Biological Condition Gradient (BCG) Assessment Models for Lake Fish Communities of Minnesota

FINAL REPORT


Photos provided by MNDNR

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EXECUTIVE SUMMARY

The objective of the Clean Water Act is to "restore and maintain physical, chemical and biological integrity of the Nation's waters." To meet this goal, we need a uniform interpretation of biological condition and operational definitions that are independent of different assessment methodologies. These definitions must be specific, well-defined, and allow for waters of different natural quality and different desired uses. The US EPA has outlined a tiered system of aquatic life use designation, along a gradient (the Biological Condition Gradient, or BCG) that describes how ecological attributes change in response to increasing levels of human disturbance. The Biological Condition Gradient is a conceptual model that describes changes in aquatic communities. It is consistent with ecological theory and has been verified by aquatic biologists throughout the US.

Specifically, the BCG describes how ten biological attributes of natural aquatic systems change in response to increasing pollution and disturbance. The ten attributes are in principle measurable, although several are not commonly measured in monitoring programs. The gradient represented by the BCG has been divided into 6 BCG levels of condition that biologists think can be readily discerned in most areas of North America, ranging from "natural or native condition" (Level 1) to "Severe changes in structure and major loss of ecosystem function" (Level 6).

This report summarizes the findings of a panel of aquatic biologists from the Minnesota Department of Natural Resources (MNDNR), the Minnesota Pollution Control Agency (MPCA), the Midwest Biodiversity Institute (MBI) and an independent contractor, who applied and calibrated the general BCG model to lakes in Minnesota. The panel was challenged to 1) assign Biological Condition Gradient attributes to fish species recorded in the dataset and 2) to achieve consensus in assigning lakes into BCG levels using the fish assemblage data. The rules used by the panelists were compiled, tested, and refined, and vetted with the panel through a series of meetings and webinars. The end products were quantitative BCG models for 4 lake groups (referred to as Groups 2, 4, 5 and 7) to predict the BCG level of a lake based on the rules developed by the panel. The BCG models for Groups 2 and 5 were calibrated for different lake size classes (based on lake surface area). In total, 194 samples were assessed. Of these, 158 were used to calibrate the models, and 36 samples were assessed to confirm the models. The Group 2 and 4 models correctly assessed 100% of the calibration and confirmation samples, the Group 5 models correctly assessed 93% of the calibration samples and 89% of the confirmation samples, and the Group 7 model correctly assessed 100% of the calibration samples and 75% of the confirmation samples.

Minnesota is in the process of revising its Water Quality Standards and Criteria to better protect designated uses of the waters and to provide goals for restoration and improvement of Minnesota's waters. For stream and rivers, they have proposed a framework based on Tiered Aquatic Life Uses (TALU), which are assigned to water bodies based on the protection and restoration of ecological potential. When developing the TALU framework, a critical component is the use of the BCG to identify thresholds for the different tiers; these thresholds then are set as the numeric criteria for water body assessment, regulation, and management (MPCA 2014). The calibrated lake BCG models, in combination with the river and stream BCG models that have

been developed by MPCA, will allow Minnesota to extend the TALU framework to assessment and criteria for lakes, and can be used to express goals and criteria for classes of water bodies in terms of their biological condition or response, including, for example, setting criteria for exceptional waters of the states, as well as defining attainable restoration goals for impaired waters.

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ACRONYMS

BCG	Biological Condition Gradient
CWA	Clean Water Act
IBI	Index of Biological Integrity
MN	Minnesota
MNDNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
MBI	Midwest Biodiversity Institute
SOP	Standard Operating Procedure
TALU	Tiered Aquatic Life Use

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1 INTRODUCTION

Minnesota is in the process of revising its Water Quality Standards and Criteria to better protect designated uses of the waters and to provide goals for restoration and improvement of Minnesota's waters. Instead of a one-size-fits-all framework, Minnesota has proposed to develop Tiered Aquatic Life Uses (TALU) in four categories: Exceptional waters (highest quality), General Use waters (meeting interim goal Clean Water Act criteria; also known as "fishable – swimmable"), Modified waters (waters with legacy physical modifications), and Limited Use waters (waters that are severely and irretrievably altered) (Yoder 2012, MPCA 2014). Details of the proposed criteria framework for streams are in MPCA 2014. The Exceptional Waters category will be especially important to protect the highest quality lakes of Minnesota.

A critical component of developing the TALU framework is the use of the Biological Condition Gradient (BCG) to identify thresholds for each of the tiers; these thresholds then are set as the numeric criteria for water body assessment, regulation, and management (MPCA 2014). Quantitative Biological Criteria for TALU have been proposed by MPCA (2014) for rivers and streams, assessed with benthic macroinvertebrate and fish sampling. The criteria are expressed as IBI scores, and were developed as thresholds based on BCG levels corresponding to points that would be protective of the tiered uses (MPCA 2014).

MPCA is considering extending the TALU framework to assessment and criteria for lakes, and hence required BCG development for lake biota. This document describes the calibration of assessment models in the framework of the Biological Condition Gradient (BCG) for lakes in Minnesota. Up until now, BCG development and calibration have been performed for flowing waters, and to a more limited extent, for estuaries and coral reef systems. This is the first known application for lakes. We focused on fish because expert panels have judged fish to be good indicators for the BCG in several open-water ecosystem types, and a fish Index of Biological Integrity (IBI) has been successfully developed and tested for small Minnesota lakes (Drake and Pereira 2002, Drake and Valley 2005) and expanded more recently to additional lake sizes and types.

The objective of this project is to develop and calibrate a BCG model for sampled fish in Minnesota lakes, to be consistent with the existing BCG models that have been developed for Minnesota's streams. The models incorporate multiple attribute decision criteria to assign lakes to levels of the BCG. The models were developed using data from the Minnesota Department of Natural Resources (MNDNR). Participants included scientists from the Minnesota Pollution Control Agency (MPCA), MNDNR, the Midwest Biodiversity Institute (MBI) and an independent contractor with expertise on nongame fish. The calibrated lake BCG models, in combination with the stream BCG models (Gerritsen et al. 2013, Gerritsen and Stamp 2012), will allow Minnesota to express goals and criteria for classes of water bodies in terms of their biological condition or response, including, for example, setting criteria for exceptional waters of the state, as well as defining attainable restoration goals for impaired waters.

1.1 The Biological Condition Gradient

The Biological Condition Gradient (BCG) is a conceptual, narrative model that describes how biological attributes of aquatic ecosystems change along a gradient of increasing anthropogenic stress. It provides a framework for understanding current conditions relative to natural, undisturbed conditions. Some states, such as Maine and Ohio, have used a BCG framework to more precisely define their designated aquatic life uses, monitor status and trends, and track progress in restoration and protection (USEPA 2011). These two states and many others have used biological assessments and BCG-like models to support water quality management over several decades. Based on these efforts, USEPA worked with biologists from across the United States to develop the BCG conceptual model (Davies and Jackson 2006.) The BCG shows an ecologically-based relationship between anthropogenic stressors affecting a waterbody (the physical, chemical, biological impacts) and the response of the aquatic community, manifested as the biological condition. The model can be adapted or calibrated to reflect specific geographic regions and waterbody type (e.g., streams, rivers, wetlands, estuaries, lakes). Approaches to calibrate the BCG to region-, state-, or tribe-specific conditions have been applied in several ecological regions by multiple states and tribes.

Practitioners can use the BCG to interpret biological condition along a standardized gradient regardless of assessment method and apply that information to different state or tribal programs. For example, Pennsylvania is using a BCG calibrated to its streams to identify exceptional and high-quality waters based on biological condition (exceptional waters may also be identified with other criteria, say, scenic or recreational value) (USEPA 2011).

The BCG is divided into six levels of biological condition along the stressor-response curve, ranging from observable biological conditions found at no or low levels of stress (level 1) to those found at high levels of stress (level 6) (Figure 1):

> **Level 1.** Native structural, functional, and taxonomic integrity is preserved; ecosystem function is preserved within range of natural variability. Level 1 describes waterbodies that are pristine, or biologically indistinguishable from pristine condition.
>
> **Level 2.** Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability.
>
> **Level 3.** Some changes in structure due to loss of some highly sensitive native taxa; shifts in relative abundance of taxa but sensitive–ubiquitous taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system, but may differ quantitatively.
>
> **Level 4.** Moderate changes in structure due to replacement of sensitive–ubiquitous taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes.
>
> **Level 5.** Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological

stress; system function shows reduced complexity and redundancy; increased buildup or export of unused organic materials.

