Pct		+							+
Sucker_TxPct									+
SuckerCatfish									
SuckerCatfish_Pct									
SuckerCatfish_TxPct									
Tolerant	+	+	+	+	+			+	+
Tolerant_Pct	IBI metric	IBI metric		+	+	+	+	+	+
Tolerant_TxPct	+	IBI metric	+	+	+	IBI metric	IBI metric	+	+
TolerantColdwater	NT	NT	NT	NT	NT	NT	NT	IBI metric	+
TolerantColdwater_Pct	NT	NT	NT	NT	NT	NT	NT	+	IBI metric
TolerantColdwater_TxPct	NT	NT	NT	NT	NT	NT	NT	+	+
VeryTolerant	+	+	+	+	IBI metric	+			+
VeryTolerant_Pct	+	+		+	+	+		+	+
VeryTolerant_TxPct	IBI metric	+	IBI metric	IBI metric	+	+	+		+
VeryTolerantColdwater	NT	NT	NT	NT	NT	NT	NT		+
VeryTolerantColdwater_Pct	NT	NT	NT	NT	NT	NT	NT	+	+
VeryTolerantColdwater_TxPct	NT	NT	NT	NT	NT	NT	NT	+	+
Wetland								+	+
Wetland_Pct		+				+		+	+
Wetland_TxPct								+	+
Wetland-Tol	+				+	+	IBI metric		
Wetland-Tol_Pct	+				+	+			
Wetland-Tol_TxPct	+				+				

Appendix C. List of metrics evaluated for inclusion in F-IBI, metric category assignments, and metric descriptions

Metric Name	Metric Category	Metric Description
BenthicFeeder	Trophic	Taxa richness of benthic feeders
BenthicFeeder_Pct	Trophic	Relative abundance (%) of benthic feeding individuals
BenthicFeeder_TxPct	Trophic	Relative abundance (%) of benthic feeding species
BenthicInsectivore	Trophic	Taxa richness of benthic insectivores
BenthicInsectivore_Pct	Trophic	Relative abundance (%) of benthic insectivore individuals
BenthicInsectivore_TxPct	Trophic	Relative abundance (%) of benthic insectivore species
BenthicInsectivore-Tol	Trophic	Taxa richness of benthic insectivores (excludes tolerant species)
BenthicInsectivore-Tol_Pct	Trophic	Relative abundance (%) of benthic insectivore individuals (excludes tolerant species)
BenthicInsectivore-Tol_TxPct	Trophic	Relative abundance (%) of benthic insectivore species (excludes tolerant species)
BenthicMinnowDarter	Trophic	Taxa richness of benthic insectivore minnows and darters
BenthicMinnowDarter_Pct	Trophic	Relative abundance (%) of benthic insectivore minnow and darter individuals
BenthicMinnowDarter_TxPct	Trophic	Relative abundance (%) of benthic insectivore minnow and darter species
Carnivore	Trophic	Taxa richness of carnivores
Carnivore_Pct	Trophic	Relative abundance (%) of carnivorous individuals
Carnivore_TxPct	Trophic	Relative abundance (%) of carnivorous species
Centrarchid	Richness	Taxa richness of Centrarchids
Centrarchid_Pct	Composition	Relative abundance (%) of Centrarchid individuals
Centrarchid_TxPct	Composition	Relative abundance (%) of Centrarchid species
Centrarchid-Tol	Richness	Taxa richness of Centrarchids (excludes tolerant species)
Centrarchid-Tol_Pct	Composition	Relative abundance (%) of Centrarchid individuals (excludes tolerant species)
Centrarchid-Tol_TxPct	Composition	Relative abundance (%) of Centrarchid species (excludes tolerant species)
Coldwater	Habitat	Taxa richness of coldwater species
Coldwater_Pct	Habitat	Relative abundance (%) of coldwater individuals
Coldwater_TxPct	Habitat	Relative abundance (%) of coldwater taxa
ColdwaterCoolwater	Habitat	Taxa richness of coldwater and coolwater species
ColdwaterCoolwater_Pct	Habitat	Relative abundance (%) of coldwater and coolwater individuals
ColdwaterCoolwater_TxPct	Habitat	Relative abundance (%) of coldwater and coolwater species
ColdwaterCoolwaterNative	Habitat	Taxa richness of native coldwater and coolwater species
ColdwaterCoolwaterNative_Pct	Habitat	Relative abundance (%) of native coldwater and coolwater individuals
ColdwaterCoolwaterNative_TxPct	Habitat	Relative abundance (%) of native coldwater and coolwater species
ColdwaterNative	Habitat	Taxa richness of native coldwater species
ColdwaterNative_Pct	Habitat	Relative abundance (%) of native coldwater individuals
ColdwaterNative_TxPct	Habitat	Relative abundance (%) of native coldwater species

Appendix C (continued)

Metric Name	Metric Category	Metric Description
ComplexLithophil	Reproductive	Taxa richness of complex lithophilic spawners
ComplexLithophil_Pct	Reproductive	Relative abundance (%) of complex lithophilic individuals
ComplexLithophil_TxPct	Reproductive	Relative abundance (%) of complex lithophilic species
Coolwater	Habitat	Taxa richness of coolwater species
Coolwater_Pct	Habitat	Relative abundance (%) of coolwater individuals
Coolwater_TxPct	Habitat	Relative abundance (%) of coolwater species
CoolwaterNative	Habitat	Taxa richness of native coolwater species
CoolwaterNative_Pct	Habitat	Relative abundance (%) of native coolwater individuals
CoolwaterNative_TxPct	Habitat	Relative abundance (%) of native coolwater species
CountofTaxa	Richness	Total taxa richness
Darter	Richness	Taxa richness of darters
Darter_Pct	Composition	Relative abundance (%) of darter individuals
Darter_TxPct	Composition	Relative abundance (%) of darter species
DarterSculpin	Richness	Taxa richness of darters and sculpins
DarterSculpin_Pct	Composition	Relative abundance (%) of darter and sculpin individuals
DarterSculpin_TxPct	Composition	Relative abundance (%) of darter and sculpin species
DarterSculpinNoturus	Richness	Taxa richness of darters, sculpins, and Noturus species
DarterSculpinNoturus_Pct	Composition	Relative abundance (%) of darter, sculpin, and Noturus individuals
DarterSculpinNoturus_TxPct	Composition	Relative abundance (%) of darter, sculpin, and Noturus species
DarterSculpinSucker	Richness	Taxa richness of darters, sculpins, and round-bodied suckers
DarterSculpinSucker_Pct	Composition	Relative abundance (%) of darter, sculpin, and round-bodied sucker individuals
DarterSculpinSucker_TxPct	Composition	Relative abundance (%) of darter, sculpin, and round-bodied sucker species
Detritivore	Trophic	Taxa richness of detritivores
Detritivore_Pct	Trophic	Relative abundance (%) of detritivorous individuals
Detritivore_TxPct	Trophic	Relative abundance (%) of detritivorous species
DetritivoreMinor	Trophic	Taxa richness of species where detritus constitutes at least 5% of their diet
DetritivoreMinor_Pct	Trophic	Relative abundance (%) of individuals where detritus constitutes at least 5% of their diet
DetritivoreMinor_TxPct	Trophic	Relative abundance (%) of species where detritus constitutes at least 5% of their diet
DetritivorePlanktivore	Trophic	Taxa richness of detritivores and planktivores
DetritivorePlanktivore_Pct	Trophic	Relative abundance (%) of detritivorous and planktivorous individuals
DetritivorePlanktivore_TxPct	Trophic	Relative abundance (%) of detritivorous and planktivorous species
DominanceOneTaxa_Pct	Composition	Relative abundance (%) of individuals of the most andundant species
DominanceThreeTaxa_Pct	Composition	Relative abundance (%) of individuals of the three most abundant species
DominanceTwoTaxa_Pct	Composition	Relative abundance (%) of individuals of the two most abundant species
Exotic	Richness	Taxa richness of exotic species
Exotic_Pct	Composition	Relative abundance (%) of exotic individuals
Exotic_TxPct	Composition	Relative abundance (%) of exotic species

Appendix C (continued)

Metric Name	Metric Category	Metric Description
FilterFeeder	Trophic	Taxa richness of filter feeders
FilterFeeder_Pct	Trophic	Relative abundance (%) of filter feeding individuals
FilterFeeder_TxPct	Trophic	Relative abundance (%) of filter feeding species
FishDELT_Pct	Composition	Relative abundance (%) of individuals with DELT anomalies (deformities, eroded fins, lesions, or tumors)
GeneralistFeeder	Trophic	Taxa richness of trophic generalists
GeneralistFeeder_Pct	Trophic	Relative abundance (%) of trophic generalist individuals
GeneralistFeeder_TxPct	Trophic	Relative abundance (%) of trophic generalist species
GeneralistFeederFrim	Trophic	Taxa richness of trophic generalists
GeneralistFeederFrim_Pct	Trophic	Relative abundance (%) of trophic generalist individuals
GeneralistFeederFrim_TxPct	Trophic	Relative abundance (%) of trophic generalist species
HeadwaterSpecialist	Habitat	Taxa richness of headwater specialists
HeadwaterSpecialist_Pct	Habitat	Relative abundance (%) of headwater specialist individuals
HeadwaterSpecialist_TxPct	Habitat	Relative abundance (%) of headwater specialist species
HeadwaterSpecialist-Tol	Habitat	Taxa richness of headwater specialists (excludes tolerant species)
HeadwaterSpecialist-Tol_Pct	Habitat	Relative abundance (%) of headwater specialist individuals (excludes tolerant species)
HeadwaterSpecialist-Tol_TxPct	Habitat	Relative abundance (%) of headwater specialist species (excludes tolerant species)
Herbivore	Trophic	Taxa richness of herbivores
Herbivore_Pct	Trophic	Relative abundance (%) of herbivorous individuals
Herbivore_TxPct	Trophic	Relative abundance (%) of herbivorous species
HerbivorousNWQ	Trophic	Taxa richness of herbivores
HerbivorousNWQ_Pct	Trophic	Relative abundance (%) of herbivorous individuals
HerbivorousNWQ_TxPct	Trophic	Relative abundance (%) of herbivorous species
Insectivore	Trophic	Taxa richness of insectivores
Insectivore_Pct	Trophic	Relative abundance (%) of insectivorous individuals
Insectivore_TxPct	Trophic	Relative abundance (%) of insectivorous species
Insectivore-Tol	Trophic	Taxa richness of insectivores (excludes tolerant species)
Insectivore-Tol_Pct	Trophic	Relative abundance (%) of insectivorous individuals (excludes tolerant species)
Insectivore-Tol_TxPct	Trophic	Relative abundance (%) of insectivorous species (excludes tolerant species)
InsectivorousCyprinid	Trophic	Taxa richness of insectivorous Cyprinids
InsectivorousCyprinid_Pct	Trophic	Relative abundance (%) of insectivorous Cyprinid individuals
InsectivorousCyprinid_TxPct	Trophic	Relative abundance (%) of insectivorous Cyprinid species
Intolerant	Tolerance	Taxa richness of intolerant species
Intolerant_Pct	Tolerance	Relative abundance (%) of intolerant individuals
Intolerant_TxPct	Tolerance	Relative abundance (%) of intolerant species
IntolerantColdwater	Tolerance	Taxa richness of species considered Intolerant in coldwater streams
IntolerantColdwater_Pct	Tolerance	Relative abundance (%) of individuals considered Intolerant in coldwater streams
IntolerantColdwater_TxPct	Tolerance	Relative abundance (%) of species considered Intolerant in coldwater streams

Appendix C (continued)

Metric Name	Metric Category	Metric Description
InvertivoreNWQ	Trophic	Taxa richness of invertivores
InvertivoreNWQ_Pct	Trophic	Relative abundance (%) of invertivorous individuals
InvertivoreNWQ_TxPct	Trophic	Relative abundance (%) of invertivorous species
LargeRiver	Habitat	Taxa richness of species that predominately utilize large river habitats
LargeRiver_Pct	Habitat	Relative abundance (%) of individuals that predominately utilize large river habitats
LargeRiver_TxPct	Habitat	Relative abundance (%) of species that predominately utilize large river habitats
Lithophil	Reproductive	Taxa richness of lithophilic spawners
Lithophil_Pct	Reproductive	Relative abundance (%) of lithophilic individuals
Lithophil_TxPct	Reproductive	Relative abundance (%) of lithophilic species
LongLived	Life History	Taxa richness of long-lived species
LongLived_Pct	Life History	Relative abundance (%) of long-lived individuals
LongLived_TxPct	Life History	Relative abundance (%) of long-lived species
MatureAge<1	Reproductive	Taxa richness of species with a female mature age <=1
MatureAge<1_Pct	Reproductive	Relative abundance (%) of individuals with a female mature age <=1
MatureAge<1_TxPct	Reproductive	Relative abundance (%) of species with a female mature age <=1
MatureAge<2	Reproductive	Taxa richness of species with a female mature age <=2
MatureAge<2_Pct	Reproductive	Relative abundance (%) of individuals with a female mature age <=2
MatureAge<2_TxPct	Reproductive	Relative abundance (%) of species with a female mature age <=2
MatureAge<2Vtol	Reproductive	Taxa richness of species with a female mature age <=2 that are also considered Very Tolerant
MatureAge<2Vtol_Pct	Reproductive	Relative abundance (%) of individuals with a female mature age <=2 that are also considered Tolerant
MatureAge<2Vtol_TxPct	Reproductive	Relative abundance (%) of species with a female mature age <=2 that are also considered Very Tolerant
MatureAge>3	Reproductive	Taxa richness of species with a female mature age >=3
MatureAge>3_Pct	Reproductive	Relative abundance (%) of individuals with a female mature age >=3
MatureAge>3_TxPct	Reproductive	Relative abundance (%) of species with a female mature age >=3
MatureAge>3-Tol	Reproductive	Taxa richness of species with a female mature age >=3 (excludes tolerant species)
MatureAge>3-Tol_Pct	Reproductive	Relative abundance (%) of individuals with a female mature age >=3 (excludes tolerant species)
MatureAge>3-Tol_TxPct	Reproductive	Relative abundance (%) of species with a female mature age >=3 (excludes tolerant species)
MatureAge>4	Reproductive	Taxa richness of species with a female mature age >=4
MatureAge>4_Pct	Reproductive	Relative abundance (%) of individuals with a female mature age >=4
MatureAge>4_TxPct	Reproductive	Relative abundance (%) of species with a female mature age >=4
MeagerSpawner	Reproductive	Taxa richness of meager spawners
MeagerSpawner_Pct	Reproductive	Relative abundance (%) of meager spawning individuals
MeagerSpawner_TxPct	Reproductive	Relative abundance (%) of meager spawning species
Migratory	Life History	Taxa richness of migratory species
Migratory_Pct	Life History	Relative abundance (%) of migratory individuals
Migratory_TxPct	Life History	Relative abundance (%) of migratory species

Appendix C (continued)

Metric Name	Metric Category	Metric Description
Minnow	Richness	Taxa richness of Cyprinids
Minnow_Pct	Composition	Relative abundance (%) of Cyprinid individuals
Minnow_TxPct	Composition	Relative abundance (%) of Cyprinid species
Minnow-Tol	Richness	Taxa richness of Cyprinids (excludes tolerant species)
Minnow-Tol_Pct	Composition	Relative abundance (%) of Cyprinid individuals (excludes tolerant species)
Minnow-Tol_TxPct	Composition	Relative abundance (%) of Cyprinid species (excludes tolerant species)
Native	Richness	Taxa richness of native species
Native_Pct	Composition	Relative abundance (%) of native individuals
Native_TxPct	Composition	Relative abundance (%) of native species
NonBenthicGeneralist	Trophic	Taxa richness of species that feed within the surface water column (not benthic exclusively) and are generalist feeders
NonBenthicGeneralist_Pct	Trophic	Relative abundance (%) of individuals that feed within the surface water column (not benthic exclusively) and are generalist feeders
NonBenthicGeneralist_TxPct	Trophic	Relative abundance (%) of species that feed within the surface water column (not benthic exclusively) and are generalist feeders
NonBenthicGeneralistTol	Trophic	Taxa richness of species that feed within the surface water column (not benthic exclusively), are considered tolerant, and are generalist feeders
NonBenthicGeneralistTol_Pct	Trophic	Relative abundance (%) of individuals that feed within the surface water column (not benthic exclusively), are considered tolerant, and are generalist feeders
NonBenthicGeneralistTol_TxPct	Trophic	Relative abundance (%) of species that feed within the surface water column (not benthic exclusively), are considered tolerant, and are generalist feeders
NonLithophilicNester	Reproductive	Taxa richness of non-lithophilic nest-guarders
NonLithophilicNester_Pct	Reproductive	Relative abundance (%) of non-lithophilic, nest-guarding individuals
NonLithophilicNester_TxPct	Reproductive	Relative abundance (%) of non-lithophilic, nest-guarding species
NumPerMeter	Composition	Number of individuals per meter of stream sampled
NumPerMeter-Tol	Composition	Number of individuals per meter of stream sampled (excludes individuals of tolerant species)
NumPerMin	Composition	Number of individuals per minute of sampling time
NumPerMin-Tol	Composition	Number of individuals per minute of sampling time (excludes individuals of tolerant species)

Appendix C (continued)

Metric Name	Metric Category	Metric Description
Ominivore	Trophic	Taxa richness of omnivores
Ominivore_Pct	Trophic	Relative abundance (%) of omnivorous individuals
Ominivore_TxPct	Trophic	Relative abundance (%) of omnivorous species
OmnivorousCyprinid	Trophic	Taxa richness of omnivorous Cyprinids
OmnivorousCyprinid_Pct	Trophic	Relative abundance (%) of omnivorous Cyprinid individuals
OmnivorousCyprinid_TxPct	Trophic	Relative abundance (%) of omnivorous Cyprinid species
Parasitic	Trophic	Taxa richness of parisitic species
Parasitic_Pct	Trophic	Relative abundance (%) of parasitic individuals
Parasitic_TxPct	Trophic	Relative abundance (%) of parasitic species
Perciformes	Richness	Taxa richness of Perciformids
Perciformes_Pct	Composition	Relative abundance (%) of Perciformid individuals
Perciformes_TxPct	Composition	Relative abundance (%) of Perciformid species
Perciformes-Tol	Habitat	Taxa richness of Perciformids (excludes tolerant species)
Perciformes-Tol_Pct	Composition	Relative abundance (%) of Perciformid individuals (excludes tolerant species)
Perciformes-Tol_TxPct	Composition	Relative abundance (%) of Perciformid species (excludes tolerant species)
Pioneer	Life History	Taxa richness of pioneer species
Pioneer_Pct	Life History	Relative abundance (%) of pioneer individuals
Pioneer_TxPct	Life History	Relative abundance (%) of pioneer species
Piscivore	Trophic	Taxa richness of piscivores
Piscivore_Pct	Trophic	Relative abundance (%) of piscivorous individuals
Piscivore_TxPct	Trophic	Relative abundance (%) of piscivorous species
Planktivore	Trophic	Taxa richness of planktivores
Planktivore_Pct	Trophic	Relative abundance (%) of planktivorous individuals
Planktivore_TxPct	Trophic	Relative abundance (%) of planktivorous species
ProlificSpawner	Reproductive	Taxa richness of prolific spawners
ProlificSpawner_Pct	Reproductive	Relative abundance (%) of prolific spawning individuals
ProlificSpawner_TxPct	Reproductive	Relative abundance (%) of proflific spawning species
Rhinichthys	Richness	Taxa richness of Rhinichthyds
Rhinichthys_Pct	Composition	Relative abundance (%) of Rhinichthyd individuals
Rhinichthys_TxPct	Composition	Relative abundance (%) of Rhinichthyd species
RiffleSpecialist	Habitat	Taxa richness of species that predominately utilize riffle habitats
RiffleSpecialist_Pct	Habitat	Relative abundance (%) of individuals that predominately utilize riffle habitats
RiffleSpecialist_TxPct	Habitat	Relative abundance (%) of species that predominately utilize riffle habitats
RoundBodiedSucker	Richness	Taxa richness of round-bodied suckers (excludes Catostomus commersonii)
RoundBodiedSucker_Pct	Composition	Relative abundance (%) of round-bodied sucker individuals (excludes Catostomus commersonii)
RoundBodiedSucker_TxPct	Composition	Relative abundance (%) of round-bodied sucker species (excludes Catostomus commersonii)

Appendix C (continued)

Metric Name	Metric Category	Metric Description
Salmonid	Richness	Taxa richness of Salmonids
Salmonid_Pct	Composition	Relative abundance (%) of Salmonid individuals
Salmonid_TxPct	Composition	Relative abundance (%) of Salmonid species
Sensitive	Tolerance	Taxa richness of sensitive species
Sensitive_Pct	Tolerance	Relative abundance (%) of sensitive individuals
Sensitive_TxPct	Tolerance	Relative abundance (%) of sensitive species
SensitiveColdwater	Tolerance	Taxa richness of species considered Sensitive in coldwater streams
SensitiveColdwater_Pct	Tolerance	Relative abundance (%) of individuals considered Sensitive in coldwater streams
SensitiveColdwater_TxPct	Tolerance	Relative abundance (%) of species considered Sensitive in coldwater streams
SerialSpawner	Reproductive	Taxa richness of serial spawners
SerialSpawner_Pct	Reproductive	Relative abundance (%) of serial spawning individuals
SerialSpawner_TxPct	Reproductive	Relative abundance (%) of serial spawning species
ShortLived	Life History	Taxa richness of short-lived species
ShortLived_Pct	Life History	Relative abundance (%) of short-lived individuals
ShortLived_TxPct	Life History	Relative abundance (%) of short-lived species
SimpleLithophil	Reproductive	Taxa richness of simple lithophils
SimpleLithophil_Pct	Reproductive	Relative abundance (%) of simple lithophilic individuals
SimpleLithophil_TxPct	Reproductive	Relative abundance (%) of simple lithophilic species
SimpleLithophilFrim	Reproductive	Taxa richness of simple lithophils
SimpleLithophilFrim_Pct	Reproductive	Relative abundance (%) of simple lithophilic individuals
SimpleLithophilFrim_TxPct	Reproductive	Relative abundance (%) of simple lithophilic species
StickebackMudminnow	Richness	Taxa richness of Umbra limi and Culaea inconstans
StickebackMudminnow_Pct	Composition	Relative abundance (%) of Umbra limi and Culaea inconstans individuals
StickebackMudminnow_TxPct	Composition	Relative abundance (%) of Umbra limi and Culaea inconstans species
SubterminalMouth	Trophic	Taxa richness of subterminal-mouthed Cyprinids (excludes exotic species)
SubterminalMouth_Pct	Trophic	Relative abundance (%) of subterminal-mouthed Cyprinid individuals (excludes exotic species)
SubterminalMouth_TxPct	Trophic	Relative abundance (%) of subterminal-mouthed Cyprinid species (excludes exotic species)
Sucker	Richness	Taxa richness of Catostomids
Sucker_Pct	Composition	Relative abundance (%) of Catostomid individuals
Sucker_TxPct	Composition	Relative abundance (%) of Catostomid species
SuckerCatfish	Richness	Taxa richness of Catostomids and Ictalurids
SuckerCatfish_Pct	Composition	Relative abundance (%) of Catostomid and Ictalurid individuals
SuckerCatfish_TxPct	Composition	Relative abundance (%) of Catostomid and Ictalurid species
Tolerant	Tolerance	Taxa richness of tolerant species
Tolerant_Pct	Tolerance	Relative abundance (%) of tolerant individuals
Tolerant_TxPct	Tolerance	Relative abundance (%) of tolerant species
TolerantColdwater	Tolerance	Taxa richness of species considered Tolerant in coldwater streams
TolerantColdwater_Pct	Tolerance	Relative abundance (%) of individuals considered Tolerant in coldwater streams

Appendix C (continued)

Metric Name	Metric Category	Metric Description
TolerantColdwater_TxPct	Tolerance	Relative abundance (%) of species considered Tolerant in coldwater streams
VeryTolerant	Tolerance	Taxa richness of very tolerant species
VeryTolerant_Pct	Tolerance	Relative abundance (%) of very tolerant individuals
VeryTolerant_TxPct	Tolerance	Relative abundance (%) of very tolerant species
VeryTolerantColdwater	Tolerance	Taxa richness of species considered Very Tolerant in coldwater streams
VeryTolerantColdwater_Pct	Tolerance	Relative abundance (%) of individuals considered Very Tolerant in coldwater streams
VeryTolerantColdwater_TxPct	Tolerance	Relative abundance (%) of species considered Very Tolerant in coldwater streams
Wetland	Habitat	Taxa richness of species that utilize wetland habitats
Wetland_Pct	Habitat	Relative abundance (%) of individuals that utilize wetland habitats
Wetland_TxPct	Habitat	Relative abundance (%) of species that utilize wetland habitats
Wetland-Tol	Habitat	Taxa richness of species that utilize wetland habitats (excludes tolerant species)
Wetland-Tol_Pct	Habitat	Relative abundance (%) of individuals that utilize wetland habitats (excludes tolerant taxa)
Wetland-Tol_TxPct	Habitat	Relative abundance (%) of species that utilize wetland habitats (excludes tolerant taxa)

Appendix D. List of Minnesota fish species and attributes used to calculate F-IBI metrics

Composition	
DSS	DarterSculpinSucker
DS	DarterSculpin
EX	Exotic
MIN-T	Minnow-Tol
PERC	Perciformes

Habitat	
CW	Coldwater
CW_N	ColdwaterNative
HW-T	HeadwaterSpecialist-Tol
WE-T	Wetland-Tol

Life History	
PI	Pioneer
SL	ShortLived

Reproductive	
MA<2	MatureAge<2
MA>3-T	MatureAge>3-Tol
NE	NonLithophilicNester
SER	SerialSpawner
SILI	SimpleLithophil

Tolerance	
I	Intolerant
I_CW	IntolerantColdwater
S	Sensitive
S_CW	SensitiveColdwater
T	Tolerant
T_CW	TolerantColdwater
VT	VeryTolerant

Trophic	
BI-T	BenthicInsectivore-Tol
DE	Detritivore
DEM	DetritivoreMinor
GE	GeneralistFeeder
HE	Herbivore
IN-T	Insectivore-Tol
IN_CYP	InsectivorousCyprinid
OM	Ominivore
PI	Piscivore

CommonName	ScientificName	Composition	Habitat	Life History	Reproductive	Tolerance	Trophic
Lampreys	Petromyzontidae					S	
lamprey ammocoete	Petromyzontidae larvae					I,S	
chestnut lamprey	Ichthyomyzon castaneus				MA>3-T	I,S	PI
northern brook lamprey	Ichthyomyzon fossor				MA>3-T	I,ICW,S,SCW	
southern brook lamprey	Ichthyomyzon gagei				MA>3-T	I,ICW,S,SCW	DE
silver lamprey	Ichthyomyzon unicuspis				MA>3-T	S	PI
American brook lamprey	Lampetra appendix		HW-T		MA>3-T	I,ICW,S,SCW	
sea lamprey	Petromyzon marinus	EX			MA>3-T		DE,PI
Sturgeons	Acipenseridae				SILI		BI-T,IN-T
lake sturgeon	Acipenser fulvescens				MA>3-T,SILI	I,S	BI-T,IN-T
shovelnose sturgeon	Scaphirhynchus platorynchus				MA>3-T,SILI		BI-T,IN-T
Paddlefishes	Polydontidae						
paddlefish	Polyodon spathula				MA>3-T,SILI	I,S	
Gars	Lepisosteidae						PI
longnose gar	Lepisosteus osseus				MA>3-T,SER		PI
shortnose gar	Lepisosteus platostomus				MA>3-T		PI
Bowfins	Amiidae						
bowfin	Amia calva				MA>3-T		PI
Mooneyes	Hiodontidae						IN-T
goldeye	Hiodon alosoides				MA>3-T		IN-T
mooneye	Hiodon tergisus					S	IN-T

Appendix D (continued)

Eels	Anguillidae						
American eel	Anguilla rostrata						PI
Herrings	Clupiidae						
skipjack herring	Alosa chrysochloris						PI
alewife	Alosa pseudoharengus	EX			MA>3-T		
gizzard shad	Dorosoma cepedianum				MA<2,SER		DEM
Minnows	Cyprinidae						
central stoneroller	Campostoma anomalum					T,TCW	HE
largescale stoneroller	Campostoma oligolepis	MIN-T			MA<2		DEM,HE
Gen: stonerollers	Campostoma	MIN-T					HE
goldfish	Carassius auratus	EX			SER	T,TCW,VT	DEM,GE,OM
redside dace	Clinostomus elongatus	MIN-T	HW-T		MA<2,SILI	I,ICW,S,SCW	IN-T,INCYP
lake chub	Couesius plumbeus	MIN-T			SILI	I,ICW,S,SCW	IN-T,INCYP
grass carp	Ctenopharyngodon idella	EX			MA<2	T,TCW	DEM,HE
red shiner	Cyprinella lutrensis			SL	MA<2,SER	T,TCW	GE
spotfin shiner	Cyprinella spiloptera	MIN-T			MA<2,SER		DE,DEM,IN-T,INCYP
common carp	Cyprinus carpio	EX			MA<2	T,TCW,VT	DE,DEM,GE,OM
gravel chub	Erimystax x-punctatus	MIN-T		SL	MA<2,SILI	I,S	BI-T,DEM,IN-T,INCYP
brassy minnow	Hybognathus hankinsoni			SL	MA<2	T,TCW	DE,DEM,HE
Mississippi silvery minnow	Hybognathus nuchalis	MIN-T				I,S	HE
pallid shiner	Hybopsis amnis	MIN-T				I,S	IN-T,INCYP
bighead carp	Hypophthalmichthys nobilis	EX			SER	T,TCW,VT	DEM
silver carp	Hypophthalmichthys molitrix	EX				T,TCW,VT	
common shiner	Luxilus cornutus	MIN-T			MA<2,SILI		DEM,GE
redfin shiner	Lythrurus umbratilis	MIN-T		SL	MA<2	S	IN-T,INCYP
shoal chub	Macrhybopsis hyostoma	MIN-T		SL	MA<2	S	BI-T,IN-T,INCYP
silver chub	Macrhybopsis storeriana	MIN-T			MA<2		BI-T,IN-T,INCYP
pearl dace	Margariscus margarita	MIN-T	HW-T, WE-T		MA<2	S,SCW	DEM,IN-T,INCYP
hornyhead chub	Nocomis biguttatus	MIN-T			MA<2,SER	S	DEM,IN-T,INCYP
golden shiner	Notemigonus crysoleucas	MIN-T	WE-T		MA<2,SER		GE
pugnose shiner	Notropis anogenus	MIN-T		SL	MA>3-T	I,S	DE,HE
emerald shiner	Notropis atherinoides	MIN-T		SL	MA<2,SILI		DEM,IN-T,INCYP
river shiner	Notropis blennius	MIN-T		SL	MA<2,SILI		DEM,IN-T,INCYP
ghost shiner	Notropis buchanani	MIN-T			MA<2,SER	I,S	DE,IN-T,INCYP
bigmouth shiner	Notropis dorsalis			SL	MA<2,SER	T,TCW,VT	DEM,INCYP
blackchin shiner	Notropis heterodon	MIN-T			MA<2,SER	I,S	DEM,IN-T,INCYP
blacknose shiner	Notropis heterolepis	MIN-T		SL	MA<2	I,S	IN-T,INCYP
spottail shiner	Notropis hudsonius	MIN-T			MA<2	S	IN-T,INCYP
Ozark minnow	Notropis nubilus	MIN-T			MA<2,SILI	I,S	DEM,HE
carmine shiner	Notropis percobromus	MIN-T		SL	MA<2,SILI	S	DE,IN-T,INCYP
sand shiner	Notropis stramineus			SL	MA<2,SER	T,TCW	DE,DEM,INCYP
weed shiner	Notropis texanus	MIN-T		SL	MA<2,SER	I,S	DE,DEM,HE

Topeka shiner	Notropis topeka	MIN-T	HW-T	SL	MA<2	I,S	IN-T,INCYP
mimic shiner	Notropis volucellus	MIN-T		SL	SER	I,S	DEM,IN-T,INCYP
channel shiner	Notropis wickliffi	MIN-T		SL	MA<2	S	IN-T,INCYP
Gen: Notropis	Notropis	MIN-T					
pugnose minnow	Opsopoeodus emiliae	MIN-T		SL	MA<2,NE,SER	I,S	DE,DEM,IN-T,INCYP
suckermouth minnow	Phenacobius mirabilis	MIN-T			MA<2,SER,SILI		BI-T,DEM,IN-T,INCYP
northern redbelly dace	Phoxinus eos	MIN-T	HW-T, WE-T	SL	MA<2,SER	S	HE
southern redbelly dace	Phoxinus erythrogaster	MIN-T	HW-T	SL	MA<2,SER,SILI		DEM,HE
finescale dace	Phoxinus neogaeus	MIN-T	HW-T, WE-T		MA<2,SER	S,SCW	IN-T,INCYP
Gen: Phoxinus	Phoxinus		HW-T				
bluntnose minnow	Pimephales notatus			PI,SL	MA<2,NE,SER	T,TCW,VT	DE,DEM,GE
fathead minnow	Pimephales promelas			PI,SL	MA<2,NE,SER	T,TCW,VT	DE,DEM,GE,OM
bullhead minnow	Pimephales vigilax	MIN-T			MA<2,NE,SER		GE
flathead chub	Platygobio gracilis	MIN-T			MA<2,SER		IN-T,INCYP
blacknose dace	Rhinichthys atratulus			SL	MA<2,SILI	T	GE
longnose dace	Rhinichthys cataractae	MIN-T			SILI	I,ICW,S,SCW	BI-T,IN-T,INCYP
Gen: Rhinichthys	Rhinichthys				SILI		
creek chub	Semotilus atromaculatus			PI	MA<2	T	GE
Suckers	Catostomiidae						
river carpsucker	Carpiodes carpio				MA>3-T		DE,DEM,GE,OM
quillback	Carpiodes cyprinus				MA>3-T		DE,DEM,GE,OM
highfin carpsucker	Carpiodes velifer				MA>3-T	S	DE,DEM,GE,OM
Gen: carpsuckers	Carpiodes						GE,OM
SubFam: buffalo/carpsuckers	Ictiobinae						GE,OM
longnose sucker	Catostomus catostomus	DSS			MA>3-T,SILI	I,ICW,S,SCW	BI-T,IN-T
white sucker	Catostomus commersonii				SILI	T	DE,DEM,GE,OM
Gen: Catostomus	Catostomus				SILI		
blue sucker	Cycleptus elongatus	DSS			SILI	I,S	BI-T,IN-T
northern hogsucker	Hypentelium nigricans	DSS			MA>3-T,SILI	S	BI-T,DEM,IN-T
smallmouth buffalo	Ictiobus bubalus				MA<2		DEM,GE,OM
bigmouth buffalo	Ictiobus cyprinellus					T,VT	DEM,GE,OM
black buffalo	Ictiobus niger						DE,DEM,GE,OM
Gen: buffalos	Ictiobus						GE,OM
spotted sucker	Minytrema melanops	DSS			MA>3-T,SILI	I,S	BI-T,DEM,IN-T
silver redhorse	Moxostoma anisurum	DSS			MA>3-T,SILI		BI-T,DEM,IN-T
river redhorse	Moxostoma carinatum	DSS			MA>3-T,SILI	I,S	BI-T,IN-T
black redhorse	Moxostoma duquesnei	DSS			MA>3-T,SILI	I,S,SCW	BI-T,IN-T
golden redhorse	Moxostoma erythrurum	DSS			MA>3-T,SILI		BI-T,DEM,IN-T
shorthead redhorse	Moxostoma macrolepidotum	DSS			MA>3-T,SILI		BI-T,DEM,IN-T
greater redhorse	Moxostoma valenciennesi	DSS			MA>3-T,SILI	I,S	BI-T,IN-T
Gen: redhorses	Moxostoma	DSS			SILI		BI-T,IN-T

Appendix D (continued)

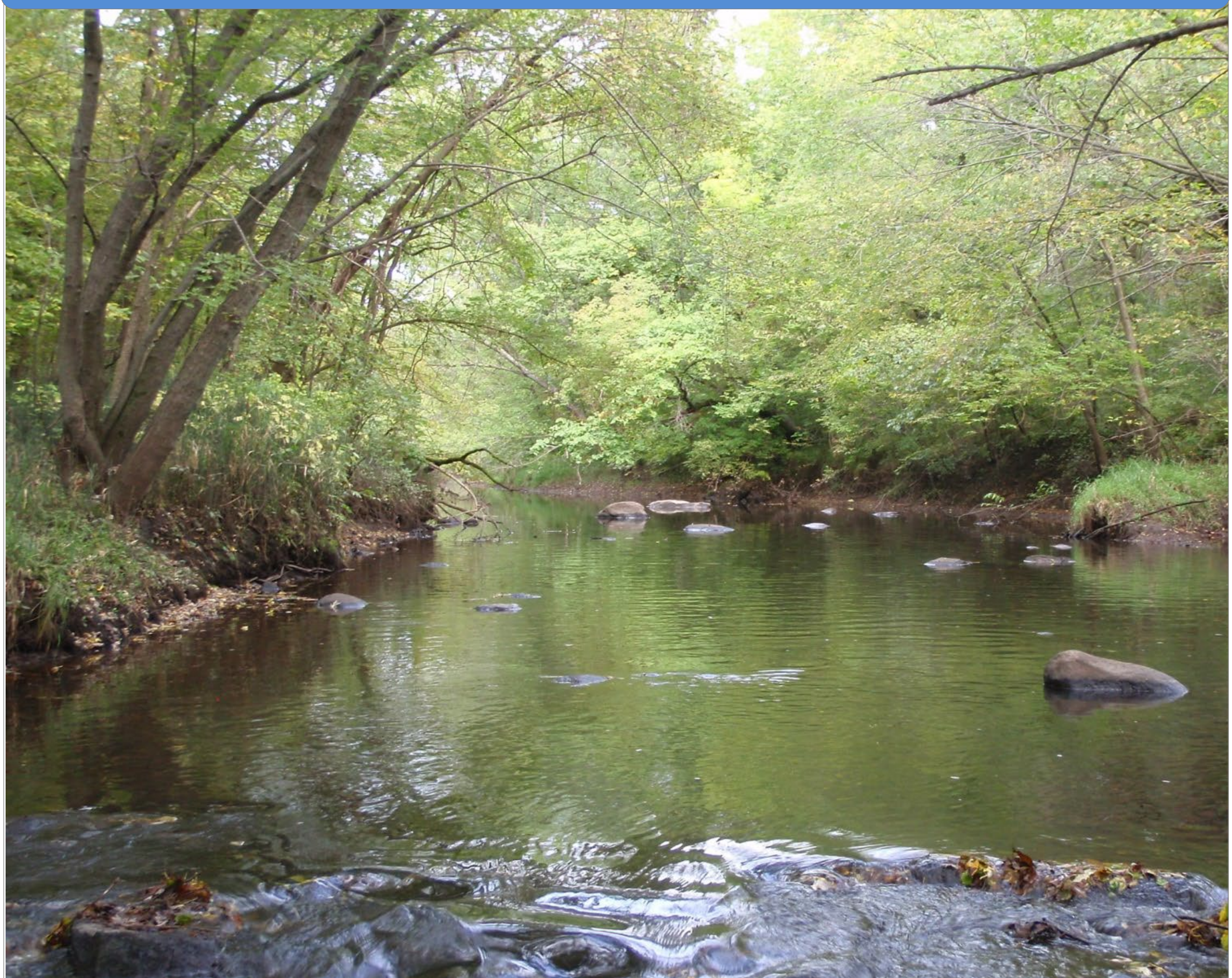
Catfishes	Ictaluridae						
black bullhead	Ameiurus melas					T,TCW,VT	DEM,GE,OM
yellow bullhead	Ameiurus natalis		WE-T		NE,SER		DEM,GE,OM
brown bullhead	Ameiurus nebulosus		WE-T		NE,SER		DEM,GE,OM
Gen: bullheads	Ameiurus						GE,OM
blue catfish	Ictalurus furcatus				NE		PI
channel catfish	Ictalurus punctatus				MA>3-T,NE		DEM,PI
slender madtom	Noturus exilis					I,S	BI-T,DE,IN-T
stonecat	Noturus flavus				MA>3-T,SER	S	BI-T,IN-T
tadpole madtom	Noturus gyrinus		WE-T		MA<2,NE,SER		BI-T,IN-T
Gen: madtoms	Noturus						BI-T,IN-T
flathead catfish	Pylodictis olivaris				MA>3-T,NE		PI
Pikes	Esocidae						PI
northern pike	Esox lucius		WE-T		MA<2		PI
muskellunge	Esox masquinongy				MA>3-T	I,S	PI
tiger musky	Esox hybrid						PI
Mudminnows	Umbridae						
central mudminnow	Umbra limi				MA<2	T,TCW,VT	
Smelts	Osmeridae						
rainbow smelt	Osmerus mordax	EX			SER		PI
Trouts	Salmonidae						
SubFam: salmonids	Salmoninae						PI
lake herring	Coregonus artedi				MA>3-T		
lake whitefish	Coregonus clupeaformis				MA>3-T		IN-T
bloater	Coregonus hoyi				MA<2		
kiyi	Coregonus kiyi				MA>3-T		
shortjaw cisco	Coregonus zenithicus				MA>3-T		
pink salmon	Oncorhynchus gorbuscha	EX	CW				PI
coho salmon	Oncorhynchus kisutch	EX	CW		MA>3-T		PI
rainbow trout	Oncorhynchus mykiss	EX	CW		MA>3-T	S,SCW	PI
chinook salmon	Oncorhynchus tshawytscha	EX	CW		MA>3-T		PI
round whitefish	Prosopium cylindraceum				MA>3-T		IN-T
Atlantic salmon	Salmo salar	EX	CW		MA>3-T		PI
brown trout	Salmo trutta	EX	CW		MA>3-T	S,SCW	PI
brook trout	Salvelinus fontinalis		CW,CWN		MA>3-T	I,ICW,S,SCW	PI
lake trout	Salvelinus namaycush		CW,CWN		MA>3-T		PI
tiger trout	Salmonidae hybrid		CW				PI
Trout-perches	Percopsidae						
trout-perch	Percopsis omiscomaycus			SL	MA<2		BI-T,IN-T
Pirate perches	Aphredoderidae						
pirate perch	Aphredoderus sayanus				MA<2		IN-T

Codfishes	Gadidae						
burbot	Lota lota				MA>3-T,SILI	I,S	PI
Silversides	Atherinidae						
brook silverside	Labidesthes sicculus			SL	MA<2	S	IN-T
Killifishes	Fundulidae						
banded killifish	Fundulus diaphanus				MA<2,SER		IN-T
starhead topminnow	Fundulus dispar		HW-T		MA<2,SER	I,S	IN-T
blackstripe topminnow	Fundulus notatus				MA<2,SER		IN-T
plains topminnow	Fundulus sciadicus			SL	MA<2	S	IN-T
Gen: topminnows	Fundulus						IN-T
Sticklebacks	Gasterosteidae						
brook stickleback	Culaea inconstans			SL	MA<2,NE	T	
threespine stickleback	Gasterosteus aculeatus	EX		SL	MA<2,NE	T,TCW	
ninespine stickleback	Pungitius pungitius				MA<2,NE		IN-T
Sculpins	Cottidae						
mottled sculpin	Cottus bairdii	DS,DSS	CW,CWN,HW-T		MA<2	S,SCW	BI-T,IN-T
slimy sculpin	Cottus cognatus	DS,DSS,PERC	CW,CWN,HW-T		MA>3-T	I,ICW,S,SCW	BI-T,IN-T
spoonhead sculpin	Cottus ricei	DS,DSS			MA<2	I,S	BI-T,IN-T
Gen: sculpins	Cottus	DS,DSS	CW,CWN			S,SCW	BI-T,IN-T
deepwater sculpin	Myoxocephalus thompsonii	DS,DSS			MA>3-T	I,S	BI-T,IN-T
Temperate Basses	Moronidae						
white perch	Morone americana	EX,PERC			MA>3-T		IN-T
white bass	Morone chrysops	PERC			MA<2		PI
yellow bass	Morone mississippiensis	PERC			MA>3-T		PI
Sunfishes	Centrarchidae						
rock bass	Ambloplites rupestris	PERC			MA>3-T,NE	S	PI
green sunfish	Lepomis cyanellus	PERC		PI	MA<2,NE	T,TCW,VT	GE
pumpkinseed	Lepomis gibbosus	PERC			MA<2,NE		IN-T
warmouth	Chaenobryttus gulosus	PERC			MA<2		PI
orangespotted sunfish	Lepomis humilis	PERC			MA<2,SER	T,TCW,VT	
bluegill	Lepomis macrochirus	PERC			MA<2,NE,SER		IN-T
longear sunfish	Lepomis megalotis	PERC			MA<2,NE	I,S	IN-T
hybrid sunfish	Lepomis hybrid					T,TCW	
Gen: common sunfishes	Lepomis						IN-T
smallmouth bass	Micropterus dolomieu	PERC			MA>3-T,NE	I,S	PI
largemouth bass	Micropterus salmoides	PERC			NE		PI
Gen: Micropterus	Micropterus						PI
white crappie	Pomoxis annularis	PERC			MA<2,NE		PI
black crappie	Pomoxis nigromaculatus	PERC			NE		PI
Gen: crappies	Pomoxis						PI
Perches	Percidae						
western sand darter	Ammocrypta clara	DS,DSS,PERC		SL	MA<2,SER,SILI	I,S	BI-T,IN-T

Appendix D (continued)

crystal darter	Crystallaria asprella	DS,DSS,PERC		SL	MA<2,SER,SILI	I,S	BI-T,IN-T
mud darter	Etheostoma asprigene	DS,DSS,PERC		SL	MA<2	S	BI-T,IN-T
rainbow darter	Etheostoma caeruleum	DS,DSS,PERC			MA<2,SER,SILI	S,SCW	BI-T,IN-T
bluntnose darter	Etheostoma chlorosomum	DS,DSS					BI-T,IN-T
Iowa darter	Etheostoma exile	DS,DSS,PERC	WE-T	SL	MA<2	S	BI-T,IN-T
fantail darter	Etheostoma flabellare	DS,DSS,PERC	HW-T		MA<2,SER	S,SCW	BI-T,IN-T
least darter	Etheostoma microperca	DS,DSS,PERC		SL	MA<2,SER	I,S	BI-T,IN-T
johnny darter	Etheostoma nigrum	DS,DSS,PERC		PI	MA<2,NE		BI-T,IN-T
banded darter	Etheostoma zonale	DS,DSS,PERC			MA<2,SER,SILI	S	BI-T,IN-T
Gen: Etheostoma	Etheostoma	DS,DSS					BI-T,IN-T
ruffe	Gymnocephalus cernuus	EX			MA<2,SER	T,TCW	
yellow perch	Perca flavescens	PERC	WE-T		MA>3-T		IN-T
logperch	Percina caprodes	DS,DSS,PERC			MA<2,SILI	I,S	BI-T,IN-T
gilt darter	Percina evides	DS,DSS,PERC			MA<2,SILI	I,S	BI-T,IN-T
blackside darter	Percina maculata	DS,DSS,PERC			MA<2,SILI		BI-T,IN-T
slenderhead darter	Percina phoxocephala	DS,DSS,PERC			MA<2,SILI	S	BI-T,IN-T
river darter	Percina shumardi	DS,DSS,PERC		SL	MA<2,SILI	I,S	BI-T,IN-T
Gen: Percina	Percina	DS,DSS			SILI		BI-T,IN-T
sauger	Sander canadensis	PERC			MA>3-T,SILI		PI
walleye	Sander vitreus	PERC			MA>3-T,SILI		PI
saugeye	Sander hybrid	PERC			SILI		PI
Gen: Sander	Sander				SILI		PI
Drums	Sciaenidae						
freshwater drum	Aplodinotus grunniens	PERC			MA>3-T		IN-T
Gobies	Gobiidae						
round goby	Neogobius melanostomus	EX			MA>3-T,NE,SER		PI
tubenose goby	Proterorhinus marmoratus	EX					IN-T

Development of a Macroinvertebrate-Based Index of Biological Integrity for Minnesota's Rivers and Streams



Minnesota Pollution Control Agency

June 2014

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1. Overview

This report documents the development of a macroinvertebrate community-based Index of Biological Integrity (M-IBI) for Minnesota's streams and rivers. The primary intended use for this tool is the assessment of aquatic life use support by the Minnesota Pollution Control Agency (MPCA). More detailed descriptions of biomonitoring, bioassessment, biological assessment guidance (MPCA 2012c), human disturbance score (HDS) (MPCA 2012d), and biological condition gradient (BCG) can be found in other documents.

The passage of Minnesota's Clean Water Legacy Act (CWLA) in 2006 provided a policy framework and resources to state and local governments to accelerate efforts to monitor, assess, and restore impaired waters, and to protect unimpaired waters. With the passage of the Clean Water, Land and Legacy Amendment in 2008, additional funding was made available to the MPCA and its partner agencies to continue and expand on the efforts outlined in the CWLA.

Beginning in 2007, the MPCA began using a 10-year, rotating watershed approach for the comprehensive monitoring and assessment of Minnesota's rivers and lakes. While the MPCA has used indices of biological integrity and chemical measures together to assess the integrity of streams since the mid-1990s, IBIs previously developed for assessing Minnesota's rivers and streams were applicable to specific regions of Minnesota and could not be used statewide. In order to conduct biological assessments in every watershed, it was necessary for the MPCA to develop new indicators that were applicable to the entire state of Minnesota. Biological assessments are a particularly powerful tool as they provide an accurate measure of the condition of the biological communities and are a direct determinant of the attainment of aquatic life uses. As a result, the development and implementation of a robust biological monitoring and assessment program is integral to Minnesota's goals of protecting and restoring the integrity of aquatic resources.

Development of the M-IBI utilized a standardized protocol developed by researchers from the United States Environmental Protection Agency and elsewhere (Whittier et al. 2007). Minnesota's streams and rivers were first partitioned into five distinct classes, and a unique IBI was developed for each. Within each stream class, biological metrics were sequentially ranked and eliminated by a series of tests, and selected for inclusion in each IBI. Among the most important tests was an evaluation of each metric's ability to distinguish most-disturbed sites from least-disturbed sites.

This document describes the process used in the development of M-IBI for Minnesota's rivers and streams, representing the state's first comprehensive, statewide tool for assessing the biological integrity of riverine macroinvertebrate communities. These indices will be utilized during the first iteration of the 10-year watershed monitoring and assessment cycle.

2. Introduction

Waterbody monitoring and condition assessment provide resource managers with information needed to guide restoration and protection efforts. A wide variety of indicators are used in water monitoring and assessment programs, but among the most useful are those that integrate and reflect cumulative impacts to aquatic systems. The degradation of surface waters can be attributed to multiple sources including: chemical pollutants from municipal and industrial point source discharges; agricultural runoff of sediment, nutrients, and pesticides; hydrologic alteration in the form of ditching, drainage, dams, and diversions; and habitat alteration associated with agricultural, urban, and residential development. The timing and magnitude of these impacts may vary through time, and be difficult to detect and measure utilizing traditional chemical evaluations that focus on a single indicator or small suite of parameters.

However, biota reside in these waterbodies, utilize the available aquatic habitats, and have life spans ranging from weeks to years. They experience the entire spectrum of environmental conditions, including stressors caused by human activities. Aquatic biota are known to be responsive to a wide variety of anthropogenic impacts and, at the community level, reflect the integrated result of physical, chemical, and biological processes through time (Barbour et al. 1999). In this manner, aquatic communities provide a direct, comprehensive perspective on water quality, and lend themselves well to tools that utilize community-level parameters, such as the Index of Biological Integrity (IBI).

The IBI was originally developed as a tool for assessing the condition of rivers and streams in the Midwestern United States (Karr 1981, Karr et al 1986). The concept has since been expanded to a wide variety of geographic regions and ecological systems, and has demonstrated its effectiveness in several applications (e.g. condition monitoring, stressor identification). At its core, the IBI provides a framework for translating biological community data into information regarding ecological integrity ("the capability of supporting and maintaining a balanced, integrated, functional organization comparable to that of the natural habitat of the region", Frey 1977). It utilizes a variety of attributes ("metrics") of the biological community, each of which responds in a predictable way to anthropogenic disturbance. The metrics are based on ecological traits of the organisms present at a given site, represent different aspects of ecological structure and function, and are scored numerically to quantify the deviation of the site from least-disturbed conditions. When the individual metric scores are summed together, the composite IBI score characterizes biological integrity (Karr et al 1986).

The composite IBI score is typically compared to a threshold to assess a waterbody's condition. However, it is also possible to deconstruct the index into its component metrics to determine which aspects of ecological structure and function are particularly robust or diminished at a given site. Relationships between specific stressors and the composite IBI or component metrics can be explored, and the trait-environment linkages that underlie the IBI concept extended to diagnostic applications (Culp et al 2010). The stressor-response relationships implicit in the IBI concept may provide important information towards stressor identification and the development of watershed protection and restoration strategies.

Since the 1990s, the MPCA has utilized the IBI concept in its stream monitoring and assessment program. Narrative language within Minnesota Administrative Rule identifies an IBI calculation as the primary determinant for evaluating impairment of aquatic biota (Chapter 7050.0150, subp. 6, Impairment of biological community and aquatic habitat). Details regarding the development and calibration of the IBI are included in an associated Statement of Need and Reasonableness, and use of this framework has been upheld in legal proceedings challenging its use.

In 2003 and 2004, IBIs based on macroinvertebrate communities were developed for streams in specific major basins of Minnesota, and used to conduct Aquatic Life Use assessments. Invertebrate IBIs were developed for the St. Croix River Basin (Chirhart, 2003), and the Upper Mississippi River Basin (Genet and Chirhart, 2004) (Figure 1). However, nearly three fourths of Minnesota's rivers and streams were not covered by these IBIs (Table 1). In 1993, macroinvertebrate data collected in the Minnesota River Basin was analyzed (Zischke and Ericksen, 1993) by looking at several aspects of the macroinvertebrate community, as well as by using an index developed for Ohio's river and streams (Ohio EPA, 1987a, 1989a). Since the index used in the Minnesota River Basin was not developed and calibrated for Minnesota streams, is was not used for aquatic life use assessment for streams subsequently sampled in the basin.

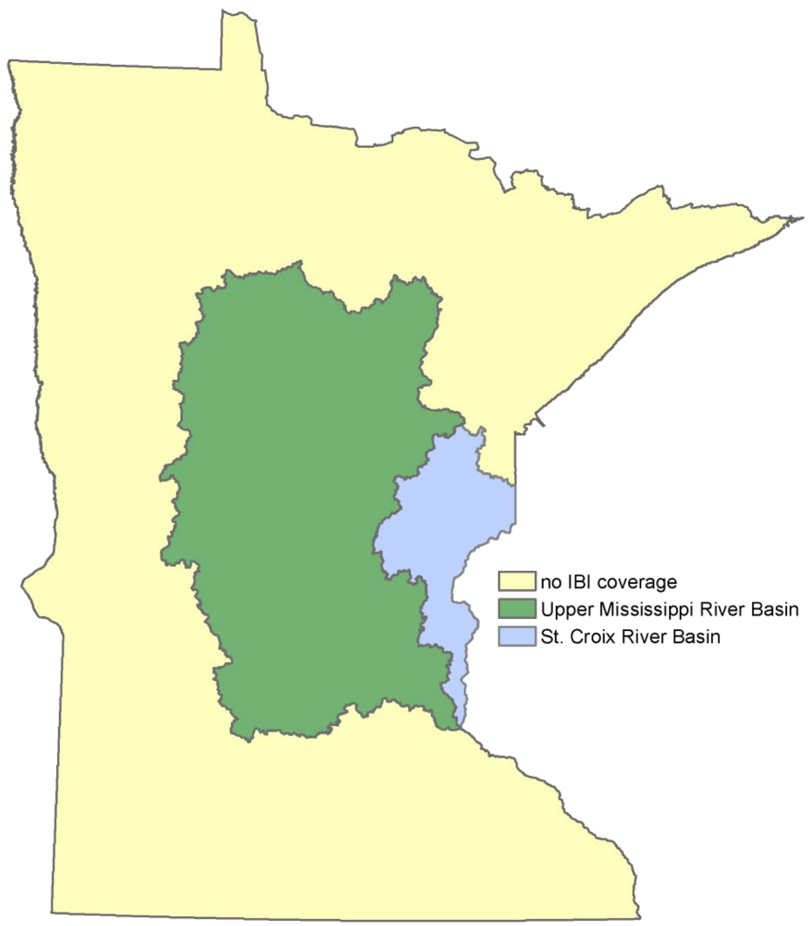


Figure 1. Map of Minnesota depicting regions previously encompassed (2003-2004) by macroinvertebrate IBIs.

Table 1. Sum of stream miles covered by previously existing macroinvertebrate IBIs (2003-2004), and percentage of Minnesota's total stream miles covered by each.

Index of Biotic Integrity	Stream Miles	Percentage
St. Croix River Basin	3775	3.7%
Upper Mississippi River Basin	19942	19.6%
No IBI	77782	76.60%

Passage of Minnesota's CWLA in 2006, and the Clean Water, Land and Legacy Amendment in 2008 accelerated efforts to monitor, assess, restore, and protect the state's water resources. With this increased emphasis on water quality, it became evident that monitoring and assessment tools applicable on a statewide scale were needed, and that the resources necessary to develop those tools were available. Our objective was to develop a series of IBIs for assessing the condition of fish communities in rivers and streams across the state of Minnesota.

In this document, we describe the development and calibration of macroinvertebrate-based Indices of Biological Integrity for streams and rivers across the State of Minnesota. Using a methodology developed by researchers at the U.S. Environmental Protection Agency's (U.S. EPA) (Whittier et al 2007), metrics representing the structure and function of Minnesota's stream macroinvertebrate communities were systematically tested for inclusion in IBIs based on statistical criteria (e.g. responsiveness to disturbance, strong signal, low noise, etc.). These IBIs will be used in conjunction with numeric biocriteria to assess the biological integrity of Minnesota's rivers and streams, and, in conjunction with water chemistry data and standards, to assess whether waterbodies are meeting their designated Aquatic Life Uses as outlined in Minnesota Rules and the federal Clean Water Act.

3. Methods

3.1 Study Area

The State of Minnesota lies in a water-rich region, at the headwaters of three major continental watersheds (Gulf of Mexico, Laurentian Great Lakes, Hudson Bay) and at the intersection of western prairies, eastern deciduous forests, and northern boreal forests (Figure 2). Much of the state lies in a transition zone between these ecotypes, and its watercourses reflect this diversity. A wide variety of rivers and streams are found within Minnesota's borders, including: short, steep bedrock-controlled cascades; broad, meandering prairie rivers; clear, cold spring-fed creeks; and tannic, low-gradient streams draining large bogs and swamps. The diversity of aquatic invertebrate fauna is a reflection of the diversity of its stream and ecotypes. Additionally, Minnesota is located at a crossroads for the distribution of many North American freshwater invertebrate taxa; many taxa in Minnesota exist at the geographic extremes of their native distributions.

Humans have substantially modified the landscape of Minnesota. Most of the native prairies have been converted to agricultural land, with extensive systems of surface and subsurface drainage. Nearly all of the native forests have been logged at some point in the past 150 years. Urban areas have been steadily expanding in all regions of the state. Associated with this transformation, many of Minnesota's waterbodies have experienced historical and ongoing impacts, including stressors related to agricultural practices, urbanization, mining, logging, channel modification, and industrial discharges. However, substantial portions of the state have retained natural vegetative cover, relatively intact stream habitats, and connectivity within watersheds. The contemporary structure and function of Minnesota's stream ecosystems are shaped by these interacting factors of natural variability and human disturbance; the resulting level of biological integrity can be interpreted by tools such as the IBI.

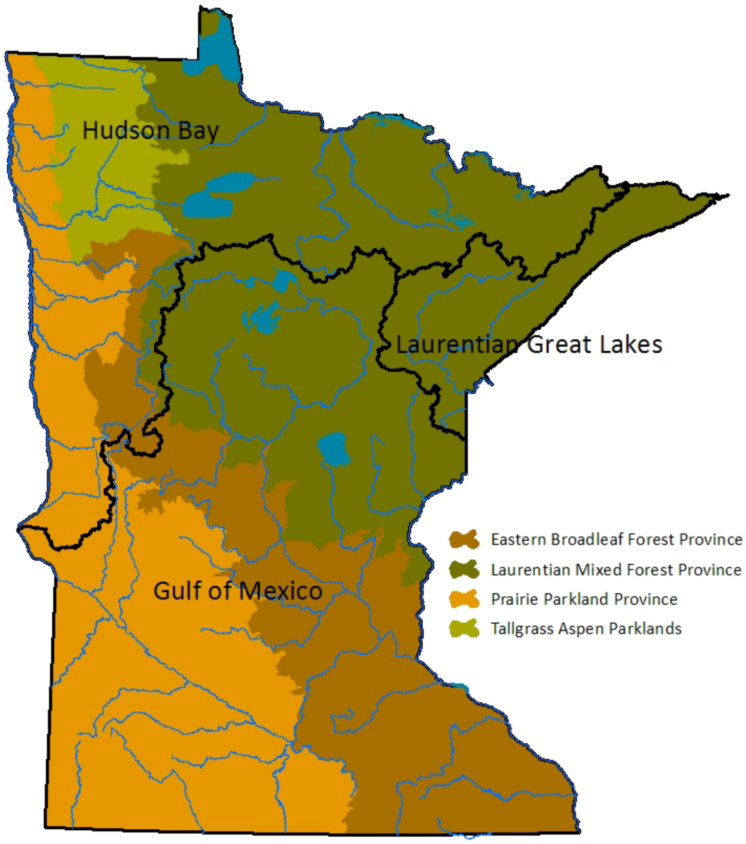


Figure 2. Map of Minnesota depicting major ecotypes (MDNR ECS Provinces), continental watersheds, major rivers and large lakes.

3.2 Program details

The Biological Monitoring Unit of the MPCA's Environmental Analysis and Outcomes Division conducts ecological surveys on rivers and streams across the state. Since the early 1990s, an extensive dataset has been maintained, describing physical, chemical, and biological characteristics of rivers and streams. As of late 2012, more than 3,500 individual stream invertebrate collection efforts are represented, from more than 3,000 monitoring sites across the state. The vast majority of these surveys were conducted by MPCA staff. These data are used to support waterbody condition assessments in concordance with state and federal requirements (Anderson et al. 2012, Figure 3).

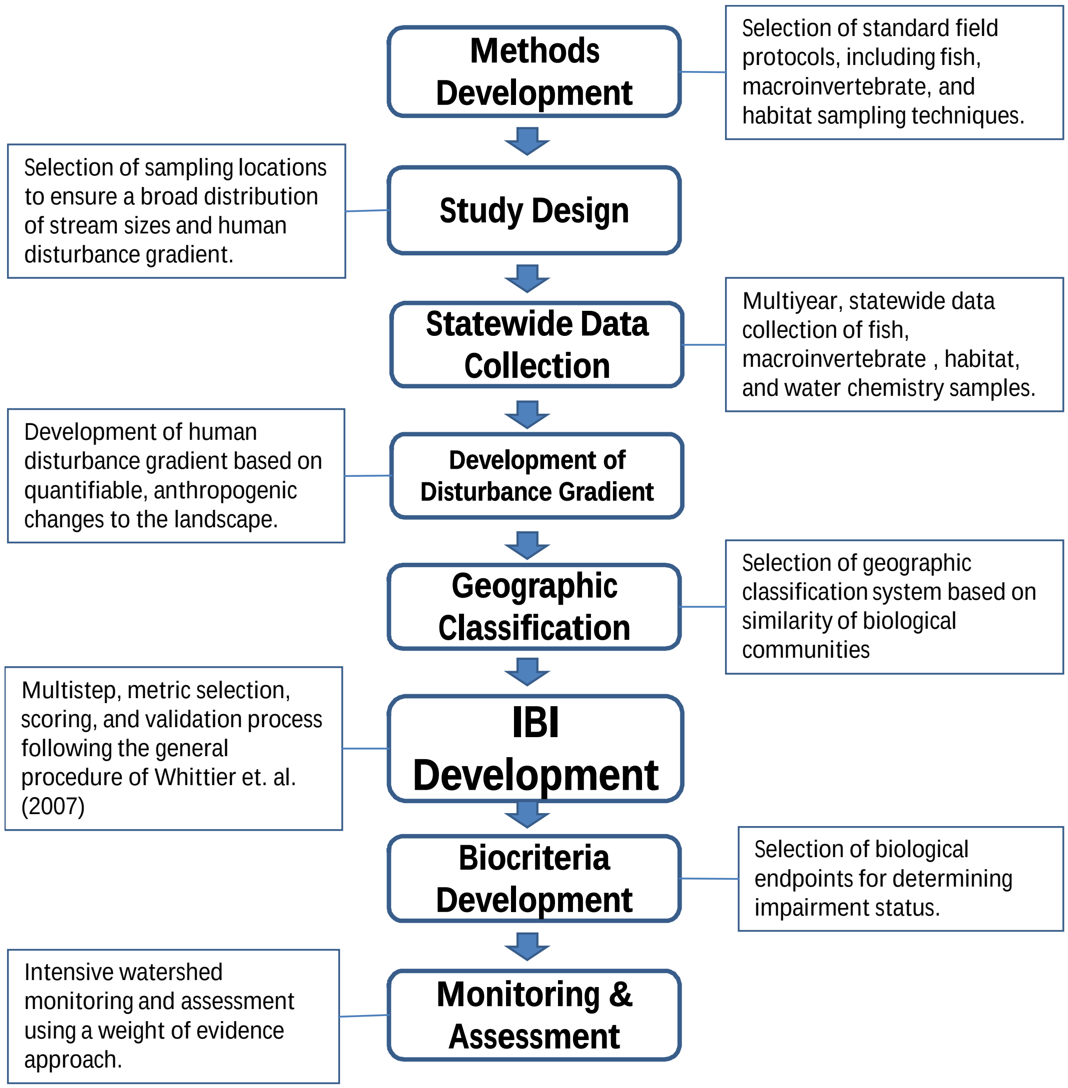


Figure 3. IBI Development process used by the MPCA

3.3 Field Methods and Processing

Field sampling was conducted during late summer base-flow conditions, August through October, with the majority of the data collected in August. Samples were collected using a d-frame dipnet with a .25 square meter opening, and a 500 micrometer mesh net. Stream reaches were established during field reconnaissance in the spring. In both wadeable and non-wadeable environments macroinvertebrate samples were collected in reaches representing 35 times the mean stream width, with a minimum reach length of 150 meters, and a maximum reach length of 500 meters (reference recon sop). Macroinvertebrate samples were collected from four primary habitats in each reach: riffle-runs, undercut banks, aquatic macrophytes, and woody debris. Sampling consisted of dividing 20 sampling efforts equally among the prevalent primary habitats present in the reach. For example, if four habitats were present in the reach, five samples were collected in each habitat (Chirhart, 2010).

Macroinvertebrate samples were processed in the laboratory using a quantitative subsampling technique and a qualitative large/rare pick. Samples were placed in a gridded tray, and random grids were picked until a minimum of 300 organisms was obtained. Each grid was picked in its entirety unless doing so would increase sample size above 20% of the target number. In this case grids were further divided and subdivided grids were randomly selected and completely picked. After the 300 organism target was reached, an additional qualitative pick was conducted, targeting large or rare organisms. Taxa added from the additional pick were applied to taxonomic richness measures. These individuals were kept separate from the initial subsample for the purposes of metric calculation to ensure that relative abundance measures were not affected.

Field habitat parameters were also collected at all sites used in the IBI development process. At wadeable streams a quantitative habitat evaluation was done (MPCA, 1998). The quantitative habitat evaluation consisted of dividing the established stream reach into 11 transects, and evaluating in-stream physical habitat characteristics, condition of stream banks, the extent and condition of the riparian zone and adjacent landuse, and the availability of cover for fish and macroinvertebrates at each transect. Measurements were also taken characterizing the channel characteristics of the entire reach, including the number, extent, and spacing of riffles, pools, runs, logjams, and bends. Water chemistry parameters were collected at all sites, and stream flow was collected at all wadeable sites (reference habitat and chemistry sop). At both wadeable and non-wadeable streams a qualitative habitat evaluation was done using the Minnesota Stream Habitat Assessment (MSHA) protocol (MPCA, 2002). The MSHA consists of assigning categorical scores on the reach scale to landuse, riparian zone, instream habitat, and channel morphology characteristics. The end result of the MSHA was a habitat score allowing the ranking of sites based on habitat quality.

3.4 Study Design/Site Selection

From 1996 through 2007, the primary objectives of the MPCA Biological Monitoring Program were to collect data for the purposes of determining biological condition at the 4-digit HUC basin scale, and the development of indices of biotic integrity. Sites were selected for basin wide condition monitoring using a random survey design established by the U.S. EPA's Environmental Monitoring and Assessment Program (EMAP). The target population was all perennial streams and rivers within Minnesota, excluding the Mississippi River in the Lower Mississippi River Basin, that were incorporated into U.S. EPA's reach file 3. Sites were selected separately for each of Minnesota's ten major basins. Within each basin sites were grouped by Strahler order class: 1^{st}, 2^{nd}, 3^{rd}, and 4^{th}+. Site selection was weighted to achieve equal distribution of sites across each of the Strahler order classes. The target sample size was 50 for the larger basins, and 25 for the smaller basins (Cedar River, DesMoines River, Missouri River).

Sites selected for the development of biotic indices were chosen to represent the spectrum of the human disturbance gradient present in each basin. Specifically, sites were targeted at the upper and lower ends of the disturbance gradient to fill in gaps left by the random surveys. We also attempted to fill in spatial gaps to ensure a comprehensive geographic coverage. In 2006, the MPCA data collection effort began a transition to an intensive watershed survey design. This intensive design is focused on the 8-digit HUC watershed scale. Sites are located throughout the watershed at the pour points of smaller watersheds, in order to provide a comprehensive perspective of watershed health. Data collected as part of this effort was used to supplement the IBI development dataset where data gaps were present.

3.5 Human Disturbance Score

A composite Human Disturbance Score (HDS) was developed to represent potential cumulative anthropogenic disturbance experienced by stream environments, assessed at both a reach- and watershed scale. The disturbance metrics selected for inclusion in the HDS are grounded in the concept of a "Generalized Stressor Gradient" (U.S. EPA 2005), and are evaluated on a site-by-site basis, using readily-available statistics on land use, feedlot and point source density and proximity, reach- and watershed-scale channelization, impervious surfaces, road density, and riparian conditions (Table 2). Eight primary metrics are first individually scored on a 0 (highly disturbed) to 10 (minimally disturbed) scale and summed to derive a composite score. Metric scores represent rescaled (0-10) values for each stressor variable, after excluding values greater or less than three times the interquartile range.

Up to seven additional "adjustment" metrics are then applied, each of which potentially deducts one point from the composite score. One of the adjustment metrics (watershed road density) may also result in the addition of a point. The final, composite Human Disturbance Score ranges from a minimum of 0 (highly disturbed) to a maximum of 81 (minimally disturbed).

3.6 Stream Classification

Indices of biological integrity provide numeric expressions of the structure of biological communities. We understand that community structures can change along natural gradients such as watershed size, gradient, and geographic location. To facilitate the development of IBIs, we attempted to develop a geographic stream classification framework for Minnesota streams based on natural differences of aquatic macroinvertebrate communities. Biological communities are affected by both broad (e.g. ecoregion) and reach-scale (e.g. stream gradient) deterministic processes. These processes are in turn influenced by the history of natural and anthropogenic impacts that have occurred in the stream channel and on the landscape. Anthropogenic influences are so significant that it is nearly impossible to factor out their influence when characterizing biological communities, as very often changes to the landscape followed natural landscape patterns. To develop a framework reflective of the natural potential of the biological community, we used least impacted reference sites, and considered broad and reach scale parameters with minimal potential influence by anthropogenic changes. Parameters, such as nutrients or total suspended solids, while naturally occurring, were not considered as potential variables because of the strong potential for anthropogenic sources of influence.

Table 2. Human Disturbance Score metrics

HDS Metric Description	Scale	Category	Scoring Range
animal unit density	watershed	land use	0-10
percent agricultural land use	watershed	land use	0-10
percent impervious surface	watershed	land use	0-10
feedlot density	watershed	land use	-1
percent agricultural land use within 100m riparian buffer	watershed	land use	-1
road/stream intersection (road crossing) density	watershed	land use	-1 or +1
percent agricultural land use on ≥3% slope	watershed	land use	-1
urban land use proximity	local	land use	-1
point source density	watershed	point source	0-10
point source proximity[1]	local	point source	-1
feedlot proximity	local	point source	-1
percent disturbed riparian habitat	watershed	riparian	0-10
riparian condition rating	local	riparian	0-10
percent of stream distance modified by channelization	watershed	channelization	0-10
site channelization rating	local	channelization	0-10

[1] applies only to streams with watershed area <50 square miles

To ensure a consistent dataset for classification analysis, we developed operational taxonomic units (OTUs) at the genus and family level, and reduced data resolution at each site when needed using an approach which removes ambiguous parent taxa when their abundance is less than the collective abundance of their children taxa (Appendix A). This approach was applied to the dataset on a statewide scale.

Stream classification was carried out separately for warm- and coldwater streams. The distinction between the two thermal classes was largely based on whether a site was located on a Minnesota Department of Natural Resources (MDNR) Designated Trout Stream, but some consideration was given towards whether coldwater fish species (e.g., trout, sculpin) were present or known to have been present in the past. A few sites on Designated Trout Streams were excluded from the Coldwater dataset, and vice-versa.

To further refine invertebrate classification analysis, we assigned each site a gradient class based on the types of habitat sampled, qualitative and quantitative habitat measurements, and observations of flow at the time of sampling. Sites in which riffles or rocky habitat were sampled, that had observable turbulent flow over riffle areas, or higher flow over deeper rocky habitats, were considered high gradient. Sites that did not meet this criteria were considered low gradient. A decision tree was used in conjunction with a weight of evidence approach when gradient classification was not clear. (Appendix B)

Within each dataset (warmwater, coldwater), a set of least-disturbed sites was identified based on the 75th percentile threshold of the HDS distribution. The classification analyses were carried out using both the least-impacted dataset and the full dataset of all eligible sites. While the most emphasis was placed on patterns emerging from the least-impacted dataset, the entire dataset was analyzed in a similar manner to provide supplementary information.

We used a two-step analytical process to evaluate various regionalization schemes to determine which classification best explained the variation in the biological data. The regionalization schemes included combinations of *a priori* geographic classifications and hydrological and reach scale parameters. Regionalization schemes for testing site classes included geographic boundaries of ecoregion (level 2, 3, 4) (Omernik, 1995), MDNR Ecological Classification System provinces (Hansen and Hargrave, 1996), 4-digit HUC drainage basins, and latitudinal/watershed areas, as well as drainage area, gradient, and site habitat characteristics. The first step included using Hierarchical Cluster Analysis to define groups of sites based on community similarity. Hierarchical cluster analysis defines groups of sites such that sites in each group are more similar to each other than sites in other groups. Clusters ranging from 2 to 15 site groups were analyzed geospatially, and summary statistics were calculated to examine relationships with natural variables. Observations of strong geographic groupings, or strong relationships with natural variables were used to determine potential classes to be analyzed in classification strength analysis. Non-metric multidimensional scaling (NMS) was used to visualize the relationship between different classification schemes in ordination space. Ordination used Bray-Curtis dissimilarities, which is considered robust for ecological analysis. A matrix of *a priori* and derived geographic classes and natural variables was used to create a series of possible classification schemes to be analyzed with ordination. The selection and analysis of environmental variables proceeded in an iterative manner, with candidate classification variables tested at different levels of partition and in combination with other variables. The strongest classifications resulting from Cluster and Ordination analyses were used to inform variable selection for classification strength analyses. Mean Similarity Analysis (MEANSIM, Van Sickle, 1998) was used to evaluate classification strength of groups by measuring within-class and between-class dissimilarity; it was used to evaluate the classification strengths of the various regionalization schemes. Each regionalization scheme was ranked based on classification strength and examined in geographic and ordination space, to determine the strongest final classification framework. The final choice was based on a balance of classification strength, compatibility with currently used frameworks, and a desire to have a reasonable number of final classes for which IBIs would be developed.

Following initial classification analysis a comparative analysis of peak community level information between potentially overlapping classes was conducted by a group of regional biologists. Genus and species level data of peak communities can reveal patterns that are masked by ordination techniques when rare community information is not included. Patterns revealed in this analysis were used to modify and retest initial classification schemes for classification strength. Each class within the strongest classification framework resulting from the classification strength analysis was analyzed to ensure an adequate range of human disturbance for metric testing and validation. An inadequate distribution of sites in either the high or low range of human disturbance can make it difficult to validate metrics on a human disturbance gradient, leading to a low number of metrics passing metric testing criteria.

Ultimately, a classification framework was developed that divides lotic sites into nine “invertebrate classes”, differentiated by region, drainage area, gradient, and thermal regime (Appendix A). An IBI was developed for five individual invertebrate class groupings, with high gradient and low gradient stream classes being combined for the purposed of metric testing and evaluation due to a lack of adequate disturbance gradient.

3.7 IBI Development Dataset

Warmwater streams were prioritized for Index of Biological Integrity (IBI) development because they make up the vast majority (>90%) of Minnesota’s stream miles and a sufficient dataset existed by 2009. Coldwater streams make up less than 10% of Minnesota’s stream miles, and evaluation of existing data indicated that additional, targeted sampling in 2010 was required to assemble a suitable IBI development dataset. The definition of “warmwater stream” used in this analysis encompassed all non-coldwater streams, including some that might be properly classified as “coolwater.” Warmwater IBI development began in 2009 and was completed in early 2010; coldwater IBI development began following the supplemental field sampling carried out in the summer of 2010, and was completed in early 2011.

Data used for the development and validation of the macroinvertebrate-based Index of Biological Integrity (M-IBI) was collected by the MPCA from 1996 to 2010. Data used for development of the warmwater MIBIs was primarily collected from 1996 to 2008.

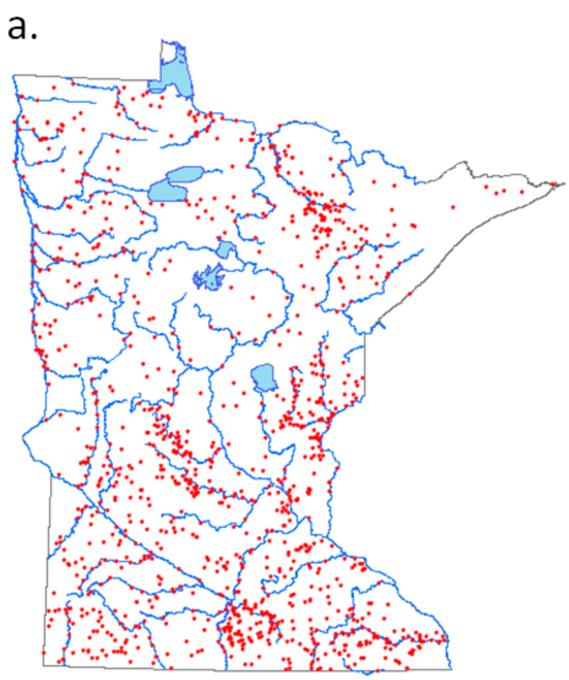


Figure 4. Maps of (a) warmwater and (b) coldwater stream monitoring sites used to develop M-IBI for the State of Minnesota. Large lakes and major rivers are also depicted.

Additional data was collected from coldwater streams through 2010 for the development of coldwater MIBIs. The 2,217 samples were collected in this period, of which 1,502 samples were used for IBI development. Samples were excluded due to study design variations or drought conditions at the time of sampling that made the associated data unsuitable for IBI development. We divided the data into calibration and validation data sets. One third of all sites were randomly selected and assigned as validation data. Only the calibration data was used for metric testing. Reference site data from both calibration and validation data sets was used to evaluate correlation with natural gradients, and to determine the resulting correction factors. Final metric and index scoring was based on the calibration dataset only. Of the 1,502 samples used for IBI development, 150 were from within year revisits. Revisit data was used to determine metric precision (signal-to-noise test), and in the development of error values for the final MIBI. In sites with more than one visit, the most recently collected sample was used for MIBI development and validation. All data was recorded electronically, and stored in a Microsoft Access database. The database was developed to automatically generate 248 metrics, all of which were evaluated in the MIBI development process. The metrics represented tolerance ranges, functional feeding and behavior groups, and taxonomic groups. Many of the metrics tested were expressed in three different manners; taxa richness, relative abundance of taxa within the subsample, and relative richness of taxa within the subsample. Some metrics were calculated with the Chironomidae grouped at both the family level, and the genus level. The HBI metrics, and all tolerance value metrics, were calculated using previously developed tolerance values (Hilsenhoff, U.S. EPA), as well as tolerance values developed using data only from Minnesota

3.8 Taxonomic Characteristics

An autecology database based on previously published sources was developed for all taxa collected where data was available, the primary source of information was a draft of the Freshwater Biological Traits Database (2012, U.S. EPA). Information for each taxon included traits such as functional feeding group, life habitat, legless condition, and lifespan. We assigned taxa tolerance values based on a generalized disturbance measure, and coldwater sensitivity values based on stream temperature readings. The disturbance measure used was the first principal component of a principal components analysis of six disturbance variables – HDS, Minnesota Stream Habitat Assessment score, total phosphorus, TSS, NH4, and nitrate/nitrite. Tolerance and coldwater sensitivity values were calculated using a weighted average approach, using taxa relative abundances as the weighting factor. Tolerance values were examined two ways, by looking at the weighted average, and weighted average plus it is standard deviation. The addition of the standard deviation is a way to understand the upper tolerance range of each taxa. For the generalized disturbance gradient, the upper tolerance range was used as the final tolerance score. For taxa that we did not have more than 10 records for, tolerance values previously develop in other regions were used.

3.9 Metric Evaluations

After an analysis of stream classification we decided to evaluate metrics at two different spatial scales due to a lack of disturbance gradient associated with four classes. We evaluated metrics at each of the classes resulting from the classification work, as well as at five broad streams types also determined to show strong classification strength. The same process was used for each stream group separately.

For warmwater streams, 230 candidate metrics were calculated from invertebrate community data. The coldwater IBI development effort included an additional five metrics for a total of 235 (Appendix B). Metrics were summarized in three ways (taxa richness, relative taxa abundance, and relative taxa richness), and were assigned to one of seven metric classes (taxa richness, composition, tolerance, life history, habitat, reproductive, trophic), intended to represent different components of biotic integrity.

To develop each IBI we evaluated metrics using a series of tests, following the general procedure of Whittier et al (2007). Metrics were tested, eliminated or selected, and scored separately within each of the nine stream classes using the same methodology throughout. The IBI development dataset was used for each test unless otherwise noted.

3.9.1 Range Test and Metric Transformation

Metrics with poor range are unlikely to differentiate disturbed and non-disturbed sites because the response gradient is highly compressed. We eliminated richness metrics if the range was less than three species and eliminated any metric if more than 75% of the values were identical.

In cases where the distribution of metric values within a class was highly skewed, transformation was used to normalize the data (or reduce skew). Several transformations were considered, including: log10, natural log, square root, and arcsine square root. Metrics were not rejected if a normal distribution could not be achieved but, in general, we attempted to reduce absolute skew values to less than one through transformation of metric values. The metric scoring process (described below) also reduced skewness in many cases.

3.9.2 Signal-to-noise test

The precision of metric values can be evaluated by comparing variance among sites ("signal") to variance within sites ("noise") (Kauffmann et al 1999). The "noise" portion of this comparison was determined by sampling a subset of sites twice within the index period of the same year. Low "signal-to-noise" ratios (S:N) indicate low-precision metrics that are unable to distinguish well among sites (Whittier et al 2007). We used a conservative approach in evaluating metric precision, calculating S:N on a statewide basis rather than individually within each class. Metrics with S:N less than two were eliminated from the candidate metric pool. In a few cases, metrics with S:N values slightly below the established threshold were allowed to "pass" this test if a strong conceptual basis existed for inclusion.

3.9.3 Correlation with natural gradients

The classification of sites into different stream classes minimized the influence of natural gradients on metric response. However, we also evaluated each metric against natural gradients within each class to further ensure that metric response was not obscured or amplified. To minimize the potentially covarying effect of human disturbance, natural gradient relationships were evaluated using the subset of least-disturbed sites within each class. We used simple linear regression to evaluate the relationship between metric values, watershed area, and stream gradient, examined plots of the data points, and calculated correlation coefficients for the relationship. For metrics where a significant (α=0.05) relationship existed and the correlation coefficient (r^2) was greater than 0.3 (or the relationship was deemed "strong" through visual inspection of plots), we derived a natural-gradient corrected metric by calculating the residual for all sites based on the regression equation. This "adjusted" metric value then replaced the original metric in the IBI development process. Both calibration and validation datasets were used to determine whether natural gradient correction was necessary, to ensure consistency across both datasets.

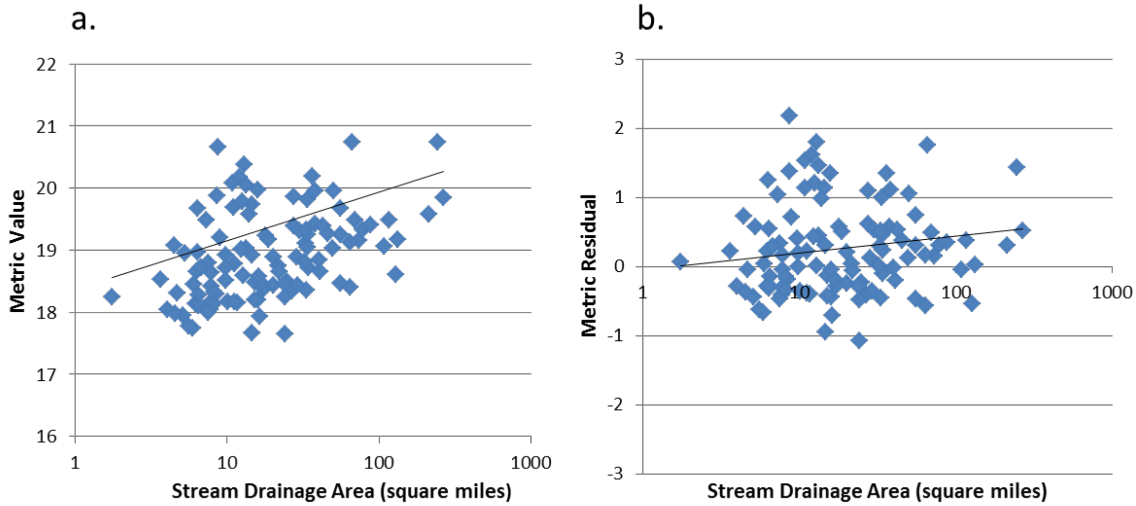


Figure 5. Example of metric value relationships with a natural gradient before and after correction. Metric value is Coldwater Biotic Index in the Southern Coldwater M-IBI class. Raw metric values (a) demonstrate a positive relationship with stream gradient. Replacing metric values with the residual values from a simple linear regression (b) reduces or eliminates the natural gradient relationship.

3.9.4 Responsiveness test

To test metric responsiveness to human disturbance, we used the non-parametric Mann-Whitney U test to evaluate the difference between metric values at least- and most-disturbed sites. The magnitude of the Mann-Whitney p-value was used to gauge responsiveness, essentially the ability of a metric to distinguish least-disturbed sites from most-disturbed sites. Spearman rank correlation between metric values and HDS was also used to evaluate metric responsiveness, primarily by ranking metrics with similar p-values according to their Spearman r_s value. Finally, box plots of metric values within each disturbance quartile were also used to visually assess metric responsiveness. Non-responsive metrics (i.e. those with non-significant *U*-statistics at the p=0.05 level) were eliminated from the candidate metric pool. The validation dataset was used to confirm the responsiveness of metrics with significant Mann-Whitney p-values; if a metric's validation dataset produced a non-significant difference, it was eliminated. In a few cases, metrics at or near the responsiveness threshold were allowed to pass the test if a strong conceptual rationale existed for inclusion. IBI development and validation datasets were evaluated separately, and metrics were considered responsive if they passed this test for both datasets

3.9.5 Redundancy test

A correlation matrix of metric values was created to examine metric redundancy and avoid selecting IBI metrics that contained redundant information. We evaluated redundancy using the subset of least-disturbed sites within each class, to avoid rejecting metrics simply because their response to disturbance was similar. We also evaluated metric redundancy using all sites, regardless of disturbance level, but more emphasis was given to correlations in the least-disturbed dataset. In general, we considered metrics to be redundant when their Spearman correlation coefficients were greater than 0.7. However, "conceptual redundancy" was also considered in cases where the Spearman coefficient approached the threshold; metrics were sometimes included despite Spearman correlations greater than 0.7 if we considered them to represent distinct components of biological integrity, and sometimes rejected despite Spearman correlations less than 0.7 if we considered them to be conceptually redundant.

Within each class, metrics that passed the Range, Signal-to-Noise, and Responsiveness tests were ranked by their Responsiveness *F*-statistic (most responsive to least responsive). Metrics were selected for inclusion in the IBI in order of descending *F*-statistic, provided they were not redundant with more-responsive metrics. To obtain representation across the seven metric classes, a maximum of two non-redundant metrics from any single metric class was chosen until each class was represented by at least one metric. In some cases, it was not possible to select a metric from each metric class, due either to a lack of metrics passing earlier tests, or redundancy with highly-responsive metrics.

3.9.6 Range test for metric scores

In cases where box plots and scatter plots indicated that a majority of sites within a class would receive the same metric score regardless of disturbance level, the metric was rejected. When metrics were eliminated by this test, we returned to the metric selection process described in the previous step and replaced it with the next most responsive metric.

3.9.7 Metric scoring and evaluation

Each selected metric was scored on a continuous scale from 0 to 10. Maximum and minimum values for each metric were defined as the 5^{th} and 95^{th} percentile values observed across all sites within each class. For positive metrics (those that decrease with disturbance), values less than the 5^{th} percentile (minimum) were given a score of 0; those with values greater than the 95^{th} percentile (maximum) were given a score of 10. Metric scores in between the 5^{th} and 95^{th} percentile were interpolated linearly.

Negative metrics (those than increase with disturbance) were scored in the same manner, with the minimum defined as the 95th percentile value and the maximum defined as the 5th percentile value. Metric scores were summed within each class, and the resulting value re-scaled to a 0-100 range (multiplied by 10, divided by the number of metrics within each index).

4. Results

4.1 Classification

At higher taxonomic levels, natural biological communities tend to become increasingly similar as you narrow the geographical scale at which they are considered. One of the useful properties of metrics is that they can provide meaningful information at broader geographic scales (Karr and Chu, 1999). A useful geographic framework should consider genus or species level similarity, as well as metric similarity. For the purpose of IBI development, we needed a geographic framework that was narrow

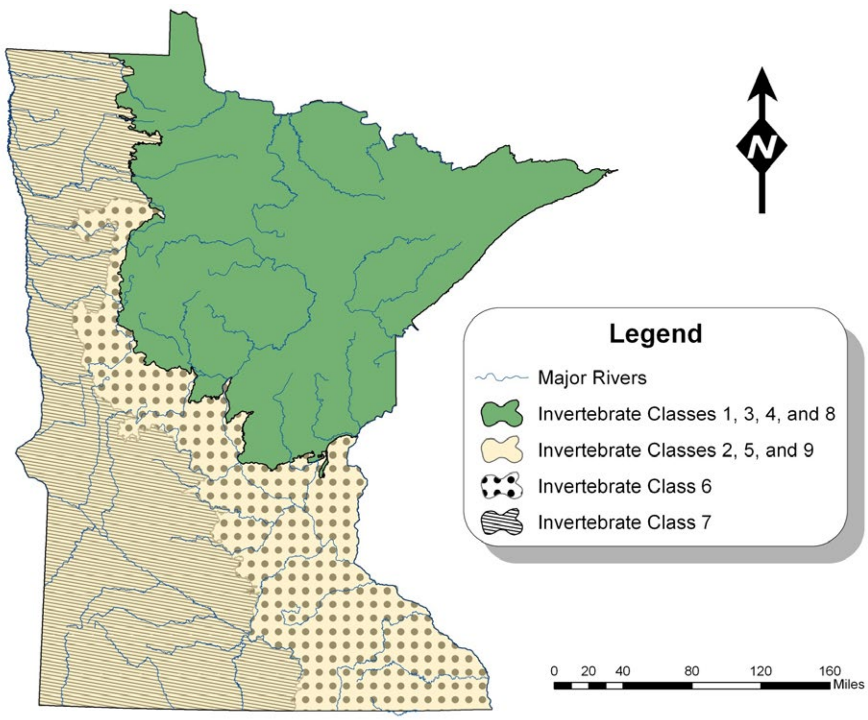


Figure 6. Map of invertebrate classes resulting from classification strength analysis.

enough to provide meaningful regional interpretation of biological community data, and broad enough to fit within existing spatial frameworks that had already been defined in Minnesota (e.g. watershed, ecoregion, agro ecoregion, ecological classification system). Cluster analysis revealed broad spatial groupings for both wadeable and non-wadeable streams. The primary geographic boundaries associated with these clusters were the boundary between the northern forest the hardwood forest and prairies. This grouping corresponds with the level two ecoregion boundaries that define many recently developed IBIs.

The results of non-metric multidimensional scaling showed a similar pattern, as well as broad groupings based on gradient (high gradient/low gradient), size class (rivers >500 square miles/streams <500 square miles), and temperature (warmwater/coldwater). The lack of coldwater information at the time of classification analysis lead us to give independent class designations to each of the coldwater regions of the state. This was justified due to the distinct temperature regimes, geology, and source water for each of the coldwater regions. Streams in the southern half of the state, particularly in the karst region of southeastern Minnesota, are groundwater dominated systems with colder temperatures, and high hardness. Coldwater streams in the northern part of the state are surface water driven, with higher average temperatures, and softer water. Once a more robust coldwater dataset had been collected, a similar analysis was repeated on just coldwater data, showing that placement in northern and southern coldwater classes was justified.

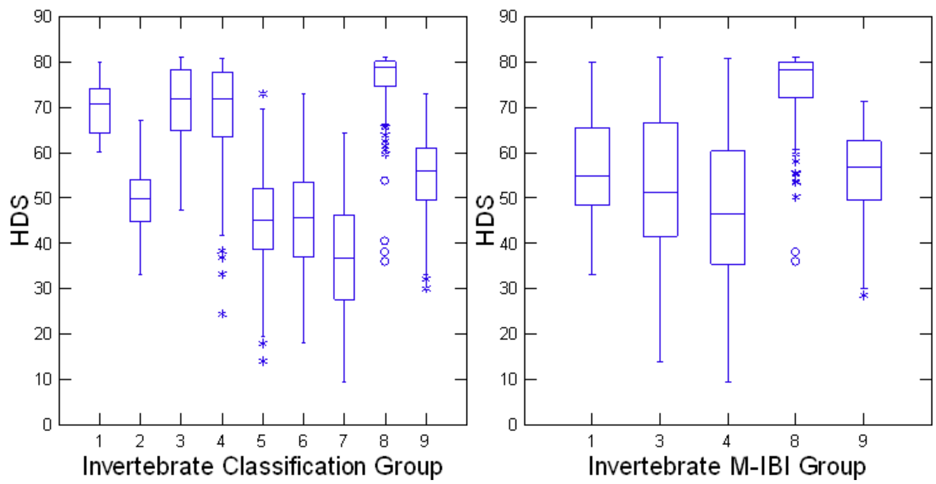
Classification strength analysis revealed the strongest classification framework to be that which factored in gradient, size class, and a distinction between northern forests, and southern hardwoods and prairies. (Figure 6). The result was a nine class classification scheme (Table 3).

Table 3. Description of site classes resulting from classification strength analysis.

Site Class	Class Geographic Criteria	Drainage Area Criteria
1	Rivers in the Laurentian Mixed Forest (LMF) province.	>= 500 Sq. Miles
2	Rivers in the Eastern Broadleaf forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces.	>= 500 Sq. Miles
3	High Gradient streams in Laurentian mixed forest ecological province.	<500 Sq. Miles
4	Low Gradient streams in the Laurentian mixed forest ecological province .	<500 Sq. Miles
5	High Gradient streams in the Eastern Broadleaf forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces, as well as streams in HUC 07030005.	<500 Sq. Miles
6	Low gradient streams in the Eastern broadleaf forest ecological province, as well as streams in HUC 07030005.	<500 Sq. Miles
7	Low gradient streams Prairie Parklands and Tall Aspen Parklands ecological provinces.	<500 Sq. Miles
8	Coldwater streams in the Northern portions of Minnesota characterized by the Laurentian Mixed Forest (LMF) ecological province.	N/A
9	Coldwater streams in the Southern portions of Minnesota, which are often characterized by the Eastern Broadleaf forest, Prairie Parklands, and Tall Aspen Parklands ecological provinces.	N/A

Analysis of disturbance gradients at each of the strongest classes, showed a lack of disturbance gradient at the low end in the northern classes, and a lack of disturbance gradient at the high end in the southern classes. A screening of commonly used metrics showed a lack of responsiveness, suggesting that an alternative framework might be necessary for metric selection.

Figure 7. Distribution of human disturbance score amongst optimal geographic classification groups, and groups selected for metric selection and M-IBI development.



4.2 Metric Selection

Due to a lack of a strong disturbance gradient in the Northern Provincial Forests, metrics were tested using two classification schemes. The first scheme consisted of five metric classes comprised of two gradient classes for wadeable streams (high gradient, low gradient), a large river class (> 500 square mile drainage area), northern coldwater streams, and southern coldwater stream. The second scheme was consisted of nine metrics classes comprised of the seven optimal classes resulting from classification strength analysis, as well as northern coldwater, and southern coldwater streams. The changes in landuse from the northeastern part of Minnesota, to the south and western parts of the state, represent the strongest disturbance gradient available for metric testing and validation (Figure 6). Using the five-metric-class scheme related to the statewide gradient resulted in a more robust set of candidate metrics passing the metric screening process. It was decided that metric selection would be based on the more robust set of candidate metrics, and that future determinations of biocriteria would be based upon the optimal classification scheme related to community similarity.

Table 4. Summary of metric count, trait category, metric type, and response for each M-IBI.

		Trait Category					Type				Response	
Invertebrate MIBI Class	number of metrics	Composition	Habitat	Richness	Tolerance	Trophic	Individual Percent	Taxa Richness	Taxa Percent	Index or Ratio	Positive	Negative
Northern & Southern Rivers	8	2		2	3	1	3	4		1	3	5
Northern & Southern High Gradient Streams	9	2	2	3	2		1	4	3	1	3	6
Northern, Prairie, & Southern Forested Low Gradient Streams	10	3	1	2	2	2	3	5	1	1	2	8
Northern Coldwater Streams	9	3	1		3	2	1	3	4	1	4	5
Southern Coldwater Streams	7	2	1		3	1	2	1	1	3	4	3
Grand Total	43	12	5	7	13	6	10	17	9	7	16	27

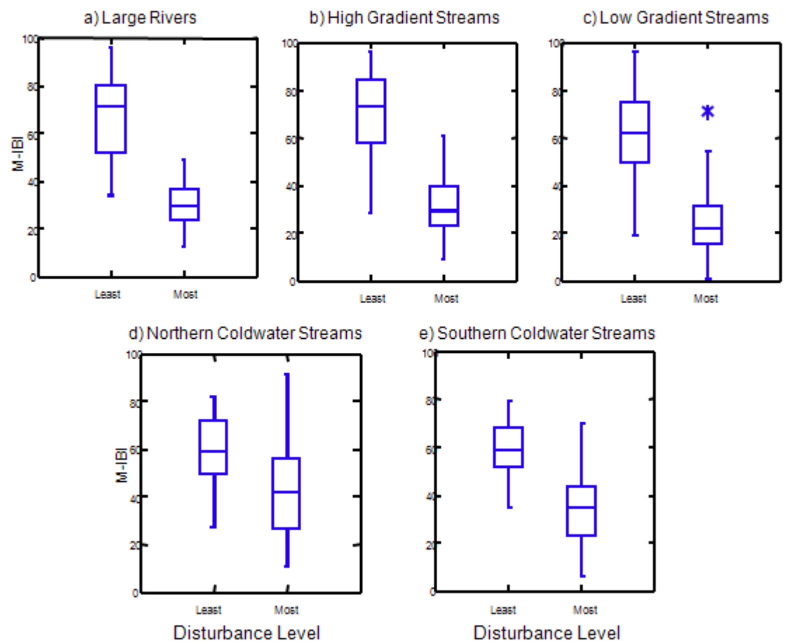
Table 5. Analysis of variance for M-IBI versus disturbance level (most, least)

M-IBI Class	F-Ratio	Error df	p-Value
Northern & Southern Rivers	153.2	73	<0.001
Northern & Southern High Gradient Streams	356.7	164	<0.001
Northern, Prairie, & Southern Forested Low Gradient Streams	516.9	318	<0.001
Northern Coldwater Streams	9.4	45	0.004
Southern Coldwater Streams	45.5	52	<0.001

Table 6. Pearson correlation coefficients for M-IBI versus HDS, watershed area, and stream gradient.

MIBI Class	HDS	watershed area	stream gradient
Northern & Southern Rivers	0.704	-0.210	0.004
Northern & Southern High Gradient Streams	0.719	0.287	-0.127
Northern, Prairie, & Southern Forested Low Gradient Streams	0.665	0.244	0.004
Northern Coldwater Stream:	0.695	0.260	0.160
Southern Coldwater Stream:	0.549	-0.142	0.131

Figure 8. M-IBI scores among least- and most-disturbed sites for each M-IBI. Differences in M-IBI scores among least - and most-disturbed sites are significant (Analysis of Variance, α=0.001).



4.3 High Gradient Streams

Table 7. Metrics selected for the Northern High Gradient streams MIBI. The p-values are from a one-way Kruskal-Wallis test to distinguish between the least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Description	Category	Response	p-value	S:N	Ceiling	Floor
ClimberCh	Taxa richness of climbers	Habitat	Decrease	<.001	2.01	12.0	2.7
ClingerChTxPct	Relative percentage of taxa adapted to cling to substrate in swift flowing water	Habitat	Decrease	<.001	3.04	46.0	20.0
DomFiveChPct	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)	Composition	Increase	<.001	2.49	38.2	78.2
HBI_MN	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	Tolerance	Increase	<.001	5.92	4.9	8.3
InsectTxPct	Relative percentage of insect taxa	Composition	Decrease	<.001	4.05	93.6	72.5
Odonata	Taxa richness of Odonata	Richness	Decrease	<.001	2.04	5.0	0.0
Plecopotera	Taxa richness of Plecoptera	Richness	Decrease	<.001	3.41	3.0	0.0
PredatorCh	Taxa richness of predators	Richness	Decrease	<.001	2.64	16.0	3.0
Tolerant2ChTxPct	Relative percentage of taxa with tolerance values equal to or greater than 6, using MN TVs	Tolerance	Increase	<.001	12.06	93.7	47.1
Trichoptera	Taxa richness of Trichoptera	Richness	Decrease	<.001	5.76	12.0	2.0

A total of 91 metrics failed either the range or signal-to-noise test in the Low Gradient Streams IBI class. There were no metrics needing correction due to a significant relationship with watershed area or gradient. An additional 29 metrics were removed due to the responsiveness test, leaving 110 metrics that met all testing criteria. Ten metrics in four categories were selected for wadeable high gradient streams (Table 7). These metrics were used in the Northern Forest Streams, High Gradient class and the Southern Streams, High Gradient class. High gradient streams M-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 5, Figure 8). We observed a strong correlation between M-IBI and HDS, a moderate correlation between M-IBI and watershed area, and a weak correlation between M-IBI and stream gradient. (Table 6).

4.4 Low Gradient Streams

Table 8. Metrics selected for Statewide Low-Gradient Streams MIBI. This includes the Northern, Prairie, and Southern Low-Gradient stream classes. The p-values are from a one-way Kruskal-Wallis test to distinguish between the least and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Description	Category	Response	p-value	S:N	Ceiling	Floor
ClimberCh	Taxa richness of climbers	Habitat	Decrease	<.001	2.01	17.0	2.0
Collector-filtererPct	Relative abundance (%) of collector-filterer individuals in a subsample	Trophic	Decrease	<.001	2.37	37.9	0.3
DomFiveChPct	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)	Composition	Increase	<.001	2.49	43.2	90.8
HBI_MN	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	Tolerance	Increase	<.001	5.92	5.8	8.8
Intolerant2Ch	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs	Tolerance	Decrease	<.001	10.88	3.0	0.0
POET	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)	Richness	Decrease	<.001	7.36	16.0	2.0
PredatorCh	Taxa richness of predators	Richness	Decrease	<.001	2.64	18.0	4.0
TaxaCountAllChir	Total taxa richness of macroinvertebrates	Richness	Decrease	<.001	3.69	53.0	19.0
TrichopteraChTxPct	Relative percentage of taxa belonging to Trichoptera	Composition	Decrease	<.001	3.99	16.4	0.0
TrichwoHydroPct	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample	Composition	Decrease	<.001	2.32	10.8	2.0

A total of 104 metrics failed either the range or signal-to-noise test in the Low Gradient Streams IBI class. There were no metrics needing correction due to a significant relationship with watershed area or gradient. An additional 14 metrics were removed due to the responsiveness test, leaving 129 metrics that met all testing criteria. Ten metrics in five metric categories were selected for low gradient streams (Table 8). These metrics were used in the Northern Forest Streams, Low Gradient class, the Southern Forest Streams, Low Gradient class, and the Prairie Streams, Low Gradient class. Low gradient streams M-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 5, Figure 8). We observed a strong correlation between M-IBI and HDS, a moderate correlation between M-IBI and watershed area, and a weak correlation between M-IBI and stream gradient. (Table 6).

4.5 Large Rivers

Table 9. Metrics selected for Statewide Rivers MIBI. This includes the Northern and Southern River stream classes. The p-values are from a one-way Kruskal-Wallis test to distinguish between the least and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Description	Category	Response	p-value	S:N	Ceiling	Floor
DomFiveCHPct	Relative abundance (%) of dominant five taxa in subsample (Chironomid genera treated individually)	Composition	Increase	<0.001	2.49	41.7	82.3
HBI_MN	A measure of pollution based on tolerance values assigned to each individual taxon within Minnesota developed by Chirhart	Tolerance	Increase	<0.001	5.92	5.5	8.3
Intolerant2lessCh	Taxa richness of macroinvertebrates with tolerance values less than or equal to 4, using MN TVs	Tolerance	Decrease	<0.001	13.23	18.2	0
Odonata	Taxa richness of Odonata	Richness	Decrease	<0.001	2.02	5	0
PredatorCh	Taxa richness of predators	Richness	Decrease	<0.001	2.64	18.3	3.5
TaxaCountAllChir	Total taxa richness of macroinvertebrates	Richness	Decrease	<0.001	3.69	57.6	24
TrichwoHydroPct	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample	Composition	Decrease	0.001	2.32	22.8	0
VeryTolerant2Pct	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 8; metric	Tolerance	Increase	0.002	4.18	12.8	78.7

A total of 104 metrics failed either the range or signal-to-noise test in the Large Rivers IBI class. There were no metrics needing correction due to a significant relationship with watershed area or gradient. An additional 63 metrics were removed due to the responsiveness test, leaving 80 metrics that met all testing criteria. Eight metrics in three metric categories were selected for non-wadeable rivers (Table 9). These metrics were used in the Northern Forest Rivers class, and the Prairie/Hardwoods River class. Larger river M-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 5, Figure 8). We observed a strong correlation between M-IBI and HDS, a moderate correlation between M-IBI and watershed area, and a weak correlation between M-IBI and stream gradient. (Table 6).

4.6 Northern Coldwater

Table 10. Metrics selected for Northern Coldwater Streams MIBI. The p-values are from a one-way Kruskal-Wallis test to distinguish between the least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Description	Category	Response	p-value	S:N	Ceiling	Floor
Percent (%) Collector-Gatherer	Relative percentage of collector-gatherer taxa	Trophic	Increase	0.003	2.31	22.1	41.90
Hilsenhoff Biotic Index, MN TVs	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	Tolerance	Increase	0.001	3.90	4.22	7.03
Intolerant Taxa Richness, 2	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, Using MN TVs	Tolerance	Decrease	<.001	10.96	12	0.00
Percent (%) Long-lived Taxa	Relative percentage of long-lived taxa	Life History	Decrease	0.012	3.34	26	6.00
Percent (%) Non-insect Taxa	Relative percentage of non-insect taxa	Composition	Increase	0.011	3.22	2.47	20.79
Percent (%) Odonata Taxa	Relative percentage of taxa belonging to Odonata	Composition	Decrease	0.002	2.15	9.5	0.00
POET	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)	Richness	Decrease	0.002	9.96	29	8.00
Predator Taxa Richness	Taxa richness of predators (excluding Chironomidae predator taxa)	Trophic	Decrease	0.008	2.85	16	5.00
Percent (%) Very Tolerant Taxa, 2	Relative percentage of taxa with tolerance values equal to or greater than 8, using MN TVs.	Tolerance	Increase	0.003	3.43	9.2	32.50

A total of 114 metrics failed either the range or signal-to-noise test in the Northern Coldwater IBI class. There were no metrics needing correction due to a significant relationship with watershed area or gradient. An additional 74 metrics were removed due to the responsiveness test, leaving 55 metrics that met all testing criteria. Nine metrics in five metric categories were selected for northern coldwater streams (Table 10). Northern Coldwater streams M-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 5, Figure 8). We observed a strong correlation between M-IBI and HDS, a moderate correlation between M-IBI and watershed area, and a weak correlation between M-IBI and stream gradient. (Table 6).

4.7 Southern Coldwater

Table 11. Metrics selected for Southern Coldwater Streams MIBI. The p-values are from a one-way Kruskal-Wallis test to distinguish between the least- and most-disturbed sites. The signal-to-noise ratio (S:N) is the ratio of variance among sites to that within sites. Floor and ceiling values are 5th and 95th percentile metric values used to define minimum and maximum metric scores.

Metric Name	Metric Description	Category	Response	p-value	S:N	Ceiling	Floor
Coldwater Biotic Index[1]	Coldwater Biotic Index score based on coldwater tolerance values derived from Minnesota taxa/temperature data.	Tolerance	Increase	<.001	3.52	-0.69	1.41
ChiroDip[1]	Ratio of Chironomidae abundance to total Dipteran abundance.	Tolerance	Increase	0.001	6.50	-40.33	37.59
Percent (%) Collector – Filterers	Relative abundance (%) of collector-filterer individuals in a subsample	Trophic	Decrease	0.088	3.85	53.41	7.36
Hilsenhoff Biotic Index, MN TVs[1]	A measure of pollution based on tolerance values assigned to each individual taxon, developed by Chirhart	Tolerance	Increase	<.001	3.90	-0.58	1.04
Intolerant Taxa Richness, 2 ch	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs	Tolerance	Decrease	0.001	10.96	3	0.00
Percent (%) Trichoptera Taxa	Relative percentage of taxa belonging to Trichoptera	Composition	Decrease	<.001	2.55	23.74	6.27
Percent (%) Very Tolerant, 2[1]	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 8, using MN	Tolerance	Increase	<.001	4.55	-10.28	35.77

[1] metric value adjusted for drainage area

A total of 137 metrics failed either the range or signal-to-noise test in the Southern Coldwater IBI class. There were 12 metrics needing correction due to a significant relationship with watershed area. An additional 96 metrics were removed due to the responsiveness test, leaving 50 metrics that met all testing criteria. Seven metrics in three metric categories were selected for the Southern Coldwater Streams class (Table 11). Southern Coldwater streams M-IBI scores differed significantly (α=0.05) between least- and most-disturbed sites (Table 5, Figure 8). We observed a strong correlation between M-IBI and HDS, a weak correlation between M-IBI and watershed area, and a weak correlation between M-IBI and stream gradient. (Table 6).

5. Discussion

The class-specific indices described here together represent the first comprehensive, statewide tool for assessing the biological integrity of aquatic macroinvertebrate communities in the State of Minnesota. Our statewide approach encompassed both the full geographic extent and variety of lotic environments found across the state, including large rivers, moderate-sized streams, headwaters, low-gradient and coldwater streams. Some transitional habitats, such as estuaries, impoundments, wetland flowages, and "Great Rivers", fell beyond the scope of this project but future work may address the development and application of macroinvertebrate community-based indicators for these systems.

The process of IBI development began as coordinated effort between groups developing indicators for fish and macroinvertebrates. The intention was to follow an identical path of developing a regional classification framework, followed by metric selection/IBI development for each class resulting from the classification analysis, as well as northern and southern coldwater classes. Early in the process it was decided that the selection of an optimal regional classification scheme would occur independently, and that it was acceptable to have differing regionalization schemes for each assemblage. This decision was based on the underlying principles that dictate the natural distribution of fishes and macroinvertebrates. Invertebrate distributions, for the most part, follow broad changes in landscape patterns. Thus, classifications such as ecoregion can be effective in capturing the natural variation of invertebrate communities. While classifications such as ecoregion have been effectively used throughout the United States in defining biomonitoring program objectives, their use may have more to do with convenience than effectiveness (Hawkins et al 2000), especially when dealing with fish communities. Ecoregions fail to account for landscape features, such as major waterfalls, that play a large role in determining fish community structure across the state. For example, within the St. Croix Basin, several species of fish are native to rivers and streams below Taylors Falls, but absent upstream; as a result, distinct differences exist between the fish assemblages above and below this barrier. The classification frameworks resulting from the independent analysis of fish and macroinvertebrate communities, showed some similarities, but were ultimately different. We acknowledge that this can cause some confusion when trying to interpret overlapping results from fish and invertebrates communities, but it was decided that the differences driving the community structures of the two assemblages were strong enough to merit independent classifications.

Most of the recent work on development of biological indicators treats regional classification similarly; either *a priori* assignments of level II or III ecoregions, or combinations of ecoregions, are made, or an analysis of classification strength is done exploring the relationship of the structure of reference biological communities between various classification frameworks to determine an optimal framework. Minnesota is located in an area that encompasses a transition between prairie and forest regions. Unlike areas of US where landscapes change abruptly, such as where prairies meet mountain ranges, the transition from prairies to forest is more subtle. As one moves from the northeastern corner of the state, to southern and western parts of the state, the landscape gradually changes from a conifer and aspen dominated ecosystem, to mixed hardwoods, oak savannah, and finally to prairies. Previously developed classification frameworks define three primary natural regions of the state, boreal forest, hardwood forest, and prairie, with the hardwood forests acting as a transitional zone. Other than in a few areas, the changes between these regions are not abrupt, thus the lines that define these natural areas are not exact. Defining differences along the transitional zone is further complicated by modifications that have been made to landscape over the past 100 years, making the hardwood forest appear more like prairie in many areas. Due to the transitional nature of Minnesota's natural landscape, it was determined that it was necessary to explore the relationship between the peak biological communities across the state, understanding that previously developed classification schemes might not adequately characterize community structures in the context of landscape changes and varying site specific habitat changes. We evaluated several possible regional frameworks (e.g. ecoregion, MDNR ecological classification system, major drainage basin), including components of gradient and streams size to allow us to further refine regional differences. We ultimately decided on a customized regional framework that made use of the MDNR Ecological Classification System province level designations, incorporating both a size and gradient/habitat component to further refine classes.

The river continuum concept suggests that stream macroinvertebrate community structure changes as streams transition from headwaters to large rivers (Vannote, et. al., 1980). These community changes are a result of the associated natural changes in energy input, flow regimes, and habitat availability that occur in streams as they increase in size. As such, a discernible change in macroinvertebrate community structure is very gradual, and measurable differences occur over broad scales. When selecting a classification scheme it must be understood that these gradual changes that occur within riverine systems will result in a loss of precision when attempting to quantify community structure across broad geographic, size, and habitat scales. In addition to establishing geographic class boundaries, the classification framework we developed further partitions stream into size and habitat/gradient classes. Despite the fact that we attempted to either correct for a correlation with drainage area, or dismissed metrics highly correlated with drainage area, there are often community structural differences between the smaller headwater streams, and streams that fall just shy of the large river size threshold of 500 square miles. These differences could be reflected in an IBI score, so it is necessary when using the associated IBIs, that we recognize these differences by ensuring that sites are classified appropriately, or consider reclassifying or excluding a site from analysis if it is determined that the assemblage associated with a site does not fit within the current set of stream classes, *i.e.,* either too small, or too large. The same goes for habitat/gradient classification. After construction and analysis of the IBI development dataset, it became apparent that some of the low gradient sites did not correspond to expectations based on our human disturbance gradient. Some very low gradient sites in pristine watersheds showed very low IBI scores, typically due to depauperate richness, with a preponderance of organisms tolerant to low dissolved oxygen. It is likely that these types of communities are naturally occurring in healthy ecosystems, but that our dataset lacked a large enough set of these sites to show a distinct class during classification analysis. As with size classes, it may be necessary to reclassify or exclude sites from analysis when the gradient conditions are such that they diverge significantly from streams commonly found in the associated class. As our dataset grows, and more sites are analyzed, it may become clear that additional streams classes will need to be explored to ensure that sites are being analyzed in a fair manner.

The approach outlined by Whittier et al (2007) provided an objective methodological template for metric evaluation. Using a series of standardized metric tests, we developed sensitive, robust, community-based indices that provide reliable information about biological integrity. This method was developed to maintain some of the structural approach of the original Karr IBI (1981) by incorporating metrics that encompass as many of the biologically important features of the assemblage. Unlike previously developed fish IBIs, invertebrate IBIs have shown considerable variability in metric use, so we did not deem it necessary to incorporate “classic” invertebrate metrics.

Our approach maintained the conceptual foundation of the IBI – a trait-based, multi-metric index that is demonstrably sensitive to anthropogenic disturbance – but we assumed little regarding the *a priori* utility of specific metrics and considered a wider variety of candidates. However, while the metric selection tests were designed with objective criteria for removing candidates from the pool, those with test values slightly over the threshold for a particular test were sometimes allowed to "pass" if a sound conceptual basis for doing so could be identified. While few of these "borderline" metrics made it into the final indices, this interplay between a conceptual and quantitative approach strengthened our understanding of how invertebrate communities respond to anthropogenic disturbance and ensured the resulting indices were well-balanced and representative of the wide spectrum of biological integrity.

The relationship between selecting a set of robust candidate metrics, and choosing an optimal classification framework was not something we considered to be problematic until we began the metric selection process. While going through the process of metric development it was soon realized that the covariance of landscape development with naturally occurring boundaries confounded our efforts to select a robust set of metrics.

The northern boreal forests, representing a region of relatively intact watersheds, with relatively little development compared to the remainder of Minnesota, showed very little range along the human disturbance gradient; most sites displayed very little to no disturbance in both landscape and habitat variables. The central hardwood region of the state showed a wide range of landscape influences, allowing for the development of a robust set of metrics, while the prairie region showed a much more heavily developed landscape, with relatively few intact watersheds. The result was that three of the seven classes had very few metrics make it through the testing and evaluation phase. And those few metrics that made it through showed a relatively weak response along the disturbance gradient. In order to increase the range of disturbance available for metric selection, metrics were grouped by size and gradient class, and tested using a statewide dataset. The resulting suite of metrics and related IBIs showed a stronger relationship with disturbance than any that were previously tested, so it was decided to use these metrics in the final M-IBI.

While the overall relationship between metrics, IBIs, and disturbance proved to be stronger when using a statewide disturbance gradient, the same relationship is not always stronger on a smaller geographic scale. It is possible that assessments resulting from the use of the M-IBI developed from the statewide dataset will not be as precise as IBI's developed at smaller scales. But this will always be the case.

When developing a classification framework, and related IBIs, we must attempt to find a balance between available data, range of disturbance, the effort related to IBI development, and the precision of the final IBI score relative to impairment status. While we were intent on developing an IBI for each class related to our classification analysis, our final assessment was that fewer IBI groups was preferable to underperforming IBIs. We also thought that fewer IBIs which function similarly across the state would be easier for stakeholders to understand.

To further validate the decision to use metrics selected on a statewide scale, we also did analysis comparing the M-IBIs from both IBI development groups using a tool designed to assign class specific biological categories to each site for the purposes of understanding the departure of the present biological community from a potential peak community (Gerritsen, 2012). This analysis showed very similar results for both IBI groups, suggesting that an IBI developed using statewide data is able to discern a change in condition equivalent to an IBI developed using a more refine dataset. The reason this is likely the case is that many metrics are known to perform well across a broad range of conditions, due to species being replaced by similar species as you move from one ecotype to another (Karr).

The development of invertebrate and fish IBIs was a parallel effort. The only notable difference between the final IBIs was related to the grouping of classes for the purpose of metric selection and IBI developed. The process of grouping similar invertebrate classes was necessitated by the lack of disturbance gradient that was related directly to the final invertebrate classification framework. This was not the case for the fish IBI development dataset and classification framework, and an IBI was able to be developed for each class related to classification analysis. Had all things been equal, the final process would have been identical for both assemblages. There is not one way to develop IBIs, so we don't think that the subtle differences in approach should have an impact on any of the resulting uses of the invertebrate or fish IBIs.

The most problematic classes in the metric selection and IBI development process were the northern classes. This was primarily due to a lack of disturbance gradient, and resulted in the eventual grouping of classes for metric selection. This was not the case for the northern coldwater class. We considered combining the northern and southern coldwater classes for the purposes of metric selection, but determined that the background geographic, geochemical, habitat, and landuse (HDS) conditions, as well as peak taxonomic communities, were different enough to merit separate efforts. One of the main problems with the streams in this part of the state is that many of them flow from a low gradient area to a high gradient area as they approach Lake Superior. Many are located in watersheds with very little to no recent history of human disturbance, additionally, many of them flow throw extensive wetland complexes. The low gradient, wetland dominated nature of these systems create stream conditions with high organic carbon, low dissolved oxygen, and often little habitat due to soft sediment stream bottoms. There were not an adequate number of low gradient sites to allow for the development of a separate, low gradient, coldwater IBI, so these sites were combined with high gradient data in the IBI development process. The result being that some of the low-gradient systems have lower IBI scores relative to the entire set of northern coldwater streams.

The MPCA has committed extensive time and effort towards the development of biological indicators and a framework for their use in its surface water monitoring and assessment process (Anderson et al. 2012). The stream classification system and macroinvertebrate-based Indices of Biological Integrity described in this document have been utilized (in concert with other indicators) since 2010 to annually assess the condition of aquatic life in Minnesota's rivers and streams. Continuing work may attempt to expand the IBI concept to waterbodies not covered here, including lakes, reservoirs, and large rivers. Diagnostic applications of the IBI and its component metrics will also be explored. Large-scale changes in environmental condition across Minnesota, or advances in the science of biological indicators may require periodic evaluation of these indices to ensure their relevancy as an assessment tools.

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Appendices

Appendix A. Data reduction for classification analysis

Removing redundant taxa from the database:

Developing a geographic classification system requires that biota be identified to a consistent level of taxonomy. The level of taxonomy used can vary among taxa, but no individuals can be ambiguous, e.g., individuals within a family cannot be identified to family part of the time, genus some of the time, and species some of the time. When we build models, we scrutinize the original data to determine the frequency with which individuals in different taxonomic groupings are identified to different levels of resolution. Depending on these frequency distributions, we make decisions to either aggregate taxa (e.g., species within genera) or exclude individuals from analyses (e.g., those individuals identified only to order or family when most others were identified to a lower level). The result of this exercise is a list of operational taxonomic units (OTUs) that can vary in their level of taxonomic resolution, but which are unique from one another.

When creating a list of OTUs several decisions must be made to ensure that the list provides the most meaningful information for the classification process. The method used by the MPCA to remove ambiguous taxa has recently been described by Cuffney et. al. The approach is described as the RPMC-G method- remove parent, or merge parent with child depending on their abundances. The method is applied in two steps depending on the status of child-parent abundances.

If the collective abundance of children is greater than the abundance of an ambiguous parent, then the remove parent keep child (RPKC) approach is taken (Step 1). If the abundance of a parent is greater than the collective abundance of the children, then the merge child with parent (MCWP) approach is taken (Step 2).

The RPKC approach removes ambiguous parents when their abundance is less than the collective abundance of their children. The approach taken by the MPCA considers the entire data set collectively when making decisions about ambiguous taxa. For this reason, it is possible to lose taxa from samples that contain ambiguous parents with no children. In this case, the abundance of the ambiguous parent is assigned to the child that occurs most frequently in the data set. This step maintains the taxonomic diversity of the sample but creates the occurrence of a taxon that was not collected in the sample. Other, less conservative options include dividing the abundance of the ambiguous parent proportionally to children that are known in the data set, or assigning the abundance of the ambiguous parent to children that are known to occur at similar sites. The later two options allow for an increase in taxonomic diversity from the original sample data, and are not used.

The MCWP approach merges the abundances of the children with their parent when the collective abundance of the children is less than the parent. The taxonomic designations and related abundances of the children are then removed from the data set.