Level 6. Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities and distributions; organism condition is often poor (e.g. diseased individuals may be prevalent); ecosystem functions are severely altered.

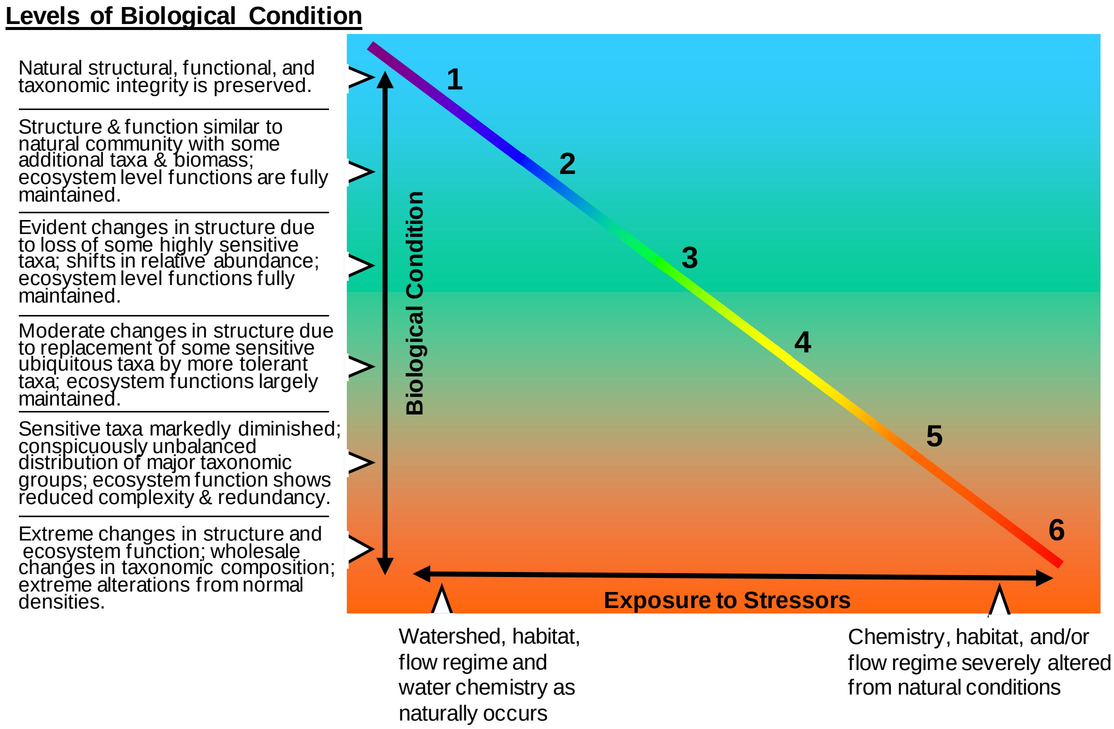

Figure 1. The Biological Condition Gradient (BCG), modified from Davies and Jackson 2006. The BCG was developed to serve as a scientific framework to synthesize expert knowledge with empirical observations and develop testable hypotheses on the response of aquatic biota to increasing levels of stress. It is intended to help support more consistent interpretations of the response of aquatic biota to stressors and to clearly communicate this information to the public, and it is being evaluated and piloted in several regions and states.

The scientific panels that developed the BCG conceptual model identified 10 attributes of aquatic ecosystems that change in response to increasing levels of stressors along the gradient, from level 1 to 6 (see Table 1). The attributes include several aspects of community structure, organism condition, ecosystem function, spatial and temporal attributes of stream size, and connectivity.

Each attribute provides some information about the biological condition of a waterbody. Combined into a model like the BCG, the attributes can offer a more complete picture about current waterbody conditions and also provide a basis for comparison with naturally expected waterbody conditions. All states and tribes that have applied a BCG used the first seven attributes that describe the composition and structure of biotic community on the basis of the tolerance of species to stressors and, where available, included information on the presence or absence of native and nonnative species and, for fish and amphibians, observations on overall condition (e.g., size, weight, abnormalities, tumors).

Table 1. Biological and other ecological attributes used to characterize the BCG.

Attribute	**Description**
I. Historically documented, sensitive, long-lived, or regionally endemic taxa	Taxa known to have been supported according to historical, museum, or archeological records, or taxa with restricted distribution (occurring only in a locale as opposed to a region), often due to unique life history requirements (e.g., sturgeon, American eel, pupfish, unionid mussel species).
II. Highly sensitive (typically uncommon) taxa	Taxa that are highly sensitive to pollution or anthropogenic disturbance. Tend to occur in low numbers, and many taxa are specialists for habitats and food type. These are the first to disappear with disturbance or pollution (e.g., most stoneflies, brook trout [in the east], brook lamprey).
III. Intermediate sensitive and common taxa	Common taxa that are ubiquitous and abundant in relatively undisturbed conditions but are sensitive to anthropogenic disturbance/pollution. They have a broader range of tolerance than Attribute II taxa and can be found at reduced density and richness in moderately disturbed sites (e.g., many mayflies, many darter fish species).
IV. Taxa of intermediate tolerance	Ubiquitous and common taxa that can be found under almost any conditions, from undisturbed to highly stressed sites. They are broadly tolerant but often decline under extreme conditions (e.g., filter-feeding caddisflies, many midges, many minnow species).
V. Highly tolerant taxa	Taxa that typically are uncommon and of low abundance in undisturbed conditions but that increase in abundance in disturbed sites. Opportunistic species able to exploit resources in disturbed sites. These are the last survivors (e.g., tubificid worms, black bullhead).
VI. Nonnative or intentionally introduced species	Any species not native to the ecosystem (e.g., Asiatic clam, zebra mussel, carp, European brown trout). Additionally, there are many fish native to one part of North America that have been introduced elsewhere.
VII. Organism condition	Anomalies of the organisms; indicators of individual health (e.g., deformities, lesions, tumors).
VIII. Ecosystem function	Processes performed by ecosystems, including primary and secondary production; respiration; nutrient cycling; decomposition; their proportion/dominance; and what components of the system carry the dominant functions. For example, shift of lakes and estuaries to phytoplankton production and microbial decomposition under disturbance and eutrophication.
IX. Spatial and temporal extent of detrimental effects	The spatial and temporal extent of cumulative adverse effects of stressors; for example, groundwater pumping in Kansas resulting in change in fish composition from fluvial dependent to sunfish.
X. Ecosystem connectivity	Access or linkage (in space/time) to materials, locations, and conditions required for maintenance of interacting populations of aquatic life; the opposite of fragmentation. For example, levees restrict connections between flowing water and floodplain nutrient sinks (disrupt function); dams impede fish migration, spawning. Extensive burial of headwater streams leads to cumulative downstream impacts to biota through energy input disruption, habitat modification, and loss of refugia and dispersing colonists.

Source: Modified from Davies and Jackson 2006.

The last three BCG attributes of ecosystem function, connectivity, and spatial and temporal extent of detrimental effects can provide valuable information when evaluating the potential for a waterbody to be protected or restored. For example, a manager can choose to target resources and restoration activities to a stream where there is limited spatial extent of stressors or there are adjacent intact wetlands and stream buffers or intact hydrology versus a stream with comparable biological condition but where adjacent wetlands have been recently eliminated, hydrology is being altered, and stressor input is predicted to increase.

1.2 Calibrating the Conceptual BCG Model to Local Conditions

The BCG can serve as a starting point for defining the response of aquatic biota to increasing levels of stress in a specific region. The model can be applied to any region or waterbody by calibrating it to local conditions using specific expertise and local data. To date, most states and tribes are calibrating the BCG using the first seven attributes that characterize the biotic community primarily on the basis of tolerance to stressors, presence/absence of native and nonnative species, and organism condition.

A multistep process is followed to calibrate a BCG to local conditions (Figure 2); to describe the native aquatic assemblages under natural conditions; to identify the predominant regional stressors; and to describe the BCG, including the theoretical foundation and observed assemblage response to stressors. Calibration begins with the assembly and analysis of biological monitoring data. Next, a calibration workshop is held in which experts familiar with local conditions use the data to define the ecological attributes and set narrative statements; for example, narrative decision rules for assigning sites to a BCG level on the basis of the biological information collected at sites. Documentation of expert opinion in assigning sites to BCG levels is a critical part of the process. A decision model can then be developed that encompasses those rules and is tested with independent data sets. A decision model based on the tested decision rules is a transparent, formal, and testable method for documenting and validating expert knowledge. A quantitative data analysis program can then be developed using those rules.