Query process:

Step 1: Determine taxa identified at the sub-generic level. Monospecific taxa can be left alone or changed to reflect the genus level determination. Multiple species representing a single genus, within and across samples must be changed to reflect genus level identification. Aggregation is done site by site.

Step 2: Determine which taxa are identified at each taxonomic step below genus. Group all taxa identified below this level to compare which taxonomic level is more frequently determined. This step involves developing queries for each taxonomic level, then comparing the individual taxa of each level to every other parent and/or child. In a typical stream invertebrate dataset there will be very few taxonomic determinations above the family level, so the majority of the work in this step involves comparing taxa at the genus, tribe, subfamily, and family level. Although comparisons must also be made at the order level and higher.

Step 3: Based on Step 2, if children are determined to be more common than parents, then parent level ID's are removed, including taxonomic designations and abundances. Using the queries in Step 2, the parent child relationship for each record is examined for occurrence and abundance. If it is clear that abundances are unduly weighted by a few records, a decision can be made to keep parents and proceed to Step 4 for the selected taxon.

Step 4: If the parent level IDs are more common than children, then children are merged with parent. As with Step 3, the parent child relationship for each record is examined for occurrence and abundance. If it is clear that abundances are unduly weighted by a few records, a decision can be made to return to Step 3 and remove parents for the selected taxon. In this step a macro was used that relied on the results of Step 2. The macro runs a series of queries that do the following.

1) Asks for a Taxonomic Serial Number (TSN) of parents for children that need to be merged with a more abundant parent that is present in the sample, and creates a table with a record for each child that needs to be merged.
2) Flags the dataset for each record identified in the previous step.
3) Deletes each record from the dataset flagged in the previous step.
4) Using the table created in the first query, the parents are updated, or merged, with the relevant children. (mcwp).
5) If no TSN is provided in the first step, asks for a TSN of children that need to be merged with parents that do not exist in the sample, then creates a table with each record for that child, and assigns it the relevant parent TSN to which it will be updated.
6) Flags the dataset for each record identified in the previous step.
7) Deletes each record from the dataset flagged in the previous step.
8) Using the table created in the first query, the nonexistent parent TSN is added to the dataset with the appropriate counts from the merged child.

Step 5: Once all records have been either merged or removed, the dataset is queried to determine rare taxa, which are those occuring at less than five percent of all sites. A backup dataset is created including all taxa remaining after Step 4, then rare taxa are removed from the working dataset.

Appendix B. Decision Criteria for Riffle Run (RR) /Glide Pool (GP) designation.

Riffle/Run (RR) vs. Glide Pool (GP) Designation Guidance

Criteria	Yes	No
1. Has the sampler indicated on the stream visit form that 'riffle/run' is the 'Dominant invertebrate habitat in reach'?	**RR**	**#2**
2. In the mulithabitat sample, was any portion collected from riffles or rocky runs?	**go to #3**	**GP**
3. Was there a riffle present in the sample reach?	**go to #4**	**GP**
4. Flow over riffle perceptible?	**go to #5**	**GP**
5. # 'Riffle/run, rocky substrate' samples > 4?	**RR**	**go to #6**
6. Use a weight of evidence approach pulling in comments from macroinvertebrate visit form, habitat data from fish visit, sample reach photos, aerial photos, and geomorphology GIS layer to address the following:		
	RR	**GP**
Extent of riffle in sample reach (%)	≥ 5%	< 5%
Gradient of sample reach	> 1	≤ 1
Geomorphology of Minnesota GIS layer, based on location of sample reach:		
TOPO =	3, 4, or 5	1 or 2
SED_ASSOC =	A, D, or T	L or P
Site photos suggests (check one)		
Aerial photos suggests (check one)		

Appendix C. List of metrics evaluated for inclusion in M-IBI, associated metric category assignments, and metric descriptions

MetricName	Metric Category	Metric Description
Amphipoda	Richness	Taxa richness of Amphipoda
AmphipodaChTxPct	Composition	Relative percentage of taxa belonging to Amphipoda
AmphipodaPct	Composition	Relative abundance (%) of amphipod individuals in subsample
Annelida	Richness	Taxa richness of Annelida
AnnelidaChTxPct	Composition	Relative percentage of taxa belonging to Annelida
AnnelidaPct	Composition	Relative abundance (%) of annelid individuals in subsample
BaetEphem	Tolerance	Percent of mayfly individuals in the family Baetidae
BaetidaeCh	Richness	Taxa richness of baetid mayflies
BaetidaeChTxPct	Composition	Relative percentage of taxa belonging to Baetidae
BaetidaePct	Composition	Relative abundance (%) of baetid individuals in subsample
Bivalvia	Richness	Taxa richness of Bivalvia
BivalviaChTxPct	Composition	Relative percentage of taxa belonging to Bivalvia
BivalviaPct	Composition	Relative abundance (%) of mussels in subsample
Burrower	Habit	Taxa richness of burrowers (excluding chironomid burrower taxa)
BurrowerCh	Habit	Taxa richness of burrowers
BurrowerChTxPct	Habit	Relative percentage of taxa that burrow
BurrowerPct	Habit	Relative abundance (%) of burrowers in subsample
CaenEphem	Tolerance	Percent of mayfly individuals in the family Caenidae
CaenidaeCh	Richness	Taxa richness of caenid mayflies
CaenidaeChTxPct	Composition	Relative percentage of taxa belonging to Caenidae
CaenidaePct	Composition	Relative abundance (%) of caenid individuals in subsample
CBI	Composition	Coldwater Biotic Index score based on coldwater tolerance values derived from Minnesota taxa/temperature data
ChiroDip	Tolerance	Ratio of chironomid abundance to total dipteran abundance
ChiroIntol	Tolerance	Taxa richness of Chironomidae with tolerance values less than or equal to 3

Appendix C. (continued)

MetricName	Metric Category	Metric Description
ChiroIntolTxPct	Tolerance	Relative percentage of intolerant chironomid taxa
ChironomidaeCh	Richness	Taxa richness of Chironomidae
ChironomidaeChPct	Composition	Relative abundance (%) of chironomid individuals in subsample
ChironomidaeChTxPct	Composition	Relative percentage of taxa belonging to Chironomidae
ChironominiCh	Richness	Taxa richness of midge tribe Chironomini
ChironominiChTxPct	Composition	Relative percentage of taxa belonging to midge tribe Chironomini
ChironominiPct	Composition	Percent of chironomid individuals in the tribe Chironomini
ChiroVeryIntol	Tolerance	Taxa richness of Chironomidae with tolerance values less than or equal to 2
ChiroVeryIntolTxPct	Tolerance	Relative percentage of chironomid taxa with tolerance values less than or equal to 2
Climber	Habit	Taxa richness of climbers (excluding chironomid climber taxa)
ClimberCh	Habit	Taxa richness of climbers
ClimberChTxPct	Habit	Relative percentage of taxa that climb
ClimberPct	Habit	Relative abundance (%) of climbers in subsample
Clinger	Habit	Taxa richness of clingers (excluding chironomid clinger taxa)
ClingerCh	Habit	Taxa richness of clingers
ClingerChTxPct	Habit	Relative percentage of taxa adapted to cling to substrate in swift flowing water
ClingerPct	Habit	Relative abundance (%) of clinger individuals in subsample
CoenagrionidaeCh	Richness	Taxa richness of Coenagrionidae
CoenagrionidaeChTxPct	Composition	Relative percentage of taxa belonging to Coenagrionidae
CoenagrionidaePct	Composition	Relative abundance (%) of coenagrionid individuals in subsample
CoenOdo	Tolerance	Percent of odonates in the family Coenagrionidae
Coleoptera	Richness	Taxa richness of Coleoptera
ColeopteraChTxPct	Composition	Relative percentage of taxa belonging to Coleoptera
ColeopteraPct	Composition	Relative abundance (%) of coleopteran individuals in subsample
Collector-filterer	Trophic	Taxa richness of collector-filterers (excluding chironomid collector-filterer taxa)
Collector-filtererCh	Trophic	Taxa richness of collector-filterers
Collector-filtererChTxPct	Trophic	Relative percentage of collector-filterer taxa
Collector-filtererPct	Trophic	Relative abundance (%) of collector-filterer individuals in subsample
Collector-gatherer	Trophic	Taxa richness of collector-gatherers (chironomid and baetid taxa each treated as one taxon)

Appendix C. (continued)

MetricName	Metric Category	Metric Description
Collector-gathererCh	Trophic	Taxa richness of collector-gatherers
Collector-gathererChTxPct	Trophic	Relative percentage of collector-gatherer taxa
Collector-gathererPct	Trophic	Relative abundance (%) of collector-gatherer individuals in subsample
Crustacea	Richness	Taxa richness of crustaceans
CrustaceaChTxPct	Composition	Relative percentage of taxa belonging to Crustacea
CrustaceaPct	Composition	Relative abundance (%) of crustacean individuals in subsample
CrustMoll	Richness	Taxa richness of Crustacea & Mollusca
CrustMollChTxPct	Composition	Relative percentage of taxa belonging to Crustacea and Mollusca
CrustMollPct	Composition	Relative abundance (%) of crustacean and molluscan individuals in subsample
CW165Pct	Tolerance	Relative abundance of organisms with coldwater tolerance of 16.5 or less
CW17Pct	Tolerance	Relative abundance of organisms with coldwater tolerance of 17 or less
CW175Pct	Tolerance	Relative abundance of organisms with coldwater tolerance of 17.5 or less
CW18Pct	Tolerance	Relative abundance of organisms with coldwater tolerance of 18 or less
CW185Pct	Tolerance	Relative abundance of organisms with coldwater tolerance of 18.5 or less
CW19Pct	Tolerance	Relative abundance of organisms with coldwater tolerance of 19 or less
CW165TaxaPct	Tolerance	Relative percentage of taxa with coldwater tolerance of 16.5 or less.
CW17TaxaPct	Tolerance	Relative percentage of taxa with coldwater tolerance of 17 or less.
CW175TaxaPct	Tolerance	Relative percentage of taxa with coldwater tolerance of 17.5 or less.
CW18TaxaPct	Tolerance	Relative percentage of taxa with coldwater tolerance of 18 or less.
CW185TaxaPct	Tolerance	Relative percentage of taxa with coldwater tolerance of 18.5 or less.
CW19TaxaPct	Tolerance	Relative percentage of taxa with coldwater tolerance of 19 or less.
CW165Taxa	Tolerance	Taxa richness of organisms with coldwater tolerance of 16.5 or less
CW17Taxa	Tolerance	Taxa richness of organisms with coldwater tolerance of 17 or less
CW175Taxa	Tolerance	Taxa richness of organisms with coldwater tolerance of 17.5 or less
CW18Taxa	Tolerance	Taxa richness of organisms with coldwater tolerance of 18 or less
CW185Taxa	Tolerance	Taxa richness of organisms with coldwater tolerance of 18.5 or less
CW19Taxa	Tolerance	Taxa richness of organisms with coldwater tolerance of 19 or less
DipNIPct	Composition	Relative abundance (%) of Diptera & non-insect individuals in subsample
Diptera	Richness	Taxa richness of Diptera (chironomid taxa treated as one taxon)

Appendix C. (continued)

MetricName	Metric Category	Metric Description
DipteraCh	Richness	Taxa richness of Diptera
DipteraChPct	Composition	Relative abundance (%) of dipteran individuals in subsample
DipteraChTxPct	Composition	Relative percentage of taxa belonging to Diptera
DipteraPct	Composition	Relative abundance (%) of dipteran individuals in subsample (excluding all chironomids)
DomFiveChAs1Pct	Composition	Relative abundance (%) of dominant five taxa in subsample (chironomids grouped at family level)
DomFiveCHPct	Composition	Relative abundance (%) of dominant five taxa in subsample (chironomid genera treated individually)
DomFivewoCHPct	Composition	Relative abundance (%) of dominant five taxa in subsample (excluding all chironomids)
DomFourChAs1Pct	Composition	Relative abundance (%) of dominant four taxa in subsample (chironomids grouped at family level)
DomFourCHPct	Composition	Relative abundance (%) of dominant four taxa in subsample (chironomid genera treated individually)
DomFourwoCHPct	Composition	Relative abundance (%) of dominant four taxa in subsample (excluding all chironomids)
DomOneChAs1Pct	Composition	Relative abundance (%) of dominant taxon in subsample (chironomids grouped at family level)
DomOneCHPct	Composition	Relative abundance (%) of dominant taxon in subsample (chironomid genera treated individually)
DomOnewoCHPct	Composition	Relative abundance (%) of dominant taxon in subsample (excluding all chironomids)
DomThreeChAs1Pct	Composition	Relative abundance (%) of dominant three taxa in subsample (chironomids grouped at family level)
DomThreeCHPct	Composition	Relative abundance (%) of dominant three taxa in subsample (chironomid genera treated individually)
DomThreewoCHPct	Composition	Relative abundance (%) of dominant three taxa in subsample (excluding all chironomids)
DomTwoChAs1Pct	Composition	Relative abundance (%) of dominant two taxa in subsample (chironomids grouped at family level)
DomTwoCHPct	Composition	Relative abundance (%) of dominant two taxa in subsample (chironomid genera treated individually)
DomTwowoCHPct	Composition	Relative abundance (%) of dominant two taxa in subsample (excluding all chironomids)
EOT	Richness	Taxa richness of Ephemeroptera, Odonata, & Trichoptera (baetid taxa treated as one taxon)
EOTCh	Richness	Taxa richness of Ephemeroptera, Odonata, & Trichoptera
EOTPct	Composition	Relative abundance (%) of Ephemeroptera, Odonata & Trichoptera individuals in subsample
EP	Richness	Taxa richness of Ephemeroptera & Plecoptera (baetid taxa treated as one taxon)
EPCh	Richness	Taxa richness of Ephemeroptera & Plecoptera
EPChTxPct	Composition	Relative percentage of taxa belonging to Ephemeroptera & Plecoptera
Ephemeroptera	Richness	Taxa richness of Ephemeroptera (baetid taxa treated as one taxon)
EphemeropteraCh	Richness	Taxa richness of Ephemeroptera
EphemeropteraChTxPct	Composition	Relative percentage of taxa belonging to Ephemeroptera
EphemeropteraPct	Composition	Relative abundance (%) of Ephemeroptera individuals in subsample

Appendix C. (continued)

MetricName	Metric Category	Metric Description
EPPct	Composition	Relative abundance (%) of Ephemeroptera & Plecoptera individuals in subsample
EPT	Richness	Taxa richness of Ephemeroptera, Plecoptera & Trichoptera (baetid taxa treated as one taxon)
EPT_Chiro	Tolerance	Ratio of EPT abundance to EPT + Chironomidae abundance
EPTCh	Richness	Taxa richness of Ephemeroptera, Plecoptera & Trichoptera
EPTChTxPct	Composition	Relative percentage of taxa belonging to Ephemeroptera, Plecoptera & Trichoptera
EPTPct	Composition	Relative abundance (%) of Ephemeroptera, Plecoptera & Trichoptera individuals in subsample
Gastropoda	Richness	Taxa richness of snails
GastropodaChTxPct	Composition	Relative percentage of snail taxa
GastropodaPct	Composition	Relative abundance (%) of snails in subsample
GathFiltPct	Trophic	Relative abundance (%) of collector-gatherer & collector-filterer individuals in subsample
HBI	Tolerance	A measure of organic pollution based on tolerance values assigned to each individual taxon developed by Hilsenhoff
HBI_MN	Tolerance	A measure of pollution based on tolerance values assigned to each individual taxon developed by Chirhart
HCDNIPct	Composition	Relative abundance (%) of Heteroptera, Coleoptera, Diptera, & non-insect individuals in subsample
HCDPct	Composition	Relative abundance (%) of Heteroptera, Coleoptera, & Diptera individuals in subsample
HetCol	Richness	Taxa richness of Heteroptera + Coleoptera
HetColChTxPct	Composition	Relative percentage of taxa belonging to Heteroptera & Coleoptera
HetColNIPct	Composition	Relative abundance (%) of Heteroptera, Coleoptera, & non-insect individuals in subsample
HetColPct	Composition	Relative abundance (%) of Heteroptera & Coleoptera individuals in subsample
Heteroptera	Richness	Taxa richness of Heteroptera
HeteropteraPct	Composition	Relative abundance (%) of heteropteran individuals in subsample
HydropsychidaeCh	Richness	Taxa richness of hydropyschid caddisflies
HydropsychidaeChTxPct	Composition	Relative percentage of taxa belonging to Hydropsychidae
HydropsychidaePct	Composition	Relative abundance (%) of hydropsychid caddisfly individuals in subsample
HydrTrich	Tolerance	Percent of caddisfly individuals in the family Hydropsychidae
Insect	Richness	Taxa richness of insects
InsectPct	Composition	Relative abundance (%) of insect individuals in subsample
InsectTxPct	Composition	Relative percentage of insect taxa
Intolerant	Tolerance	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2 (excluding intolerant chironomid and baetid taxa)

Appendix C. (continued)

MetricName	Metric Category	Metric Description
Intolerant2	Tolerance	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, Using MN TVs
Intolerant2ch	Tolerance	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2, using MN TVs
Intolerant2chTxPct	Tolerance	Relative percentage of taxa with tolerance values less than or equal to 2, using MN TVs
Intolerant2less	Tolerance	Taxa richness of macroinvertebrates with tolerance values less than or equal to 4 (excluding intolerant chironomid and baetid taxa), using MN TVs
Intolerant2lessCh	Tolerance	Taxa richness of macroinvertebrates with tolerance values less than or equal to 4, using MN TVs
Intolerant2LessChTxPct	Tolerance	Relative percentage of taxa with tolerance values less than or equal to 4, using MN TVs
Intolerant2lessPct	Tolerance	Relative abundance (%) of macrioinvertabrate individuals in subsample with tolerance values less than or equal to 4
Intolerant2Pct	Tolerance	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values less than or equal to 2
IntolerantCh	Tolerance	Taxa richness of macroinvertebrates with tolerance values less than or equal to 2
IntolerantChTxPct	Tolerance	Relative percentage of taxa with tolerance values less than or equal to 2
IntolerantPct	Tolerance	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values less than or equal to 2
Isopoda	Richness	Taxa richness of Isopoda
IsopodaChTxPct	Composition	Relative percentage of taxa belonging to Isopoda
IsopodaPct	Composition	Relative abundance (%) of isopod individuals in subsample
LeglessCh	Habit	Taxa richness of legless macroinvertebrates
LeglessChTxPct	Habit	Relative percentage of taxa without legs
LeglessPct	Habit	Relative abundance (%) of legless individuals in subsample
LongLived	Life History	Taxa richness of longlived macroinvertebrates
LongLivedChTxPct	Life History	Relative percentage of longlived taxa
LongLivedPct	Life History	Relative abundance (%) of longlived individuals in subsample
Mollusca	Richness	Taxa richness of Mollusca
MolluscaChTxPct	Composition	Relative percentage of taxa belonging to Mollusca
MolluscaPct	Composition	Relative abundance (%) of Mollusca individuals in subsample
NonInsect	Richness	Taxa richness of non-insect macroinvertebrates
NonInsectPct	Composition	Relative abundance (%) of non-insect individuals in subsample
NonInsectTxPct	Composition	Relative percentage of non-insect taxa

Appendix C. (continued)

MetricName	Metric Category	Metric Description
Odonata	Richness	Taxa richness of Odonata
OdonataChTxPct	Composition	Relative percentage of taxa belonging to Odonata
OdonataPct	Composition	Relative abundance (%) of Odonata individuals in subsample
Oligochaeta	Richness	Taxa richness of Oligochaeta
OligochaetaChTxPct	Composition	Relative percentage of taxa belonging to Oligochaeta
OligochaetaPct	Composition	Relative abundance (%) of oligochaete individuals in subsample
OligoHir	Richness	Taxa richness of Oligochaeta + Hirudinea
OligoHirChTxPct	Composition	Relative percentage of taxa belonging to Oligochaeta & Hirudinea
OligoHirPct	Composition	Relative abundance (%) of Oligochaeta & Hirudinea individuals in subsample
OrthocladiinaeCh	Richness	Taxa richness of Orthocladiinae
OrthocladiinaeChTxPct	Composition	Relative percentage of taxa belonging to Orthocladiinae
OrthocladiinaePct	Composition	Percent of chironomid individuals in the subfamily Orthocladiinae
OrthoTanyCh	Tolerance	Taxa richness of Orthocladiinae & Tanytarsini
OrthoTanyChTxPct	Tolerance	Relative percentage of taxa belonging to Orthocladiinae & Tanytarsini
OrthoTanyPct	Tolerance	Relative abundance (%) of Orthocladiinae & Tanytarsini individuals in subsample
OT	Richness	Taxa richness of Odonata & Trichoptera
OTPct	Composition	Relative abundance (%) of Odonata & Trichoptera individuals in subsample
Plecoptera	Richness	Taxa richness of Plecoptera
PlecopteraChTxPct	Composition	Relative percentage of taxa belonging to Plecoptera
PlecopteraPct	Composition	Relative abundance (%) of Plecoptera individuals in subsample
POET	Richness	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera (baetid taxa treated as one taxon)
POETCh	Richness	Taxa richness of Plecoptera, Odonata, Ephemeroptera, & Trichoptera
POETChTxPct	Composition	Relative percentage of taxa belonging to Plecoptera, Odonata, Ephemeroptera, & Trichoptera
POETPct	Composition	Relative abundance (%) of Plecoptera, Odonata, Ephemeroptera & Trichoptera individuals in subsample
Predator	Trophic	Taxa richness of predators (excluding chironomid predator taxa)
PredatorCh	Trophic	Taxa richness of predators
PredatorChTxPct	Trophic	Relative percentage of predator taxa
PredatorPct	Trophic	Relative abundance (%) of predator individuals in subsample
Scraper	Trophic	Taxa richness of scrapers (excluding chironomid and baetid scraper taxa)

Appendix C. (continued)

MetricName	Metric Category	Metric Description
ScraperCh	Trophic	Taxa richness of scrapers
ScraperChTxPct	Trophic	Relative percentage of scraper taxa
ScraperPct	Trophic	Relative abundance (%) of scraper individuals in subsample
ScrapFilt	Trophic	Ratio of scraper abundance to scraper + collector-filterer abundance
ScrapHerb	Trophic	Taxa richness of scrapers and herbivores
Shannon	Composition	Shannon Diversity Index: -1*sum(p*natural log(p))
Shredder	Trophic	Taxa richness of shredders (excluding chironomid and baetid scraper taxa)
ShredderCh	Trophic	Taxa richness of shredders
ShredderChTxPct	Trophic	Relative percentage of shredder taxa
ShredderPct	Trophic	Relative abundance (%) of shredder individuals in subsample
Simpson	Composition	Simpson Diversity Index: sum((n*(n-1))/(N*(N-1)))
SimuliidaeCh	Richness	Taxa richness of Simuliidae
SimuliidaeChTxPct	Composition	Relative percentage of taxa belonging to Simuliidae
Sprawler	Habit	Taxa richness of sprawlers (excluding chironomid and baetid sprawler taxa)
SprawlerCh	Habit	Taxa richness of sprawlers
SprawlerChTxPct	Habit	Relative percentage of sprawler taxa
SprawlerPct	Habit	Relative abundance (%) of sprawler individuals in subsample
Swimmer	Habit	Taxa richness of swimmers (excluding chironomid, baetid taxa treated as one taxon)
SwimmerCh	Habit	Taxa richness of swimmers
SwimmerChTxPct	Habit	Relative percentage of swimmer taxa
SwimmerPct	Habit	Relative abundance (%) of swimmer individuals in subsample
TanypodinaeCh	Richness	Taxa richness of Tanypodinae
TanypodinaeChTxPct	Composition	Relative percentage of taxa belonging to Tanypodinae
TanypodinaePct	Composition	Percent of chironomid individuals in the subfamily Tanypodinae
TanytarsiniCh	Richness	Taxa richness of Tanytarsini
TanytarsiniChTxPct	Composition	Relative percentage of taxa belonging to Tanytarsini
TanytarsiniPct	Composition	Percent of chironomid individuals in the tribe Tanytarsini
TaxaCount	Richness	Total taxa richness of macroinvertebrates (chironomid and baetid taxa each treated as one taxon)
TaxaCountAllChir	Richness	Total taxa richness of macroinvertebrates

Appendix C. (continued)

MetricName	Metric Category	Metric Description
Tolerant	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 6 (excludes tolerant baetid taxa and treats tolerant chironomid taxa as one taxon)
Tolerant2	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 6 (excludes tolerant baetid taxa and treats tolerant chironomid taxa as one taxon)
Tolerant2Ch	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 6, Using MN TVs
Tolerant2ChTxPct	Tolerance	Relative percentage of taxa with tolerance values equal to or greater than 6, using MN TVs
Tolerant2Pct	Tolerance	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 6
TolerantCh	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 6
TolerantChTxPct	Tolerance	Relative percentage of taxa with tolerance values equal to or greater than 6
TolerantPct	Tolerance	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 6
Trichoptera	Richness	Taxa richness of Trichoptera
TrichopteraPct	Composition	Relative abundance (%) of Trichoptera individuals in subsample
TrichwoHydroPct	Composition	Relative abundance (%) of non-hydropsychid Trichoptera individuals in subsample
VeryTolerant	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 8 (excluding very tolerant chironomid and baetid taxa)
VeryTolerant2	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 8 (excluding very tolerant chironomid and baetid taxa)
VeryTolerant2Ch	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 8
VeryTolerant2ChTxPct	Tolerance	Relative percentage of taxa with tolerance values equal to or greater than 8, using MN TVs
VeryTolerant2Pct	Tolerance	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 8, Using MN TVs
VeryTolerantCh	Tolerance	Taxa richness of macroinvertebrates with tolerance values equal to or greater than 8
VeryTolerantChTxPct	Tolerance	Relative percentage of taxa with tolerance values equal to or greater than 8
VeryTolerantPct	Tolerance	Relative abundance (%) of macroinvertebrate individuals in subsample with tolerance values equal to or greater than 8

Appendix D. List of metrics evaluated for inclusion in F-IBI. (+) indicates metric satisfied all testing criteria within a particular class. (IBI metric) indicates metric was included in F-IBI within a particular class. (NT) indicates metric was not tested within a particular class.

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
Amphipoda					
AmphipodaChTxPct					
AmphipodaPct	x		x		x
Annelida					
AnnelidaChTxPct					
AnnelidaPct					
BaetEphem				x	
BaetidaeCh			x		
BaetidaeChTxPct			x		
BaetidaePct			x		
Bivalvia					
BivalviaChTxPct					
BivalviaPct					
Burrower					
BurrowerCh					
BurrowerChTxPct					
BurrowerPct	x	x	x		
CaenEphem		x	x		
CaenidaeCh					
CaenidaeChTxPct		x	x		
CaenidaePct		x			
CBI	NT	NT	NT		IBI Metric

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
ChiroDip		x		x	IBI Metric
ChiroIntol					
ChiroIntolTxPct					
ChironomidaeCh	x	x	x		
ChironomidaeChPct	x		x		x
ChironomidaeChTxPct					x
ChironominiCh					
ChironominiChTxPct					
ChironominiPct					
ChiroVeryIntol					
ChiroVeryIntolTxPct					
Climber	x	x	x		x
ClimberCh	x	IBI Metric	x		x
ClimberChTxPct	x		x		
ClimberPct					
Clinger	x	x	x		
ClingerCh	x	x	IBI Metric		
ClingerChTxPct		IBI Metric	x		x
ClingerPct		x	x		
CoenagrionidaeCh					
CoenagrionidaeChTxPct		x	x		
CoenagrionidaePct		x	x		
CoenOdo		x	x		
Coleoptera					
ColeopteraChTxPct					

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
ColeopteraPct					
Collector-filterer		x	x		
Collector-filtererCh		x	x		
Collector-filtererChTxPct	x		x		
Collector-filtererPct		x	IBI Metric		
Collector-gatherer					IBI Metric
Collector-gathererCh					
Collector-gathererChTxPct				IBI Metric	
Collector-gathererPct		x			
Crustacea					
CrustaceaChTxPct				x	
CrustaceaPct	x		x	x	x
CrustMoll					
CrustMollChTxPct	x	x	x		
CrustMollPct	x		x		
CW165Pct	NT	NT	NT		
CW17Pct	NT	NT	NT		
CW175Pct	NT	NT	NT	x	x
CW18Pct	NT	NT	NT		
CW185Pct	NT	NT	NT	x	x
CW19Pct	NT	NT	NT		
CW165TaxaPct	NT	NT	NT		
CW17TaxaPct	NT	NT	NT		
CW175TaxaPct	NT	NT	NT		
CW18TaxaPct	NT	NT	NT	x	x

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
CW185TaxaPct	NT	NT	NT		
CW19TaxaPct	NT	NT	NT		
CW165Taxa	NT	NT	NT		
CW17Taxa	NT	NT	NT		
CW175Taxa	NT	NT	NT		
CW18Taxa	NT	NT	NT	x	x
CW185Taxa	NT	NT	NT		
CW19Taxa	NT	NT	NT		
DipteraCh	x	x	x		
DipteraChPct			x		
DipteraChTxPct		x			
DipteraPct		x	x		x
DomFiveChAs1Pct	x	x	x		
DomFiveCHPct	IBI Metric	IBI Metric	IBI Metric		
DomFivewoCHPct		x	x	x	x
DomFourChAs1Pct		x	x		
DomFourCHPct	x	x	x		x
DomFourwoCHPct		x	x	x	x
DomOneChAs1Pct					
DomOneCHPct					
DomOnewoCHPct					
DomThreeChAs1Pct		x	x		
DomThreeCHPct		x	x		x
DomThreewoCHPct		x	x	x	x
DomTwoChAs1Pct					

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
DomTwoCHPct		x	x		x
DomTwowoCHPct		x	x	x	x
EOT	x	x	x	x	
EOTCh	x	x	x	x	
EOTChTxPct		x	x	x	
EOTPct	x	x	x		
EP		x	x	x	
EPCh		x	x	x	
EPChTxPct	x		x	x	
Ephemeroptera		x	x	x	
EphemeropteraCh		x	x		
EphemeropteraChTxPct	x		x		
EphemeropteraPct	x		x		
EPPct	x		x		
EPT	x	x	x	x	
EPT_Chiro			x		x
EPTCh	x	x	x	x	
EPTChTxPct		x	x	x	x
EPTPct	x	x	x		
Gastropoda					
GastropodaChTxPct		x	x		
GastropodaPct					
GathFiltPct			x		x
HBI	x	x	x		x
HBI_MN	IBI Metric	IBI Metric	IBI Metric	IBI Metric	IBI Metric

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
HCDNIPct	x	x	x		
HCDPct					
HetCol					
HetColChTxPct			x		
HetColNIPct	x	x	x		
HetColPct					
Heteroptera					
HeteropteraChTxPct					
HeteropteraPct					
HydropsychidaeCh	x	x	x		
HydropsychidaeChTxPct	x		x		
HydropsychidaePct	x		x		
HydrTrich	x	x	x		
Insect	x	x	x		x
InsectPct	x	x	x		
InsectTxPct	x	IBI Metric	x	x	
Intolerant		x	x	x	x
Intolerant2	x	x	x	IBI Metric	x
Intolerant2ch		x	IBI Metric	x	IBI Metric
Intolerant2chTxPct	x	x	x	x	x
Intolerant2less	x	x	x	x	x
Intolerant2lessCh	IBI Metric	x	x	x	x
Intolerant2LessChTxPct	x	x	x	x	x
Intolerant2lessPct	x	x	x	x	x
Intolerant2Pct	x	x	x	x	x

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
IntolerantCh		x	x	x	
IntolerantChTxPct	x	x	x	x	x
IntolerantPct		x	x		x
Isopoda					
IsopodaChTxPct				x	
IsopodaPct				x	x
Legless					
LeglessCh					
LeglessChTxPct		x	x		
LeglessPct		x	x	x	
LongLived	x	x	x	x	
LongLivedChTxPct		x		IBI Metric	
LongLivedPct		x			
Mollusca			x		
MolluscaChTxPct	x	x	x		
MolluscaPct					
NonInsect					
NonInsectPct	x	x	x		
NonInsectTxPct	x	x	x	IBI Metric	
Odonata	IBI Metric	IBI Metric	x	x	
OdonataChTxPct	x	x		IBI Metric	
OdonataPct	x	x			
Oligochaeta					
OligochaetaChTxPct					
OligochaetaPct					

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
OligoHir					
OligoHirChTxPct					
OligoHirPct					
OrthocladiinaeCh	x	x	x		
OrthocladiinaeChTxPct					
OrthocladiinaePct					
OrthoTanyCh					
OrthoTanyChTxPct					
OrthoTanyPct					
OT	x	x	x	x	
OTChTxPct	x	x	x	x	x
OTPct		x	x		
Plecoptera		IBI Metric	x	x	
PlecopteraChTxPct		x	x	x	
PlecopteraPct					
POET	x	x	IBI Metric	IBI Metric	
POETCh	x	x	x	x	
POETChTxPct		x	x	x	
POETPct	x	x	x		
Predator	x	x	x	x	
PredatorCh	IBI Metric	IBI Metric	IBI Metric	IBI Metric	
PredatorChTxPct		x	x		
PredatorPct					
Scraper					
ScraperCh					

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
ScraperChTxPct					
ScraperPct					
ScrapFilt			x		
ScrapHerb					x
Shannon	x	x	x		x
Shredder					
ShredderCh					
ShredderChTxPct					
ShredderPct					
Simpson	x	x	x		
SimuliidaeCh					
SimuliidaeChTxPct					x
SimuliidaePct			x	x	x
Sprawler					
SprawlerCh					
SprawlerChTxPct					
SprawlerPct		x			x
Swimmer					
SwimmerCh					
SwimmerChTxPct					
SwimmerPct			x		
TanypodinaeCh					
TanypodinaeChTxPct					
TanypodinaePct					
TanytarsiniCh					

Appendix D. (continued)

MetricName	Northern and Southern Rivers	Northern and Southern High Gradient Streams	Northern, Prarie, and Southern Forested Glide Pool Streams	Northern Coldwater Streams	Southern Coldwater Streams
TanytarsiniChTxPct					
TanytarsiniPct					
TaxaCount	x	x	x		
TaxaCountAllChir	IBI Metric	x	IBI Metric		x
Tolerant					
Tolerant2					
Tolerant2Ch				x	x
Tolerant2ChTxPct	x	IBI Metric	x	x	x
Tolerant2Pct	x	x	x	x	x
TolerantCh					
TolerantChTxPct		x	x	x	x
TolerantPct	x	x	x		
Trichoptera	x	IBI Metric	x		
TrichopteraChTxPct		x	IBI Metric		IBI Metric
TrichopteraPct		x	x		
TrichwoHydroPct	IBI Metric	x	IBI Metric		
VeryTolerant	x				x
VeryTolerant2					
VeryTolerant2Ch					
VeryTolerant2ChTxPct	x	x	x	IBI Metric	x
VeryTolerant2Pct	IBI Metric	x	x		IBI Metric
VeryTolerantCh					
VeryTolerantChTxPct		x	x		
VeryTolerantPct	x	x	x		x

2016

Identification of Predictive Habitat Attributes for Minnesota Streams to Support Tiered Aquatic Life Uses

Midwest Biodiversity Institute

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Columbus, Ohio

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Appendices

Note: This document was updated in June of 2016 to correct some minor errors in text and tables. This document established a methodology for exploring MSHA habitat attributes associated with higher FIBI or MIBI scores ("good" habitat attributes) or lower FIBI or MIBI scores ("poor" habitat attributes) that can be used as an aid in determining whether habitat may be limiting to aquatic life when conducting stressor analyses and determining likely aquatic life use potential for Use Attainability Analyses. The State of Minnesota conducted further analyses with additional, newer data and derived logistic regression models to predict limiting effects of habitat on FIBI and MIBI (MPCA 2015) and that report supersedes the analyses in this report for conducting UAAs and stressor identification in Minnesota.

Introduction

Physical habitat characteristics are fundamental to the distribution and occurrence of aquatic assemblages in streams and rivers (Gorman and Karr 1978, Schlosser 1982, Maddock 1999). These physical features include the substrate and stream bottom attributes, stream channel features such as riffles, runs and pools, and in-stream structures such as boulders, logs, rootwads, aquatic plants, and undercut banks. Perhaps the most important physical feature in the formation of the aforementioned habitat characteristics is flow which has been termed the “master variable” (Poff et al. 2009). Historically, most streams and rivers had diverse habitat features related to the undisturbed interaction between landscapes and their geologic context, river bottom forests, swamps, oxbows and the natural hydrology. The settlement of Europeans who brought their culture and technology of intensive agriculture and agricultural drainage practices substantially altered stream habitat conditions compared to “as naturally occurred” conditions, especially in the Midwest.

The Clean Water Act (CWA) directs states to protect and restore the chemical, physical and biological integrity of streams and provides a water quality standards (WQS) framework that includes “designated aquatic life uses” and the development of stressor criteria to protect these uses. The development of tiered aquatic life uses (TALUs) necessitates an understanding and quantification of human alterations to the landscape that have substantially altered the biological potential of rivers. In the Midwest the influence of landscape and land use changes are particularly in evidence in the habitat features characteristic of streams and rivers. Instream habitat features are the product of both upstream changes to hydrology, geomorphology, sediment supply, etc., and direct alterations to habitat that include channelization, removal of riparian habitat and loss of wetland features once integral to the functioning of Midwest streams and rivers.

Accurate assessment of stream habitat characteristics is essential to the protection, restoration and enhancement of aquatic life uses. The ability to manage rivers in a tiered framework provides benefits in protecting truly high quality rivers, insight into aspects of restoring river habitats, and an ability to resolve management issues for rivers where full restoration is not feasible. Availability of habitat assessment tools that balance accuracy and precision with cost-effectiveness and that match the resolution of biological assessment tools is a key aspect of managing rivers using TALUs. The goal of this work is to establish baseline relationships between habitat as measured by the Minnesota Stream Habitat Assessment (MSHA) index and fish and macroinvertebrate assemblages in Minnesota. The purpose is to identify habitat features that can limit the performance of key aquatic response metrics and that can be used to characterize tiers of aquatic life uses in Minnesota. Ideally these habitat attributes can be used to accurately identify habitat stressors limiting to aquatic life and enable analyses to determine whether such attributes are feasibly restorable or likely to provide a ceiling to aquatic life use attainment under acceptable best management practices. It is important to minimize the misclassification of habitat limited sites that might be a candidate for a “modified” use, and less stringent aquatic life use goals. Thus we need to understand the links between habitat and biological performance and to be able to identify exceptions where high biological performance can be attained despite poor habitat.

Background

Ohio was one of the first states to develop biocriteria and to develop "modified" aquatic life uses based on identified limitations to aquatic biota related to habitat alteration deemed to be not feasibly restorable with accepted management practices and feasible restoration options (Yoder and Rankin 1999). Analyses of streams in Ohio found strong associations between biodiversity and biological condition and measures of habitat diversity and condition as measured by the Qualitative Habitat Evaluation Index (QHEI; Rankin 1986; 1995). The QHEI measures multiple aspects of stream habitat and the condition of these features (*e.g.*, degree of siltation, embeddedness, and channelization) associated with human alteration of the stream itself and its surrounding landscape. Ohio EPA has used the QHEI since the mid 1980s and has derived habitat "attributes" that are predictive of high quality or poor quality fish assemblages (Rankin 1989, 1995). The accumulation of identified positive ("good") or negative ("poor") habitat attributes at sites or reaches has been a useful tool in assigning causes of impairment and discerning whether physical characteristics were limiting to aquatic life. These attributes provide information that is used to determine whether limitations are extensive enough and permanent enough to justify an alternative tier of aquatic life use. In Ohio there are occasional exceptions to the typical habitat-biology relationship where habitat is rather poor, yet biology attains the CWA biological goals. These streams are protected because Ohio relies on the biota as the ultimate arbiter of aquatic life use attainment and these exceptions are uncommon, but explainable (*e.g.*, high groundwater derived baseflows and cooler water counter some of the impacts of channelization; very localized scale of habitat degradation compensated by nearby excellent habitat). The purpose of this analysis is to develop a similar list of "positive" and "negative" habitat attributes for Minnesota streams and rivers that will be predictive of biological performance, provide a template for TALU designations, identify scenarios where biological performance is high despite localized habitat degradation and provide a framework for habitat-based stressor analysis for Minnesota warm water streams.

Methods

Habitat Data

We used the Minnesota Pollution Control Agency's (MPCA) Minnesota Stream Habitat Assessment (MSHA) data collected under standardized protocols (MPCA 2009a, Appendix 1). The MSHA is similar to the QHEI, but has been modified for conditions found in Minnesota streams. The MSHA is a visual tool that rates key habitat features of streams and rivers including surrounding or floodplain land use, riparian zone features including width, bank erosion, and shade, instream conditions including substrate size, types, embeddedness and siltation and, instream structure (cover) types and amount, characteristics of stream channel condition including sinuosity, development, channel modification and stability, velocity types, depth variability, and pool to riffle width ratio (MPCA 2009a). The index is composed of a series of attributes (individual scoring choices or "boxes" that can aggregated into sub-metric scores or metric scores which are then aggregated into the final MSHA score which ranges from approximately 0 to 100. All scorers were qualified biologists and received training and annual internal reviews and conduct periodic self-checks by comparing results with other trained scores (MPCA 2009a).

Minnesota's Human Disturbance Score

Minnesota has created a Human Disturbance Score (HDS) as an integrated scoring of disturbance along which to ordinate biological assemblage data and account for potential changes from natural conditions in streams (MPCA 2016). It consists of a series of metrics and adjustment scores and ranges from 0 (most disturbed) to 81 (least disturbed). We used these data to censor sites with potential point source impacts, impervious surface impacts or acute livestock impacts that could confound the habitat gradient in the MSHA. For most analyses sites were excluded that: 1) had continuous point sources discharges <5 stream miles from a site where the stream was less than 50 mi^2 drainage; 2) had visual evidence of a feedlot at a site or immediately upstream of a site; or 3) had a city or town at the site or immediately adjacent to the site (proximity scores of -1 in the HDS, Table 1).

Table 1. Variables of the Minnesota human disturbance score (HDS)

Metric	Range	Type/Scale	Description
audenscore	0-10	watershed	# of animal units per km2 (feedlots)
pctagsco	0-10	watershed	% agriculture in watershed
ptscore	0-10	watershed	# of point sources per km2
pctimpscore	0-10	watershed	% impervious surface in watershed
pctdistripscore	0-10	watershed	% disturbed riparian habitat in the watershed
DITCHPCTSCORE	0-10	watershed	% channelized stream per stream km
siteriparian	0-10	reach	"intactness" of site riparian zone
stiechannel	0-10	reach	channel condition
pointsourceprox	-1	proximity adjustment	Continuous discharge <5 stream miles into stream <50SqMi.
feedlotprox	-1	proximity adjustment	Visual evidence (from DOQ) of feedlot at site or immediately upstream of site
urbanluprox	-1	proximity adjustment	City or town at the site or immediately adjacent to site

feedscore	-1	adjustment	
roadscore	-1 or +1	adjustment	
ag3pctscore	-1	adjustment	Amount of agricultural landuse on 3% slope as a percentage of total watershed area
pctagripscor	-1	adjustment	% agriculture in 100 meter buffer

Biological Data

Fish data were collected by the MPCA from 1996-2009 during multiple projects. Fish were collected with pulsed DC electrofishing as described by MPCA (MPCA 2009b). Fish were processed in the field and identified to species and counted, weighed, and examined for any external abnormalities (deformities, eroded fins, lesions or tumors). We used the Minnesota Fish Index of Biological Integrity (FIBI; MPCA 2014a) for each classification strata and key individual metrics (*e.g.,* sensitive species richness) as response variables. Where multiple fish samples were collected at a site during a year, but only a single MSHA score was recorded, each IBI score was considered an independent sample. In addition to the fish assemblage we used Minnesota's macroinvertebrate data and their Macroinvertebrate IBI (MIBI) as an additional response variable (MPCA 2000, MPCA 2014b). Sites where IBI scores were not calculated or where samples were considered invalid because of flow or other problems were excluded from analyses.

Table 2. Symbol codes for plots of Minnesota Fish data by classification strata used in this report

Classification Strata	Symbol/Color
Southern Rivers	o
Southern Streams	i
Southern Headwaters	Δ
Northern Rivers	n
Northern Streams	l
Northern Headwaters	p
Low Gradient	t
Sites Combined	i

Stream Classification

Minnesota has examined the strength of different classification strata on fish assemblages (MPCA 2014a) and macroinvertebrate assemblages. For fish they have defined seven warmwater stream classes that reflect a stream size gradient, a north-south gradient, and a local reach classification (low gradient streams) that explain much of the natural variation in fish assemblage differences (Table 2). For macroinvertebrates there are also seven stream classes that reflect a similar North-South gradient and a Prairie stream classification and gradients related to riffle/run versus glide/pool type streams (MPCA 2014b). For certain analyses we aggregated data, but at a minimum analyzed data separately for each classification stratum. To ease interpretation of graphs we standardized symbol types and colors by classification on plots (Tables 2 and 3).

Table 3. Symbol codes for plots of Minnesota Macroinvertebrate data by classification strata used in this report

Classification Strata	Symbol/Color
Prairie Forest Rivers	2
Prairie Streams (Glide/Pool)	$
Northern Forest Rivers	n
Northern Forest Streams (Riffle/Run)	l
Northern Forest Streams (Glide/Pool)	a
Southern Streams (Riffle/Run)	i
Southern Streams (Glide/Pool)	t
Sites Combined	i

Statistical Analyses

We used classification tree analyses as an initial exploratory approach to understanding the strength of association between the FIBI and MIBI and individual habitat submetrics and HUC-8 average habitat scores for each classification stratum. We also examined data summarized at the HUC-10 and HUC-12 scales, but did not include these in the classification tree analyses because there were too many watersheds with insufficient data. Instead we analyzed this data separately and recommend how it can be included in the decisions about the attainability of uses in addition to HUC-8 data. We used the provisional impairment thresholds for each classification unit as the response variable (Attaining versus Impaired) and submetric scores as the independent variables to gain insight into which categories of habitat appear to be limiting within each region. We also used the HUC-8 average total MSHA score as a measure of effect of the scale of habitat degradation on assemblages at sites.

We used correlation analyses to explore the relationships between individual and composite habitat metrics, submetrics or attributes (Table 4) of the MSHA and biological response measures including the FIBI and MIBI, their metrics, as well as other candidate metrics not kept as components of these IBIs. We identified meaningful MSHA habitat attributes, defined as whether FIBI scores or MIBI scores varied significantly ($P < 0.05$) between attributes, in an exploratory mode, using an Analysis of Variance (ANOVA) (KaleidaGraph 4.1, Synergy Inc.). Where differences were significant we ran Tukey multiple comparisons to help us identify attributes most associated with higher FIBI and MIBI scores ("good" habitat attributes) or lower FIBI and MIBI scores ("poor" habitat attributes). Professional judgment was used to select final attributes, particularly where statistical results were marginal because of reduced sample sizes in rare categories. The Tukey test is a pairwise test, so that we looked for differences between any pair to identify that the attribute was contributing to either a high or low FIBI or MIBI score. We used the strength of the difference (P-value) to arrive at a weighting of attributes. Attributes significant at greater than at $P<0.001$ were given a weighting of 2 points (to each attribute in the pair), those with a significance >0.001, but less than $P<0.05$ were given a weighting of 1 point, and those less significant, but strongly trending or where a lack of significance was due to small sample size were give a weighting of 0.5 points. The ANOVA and Tukey test were not used in a strict hypothesis testing mode, but rather as a method to construct indices (*i.e.,* attributes) to help predict direction and strength of IBI scores with aggregations of habitat attributes. Identification of key habitat attributes could be selected based on literature citations or best professional judgement. Our method here is less arbitrary than professional judgement alone, although it uses judgement in weighting weaker attributes that may be important, but uncommon in classification strata.

Sites identified as having modified channels were given an additional score of 5 points to the poor attributes. Results are illustrated in tables of FIBI or MIBI scores by metrics for individual MSHA attributes. In some cases we contrasted results from Minnesota with similar data from Ohio which has a very strong habitat gradient. Ohio's relationship may be particularly strong because the extensive wetland and base flow losses in Ohio tend to intensify the habitat impacts and its more southern latitude and warmer maximum stream temperatures compared to Minnesota may also contribute to this association.

Table 4. Hierarchy of habitat variables used in this study		
Metrics/ Variables	**Sub-metrics**	**Attributes**
Substrate Score	Predominate Substrate Types	Boulder, Cobble, Gravel, Bedrock, Sand, Silt, Muck, Detritus, Sludge (by habitat type (pool, glide, riffle, run)
	Embeddedness	None, Light, Moderate. Severe, No Coarse Substrate
	Number of Types	Greater than 4, Less than or equal to 4
Land Use Score	-	Forest, Wetland, Prairie, Shrub; Residential/Park; Old Field/Hay Field; Urban/Industrial; Fenced Pasture; Open Pasture ; Conservation Tillage, No Till; Row Crop
Riparian	Riparian Width, Bank Erosion, Shade	Width: Extensive, Wide, Moderate, Narrow, Very Narrow, None Erosion: None, Little, Moderate, Heavy, Severe Shade: Heavy, Substantial, Moderate, Light, None
Cover	Number of Types, Cover Amount	Types: Undercut Banks, Macrophytes, Overhanging Vegetation, Deep Pools, Logs or Woody Debris, Boulders, Rootwads Amount: Extensive, Moderate, Sparse, Nearly Absent, Choking Vegetation
Channel	Depth Variability, Channel Stability, Velocity Types, Sinuosity, Morphology, Channel Development	Depth Variability: Deep, Moderate, Shallow Stability: High, Moderate/High, Moderate, Low Velocity Types: Torrential, Fast, Moderate, Slow, Eddies, Intermittent, Interstitial Sinuosity: Excellent, Good, Fair, Poor Development: Excellent, Good, Fair, Poor Morphology: Poor Width > Riffle Width, Poor Width = Riffle Width, Poor Width < Riffle Width, No Riffle
HUC-8, HUC-10 and HUC-12 Average MSHA Scores		

The use of biological indicators is typically anchored to some form of reference condition (Stoddard et al. 2006) with the most advanced approach anchored to a "as naturally occurs" condition which allows a consistent context for determining the biological condition of streams along a gradient especially where tiers of aquatic life uses are to be constructed (Davies and Jackson 2006). Anchoring stressor conditions (*e.g.,* physical habitat) in a "as naturally occurs" condition can create a strong foundation for interpreting tiers of condition that deviate from these conditions with human changes in landscape condition. We begin the analyses by extrapolating the MSHA to periods of time during early or pre-European settlement (an "as naturally occurred" condition) based on historical descriptions of the land use and cover during these periods.

Results

Fish and Macroinvertebrate Assemblages

In the next sections of the report we examine the correlation of the FIBI and MIBI scores by individual MSHA metrics, sub-metrics and attributes to identify potential indicators of habitat impact. The goal of these analyses is to identify attributes that more consistently represent the potential candidate "good" or "poor" habitat attributes that can form the basis for interpreting potential mechanisms of impact related to habitat conditions. The accrual of poor habitat attributes that cannot be readily restored will form the basis for decision trees that support designation of "Modified" or "Limited" aquatic life uses. In this process we will "err" in favor of a higher aquatic life use to minimize an error where we designate a "lower" use when a higher, more protective use is attainable. The procedure need not be onerous, but must be based in sound science. Prior to these detailed analyses; however, we consider the natural state of stream habitats in Minnesota and the relationship between Minnesota fish assemblages, the biological condition gradient (BCG) levels, and the MSHA.

Exploration of Natural Habitat Conditions in Minnesota's Fish Regions

Minnesota developed an aquatic classification system for fish that divided warmwater streams in the State into 7 classification strata: Northern Rivers, Southern Rivers, Northern Streams, Southern Streams, Northern Headwaters, Southern Headwaters, and Low Gradient Streams (Table 2; MPCA 2014a). Similarly Minnesota was divided into seven warmwater classification strata for macroinvertebrates (Table 3; MPCA 2014b). The classification strata were selected to minimize variation in assemblage structure that could be attributable to natural variation in a North-South gradient, a stream size gradient, and in low versus higher gradient streams. The North-South gradient reflects both a temperature classification and a biogeographic classification. Minnesota completed a BCG exercise which uses a combination of data and expert opinion to identify attributes of assemblages that approximate "natural" conditions as well those that exhibit substantial stress from pollutants and physical stressors (*e.g.,* flow and habitat) that commonly occur within each region (Gerritsen *et al.* 2013).

We suggest an important component is to describe the "natural" habitat conditions that likely existed prior to substantial human disturbance, sometimes termed "hindcasting." One goal of this study is to consider the implementation of a "modified" stream use related to the effects of channelization that cannot be feasibly restored. FIBI scores in boatable sites (Northern Rivers and Southern Rivers types) indicated warmwater habitat (WWH) conditions are typically attainable, thus we did not consider boatable rivers in this analysis. In this effort we use the sites identified as having BCG Level 2 biological assemblages, along with historical descriptions of Midwest streams from settler and early naturalists to help set bounds on the likely habitat that exists in "Level 1" streams in terms of a physical disturbance gradient. During the BCG exercise no wadeable or headwater sites were classified as "Level 1" (Gerritsen et al. 2013) which is a "pristine" anchor. Level 2 is defined as having: "minimal changes in structure of the biotic community and minimal changes in ecosystem function" (Davies and Jackson 2009). Minnesota was characterized by diverse natural vegetation types during the early European settlement period that included aspen, hardwood and pine forests, bottomland forests, prairie and wet prairie, muskeg and pine barrens (Figure 1). Approaches including historical survey data and pollen surveys have been useful in examining changes in landuse from pre-settlement to current conditions (Sisk 1998, Cole et al. 1998). Land use in the Great Lakes region has changed more in the past 150 years than it did in the 1,000 years prior (Cole 1998). The dominance of natural vegetation in pre-settlement conditions (Figure 1), although varied, would maximize the MSHA land use, riparian, bank erosion, substrate, cover and channel metrics. The amount of shading might vary with stream type with streams in prairie areas, areas dominated by wetlands, or where beavers impounded or removed riparian trees resulting in more open channels. With the high proportion of mature vegetation (*e.g.*, forest, wetland) one would expect little erosion of fines. The extensive vegetation and wetlands, often mediated by beavers in many areas, would contribute to stable and strong base flows compared to today's heavily drained landscapes, particularly in the southern part of the State. Sedimentation rates are significant higher now than they were in pre-settlement periods: a study in Lake Pepin using sediment cores demonstrated a large increase in sediment accumulation beginning with European settlement in 1830 (Engstrom et l. 2009). Although historical levels of excess sediments were likely low historically, bottom substrates would vary with natural conditions (*e.g.,* low versus high gradient, types of natural outwash materials versus bedrock, *etc*.). In Figure 2 we illustrate actual MSHA scores at Level 2 and Level 6 sites with the hypothetical "hind-casted" Level 1 scores superimposed. It is likely Level 1 sites would have more of a tail of score distributions than depicted here that would overlap with existing scores caused by natural disturbances (*e.g.,* fire, landslides, *etc*.), natural climatic fluctuations in precipitation that could alter background erosion rates, or from localized disturbance by Native Americans (*e.g.*, setting of fires, agriculture). There is overlap with some Level 2 sites in the Northern streams and headwaters, but in general the distribution of scores is lower than Level 1 site habitat scores. Level 6 sites represent a substantial difference from Level 1 and Level 2 scores (Figure 2).

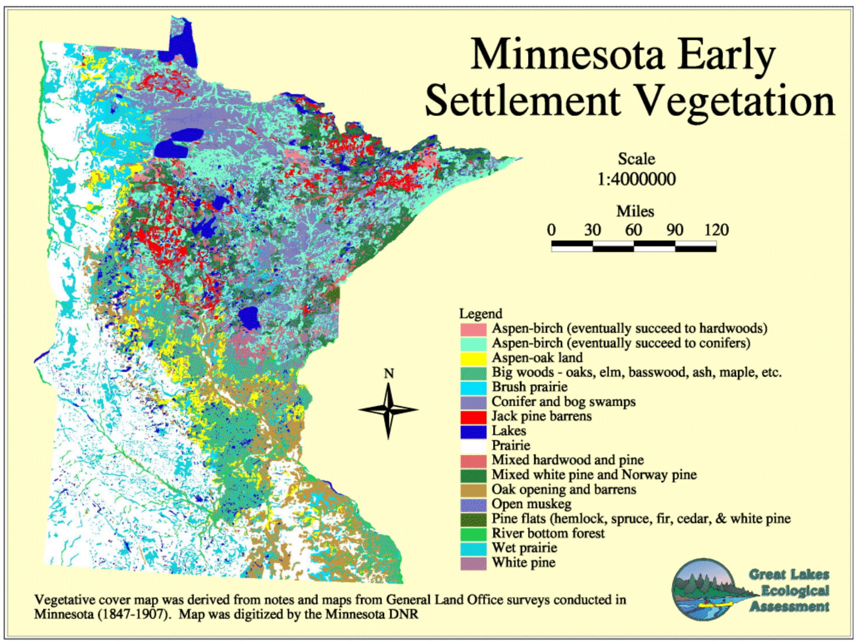


Figure 1. Map of Minnesota's early settlement vegetation (source: Minnesota DNR).

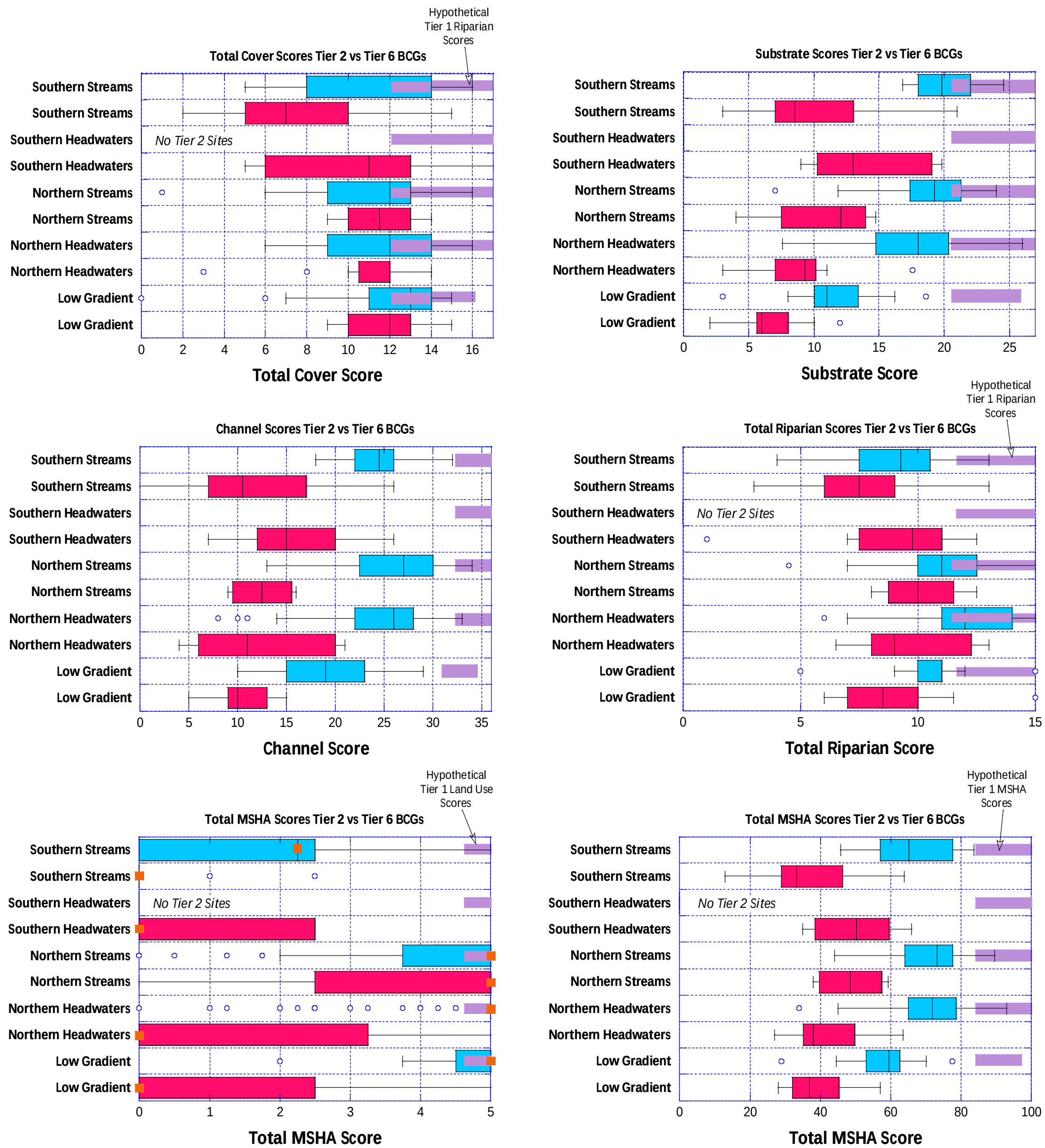
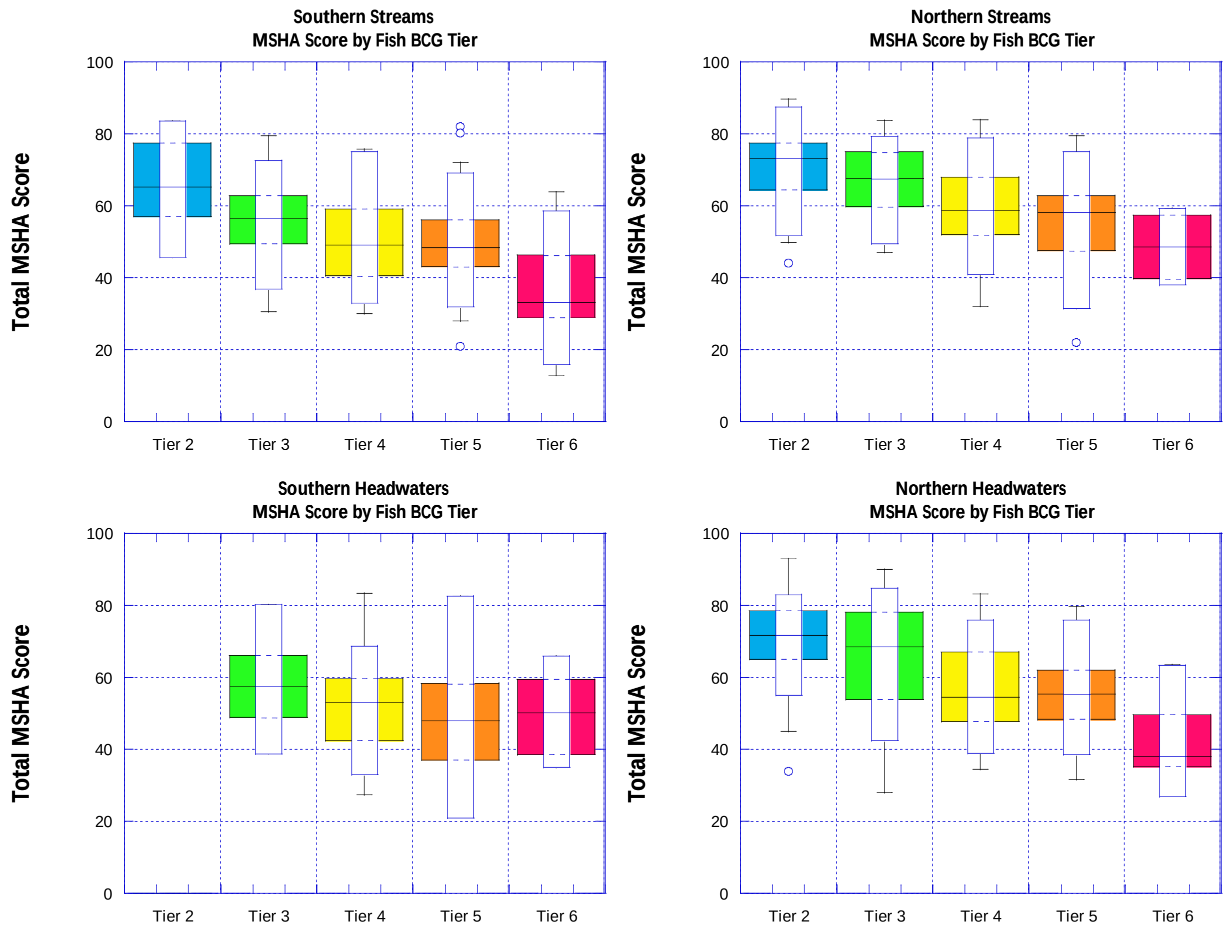


Figure 2. Box and whisker plots of MSHA metric scores by classification strata for Minnesota stream and by BCG Level 2 (blue) and Level 6 (red) sites. Theoretical maximum historical ("pre-settlement") scores are indicated by smaller purple boxes. Data represents summary metric scores (cover, upper left; substrate, upper right; channel, middle left; riparian, middle right; land use, lower left) and the total MSHA score (lower right).

As depicted in Figure 2, for most metrics and for the total MSHA score there is a clear difference between Level 2 and Level 6 sites. When we examined the total MSHA score for each classification strata by BCG Level (Figure 3), there is generally a pattern of decreasing scores with decreasing Tiers between Levels 2 through 4; however, Level 4 and Level 5 are not particularly different from one another. The demarcation between Level 4 and Level 5 is generally the region where CWA aquatic life use attainment thresholds are set. One goal for this paper to consider is whether certain habitat attributes are more predictive of the Level 4 – Level 5 threshold and the actual FIBI/MIBI thresholds derived by Minnesota as their attainment thresholds for their baseline or minimum CWA aquatic life use.

There are several explanations that we will consider to this end. Separation of the total MSHA score between Level 4 and Level 5 conditions could be confounded by metrics that have lesser influence on aquatic life. In Figure 2 the substrate and channel conditions had the greatest difference between Level 2 and Level 6 sites while cover and riparian differences were lesser and more variable. We will also explore the influence of cumulative watershed habitat impacts on biological condition. It may be that very local disturbances in watersheds where habitat is generally very intact (*e.g.,* Northern streams and headwaters) may have muted effects on assemblage condition. In contrast, in watersheds where habitat impacts related to channelization are widespread, local high quality reaches may perform poorly biologically because watershed scale effects limit populations of habitat sensitive species. Finally, strong base stream flow and lower stream temperature may moderate some of the potential effects of habitat degradation particularly where the extent of habitat loss is not overwhelming. In such cases, channelization caused habitat degradation may not be limiting the attainment of the baseline CWA aquatic life use goal, although it may limit the ability to attain a higher tier use.



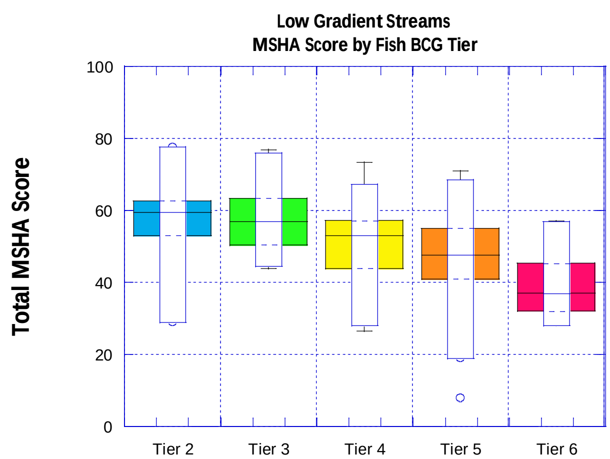


Figure 3. Box and whisker plot of MSHA scores by Fish BCG Level for Southern streams (top left), Northern streams (top right), Southern headwaters (middle left), Northern headwaters (middle right) and low gradient streams (bottom, left). Boxes reflect medians, 25th and 75th percentiles and 10th and 90th percentiles.

Identification of Key Habitat Attributes

The results of our analyses are presented hierarchically with a focus on metrics (correlation), then sub-metrics (classification tree analyses) and finally individual attributes to arrive at lists of attributes for each classification strata that are the best predictors that the habitat that is either limiting attainment of a higher use or confirms that a higher use is attainable. There is an aspect of the scale of habitat impacts (*i.e.,* cumulative impacts) that is important to this process as well. Habitat limitations tend to act at multiple spatial scales. The end product of these analyses results in a continuum of habitat effects on aquatic life that includes scale of impact. At the extremes of the habitat continuum decisions are rather simple (high quality habitat within watersheds with largely intact habitats versus poor quality habitats in watersheds with widely disturbed and modified habitats); however, other situations are more complex and these results are designed to give scientists and managers the tools to conduct a weight-of-evidence risk assessment for assigning tiered use designations. Central to this approach is consideration of whether the habitat limitations to the biota are feasibly restorable over a short time frame (*e.g.,* typically 10-20 years) or can recover naturally versus the need and feasibility of more active restoration actions. The results of these analyses can also be valuable in identifying habitat features that should be included in the design of stream restoration efforts. In this analysis we explicitly added points to the poor habitat scores when watersheds exceeded a specified level of cumulative habitat loss as well as when the stream had been channelized. Alternatively, these factors can be considered separately[1] and not “baked-into” the attribute scores.

The form of the FIBI and MIBI in Minnesota varies with each of the seven classification strata for each index and as a result identical scores, although generally similar, do not necessary represent the same level of biological condition among regions. Because of this we did not conduct analyses at a statewide scale, but rather separately for each of the seven classification strata. The first analyses we performed were simple correlations between the FIBI and the total MSHA score. The Minnesota FIBI was most strongly associated with the total MSHA score in the Low Gradient, Southern Stream, Northern Stream and Northern Headwater strata and more weakly associated with the MSHA in the Northern and Southern Rivers and Southern Headwaters (Figure 4). For the MIBI the relationship was strongest in the Glide/Pool strata and weakest in Rivers and Riffle/Run streams (Figure 5). Thus the MSHA is correlated with FIBI and MIBI, but not strongly enough to where the overall MSHA score alone is predictive of limitations to the FIBI or MIBI. Low total MSHA scores at individual sites are not sufficient by themselves to classify a site as being a likely “Modified” aquatic life use because high IBI scores, consistent with CWA goal tiers, can occur commonly at such sites.

[1] The approach taken in the more recent Minnesota Habitat Tool (MPCA 2015) analyses excluded the watershed score from the attribute calculation

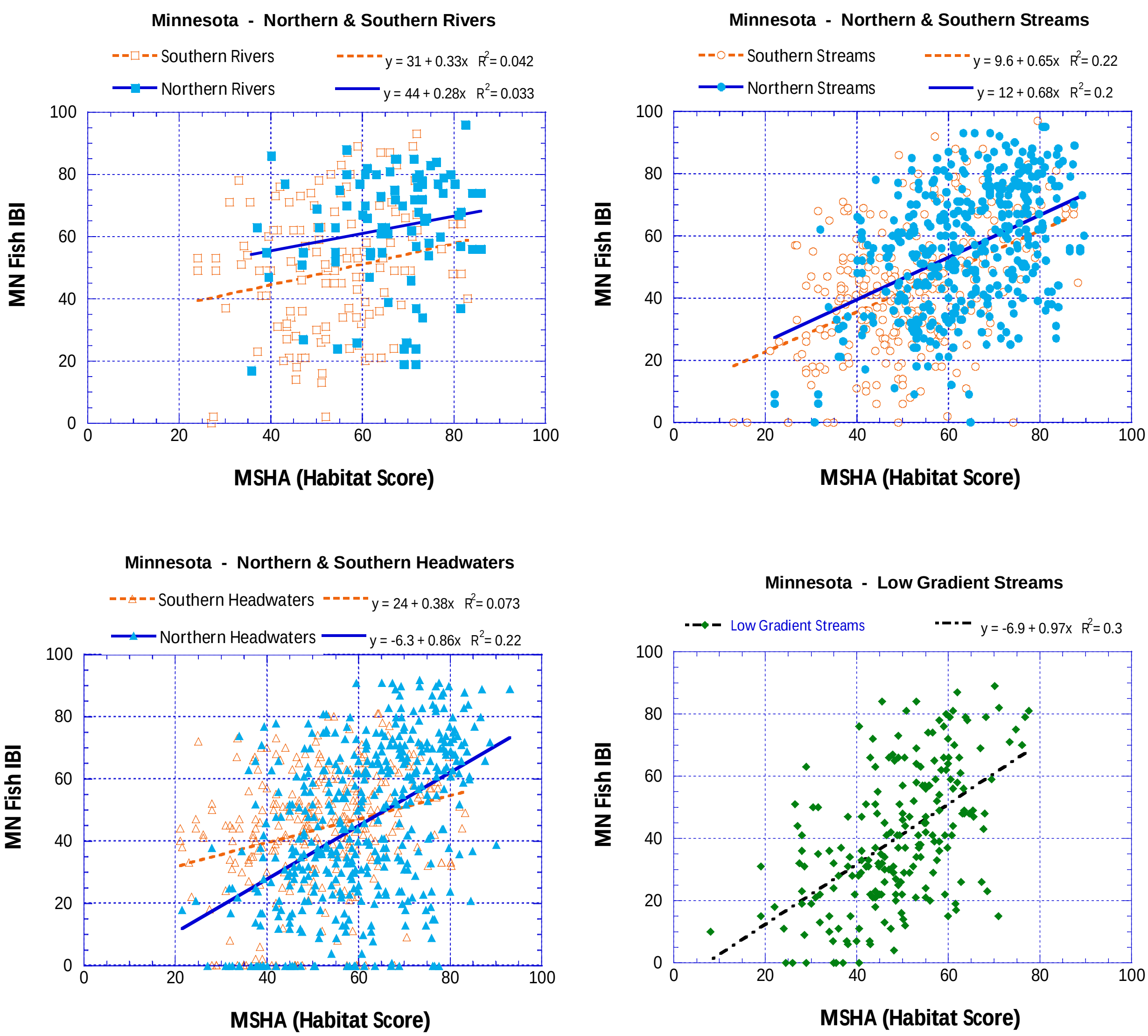


Figure 4. Plots of Fish IBI versus MSHA separately for Minnesota Northern and Southern rivers (top left), streams (top right), headwaters (bottom left) and statewide for low gradient streams (bottom right).

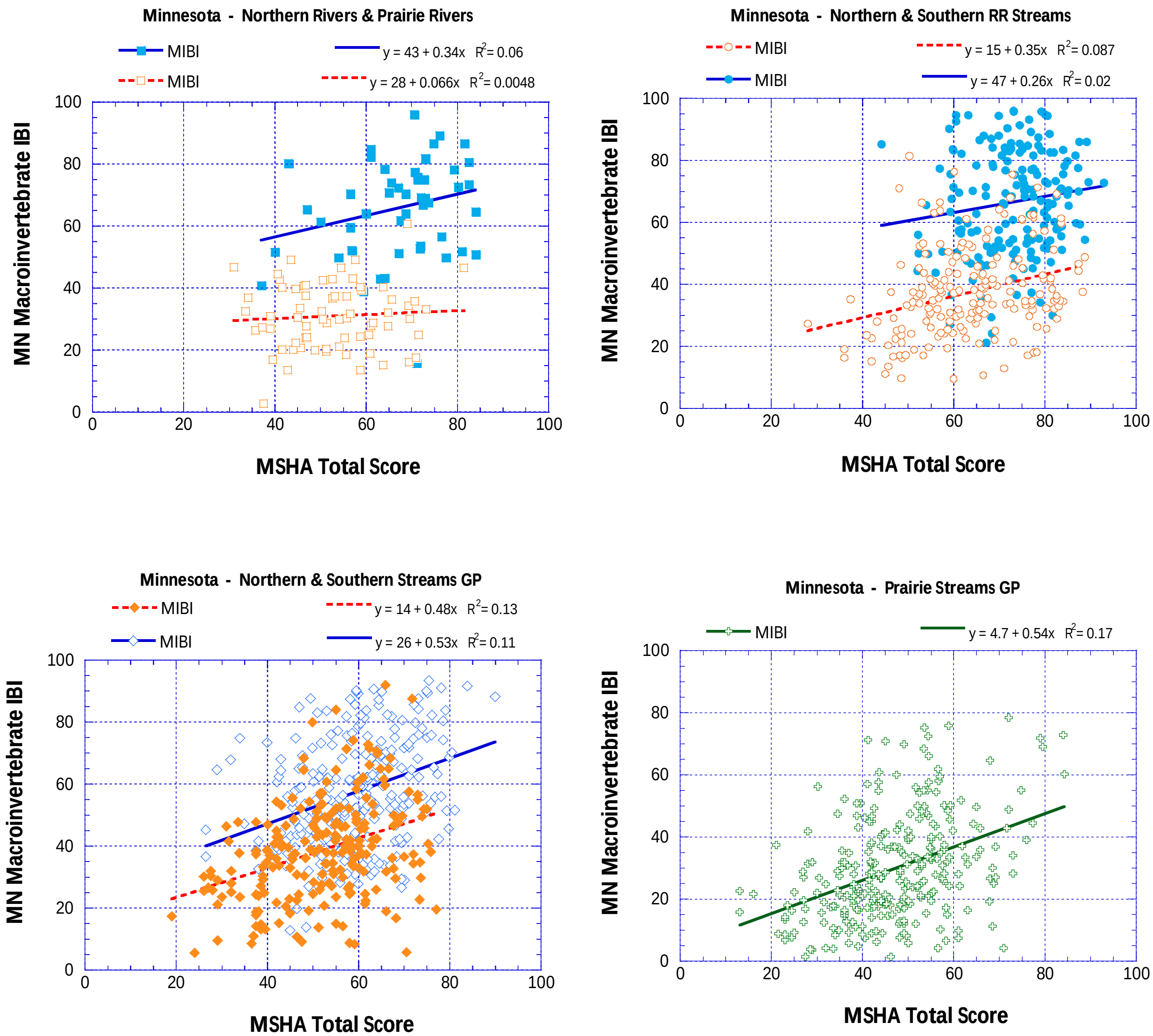


Figure 5. Plots of MIBI versus Total MSHA score separately for Minnesota Northern Forest and Prairie rivers (top left), Northern and Southern Riffle/Run streams (top right), Northern and Southern Glide/Pool streams (bottom left) and Prairie Glide/Pool streams(bottom right).

Watershed and Basin Scale Habitat Effects

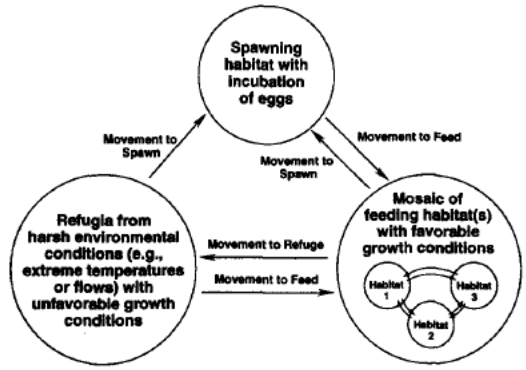


Fig. 1. The basic life cycle of stream fish with emphasis on patterns of habitat use and movement.
[Based on Jones (1968), Northcote (1978), and Schlosser (1991).]

Figure 6. Figure from Schlosser (1995) illustrating the movement between different habitats for headwater fish species.

Before we examined the local scale effects of metrics, submetrics, and attributes on the FIBI and MIBI, we explored the influence of the scale of habitat impact on aquatic assemblages. Stream ecosystems are largely “open” ecosystems with organisms often spending different parts of their life histories in different reaches of the stream “continuum.” Many species spawn in headwaters or smaller streams and then migrate to downstream reaches as they grow and feed and may move to refuges during periods of environmental stress (*e.g.,* deep pools during droughts, banks and cover during winter, etc.). A number of recent authors have summarized the influence of cumulative, watershed scale influence of habitat on aquatic assemblage condition (Richards et al. 1996; Wang et al. 2003; Brazner et al. 2005; Pease et al. 2011, Alford 2014; Radinger et al. 2015) and the relative influence of large scale habitat (*i.e.,* cumulative) effects appear stronger as human influence increases (Wang et al. 2003). Schlosser (1995) summarizes some of these needs and complexities for populations of headwater species (Figure 6). Even for species that generally have small home ranges, abiotic events (*e.g.,* storms, floods) tend to redistribute organisms within a watershed. As a result populations not only reflect local habitat conditions, but also upstream and downstream habitats. As crucial habitat types become scarce, the likelihood of local extirpations increases and may affect the species pool available to colonize suitable habitats for other life history stages.

Figure 7 (top left) is a plot of HUC-8 watershed average MSHA scores versus average FIBI scores for HUC-8 watersheds. Although the specific FIBIs do vary in meaning between classifications, the overall pattern is clearly one where average habitat quality in HUC-8 watersheds influences and limits the FIBI in these watersheds. We also examined the pattern in three key FIBI metrics common to most of the IBI variations: the number of sensitive fish species, the percent of species that are sensitive and the percent of fish individuals that are sensitive. These plots also showed a strong correlation and the limiting effects of habitat on the number of sensitive species collected (Figure 7, top right), the percent of species that are sensitive (middle left) and the percent sensitive species at stations (Figure 7, middle right). This supports the contention that as habitat degradation accumulates in a watershed it decreases or eliminates populations of sensitive fish species. The mechanism is likely a loss of critical habitat types for key life history aspects (*e.g.,* spawning, feeding, and refuge) of these species. We observed a similar relationship when we plotted the average HUC-8 habitat conditions versus the MIBI (Figure 7, lower left). A significant correlation between average HUC-8 FIBIs versus average HUC-8 MIBIs provides evidence that both organism groups are responding to cumulative habitat impacts in a similar fashion (Figure 7, lower right). We also looked at smaller watershed scales (HUC-10 and HUC-12) and observed very similar responses (Figures 8 and 9). At these smaller scales some watersheds have insufficient sites to include in the analyses. We used watersheds where we had greater than five sites for HUC-8 and HUC-10 plots and greater than three sites for the smallest HUC-12 scale. We are developing our analyses based on the HUC-8 watershed scale because the data is available for most of the sites and patterns between scales are similar. As Minnesota accumulates more data at smaller watershed scales (*e.g.,* HUC-10) it may want to rely on these smaller scales as being more accurate and appropriate when extrapolating physical limitations in a given stream.

The pattern of cumulative impacts observed in Minnesota is consistent with that described in the ecological literature. The concept of “sources and sinks” in terms of population biology and landscape ecology has been explicitly discussed in the ecological literature for several decades (*e.g.,* Pulliam 1988, Wiens et al. 1993, Lowe et al. 2006, Waits et al. 2008). Essentially some habitats are “sources” of individuals of a certain species (*e.g.,* sensitive) because of positive ecological attributes (*e.g.,* habitat features, prey) that support successful reproduction of that species. Other habitats are marginal and are considered sinks, where species may persist only because adjacent areas of good habitat produce individuals that migrate into these more marginal habitats. These marginal habitats alone would not be sufficient to maintain persistent populations of that specific species (*e.g.,* sensitive taxa or species). This concept has recently been expanded by Vandermeer et al. (2010). As habitats are degraded in a watershed, habitat sensitive fish populations may respond by declining in abundance or become extirpated in a reach of stream. As degradation accumulates in a watershed death rates may increase, birth rates may decrease, and migration rates may decline until a species is extirpated or rare in a watershed of a given scale. This occurs at multiple spatial scales and this scale can impact whether a reach of “good” habitat is large enough to act as refuge for a species or whether the population dynamics are such that during natural bottlenecks (*e.g.,* drought, flood, etc.) the species is extirpated.

From a practical “designated use” perspective this scale of impact can be important in determining whether a given aquatic life use can be attained in a given stream. If a stream is habitat degraded, but adjacent to patches of excellent habitat, the aquatic community may perform better than expected based on local habitat alone and be able to attain a higher tier of aquatic life use. Alternatively an “oasis” stream within a watershed of degraded habitat sinks may not be able to attain a regional biological endpoint because the species need to support the FIBI or MIBI may be extirpated or in low abundance. Our goal is to identify the key habitat gradients along which the biological indices change. The ends of the gradients often form obvious management endpoints where biology is attainable or likely not attainable. The selection of the breakpoint for identifying the threshold for tiered uses should consider the feasibility of restoration including economic and social factors in addition to scientific constraints.

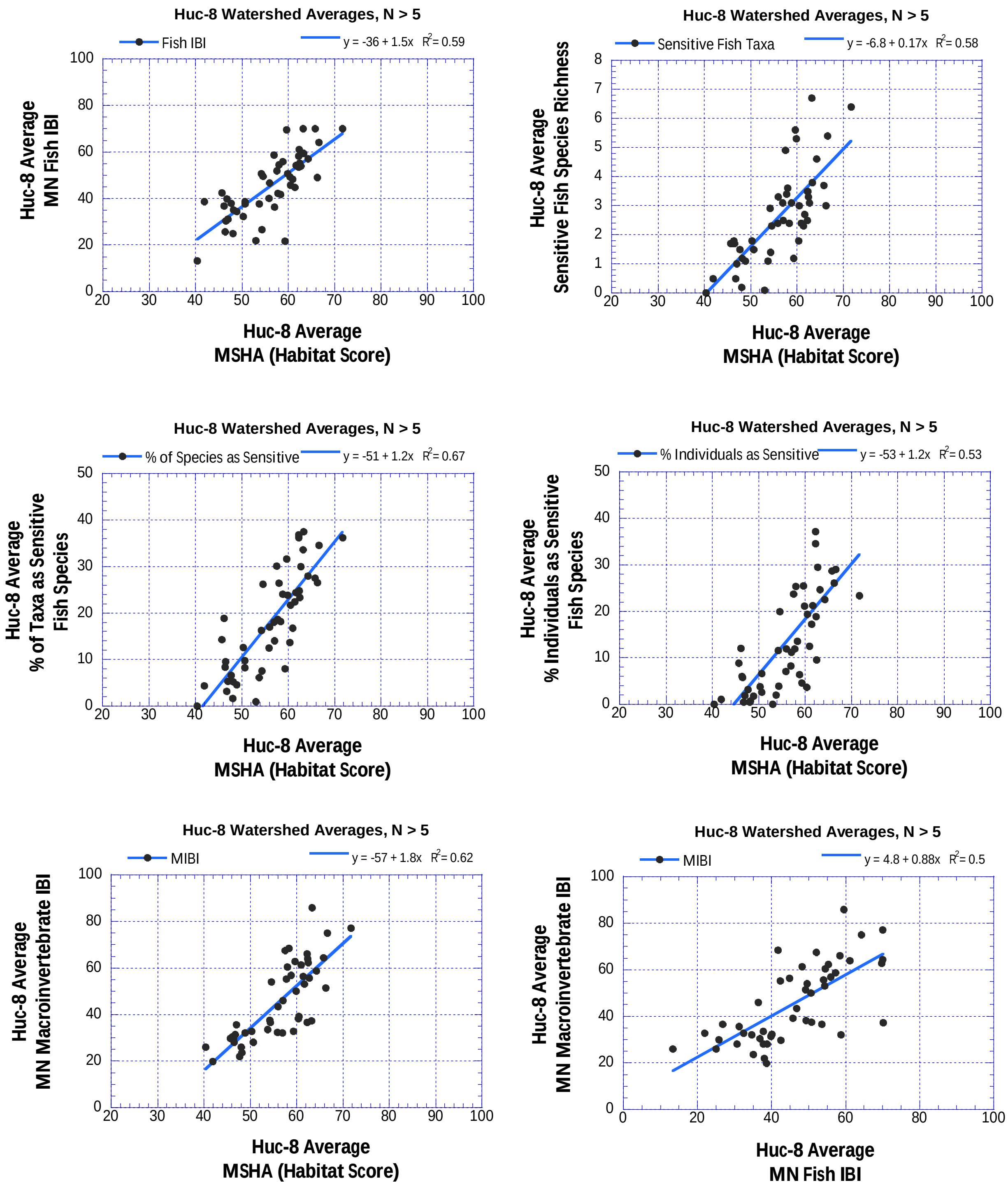


Figure 7. Plot of HUC-8 average MSHA scores versus HUC-8 average fish IBI scores (top left), average number of sensitive fish species (top right), average percent of taxa as sensitive (bottom left), average percent sensitive individuals (bottom right), MIBI (bottom left) and a plot of HUC-8 average fish IBI versus HUC-8 average MIBI (bottom right).

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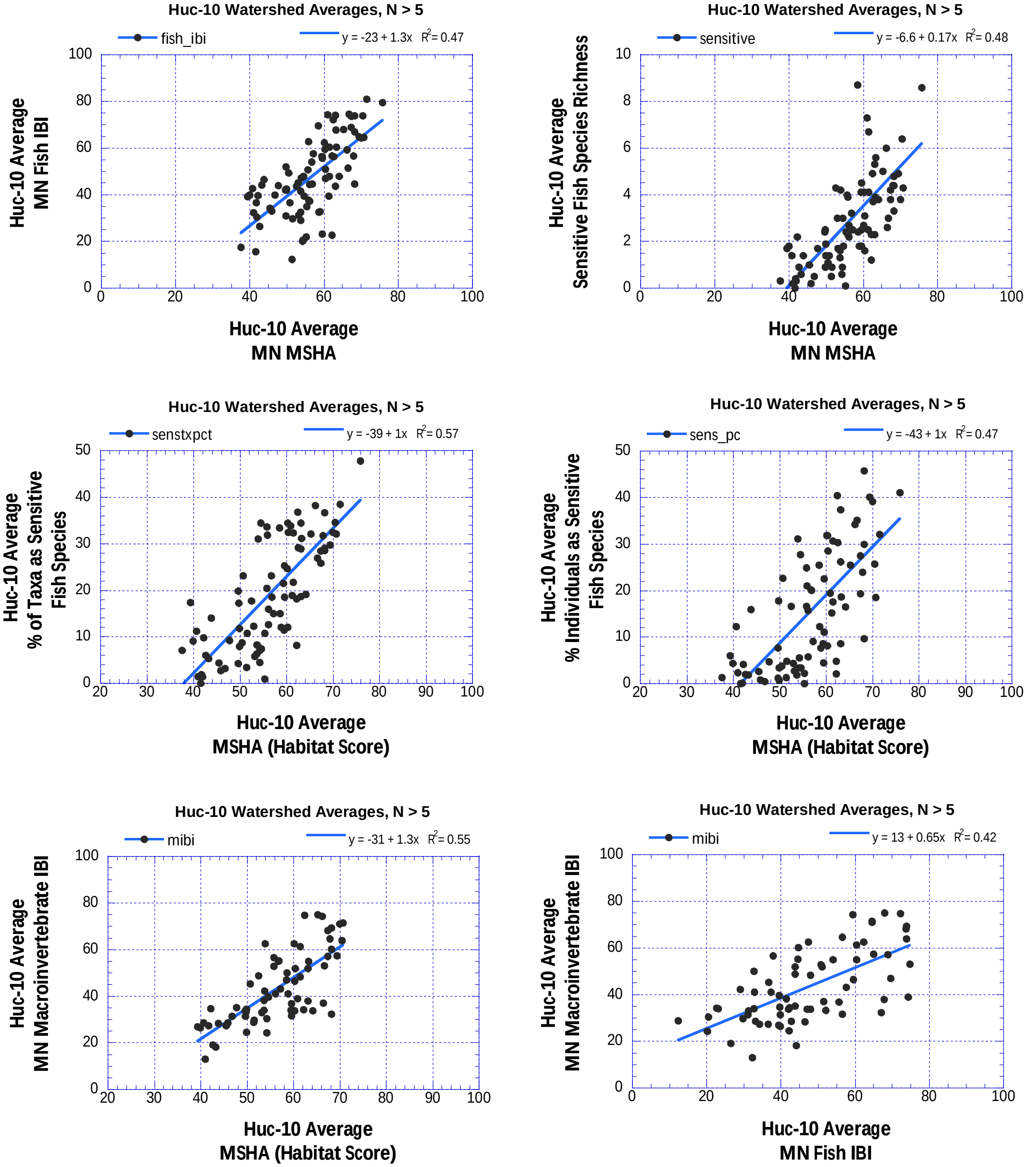

Figure 8. Plot of HUC-10 average MSHA scores versus HUC-10 average fish IBI scores (top left), average number of sensitive fish species (top right), average percent of taxa as sensitive (middle left), average percent sensitive individuals (middle right), MIBI scores (bottom left) and a plot of HUC-10 average fish IBI scores versus HUC-10 average MIBI scores (bottom right).

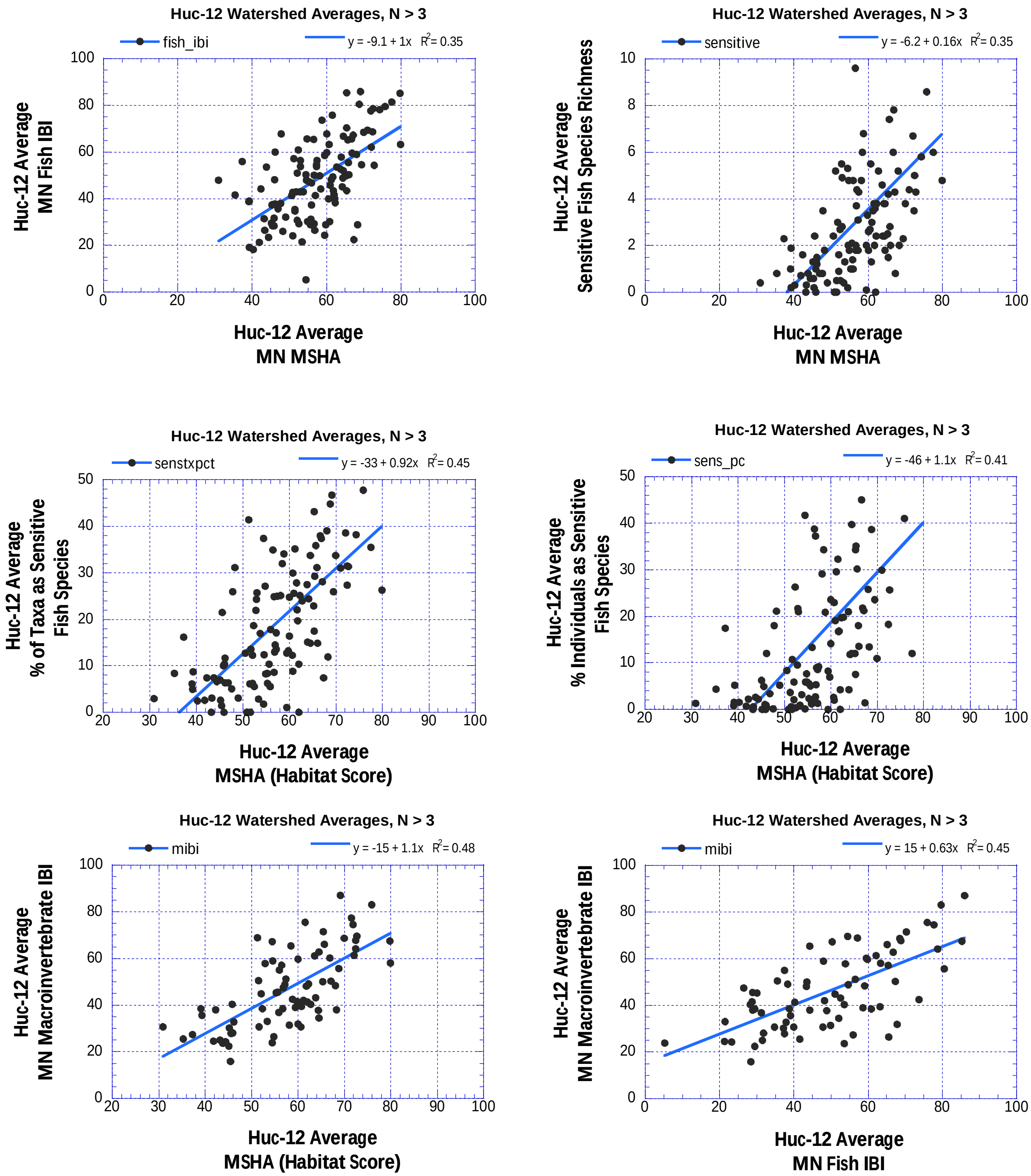

Figure 9. Plot of HUC-12 average MSHA scores versus HUC-12 average fish IBI scores (top left), average number of sensitive fish species (top right), average percent of taxa as sensitive (middle left), average percent sensitive individuals (middle right), MIBI scores (bottom left) and a plot of HUC-12 average fish IBI scores versus HUC-12 average MIBI scores (bottom right).

Classification Tree Results

Classification tree plots for each region with and without HUC-8 average MSHA habitat data as a variable are found in Appendix 2 for fish assemblages and Appendix 3 for macroinvertebrates. Important variables in explaining deviation in attainment status of fish assemblages within each region are summarized in Table 5. The dependent variable was attainment or non-attainment based on the interim FIBI biocriteria for each classification strata. The most important variable in explaining variance is at the "root" of the tree (primary variable) and nodes or branches decrease in importance with the distance from the root (*e.g.,* secondary and then other variables). The distance on the plots is proportional to the deviance explained. De'ath and Fabricus (2000) illustrated the usefulness of regression trees for "interactive exploration and for description and prediction of patterns and processes" and listed a number of key advantages over more traditional statistical tools including the ease and robustness of construction and ease of interpretation. In every classification strata where we included HUC-8 average MSHA score as a variable, it came out as the most important "primary" split in the analyses. Because of the dominance of average habitat conditions we also ran analyses with the average MSHA excluded to explore the relative importance of local submetrics. For both Northern and Southern rivers, cover amount (Southern) or cover type (Northern) was an important (Table 5, Appendix 2) classification variable as was channel stability (Northern) or channel development (Southern). In addition, other features related to channel and banks (sinuosity, riparian and bank erosion) were also identified as important, but at lower levels in the classification trees.

In Southern headwaters, good substrate type scores were a key factor explaining FIBI scores as was lack of shade. Occasionally terminal leaf variables can be counter-intuitive (*e.g.,* high sinuosity associated with impaired IBIs) although this may be related to lesser gradient in streams with high sinuosity, compared to straighter, faster flowing waters. In Northern headwaters, land use score was the primary explanatory variable and other variables were more "distantly" important and somewhat counter-intuitive. It is likely that the overwhelming importance of the small scale of habitat degradation or intactness is overwhelming other variables in this region. Northern strata results are also confounded somewhat by an "incomplete" habitat gradient with fewer habitat-degraded sites.

In Southern streams, sites with few cover types were usually impaired while sites with a diversity of current types (score > 3.5) were attaining IBI thresholds. Less strongly, sites with poor land use scores (< 0.25 of 5) were impaired and sites with better land uses attained when channel stability was > 1.5. For Northern streams, sites with land use scores > 4.8 (near the maximum of 5) attained and other streams were impaired when embeddedness was high. For low gradient streams the primary split was on land uses with scores < 1.9 (impaired) and sites with better channel development attained while heavily embedded streams were more likely impaired.

Overall, these analyses indicate that widespread habitat degradation has a scale effect that is, of greater influence on attaining an IBI threshold than any single local habitat variable. This suggests that whether a stream is capable of attaining an IBI threshold is related to the scale of habitat impact.

Table 5. Key variables explaining deviance in the attainment of the FIBI region for each of the seven classification regions in Minnesota. Classification tree analyses done with sub-metrics alone and sub-metrics plus the average MSHA score for each HUC-8 watershed as a variable.

Classification and Independent Variables	Response Variable	Primary Variable	Secondary Variables	Other Variables
Southern Rivers versus Sub-metrics	Attainment	Channel Development > 7.5	Two Predom. Substrates > 7.5 (Attain)	Cover Amount > 4.5 (Attain) Embeddedness < 0.5 (Attain) Substrate Type Score ≥ 12.4 (Attain)
Southern Rivers versus Sub-metrics and HUC-8 MSHA Average	Attainment	MSHA HUC-8 > 54.2 (Attain)	Channel Development > 7.5 (Attain)	Substrate Metric < 9.2 (Attain) Cover Metric < 7.5 (Impaired)
	Poor (Lower CI)	MSHA HUC-8 > 53.8 (Not Poor)	Cover Metric > 9.5 (> Poor)	Low Depth Variation (Poor) Low Shade (Poor)
	Good (Upper CI)	MSHA HUC-8 > 54.2 (Good)		
	Regression Tree (Node Mean)	MSHA HUC-8 > 54.2 (72.5)	Substrate Metric < 7.6 (62.1)	Cover Metric ≥ 9.5 (47.4) Cover Metric < 9.5 (35.8)
Southern Headwaters versus Sub-metrics	Attainment	Pool Substrate Score > 1.5 (Attain) < 1.5 (Impaired)	Current Types > 3.5 (Attain)	Cover Amount <1.5 (Impaired) Channel Stability (Attain) Rip. Width (Impaired)
Southern Headwaters versus Sub-metrics and HUC-8 MSHA Average	Attainment	MSHA HUC-8 > 53.8	Pool Substrate Score ≥ 0.3 (Attain) Pool Substrate Score > 0.3 (Impaired)	Current Types > 3.5 (Attain) MSHA HUC-8 < 46.3 and Land Use Metric > 0.25 (Attain) Otherwise (Impaired)
	Poor (Lower CI)	MSHA HUC-8 > 49.5 (Not Poor)	Substrate Type Score < 8 (Poor)	Current Types > 3.5 (Not Poor) Riparian Metric > 9.3 (Not Poor) Otherwise (Poor)
	Good (Upper CI)	MSHA HUC-8 > 53.8 (< Good)	Single Good Node: Pool Substrate > 1.5 and MSHA HUC-8 < 45.7 and Land Use Metric > 0.63	
	Regression Tree (Node Mean)	MSHA HUC-8 > 53.8 (54.1)	Substrate Type Score > 7.6 (41.0)	MSHA HUC-8 > 49.5 (36.2) Otherwise (7.8)
Southern Streams versus Sub-metrics	Attain	Shade > 1.3	Substrate Metric Score > 20.3 (Attain)	Riparian Metric Score < 6.3 (Impaired) Two Predominant Substrate < 6.5 (Attain) Otherwise (Impaired)
Southern Streams versus Sub-metrics and HUC-8 MSHA Average	Attain	MSHA HUC-8 < 53	Pool Substrate Score > 0.95 (Attain) else (Impaired) Riparian Metric Score < 6.3 (Impaired	Channel Metric Score > 25.5 (Attained) Else (Mostly Impaired)
	Poor (Lower CI)	Shade > 1.3	Substrate Metric Score > 17.9 (Not Poor unless Run Substrate < 6.8) or Riparian Metric Score > 6.3 (Not Poor) otherwise (Poor)	
	Good (Upper CI)	MSHA HUC-8 > 55 (Good unless Run Substrate > 12.4)	Channel Metric > 26.5 (Good) Otherwise (< Good)	
	Regression Tree (Node Mean)	MSHA HUC-8 > 56.2 (71.8)	Channel Metric Score > 26.5 (56.6)	Cover Types Score > 2.5 (36.8) Substrate Metric Score > 7.4 (33.7) Otherwise (8.2)

Northern Rivers versus Sub-metrics	Attain	Cover Amount > 5 (Attain)	Run Substrate < 9.4 (Attain)	Sinuosity Score > 3 (Impaired) Otherwise (Attain)
Northern Rivers versus Sub-metrics and HUC-8 MSHA Average	Attain	MSHA HUC-8 < 54.9 (Impaired) Otherwise (Attain)		
	Poor (Lower CI)	Insufficient Poor Sites		
	Good (Upper CI)	MSHA HUC-8 > 54.9 (Good)	Cover Metric Score < 12.5 (Good)	MSHA HUC-8 > 59.7 (Good) Otherwise (Not Good)
	Regression Tree (Node Mean)	MSHA HUC-8 < 54.9 (22.5)	MSHA HUC-8 > 60.7 (71.7) Otherwise (59.3)	
Northern Headwaters versus Sub-metrics	Attain	Land Use Score > 3.6 (Attain)	Substrate Metric Score 17.95 (Attain) Otherwise (Impaired)	
Northern Headwaters versus Sub-metrics and HUC-8 MSHA Average	Attain	Land Use Score > 3.6	MSHA HUC-8 > 61.6 (Attain) Substrate Metric Score ≥ 18 (Attain)	MSHA HUC-8 < 61.6 Riffle Substrate Score > 1.5 (Attain) Otherwise (Impaired) Substrate Metric Score < 18 (Impaired)
	Poor (Lower CI)	Land Use Score > 4.13 (Not Poor)	Pool Substrate Score > 3.5 (Not Poor)	Cover Types Score < 2.5 (Poor) Shade Score < 4.5 (Poor) Riffle Substrate > 5 (Not Poor) else (Poor)
	Good (Upper CI)	Land Use Score < 4.8 (Not Good)	Substrate Type Score > 11.5 (Good) Otherwise (Not Good)	
	Regression Tree (Node Mean)	Land Use Score < 4.8 and Substrate Score > 18 (47.6) Otherwise (29.9) Land Use Score ≥ 4.8 and Substrate Score > 20 (73.6) Otherwise (55.5)		
Northern Streams versus Sub-metrics	Attain	Land Use Score ≥ 2.6 and Riffle Substrate > 0.95 (mostly attain, except where current type score < 1.5 Land Use Score < 2.6 and Pool Substrate Score > 0.9 (Attains), Otherwise Impaired)		
Northern Streams versus Sub-metrics and HUC-8 MSHA Average	Attain	MSHA HUC-8 > 60.7 (Attain)	MSHA HUC-8 < 54.6 (Impaired) Otherwise (Attain)	
	Poor (Lower CI)	MSHA HUC-8 > 60.7 (Not Poor)	MSHA HUC-8 < 41.8 (Poor)	MSHA HUC-8 ≥ 41.8 and Riffle Substrate Score < 0.9 (Poor) Otherwise (Not Poor)
	Good (Upper CI)	MSHA HUC-8 > 59.4 (Good)	MSHA HUC-8 > 54.6 and Erosion Score <2.8 (Good)	Otherwise (Not Good)
	Regression Tree (Node Mean)	MSHA HUC-8 ≥ 60.7 and Substrate Metric Score > 18.2 (73.9); Substrate Metric Score < 18.2 (59.5) MSHA HUC-8 < 60.7 and MSHA HUC-8 ≥ 41.8 (45.7); MSHA HUC-8 < 41.8 (17.2)		
Low Gradient Streams versus Sub-metrics	Attain	Land Use Score < 1.9 (Impaired)	Channel Metric Score > 17.5 (Attain)	Riparian Metric Score < 6.3 (Attain) Riparian Metric Score ≥ 6.3 and Pool Substrate Score > 3.1 and Cover Amount Score < 8.5 (Attain), Otherwise (Impaired)
Low Gradient Streams versus Sub-metrics and	Attain	MSHA HUC-8 < 54.2 (Impaired)	Channel Metric Score ≥ 16.5 and Land Use Metric Score > 3.6 (Attain) Channel Metric Score < 16.5 and Riparian Metric Score > 6.8 and MSHA HUC-8 < 62 (Impaired) Otherwise (Attain)	

HUC-8 MSHA Average	Poor (Lower CI)	MSHA HUC-8 < 54.1 (Poor)	Channel Metric Score ≥ 17.5 (Not Poor) Channel Metric Score <17.5 and Riparian Metric ≥ 9.8 and MSHA HUC-8 <60 (Poor) Otherwise (Not Poor)	
	Good (Upper CI)	Land Use Metric Score < 1.9 (Not Good)	Channel Metric Score ≥ 17.5 (Good) Channel Metric Score < 17.5 and Erosion Score < 3.8 (Good),Otherwise (Not Good)	
	Regression Tree (Node Mean)	MSHA HUC-8 < 54.1 (16.5)	Channel Metric Score < 17.5 (35.7)	Channel Metric Score ≥ 17.5 MSHA HUC-8 < 64.9 (49.7) MSHA HUC-8 ≥ 64.9 (71.9)

Metric-by-Metric Analyses

The next sections focus on a MSHA metric-by-metric exploration of effects on the FIBI and MIBI and other key biological metrics by classification strata to identify, where possible, key attributes that might be limiting these assemblages. Our goal was to derive a list of "good" and "poor" habitat attributes for each organism group and classification strata that can serve as indicators when selecting appropriate and protective aquatic life uses

Substrate Metrics

Substrate types and condition (*i.e.*, siltation and sedimentation) can have substantial impacts on aquatic life (Waters 1995). Coarse substrates have important functions including feeding and spawning sites, habitat niches for macroinvertebrates, providing areas of reduced velocity as well as increased turbulence in fast flowing areas, and providing stable surface area for biofilms for lower taxonomic groups (*e.g.*, periphyton, protists, and bacteria). Measures of bed stability including visual methods have been correlated to macroinvertebrate composition and diversity (Schwendel et al. 2011). Other workers have identified association of sensitive fish assemblages with coarse or rocky substrates and more tolerant species with finer and mud/silt substrates (Berkman and Rabeni 1987; Pease et al. 2011, Bey and Sullivan 2015) or with the aggradation of fines that embed coarser substrates (Sullivan and Watzin 2010).

Scatter plots of the summary substrate metric versus FIBI are illustrated in Figure 10 for each classification strata. Substrate is a key metric of the MSHA. The MSHA substrate *type* metric differs from the QHEI substrate type metric in that it separately identifies predominate materials in pool, runs, riffles and glides; whereas the QHEI identifies predominate substrate types over the entire reach. Overall correlation of the FIBI to the MSHA substrate metric score was weak for all of the classification strata although there seems to be somewhat of a limiting threshold for the Northern and Southern stream classes and at the upper and lower end of the substrate score gradient. Plot of a key habitat-sensitive metric, the number of sensitive fish species demonstrated a stronger threshold response than did the FIBI (Figure 11). An alternate measure of sensitivity, the number of sensitive fish taxa showed a more variable threshold. This may be related to loss of species at sites with the most degraded substrates which led to greater variability in the metric at the most degraded sites.

The MIBI also showed a rather weak association with the substrate metric score, especially for rivers and riffle/run type streams (Figure 12). Relationships were stronger in "Glide/Pool" morphology streams versus "Riffle/Run" type streams. Riffle/Run type streams generally had higher average substrate scores and were likely less susceptible to accumulating fines because of their gradients and morphology. Glide/Pool streams tend to have lower gradients and, with depositional type habitats, are more likely affected by fines. The Glide/Pool streams had a wider range of substrate scores and better correlations than Riffle/Run streams.

Substrate Submetrics

To identify key habitat attributes we examined which substrate types were strongly associated with high and low FIBI scores using box and whisker plots, ANOVA and the Tukey multiple comparison tests in an exploratory mode to identify potential good and/or poor habitat attributes and to compose a weighted index of total good or poor habitat attributes. Certain substrate types occurred infrequently within certain stream size categories and were usually ignored if sample size was less than 5. We identified two sets of attributes for Minnesota streams, one based on "theoretical" expectations based on literature and experience and second set that was more data driven based on the results of the ANOVAs and Tukey comparisons within each classifications strata.

Substrates are scored separately for pool, riffle, run, and glide habitats in the MSHA and will be discussed individually. Aside from river classifications, coarser materials in pools were typically more often associated with higher IBIs scores and fine materials (silts) were associated with lower IBI scores on average (Tables 6 and 7). There was some variation between fish (Table 6) and macroinvertebrate strata (Table 7) with macroinvertebrate assemblages showing more variation between strata than fish. Low sample sizes can have some effect on the identification of significant patterns by substrate type. Coarser materials (*e.g.,* boulder, cobble) were less often present in macroinvertebrate strata defined by glide and pool habitats (Table 11 and 13).

In riffles, boulders were identified as important substrate types in three fish strata, but the influence of finer substrate types as negative attributes (*e.g.,* silts) were less commonly identified in riffles (Table 8). This is largely because such fines are typically not found where water velocity is high enough to flush most of these out with exception of Southern Streams where sand was also a negative attribute. Riffle substrates were a weak predictor of MIBIs. Again, where riffles are an important feature, velocities define the types likely to be chosen as a predominant type (Table 8 and 9).

For fish assemblages in run habitats, with the exception of river and low gradient strata, coarse substrates were generally associated with higher IBI scores and silts were associated with lower IBI scores (Table 10). For macroinvertebrates that pattern was evident in Southern or Glide/Pool type strata, but results were not significant in Northern and Prairie Rivers where fines were uncommon (Table 11). No significant relationships were observed between substrate types in glides and FIBI or MIBI in any strata, largely because these habitat types were rarely identified in sufficient numbers to test for many strata (Tables 12 and 13).

Embeddedness

In addition to the identification of predominant major substrate types that comprise the stream bed, the MSHA measures substrate condition by estimating the embeddedness of substrates in the reach. Besides the silt fraction of the bedload of rivers, aggradation of sands and fine gravels on coarser sediments (*e.g.*, cobbles, boulders) has also been identified as a problem in Midwest streams and rivers. In some severe cases, particularly in lower gradient reaches; "sand slugs" have been identified and shown to impact fisheries (Bond and Lake 2005). Concerns related to populations of large Midwest species such as paddlefish have been related to smothering of eggs and embryos by bedload (Jennings and Zigler 2000). Work in southern Appalachian streams identified a 5 to 9-fold increase in bedload in disturbed streams compared to reference streams (Sutherland *et al*. 2002). Similarly, key fish metrics in Georgia streams responded to a key number of key substrates measures such as embeddedness (Rashleigh and Kennen 2003). In Minnesota (Nerbonne and Vondracek 2001) found that percent fines and embeddedness were negatively correlated with buffer width and Wang et al. (2006) reported that in Wisconsin the installation of best management practices (*e.g.,* fencing) increased substrate size, reduced sediment depth, embeddedness, and bank erosion.

For fish assemblages we saw a significant association between severe embeddedness and lower IBI scores and low to no embeddedness and higher IBI scores in all strata except Northern Rivers where severe embeddedness was rare (Table 14). For macroinvertebrates there was a less uniform pattern with higher IBIs in streams with low to no embeddedness in Northern streams (severe embeddedness being less common) and less of a relationship in River and Southern strata, although there was a significant pattern in Prairie Glide/Pool streams (Table 15). Stronger relationships may have been observed if there were more "severely embedded" sites in Northern streams and more sites with "no embeddedness" in Southern streams to increase the range of scores

Substrate Types

The MSHA tracks the number of substrate types as a measure of how many stream bottom types may be available to organisms (≤ 4 types or > 4 types). We only observed a strong relationship in the fish assemblages in Northern Headwaters and Low Gradient strata (Table 16) and in macroinvertebrates in Northern Glide/Pool and Prairie Glide/Pool strata (Table 17). Ohio uses a similar metric in their QHEI, but altered it several years ago to only count "high quality" substrates after they recognized that a higher score a site might occur because of silt or muck being the 5th substrate type. This could be responsible for the lack of association in Southern Strata (Tables 16 and 17) or the positive association in the Northern Headwaters for fish where silts were uncommon and > 4 types represented a richness of good substrate types.

Tables 18 and 19 summarize the variables selected as key "good" or "poor" substrate habitat attributes by organism group and classification strata. The presence of any of these key attributes will contribute to the count of good versus poor habitat attributes and can become a factor in determining whether some habitat alteration is feasibly restorable or likely to lead to biological limitation of achieving an aquatic life goal.

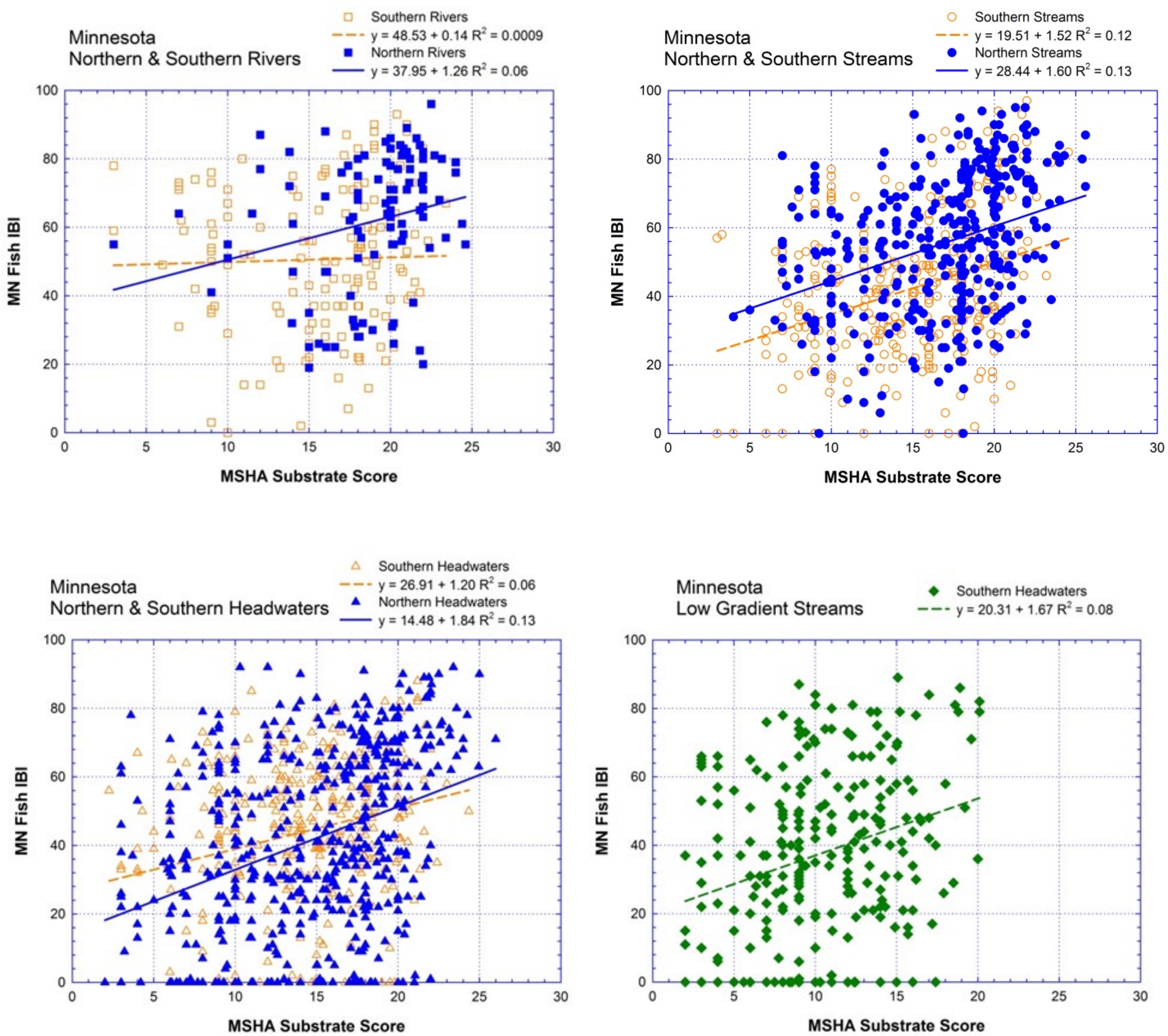

Figure 10. Plots of Fish IBI scores versus MSHA substrate score separately for Minnesota Northern and Southern rivers (top left), streams (top right), headwaters (bottom left) and statewide for low gradient streams (bottom right).

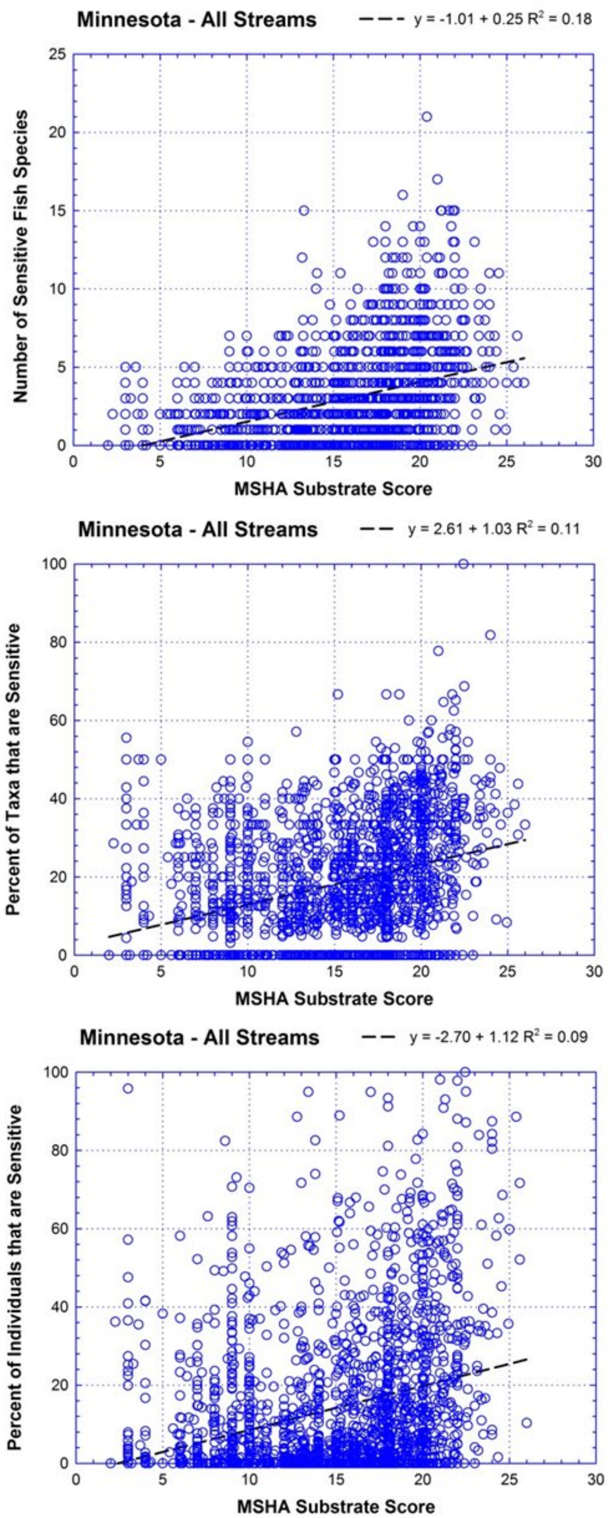

Figure 11. Plots of MSHA substrate metric score versus number of sensitive fish taxa (top) and percent of taxa that are sensitive (bottom). All classifications combined.

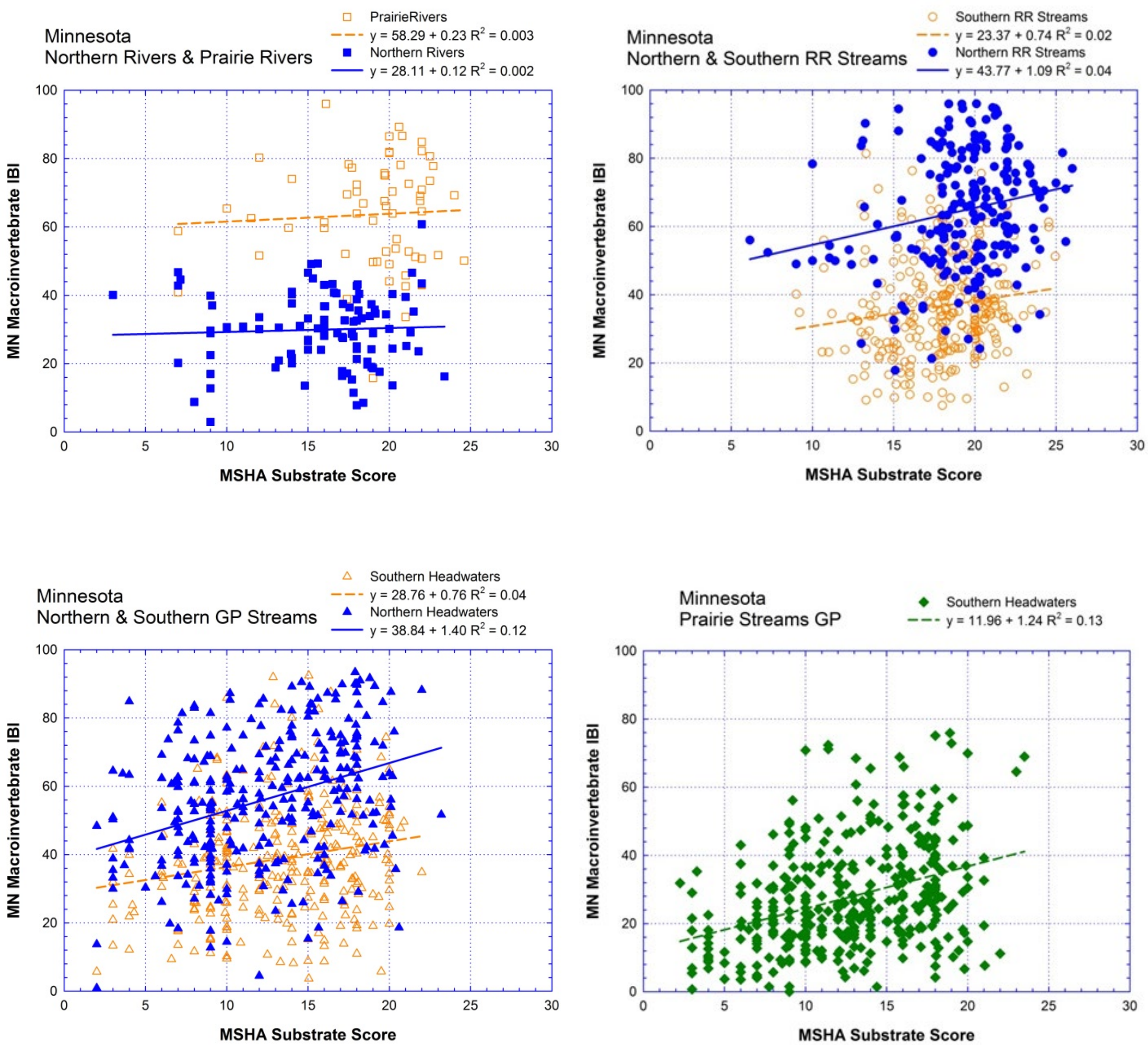

Figure 12. Plots of MIBI scores versus MSHA substrate score separately for Minnesota Northern and Prairie rivers (top left), Northern and Southern Riffle/Run streams (top right), Northern and Southern Glide/Pool streams (bottom left) and Prairie Glide/Pool streams (bottom right).