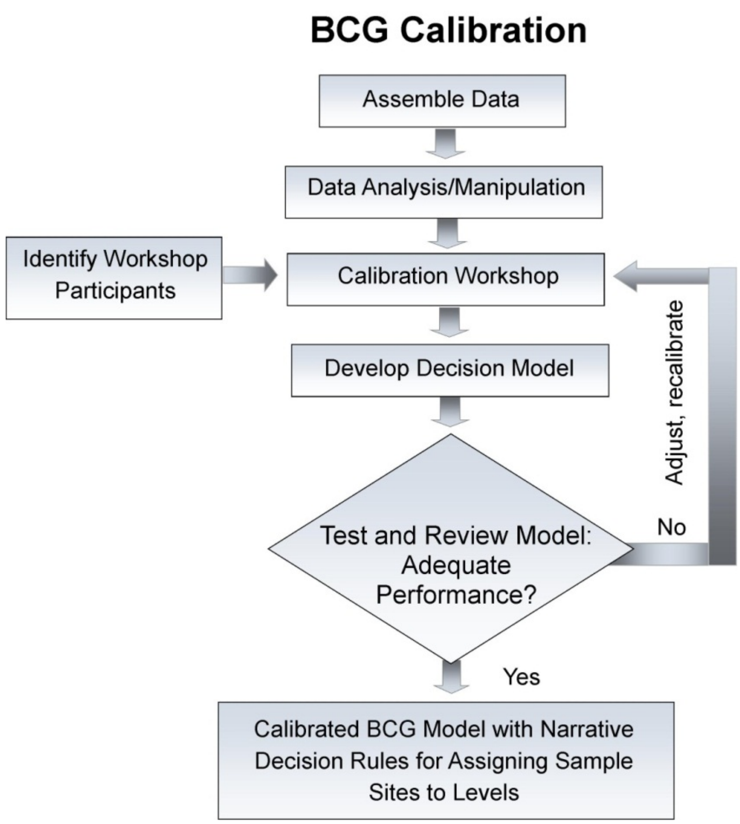

Figure 2. Steps in a BCG calibration.

2 METHODS AND DATA

General methods of calibrating a BCG model are described in Gerritsen et al. (2013), and will not be repeated here. Below, we describe methods specific to the calibration process for Minnesota's lakes.

2.1 Biological Data

MNDNR provided the data that were used for this project. The dataset was comprised of 650 samples from 545 unique lakes, and included data collected from 2005 to 2013. MNDNR utilizes three different collection methods when sampling lake fish communities: active gears (seining and electrofishing) for nearshore sampling following the methods of Drake and Pereira (2002) and Drake and Valley (2005), and passive gears (trap nets and gill nets) for sampling littoral and limnetic areas, respectively, using MNDNR's lake survey methods (MNDNR 1993). Data from all these sampling methods were used for the BCG calibration exercise.

Nearshore sampling was conducted from June 10 – September 20. Adjustments were made for late springs or early falls if it was suspected that fish were out of their typical summer pattern or the lake had turned over. Shoreline seining and electrofishing were combined to obtain a single representation of the nearshore fish assemblage (Drake and Pereira 2002). Nearshore samples were collected at 30-m long sampling stations equally spaced along the lakeshore. The number of nearshore sampling stations ranged from 10 to 24 depending on lake size (Table 2). On average, the nearshore method sampled 6% of the total shoreline for lakes of 100 – 500 acres (Drake and Pereira 2002), but a smaller percentage for larger lakes.

Table 2. Target number of nearshore sampling stations by lake size.

Lake Surface Area (acres)	# of Stations
< 500 acres	10
500 to 1199	14
1200 to 1999	18
>2000	24

Two electrofishing passes were conducted at each station: one near the shoreline and one at a depth of approximately 75–100 cm. In addition, one 30-m seine haul parallel to the shoreline and out to the length of the seine or to the maximum wadeable depth (approximately 1.3-m) was completed at each station. The seine was 15.2 X 1.5-m with a bag and 3-mm nylon mesh. In cases where a 15-m seine could not be deployed across the entire station, crews seined as much of the area as possible. In some cases, a 4.5 X 1.5-m seine was used. Electrofishing is limited by high specific conductivity (>0.500 mmho/cm) and turbidity, while the seining can be limited by inshore depth gradients, substrate firmness, and vegetation.

At each station, species were identified and counted. Seining and electrofishing data from all stations on a lake were combined, and a voucher of each species was retained for species assignment verification. Shoreline seining and backpack electrofishing were typically completed on the same day, but if not, as close to the same day as possible. Approximately 70% of the species found in a lake were collected by nearshore sampling and typically included more intolerant, habitat specialist, small nongame species like darters and cyprinids (Drake and Pereira 2002, Drake and Valley 2005).

Trap netting occurred between May and September. The number of trap nets set per lake depended on lake size. Trap net sites were chosen to represent available habitats, and were generally set perpendicular to shore in water less than 2.4-m in depth. Trap nets had a 12.2-m lead and were approximately 1.1-m deep with two 1.8 x 0.9-m frames and six 0.76-m hoops with a 13-cm-diameter throat. All mesh was 19-mm bar nylon. Nets were set overnight and emptied the next day. Species were identified, counted, and measured, and a subset weighed. Standard length-weight regression equations were used to estimate weights of unweighed fish.

Gill netting took place between June and September. As with the trap nets, the number of gill nets set per lake depended on lake size, and net sites were chosen to represent available habitats. Gill nets were generally set in offshore areas in water deeper than 2.7-m. Fish are captured by swimming into the net and becoming entangled. Gill nets were 76-m x 1.8-m with six 15.2-m panels of 19-, 25-, 32-, 38-, and 51-mm bar mesh (MNDNR 1993). Nets were set overnight and emptied the next day. Species were identified, counted, measured and in some cases weighed. Standard length-weight regression equations were used to estimate weights of unweighed fish.

Some of the samples from the original dataset were excluded from the BCG calibration dataset for the following reasons:

1) concerns about identifications based on vouchered specimens.
2) if sites had a history of observed winterkill within 10 years prior to the survey.
3) if staff did not complete seining or backpack electrofishing sampling on at least 5 stations.
4) if nearshore survey work was done before June 10 or after September 20.
5) if lakes were less than 100 acres.
6) if lakes were riverine or were substantially altered by impoundment.
7) if a lake had a significant open-water connection to a larger lake, such that the fish community could not be considered independent of the connected lake.

2.2 Classification

Experience has shown that a robust biological classification is necessary to calibrate the BCG, because the natural biological class indicates the species expected to be found in undisturbed, high-quality sites. To use streams as an example, low-gradient prairie or wetland-influenced streams typically contain species that are adapted to slow-moving water and often to hypoxic conditions. These same species found in a high-gradient, forested streams could indicate habitat degradation and organic enrichment.

Schupp (1992) developed a classification scheme for Minnesota lakes, comprised of 44 classes based on a combination of factors such as lake size, depth, water chemistry and fish assemblages. For this project, we evaluated lakes from a subset of Schupp Lake Classes (20-43). For purposes of BCG model development, lakes from the different Schupp classes were collapsed into 4 broad groups, as follows:

- Group 2: contains Schupp classes 20, 22, 23, 24, 25and 27
- Group 4: contains Schupp classes 28, 29, 30 and 31
- Group 5: contains Schupp classes 32, 34, 35 and 39
- Group 7: contains Schupp classes 38, 41, 42 and 43

These broad groupings were informed by analyses conducted by MNDNR. The MNDNR analyses were based on 8 lake attributes: total area, maximum depth, proportion littoral area, shoreline development index, total alkalinity, volume, area:shoreline ratio, and growing degree days. Figures 3 and 4 show the distributions of morphological characteristics (lake area, littoral area and maximum depth) and three measures of trophic state (phosphorus, chlorophyll a and Secchi depth) within the lake groups, and Figure 5 shows the spatial distribution of lakes assessed in this report across Minnesota, coded by lake group.

On average, Group 2 lakes are the deepest. They span a wide range of sizes, and phosphorus and chlorophyll a concentrations are generally low (Figures 3 & 4). For purposes of BCG model calibration, lakes in Group 2 were subdivided into 3 groups based on lake area: ≤ 700 acres, 701 to 2500 acres and > 2500 acres. BCG models were calibrated for each of these 3 size classes. Thresholds were selected based on input from the expert panel and from evaluations of fish richness versus lake area plots.

Group 4 lakes are generally the smallest and tend to have low total phosphorus and chlorophyll *a* concentrations. Group 5 lakes are slightly larger and shallower than Group 4 lakes and have slightly higher phosphorus and chlorophyll a concentrations (Figure 3 & 4). For the BCG calibration exercise, the Group 5 lakes were divided into 2 size classes: ≤ 300acres and > 300 acres. Finally, Group 7 lakes are the shallowest, have more littoral area and higher phosphorus and chlorophyll *a* concentrations than the other lake groups (Figure 3 & 4). Group 7 lakes occur primarily in the southern part of Minnesota (Figure 5), where agricultural land use is prevalent.

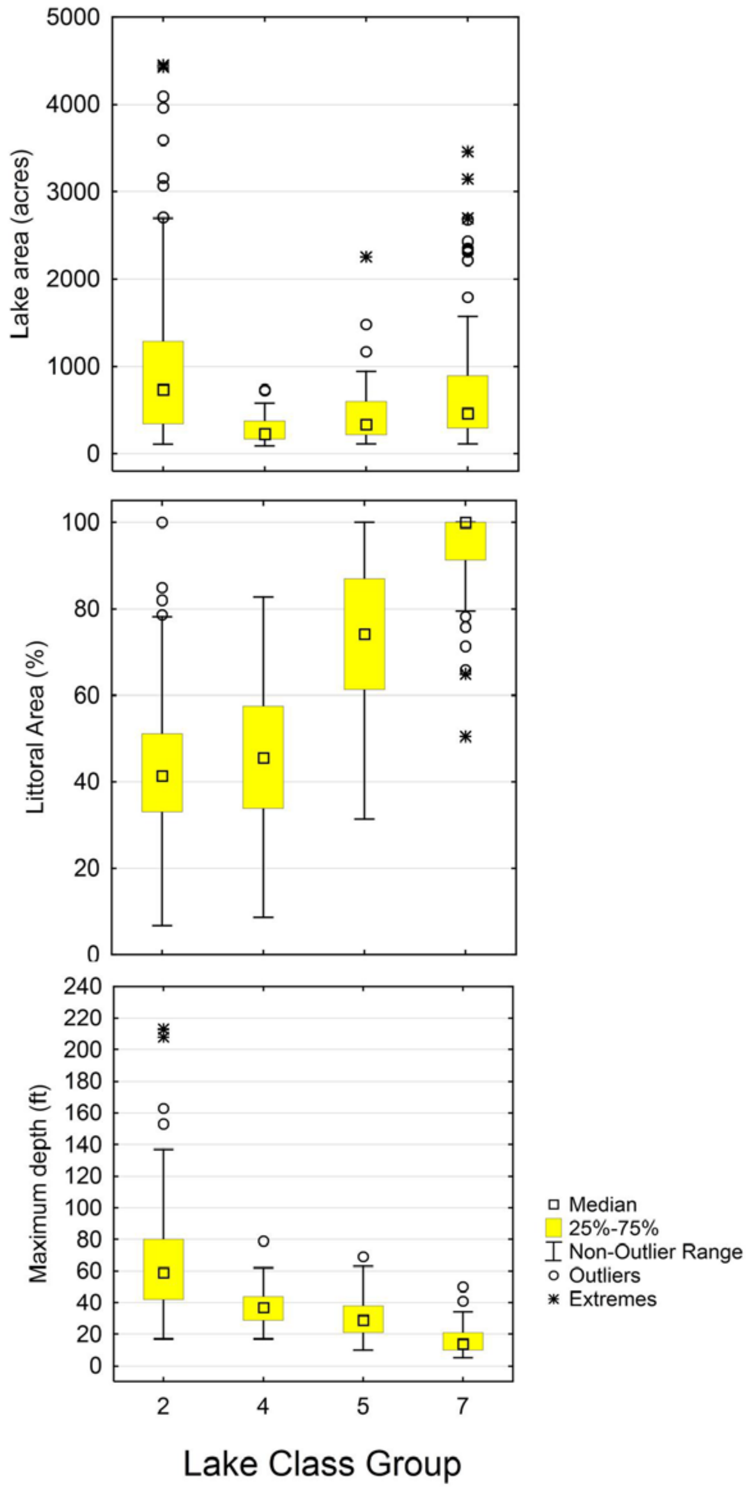

Figure 3. Box plots showing distributions of morphological characteristics (lake area, percent littoral area and maximum depth) within lake class groups.

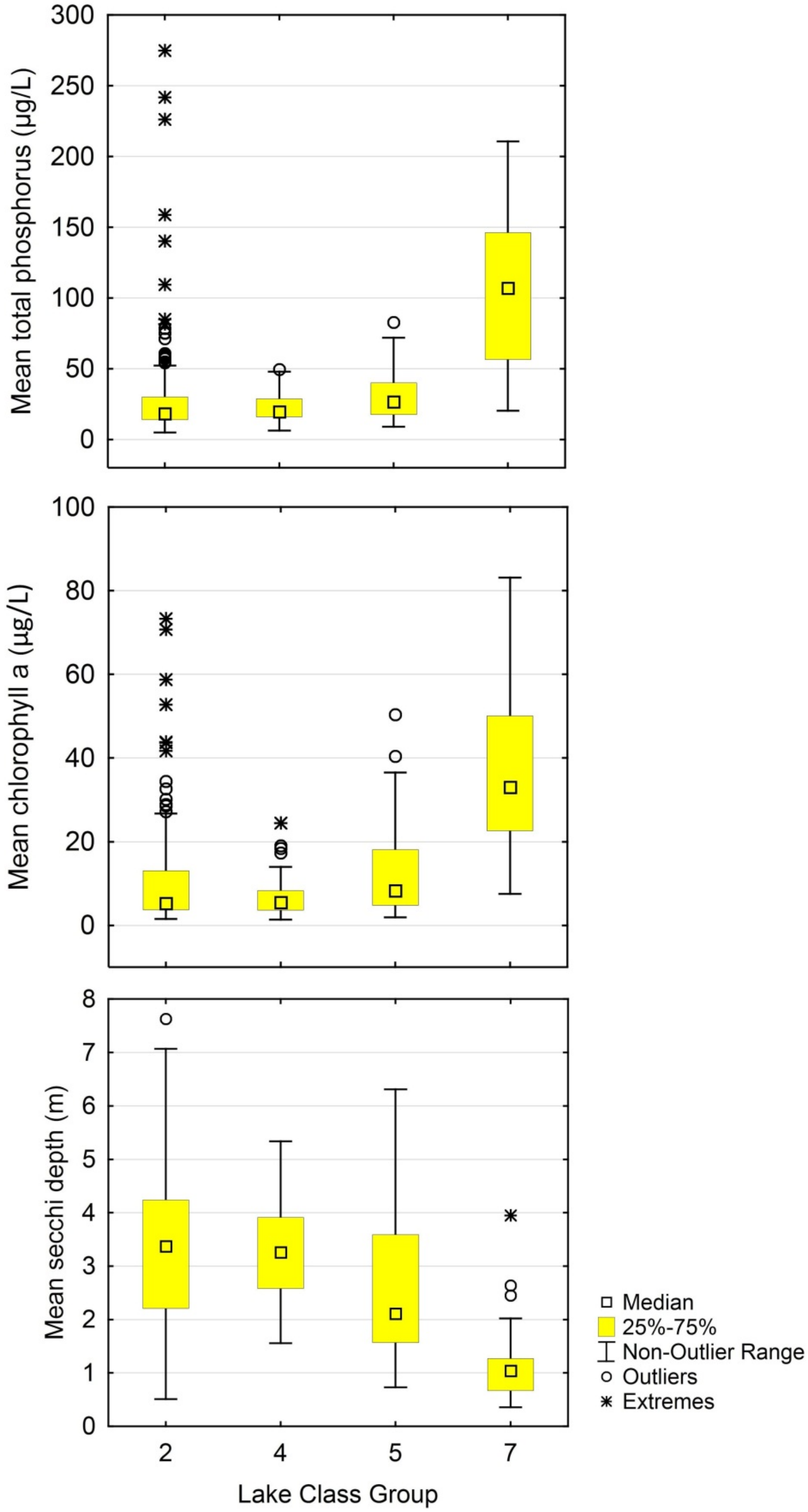

Figure 4. Box plots showing distributions of trophic state (total phosphorus, chlorophyll *a* and Secchi depth) within lake class groups.