Table 6. Mean Fish IBI values (SE) for individual MSHA substrate types in pool habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Boulder	Pool	46.9 (6.4)	44.4 (8.5)	56.8 (6.2)	65.5 (3.8)	68.7 (3.0)	53.5 (5.2)	42.0 (12.8)
Cobble	Pool	58.9 (7.2)	53.3 (4.5)	57.5 (5.0)	66.1 (4.1)	68.9 (2.2)	50.6 (2.6)	-
Gravel	Pool	47.9 (4.3)	47.1 (2.2)	50.2 (2.3)	60.0 (3.5)	57.7 (1.7)	47.7 (2.0)	39.1 (5.7)
Sand	Pool	49.2 (2.5)	44.1 (1.5)	48.3 (1.3)	59.9 (2.6)	53.3 (1.3)	44.6 (1.4)	41.3 (2.2)
Clay	Pool	59.4 (2.9)	42.9 (2.8)	40.8 (3.5)	73.6 (3.0)	55.5 (2.5)	43.9 (3.5)	43.9 (5.3)
Bedrock	Pool	-	-	-	-	-	-	-
Silt	Pool	46.4 (3.4)	40.1 (2.0)	46.0 (1.9)	58.4 (7.2)	48.0 (1.8)	39.4 (1.8)	44.1 (2.0)
Muck	Pool	-	-	-	-	-	-	31.3 (6.5)
Detritus	Pool	-	-	39.0 (9.6)	-	35.5 (5.8)	32.7 (4.2)	45.4 (4.6)
ANOVA		**F=1.524 P=0.185 NS**	**F=2.208 P=0.0526 NS**	**F= 2.197 P=0.0421 ***	**F=1.276 P=0.278 NS**	**F=13.590 P<0.0001 ***	**F=4.160 P=0.0004 ***	**F=0.580 P=0.7460 NS**
Attribute Scores		**Good: P<0.001**		**Good: P<0.05-0.001**		**Good: > 0.05 but trending or low sample size**		
		Poor: P<0.001		**Poor: P<0.05-0.001**		**Poor: > 0.05 but trending or low sample size**		

Table 7. Mean Macroinvertebrate IBI values (SE) for individual MSHA substrate types in pool habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Boulder	Pool	70.5 (4.2)	35.6 (2.7)	67.5 (2.7)	59.7 (5.9)	35.8 (3.1)	38.4 (8.4)	-
Cobble	Pool	63.9 (4.5)	33.5 (4.0)	70.1 (1.5)	64.6 (8.7)	43.6 (2.4)	34.3 (11.2)	32.6 (7.5)
Gravel	Pool	66.9 (4.0)	29.1 (2.3)	67.5 (1.6)	61.9 (2.2)	38.3 (1.3)	40.1 (2.5)	34.1 (2.8)
Sand	Pool	63.1 (2.5)	29.7 (1.4)	62.6 (1.6)	58.1 (1.5)	36.8 (0.9)	41.9 (1.2)	31.3 (1.2)
Clay	Pool	68.1 (4.8)	32.0 (3.8)	56.8 (3.0)	60.3 (2.1)	29.8 (2.7)	33.9 (3.1)	25.9 (2.0)
Bedrock	Pool	-	-	-	-	-	-	-
Silt	Pool	54.2 (4.0)	31.1 (2.1)	50.2 (2.5)	53.6 (1.4)	32.6 (1.6)	40.0 (1.4)	28.3 (1.2)
Muck	Pool	-	-	-	-	-	23.4 (5.2)	-
Detritus	Pool	-	-	-	52.1 (3.8)	-	34.5 (4.5)	25.7 (5.7)
ANOVA		**F=1.096 P=0.369 NS**	**F=0.695 P=0.628 NS**	**F=9.096 P<0.0001 ***	**F=2.602 P=0.0172 ***	**F=4.718 P=0.0003 ***	**F=1.997 P=0.0543 NS**	**F=1.730 P=0.128 NS**

Table 8. Mean Fish IBI values (SE) for individual MSHA substrate types in riffle habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Boulder	Riffle	55.2 (4.2)	42.4 (4.9)	45.7 (7.6)	65.7 (4.2)	70.6 (2.1)	55.7 (3.5)	49.4 (8.7)
Cobble	Riffle	48.6 (2.9)	51.6 (2.2)	51.1 (2.3)	60.2 (3.0)	63.9 (1.5)	49.0 (1.9)	56.5 (7.3)
Gravel	Riffle	42.7 (2.6)	47.9 (1.7)	48.6 (1.4)	56.6 (3.6)	56.4 (1.7)	43.8 (1.8)	46.4 (4.9)
Sand	Riffle	54.7 (3.9)	40.9 (2.0)	46.9 (1.8)	48.6 (9.8)	49.6 (2.3)	41.2 (2.4)	46.5 (4.0)
Clay	Riffle	-	43.1 (6.8)	-	-		43.5 (14.9)	-
Bedrock	Riffle	-	-	-	-		-	-
Silt	Riffle	-	33.0 (7.1)	19.2 (11.0)	-		32.6 (6.8)	46.4 (5.7)
Muck	Riffle	-	-	-	-		-	-
Detritus	Riffle	-	-	-	-		-	-
		F=3.448 P=0.0189 *	**F=3.02 P=0.0111 ***	**F=3.954 P=0.0037 ***	**F=1.403 P=0.246 NS**	**F=17.24 P<0.0001 ***	**F=4.002 P=0.0014 ***	**F=0.456 P=0.7680 NS**

Table 9. Mean Macroinvertebrate IBI values (SE) for individual MSHA substrate types in riffle habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Boulder	Riffle	65.9 (3.1)	26.9 (3.4)	68.2 (1.7)	55.4 (7.4)	41.2 (2.3)	-	46.9 (11.1)
Cobble	Riffle	66.4 (2.5)	29.5 (1.7)	66.0 (1.3)	57.7 (4.0)	38.0 (1.1)	46.2 (4.8)	32.3 (3.3)
Gravel	Riffle	67.7 (3.9)	31.3 (1.6)	63.3 (1.7)	61.4 (2.7)	35.4 (0.9)	41.5 (1.7)	33.4 (1.5)
Sand	Riffle	80.6 (1.1)	28.1 (2.8)	50.9 (4.3)	54.6 (2.6)	35.0 (1.7)	40.5 (1.7)	33.3 (1.8)
Clay	Riffle	-	-	-	-	-	-	32.9 (6.6)
Bedrock	Riffle	-	-	-	-	-	-	-
Silt	Riffle	-	-	-	46.4 (4.2)	-	31.5 (3.6)	21.4 (5.9)
Muck	Riffle	-	-	-	-	-	-	-
Detritus	Riffle	-	-	-	-	-	-	-
		F=1.105 P=0.355 NS	**F=0.773 P=0.512 NS**	**F=6.042 P=0.0005 ***	**F=1.419 P=0.2310 NS**	**F=2.778 P=0.0407 ***	**F=1.388 P=0.247 NS**	**F=1.268 P=0.2790 NS**

Table 10. Mean Fish IBI values (SE) for individual MSHA substrate types in run habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Boulder	Run	56.1 (6.1)	49.4 (12.2)	-	66.2 (2.2)	74.9 (2.9)	60.6 (5.1)	-
Cobble	Run	55.8 (3.6)	55.7 (3.2)	55.0 (4.1)	68.7 (3.3)	68.8 (1.6)	57.3 (2.1)	-
Gravel	Run	44.6 (2.4)	45.1 (1.5)	46.0 (1.6)	58.8 (2.7)	55.7 (1.3)	44.1 (1.6)	38.4 (3.9)
Sand	Run	49.6 (2.1)	40.9 (1.2)	46.2 (1.2)	57.9 (2.5)	49.5 (1.2)	39.7 (1.4)	41.8 (1.8)
Clay	Run	59.8 (3.2)	40.2 (2.6)	38.1 (3.9)	72.4 (7.0)	53.6 (3.0)	33.5 (4.4)	33.4 (4.5)
Bedrock	Run	-	-	-	-	-	-	-
Silt	Run	49.4 (3.7)	33.9 (2.2)	41.3 (1.9)	56.2 (4.5)	44.7 (2.4)	32.9 (1.9)	37.0 (2.1)
Muck	Run	-	-	-	-	-	-	-
Detritus	Run	-	-	22.9 (5.8)	-	-	26.2 (3.4)	34.8 (3.9)
		F=2.455 P=0.0339 *	**F=8.456 P<0.0001 ***	**F=5.725 P<0.0001 ***	**F=2.323 P=0.0447 ***	**F=25.74 P<0.0001 ***	**F=16.77 P<0.0001 ***	**F=1.448 P=0.217 NS**

Table 11. Mean Macroinvertebrate IBI values (SE) for individual MSHA substrate types in run habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Boulder	Run	57.4 (3.0)	33.5 (5.6)	68.9 (2.6)	-	50.7 (4.5)	-	38.9 (12.6)
Cobble	Run	66.1 (3.1)	33.8 (2.6)	68.8 (1.4)	62.1 (4.8)	42.3 (1.6)	40.3 (6.3)	36.7 (5.0)
Gravel	Run	65.8 (2.6)	30.2 (1.5)	64.8 (1.5)	64.3 (1.9)	36.5 (0.9)	41.4 (1.6)	31.1 (1.2)
Sand	Run	62.0 (2.7)	29.4 (1.1)	59.4 (1.8)	57.5 (1.2)	35.3 (0.9)	41.0 (1.0)	30.2 (1.0)
Clay	Run	-	30.6 (5.1)	-	57.4 (2.9)	30.0 (3.3)	40.5 (4.6)	24.9 (1.5)
Bedrock	Run	-	-	-	-	-	-	-
Silt	Run	-	28.1 (2.8)	49.4 (2.0)	51.5 (1.4)	31.7 (2.9)	35.2 (1.4)	24.1 (1.2)
Muck	Run	-	-	-	-	-	-	-
Detritus	Run	-	-	-	48.0 (3.2)	-	27.3 (3.0)	21.0 (3.6)
		F=1.148 P=0.334 NS	**F=0.733 P=0.599 NS**	**F=6.487 P<0.0001 ***	**F=7.367 P<0.0001 ***	**F=5.089 P=0.0001 ***	**F=3.978 P=0.0015 ***	**F=5.571 P<0.0001 ***

Table 12. Mean Fish IBI values (SE) for individual MSHA substrate types in glide habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Boulder	Glide	-		-	-	-	-	-
Cobble	Glide	-	-	-	-	73.8 (3.3)	-	-
Gravel	Glide	-	-	-	-	70.7 (8.7)	-	-
Sand	Glide	-	25.0 (4.4)	-	-	78.2 (3.2)	36.8 (10.2)	25.8 (8.9)
Clay	Glide	-	-	-	-	-	-	24.3 (9.2)
Bedrock	Glide	-	-	-	-	-	-	-
Silt	Glide	-	24.4 (7.4)	-	-	-	35.0 (10.9)	21.0 (5.8)
Muck	Glide	-	-	-	-	-	-	-
Detritus	Glide	-	-	-	-	-	-	-
		-	**F=0.004 P=0.951 NS**	**-**	**-**	**F=0.422 P=0.6640 NS**	**F=0.014 P=0.907 NS**	**F=0.116 P=0.8910 NS**

Table 13. Mean Macroinvertebrate IBI values (SE) for individual MSHA substrate types in glide habitats. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Boulder	Glide	-		-	-	-	-	-
Cobble	Glide	-	-	-	-	-	-	-
Gravel	Glide	-	-	-	-	-	-	-
Sand	Glide	-	-	-	65.3 (6.8)	-	16.8 (3.8)	22.2 (3.0)
Clay	Glide	-	-	-	-	-	-	15.8 (3.2)
Bedrock	Glide	-	-	-	-	-	-	-
Silt	Glide	-	-	-	51.6 (9.3)	-	19.0 (2.7)	15.9 (3.0)
Muck	Glide	-	-	-	-	-	-	-
Detritus	Glide	-	-	-	-	-	-	-
		-	**-**	**-**	**F=1.488 P=0.2380 NS**	**-**	**F=0.2280 P=0.6440 NS**	**F=1.240 P=0.3120 NS**

Table 14. Mean Fish IBI values (SE) for the MSHA embeddedness score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Embedded-ness Score	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
No Coarse	All	52.2 (1.7)	34.2 (1.3)	38.8 (2.1)	-	47.7 (1.9)	35.0 (2.1)	32.4 (2.2)
Severe	All	40.3 (8.0)	37.0 (2.0)	39.9 (3.6)	-	40.5 (3.5)	37.7 (3.0)	27.2 (3.9)
Moderate	All	42.8 (2.7)	41.9 (2.0)	45.8 (1.7)	52.9 (5.2)	51.1 (1.8)	36.6 (2.1)	41.0 (3.5)
Light	All	53.5 (2.6)	48.6 (2.1)	47.4 (1.8)	62.5 (2.3)	56.8 (1.7)	50.2 (1.8)	44.3 (3.8)
None	All	-	41.6 (5.7)	35.9 (4.7)	-	67.6 (2.9)	57.9 (3.8)	44.0 (4.7)
		F=5.57 P=0.001 *	**F=5.41 P<0.001 ***	**F=3.62 P<0.007 ***	**F=3.19 P=0.08 NS**	**F=10.39 P<0.001 ***	**F=16.83 P<0.001 ***	**F=3.67 P=0.006 ***

Table 15. Mean Macroinvertebrate IBI values (SE) for individual MSHA embeddedness score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Embedded-ness Score	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
No Coarse [0]	All	-	36.3 (2.7)	-	49.9 (1.8)	34.4 (1.4)	38.3 (1.6)	26.3 (1.3)
Severe [-1]	All	-	-	-	52.4 (3.1)	34.3 (4.0)	35.5 (2.0)	27.1 (1.7)
Moderate [1]	All	69.2 (5.2)	28.5 (1.6)	57.3 (2.5)	59.7 (2.2)	32.3 (1.3)	39.3 (1.9)	30.1 (1.3)
Light [3]	All	62.2 (2.4)	31.2 (1.7)	64.2 (1.7)	61.6 (2.1)	38.0 (1.1)	41.2 (1.6)	33.5 (1.9)
None [5]	All	-	-	76.1 (2.0)	60.8 (3.2)	44.7 (4.4)	36.4 (4.3)	28.0 (6.2)
		F=1.04 P=0.315 NS	**F=0.002 P=0.99 NS**	**F=10.45 P<0.001 ***	**F=9.049 P<0.001 ***	**F=3.11 P<0.027 ***	**F=1.127 P=0.344 NS**	**F=5.22 P<0.001 ***

Table 16. Mean Fish IBI values (SE) for individual MSHA number of substrate types (>4 or < 4). Attributes with < 5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

No. of Substrate Types	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
> 4	All	46.0 (3.1)	44.9 (2.0)	44.9 (2.0)	65.4 (2.4)	56.3 (1.4)	50.3 (1.8)	45.0 (3.7)
< 4	All	52.0 (1.4)	39.2 (1.1)	36.0 (1.3)	60.7 (1.4)	52.6 (1.3)	38.3 (1.4)	30.8 (1.6)
		F=4.61 P=0.034 *	**F=2.04 P=0.15 NS**	**F=1.94 P=0.165 NS**	**F=0.917 P=0.34 NS**	**F=0.714 P=0.398 NS**	**F=19.64 P<0.001 ***	**F=8.457 P=0.004 ***

Table 17. Mean Macroinvertebrate IBI values (SE) for individual MSHA number of substrate types (>4 or < 4). Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

No. of Substrate Types	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
> 4	All	66.1 (2.8)	30.9 (2.0)	65.0 (1.5)	61.2 (1.7)	36.6 (1.1)	39.4 (2.1)	34.4 (1.7)
< 4	All	69.2 (2.6)	34.9 (1.7)	70.3 (1.9)	55.1 (1.3)	37.6 (1.4)	39.4 (1.1)	28.5 (1.1)
		F=0.011 P=0.917 NS	**F=0.004 P=0.944 NS**	**F=3.422 P=0.066 NS**	**F=8.17 P=0.005 ***	**F=2.32 P=0.128 NS**	**F=0.00 P=0.999 NS**	**F=11.83 P<0.001 ***

Table 18. Theoretical and data-driven "good" and "poor" habitat attributes for the substrate metric for fish assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher fish IBI scores and "poor" attributes are those expected to be associated with lower fish IBI scores. Numbers in bracket are weighted scores using to calculate the good or bad attribute score.

Sub-Metric	Theoretical Attributes	Data Driven Attributes						
		Southern Rivers (1)	Southern Streams (2)	Southern Headwaters (3)	Northern Rivers (4)	Northern Streams (5)	Northern Headwaters (6)	Low Gradient Streams (7)
Substrate Metric								
Good Pool Substrate Types	Boulder, Cobble, Gravel	-	Cobble [1]	Boulder[.5] Cobble[.5]	-	Boulder[2] Cobble[2] Gravel[1]	Boulder[.5] Cobble[1] Gravel[1]	-
Poor Pool Substrate Types	Silt	-	Silt [1]	Clay[.5] Detritus[.5]	-	Silt[2] Sand[2] Clay[1] Detritus[2]	Silt[1] Detritus[1]	-
Good Riffle Substrate Types	Boulder, Cobble, Gravel	Boulder[.5] Sand[1]	Cobble[1]	Boulder[.5] Cobble[1] Gravel[1] Sand[1]	-	Boulder[2] Cobble[2]	Boulder[1]	-
Poor Riffle Substrate Types	Silt,	Gravel[1]	Sand[1] Silt[.5]	Silt[1]	-	Gravel[2] Sand[2]	Gravel[1] Sand[1] Silt[.5]	-
Good Run Substrate Types	Boulder, Cobble, Gravel	Clay[1]	Boulder[.5] Cobble[2] Gravel[2]	Cobble[2] Gravel[1] Sand[1]	Cobble[1]	Boulder[2] Cobble[2]	Boulder[2] Cobble[2] Gravel[2]	-
Poor Run Substrate Types	Silt	Gravel[1]	Sand[2] Clay[1] Silt[2]	Clay[1] Silt[1] Detritus[2]	Sand[1]	Gravel[2] Sand[2] Clay[2] Silt[2]	Sand[2] Clay[2] Silt[2] Detritus[2]	-
Good Embedded -ness	None	No Coarse[1] Light[2]	Light[1]	Light[1]	-	None[2] Light[1]	None[2] Light[2]	Light[1] None[.5]
Poor Embedded -ness	Severe	Severe[2]	Severe[1] No Coarse[1]	Severe[.5] No Coarse[1]	-	Severe[2] No Coarse[2]	Moderate[2] Severe[1] No Coarse[2]	Severe[1] No Coarse[.5]
Good – No. Substrate Types	> 4	≤4 [.5]	> 4 [.5]	> 4 [.5]	> 4 [.5]	-	> 4 [2]	> 4 [1]
Poor – No. Substrate Types	≤ 4	> 4 [.5]	≤4 [.5]	≤4 [.5]	≤4 [.5]	-	≤ 4 [2]	≤ 4 [1]

Table 19. Theoretical and data-driven "good" and "poor" habitat attributes for the substrate metric for macroinvertebrate assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher fish IBI scores and "poor" attributes are those expected to be associated with lower fish IBI scores. Numbers in bracket are weighted scores using to calculate the good or bad attribute score.

		Data Driven Attributes						
Sub-Metric	***Theoretical Attributes***	***Northern Forest Rivers (1)***	***Prairie Forest Rivers (2)***	***Northern Streams Riffle-Run (3)***	***Northern Streams Glide-Pool (4)***	***Southern Streams Riffle-Run (5)***	***Southern Streams Glide-Pool (6)***	***Prairie Streams Glide-pool (7)***
Substrate Metric								
Good Pool Substrate Types	Boulder, Cobble, Gravel	-	-	Boulder[2] Cobble[2] Gravel[2]	Boulder[.5] Gravel[.5] Clay[.5]	Cobble[1]	-	-
Poor Pool Substrate Types	Silt, Clay	-	-	Sand[1] Clay[.5] Silt[2]	Silt[.5] Detritus[.5]	Clay[1] Silt[2]	-	-
Good Riffle Substrate Types	Boulder, Cobble, Gravel	-	-	Boulder[2] Cobble[1] Gravel[1]	-	Boulder[.5]	-	-
Poor Riffle Substrate Types	Silt, Clay	-	-	Sand[2]	-	Gravel[.5] Sand[.5]	-	-
Good Run Substrate Types	Boulder, Cobble, Gravel	-	-	Boulder[1] Cobble[2] Gravel[.5]	Gravel[2]	Boulder[1] Cobble[1]	Cobble[.5] Gravel[1] Sand[1]	Boulder[.5] Cobble[.5] Gravel[1] Sand[1]
Poor Run Substrate Types	Silt, Clay	-	-	Sand[2] Silt[1]	Sand[1] Silt[2] Detritus[2]	Gravel[1] Sand[1] Clay[1] Silt[1]	Silt[1] Detritus[1]	Clay[.5] Silt[1] Detritus[.5]
Good Embedded-ness	None	-	-	None[2]	None[1] Light[1]	None[1]	-	Light[1] Moderate[1]
Poor Embedded-ness	Severe	-	-	Moderate[2]	Severe[.5] No Coarse[2]	-	-	No Coarse[2]
Good – No. Substrate Types	> 4	-	-	-	> 4[1]	-	-	> 4[2]
Poor – No. Substrate Types	≤ 4	-	-	-	≤ 4[1]	-	-	≤ 4[2]

Instream Structure or "Cover"

There is extensive literature linking various types of instream cover to abundance and biomass of various fish species (Angermeier and Karr 1984, Hrodey et al. 2009, Simon and Morris 2014). Macroinvertebrate taxa have also been associated with various cover types, especially types such as large woody debris (Angermeier and Karr 1984, Smock et el. 1989, Wallace et al. 1995, Benke and Wallace. 2003). Sport fish populations have been manipulated by the addition of instream cover as a way to increased sport fish biomass in streams although many restoration projects have insufficient monitoring data to assess the efficacy of such projects (Brooks et al. 2002, Bernhardt et al. 2005, Roni et al. 2008) and results at the reach level have been mixed, especially for macroinvertebrates (Palmer et al. 2010). The presence of high quality cover (*e.g.*, rootwads, logs, undercut banks) has also been associated with presence of highly sensitive fish species and large woody debris can be fundamental to development of heterogeneous channels and pool/riffle habitats (Davidson and Eaton 2013).

There were only weak relationships in associations between the overall cover metric score and fish assemblages (Figure 13) or macroinvertebrate assemblages (Figure 14) in any of the classification strata. There does seem to be a threshold response with fish assemblages at the lowest scores for most regions and along the range of scores for low gradient streams (Figure 13). This is weaker to non-existent in the macroinvertebrate plots (Figure 14).

Cover Types

ANOVA results for individual cover types were similarly weak with differences related to slightly higher FIBI scores associated with rootwads and logs and woody debris in Southern Streams, rootwads and deep pools in Southern Headwaters, and boulders, in Northern Streams and Northern Headwaters (Table 20). Single cover types may not be expected to be strongly correlated by themselves, but rather with a diversity of cover types instead. For macroinvertebrates slightly higher MIBI scores were associated with logs and woody debris in Southern GP Streams and deep pools, rootwads, logs and boulders in Prairie GP Streams (Table 21). For this reason we did not select the presence of any single cover type as indicators of good or poor habitat attributes, but concentrated on the amount of overall cover among sites.

Cover Score

There were stronger associations between FIBI and number of cover types with low FIBIs associated with sites with only 1-2 cover types in all but Northern and Southern Rivers and high numbers of cover types (5-7) associated with higher FIBI scores in all but Northern and Southern Rivers and Northern Streams (Table 22). Few cover types ($\leq$ 3) were associated with lower MIBI scores in Southern RR and GP streams and Prairie GP Streams and more cover types (6-7) were associated with higher MIBI scores in these same strata (Table 23).

Cover Amount

In addition to identifying each type of cover present, the MSHA tracks the overall amount of cover available to organisms. Overall estimates of cover amount (sparse to extensive) did show a significant or trending relationships with higher FIBI scores with more extensive cover and lower scores with more sparse cover in all but Southern and Northern Rivers (Table 24). However, macroinvertebrates showed no trend with cover amount (Table 25).

The pattern of little to no difference may be partially an artifact of the original scoring of the QHEI cover presence/absence attributes that were used in the MSHA. This method identifies either absence (none of a cover type) or presence which can range from a relative small amount to a large, well developed amount of cover. We observed the same pattern in Ohio wadeable streams where no single cover type was more strongly associated with IBIs than any other (P>0.05). QHEI cover scoring and was modified several years ago to rate each cover type individually with regard to cover amount and quality.

Tables 26 and 27 summarize the "good" and "poor" habitat attributes selected for fish and macroinvertebrate assemblage by classification strata. This metric is more influential for fish assemblages than macroinvertebrates (note numbers of attributes on Table 26 versus Table 27). Part of this may be related to the scale at which we measure habitat features such as cover. Macroinvertebrate taxa may be able to persist and thrive where certain cover types may be in low abundance. In addition many of the invertebrate taxa that make up certain substrate metric s are more substrate dependent than "cover"-dependent. Loss of cover is often associated with stream channelization, but the MIBI may be responding to losses of substrate quality that often co-occur with channel modification (Figure 15).

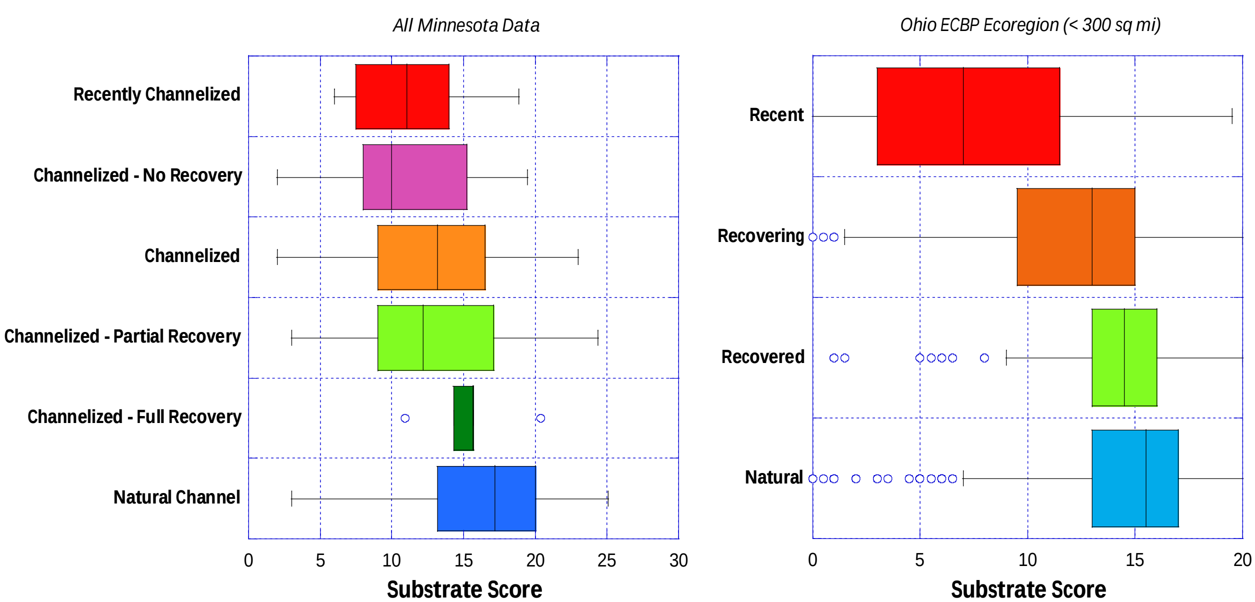

Figure 13. Box and whisker plot of MN MSHA channel modification state and MSHA substrate score (left) and box and whisker plot of QHEI channel modification state and QHEI substrate score (right) in wadeable streams of the ECBP ecoregion

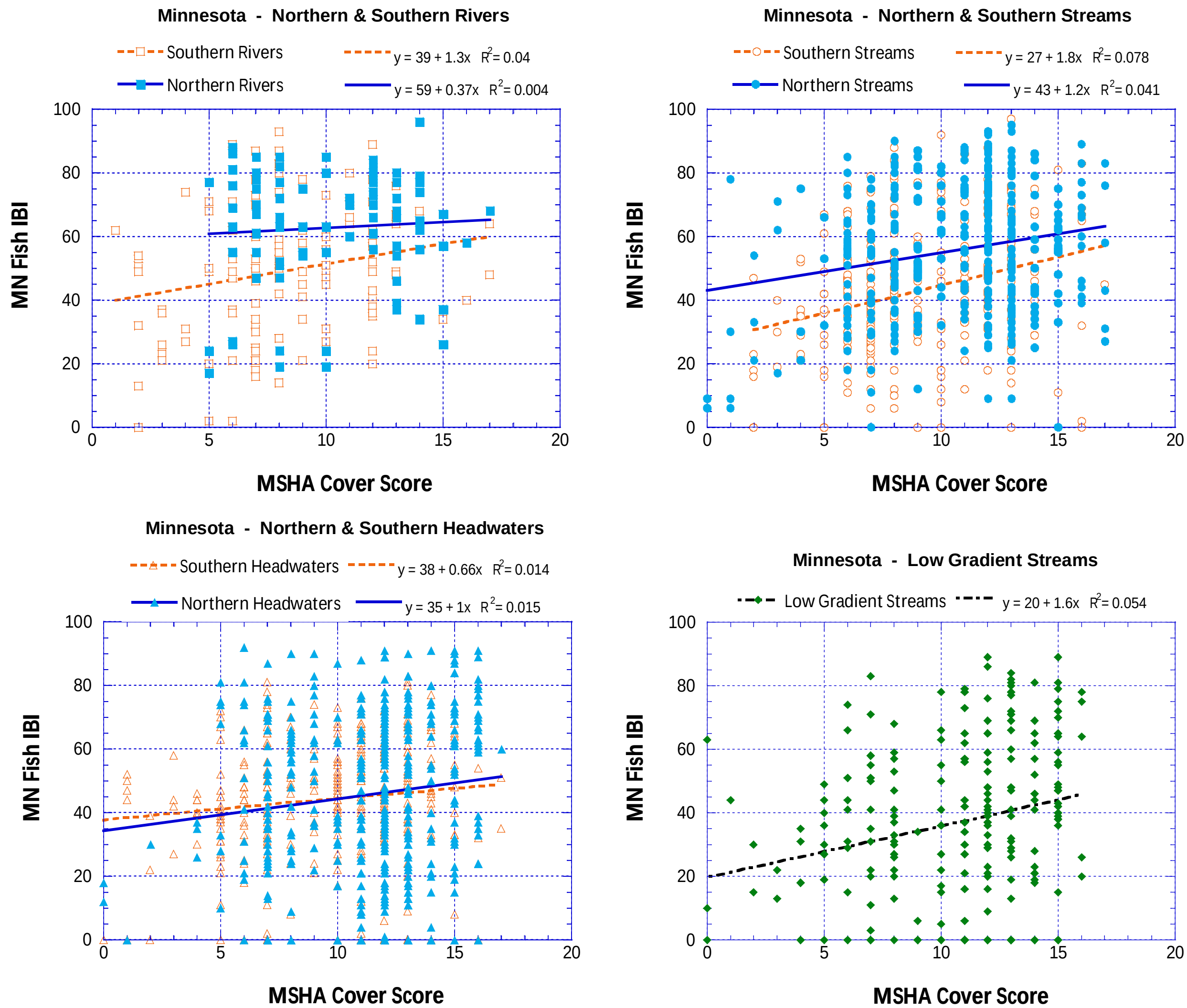

Figure 14. Plots of Fish IBI scores versus MSHA cover score separately for Minnesota Northern and Southern rivers (top left), streams (top right), headwaters (bottom left) and statewide for low gradient streams (bottom right).

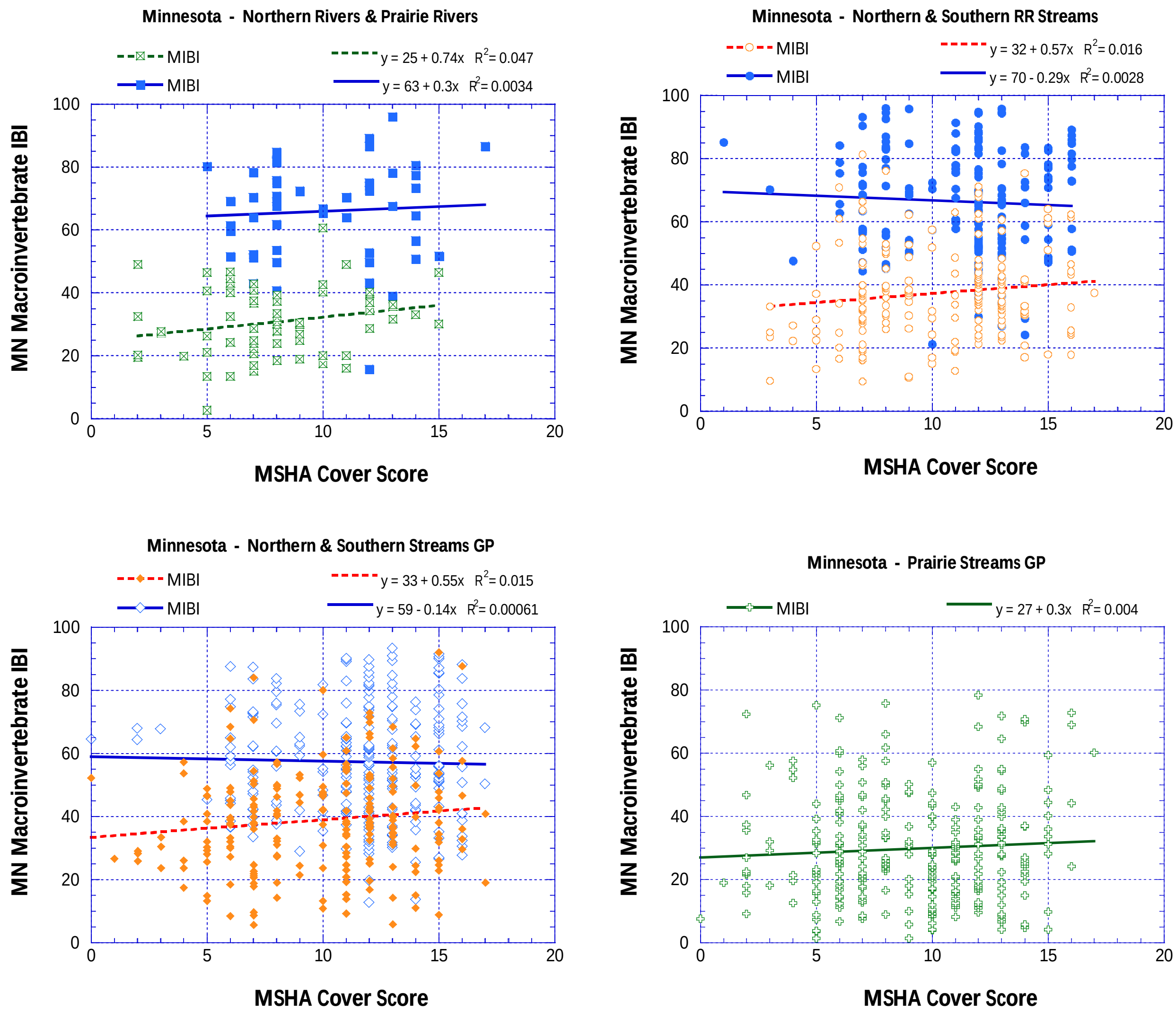

Figure 15. Plots of MIBI scores versus MSHA cover score separately for Minnesota Northern and Prairie rivers (top left), Northern and Southern Riffle/Run streams (top right), Northern and Southern Glide/Pool streams (bottom left) and Prairie Glide/Pool streams (bottom right).

Table 20. Mean FIBI values (SE) for individual MSHA cover types. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Cover Type	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Undercut Banks	All	44.6 (2.5)	43.1 (1.3)	45.4 (1.4)	59.7 (3.1)	53.8 (1.3)	42.8 (1.4)	42.6 (2.0)
Overhang Vegetation	All	50.3 (2.1)	41.8 (1.2)	44.6 (1.1)	60.1 (2.4)	53.7 (1.2)	42.1 (1.2)	36.9 (1.7)
Deep Pools	All	52.4 (2.0)	46.7 (1.5)	49.4 (1.3)	61.2 (2.1)	56.6 (1.2)	45.3 (1.4)	42.4 (2.4)
Logs and Woody Debris	All	51.7 (1.8)	47.6 (1.3)	47.4 (1.4)	60.8 (2.0)	55.4 (1.1)	44.3 (1.3)	42.8 (1.9)
Boulders	All	49.6 (2.1)	45.1 (1.6)	46.5 (1.7)	62.2 (2.1)	57.5 (1.3)	48.7 (1.6)	46.7 (3.8)
Rootwads	All	53.9 (2.7)	48.8 (2.3)	51.4 (2.2)	53.8 (4.2)	52.7 (2.3)	45.1 (3.3)	41.2 (3.9)
Macrophytes	All	51.2 (2.6)	40.5 (1.4)	42.9 (1.3)	63.6 (1.9)	54.7 (1.2)	42.4 (1.2)	36.5 (1.6)
		F=0.118 P=0.312 NS	**F=4.14 P<0.001 ***	**F=3.17 P=0.004 ***	**F=0.83 P=0.547 NS**	**F=1.38 P=0.218 NS**	**F=2.48 P=0.022 ***	**F=2.76 P=0.011 NS**

Table 21. Mean MIBI values (SE) for individual MSHA cover types. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Cover Type	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Undercut Banks	All	71.8 (3.8)	30.3 (2.2)	66.3 (1.8)	58.9 (1.4)	36.6 (1.2)	42.1 (1.4)	31.3 (1.3)
Overhang Vegetation	All	67.3 (2.9)	32.3 (1.5)	65.5 (1.4)	56.9 (1.2)	36.6 (1.1)	39.2 (1.1)	29.8 (1.0)
Deep Pools	All	64.5 (2.6)	30.5 (1.4)	66.6 (1.4)	59.2 (1.4)	39.3 (1.2)	40.8 (1.2)	35.3 (1.6)
Logs and Woody Debris	All	65.7 (2.3)	31.0 (1.3)	66.3 (1.3)	57.9 (1.1)	39.4 (1.1)	43.0 (1.2)	35.8 (1.5)
Boulders	All	66.8 (2.3)	30.6 (1.5)	66.0 (1.3)	60.0 (1.9)	38.4 (1.1)	39.7 (1.8)	34.0 (1.7)
Rootwads	All	63.1 (7.3)	33.4 (1.9)	60.2 (3.2)	58.3 (2.5)	37.9 (1.6)	40.7 (2.2)	38.1 (3.1)
Macrophytes	All	67.2 (2.2)	31.0 (2.3)	65.9 (1.3)	56.8 (1.1)	37.4 (1.3)	37.6 (1.1)	28.1 (1.1)
		F=0.53 P=0.797 NS	**F=.379 P=0.892 NS**	**F=0.479 P=0.824 NS**	**F=0.699 P=0.650 NS**	**F=0.969 P=0.444 NS**	**F=2.221 P=0.039 ***	**F=5.78 P<0.001 ***

Table 22. Mean FIBI values (SE) for number of MSHA cover score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Cover Score	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
1	All	-	22.7 (5.4)	26.4 (5.7)	-	37.9 (9.1)	18.0 (4.6)	19.1 (7.5)
2	All	47.1 (6.0)	31.7 (3.5)	35.5 (3.0)	43.5 (8.9)	40.4 (5.1)	26.0 (4.8)	22.5 (3.5)
3	All	51.4 (3.6)	37.1 (2.4)	41.8 (2.5)	63.9 (6.6)	46.9 (2.9)	35.5 (2.8)	30.0 (3.8)
4	All	50.5 (4.2)	42.5 (2.1)	47.6 (1.9)	65.3 (3.6)	54.1 (2.2)	38.9 (2.2)	36.3 (2.9)
5	All	51.8 (3.2)	47.1 (2.3)	48.6 (2.2)	63.7 (3.2)	56.3 (1.9)	44.0 (1.8)	44.5 (2.7)
6	All	48.3 (4.1)	49.4 (2.9)	46.6 (3.1)	60.3 (3.3)	57.5 (2.1)	52.9 (2.6)	55.9 (5.4)
7	All	-	50.9 (6.0)	55.3 (5.1)	50.8 (7.3)	54.3 (5.3)	53.6 (7.2)	-
		F=0.211 P=0.932 NS	**F=5.35 P<0.001 ***	**F=5.59 P<0.001 ***	**F=1.89 P=0.102 NS**	**F=3.078 P=0.006 ***	**F=8.069 P<0.001 ***	**F=8.50 P<0.001 ***

Table 23. Mean MIBI values (SE) for individual MSHA cover score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Cover Score	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
1	All	-	-	-	-	-	-	32.8 (2.4)
2	All	-	-	-	-	-	-	25.6 (4.3)
3	All	-	29.2 (3.8)	-	48.9 (4.1)	27.4 (5.0)	31.5 (2.2)	24.0 (2.3)
4	All	61.8 (2.8)	33.7 (2.7)	67.7 (5.6)	51.8 (2.7)	33.1 (4.1)	38.8 (2.3)	26.6 (1.6)
5	All	63.0 (3.1)	27.9 (2.7)	67.9 (2.3)	56.5 (2.0)	34.9 (2.2)	37.0 (2.1)	28.2 (1.7)
6	All	66.1 (3.6)	32.2 (1.8)	66.3 (2.0)	59.3 (1.9)	42.5 (1.8)	42.7 (1.9)	38.7 (2.4)
7	All	-	29.4 (2.2)	65.1 (2.5)	59.9 (2.6)	38.2 (1.7)	44.0 (2.7)	42.4 (4.1)
		F=0.268 P=0.766 NS	**F=0.782 P=0.541 NS**	**F=0.221 P=0.881 NS**	**F=1.93 P=0.124 NS**	**F=3.47 P=0.009 ***	**F=3.12 P=0.016 ***	**F=8.03 P<0.001 ***

Table 24. Mean FIBI values (SE) for overall MSHA cover amount. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Cover Amount	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Choking Veg. [-1]	All	-	-	13.5 (6.8)	-	-	14.3 (6.1)	30.0 (7.2)
Absent [0]	All	48.5 (1.8)	33.0 (1.3)	39.3 (2.4)	-	48.2 (2.6)	41.2 (3.6)	-
Sparse [3]	All	49.4 (2.3)	41.5 (1.3)	43.7 (1.7)	57.4 (3.3)	50.8 (1.8)	40.8 (2.0)	33.2 (2.7)
Moderate [7]	All	56.9 (2.5)	48.6 (2.2)	49.4 (1.5)	65.1 (2.4)	58.0 (1.5)	42.5 (1.7)	41.5 (2.9)
Extensive [10]	All	-	36.4 (4.3)	35.0 (3.2)	58.4 (5.0)	52.6 (2.6)	43.4 (2.3)	35.1 (2.7)
		F=5.979 P=0.003 *	**F=8.29 P<0.001 ***	**F=8.702 P<0.001 ***	**F=1.82 P=0.168 NS**	**F=4.891 P=0.002 ***	**F=2.67 P=0.047 ***	**F=1.77 P=0.15 NS**

Table 25. Mean MIBI values (SE) for overall MSHA cover amount. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Cover Amount	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Choking Vegetation	All	-	-	-	-	-	-	-
Absent	All	-	37.7 (2.8)	-	-	33.9 (1.5)	39.7 (2.4)	32.5 (2.1)
Sparse	All	65.1 (2.6)	30.3 (1.7)	67.9 (2.0)	58.6 (2.1)	37.4 (1.7)	37.9 (1.6)	31.1 (1.5)
Moderate	All	66.2 (4.5)	33.9 (2.0)	64.1 (1.9)	57.9 (1.6)	38.3 (1.5)	41.8 (1.6)	29.7 (1.7)
Extensive	All	66.3 (5.0)	-	69.9 (2.5)	55.4 (2.1)	38.6 (3.5)	37.7 (2.8)	27.4 (2.1)
		F=0.032 P=0.968 NS	**F=1.56 P=0.218 NS**	**F=1.856 P=0.159 NS**	**F=0.75 P=0.472 NS**	**F=1.99 P=0.116 NS**	**F=1.019 P=0.385 NS**	**F=0.763 P=0.515 NS**

Table 26. Theoretical and data-driven "good" and "poor" habitat attributes for the cover metric for fish assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher FIBI scores and "poor" attributes are those expected to be associated with lower FIBI scores. Numbers in bracket are weighted scores using to calculate the good or bad attribute score.

Sub-Metric	***Theoretical Attributes***	***Data Driven Attributes***						
		Southern Rivers (1)	***Southern Streams (2)***	***Southern Headwaters (3)***	***Northern Rivers (4)***	***Northern Streams (5)***	***Northern Headwaters (6)***	***Low Gradient Streams (7)***
Cover Metric								
Good Cover Types	-	-	Logs[1] Rootwad[1] Deep pools[.5]	Deep Pools[1] Rootwads[1]	-	-	Boulders[1]	Boulders[.5]
Poor Cover Types	-	-	-	-	-	-	-	Overhang. Veg[.5] Macro-phytes[.5]
Number of Cover Types – Good	5-7	-	6[1] 7[1] 5[.5]	7[2] 6[.5] 5[1] 4[1]	-	-	6[2] 7[1]	6[2] 5[1]
Number of Cover Types – Poor	0-2	-	1[1] 2[1] 3[.5]	1[2] 2[1]	2[.5]	1[.5] 2[.5]	1[2] 2[2] 3[1] 4[1]	1[2] 2[2] 3[1]
Good Overall Cover Amount	Extensive	Mod.[1]	Mod.[2]	Mod.[1]	-	Mod.[1]	Mod.[1] Extensive[1]	Mod.[.5]
Poor Overall Cover Amount	Sparse, Choking	Absent[1] Sparse[.5]	Absent[2] Sparse[.5]	Absent[1] Choking Veg.[.5]	-	Absent[1] Sparse[.5]	Absent[1]	-

Table 27. Theoretical and data-driven "good" and "poor" habitat attributes for the cover metric for macroinvertebrate assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher MIBI scores and "poor" attributes are those expected to be associated with lower MIBI scores. Numbers in bracket are weighted scores using to calculate the good or bad attribute score.

Sub-Metric	***Theoretical Attributes***	***Data Driven Attributes***						
		Northern Forest Rivers (1)	***Prairie Forest Rivers (2)***	***Northern Streams Riffle-Run (3)***	***Northern Streams Glide-Pool (4)***	***Southern Streams Riffle-Run (5)***	***Southern Streams Glide-Pool (6)***	***Prairie Streams Glide-Pool (7)***
Cover Metric								
Good Cover Types	-	-	--	-	-	-	Logs[.5]	Logs[1] Deep Pools[1] Rootwads[1] Boulders[1]
Poor Cover Types	-	-	-	-	-	-	-	Macrophytes[1]
Number of Cover Types – Good	5-7	-	-	-	6[.5] 7[.5]	6[1] 7[.5]	6[1] 7[1]	6[2] 7[2]
Number of Cover Types – Poor	0-2	-	-	-	-	3[1]	3[1]	1[1] 2[1] 3[2] 4[1]
Good Overall Cover Amount	Extensive	-	-	-	-	-	-	-
Poor Overall Cover Amount	Sparse, Choking	-	-	-	-	-	-	-

Stream Channel Characteristics

Stream channel characteristics are typically among the strongest predictors of aquatic life potential at a site and have been frequently modified in Midwest Rivers (Weigel *et al*. 2006). Many of the channel attributes integrate the co-occurrence of multiple positive habitat attributes under natural conditions (*e.g.*, natural channel, high sinuosity) or the loss of attributes when a stream is modified (*e.g.*, channelized or impounded). Numerous authors have identified the detrimental effects of channelization or impoundment (see Baxter 1977) on fish assemblages and the attributes of the stream channel metric is an attempt to capture both the positive and negative aspects related to both of these activities. Similar effects of channelization on invertebrates have also been observed (Heatherly et al. 2007, Kennedy and Turner 2011).

The channel metric score was among the strongest correlates with the FIBI (Figure 16), but the relationship between the MIBI was weaker (Figure 17) and there was still a great deal of scatter in the relationships. As was discussed earlier, we attribute some of this variation to watershed scale impacts on assemblages. Watersheds with predominantly natural channels can compensate for short reaches of modified channels while watersheds with widespread channel modifications reduces populations of species that might otherwise exist in short reaches with natural channel characteristics. It appears the open nature of these ecosystems (*i.e.,* ecosystem impacts in upstream and downstream directions) exerts a strong impact on local assemblage condition. In addition, cool water temperatures and strong base flows may moderate some of the most negative effects in certain watersheds. Some evidence for this may come from comparing Minnesota streams to Ohio streams. In Figure 18 we compare the Ohio FIBI scores by the QHEI channel metric divided in approximate quartiles of value with the MN FIBI scores for the Southern Streams strata were the channel metric had the strongest correlation with a MN FIBI (see Figure 16). The Ohio data showed less variability in biological response to altered channel conditions, particularly where channels were more severely altered (lower quantiles of channel scores for QHEI and MSHA, red boxes). Ohio streams can have higher average temperatures during summer because of latitudinal differences in climate. In addition, measures of baseflow (*i.e.*, percent of low flows as base flow) are generally higher in Minnesota compared to Ohio except for perhaps the Red River basin and some of the western-most streams (Santhi et al. 2008). Higher baseflow tends to moderate extreme temperatures and dissolved oxygen swings. Some authors suggest that

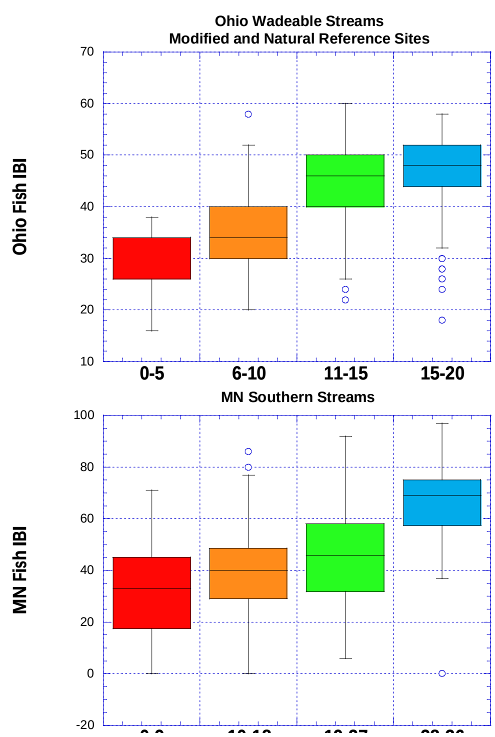

Figure 16. Box and whisker plots of the Ohio fish IBI versus ranges of the QHEI channel score (top) and the MN fish IBI and ranges of the MSHA channel score (bottom)

areas of high base flow can provide refuge for macroinvertebrates sensitive to low or high flow events and explain persistence of sensitive macroinvertebrate taxa (Lancaster and Hildrew 1993).

To bolster this contention we used the QHEI and MSHA identifications of intermittent and interstitial flows plotted by drainage size category ranges (3 mi^2 intervals) (Figure 19). Although the percent of sites sampled that were characterized as interstitial were similar between states, Ohio characterized more sites as intermittent (more flow starved than interstitial) particularly at large drainage areas; this may reflect greater cumulative loss of flows at watershed scales or the cumulative effects of having less base flow in general in Ohio streams. In any case altered channels in Ohio may result in more severe impacts to biota which may interact with high nutrients to create more severe habitat influenced biological impairments. Lower water temperatures, higher flows and less nutrient enrichment may explain the somewhat weaker correlations between the MSHA metrics such as channel condition and fish assemblage condition as measured by the FIBI and MIBI. Even so there is a correlation with multiple aspects of channel condition which may be used to identify watersheds where habitat factors may be limiting to one or more biological criteria goals.

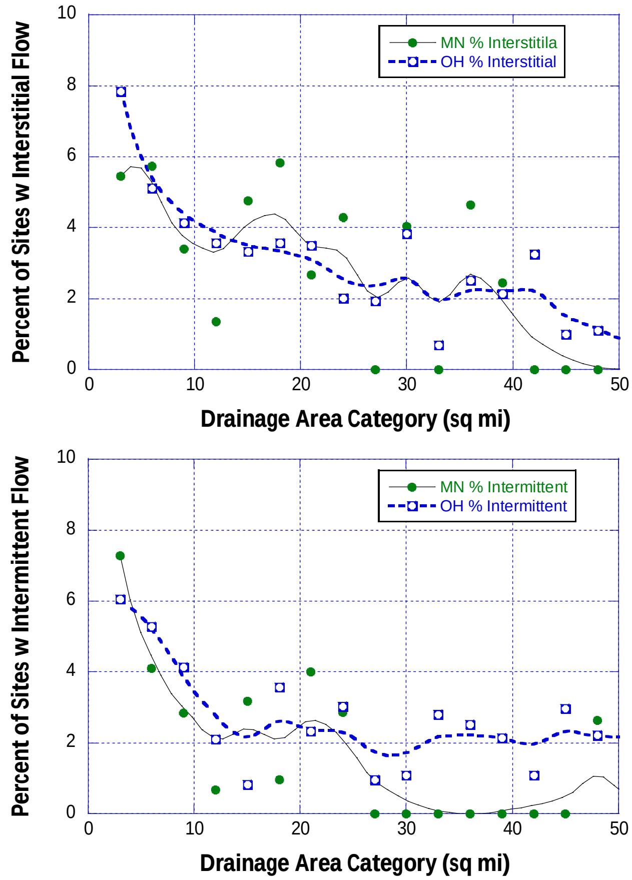

Figure 17. Plots of percent of sites with interstitial (top) or intermittent (bottom) flows by drainage size category for MN streams (green dots) or OH streams (open squares).

Sinuosity

The sinuosity of the channel of rivers provides substantial insight, in many cases, as to whether natural channel characteristics are present. Neither fish nor macroinvertebrate assemblages showed significant variation in IBIs in large river strata (Tables 28 and 29). For fish, poor sinuosity was significantly associated with lower FIBIs in all wadeable stream strata, although excellent sinuosity was only associated with high FIBIs in Northern Headwaters and Low Gradient Streams (Table 28). MIBIs were generally lower in streams with poor sinuosity in all wadeable strata, except the Northern Stream Riffle/Run strata. High gradient streams reaches can often run rather straight compared to more meandering lower gradient streams with Glide/Pool morphologies. In such streams, sinuosity typically results in pool formation on outside bends and deposition on inside bends and this increases depth and habitat heterogeneity.

Table 28. Mean FIBI values (SE) for MSHA channel sinuosity categories. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Sinuosity Score	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Excellent [6]	All	50.7 (3.6)	43.7 (2.7)	48.7 (2.5)	60.9 (7.9)	51.5 (1.8)	51.9 (2.7)	47.8 (3.3)
Good [4]	All	49.3 (2.5)	48.1 (2.0)	47.9 (2.1)	58.7 (2.9)	60.3 (1.7)	48.0 (2.0)	44.4 (3.1)
Fair [2]	All	53.8 (3.2)	44.2 (2.1)	47.9 (2.3)	65.1 (2.9)	54.3 (2.1)	40.7 (2.0)	34.5 (3.3)
Poor [0]	All	49.4 (1.9)	33.6 (1.2)	37.7 (1.5)	61.0 (1.4)	44.4 (2.0)	33.4 (1.9)	28.0 (2.2)
		F=1.22 P=0.303 NS	**F=9.65 P<0.001 ***	**F=8.97 P<0.001 ***	**F=1.005 P=0.394 NS**	**F=15.74 P<0.001 ***	**F=19.44 P<0.001 ***	**F=9.86 P<0.001 ***

Table 29. Mean MIBI values (SE) for MSHA channel sinuosity categories. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Sinuosity Score	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Excellent [6]	All	74.0 (4.6)	28.7 (2.2)	64.8 (2.9)	59.4 (1.9)	41.0 (1.9)	45.8 (2.5)	39.7 (3.7)
Good [4]	All	68.3 (3.5)	34.5 (1.9)	71.1 (1.7)	60.5 (1.8)	39.7 (1.6)	41.9 (1.7)	37.3 (2.0)
Fair [2]	All	65.0 (3.0)	27.9 (2.6)	63.3 (2.1)	54.9 (2.2)	36.4 (2.2)	41.6 (1.9)	27.1 (1.8)
Poor [0]	All	-	37.9 (2.7)	67.0 (3.3)	51.7 (2.8)	31.7 (1.4)	31.8 (1.5)	28.2 (1.2)
		F=0.814 P=0.449 NS	**F=2.27 P=0.089 NS**	**F=4.557 P=0.004 ***	**F=4.64 P=0.003 ***	**F=9.05 P<0.001 ***	**F=13.96 P<0.001 ***	**F=9.20 P<0.001 ***

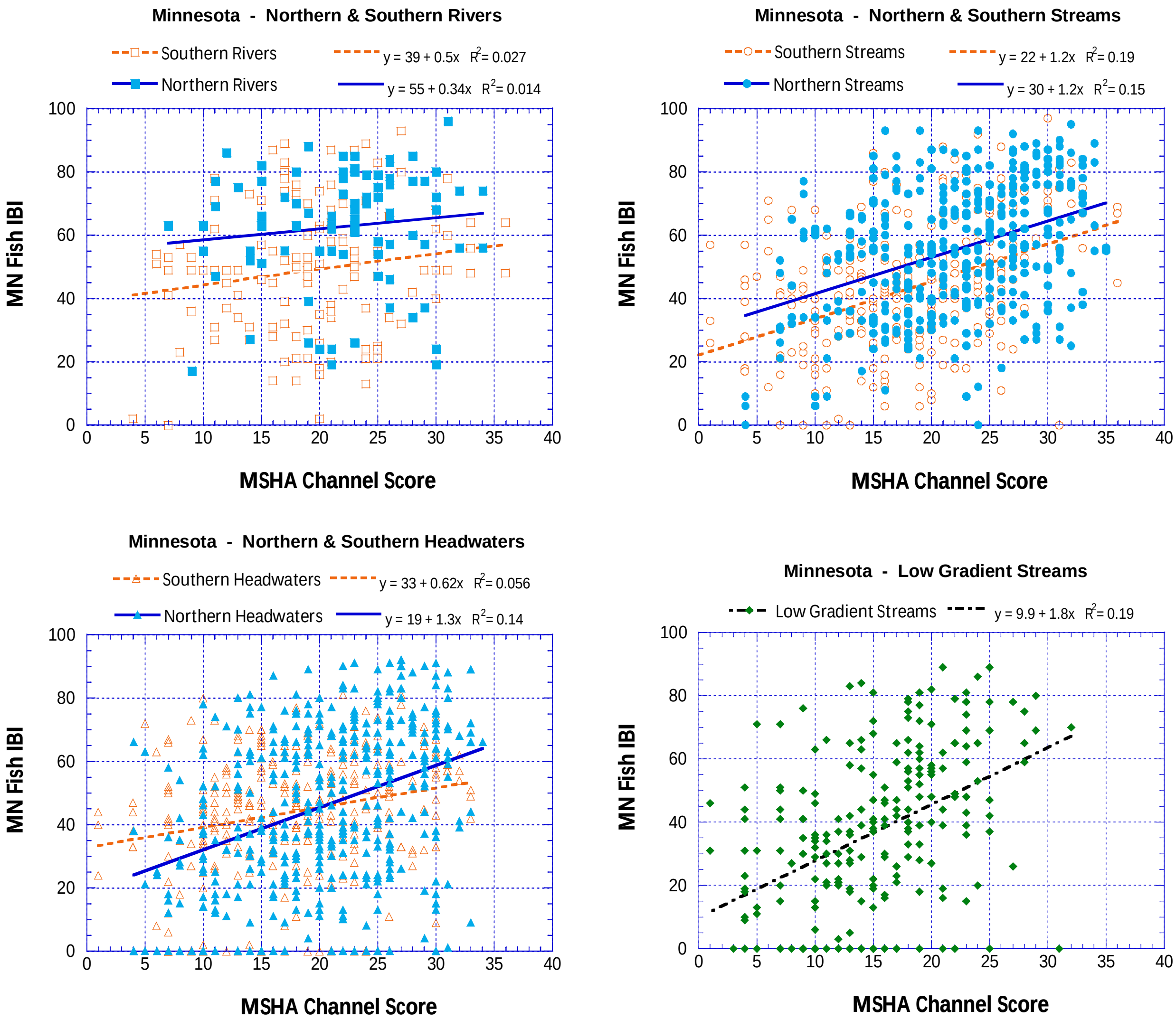

Figure 18. Plots of Fish IBI versus MSHA channel score separately for Minnesota Northern and Southern rivers (top left), streams (top right), headwaters (bottom left) and statewide for low gradient streams (bottom right).