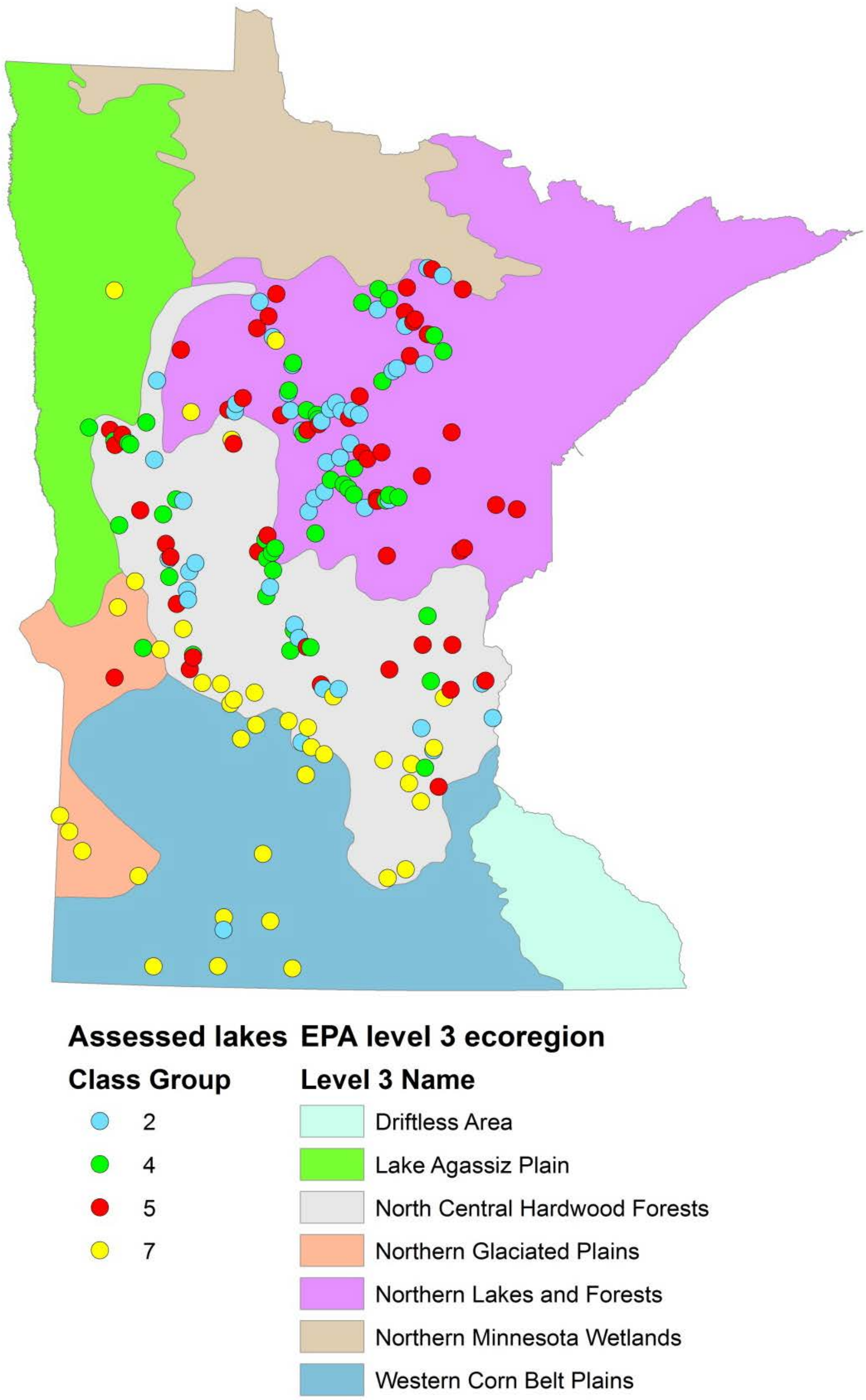

Figure 5. Locations of lakes that were assessed during the BCG exercise, coded by lake class group. EPA level 3 ecoregions (Omernik 1987) are also shown.

2.3 BCG Calibration Exercise

Calibration of the BCG for a region is a collective exercise among regional biologists to develop consensus assessments of sites, and then to elicit the rules that the biologists use to assess the sites (Davies and Jackson 2006). During October 14-17, 2013, MPCA and MNDNR convened a panel of scientists with expertise in lake ecology and fish community assessments. The experts attending the meeting included scientists from MPCA, MNDNR, MBI and an independent contractor with expertise on nongame fish.

The goal was to develop a set of decision criteria rules for assigning sites to the BCG levels for Minnesota lake fish communities. As part of this process, panelists first assigned BCG attributes to fish taxa (Appendix A). Within the tolerant group (Attribute V) panelists expressed the need to distinguish moderately tolerant from extremely tolerant taxa. Similarly, nonnative taxa can also be divided among sensitive (e.g., brown trout), intermediate (e.g., rainbow smelt), and tolerant (e.g., common carp) groups. Table 2 contains a summary of how many fish taxa were assigned to each attribute group. Examples of fish taxa that were assigned to each attribute group are listed in Table 3. Prior to making attribute assignments, panelists reviewed plots showing the capture probabilities of fish taxa versus a disturbance gradient to help inform their decisions. These plots are shown in Appendix B.

During the October workshop, the panelists examined biological data from individual lakes and assigned those samples to levels 1 to 6 of the BCG. The intent was to achieve consensus and to identify rules that experts were using to make their assignments. The data that the experts examined when making BCG level assignments were provided in worksheets. The worksheets contained lists of taxa, taxa abundances and weights, BCG attribute levels assigned to the taxa, BCG attribute metrics and limited site information, such as Schupp class, lake area, littoral area, maximum depth, trophic status, alkalinity, connectivity to streams (number of stream inflows), and land use. Participants were not allowed to view station identifiers or lake names when making BCG level assignments, as this might bias their assignments. A sample worksheet can be found in Appendix C.

A preliminary set of decision rules were developed based on these calibration worksheets. In the final session of the workshop, panelists were asked to review decisions and notes, and identify the rules they used to make those decisions. These rules were later quantified and automated in an Excel spreadsheet and BCG level assignments were calculated for each sample. The model-assigned BCG level assignments were then compared to the BCG level assignments that had been made by the panelists to evaluate model performance. Follow-up webinars were held on February 5, February 12, February 24, March 12 and April 1 to discuss rules and the performance of the models, reach consensus on samples where the BCG model output did not match exactly with the group consensus and to assess additional samples. Decision rules were adjusted based on group consensus. The models were finalized in July, after the panelists worked individually to make BCG level assignments on additional samples to confirm the BCG models for Lake Groups 4 and 5.

Quantitative rules to assign BCG levels work as a logical cascade from BCG Level 1 to Level 6. A sample is first tested against the Level 1 rules; if the combined rule fails, then the Level fails, and the assessment moves down to Level 2, and so on (Figure 6). All required rules must be true for a site to be assigned to a level. The output of the inference model may include membership of a sample in a single level only, ties between levels, and varying memberships among two or more levels. The level with the highest membership value is taken as the nominal level.

Table 3. Descriptions of the BCG attributes assigned to taxa for this exercise, plus a summary of how many taxa were assigned to each attribute group. In most cases, taxa that received attribute assignments of 'x' were riverine species, where their presence in lakes was mostly a function of lake hydrology.

BCG Attribute	Description	# Fish Taxa
I	Historically documented, sensitive, long-lived or regionally endemic taxa	6
II	Highly sensitive taxa, often occur in low abundance	6
III	Intermediate sensitive taxa	9
IV	Taxa of intermediate tolerance	24
V	Tolerant native taxa	3
Va	Extra tolerant native taxa	3
VI	Non-native taxa	7
VIi	Sensitive non-native (e.g., highly-valued recreational taxa like salmonids)	3
VIm	Non-native taxa of intermediate tolerance	2
VIt	Highly tolerant non-native taxa	2
x	No attribute assignment (insufficient information)	47
Totals		***105***

Table 4. Examples of fish by attribute group.

Ecological Attribute	Number of species	Example Species
I Endemic, rare	6	Greater redhorse, Lake sturgeon, Lake trout, Lake whitefish, Longear sunfish, Pugnose shiner
II Highly Sensitive	6	Blackchin shiner, Blacknose shiner, Burbot, Cisco, Least darter, Mottled sculpin
III Intermediate Sensitive	9	Banded killifish, Iowa darter, Logperch, Mimic shiner, Pumpkinseed, Rock bass, Smallmouth bass
IV Intermediate Tolerant	24	Black crappie, Bluegill, Bluntnose minnow, Bowfin, Brown and yellow bullhead, Central mudminnow, Hybrid sunfish, Largemouth bass, Northern pike, Walleye, Yellow perch
V Tolerant	3	Green sunfish, Freshwater drum, Bigmouth buffalo
Va – Extra tolerant	3	Black bullhead, Fathead minnow, Orangespotted sunfish
VIi Sensitive Nonnative	3	Brook trout, Brown trout, Rainbow trout
VIm Intermediate nonnative	2	Rainbow smelt, Tiger muskellunge
VIt Tolerant nonnative	2	Common carp, Goldfish

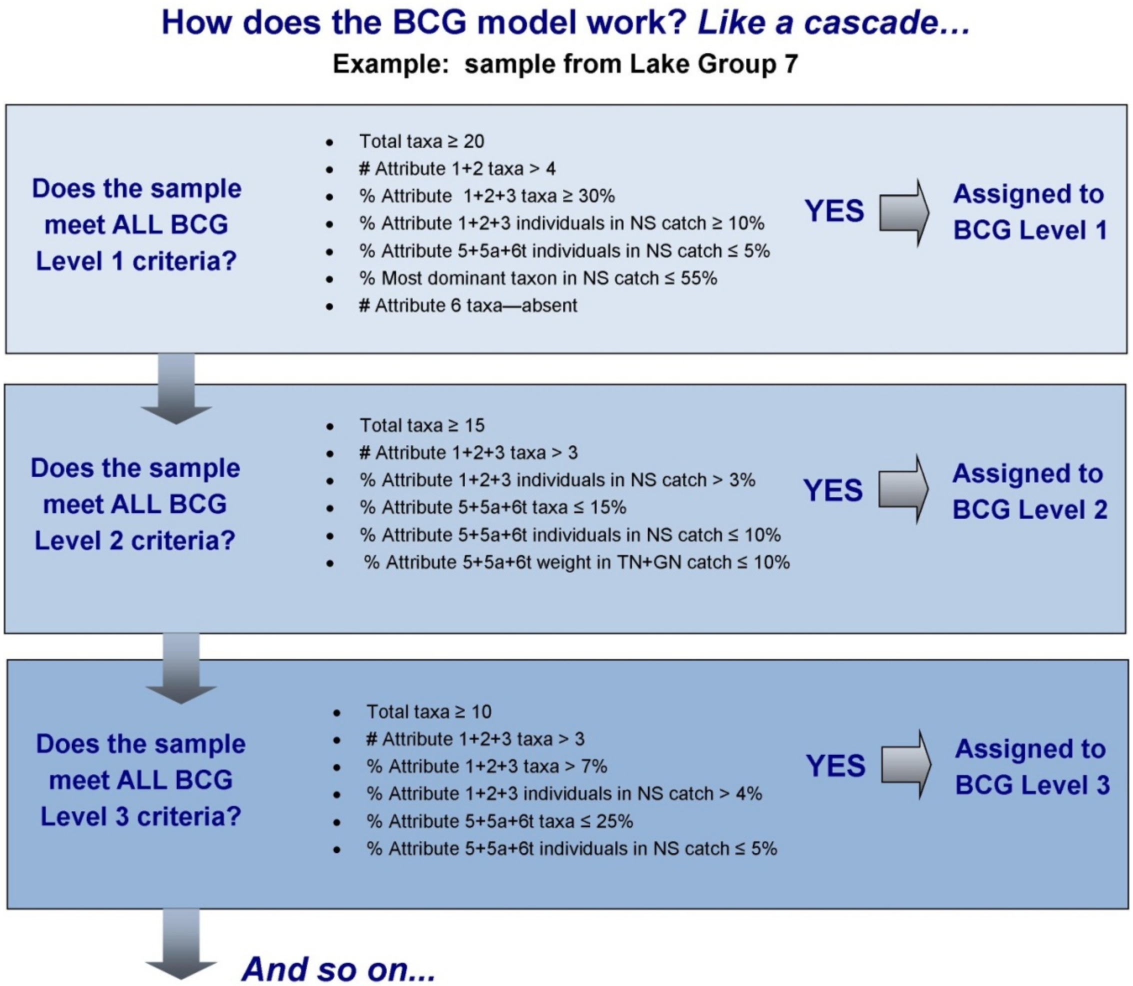

Figure 6. Example flow chart depicting how rules work as a logical cascade in the BCG model.

3 DECISION RULES AND BCG MODELS FOR LAKE GROUP 2

BCG models for Group 2 lakes were calibrated for 3 lake area-based size classes: small/medium: ≤ 700 acres; large: 701 to 2500 acres; and very large: > 2500 acres. During the calibration exercise, panelists made BCG level assignments on 40 samples. In order to confirm the model, panelists made BCG level assignments on 10 additional samples. BCG level assignments for these 50 samples are summarized in Appendix D.

3.1 Site Assignments and BCG Level Descriptions

Panelists assigned samples to 5 BCG levels (BCG levels 1-5). Most of the samples are in the small/medium and large size classes (Table 5). Locations of the assessed Group 2 lakes are shown in Figure 7. Of the 50 samples that were assessed, 22 represent very high quality waters, with 8 being assigned to BCG level 1 and 14 to BCG level 2. The 4 lakes that were assigned to BCG level 5 are located in the southern part of the state (Figure 8).

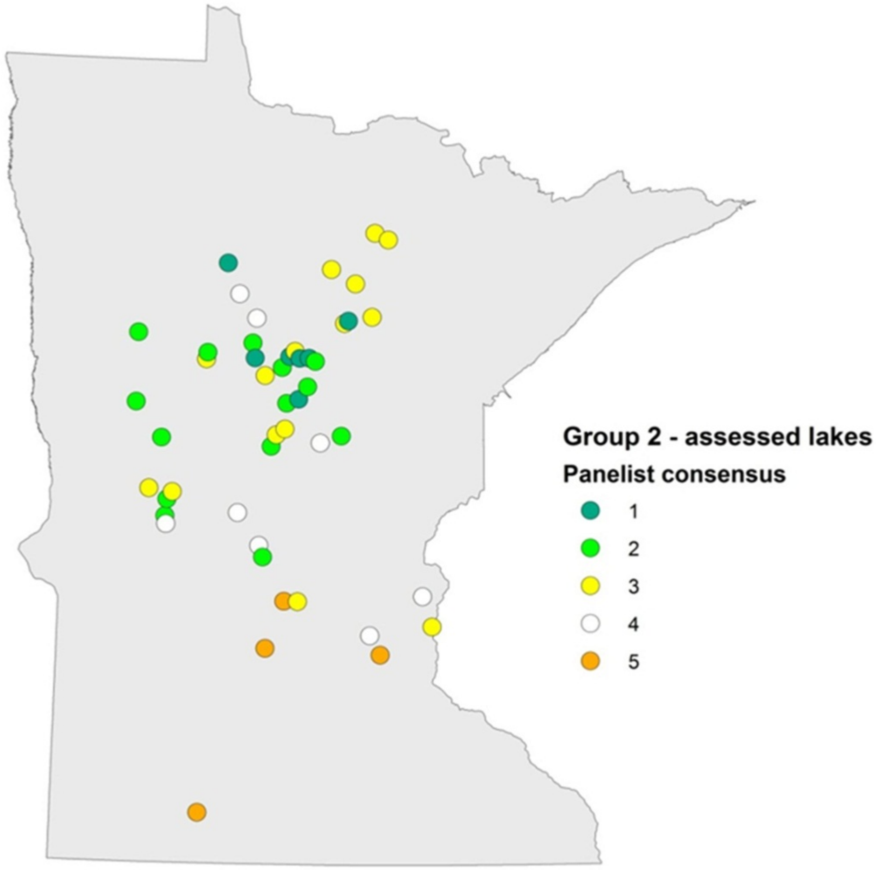

Figure 7. Locations of Group 2 lakes that were assessed during the BCG exercise, coded by panelist BCG level assignment.

Table 5. Number of Group 2 calibration and confirmation samples that were assessed, organized by BCG level (group consensus).

BCG level	Calibration			Confirmation		
	Small/Medium	Large	Very Large	Small/Medium	Large	Very Large
1	3	4	0	0	0	1
2	3	5	0	3	2	1
3	3	8	3	0	1	0
4	4	4	0	0	0	0
5	1	2	0	2	0	0
6	0	0	0	0	0	0
Totals	***14***	***23***	***3***	***5***	***3***	***2***

3.2 BCG Attribute Metrics

Examinations of taxonomic attributes among the BCG levels determined by the panel showed that several of the attributes are useful in distinguishing levels, and indeed, were used by the panel's biologists for decision criteria. The most important considerations were number of total taxa and richness, abundance and biomass metrics related to sensitive (Attribute I, II, III) and tolerant (Attribute V, Va, VIt) organisms. The total richness metric increased with lake size, consistent with known species-area relationships (Figure 8). Tolerant taxa metrics increased and sensitive taxa metrics decreased as the assigned BCG levels increased from 1 to 5 (Figure 9). The number of Attribute I+II taxa metric is particularly effective at discriminating between BCG levels 1, 2 and 3, and the percent Attribute V+Va+VIt taxa metric discriminates well between BCG levels 4 and 5. Box plots for all metrics that were considered during the Group 2 calibration process can be found in Appendix E.