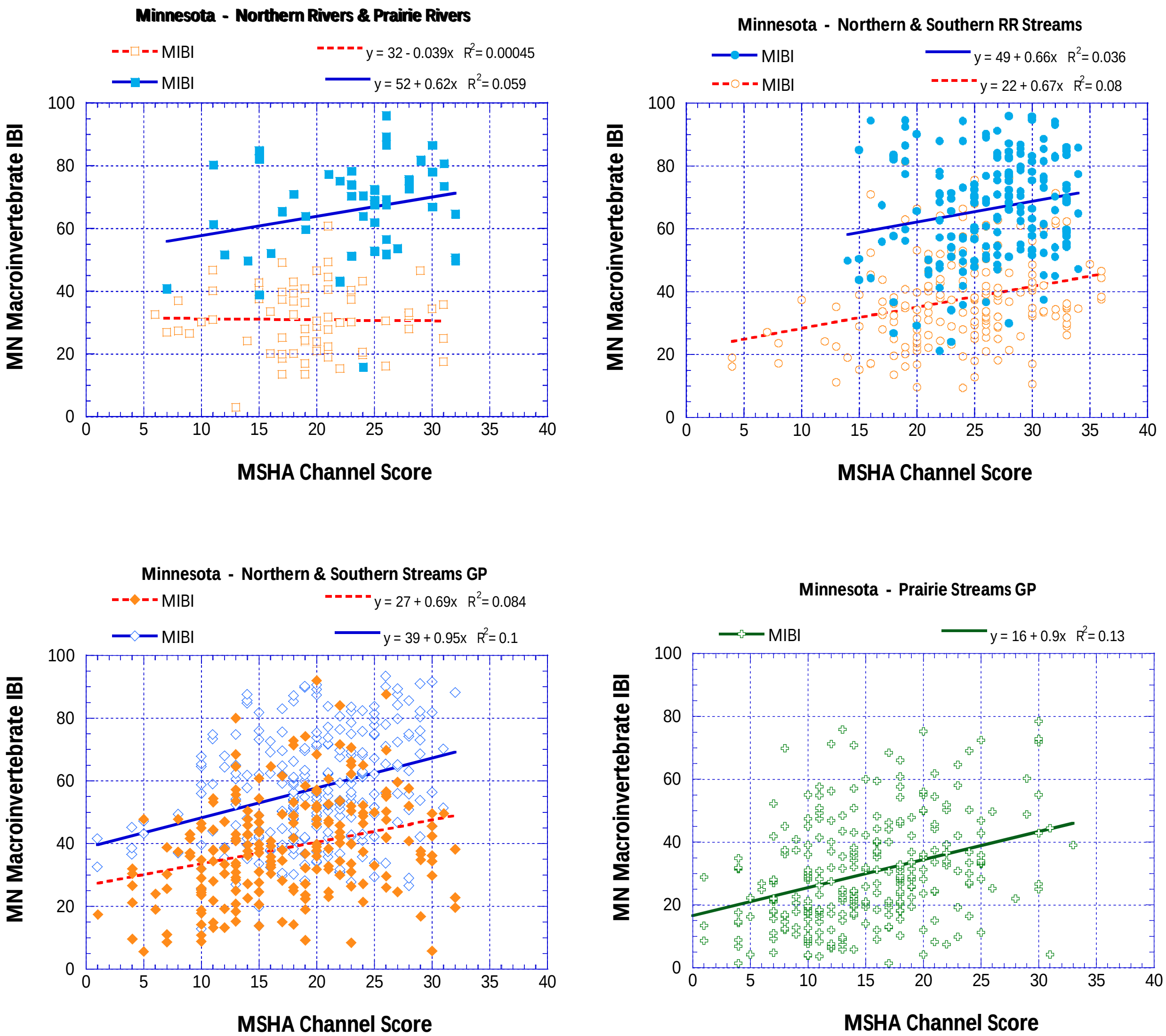

Figure 19. Plots of MIBI versus MSHA channel score separately for Minnesota Northern and Prairie Rivers (top left), Northern and Southern Riffle/Run streams (top right), Northern and Southern Glide/Pool Streams (bottom left) and Prairie GP Streams (bottom right).

Pool Width versus Riffle Width Score

The morphology and formulation of riffle and pool sequences has been an active subject for geomorphologists (*e.g.*, Yang 1971, Pasternack et al. 2008), but the characteristics of pool/glide and riffle/run habitats are also fundamental to the distribution and population of aquatic organisms. The lack of a riffle in the sample reach was a negative attribute for four fish and two macroinvertebrate stream strata (Table 30, Table 31). Pool widths greater than or equal to the width of the riffle was largely a positive attribute for several fish and macroinvertebrate stream strata.

Table 30. Mean FIBI values (SE) for the MSHA Pool Width/Riffle Width score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Pool Width/Riffle Width	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
PW>RW	All	48.0 (2.6)	46.3 (1.8)	49.1 (1.6)	48.4 (6.6)	57.8 (2.1)	43.4 (2.1)	46.8 (4.7)
PW=RW	All	47.0 (3.0)	48.3 (2.7)	44.4 (2.6)	61.6 (8.0)	52.4 (3.8)	44.6 (4.4)	28.0 (6.4)
PW<RW	All	-	-	-	-	-	-	-
No Riffle	All	50.6 (2.2)	35.1 (1.4)	38.3 (1.8)	63.7 (3.2)	53.9 (1.9)	36.2 (1.9)	31.2 (2.1)
ANOVA		**F=0.479 P=0.62 NS**	**F=16.39 P<0.0001 ***	**F=30.12 P<0.0001 ***	**F=2.304 P=0.109 NS**	**=1.32 P=0.269 NS**	**F=3.747 P=0.0245 ***	**F=5.427 P=0.0052 ***

Table 31. Mean MIBI values (SE) for individual MSHA Pool Width/Riffle Width score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Pool Width/Riffle Width	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
PW>RW	All	69.3 (5.4)	31.8 (2.7)	65.1 (1.5)	57.4 (2.4)	36.2 (1.3)	37.9 (1.9)	32.3 (2.1)
PW=RW	All	61.4 (7.0)	-	66.1 (4.6)	57.9 (3.9)	35.4 (2.6)	49.4 (2.7)	33.0 (3.2)
PW<RW	All	-	-	-	-	-	-	-
No Riffle	All	63.2 (2.2)	28.4 (1.5)	67.3 (3.0)	56.5 (1.4)	40.9 (3.3)	37.9 (1.6)	24.5 (1.2)
ANOVA		**F=0.553 P=0.578 NS**	**F=1.106 P=0.297 NS**	**F=0.278 P=0.758 NS**	**F=0.078 P=0.925 NS**	**F=1.272 P=0.283 NS**	**F=5.25 P=0.00598 ***	**F=7.503 P=0.0007 ***

Channel Development

The channel development submetric of the MSHA is similar to the pool/riffle development metric of the QHEI and tracks “the complexity of the stream channel or the degree to which the stream has developed different channel types, creating sequences of riffles, runs, and pools.” These are rated excellent, good, fair or poor. There was no significant association between channel development and FIBI scores in Northern or Southern Rivers or with MIBI scores in Northern or Prairie River strata (Tables 32 and 33). For both fish and macroinvertebrates in wadeable streams poor development was associated with lower FIBI and MIBI scores. Either good or excellent attributes were associated with higher FIBI or MIBI scores for wadeable streams with small sample size often associated with increased variation and non-significance of attributes.

Table 32. Mean FIBI values (SE) for MSHA channel development attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Channel Develop Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Excellent [9]	All	54.5 (3.4)	54.0 (3.9)	44.9 (3.4)	66.7 (4.9)	64.2 (2.4)	53.9 (2.7)	46.3 (9.0)
Good [6]	All	47.0 (3.5)	48.8 (2.0)	48.3 (2.0)	59.6 (2.8)	57.7 (1.6)	47.7 (2.0)	51.4 (4.4)
Fair [3]	All	52.8 (2.5)	40.9 (1.8)	46.0 (1.8)	61.3 (3.9)	49.1 (1.9)	40.0 (1.8)	40.3 (2.2)
Poor [0]	All	49.6 (1.7)	33.5 (1.1)	37.8 (1.7)	61.1 (1.4)	46.2 (1.9)	33.1 (2.1)	27.1 (2.2)
		F=1.12 P=0.342 NS	**F=14.41 P<0.001 ***	**F=6.50 P<0.001 ***	**F=0.671 P=0.572 NS**	**F=15.03 P<0.001 ***	**F=19.88 P<0.001 ***	**F=10.77 P<0.001 ***

Table 33. Mean MIBI values (SE) for individual MSHA channel development attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Channel Develop Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Excellent	All	70.5 (2.8)	-	71.1 (1.7)	68.9 (4.3)	42.7 (1.8)	37.4 (6.2)	46.0 (5.6)
Good	All	67.0 (4.1)	28.6 (2.1)	63.9 (1.7)	60.5 (2.3)	38.1 (1.4)	42.1 (1.9)	38.2 (2.3)
Fair	All	59.6 (3.4)	31.0 (2.0)	65.4 (3.8)	56.7 (1.4)	34.0 (2.4)	42.2 (1.6)	31.3 (1.6)
Poor	All	-	39.0 (2.5)	-	54.1 (2.3)	33.5 (1.6)	33.9 (1.5)	26.4 (1.2)
		F=1.749 P=0.186 NS	**F=0.69 P=0.503 NS**	**F=3.35 P=0.037 ***	**F=3.57 P=0.015 ***	**F=5.61 P=0.001 ***	**F=6.42 P<0.001 ***	**F=15.76 P<0.001 ***

Channel Stability

Channel stability refers to the permanence of key channel structures such as riffle and run features with indicators of instability including aggradation of fines and eroding banks. Increasing instability is associated with degraded biological assemblages because of unstable habitat features not compatible with various life history aspects of sensitive organism (*e.g.,* spawning, feeding, and refuge). High stability was associated with higher FIBI scores in Southern River, Northern Streams and Headwaters and in Low Gradient streams, but low stability was only clearly associated with low stability in Southern Streams (Table 34). The macroinvertebrates were only weakly associated with channel stability in Northern Riffle Run streams and Southern Glide/Pool streams (Table 35).

Table 34. Mean FIBI values (SE) for MSHA channel stability attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Channel Stability Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
High [9]	All	61.1 (5.2)	41.3 (3.6)	41.9 (2.8)	64.4 (2.6)	62.7 (1.8)	47.5 (2.2)	42.7 (3.5)
Mod.-High [6]	All	52.4 (3.1)	40.9 (2.5)	41.1 (1.9)	58.5 (3.7)	51.0 (1.8)	41.9 (1.8)	35.5 (2.4)
Moderate [3]	All	48.6 (2.6)	44.2 (1.5)	47.5 (1.8)	60.2 (3.5)	50.0 (1.9)	37.4 (2.0)	32.2 (2.7)
Low [0]	All	49.3 (1.7)	35.6 (1.2)	41.1 (2.1)	-	48.2 (2.4)	40.6 (3.3)	31.2 (4.0)
		F=2.21 P=0.0895 NS	**F=0.081 P=0.493 NS**	**F=2.384 P=0.069 NS**	**F=0.953 P=0.389 NS**	**F=11.49 P<0.001 ***	**F=6.26 P<0.001 ***	**F=2.019 P=0.111 NS**

Table 35. Mean MIBI values (SE) for individual MSHA channel stability attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Channel Stability Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
High [9]	All	67.0 (3.1)	29.7 (4.1)	69.8 (1.6)	58.2 (2.1)	39.0 (2.4)	32.9 (2.2)	28.4 (2.0)
Mod.-High	All	68.1 (3.9)	29.4 (3.2)	59.6 (2.3)	58.5 (1.7)	35.6 (2.0)	41.4 (1.7)	28.7 (1.6)
Moderate	All	59.8 (4.3)	32.4 (1.5)	62.5 (3.0)	56.0 (2.1)	38.1 (1.6)	39.7 (1.6)	30.5 (1.7)
Low	All	-	37.7 (2.4)	-	-	35.5 (1.4)	40.5 (2.2)	33.4 (2.0)
		F=1.014 P=0.370 NS	**F=0.343 P=0.794 NS**	**F=6.881 P=0.001 ***	**F=0.435 P=0.648 NS**	**F=0.52 P=0.669 NS**	**F=2.743 P=0.044 ***	**F=1.086 P=0.355 NS**

Depth Variability

Depth variability is “the difference in thalweg depth between the shallowest stream cross section and the deepest stream cross section and indicates the degree to which the thalweg depths vary within the stream reach.” This attribute, except for rivers, was one of the strongest submetrics across all strata with streams with good variation in depth associated with higher FIBI scores (Table 36) and in most cases MIBI scores (Table 37). Northern RR streams had few sites with low depth variation which explains the lack of a significant difference in this stratum. Channelized streams often have less depth variation than natural streams and this metric may track the degree of channel modification.

Table 36. Mean FIBI values (SE) for MSHA depth variability attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Depth Variability Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
4X Var [6]	All	53.0 (2.2)	48.1 (1.5)	46.0 (1.5)	60.5 (2.4)	57.1 (1.3)	45.4 (1.5)	43.1 (2.8)
2-4X Var [3]	All	46.3 (3.3)	37.1 (1.9)	45.6 (1.7)	62.7 (4.2)	50.7 (2.0)	39.3 (1.9)	40.3 (2.4)
<2X Var [0]	All	43.7 (4.6)	33.2 (1.2)	36.4 (2.1)	61.4 (1.4)	46.3 (2.1)	35.9 (2.7)	24.6 (2.3)
		F=2.32 P=0.102 NS	**F=19.73 P<0.001 ***	**F=10.33 P<0.001 ***	**F=0.097 P=0.907 NS**	**F=11.16 P<0.001 ***	**F=12.03 P<0.001 ***	**F=15.64 P<0.001 ***

Table 37. Mean MIBI values (SE) for MSHA depth variability attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Depth Variability Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
4X Var [6]	All	65.5 (2.6)	31.1 (1.5)	66.3 (1.3)	60.6 (1.6)	38.5 (1.1)	43.4 (1.4)	34.9 (1.6)
2-4X Var [3]	All	65.4 (4.0)	31.9 (2.4)	67.2 (3.3)	56.1 (1.7)	36.9 (2.8)	38.2 (1.7)	27.9 (1.6)
<2X Var [0]	All	-	38.7 (2.9)	-	51.9 (2.6)	33.1 (1.6)	32.5 (1.9)	27.4 (1.5)
		F=0.001 P=0.873 NS	**F=0.282 P=0.755 NS**	**F=0.07 P=0.790** NS	**F=6.80 P=0.001 ***	**F=6.869 P=0.001 ***	**F=13.80 P<0.001 ***	**F=11.716 P<0.001 ***

Current Velocity Types

Stream flow and current velocity has been shown to be critical factors for many species of fishes and macroinvertebrates in flowing waters with some species/taxa being identified as fluvial specialists or dependents related to their reliance on flow for one or more parts of their life histories (Allan 2007, Arthington et al 2006). We examined both the occurrence of IBIs in response to the occurrence individual current velocity types (*e.g.,* fast, moderate, slow) and in response to the cumulative association measure based on a sum of the scores of all types found in a reach. The association of any single flow attribute was rather weak with the presence of fast flow and eddies in Southern Streams showing a significant association with higher FIBI scores (Table 38). For macroinvertebrates fast flow was associated with higher MIBI scores in Northern and Prairie Glide/Pool streams and higher MIBI scores were associated with eddies in the Northern and Southern Glide/Pool streams (Table 39).

Table 38. Mean FIBI values (SE) for MSHA current velocity attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Depth Variability Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Torrential	All	-	-	-	-		-	-
Fast	All	51.3 (2.3)	49.1 (1.9)	47.9 (1.8)	60.3 (2.7)	58.6 (1.6)	48.1 (2.2)	45.2 (5.1)
Moderate	All	50.1 (1.7)	45.2 (1.2)	45.7 (1.2)	59.7 (2.1)	55.0 (1.2)	42.9 (1.3)	41.2 (2.1)
Slow	All	51.3 (1.8)	42.0 (1.2)	45.6 (1.2)	62.3 (2.1)	54.8 (1.1)	42.2 (1.2)	36.8 (1.6)
Eddies	All	48.7 (2.2)	50.0 (2.1)	50.8 (2.2)	63.2 (2.8)	58.1 (1.9)	48.3 (2.8)	38.9 (6.4)
Interstitial	All	-	-	54.0 (3.9)			56.5 (4.3)	-
Intermittent	All	-	-	-			45.9 (11.6)	-
		F=0.35 P=0.790 NS	**F=5.67 P<0.001 ***	**F=1.388 P=0.236 NS**	**F=.456 P=0.713 NS**	**F=1.38 P=0.239 NS**	**F=3.23 P=0.006 ***	**F=1.87 P=0.114 NS**

Table 39. Mean MIBI values (SE) for MSHA current velocity attributes. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Depth Variability Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Torrential	All	-	-	-	-	-	-	-
Fast	All	67.5 (2.5)	29.3 (1.6)	69.0 (1.7)	68.3 (3.2)	39.7 (1.2)	42.7 (1.8)	39.5 (2.4)
Moderate	All	66.0 (2.4)	30.7 (1.3)	67.1 (1.3)	61.4 (1.4)	38.1 (1.1)	42.0 (1.2)	32.6 (1.2)
Slow	All	66.5 (2.1)	30.9 (1.3)	66.7 (1.3)	57.5 (1.1)	38.0 (1.2)	39.5 (1.1)	29.4 (1.1)
Eddies	All	69.1 (2.7)	30.6 (1.4)	66.8 (2.3)	65.8 (2.3)	39.4 (1.6)	47.8 (2.5)	32.6 (2.3)
Interstitial	All	-	-	57.3 (5.6)	-	-	-	-
Intermittent	All	-	-	-	-	-	-	-
		F=0.237 P=0.870 NS	**F=0.206 P=0.892 NS**	**F=1.206 P=0.307 NS**	**F=5.843 P>0.001 ***	**F=0.505 P=0.679 NS**	**F=3.568 P=0.014 ***	**F=5.48 P=0.001 ***

Current Velocity Cumulative Score

Outside of rivers, wadeable streams showed higher FIBIs (Table 40) and MIBIs (Table 41) in most stream strata with current scores of 4 (fish) or scores of 3-4 (macroinvertebrates) and generally lower scores with current scores of only 1 in most strata. In most strata, sites with intermittent or interstitial flow (only) were uncommon. These results are consistent with the ecological literature which shows an increase in biodiversity with an increasing diversity of current types (Gorman and Karr 1978).

Table 40. Mean FIBI values (SE) for MSHA current velocity scores. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Current Velocity Score	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
-2	All	-	-	-		-	45.9 (12.9)	
-1	All	-	-	-		-	-	27.0 (7.1)
0	All	-	-	-	-	-	45.4 (3.6)	28.5 (4.2)
1	All	40.8 (8.5)	34.9 (2.1)	36.7 (2.1)	58.3 (5.0)	48.3 (2.4)	38.3 (2.1)	32.9 (2.4)
2	All	50.1 (3.0)	38.1 (1.7)	47.1 (1.6)	61.4 (3.5)	50.3 (1.9)	40.1 (1.7)	41.2 (2.3)
3	All	53.7 (3.0)	48.5 (2.1)	47.1 (2.1)	61.3 (3.8)	58.2 (1.7)	46.6 (2.7)	39.4 (6.5)
4	All	48.7 (2.9)	52.9 (3.1)	53.5 (2.8)	61.4 (3.7)	59.5 (2.7)	50.4 (3.9)	-
		F=1.21 P=0.307 NS	**F=13.637 P<0.001 ***	**F=8.242 P<0.001 ***	**F=.104 P=0.957 NS**	**F=6.36 P<0.001 ***	**F=2.39 P=0.037 ***	**F=2.38 P=0.085 NS**

Table 41. Mean MIBI values (SE) for individual MSHA current velocity scores. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Current Velocity Score	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
-2	All	-	-	55.8 (5.0)	-	-	-	22.0 (3.1)
-1	All	-	-	55.8 (5.0)	44.7 (9.9)	-	-	22.0 (3.1)
0	All	-	-	70.4 (3.5)	55.9 (4.7)	35.1 (1.6)	39.2 (3.0)	32.6 (2.4)
1	All	59.9 (4.9)	36.6 (3.8)	60.8 (3.6)	50.9 (1.6)	25.9 (3.2)	31.4 (1.6)	25.3 (1.4)
2	All	65.5 (4.5)	34.0 (3.6)	64.8 (2.4)	58.7 (1.6)	33.7 (1.6)	40.8 (1.6)	30.6 (1.7)
3	All	64.6 (5.3)	28.6 (1.8)	67.6 (1.9)	70.8 (2.9)	39.4 (1.9)	43.6 (2.1)	37.1 (2.5)
4	All	69.3 (2.6)	30.6 (1.9)	70.6 (2.9)	65.2 (3.4)	40.7 (1.8)	48.1 (3.0)	37.3 (4.2)
		F=0.584 P=0.628 NS	**F=1.256 P=0.297 NS**	**F=1.726 P=0.163 NS**	**F=13.33 P<0.001 ***	**F=5.39 P=0.001 ***	**F=10.26 P<0.001 ***	**F=7.75 P<0.001 ***

Table 42. Theoretical and data-driven “good” and “poor” habitat attributes for the channel metric for fish assemblages in Minnesota rivers and streams. “Good” attributes are those expected to be associated with higher FIBI scores and “poor” attributes are those expected to be associated with lower FIBI scores.

Sub-Metric	*Theoretical Attributes*	*Data Driven Attributes*						
		Southern Rivers (1)	*Southern Streams (2)*	*Southern Headwaters (3)*	*Northern Rivers (4)*	*Northern Streams (5)*	*Northern Headwaters (6)*	*Low Gradient Streams (7)*
Channel Metric								
Good Sinuosity	Excellent	-	Excell.[1] Good[2] Fair[1]	Excell.[1] Good[2] Fair[1]	-	Excell.[2] Good[2] Fair[2]	Excell.[2] Good[2] Fair[1]	Excel2] Good[1]
Poor Sinuosity	Poor	-	Poor[2]	Poor[2]	-	Poor[2]	Poor[2]	Poor[2]
Good Pool Width/Riffle Width	PW>RW	-	PW>RW[2] PW=RW[2]	PW>RW[2]	-	-	PW>RW[1]	PW>RW[1]
Poor Pool Width/Riffle Width	No Riffle, Impounded	-	No Riffle[2]	No Riffle[2]	-	-	No Riffle[1]	No Riffle[1]
Good Channel Development	Excellent	-	Excell.[2] Good[2]	Excell.[.5] Good[2]	-	Excell.[2] Good[1]	Excell.[2] Good[1]	Excell.[.5] Good[2]
Poor Channel Development	Poor	-	Fair[1] Poor[2]	Poor[2]	-	Fair[1] Poor[2]	Fair[1] Poor[2]	Poor[2]
Good Channel Stability	High	High[.5]	-	-	-	High[2]	High[2]	High[.5]
Poor Channel Stability	Poor	Low[.5]	Low[.5]	-	-	Mod.[1] Low[2]	Mod.[2] Low[1]	Low[.5]
Good – Depth Variation	>4X	>4X[.5]	>4X[2]	>4X[2]		>4X[2]	>4X[2]	>4X[2]
Poor – Depth Variation	<2X	<2X[.5]	<2X[2]	<2X[2]		<2X[2]	<2X[2]	<2X[2]
Good – Current Types	Fast, Eddies	-	Fast[1] Eddies[1]	Eddies[.5]		Fast[.5] Eddies[.5]	Fast[.5] Eddies[.5] Interstit.[1]	Fast[.5]
Poor – Current Types	Intermittent	-	Slow[1]	-	-	-	-	-
Good – Current Score	4	-	4[2] 3[2]	4[1] 3[1]		4[1] 3[1]	4[.5]	-
Poor – Current Score	≤1	-	2[1] 1[2]	1[1]	-	2[1] 1[1]	1[.5]	1[1] -1[.5]

Table 43. Theoretical and data-driven "good" and "poor" habitat attributes for the channel metric for macroinvertebrate assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher MIBI scores and "poor" attributes are those expected to be associated with lower MIBI scores.

Sub-Metric	***Theoretical Attributes***	***Data Driven Attributes***						
		Northern Forests Rivers (1)	***Prairie Forest Rivers (2)***	***Northern Streams Riffle-Run (3)***	***Northern Streams Glide-Pool (4)***	***Southern Streams Riffle-Run (5)***	***Southern Streams Glide-Pool (6)***	***Prairie Streams Glide-Pool (7)***
Channel Metric								
Good Sinuosity	Excellent	-	-	Good[1]	Excell.[1] Good[1]	Excell.[2] Good[2]	Excell.[2] Good[1] Fair[1]	Excell.[1] Good[2]
Poor Sinuosity	Poor	-	-	Fair[1] Poor[1]	Poor[1]	Poor[2]	Poor[2]	Fair[1] Poor[2]
Good Pool Width/Riffle Width	PW>RW	-	-	-	-	-	PW=RW[1]	PW>RW[1] PW=RW[1]
Poor Pool Width/Riffle Width	No Riffle, Impounded	-	-	-	-	-	PW>RW[1] No Riffle[1]	No Riffle[1]
Good Channel Development	Excellent	Excell.[.5]	-	Excell.[1]	Excell.[1[Good[1]	Excell.[1[Good[1]	Excell.[.5] Good[1] Fair[1]	Excell.[2] Good[2]
Poor Channel Development	Poor	-	-	-	Poor[1]	Poor[1]	Poor[2]	Poor[2]
Good Channel Stability	High	-	-	High[1]	-	-	Mod.[1]	-
Poor Channel Stability	Poor	-		-	-	-	-	-
Good – Depth Variation	>4X	-	-	-	>4X[1] 2-4X[.5]	>4X[2] 2-4X[1]	>4X[2] 2-4X[1]	>4X[2]
Poor – Depth Variation	<2X	-	-	-	<2X[1]	<2X[2]	<2X[2]	<2X[2]
Good – Current Types	Fast, Eddies	-	-	-	Fast[1] Eddies[1]	-	Eddies[1]	Fast[2]
Poor – Current Types	Intermittent	-	-	-	Slow[1]	-	-	Slow[2]
Good – Current Score	4	-	-	-	4[1] 3[2]	4[1] 3[1]	4[2] 3[2]	4[1] 3[2]
Poor – Current Score	≤1	1[.5]	-	1[.5]	1[2]	1[1]	1[2]	1[2]

Riparian Metric

Riparian zones are integral to stream ecosystems and numerous studies have identified the importance of natural riparian vegetation at multiple spatial scales, although its influence may vary with the relative impact types in a watershed (*e.g.,* agricultural versus urban versus least disturbed, Wang *et al*. 2003). There was little correlation between the riparian metrics scores and the FIBI (Figure 20) or MIBI (Figure 21) for any classification strata. The riparian metric of the MSHA includes a riparian width submetric, a bank erosion submetric and a shade submetric.

Riparian Width

Although there was no relationship between riparian width in rivers and FIBI or MIBI (Tables 44 and 45), there was an association between extensive or wide-to-extensive riparian zones and FIBI and MIBI for most wadeable strata and narrow-to-no riparian zones and low IBI scores (Tables 44 and 45).

Table 44. Mean FIBI values (SE) for average MSHA riparian width attribute. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Average Riparian Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Extensive	All	50.4 (4.7)	49.7 (2.8)	50.0 (3.6)	65.9 (2.3)	57.5 (1.5)	54.3 (1.9)	49.0 (2.5)
Wide	All	52.9 (3.6)	41.2 (2.5)	42.8 (3.0)	58.2 (4.6)	53.4 (2.2)	46.7 (2.2)	40.5 (3.5)
Moderate	All	49.0 (2.4)	44.5 (2.1)	47.6 (1.9)	52.4 (5.0)	52.1 (2.6)	32.0 (2.1)	29.8 (3.0)
Narrow	All	53.7 (5.6)	38.9 (2.3)	42.4 (1.9)	61.5 (6.5)	35.4 (4.7)	28.3 (2.8)	18.2 (2.5)
V. Narrow	All	47.3 (6.5)	40.2 (6.1)	37.4 (3.4)	-	46.7 (2.9)	21.1 (3.1)	15.3 (4.6)
None	All	-	34.7 (1.3)	42.0 (2.4)	-	50.6 (2.3)	44.5 (3.0)	33.8 (4.4)
		F=0.35 P=0.84 NS	**F=1.91 P=0.091 NS**	**F=2.173 P=0.057 NS**	**F=2.429 P=0.07 NS**	**F=4.22 P<0.001 ***	**F=25.27 P<0.001 ***	**F=19.8 P<0.001 ***

Table 45. Mean MIBI values (SE) for average MSHA riparian width attribute. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Average Riparian Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Extensive	All	70.1 (2.4)	32.3 (3.3)	68.2 (1.7)	59.3 (1.4)	43.2 (2.2)	42.3 (2.4)	37.5 (3.1)
Wide	All	60.2 (5.8)	27.9 (3.2)	68.0 (2.2)	55.2 (2.1)	37.9 (1.9)	44.7 (2.4)	36.7 (2.9)
Moderate	All	61.0 (4.1)	32.6 (1.7)	58.3 (3.4)	55.7 (3.5)	36.5 (2.0)	39.5 (1.8)	30.6 (1.8)
Narrow	All	-	27.7 (2.5)	42.8 (5.8)	47.3 (3.8)	30.9 (1.9)	34.8 (1.9)	25.5 (1.4)
V. Narrow	All	-	-	-	54.3 (11.0)	33.5 (6.3)	30.8 (2.7)	21.2 (2.6)
None	All	-	-	-	-	35.1 (1.5)	37.1 (2.6)	32.6 (2.3)
		F=2.28 P=0.11 NS	**F=0.995 P=0.401 NS**	**F=4.376 P<0.001 ***	**F=2.006 P=0.114 NS**	**F=2.58 P=0.028 ***	**F=4.090 P=0.001 ***	**F=6.22 P<0.001 ***

Bank Erosion Submetric

The bank erosion submetric showed little association with the FIBI or MIBI in most of the classification strata (Tables 46 and 47). In fact where results were significant statistically they were somewhat confounding biologically. For fish in the Southern Streams and Headwaters strata the FIBI scores were low where there was no erosion. This can occur where a heavily grassed bank shows little active erosion, even though very large storms can occasion cause bank failures in such reaches. There was little association between bank erosion and the MIBI (Table 47).

Table 46. Mean FIBI values (SE) for individual MSHA bank erosion score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Erosion Score	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Severe [0]	All	50.3 (1.7)	38.0 (1.3)	33.2 (1.8)	-	-	-	-
Heavy [1]	All	52.7 (3.8)	43.5 (4.2)	30.2 (6.9)	-	51.1 (6.0)	40.1 (5.7)	-
Moderate [3]	All	46.3 (3.1)	46.2 (3.1)	50.2 (3.0)	64.0 (5.8)	52.7 (2.9)	41.6 (5.1)	22.5 (6.5)
Little [4]	All	51.6 (4.0)	46.1 (1.9)	46.2 (1.9)	65.5 (3.3)	54.8 (1.7)	46.8 (2.7)	39.3 (3.5)
None [5]	All	56.0 (5.1)	35.5 (2.5)	36.2 (2.2)	64.5 (2.7)	57.4 (1.7)	42.5 (1.6)	36.4 (2.0)
		F=1.55 P=0.191 NS	**F=2.785 P=0.027 ***	**F=7.111 P<0.001 ***	**F=0.036 P=0.964 NS**	**F=1.16 P=0.325 NS**	**F=0.789 P=0.501 NS**	**F=1.49 P=0.227 NS**

Table 47. Mean MIBI values (SE) for MSHA bank erosion score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Erosion Score	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Severe	All	-	39.9 (2.7)	-	-	-	-	32.9 (2.4)
Heavy	All	-	29.7 (3.1)	76.0 (6.1)	-	39.2 (3.7)	42.4 (2.5)	37.6 (3.4)
Moderate	All	55.8 (5.6)	30.7 (2.6)	66.8 (5.0)	70.0 (3.2)	38.1 (2.0)	44.0 (3.1)	33.7 (3.2)
Little	All	67.5 (3.6)	31.0 (1.6)	62.8 (2.3)	58.8 (2.0)	36.2 (1.7)	40.9 (1.6)	30.6 (1.7)
None	All	68.0 (2.9)	31.3 (6.0)	67.4 (1.6)	55.0 (1.4)	37.6 (2.4)	36.4 (1.6)	27.3 (1.4)
		F=1.609 P=0.211 NS	**F=0.19 P=0.94 NS**	**F=1.537 P=0.207 NS**	**F=7.977 P<0.001 ***	**F=0.521 P=0.72 NS**	**F=2.29 P=0.078 NS**	**F=2.34 P<0.055 NS**

Stream Shade

Unlike bank erosion, the amount of shade showed some association with the FIBI and MIBI scores (Tables 48 and 49). For fish assemblages Southern and Northern Streams and Southern Rivers had lower FIBI scores when shade was absent or light and higher FIBI scores with moderate or substantial shade. For macroinvertebrates a similar pattern occurred in Southern Streams (Riffle/Run and Glide Pool) and for Prairie Glide/Pool streams (Table 49). Thus shading was more of an issue in Southern Streams where stream modifications were more prevalent and temperatures generally higher; in such cases lack of shade may be a surrogate for channelization.

Table 48. Mean FIBI values (SE) for individual MSHA shade score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Shade Score	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
None [0]	All	50.0 (1.8)	37.3 (1.2)	33.4 (1.7)	-	48.6 (1.8)	39.0 (2.1)	23.1 (2.7)
Light [1]	All	47.4 (2.4)	37.0 (1.7)	39.3 (2.4)	63.3 (2.9)	52.8 (2.0)	39.6 (2.5)	38.1 (2.3)
Moderate [2]	All	58.6 (3.3)	51.3 (2.6)	43.5 (2.9)	64.5 (3.1)	59.3 (1.9)	48.2 (2.5)	39.1 (3.3)
Substantial [4]	All	50.1 (6.8)	51.2 (3.7)	46.9 (2.3)	56.3 (7.8)	56.4 (2.5)	49.3 (2.3)	41.5 (6.3)
Heavy [5]	All	-	40.0 (5.9)	40.2 (4.2)	-	56.2 (2.0)	35.6 (3.3)	29.3 (7.7)
		F=4.799 P=0.004 *	**F=8.65 P<0.001 ***	**F=1.29 P=0.272 NS**	**F=0.50 P=0.609 NS**	**F=4.107 P=0.003 ***	**F=4.249 P=0.002 ***	**F=1.89 P=0.113 NS**

Table 49. Mean MIBI values (SE) for MSHA shade score. Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Shade Score	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
None	All	-	35.2 (3.0)	-	57.4 (4.0)	32.5 (1.3)	34.4 (1.8)	27.8 (1.4)
Light	All	65.7 (3.1)	29.6 (1.6)	67.2 (2.4)	54.0 (1.8)	31.3 (1.4)	35.5 (1.4)	27.7 (1.2)
Moderate	All	64.1 (2.8)	31.8 (1.6)	69.9 (2.1)	57.9 (1.8)	40.3 (1.5)	42.8 (1.7)	29.8 (1.6)
Substantial	All	-	35.1 (2.8)	61.4 (2.4)	56.8 (2.9)	38.1 (1.5)	44.0 (2.7)	32.9 (2.6)
Heavy	All	-	-	57.6 (2.8)	56.6 (3.9)	37.6 (2.4)	40.7 (2.8)	35.5 (4.2)
		F=0.04 P=0.841 NS	**F=1.38 P=0.34 NS**	**F=3.449 P=0.018 ***	**F=0.694 P=0.56 NS**	**F=7.85 P<0.001 ***	**F=6.47 P<0.001 ***	**F=3.001 P=0.019 ***

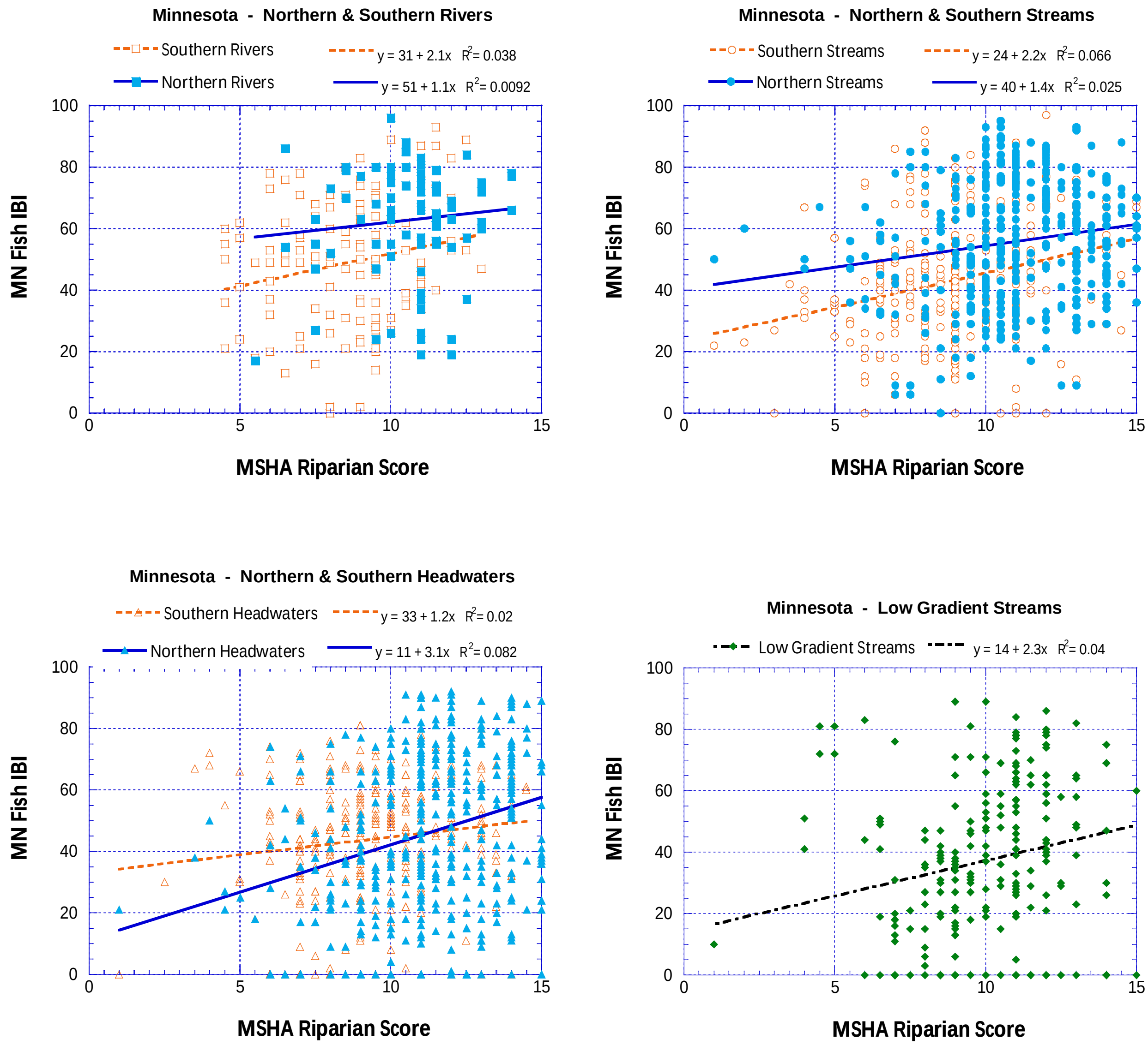

Figure 20. Plots of Fish IBI versus MSHA riparian score for Minnesota Northern and Southern rivers (top left), streams (top right), headwaters (bottom left) and statewide for low gradient streams (bottom right).

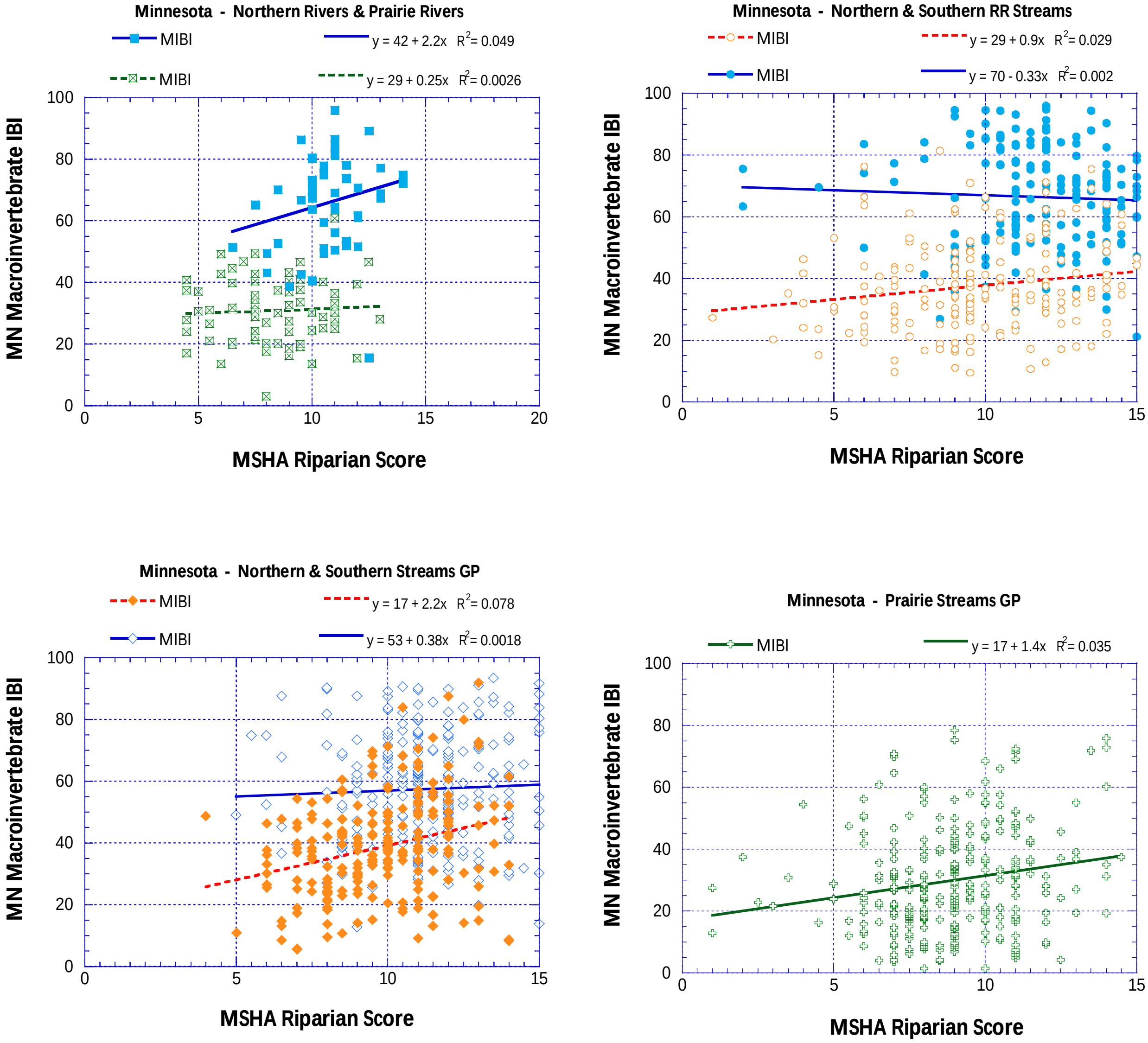

Figure 21. Plots of MIBI versus MSHA riparian score for Minnesota Northern and Prairie rivers (top left), Northern and Southern Riffle/Run streams (top right), Northern and Southern Glide/Pool streams (bottom left) and Prairie Glide/Pool streams (bottom right).

Table 50. Theoretical and data-driven "good" and "poor" habitat attributes for the riparian metric for fish assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher FIBI scores and "poor" attributes are those expected to be associated with lower FIBI scores.

Sub-Metric	***Theoretical Attributes***	***Data Driven Attributes***						
		Southern Rivers (1)	***Southern Streams (2)***	***Southern Headwaters (3)***	***Northern Rivers (4)***	***Northern Streams (5)***	***Northern Headwaters (6)***	***Low Gradient Streams (7)***
Riparian Metric								
Good Riparian Width	Extensive, Wide	-	Extens.[.5]	Extens.[.5]	Extens.[.5]	Extens.[1] Wide[1]	Wide[2] Extens.[2]	Wide[2] Extens.[2]
Good Riparian Width	None	-	None[.5]	V. Narrow[.5] None[.5]	-	Narrow[1] V. Narrow[1] None[1]	Mod.[2] Narrow[2] V. Narrow[2] None[2]	Mod.[1] Narrow[2] V. Narrow[2] None[1]
Good Bank Erosion	Little, None	-	-	-	-	None[.5]	-	-
Poor Bank Erosion	Heavy, Severe	-	None[.5]	Severe[.5] Heavy[.5] None[.5]	-	-	-	-
Good Shade	Substantial, Heavy	Mod.[1]	Mod.[2] Subst.[1]	Subst.[.5]	-	Mod.[1] Subst.[1] Heavy[1]	Mod.[.5] Subst.[1]	-
Poor Shade	Light, None	None[1] Light[1]	None[2] Light[2]	None[.5]	-	None[1]	None[.5] Light[.5]	None[.5] Subst.[.5]

Table 51. Theoretical and data-driven "good" and "poor" habitat attributes for the riparian metric for macroinvertebrate assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher MIBI scores and "poor" attributes are those expected to be associated with lower MIBI scores.

Sub-Metric	*Theoretical Attributes*	*Data Driven Attributes*						
		Northern Forests Rivers (1)	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Poo (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Riparian Metric								
Good Riparian Width	Extensive, Wide	Extens.[.5]	-	Extens.[1] Wide[1]	-	Extens.[1]	Extens.[.5] Wide[1]	Extens.[2] Wide[1]
Good Riparian Width	None	-	-	Narrow[1]	Narrow[.5] V. Narrow[.5]	Narrow[1] V. Narrow[.5] None[.5]	Narrow[1] V. Narrow[1] None[.5]	Narrow[1] V. Narrow[2] None[.5]
Good Bank Erosion	Little, None	-	-	-	Mod.[2]	-	-	-
Poor Bank Erosion	Heavy, Severe	Mod.[.5]	-	-	-	-	-	-
Good Shade	Substantial, Heavy	-	-	-	-	Mod.[1] Subst[1] Heavy[1]	Mod.[1] Subst[1] Heavy[1]	Subst[.5] Heavy[.5]
Poor Shade	Light, None	-	-	Heavy[1]	-	None[2] Light[2]	None[2] Light[1]	None[.5] Light[.5]

Land Use

Land use in a watershed has been shown in a wide number of studies to have influence on aquatic assemblages related most often to polluted runoff and changes to hydrology compared to natural land cover types (*e.g.,* Wang et al. 1997, Allan 2004). Correlations between the overall metric score and the FIBI or MIBI scores were weak for most classification strata (Figures 22-23). For fish assemblages in most classification strata the occurrence of natural land uses was most often associated with higher FIBI and MIBI scores and row crop was most often associated with lower FIBI and MIBI scores (Tables 52 and 53). Certain land uses were purposely unrepresented in the data set to exclude impacts likely to confound the effects of habitat (*e.g.,* urban). We saw a similar pattern for most classification strata for macroinvertebrates except for Northern and Prairie Rivers and Northern Glide/Pool Streams (Table 53). Attributes selected as good and poor habitat attributes are summarized in Tables 54 and 55.

Table 52. Mean FIBI values (SE) for individual MSHA land use types (attributes). Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Southern Rivers*	*Southern Streams*	*Southern Headwaters*	*Northern Rivers*	*Northern Streams*	*Northern Headwaters*	*Low Gradient Streams*
Natural	All	56.1 (3.0)	50.1 (2.4)	46.3 (3.1)	64.5 (2.2)	58.3 (1.2)	49.6 (1.5)	44.8 (1.9)
Old Field	All	-	32.2 (10.1)	39.5 (4.9)	-	58.1 (3.0)	34.9 (3.4)	37.7 (5.0)
Pasture	All	-	36.6 (7.9)	46.5 (7.3)	-	65.2 (4.0)	33.9 (6.4)	-
No Till	All	-	-	-	-	-	43.6 (7.0)	29.3 (7.4)
Park	All	-	-	47.1 (5.7)	-	56.3 (3.3)	31.7 (4.6)	21.9 (4.9)
Urban	All	-	-	-	-	-	49.4 (6.2)	-
Row Crop	All	48.3 (2.1)	41.8 (1.6)	43.0 (1.4)	59.6 (6.1)	42.4 (2.1)	30.0 (2.2)	24.7 (2.5)
		F=4..478 P=0.036 *	**F=3.25 P=0.022 ***	**F=0.574 P=0.681 NS**	**F=0.527 P=0.47 NS**	**F=10.56 P<0.001 ***	**F=12.023 P<0.001 ***	**F=9.69 P<0.001 ***

Table 53. Mean MIBI values (SE) for individual MSHA land use types (attributes). Attributes with <5 samples are not included. Highest values are highlighted in blue (+) or red (-). Darker shades are significant (Tukey) and light shades are near significant and biologically meaningful. ANOVA results are at bottom. Tests with asterisks are significant at P<0.05 were followed with a Tukey multiple comparison test.

Attribute	*Reach Type*	*Northern Forests Rivers (1)*	*Prairie Forest Rivers (2)*	*Northern Streams Riffle-Run (3)*	*Northern Streams Glide-Pool (4)*	*Southern Streams Riffle-Run (5)*	*Southern Streams Glide-Pool (6)*	*Prairie Streams Glide-Pool (7)*
Natural	All	66.3 (2.2)	31.3 (2.1)	67.4 (1.3)	57.7 (1.1)	44.7 (1.6)	45.5 (1.6)	38.6 (2.2)
Old Field	All	-	-	67.0 (2.8)	58.2 (2.8)	42.2 (5.0)	41.7 (4.1)	37.5 (6.8)
Pasture	All	-	-	68.4 (3.6)	59.2 (8.7)	36.4 (6.0)	37.3 (5.7)	-
No Till	All	-	-	-	-	-	-	37.5 (4.7)
Park	All	-	-	60.9 (4.8)	52.6 (4.2)	48.2 (5.1)	44.2 (3.1)	-
Urban	All	-	-	-	-)	-	45.6 (5.0)	20.7 (3.8)
Row Crop	All	-	30.3 (1.4)	48.7 (3.5)	50.3 (3.7)	33.8 (1.2)	36.7 (1.2)	28.1 (1.0)
		-	**F=0.161 P=0.689 NS**	**F=4.958 P<0.001 ***	**F=1.019 P=0.397 NS**	**F=8.345 P<0.001 ***	**F=4.40 P<0.001 ***	**F=7.946 P<0.001 ***

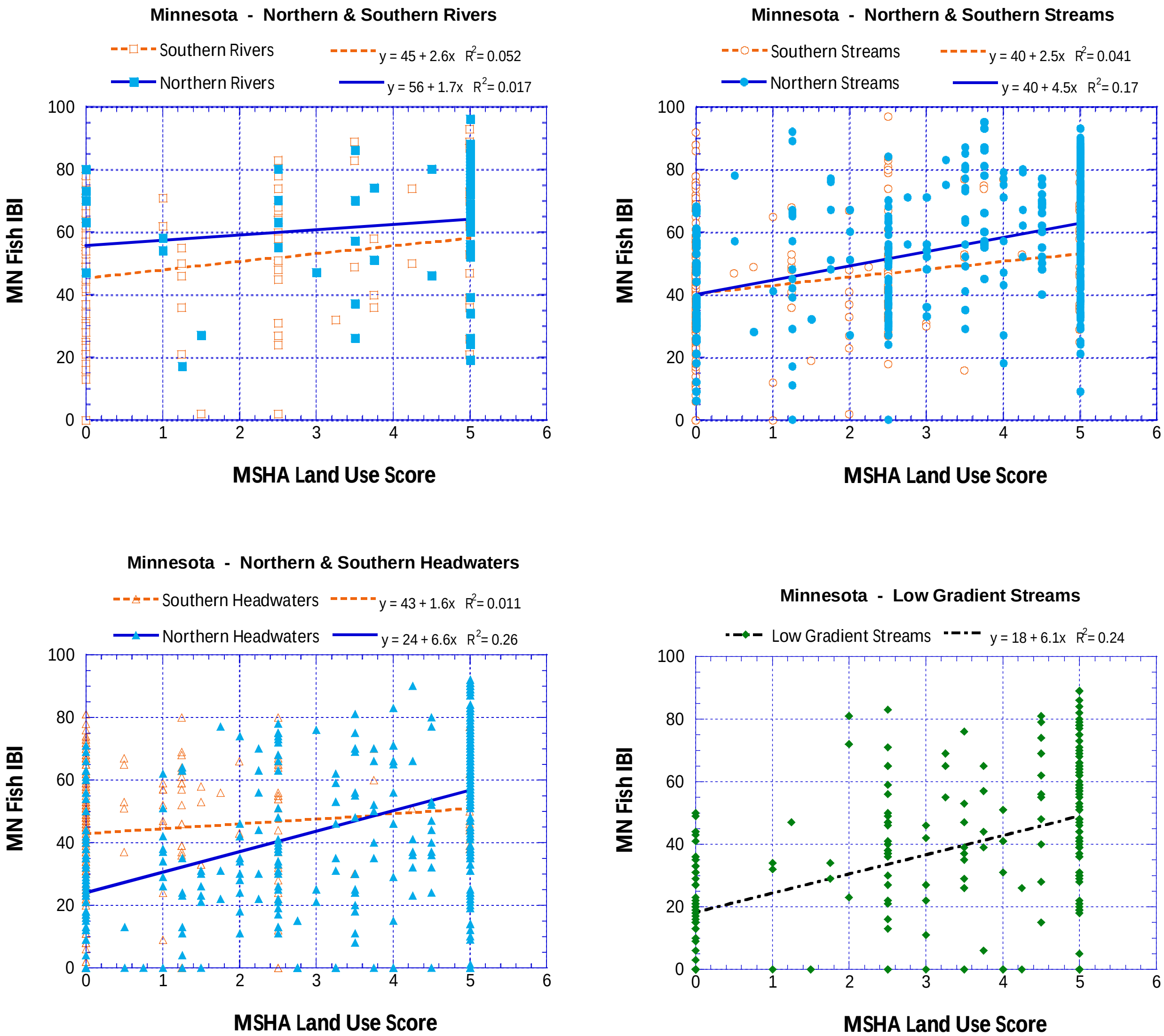

Figure 22. Plots of Fish IBI scores versus MSHA riparian score separately for Minnesota Northern and Southern rivers (top left), streams (top right), headwaters (bottom left) and statewide for low gradient streams (bottom right).

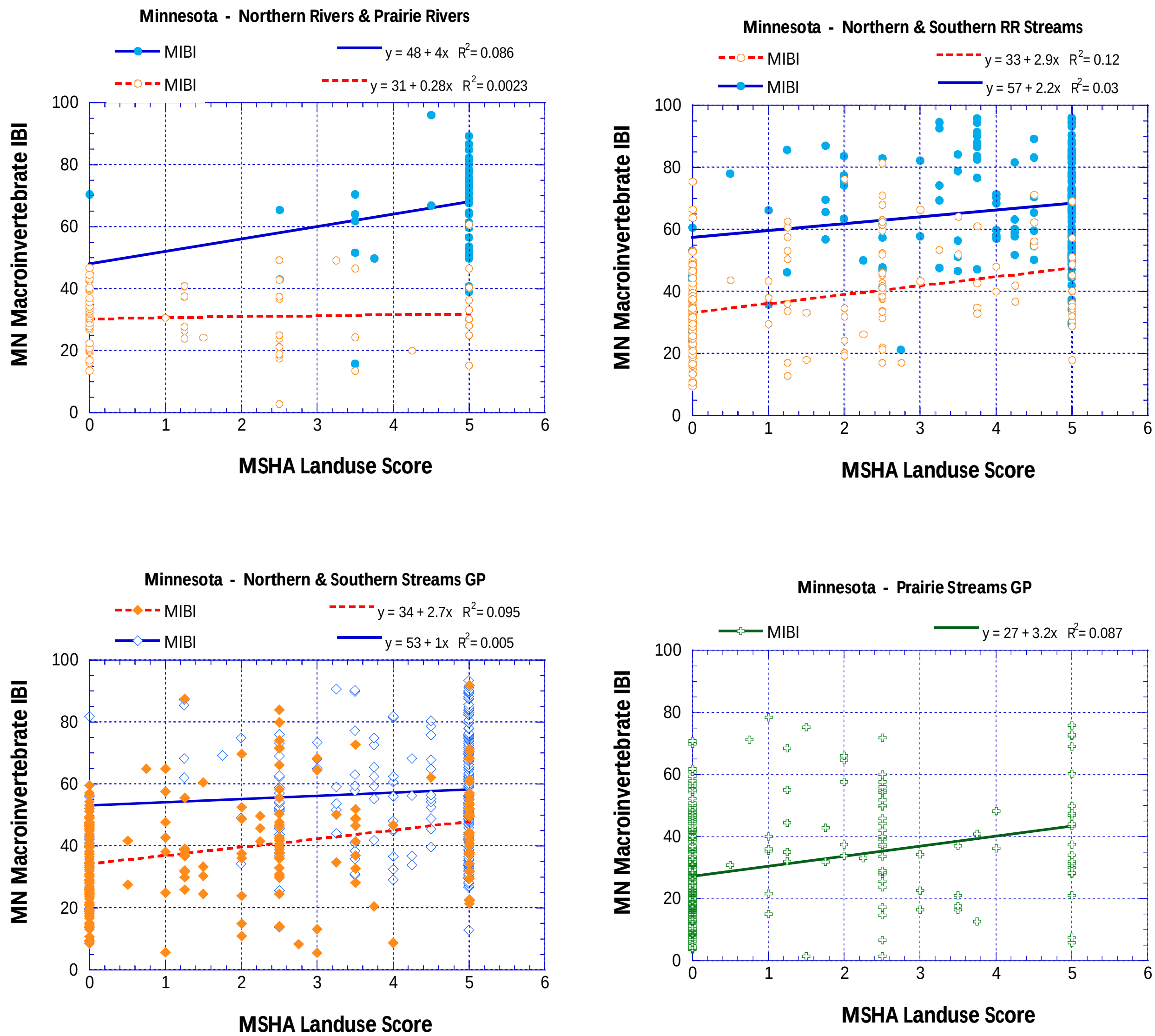

Figure 23. Plots of MIBI scores versus MSHA riparian score separately for Minnesota Northern and Prairie rivers (top left), Northern and Southern Riffle/Run streams (top right), Northern and Southern Glide/Pool streams (bottom left) and Prairie Glide/Pool streams (bottom right).

Table 54. Theoretical and data-driven "good" and "poor" habitat attributes for the land use metric for fish assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher FIBI scores and "poor" attributes are those expected to be associated with lower FIBI scores.

Sub-Metric	***Theoretical Attributes***	***Data Driven Attributes***						
		Southern Rivers (1)	***Southern Streams (2)***	***Southern Headwater (3)***	***Northern Rivers (4)***	***Northern Streams (5)***	***Northern Headwaters (6)***	***Low Gradient Streams (7)***
Land Use Metric								
Good Land uses	Natural	Natural[1]	Natural[1]	-	-	Natural2] Old Field[1] Park[1] Pasture[.5]	Natural[2] No Till[.5]	Natural[2] Old Field[1]
Poor Land Uses	Urban, Row crop	Row crop[1]	Row crop[1]	-	-	Row crop[2]	Row crop[2]	Row crop[2]

Table 55. Theoretical and data-driven "good" and "poor" habitat attributes for the land use metric for macroinvertebrate assemblages in Minnesota rivers and streams. "Good" attributes are those expected to be associated with higher MIBI scores and "poor" attributes are those expected to be associated with lower MIBI scores.

Sub-Metric	***Theoretical Attributes***	***Data Driven Attributes***						
		Northern Forests Rivers (1)	***Prairie Forest Rivers (2)***	***Northern Streams Riffle-Run (3)***	***Northern Streams Glide-Pool (4)***	***Southern Streams Riffle-Run (5)***	***Southern Streams Glide-Pool (6)***	***Prairie Streams Glide-Pool (7)***
Land Use Metric								
Good Land uses	Natural	-	-	Natural[2], Old Field[1] Pasture[1]	-	Natural[2], Old Field[.5] Park[.5]	Natural[2] Park[.5]	Natural[2], Old Field[.5] No Till[.5]
Poor Land Uses	Urban, Row crop	-	-	Row crop[2]	Row crop[.5]	Row crop[2]	Row crop[2]	Row crop[2]

Sources of Variation in the MSHA-FIBI Relationship

Compared to correlations of a similar nature conducted in Ohio (**Error! Reference source not found.**, left), even though the trend of association between MSHA and the FIBI was positive, there was substantial variation in the relationship (**Error! Reference source not found.**, right). Of particular interest are situations where habitat is relatively poor (MSHA scores < 45) and biological performance would be attaining the threshold criteria for a region (Southern Streams = 43) (red boxed area of **Error! Reference source not found.**, right). In Ohio's Ohio River basin, a relationship among similar sized streams shows many fewer outliers (*i.e.,* good biology) at sites with poor habitat (**Error! Reference source not found.**, left). The importance of resolving the cause of these outliers is important because it affects the ease and accuracy of assigning a "modified" stream classification as was done for Ohio streams.

There are a number of possible explanations for the outliers in **Error! Reference source not found.**, right:

1) *Stream Temperature and/or Stream Flow*. Data from Ohio in the upper Great Miami River (Ohio EPA 2011) showed that sites with enhanced base flow were significantly more likely to attain their Warmwater (WWH) aquatic life use than sites without such flow, even when streams had been channelized. Streams with enhanced flows had more cool water fish and macroinvertebrate taxa, less variability in stream temperature, lower nutrients and higher dissolved oxygen levels than streams without enhanced flow (Ohio EPA 2011). The cooler temperatures are hypothesized to slow or minimize the effects of increased nutrients and maintain higher dissolved oxygen levels. These conditions would be important during typical summer "bottlenecks" of stress than can occur when temperatures and nutrients are high which can result in lower dissolved oxygen. In addition, higher flow rates can act to sweep riffle features free of silts and fine sediments. Finally, in small streams, risk of desiccation is lower where summer flows are more permanent.
2) Scale of Habitat Degradation. Streams are "open" systems and the biota that occurs at a site is a product of habitat conditions upstream and downstream of a reach in addition to habitat conditions within a reach. Outliers where habitat is poor and FIBI scores are good could be a

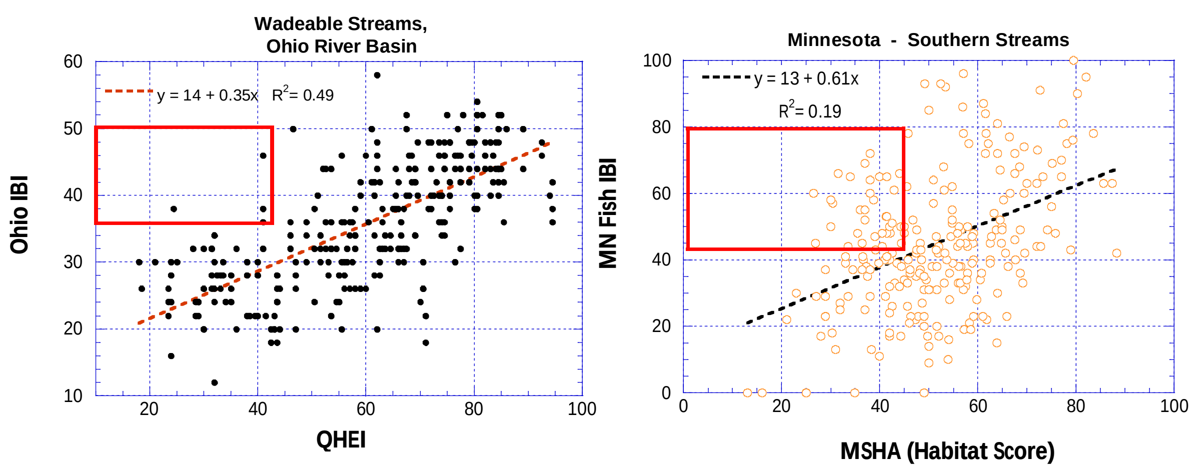

Figure 24. Scatter plots of QHEI versus Ohio wadeable Fish IBI scores (left) and MSHA Total Score versus MN Fish IBI scores in Minnesota Southern Streams. Red boxes encompass sites where sites achieve good biological conditions at sites with poor habitat.

result of nearby good habitats “propping” up assemblages in short habitat-degraded segments.

Correlation between Habitat Metrics

Many habitat features tend to co-occur, so an assessment of correlations between habitat metrics can be important to understand the possible mechanism of habitat effects on aquatic assemblages and individual species. This in turn can be useful when determining whether habitat limitations are feasibly restorable. The figures in this section depict correlations between individual major metrics and the final MSHA score. We also present similar correlations between metrics of the QHEI for the Lake Erie basin of Ohio to explore whether correlations differ among these regions.

The correlation between each individual metric and the total MSHA score is obviously dependent on the weighting of each metric towards the total score. The Land Use metric only comprises 5 points of the total score and is uncorrelated with other metrics other than the riparian metric (Figure 25) suggesting local land use does not limit or strongly influence other habitat attributes. This metric is correlated with the riparian metric because it reflects land use adjacent to the stream which is often a continuation of land uses further from the stream. The lack of a strong correlation between land use and stream habitat is important because it demonstrates that a land use type does not necessarily limit habitat quality in a stream. A heavily agricultural watershed can be comprised of streams with high quality habitats including MSHA scores that approach the maximum observed in Minnesota.

Unlike the Land Use metric, the Riparian metric does show a significant, but weak correlation and a threshold response to other MSHA metrics. The best performance of the substrate, cover and channel metrics only occur at sites with the best performing riparian metric scores (Figure 26). This pattern is similar to what was observed in Ohio with the QHEI (Figure 27). This association is likely related to the ability of intact riparian areas to reduce inputs of fines, reduce, bank erosion, provide high quality woody debris for cover, and allow evolution of channel form to enhance riffle/run/pool features. The substrate metric was not correlated with the cover metric, but did show a significant, but somewhat variable correlation and threshold response with the channel metric (Figure 28). Sites with low substrate scores generally also had only moderate or low channel scores. This may be attributable to more bank erosion in streams with modified or stressed channels and the accumulation of fines in entrenched channels. The Ohio data show similar correlations (Figure 29) although there was a weak correlation between substrate scores and cover scores perhaps related to sites where boulders are a characteristic substrate and cover type.

The cover score is only weakly correlated with the channel scores with a threshold evident at sites with low cover scores (*i.e.,* lack of association with sites with good channel conditions). Sites with stable, natural channel features are more likely to have good-excellent cover (Figure 30) and good-excellent substrate conditions (Figure 30). The channel metric comprises the largest component of the MSHA (36 of 100 points) and is, as expected most strongly correlated ($r^2 = 0.80$) with the total MSHA score. The channel metric of the QHEI is similarly correlated ($r^2 = 0.83$) with the total QHEI (Figure 31) even though it comprises only 20% of the potential scoring of the QHEI (20 of 100). Overall, the MSHA shows similar correlations between its component metrics as does QHEI. The process used elsewhere in this document to identify strong "positive" and "negative" habitat attributes is designed to extract those features that may be most limiting or most associated with aquatic life indicators.

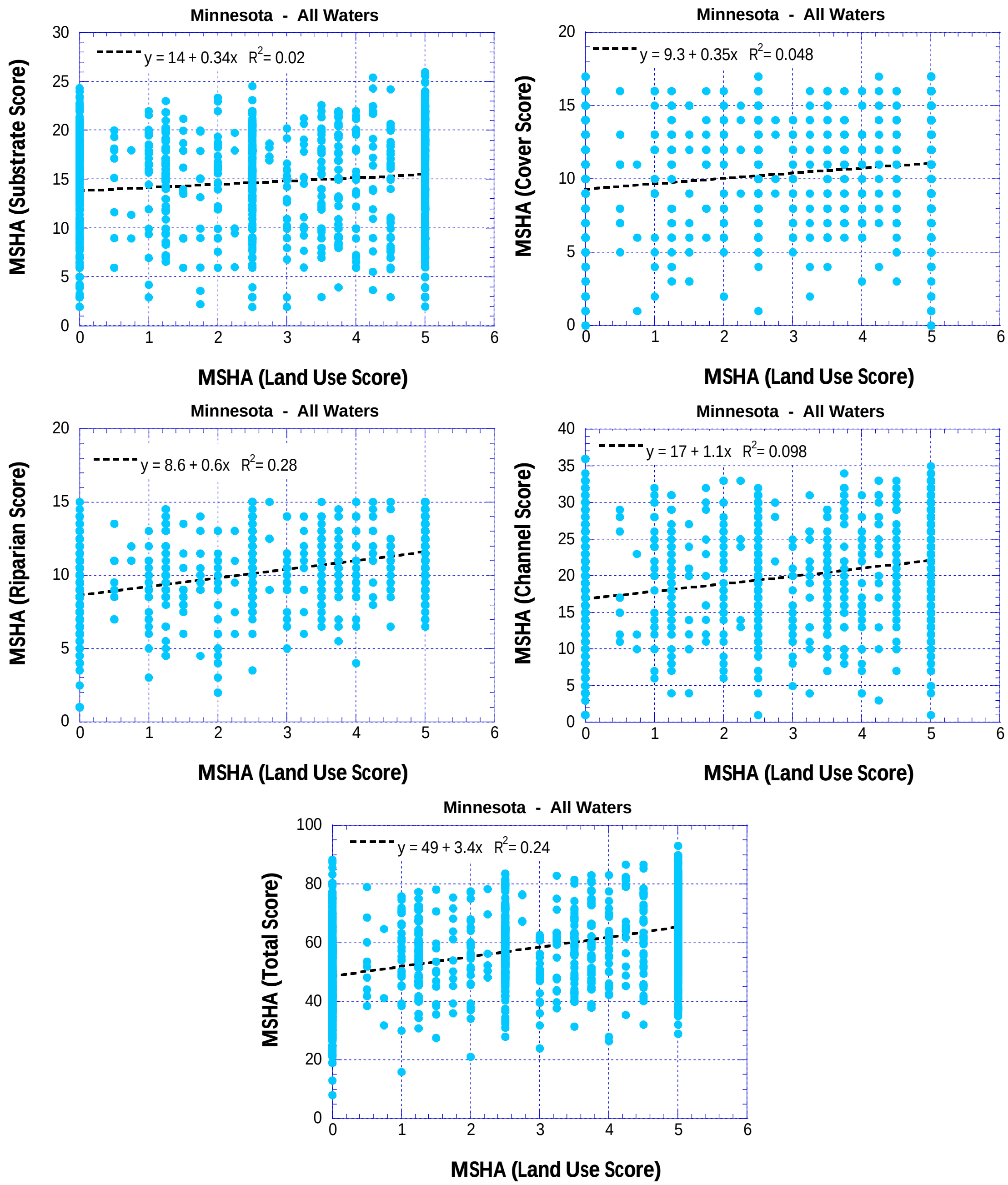

Figure 25. Correlations between the MSHA land use score and other MSHA metrics and the MSHA total score. All regions combined.

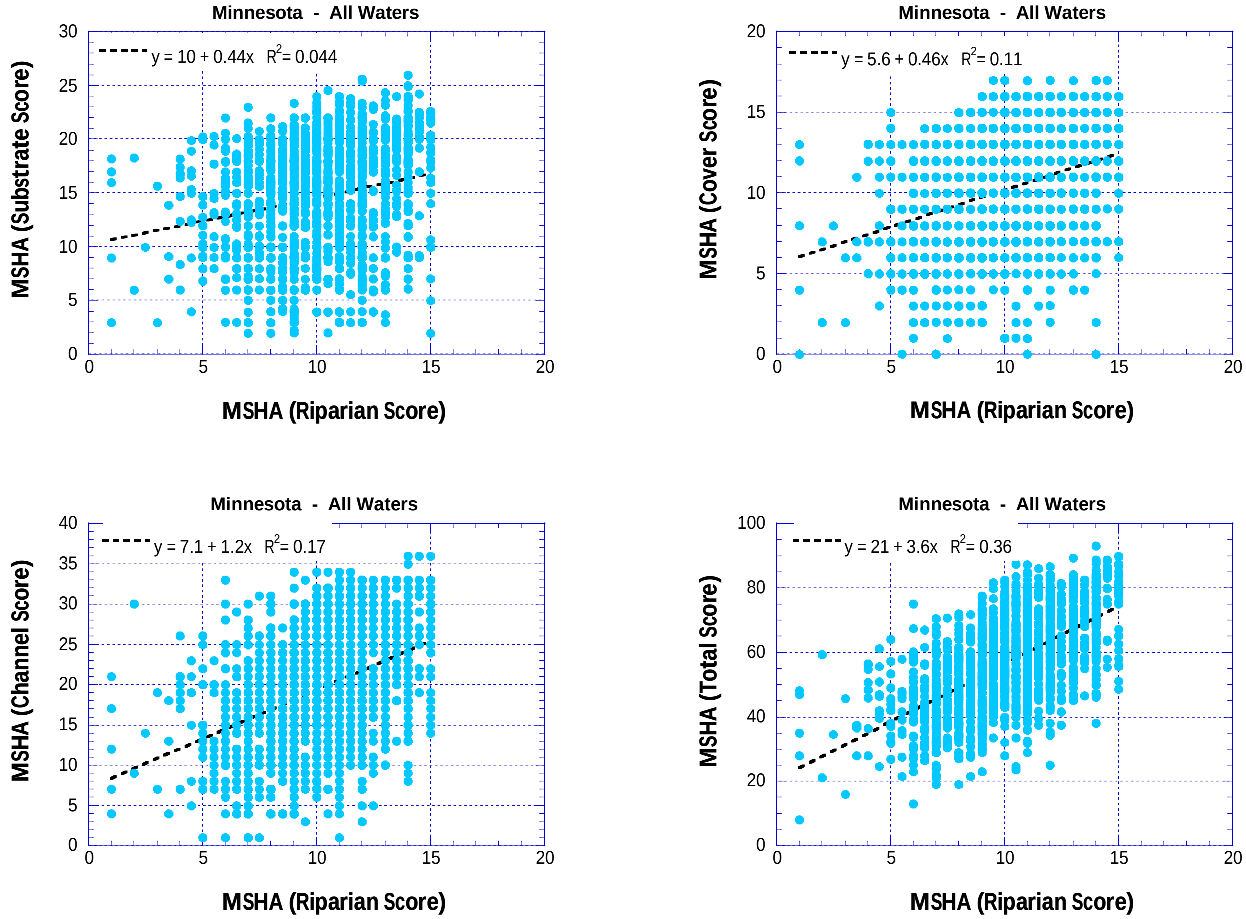

Figure 26. Correlations between the MSHA riparian score and other MSHA metrics and the MSHA total score. All regions combined.

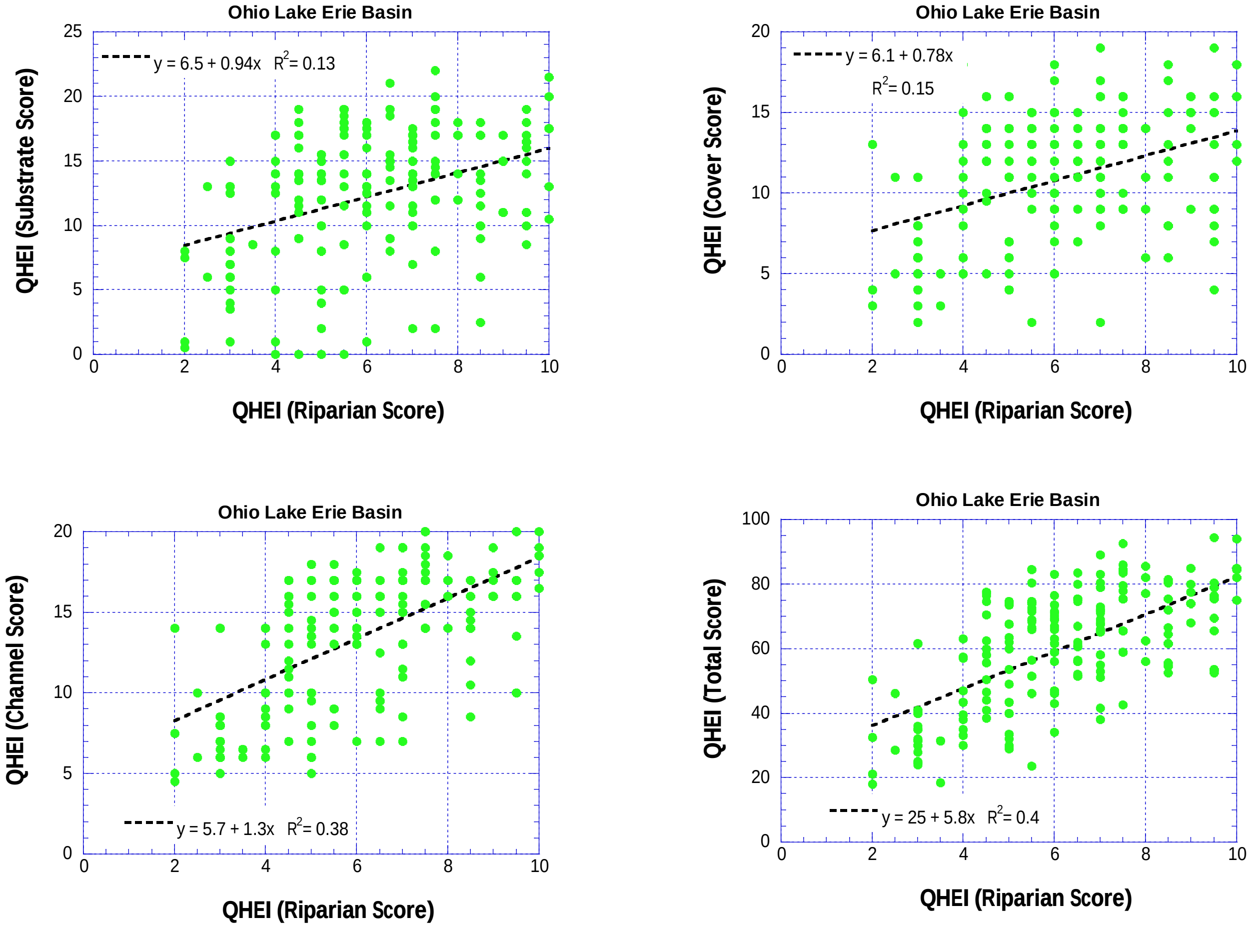

Figure 27. Correlations between the QHEI riparian score and other QHEI metrics and the QHEI total score. All regions combined.

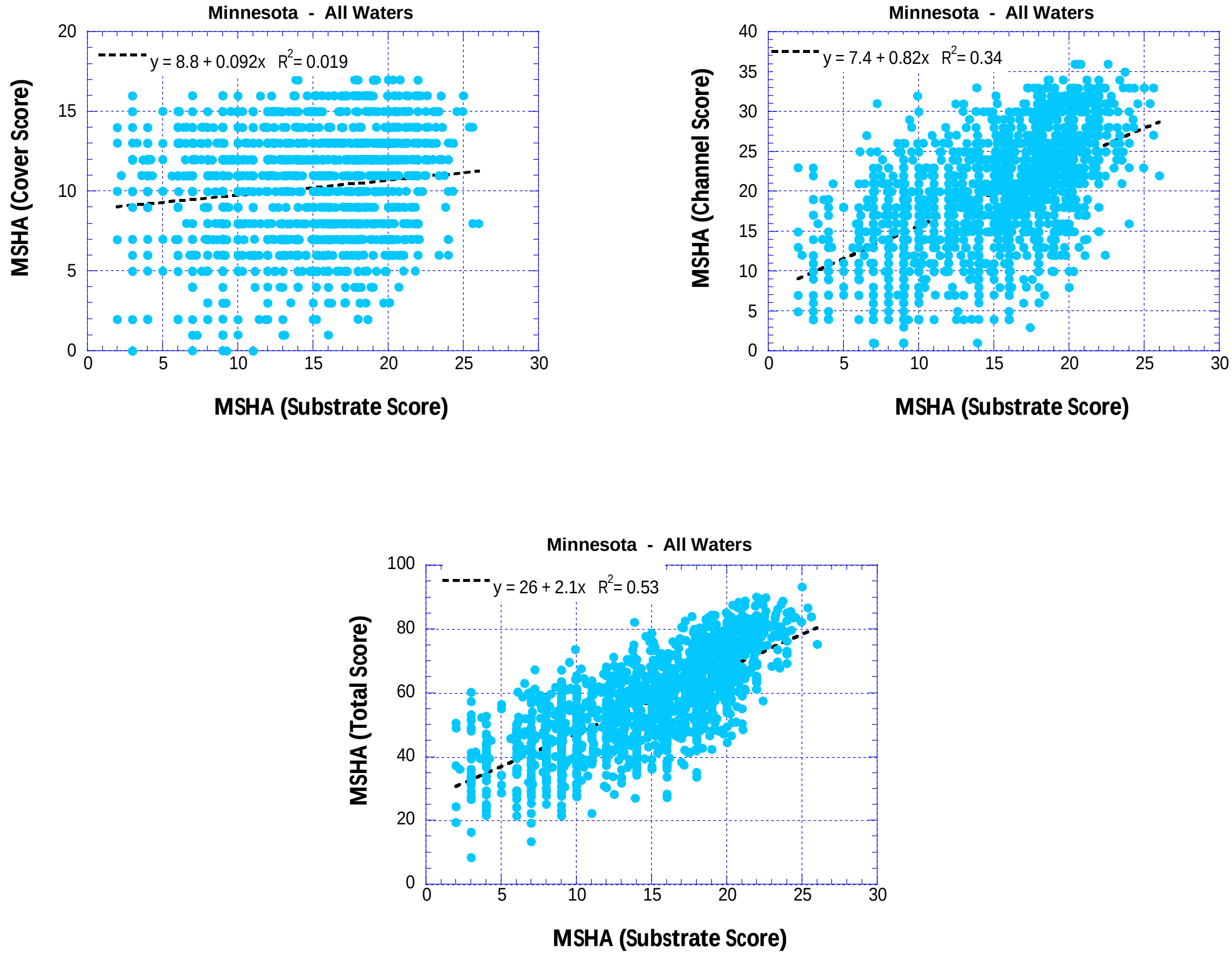

Figure 28. Correlations between the MSHA substrate score and other MSHA metrics and the MSHA total score.

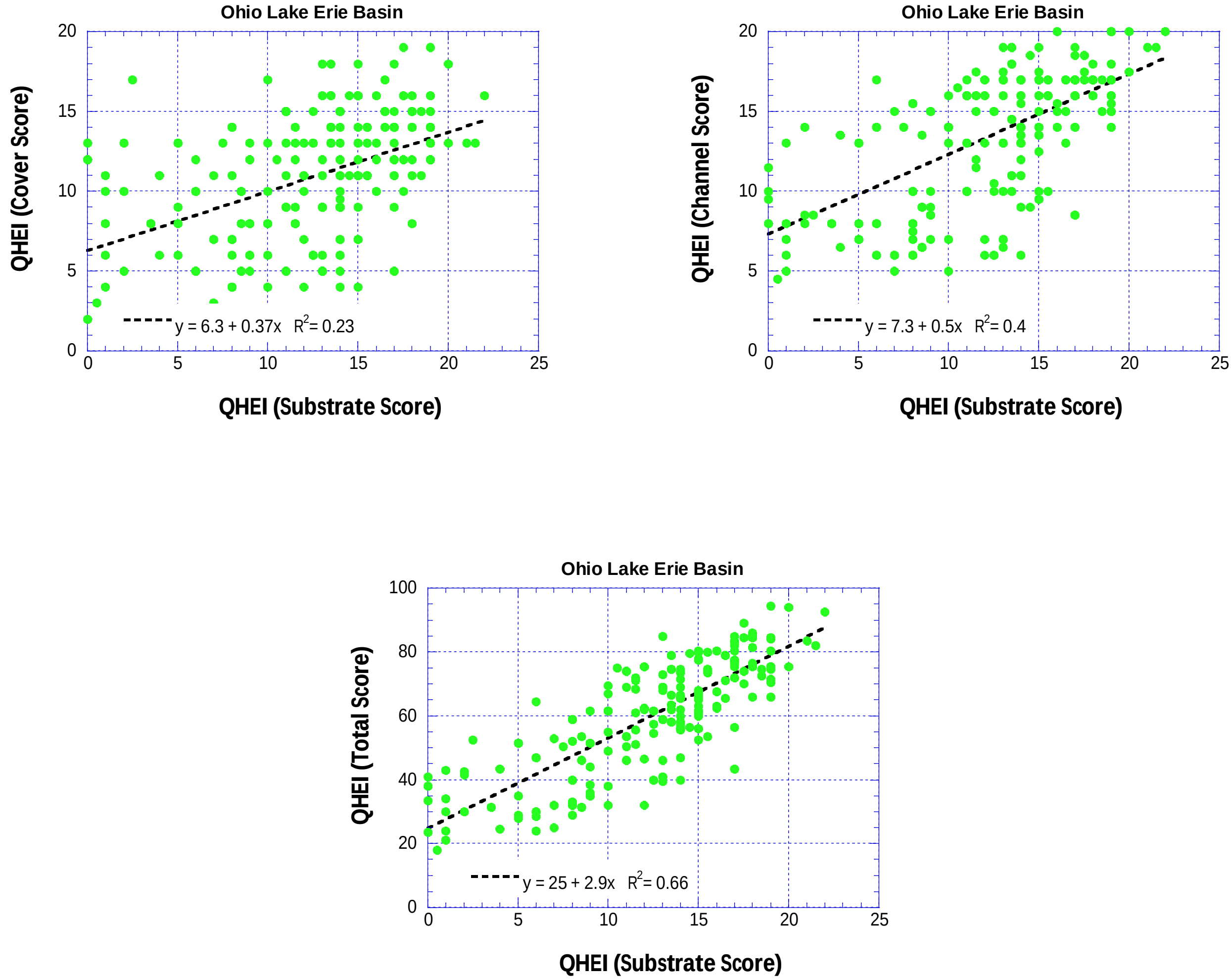

Figure 29. Correlations between the QHEI substrate score and other QHEI metrics and the QHEI total score for Ohio streams of the Lake Erie basin

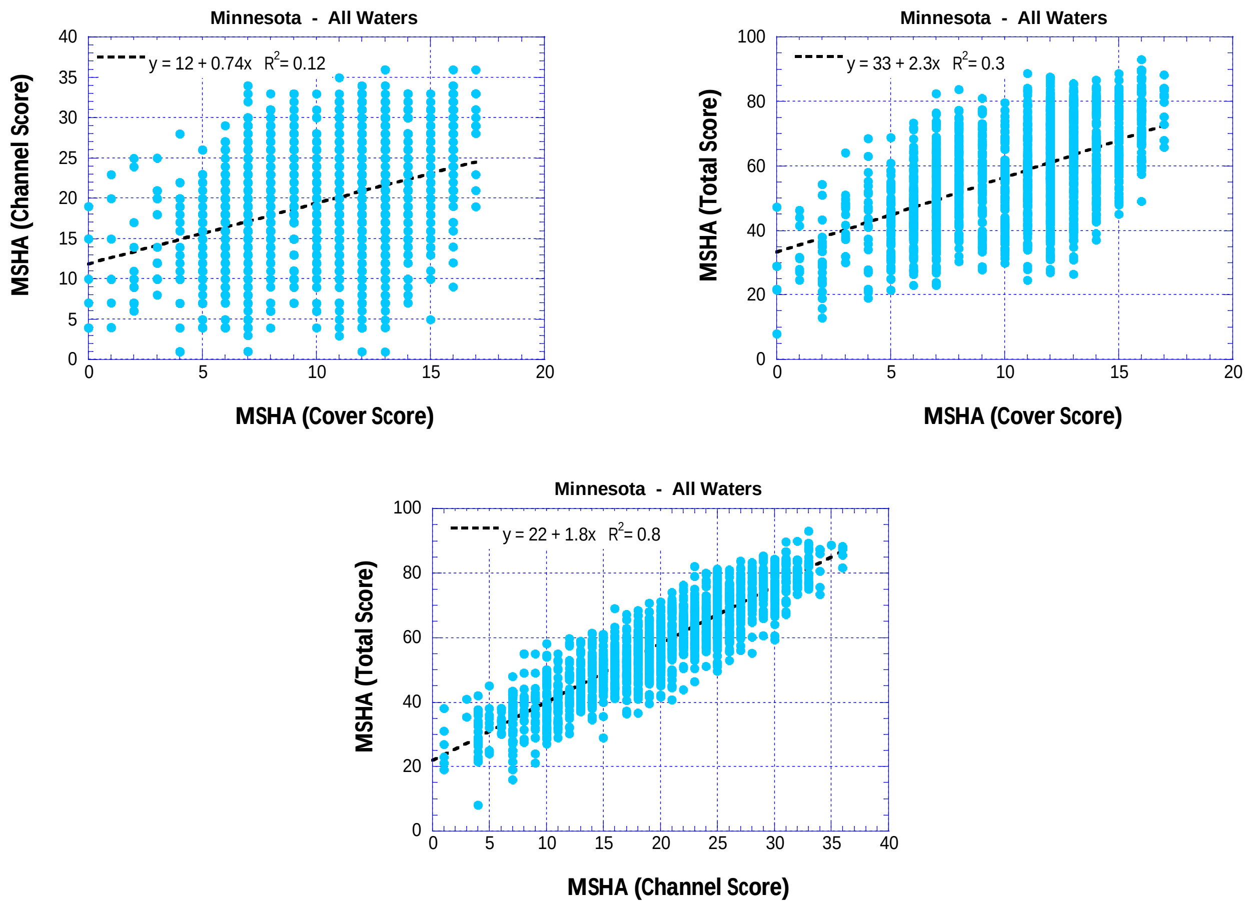

Figure 30. Correlations between the MSHA channel score and other MSHA metrics and the MSHA total score.

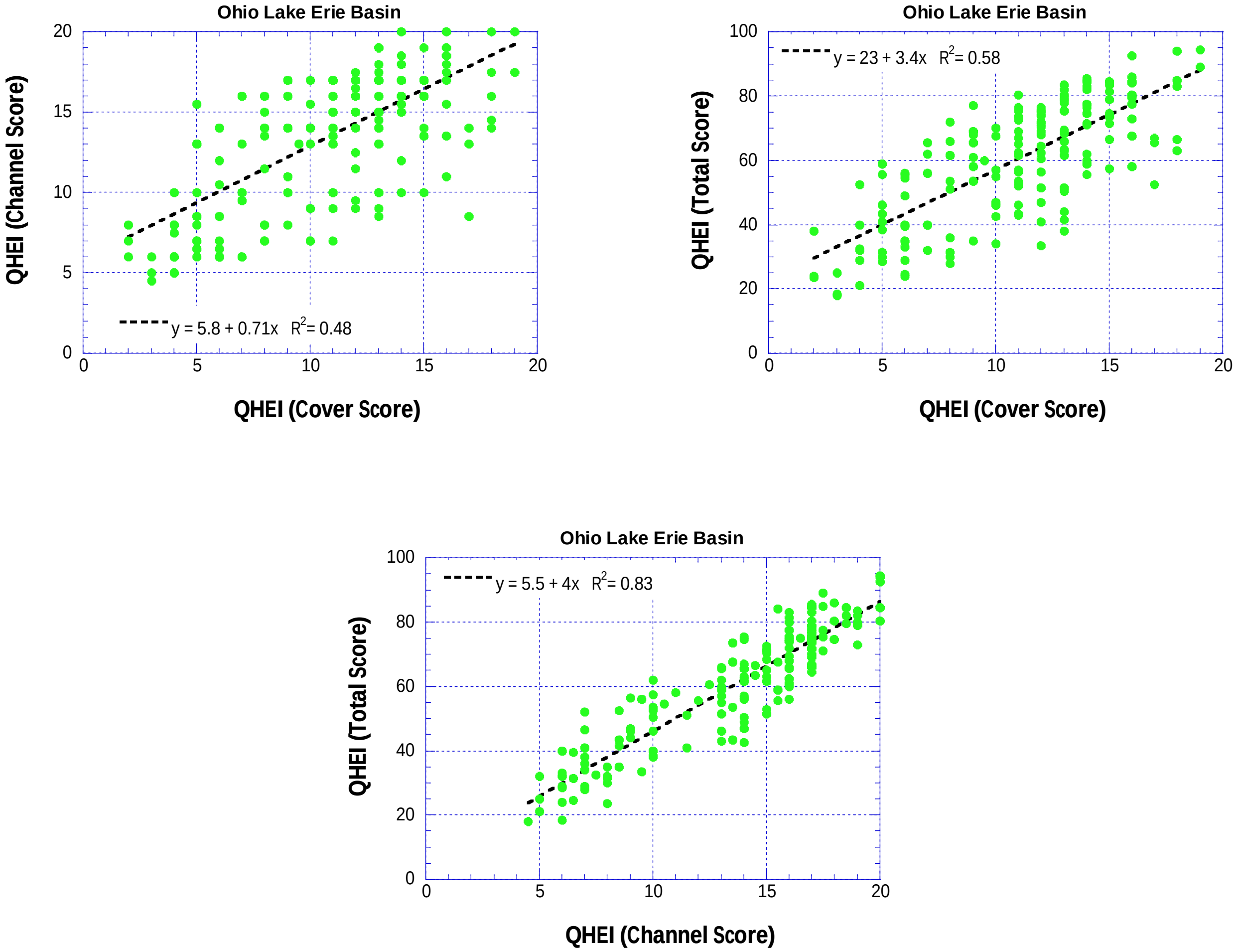

Figure 31. Correlations between the QHEI channel score and other QHEI metrics and the QHEI total score for Ohio streams of the Lake Erie basin

Good versus Poor Habitat Attributes

Rankin (1989, 1995) used the numbers of habitat attributes identified as associated with high IBIs ("good" attributes) or low IBIs ("poor" attributes) to explain variation in the Ohio fish IBI. These attributes were used as key factors in assigning aquatic life uses for streams that were deemed unable to attain the WWH or better aquatic life uses in Ohio because of essentially irretrievable[2] channel modifications. We attempted a similar approach in this study and in the preceding sections identified variables that would serve as "good" or "poor" habitat attributes for each metric for MN streams based on the analyses of which features were most strongly associated with low or high FIBIs and MIBIs within each of their classification strata.

Calculation of Weighted Poor and Good Habitat Attributes

The identification of "good" (or "Warmwater") and "poor" (or Modified Warmwater) habitat attributes with the Ohio QHEI and IBI distinguished between "high" influence and "moderate" influence habitat attributes based on the strength of the statistical correlation between the QHEI attribute and the Ohio IBI. After initially identifying good and poor habitat attributes for Minnesota streams based largely on statistical significance (P<0.05), we re-analyzed the data and distinguished among highly significant attributes (P<0.001) and those significant at P<0.05. We assigned a weight of 2 for highly significant attributes and 1 for those significant only at P<0.05, but less than P<0.001. In addition, because we analyzed each classification strata independently due to the non-equivalence of IBI scores we identified attributes that were trending towards significance where biological judgment suggested that low sample size may preclude certain attributes from being classified as significant attributes. These were assigned a weight of 0.5. Another difference with the Ohio method was additional weights given for watershed scale habitat conditions (or in several cases land use data) based on classification tree analyses and plots of watershed average MSHA versus IBI which identified a strong influence of watershed scale habitat condition on biological performance. These data were used to add 5 points to either the positive or negative attribute scores (Table 56). The strong influence of watershed scale habitat impacts on IBI in Ohio was quantified subsequent to the identification of good and poor habitat attributes. To further separate natural from channel modified sites an additional 5 points was added to the negative attribute score when a channel was identified as channelized (either old channelization or recent channelization). Although we added the extra points here to the attribute scores such factors could be considered separately as was done in the later effort by MPCA to fit attributes using logistic regression (MPCA 2015).

Once the "good" and "poor" habitat attribute scores were calculated they were plotted versus the IBI values, coded by channelization status, to help visualized the cumulative influence of habitat loss on aquatic life. As was discussed earlier, the Ohio dataset had sharp relationships between the QHEI and IBI with fewer "outliers" than observed in the Minnesota data. We attribute these differences to factors such as baseflow (lower in Ohio), summer stream temperatures (higher in Ohio) and the influence of these factors on nutrients (higher in Ohio) and nutrient processing and assimilation.

[2] These were activities deemed not to be restorable with feasible restoration designs or where natural recovery was likely within the next 5+ years.

Table 56. Additional scoring modifications based on scale of habitat disturbance by HUC-8 for fish and macroinvertebrates

Fish	Southern Rivers (1)	Southern Streams (2)	Southern Headwaters (3)	Northern Rivers (4)	Northern Streams (5)	Northern Headwaters (6)	Low Gradient Streams (7)
Watershed Av. MSHA (5 pts)	>54.2	>53.8	>53	>54.9	>60.7	*	> 54.2
Watershed Av. MSHA (- 5 pts)	<50	<49.5	< 50	< 50	< 41.8	<50	< 50
Macros	Northern Forests Rivers (1)	Prairie Forest Rivers (2)	Northern Streams Riffle-Run (3)	Northern Streams Glide-Pool (4)	Southern Streams Riffle-Run (5)	Southern Streams Glide-Pool (6)	Prairie Streams Glide-Pool (7)
Watershed Av. MSHA (5 pts)	≥61.3	**	≥65.9	>60.5	>54.185	> 56.68	***
Watershed Av. MSHA (- 5 pts)	<50	<49.5	< 50	< 50	< 41.8	<50	< 50

*- Land Use Score > 3.6
**-Land Use Score > 2.875
***- Land Use Score > 0.375

To improve the visualization of the data we used both scatter plots of good attributes, poor attributes and the ratio of poor/good attributes versus the FIBI and MIBI. This assignment of tiered aquatic uses is a risk-based approach to stream management and we want to minimize the risk of designating a stream with a lower than CWA use (*e.g.,* channel modified use). To this end we converted the IBI data for ranges of MSHA weighted attributes to the probability of attainment of FIBI or MIBI thresholds and plotted these data by ranges of these attributes. Thus for a given range of weighted attributes (*e.g.,* good, poor, or poor/good ratio) we can calculate the probability that a site attains a use within a classification strata based on existing data. We then looked for ranges where the probability of attainment of a 2B use was low (*e.g.,* < 25%) to identify candidate reaches for a use attainability analysis (UAA).

Fish Data

Figures 32-38 present scatter and probability plots, by classification strata of good attribute scores (top), poor attribute scores (middle), and the ratio of poor-good attributer scores (bottom) for the FIBI. For most strata the probability of attaining an FIBI benchmark is strongly related to the attribute scores. In general the relationship is weakest for rivers and stronger for Southern strata and low gradient streams than Northern strata and for poor attributes versus good attributes or the ratio of poor/good attributes. Channelized versus natural stream channels separate most distinctly along the poor attribute scores and for streams, headwaters, and low gradient strata versus rivers. This data suggests that modified uses (*i.e.,* severe habitat limitations) would be most common in Southern streams and headwaters and low gradient streams and less likely in Northern strata and in river strata.

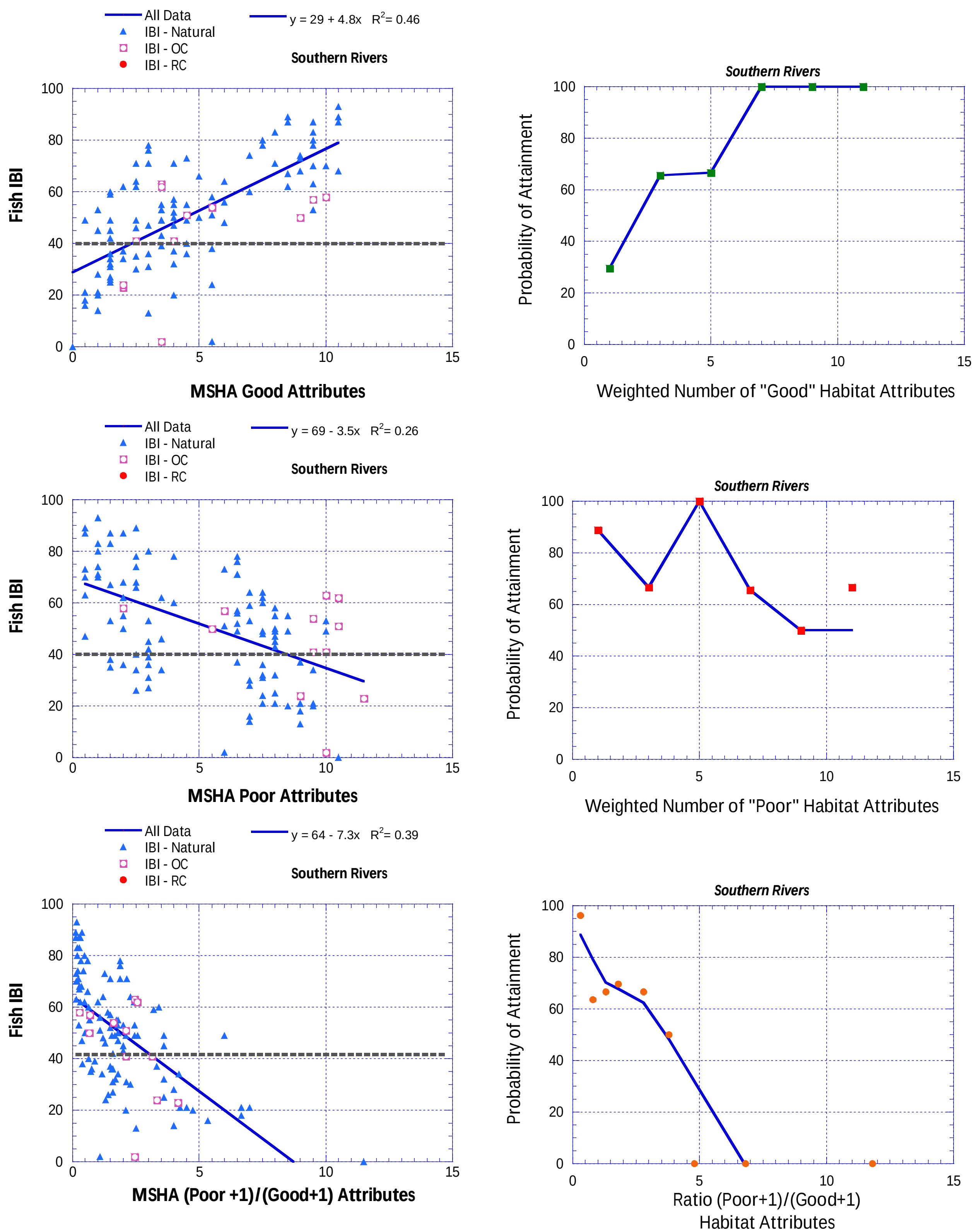

Figure 32. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Southern Rivers classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

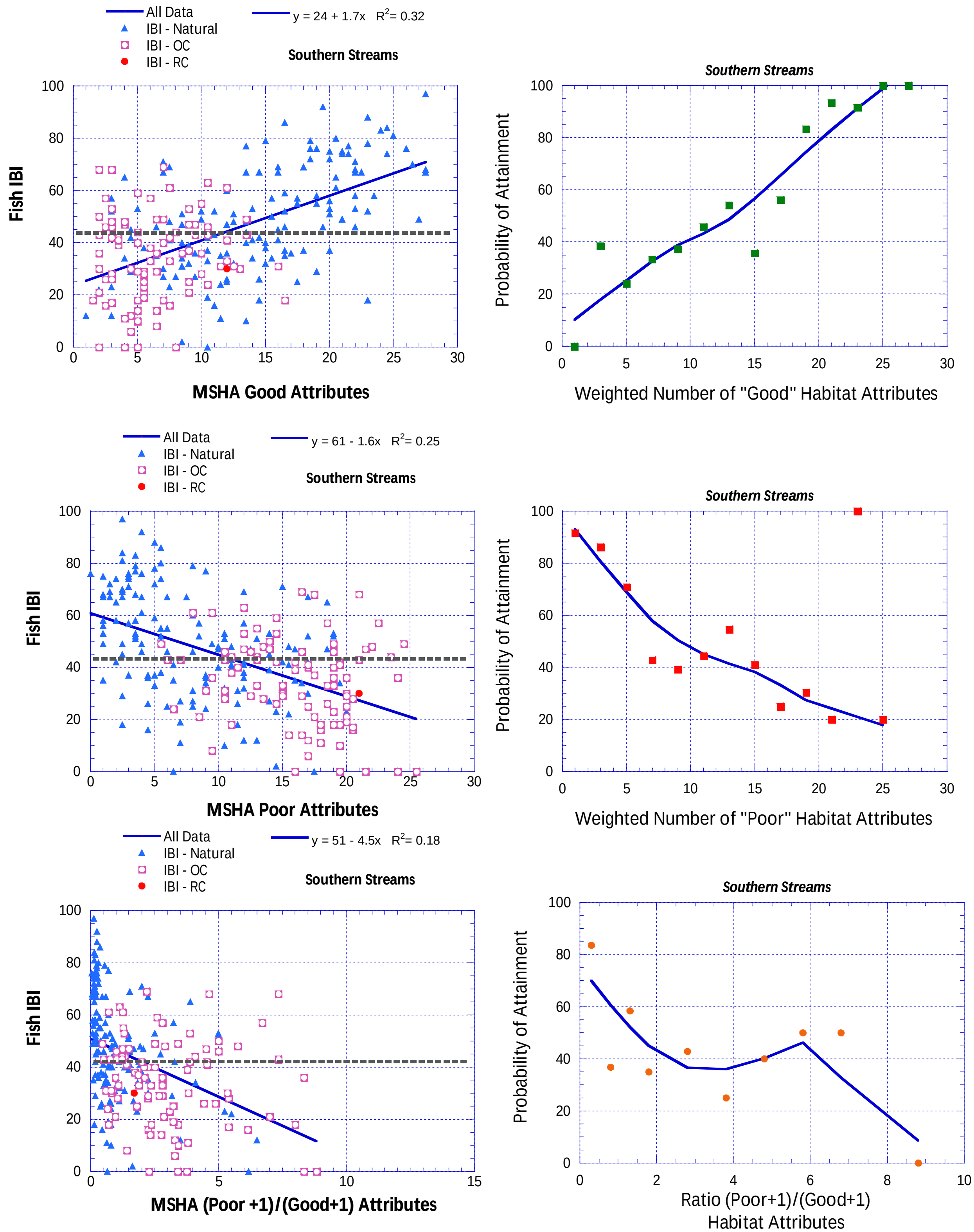

Figure 33. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Southern Streams classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

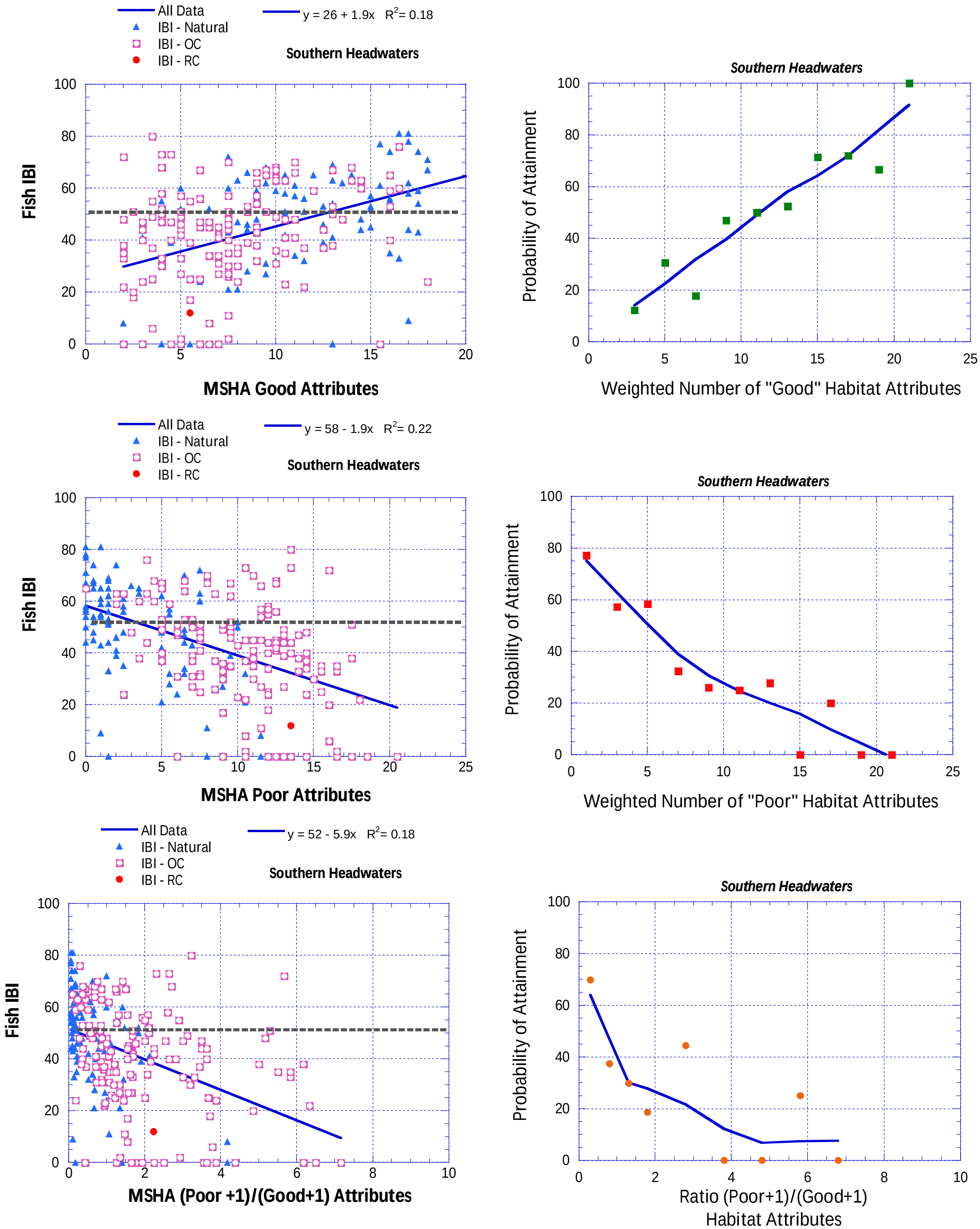

Figure 34. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and the ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Southern Headwaters classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

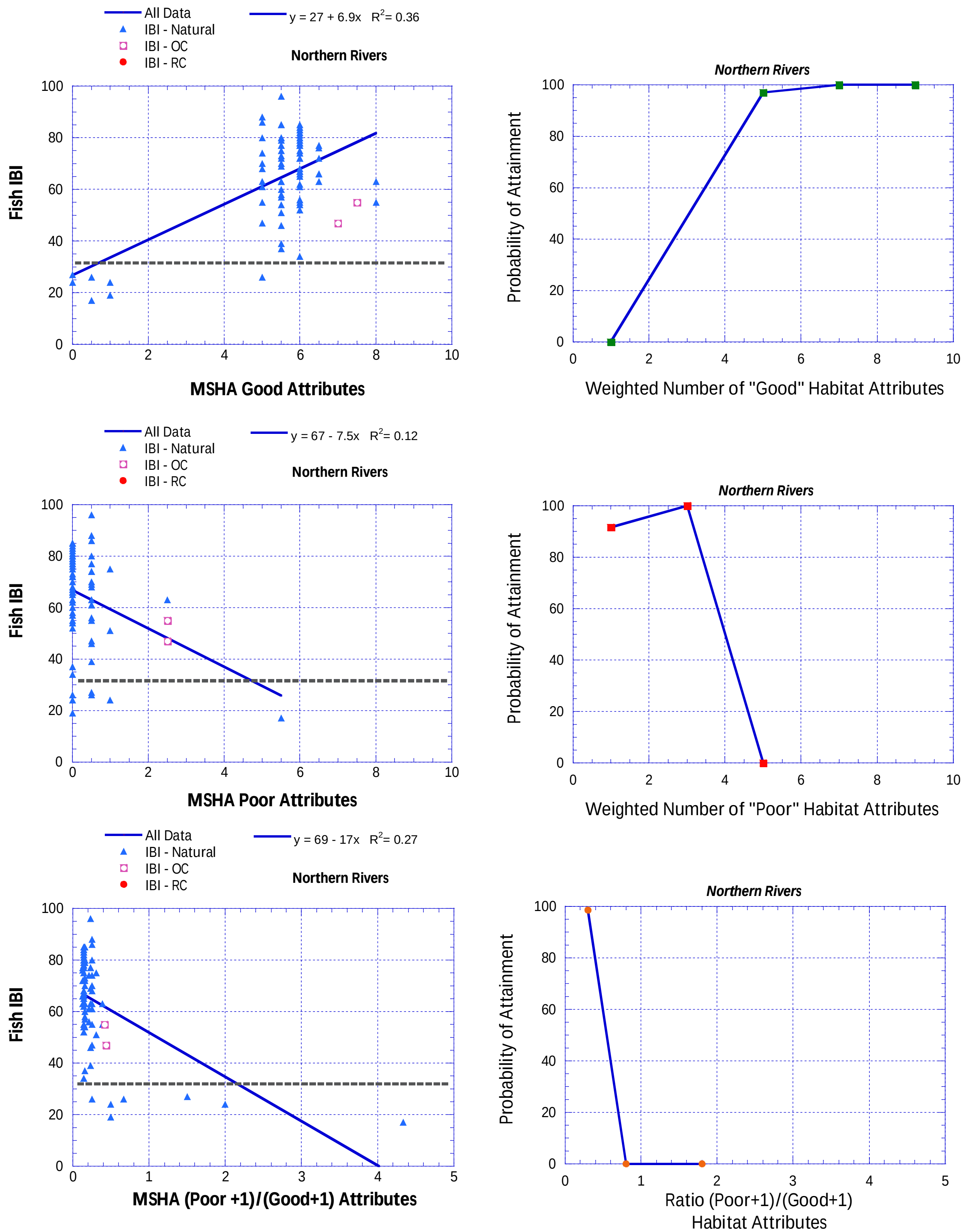

Figure 35. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and the ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Northern Rivers classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

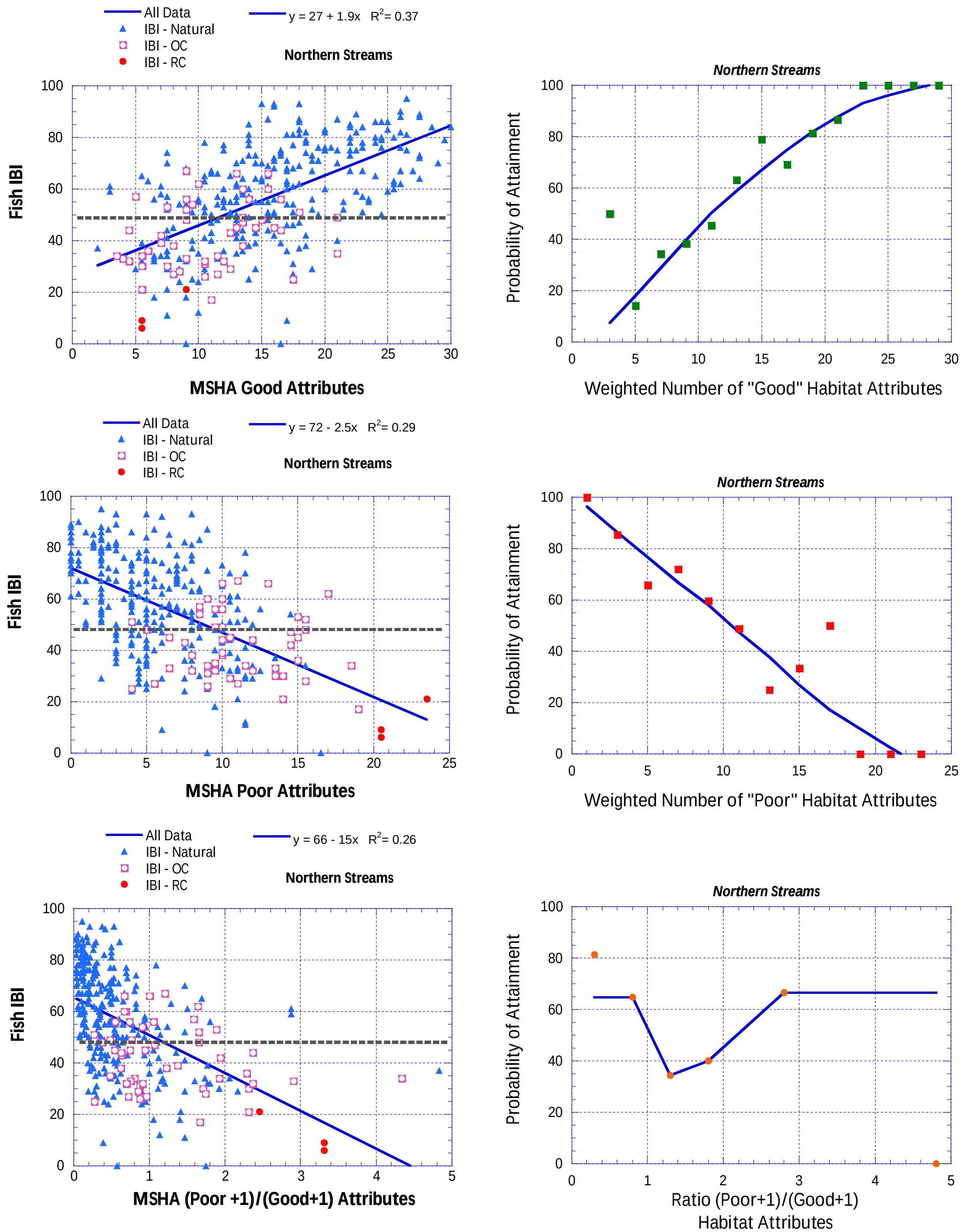

Figure 36. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and the ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Northern Streams classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

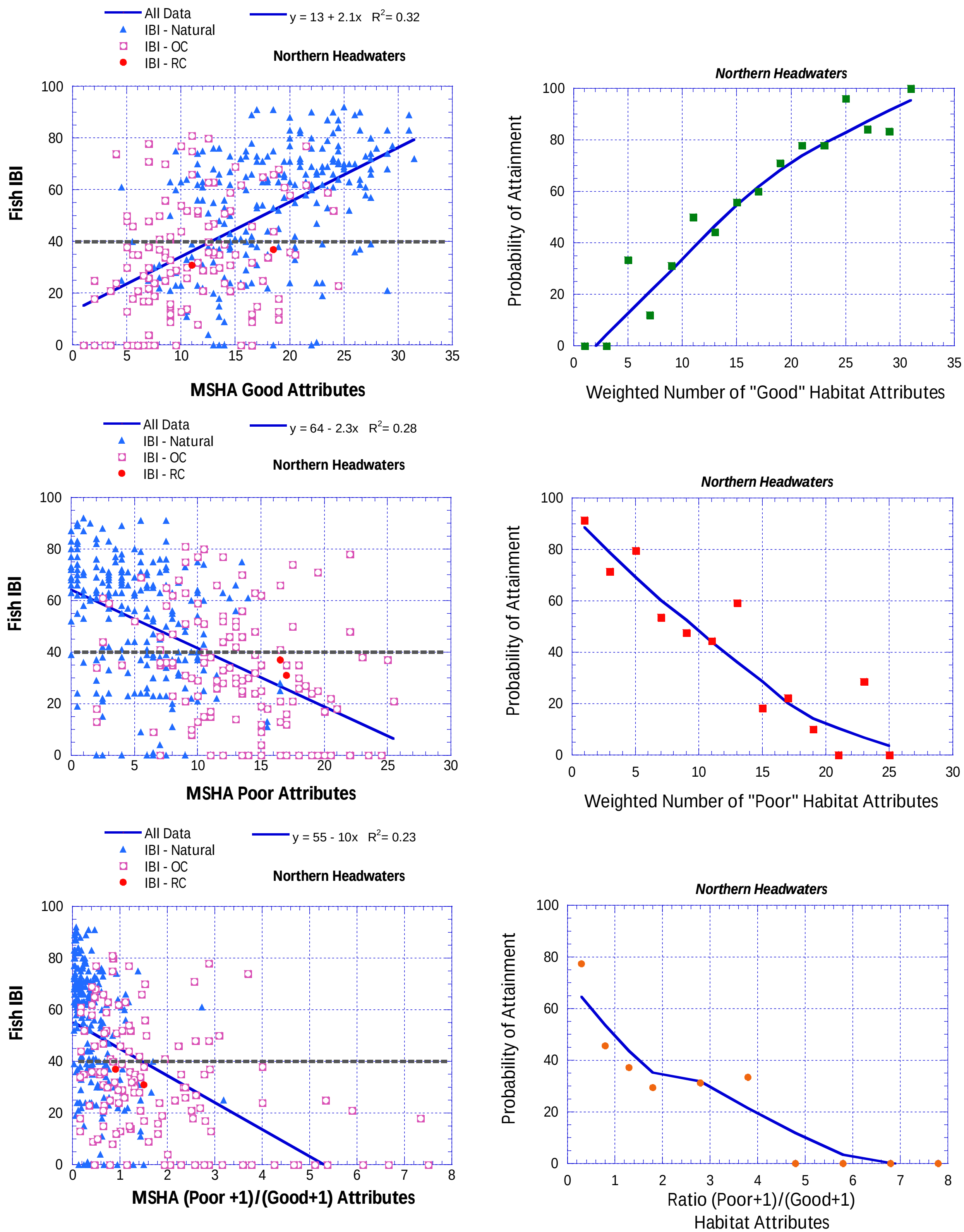

Figure 37. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and the ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Northern Headwaters classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

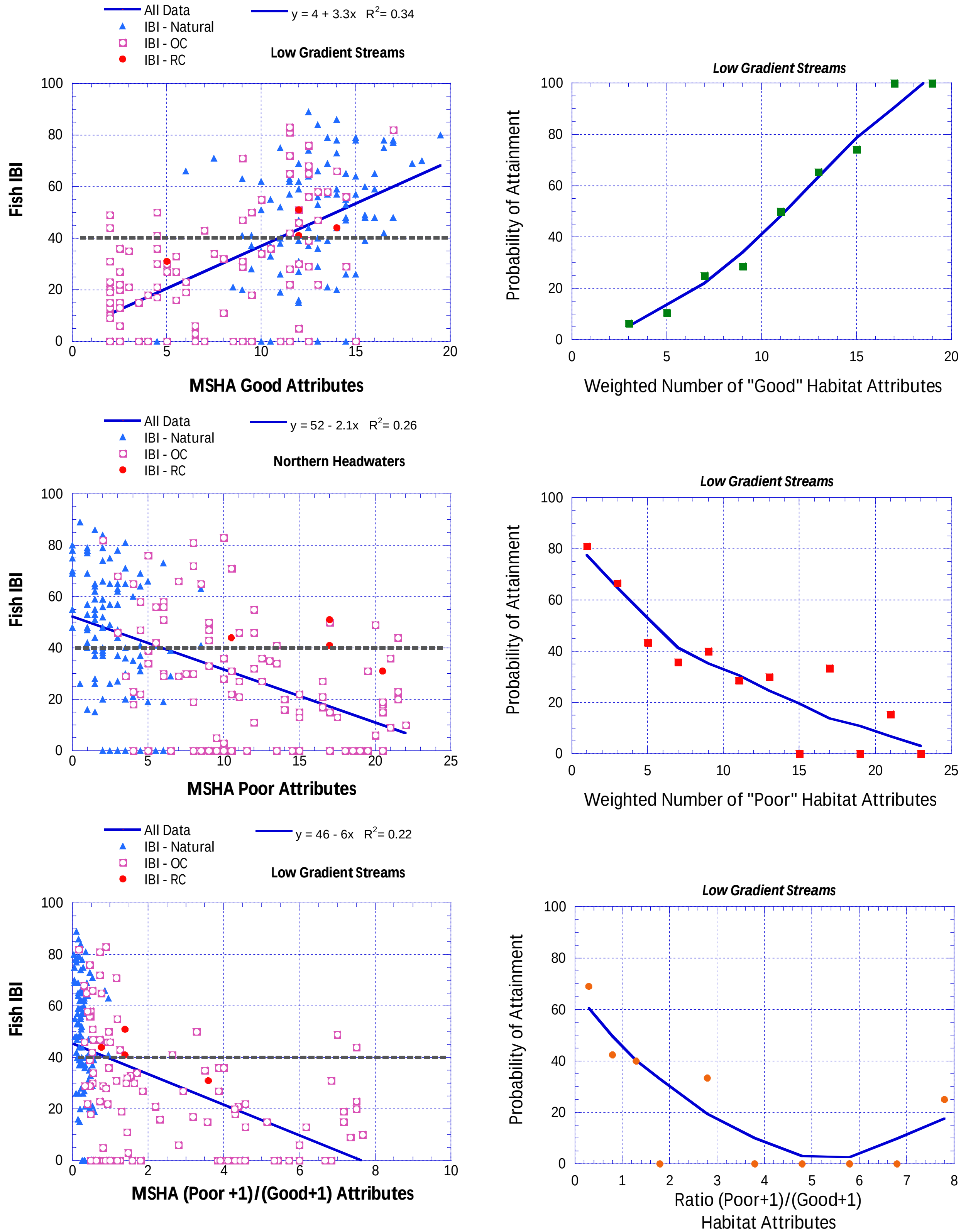

Figure 38. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus Fish IBI scores for the Low Gradient Streams classification. Plots on the right illustrate the percent of sites attaining the IBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

Macroinvertebrate Data

The classification strata for the MIBI differs from the classification scheme for the FIBI, but has some similarities in that it uses a North/South breakdown and the consideration of low gradient streams in distinguishing among riffle/run versus glide pool types habitat types in the classification strata. As with the fish assemblages there is a relationship between habitat and biological condition in rivers (Figures 39 and 40); however, habitat modifications are not widespread in the rivers sampled and a channel modified aquatic life use is not warranted.