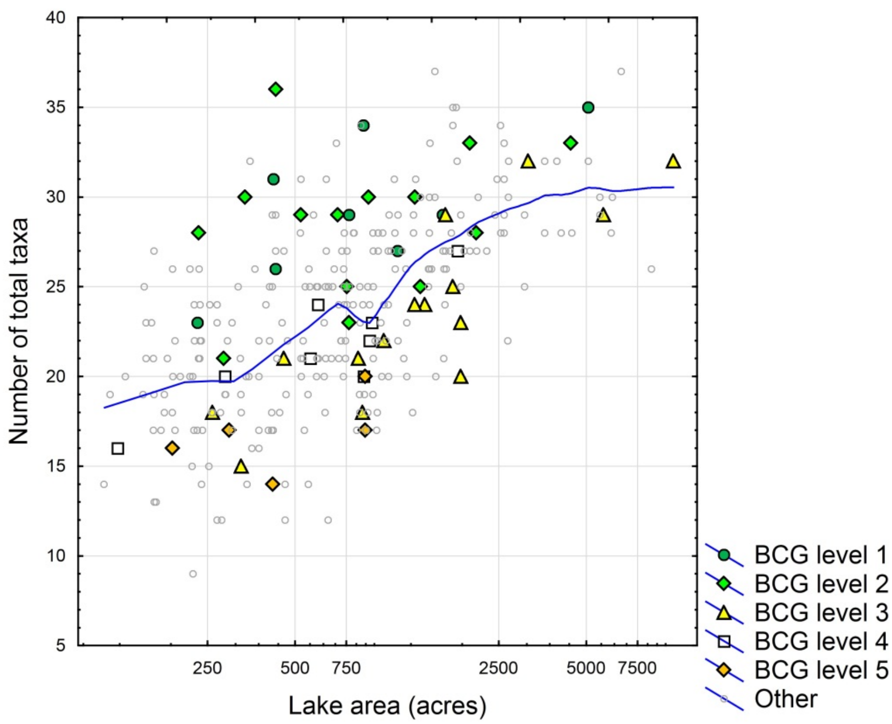

Figure 8. Relationship between total taxa metric values and lake area for Group 2 samples, fit with a Lowess trend line. Samples are coded by nominal BCG level (group median choice). The x-axis is log-transformed.

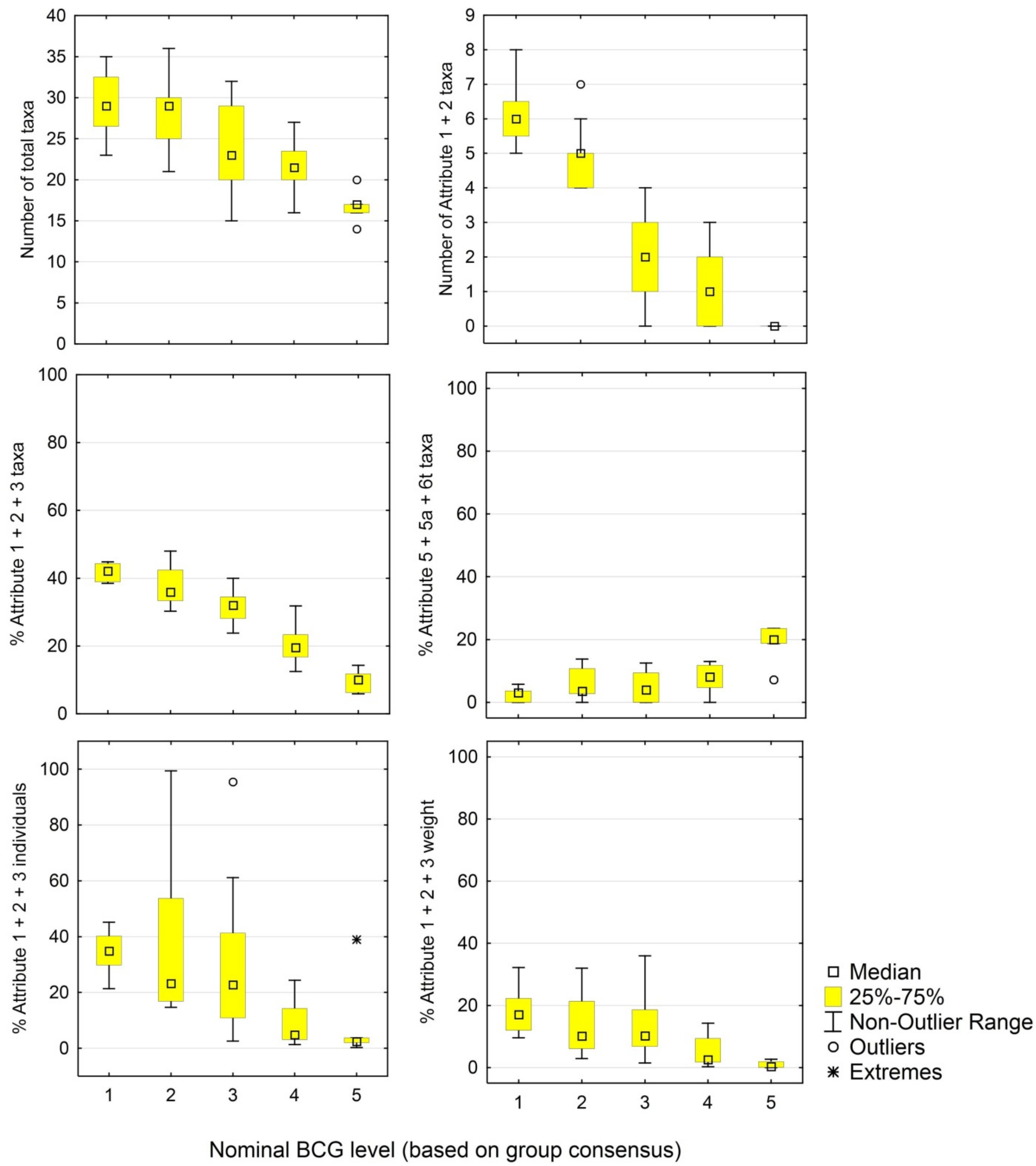

Figure 9. Box plots of a subset of metrics that comprise the Group 2 BCG model, grouped by nominal BCG level (group median choice). These include richness, abundance and biomass metrics for sensitive (Attribute I, II, III) and tolerant (Attribute V, Va & VIt) taxa. Sample sizes for each BCG level are summarized in Table 5.

3.3 BCG Rule Development

The rules in Table 6 were developed for distinguishing BCG levels for fish assemblages in Group 2 lakes. Rules were derived from discussions with the panelists on why individual sites were assessed at a certain level. The rules were calibrated and confirmed with the 50 fish samples rated by the group, and were adjusted so that the model would replicate the panel's decisions as closely as possible. Inevitably, there were some decisions where the panel may have used different, unstated rules, or where rules were inconsistently applied. The panel considered both lake size and lake connectivity (streams flowing in and out) in making assessments. Rules taking into account lake connectivity were not important in the final rule sets, but there were some differences in expectations related to lake size, so BCG models were calibrated for 3 lake area-based size classes (small/medium: ≤ 700 acres; large: 701 to 2500 acres; and very large: > 2500 acres).

The general pattern of decreasing richness of sensitive taxa and increasing relative abundance of tolerant individuals as biological condition degrades (Figure 9) forms the basis of the decision rules (Table 6). There are 9 quantitative rules for BCG level 1 samples. These are the same across all 3 size classes (Table 6). Rules for BCG level 2 are similar to Level 1, except thresholds for the sensitive and tolerant taxa metrics are less stringent, such that slightly fewer sensitive taxa are required and more tolerant taxa are allowed (Table 6). Rules for BCG level 3 continue the trend of relaxed thresholds; for example, the total taxa richness threshold decreases from 20 to 15 (Table 6). As sensitive taxa disappear with increasing biological degradation, they also are dropped from the rules. In BCG Levels 2 and 3, for example, Attribute I taxa are no longer required so there is no rule for them (Table 6). Level 3 does require presence of at least one Attribute I or II taxon in the medium and large lakes. The rules for BCG level 4 require only 2 or more sensitive taxa to be present, at reduced abundances. At the same time, tolerant taxa and percent individuals are allowed to be higher than in BCG Levels 1, 2, or 3 (Table 6). Rules for BCG level 5 are characterized by sharply decreased taxa richness, absence of sensitive taxa, and greater abundance of tolerant taxa. Samples that fail to meet minimum BCG level 5 requirements are assigned to BCG level 6.