Northern streams typified by riffle/run morphology had few sites that had been channelized and although there is a relationship between habitat attributes and the MIBI there are too few directly modified channels to consider a modified use within these macroinvertebrate classification strata (Figure 40). The macroinvertebrate classification strata where a modified aquatic life use would be considered include the Southern Riffle/Run streams, the Northern and Southern Glide/Pool streams and the Prairie Glide/Pool Streams (Figures 41-44).

Within the four classification strata where modified aquatic uses are a possibility, the weighted number of “poor” habitat attributes tends to separate modified from natural sites more clearly than the weighted number of “good” habitat attributes at a site (Figures 41-44). This pattern is similar to what we observed in the fish data (Figures 32-38). To help to convert these scatter plots into a more understandable pattern we plotted the probability of attaining the MIBI threshold by range of habitat attribute scores. These are located to the right of each attribute/IBI plot. (Figures 38-44)

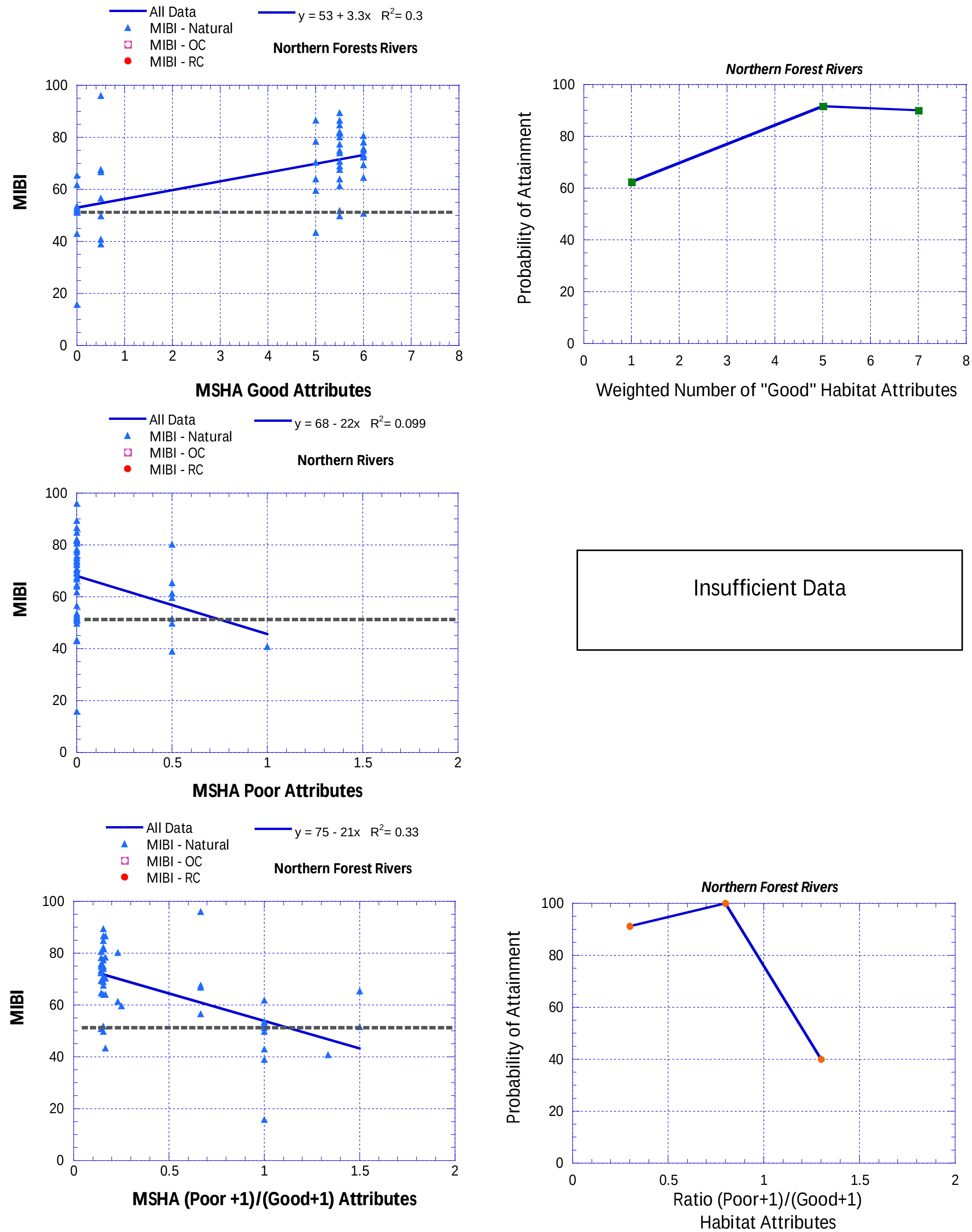

Figure 38. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and the ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Northern Forest Rivers classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

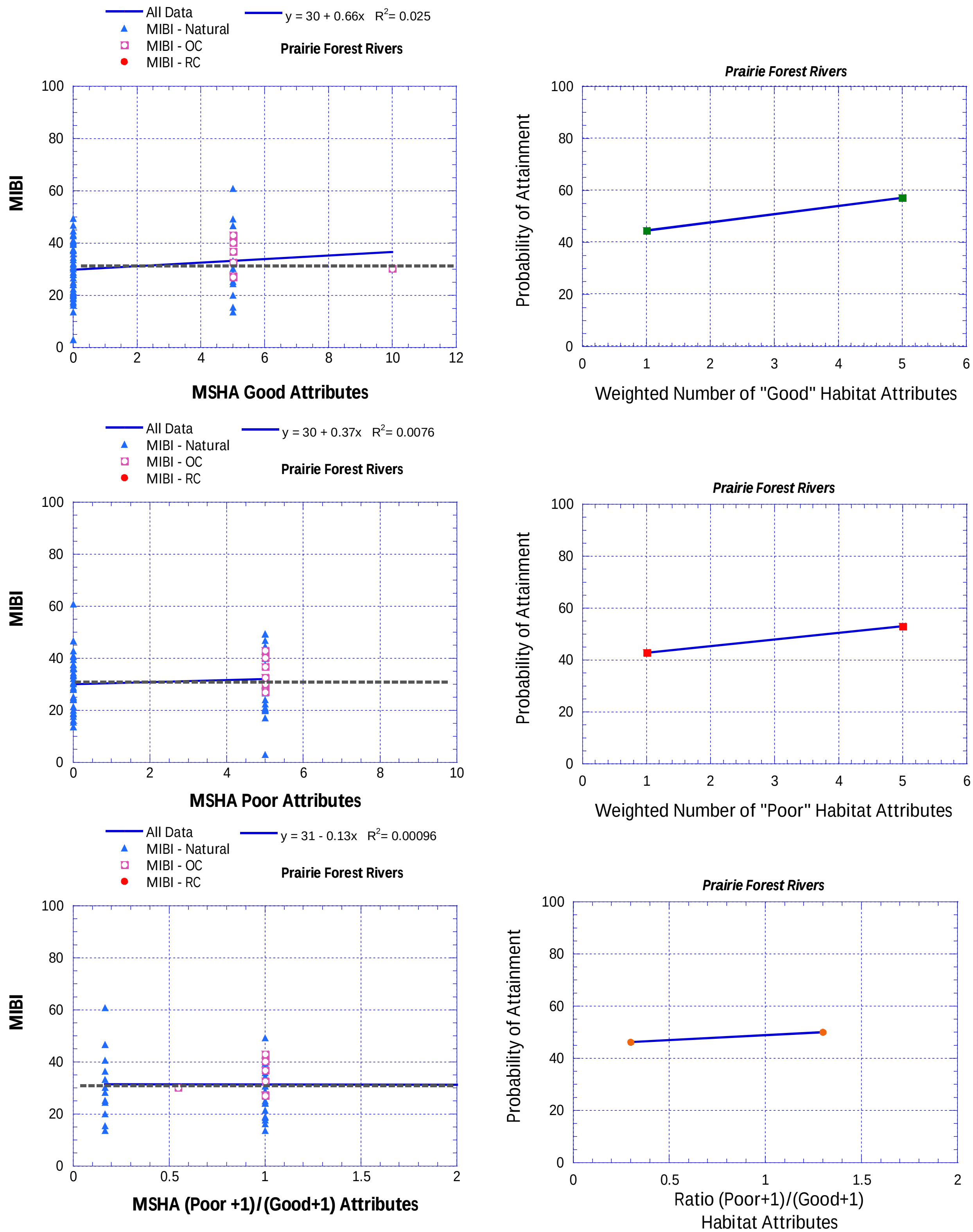

Figure 39. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and the ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Prairie Forest Rivers classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

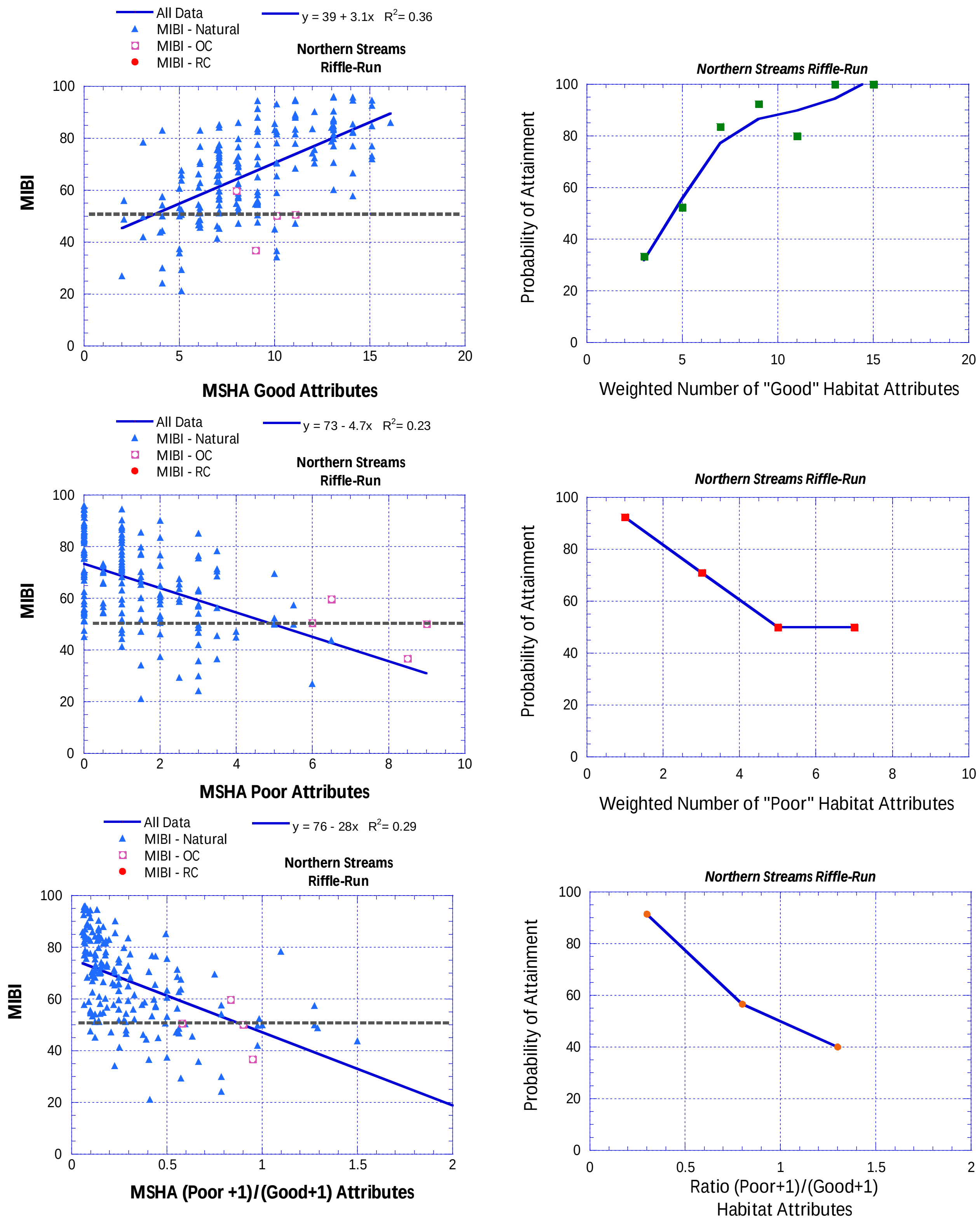

Figure 40. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Northern Streams Riffle/Run classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

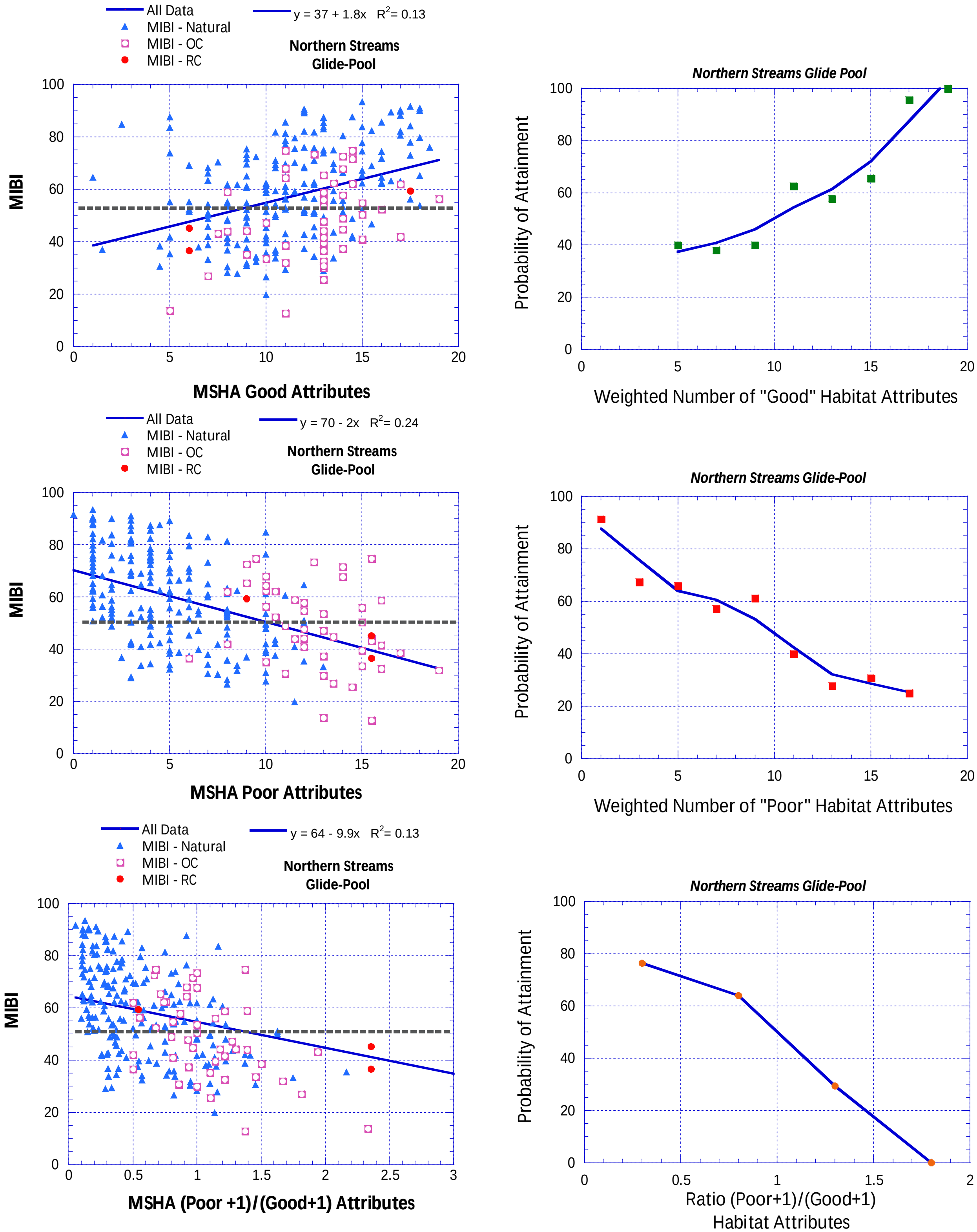

Figure 41. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Northern Streams Glide/Pool classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

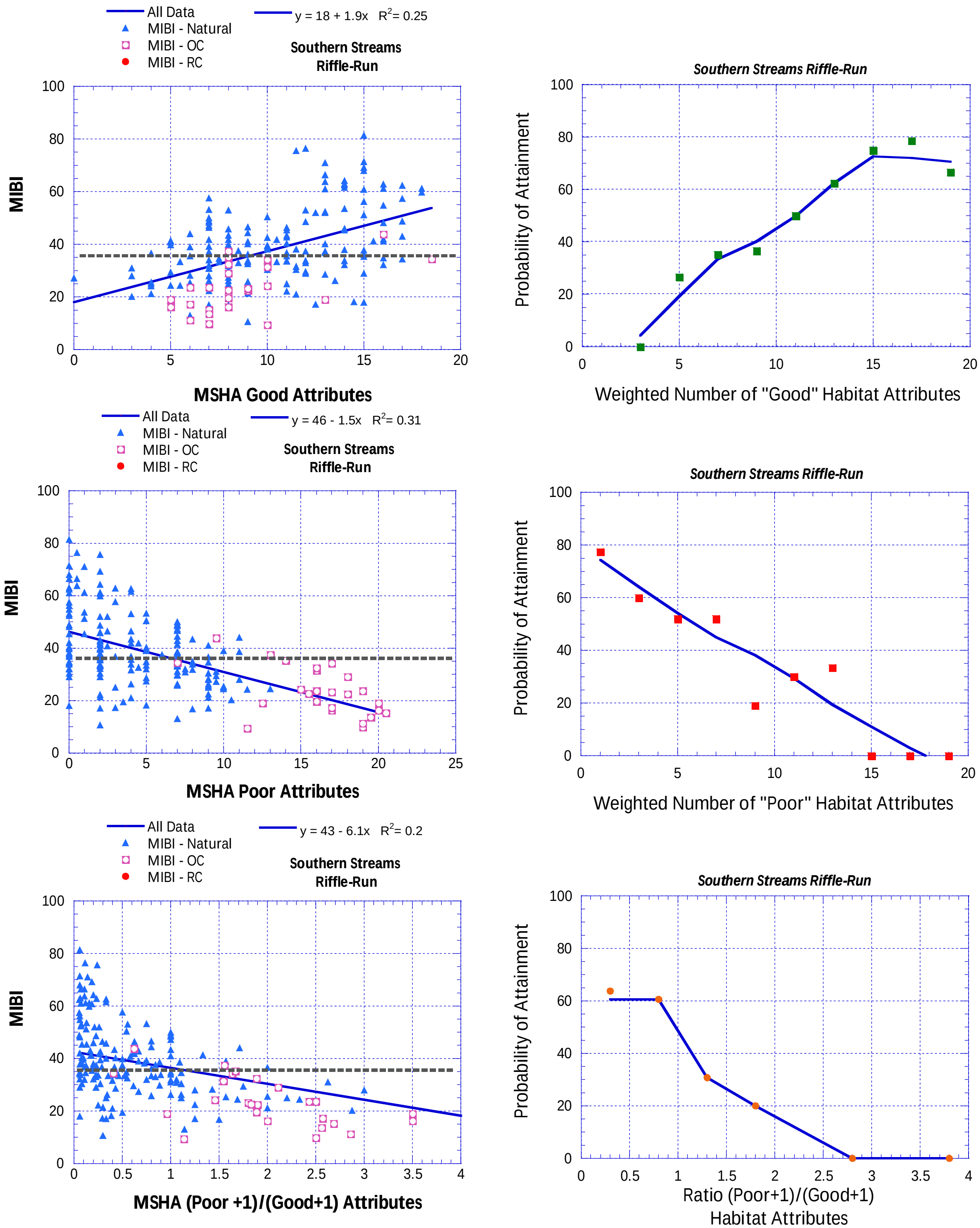

Figure 42. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Southern Streams Riffle/Run classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

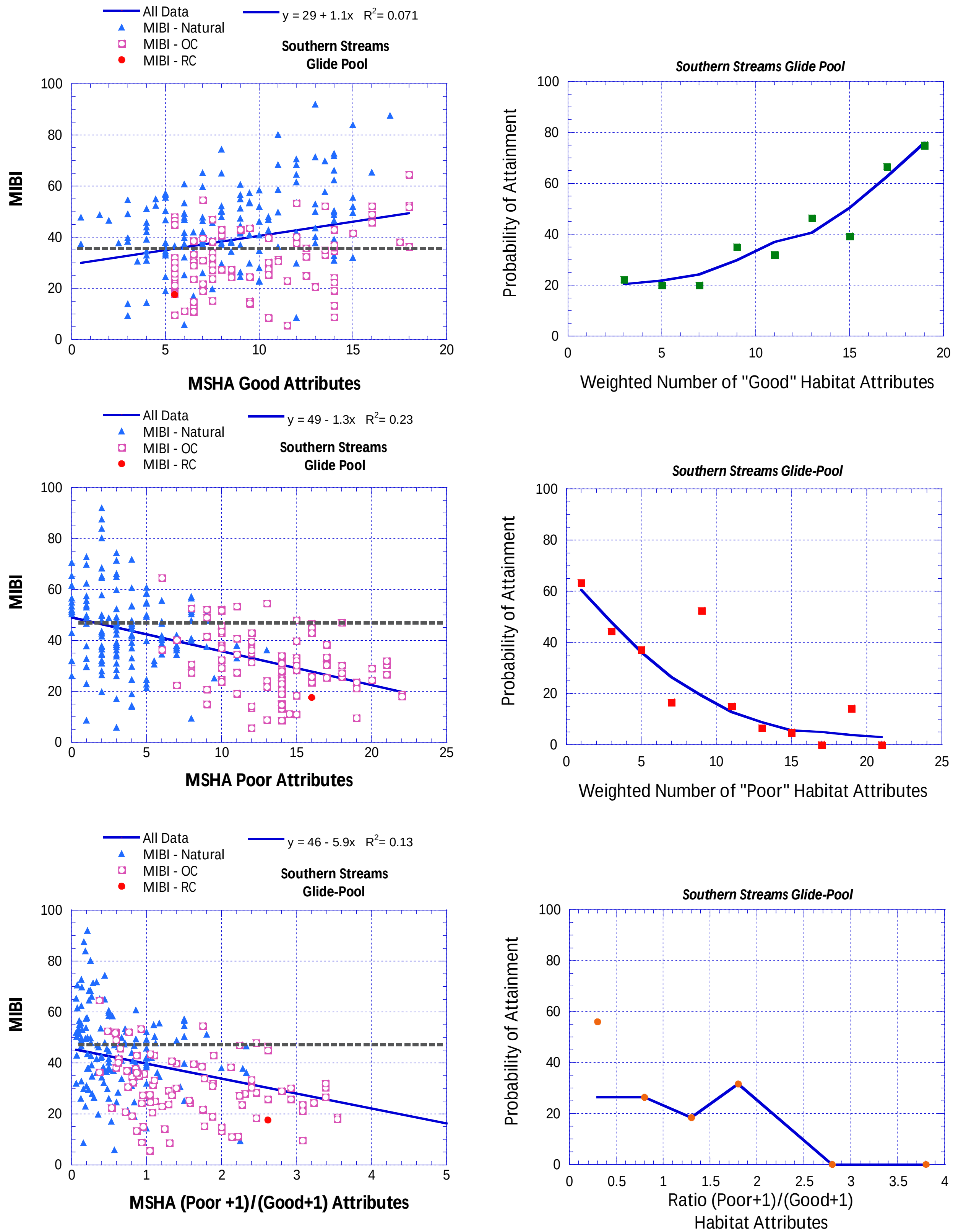

Figure 43. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Southern Streams Glide/Pool classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

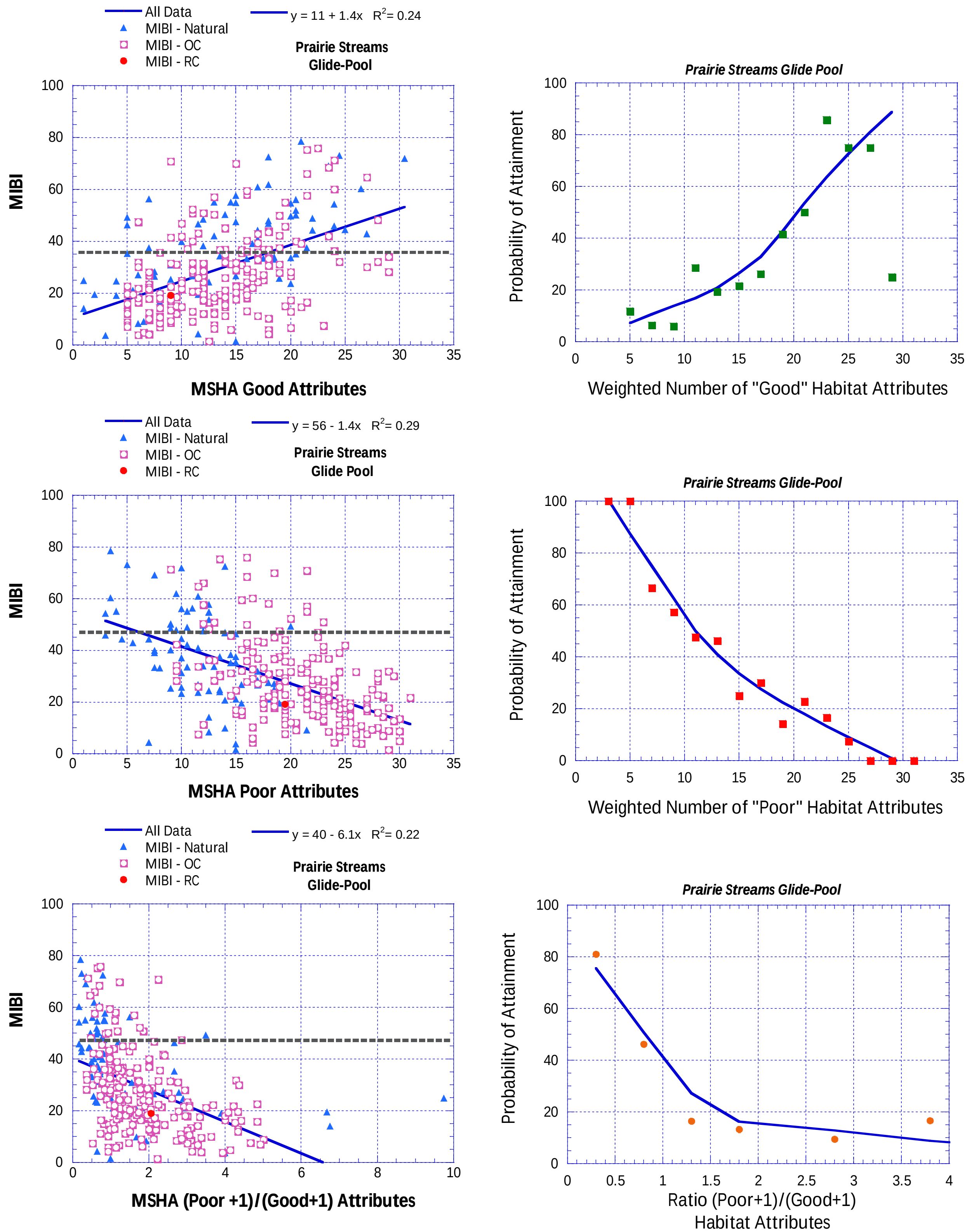

Figure 44. Plots of MSHA "good" habitat attributes (top left), "poor" habitat attributes (middle left) and a ratio (good+1/poor+1, bottom left) of attributes versus MIBI scores for the Prairie Streams Glide/Pool classification. Plots on the right illustrate the percent of sites attaining the MIBI threshold by ranges of the attribute measure. Sites are coded as natural and channelized (OC – old channelization, RC – recent channelization).

Figure 45. Map of "outliers' where MSHA habitat scores were < 50, but FIBI (top) or MIBI exceeded biological thresholds for each classification strata. Grey triangles are site with MSHA scores > 50 or with MSHA scores < 50 and impaired IBI or MIBI scores. Size of point increases with the magnitude IBIs above the thresholds.

Modified Stream Use Attainability analyses: Using the Good and Poor Habitat Attributes to Help Determine CWA Use Attainability

The presence of channelization is not by itself sufficient evidence that a stream cannot achieve an aquatic life use goal commensurate with the CWA interim goal (*i.e.,* fishable-swimmable). Some streams can attain a CWA use despite habitat losses due to channelization where activities are of a local nature and the biota is more strongly influenced by nearby reaches of good, productive habitat. In some places where habitat modification is more extensive biological assemblage impacts may be moderated by high base flows and lower summer stream temperatures. The modes of habitat effects on aquatic life are varied, but include more severe nutrient related impacts related to opening of the stream channel to unlimited sunlight, loss of buffers from adjacent land uses (*e.g.,* row crop), and geomorphic changes (*e.g.,* loss of flood prone areas) that act to concentrate nutrients and fine sediments within the wetted stream channel. Where base flows are high and/or stream temperatures are low these ecological processes can be slowed and effects on the biota moderated. In any case the attainment of CWA aquatic life use goals in channel modified streams is the best arbiter of "attainability" and the starting point for consideration of whether such goals are attainable. Figure 47 charts the first steps of the UAA process for consideration of a modified use which, assuming data is adequate, first asks whether CWA uses (2B or E2B) are attainable.

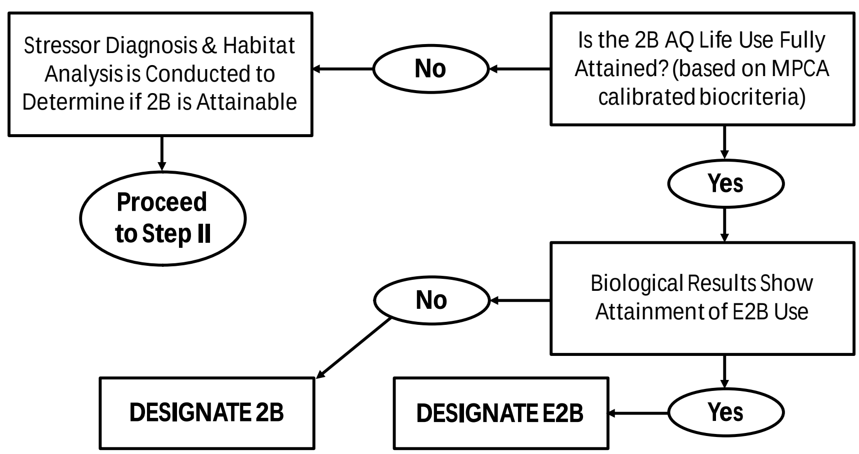

Figure 46. Initial steps in the UAA process for aquatic life uses.

The remainder of this section will focus on the decision points related to whether the weight of evidence is sufficient to conclude that a Class 2B CWA use is not attainable because of habitat limitations that are not ***feasibly restorable***. Part of this discussion is a "scientific" exercise that weighs data collected on habitat conditions at multiple spatial scales to assess the probability of attaining a CWA use after the adoption of reasonable best management practices on the landscape. This process also includes a socio-economic component that requires some definition of what "reasonable" best management practices are with regard to stream modification impacts. Stream that are considered feasibly restorable would not be candidates for a channel modified use, but if impaired would be placed on a state's TMDL list. This part of the decision making process is outlined in Figure 47. Sites that have not been directly modified by activities such as channelization would not be candidates for a channel modified use (Figure

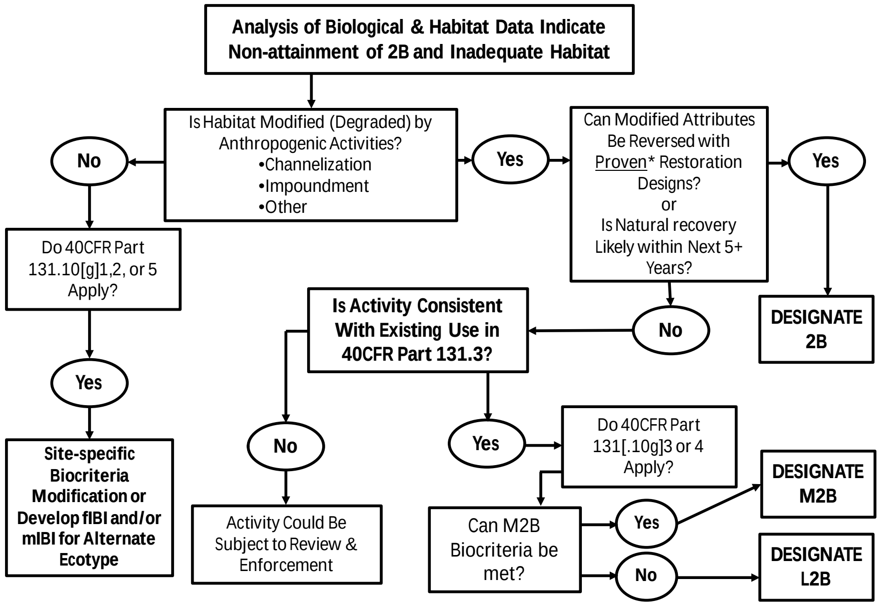

Figure 47. Flow chart illustrating decision points related to feasibility of restoration and assigning tiered aquatic life uses.

47). Sites with poor habitat features that are the result of "natural" factors might be candidates for a site-specific criteria modification (see Figure 47). Modified streams that are expected to recover naturally within a relatively short time frame would also not be candidates for a channel modified use (Figure 47).

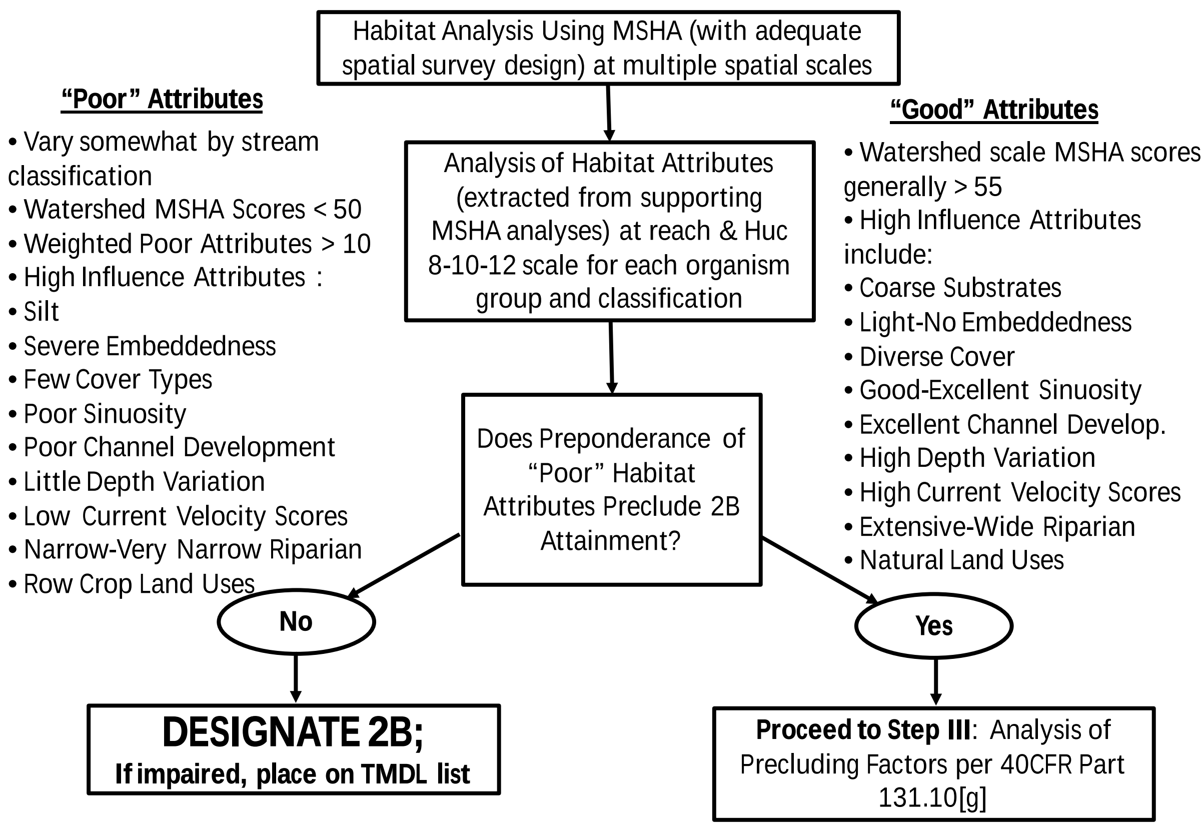

Figure 48. Flow chart summarizing the analysis of habitats attributes used in an UAA process for a channel modified aquatic life use

The list of attributes associated with assemblages' not attaining thresholds varied by classification strata by for both fish and macroinvertebrates as discussed in the sections for each habitat metric. The most frequently identified good and poor habitat attributes are summarized in Figure 48. For both fish and macroinvertebrates it does not appear that assemblages in river classifications are limited by habitat modifications to the extent that application of a channel modified use is warranted. Similarly for streams in the macroinvertebrates Northern Streams Riffle/Run classification strata do not have sufficient modified streams to justify consideration of a channel modified use.

Southern classifications (Fish Southern Streams and Southern Headwaters) and lower gradient classifications (Fish: Low Gradient streams; Macros Southern and Prairie Glide/Pool streams) have the greatest number of sites with high levels of poor attributes and sites that have non-attaining biological index scores. There were a substantial number of sites that reached an IBI threshold despite rather poor habitat, thus it will be important to address such streams up front in the process. The distribution of such outlier points was in some cases clustered within the same watershed (Figure 45) which should help focus on where modified uses are more or less likely. In addition, in many cases these clusters were similarly located for both fish and macroinvertebrates.

We transformed the data from the scatter plots of good and poor weighted attribute scores versus the FIBI and MIBI to plots of the percent of sites attaining thresholds within each classification to help in identifying candidates for channel modified uses. These plots represent a risk-based approach to identifying streams that are candidates for modified uses. Because of outliers few streams can be identified up front as with a single criterion (*e.g.,* weighted poor attribute score > 25) as likely channel modified streams, however the risk based probability data can identify groups of streams that are likely candidates which can then be subjected to a UAA analysis.

The watershed-based average MSHA and average IBI/MIBI data were strong classifying factors in identifying candidate streams for modified uses and clusters of streams where modifications of habitat may limit Class 2B uses. We produced an initial data printout organized by HUC-8 and HUC-10 watersheds that provide data on the MSHA scores, metric scores and metric attributes that will be useful in identifying candidate streams. In addition, these tables (Appendix 4 and 5) provide weighted poor habitat attribute scores and counts of the high, moderate and low influence good and poor habitat attributes. It also identified "outliers" up front where habitat scores were < 50, but FIBI or MIBI scores were above threshold values for their classification strata. **Error! Reference source not found.** provides a section of the printout for the Partridge River for the fish (top) and macroinvertebrates (bottom) and Table 57 summarized the FIBI and MIBI scores for these sites. These data represent good to excellent MSHA scores, few poor attributes, high average watershed habitat scores and have natural channels. They are in the Northern Streams and Headwater strata (fish) and the Northern Riffle/Run and Northern Glide/Pools strata (macroinvertebrates). These sites clearly have sufficient habitat to support the Class 2B aquatic life use and, without any channel modifications, would not be candidates for any modified use.

Table 57. Summary of FIBI, MIBI and MSHA scores for the Partridge River and So. Branch Partridge River in the St. Louis River basin in Minnesota.

Site Number Sample Year	Fish Classification Strata - Threshold	FIBI	Macro. Classification Strata - Threshold	MIBI	MSHA	Wt'd Negative Attributes
Partridge River						
09LS102 2009	No. Streams [48]	40[a]	-	-	76.25	3.0
09LS105 2009	No. Streams [48]	86	No. Streams Riffle/Run [50.3]	70.98	83.6	0.0
South Branch Partridge River						
97LS077 1997	No. Headw. [40]	61	No. Streams Riffle/Run [50.3]	78.26	84.3	1.0
97LS077 2009	No.Headw. [40]	61	-	-	-	-

[a] Low end scored

Figure 49. Habitat attribute table for sites in the Partridge River and South Branch Partridge, tributary in the St. Louis River watershed.

Field-num	Visit Date	River	Fish Class	MSHA	Substrate Scr/Good/Poor	Channel Scr/Good/Poor	Land Use Scr/Good/Poor	Riparian Scr/Good/Poor	Cover Scr/Good/Poor	Mean Huc 8 Watershed MSHA	Wt'd Poor Attr	Number Good Attributes H	M	L	Number Poor Attributes H	M	L	Out-lier*
Huc-8 Watershed: ***St. Louis***																		
Huc-10 Watershed: ***0401020101***																		
09LS102	08/18/2009	Partridge River	5	76.25	23.3/ 5.0/ 1.0	25.0/ 3.0/ 1.0	5.0/ 1.0/ 0.0	10.0/ 1.0/ 0.0	13.0/ 1.0/ 0.0	60.90	3.0	5	6	0	1	1	0	
09LS105	07/15/2009	Partridge River	5	83.60	25.6/ 4.0/ 0.0	27.0/ 7.0/ 0.0	5.0/ 1.0/ 0.0	12.0/ 3.0/ 0.0	14.0/ 0.0/ 0.0	60.90	0.0	6	6	3	0	0	0	
97LS077	07/23/1997	South Branch Partridge	6	84.25	23.3/ 6.0/ 1.0	30.0/ 6.0/ 0.0	5.0/ 1.0/ 0.0	11.0/ 1.0/ 1.0	15.0/ 2.0/ 0.0	60.90	1.5	7	7	2	0	1	1	
97LS077	07/16/2009	South Branch Partridge	6	77.00	22.0/ 5.0/ 1.0	24.0/ 3.0/ 0.0	5.0/ 1.0/ 0.0	14.0/ 3.0/ 0.0	12.0/ 2.0/ 0.0	60.90	2.0	6	6	2	1	0	0	
09LS106	07/15/2009	Colvin Creek	7	62.00	18.0/ 1.0/ 0.0	20.0/ 1.0/ 1.0	5.0/ 1.0/ 0.0	11.0/ 1.0/ 0.0	8.0/ 2.0/ 2.0	60.90	2.0	3	2	1	0	1	2	
Huc-8 Watershed: ***St. Louis***																		
Huc-10 Watershed: ***0401020101***																		
09LS105	/ /	Partridge River	3	83.6	25.6/ 2.0/ 0.0	27.0/ 1.0/ 1.0	5.0/ 1.0/ 0.0	12.0/ 1.0/ 0.0	14.0/ 0.0/ 0.0	60.90	1.0	2	2	1	0	1	0	
97LS077	/ /	South Branch Partridge	3	84.3	23.3/ 3.0/ 0.0	30.0/ 2.0/ 1.0	5.0/ 1.0/ 0.0	11.0/ 1.0/ 0.0	15.0/ 0.0/ 0.0	60.90	1.0	4	2	1	0	1	0	
09LS106	/ /	Colvin Creek	4	62.0	18.0/ 2.0/ 1.0	20.0/ 2.0/ 2.0	5.0/ 0.0/ 0.0	11.0/ 0.0/ 0.0	8.0/ 0.0/ 0.0	60.90	5.0	0	4	0	2	1	0	

In contrast to the Partridge River is County Ditch # 6 in the Le Sueur watershed. Several of the sites have channel modifications (purple square next to MSHA score), high weighted poor habitat attributes and very poor MSHA scores and no outlier scores (Figure 50). Figure 50 provides a section of the printout for County Ditch #6 for the fish (top) and macroinvertebrates (bottom) and Table 58 summarized the FIBI and MIBI scores for these sites. Biological scores at the channelized sites are below the thresholds for the strata. The sites are classified for fish in the Southern Streams strata and for macroinvertebrates for Southern Glide/Pools strata. The modified sites on this table would be candidates for a channel modified use. As a confounding factor however, is a non-modified site also on County Ditch 6 which has a good

MSHA score, but is situated in fairly degraded watershed (Mean MSHA = 49). The site with good habitat has an IBI of 46 which is above the threshold [43], although the MIBI (33.36) is below the MIBI threshold [46.8].

Table 58. Summary of FIBI, MIBI and MSHA scores for the County Ditch # 6 in the Minnesota River basin in Minnesota. Underlined FIBI or MIBI scores are below the biological threshold.

Site Number Sample Year	Fish Classification Strata - Threshold	FIBI	Macro. Classification Strata - Threshold	MIBI	MSHA	Wt'd Negative Attributes
			Partridge River			
07MN068 2007	So. Streams [43]	34	-	-	38.0	20.5
07MN068 2008	So. Streams [43]	17	So. Streams Glide/Pool [46.8]	9.57	29.0	23.5
07MN068 2008	So. Streams [43]	28	-	-	29.0	23.5
08MN047 2008	So. Streams [43]	16	-	-	29.0	23.5
08MN082	So. Streams [43]	46	So. Streams Riffle/Run [46.8]	33.36	75.8	6.0

[a]Low end scored

Figure 50. Habitat attribute table for sites in County Ditch # 6, a tributary in the Le Sueur River watershed (Minnesota River basin). Upper block of data is for fish assemblage and bottom for macroinvertebrates.

Field-num	Visit Date	River	Fish Class	MSHA	Substrate Scr/Good/Poor	Channel Scr/Good/Poor	Land Use Scr/Good/Poor	Riparian Scr/Good/Poor	Cover Scr/Good/Poor	Mean Huc 8 Watershed MSHA	Wt'd Poor Attr	Number Good Attributes H	M	L	Number Poor Attributes H	M	L	Out-lier*
07MN068	08/14/2007	County Ditch 6	2	38.00	16.0/ 2.0/ 1.0	7.0/ 2.0/ 4.0	0.0/ 0.0/ 1.0	8.0/ 0.0/ 1.0	7.0/ 0.0/ 1.0	49.07	20.5	0	3	1	3	4	1	
07MN068	07/07/2008	County Ditch 6	2	29.00	10.0/ 1.0/ 1.0	4.0/ 0.0/ 5.0	0.0/ 0.0/ 1.0	8.0/ 0.0/ 1.0	7.0/ 1.0/ 1.0	49.07	23.5	0	0	2	5	3	1	
07MN068	08/20/2008	County Ditch 6	2	29.00	10.0/ 1.0/ 1.0	4.0/ 0.0/ 5.0	0.0/ 0.0/ 1.0	8.0/ 0.0/ 1.0	7.0/ 1.0/ 1.0	49.07	23.5	0	0	2	5	3	1	
08MN047	07/07/2008	County Ditch 6	2	29.00	8.0/ 0.0/ 3.0	10.0/ 0.0/ 4.0	0.0/ 0.0/ 1.0	9.0/ 0.0/ 2.0	2.0/ 1.0/ 1.0	49.07	23.5	0	0	1	4	4	3	
08MN082	08/19/2008	County Ditch 6	2	75.80	21.8/ 5.0/ 0.0	24.0/ 5.0/ 1.0	5.0/ 1.0/ 0.0	11.0/ 2.0/ 0.0	14.0/ 5.0/ 0.0	49.07	6.0	6	8	4	0	1	0	
08MN082	2008	County Ditch 6	5	75.8	21.8/ 0.0/ 0.0	24.0/ 4.0/ 0.0	5.0/ 1.0/ 0.0	11.0/ 2.0/ 0.0	14.0/ 1.0/ 0.0	49.07	5.0	3	4	1	0	0	0	
07MN068	2008	County Ditch 6	6	29.0	10.0/ 0.0/ 0.0	4.0/ 0.0/ 3.0	0.0/ 0.0/ 1.0	8.0/ 1.0/ 1.0	7.0/ 0.0/ 0.0	49.07	19.0	0	0	1	4	1	0	
07MN068	2008	County Ditch 6	6	29.0	10.0/ 0.0/ 0.0	4.0/ 0.0/ 3.0	0.0/ 0.0/ 1.0	8.0/ 1.0/ 1.0	7.0/ 0.0/ 0.0	49.07	19.0	0	0	1	4	1	0	

Several tributaries in the Whiteface River watershed provide examples of sites with multiple outlier points. Figure 51provides a section of the printout for tributaries in the Whiteface River watershed for the fish (top) and macroinvertebrates (bottom) and Table 59 summarized the FIBI and MIBI scores for these sites. These tributaries are modified and have high weighted poor habitat attribute scores and high numbers of high influence poor attributes, but three of the five sites for fish and two of four for macroinvertebrates have FIBI or MIBI sites well above the threshold. The sites are classified within the

Northern Streams strata (fish) and the Northern Stream Glide/Pool strata (macroinvertebrates). Clearly some factor (*e.g.,* flow or temperature) is moderating the effects of the degraded habitat.

Table 59. Summary of FIBI, MIBI and MSHA scores for the Co. Ditch to the Whiteface River and the Little Whiteface River in Minnesota.

Site Number Sample Year	Fish Classification Strata - Threshold	FIBI	Macro. Classification Strata - Threshold	MIBI	MSHA	Wt'd Negative Attributes
Co. Ditch to the Whiteface River						
98LS018 1998	No. Streams [48]	62	No. Streams Glide/Pool [52.4]	67.9	32.0	20.0
98LS018 2009	No.Streams [48]	48	No. Streams Glide/Pool [52.4]	70.98	40	18.5
98LS018 2009	No.Streams [48]	52	-	-	40	18.5
Little Whiteface River						
98LS045 1998	No.Streams [48]	66	-	-	40.1	13.0
98LS045 2009	No.Streams [48]	45	No. Streams Glide/Pool [52.4]	56.39	60.1	18.0
98LS005 2009	-	-	No. Streams Glide/Pool [52.4]	42.06	59.2	8.0

[a] Low end scored

Figure 51. Habitat attribute table for sites in a County Ditch, and the Little Whiteface River, tributaries in the Whiteface River watersheds. Upper block of data is for fish assemblages and bottom for macroinvertebrates.

Field-num	Visit Date	River	Fish Class	MSHA	Substrate Scr/Good/Poor	Channel Scr/Good/Poor	Land Use Scr/Good/Poor	Riparian Scr/Good/Poor	Cover Scr/Good/Poor	Mean Huc 8 Watershed MSHA	Wt'd Poor Attr	Number Good Attributes H	M	L	Number Poor Attributes H	M	L	Out-lier*
98LS018	08/10/1998	Co. ditch to Whiteface	5	32.00	8.0/ 0.0/ 4.0	10.0/ 0.0/ 4.0	4.5/ 1.0/ 0.0	6.5/ 1.0/ 1.0	3.0/ 0.0/ 1.0	60.90	20.0	1	1	0	5	5	0	14.00
98LS018	06/11/2009	Co. ditch to Whiteface	5	40.00	8.0/ 0.0/ 4.0	11.0/ 0.0/ 4.0	3.0/ 1.0/ 0.0	9.0/ 1.0/ 0.0	9.0/ 0.0/ 1.0	60.90	18.5	0	2	0	5	3	1	
98LS018	08/05/2009	Co. ditch to Whiteface	5	40.00	8.0/ 0.0/ 4.0	11.0/ 0.0/ 4.0	3.0/ 1.0/ 0.0	9.0/ 1.0/ 0.0	9.0/ 0.0/ 1.0	60.90	18.5	0	2	0	5	3	1	4.00
98LS045	08/10/1998	Little Whiteface River	5	40.10	7.6/ 0.0/ 4.0	14.0/ 2.0/ 3.0	4.5/ 1.0/ 0.0	9.0/ 2.0/ 0.0	5.0/ 0.0/ 2.0	60.90	13.0	3	2	0	5	2	2	18.00
98LS045	06/10/2009	Little Whiteface River	5	60.10	12.1/ 0.0/ 5.0	18.0/ 4.0/ 3.0	5.0/ 1.0/ 0.0	14.0/ 2.0/ 0.0	11.0/ 1.0/ 0.0	60.90	18.0	2	4	2	5	3	0	
67LS005	2009	Little Whiteface River	4	59.2	15.7/ 3.0/ 1.0	18.0/ 1.0/ 1.0	5.0/ 0.0/ 0.0	11.5/ 1.0/ 0.0	9.0/ 1.0/ 0.0	60.90	8.0	2	2	2	1	1	0	
98LS018	1998	Co. ditch to Whiteface	4	32.0	8.0/ 2.0/ 3.0	10.0/ 1.0/ 3.0	4.5/ 0.0/ 0.0	6.5/ 0.0/ 1.0	3.0/ 0.0/ 0.0	60.90	14.0	1	2	0	3	2	2	15
98LS018	2009	Co. ditch to Whiteface	4	40.0	8.0/ 1.0/ 4.0	11.0/ 1.0/ 2.0	3.0/ 0.0/ 0.0	9.0/ 0.0/ 0.0	9.0/ 1.0/ 0.0	60.90	12.5	0	2	1	2	3	1	21
98LS045	2009	Little Whiteface River	4	60.1	12.1/ 3.0/ 2.0	18.0/ 4.0/ 2.0	5.0/ 0.0/ 0.0	14.0/ 0.0/ 0.0	11.0/ 0.0/ 0.0	60.90	10.0	2	5	0	1	3	0	

The number of poor attributes and the plots that identify the probability of attaining a Class 2B aquatic life use can be combined with data on watershed location and average MSHA scores to select candidates for channel modified uses. Examination of the biological attributes is also a useful tool in estimating the limitations of habitat impacts from channel modifications. In Ohio, channel modifications have a specific influence on populations of sensitive and intolerant fish species. While many of these species are sensitive to a wide range of stressors they are often particularly sensitive to habitat stressors. Many are fluvial specialists or fluvial dependents and decline where channelization has exacerbated low flow conditions. This may also explain why streams with high base flows may act as outliers from the effects of channel modifications. Other sensitive species are simple lithophilic spawners and are susceptible to siltation and sedimentation that often results from channel disturbance. High MSHA channel scores are typically associated with high MSHA substrates scores (Figure 28), but degraded channels can have poor substrates, a pattern we have also seen in Ohio streams (Figure 29).

The watershed average MSHA used in this system of weighted good and poor attribute scores was calculated at the HUC-8 watershed scale because this was the scale where data was most available. A perusal of Appendices 4 and 5 indicate variability within HUC-8 watersheds because of their size. We suggest that where data is available the spatial extent of habitat loss should be considered at the HUC-10 and HUC-12 scales.

The results presented here are meant as a coarse focus for conducting UAAs and expect that local stressor data and biological responses will be incorporated into a stressor identification process that is at the core of the UAA process. Performed in a “biocentric” manner, incorporating data on biological responses and on the feasibility of stream restoration should not create an onerous process for conducting UAAs. Minnesota has a mix of warmwater and coldwater systems which can be nearby one another and may confound this process and explain some of the variability in the relationships between habitat attributes and biological potential. We expect that applying the variables we derived here to specific streams and subwatersheds can help to refine thresholds for identifying modified aquatic life uses and exceptions or outliers to the process.

A companion effort to the identification of modified waters is the derivation of biocriteria for these waters. Modified aquatic life uses should have baseline biological expectations associated with managing such streams with best management practices for ditches. While this may seem to be an oxymoron, maximizing the ecological functions of even habitat limited waters can have downstream benefits related to control of erosion, nutrients and flow. Many states develop stream management guidelines that provide both minimum and better stream management practices that should be compatible with biological baselines developed for such streams. As stream restoration practice improves over time, such efforts can be used to improve ecological conditions in streams and to provide a basis for exploring new practices that can further enhance or perhaps even restore streams to CWA conditions while maintaining economic viability.

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Nankivel, Carol (MPCA)

From:	Maureen Johnson <mjsciled@earthlink.net>
Sent:	Wednesday, October 15, 2014 9:28 AM
To:	Nankivel, Carol (MPCA)
Subject:	Comments, Planned Amendments to Water Quality Standards to incorporate a classification system based on application of tiered aquatic life uses.

Hello, Carol,

I am concerned about these proposed amendments for tiered aquatic life uses. The biological principles are important to be included in the rules, but the rules must include more protection to assure water bodies actually are appropriately tiered.

As I read the proposed rule, some impacted streams could be tiered in such a way that those streams would remain impacted, which would not comply with the federal Clean Water Act. The CWA goal is to minimize impacts AND RESTORE waters. The designation for each water body can easily be subject to subtle influences if precautions are not written into the rules.

The tier designation for each water body must be based on the water body's original, native condition. If it is unknown, as the 7050 rules state for other purposes, a similar water body that is known to be unimpacted by man must be used to identify its native condition. To achieve this, the rules must allow all data with proper Quality Assurance/ Quality Control including that older than 1985 to be acceptable.

The rules should require public comment on the recommended tier for each water body, so that community involvement in the tier decisions and management is provided.

Subsequent to that native tier designation, the proposed should require short-term and long-term processes for impacted water bodies to be
restored. The short-term and long-term restoration process for each
water body should also be open to public comment.

The new rule should provide that new tiered designations and processes are automatically incorporated into NPDES permits, so that the established process must be addressed by a permittee within a year of a water body designation. This would resolve the MPCA's "difficulty" with finding time to amend permits to include the new rules.

Sincerely,

Maureen Johnson

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

OCT 16 2014

RECEIVED
OCT 20 2014
BY:

REPLY TO THE ATTENTION OF:
WQ-161

Carol Nankivel
MPCA/RMAD
520 Lafayette Road
St. Paul, MN 55155-4194
[transmitted electronically: carol.nankivel@state.mn.us]

Dear Ms. Nankivel:

Thank you for the opportunity to review Minnesota's Planned Amendments to Water Quality Standards to Incorporate a Classification System Based on the Application of Tiered Aquatic Life Uses that are currently available for public review and comment. My staff have completed review of the planned revisions to Minnesota's water quality standards at 7050, 7052, and 7053. We have no comments or recommendations to make on the planned revisions at this time. We commend the Minnesota Pollution Control Agency on its effort to incorporate a refined aquatic life use classification system and corresponding biological standards into Minnesota's water quality standards.

These comments are the U.S. Environmental Protection Agency's preliminary review for purposes of technical support of Minnesota's rulemaking efforts and do not constitute a final EPA action under section 303(c) of the Clean Water Act. Consistent with section 303(c) of the Clean Water Act, EPA must approve or disapprove new and revised water quality standards following adoption by the state and submittal of the adopted standards to EPA.

We look forward to working with the State as the rulemaking moves forward and reviewing the final rule when it is adopted. If you have any questions please contact Ed Hammer at (312) 886-3019.

Sincerely,

Linda Holst

Linda Holst
Chief, Water Quality Branch

cc: Mark Tomasek [Mark.Tomasek@state.mn.us]
Will Bouchard [Will.Bouchard@state.mn.us]

Department of Public Works
James Tolaas, P.E., Director and County Engineer

1425 Paul Kirkwold Drive
Arden Hills, MN 55112-3933 • (651) 266-7100 • Fax (651) 266-7110
E-mail: Public.Works@co.ramsey.mn.us

RECEIVED SEP 12 2014 BY:

September 10, 2014

Carol Nankivel
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155-4194

RE: Comments on Planned Amendments to Water Quality Standards for Tiered Aquatic Life Uses in Rivers and Streams

Dear Ms. Nankivel:

Below are comments submitted on behalf of Ramsey County on the proposed amendments to the Water Quality Standards related to the Tiered Aquatic Life Uses (TALU) classification for rivers and streams. I have based my comments on review of the related framework and preliminary concept plan documents cited on the MPCA TALU webpage.

Comments

The County supports the implementation of the state's WQS standards to incorporate TALU criteria. Measurement of representative biological assemblages should reflect the combined influence of all stressors better than a single or specific chemical or physical parameter. Coordination with the revolving watershed monitoring approach should increase the ability to monitor water quality improvements as well as modify the WQS's as additional monitoring data are available. The TALU criteria are associated with designated use categories, including Exceptional, General, Modified, and Limited, that can be used in management, planning, assessment, and regulatory activities.

The preliminary concept plan states that the TALU classifications will be defined in revised 7050.0222. All rivers and streams will be listed in 7050.0470 with their identified TALU designated use. At present very few (less than 5) Ramsey County rivers and streams are listed in 7050.0470.

- Will only streams listed in the revised 7050.0470 be regulated by the planned TALU classification system?
- Will the list of Ramsey County streams included in the revised 7050.0470 be consistent with the DNR's Public Water Inventory watercourses, which currently has 19 watercourses; or will it include additional streams or segments that are identified using the MPCA website's lake and stream search tool?
- Will public ditches be included in TALU?

The TALU classification depends on identifying minimally disturbed reference streams to determine attainable use levels. Most Ramsey County streams are generally described by planned Waterbody Types Southern Streams, Southern Headwaters, and Low Gradient.

- Have reference streams been identified throughout the Metro Area to develop numerical criteria for Waterbody Types applicable to Ramsey County streams?
- Do planned TALU numerical criteria for these Waterbody Types reflect the range of urban land use found within Ramsey County?

Ramsey County appreciates the opportunity to comment on the planned amendments to the State's Water Quality Standards for rivers and streams. If I can clarify any of my comments, please contact me at (651) 266-7160.

Sincerely,

Terry Noonan

Terry Noonan
Environmental Services Supervisor & Project Manager – Water Resources

Nankivel, Carol (MPCA)

From:	Valerie J Brady <vbrady@d.umn.edu>
Sent:	Monday, August 25, 2014 11:04 AM
To:	Nankivel, Carol (MPCA)
Cc:	'Jo Thompson'; 'Sue Lawson'
Subject:	TALU: what additional protections for exceptional waters?

Carol:

I live in Duluth Township, east of Duluth. We have a number of trout streams that flow through our township, so it is likely that most of these will be classed as exceptional/high quality waters under TALU. I am also an aquatic ecologist with the Natural Resources Research Institute, University of Minnesota Duluth, and have sampled aquatic macroinvertebrates, fish, and habitat on many of these streams, so I'm familiar with the resources, critters, and the basics of TALU.

Our township does its own planning and zoning regulation, and we have tried to strike a good balance between environmental protection and private property rights, and have required at least the minimum setbacks from streams and water bodies, and greater setbacks and restrictions in steep and vulnerable areas.

The request for public comments specifically asks if local governments will be required to create new ordinances or change/add regulations as a result of implementing TALU. However, I've not been able to find anything on the TALU webpages that hints at what the increased requirements for protection of exceptional/high quality waters might be under TALU. Without that information, it is difficult to determine what our township may have to do.
Can you please point me to this information so that our township can understand the implications and make an informed response during this comment period?

Thank you,
Valerie Brady

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Valerie Brady, PhD, Research Associate
Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Hwy
Duluth, MN 55811
Ph: 218-720-4353; fax: 218-720-4328
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