Table 6. BCG quantitative decision rules for Group 2 fish assemblages in small/medium (**≤ 700 acres**), large (701-2500 acres) and very large lakes (> 2500 acres). The numbers in parentheses represent the lower and upper bounds of the fuzzy sets. Cells are highlighted in orange if bounds differ across size classes.

BCG Level 1	**Small/Medium (≤ 700 acres)**	**Large (701-2500 acres)**	**Very large (> 2500 acres)**
Metrics	**rule**	**rule**	**rule**
# Total taxa	> 22 (15-30)	> 22 (15-30)	> 22 (15-30)
# Attribute I taxa	> 0 (0-1)	> 0 (0-1)	> 0 (0-1)
# Attribute I+II taxa	≥ 5 (3-7)	≥ 5 (3-7)	≥ 5 (3-7)
% Attribute I+II weight in TN+GN catch	> 0% (-0.9-1)	> 0% (-0.9-1)	> 0% (-0.9-1)
% Attribute I+II+III taxa	≥ 35% (30-40)	≥ 35% (30-40)	≥ 35% (30-40)
% Attribute I+II+III individuals in NS catch	≥ 20% (15-25)	≥ 20% (15-25)	≥ 20% (15-25)
% Attribute V+Va+VIt individuals in NS catch	≤ 5% (4-6)	≤ 5% (4-6)	≤ 5% (4-6)
% Most dominant taxon in NS catch	≤ 60% (55-65)	≤ 60% (55-65)	≤ 60% (55-65)
# Attribute VI taxa (includes VIi, VIm or VIt)	absent (0-1)	absent (0-1)	absent (0-1)
BCG Level 2	**Small/Medium (≤ 700 acres)**	**Large (701-2500 acres)**	**Very large (> 2500 acres)**
Metrics	**rule**	**rule**	**rule**
# Total taxa	≥ 20 (15-25)	≥ 20 (15-25)	≥ 20 (15-25)
# Attribute I+II taxa	≥ 4 (2-5)	≥ 4 (2-5)	≥ 5 (3-7)
% Attribute I+II weight in TN+GN catch	> 0%	> 0%	> 0%
% Attribute I+II+III taxa	≥ 30% (25-35)	≥ 30% (25-35)	≥ 30% (25-35)
% Attribute I+II+III individuals in NS catch	> 14% (9-20)	> 14% (9-20)	> 14% (9-20)
% Attribute Va+VIt individuals in NS catch	≤ 5% (4-6)	≤ 5% (4-6)	≤ 5% (4-6)
% Attribute V+Va+VIt weight in TN+GN catch	≤ 20% (15-25)	≤ 20% (15-25)	≤ 20% (15-25)
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	≤ 55% (50-60)	≤ 55% (50-60)	≤ 55% (50-60)

Table 6 continued…

BCG Level 3	**Small/Medium (≤ 700 acres)**	**Large (701-2500 acres)**	**Very large (> 2500 acres)**
Metrics	**rule**	**rule**	**rule**
# Total taxa	≥ 15 (10-20)	≥ 15 (10-20)	≥ 15 (10-20)
# Attribute I+II taxa	--	> 0	> 0
% Attribute I+II+III taxa	≥ 20% (15-25)	≥ 20% (15-25)	≥ 20% (15-25)
% Attribute I+II+III individuals in NS catch	> 0	> 0	> 0
% Attribute I+II+III weight in TN+GN catch	> 0	> 0	> 0
MAX metric membership value (% Attribute I+II+III individuals in NS catch ≥ 10 (2-18)) or (% Attribute I+II+III weight in TN+GN catch ≥ 5 (0-10))			
% Attribute V individuals in NS catch	≤ 20% (15-25)	≤ 20% (15-25)	≤ 20% (15-25)
% Attribute V+Va+VIt taxa	≤ 15% (10-20)	≤ 15% (10-20)	≤ 15% (10-20)
% Attribute Va+VIt individuals in NS catch	< 8% (5-10)	< 8% (5-10)	< 8% (5-10)
% Attribute V+Va+VIt weight in TN+GN catch	≤ 20% (15-25)	≤ 20% (15-25)	≤ 20% (15-25)
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	≤ 55% (50-60)	≤ 55% (50-60)	≤ 55% (50-60)
BCG Level 4	**Small/Medium (≤ 700 acres)**	**Large (701-2500 acres)**	**Very large (> 2500 acres)**
Metrics	**rule**	**rule**	**rule**
# Total taxa	≥ 15 (10-20)	≥ 15 (10-20)	≥ 15 (10-20)
# Attribute I+II+III taxa	> 2 (1-5)	> 2 (1-5)	> 2 (1-5)
% Attribute I+II+III individuals in NS catch	≥ 1% (0-2)	≥ 1% (0-2)	≥ 1% (0-2)
% Attribute V+Va+VIt individuals in NS catch	≤ 40% (35-45)	≤ 40% (35-45)	≤ 40% (35-45)
% Attribute V+Va+VIt taxa	≤ 25% (20-30)	≤ 25% (20-30)	≤ 25% (20-30)
% Attribute Va weight in TN+GN catch	≤ 20% (15-25)	≤ 20% (15-25)	≤ 20% (15-25)
% Attribute VIt weight in TN+GN catch	≤ 50% (45-55)	≤ 50% (45-55)	≤ 50% (45-55)

Table 6 continued…

BCG Level 5	**Small/Medium (≤ 700 acres)**		**Large (701-2500 acres)**		**Very large (> 2500 acres)**	
Metrics	**rule**	**alt rule**	**rule**	**alt rule**	**rule**	**alt rule**
# Total taxa	≥ 10 (5-15)		≥ 10 (5-15)		≥ 10 (5-15)	
% Attribute V+Va+VIt taxa	≤ 50% (45-55)		≤ 50% (45-55)		≤ 50% (45-55)	
% Attribute V+Va+VIt individuals in NS catch	≤ 90% (85-95)	--	≤ 90% (85-95)	--	≤ 90% (85-95)	--
% Attribute V+Va+VIt weight in TN+GN catch	--	≤ 90% (85-95)	--	≤ 90% (85-95)	--	≤ 90% (85-95)

3.4 Model Performance

To evaluate the performance of the 40-sample calibration dataset and the 10-sample confirmation dataset, we assessed the number of samples where the BCG decision model's nominal level exactly matched the panel's majority choice ("exact match") and the number of samples where the model predicted a BCG level that differed from the majority expert opinion ("anomalous" samples). Then, for the anomalous samples, we examined how big the differences were between the BCG level assignments, and also whether there was a bias (e.g., did the BCG model consistently rate samples better or worse than the panelists).

Two types of ties were taken into account: 1) BCG model ties, where there is nearly equal membership in 2 BCG levels (e.g., membership of 0.5 in BCG level 2 and membership of 0.5 in BCG level 3); and 2) panelist ties, where the difference between counts of panelist primary and secondary calls is less than or equal to 1 (e.g., 4-4, or 5-4 decisions). If the BCG model assigned a tie, and that tie did not match with the panelist consensus, we considered this to be a difference of half a BCG level (e.g., if the BCG model assignment was a BCG level 2/3 tie and panelist consensus was a BCG level 2, the model was considered to be 'off 'by a half BCG level; or more specifically, the model rating was ½ BCG level worse than the panelists' consensus). The BCG model was also considered to differ by a half level if the panelists assigned a tie and the BCG model did not.

Results show that the Group 2 BCG models perform well. The models assign scores that are within a half BCG level or better on 100% of the samples in both the calibration and confirmation datasets (Table 7). When half levels are considered, the BCG model rated 7 of the calibration samples a half level worse than the panelists, and 1 sample received a rating that was a half level better. In the confirmation dataset, the model rated 1 sample a half level better than the panel consensus, and the rest were exact matches (Table 7). Based on results from the calibration dataset, the model has a slight bias towards rating samples a half level worse than the panel consensus. These half-level differences generally occur because metrics related to sensitive taxa are close to their threshold values, but this pattern in the Group 2 BCG models cannot be linked to a single metric.

Table 7. Model performance for Group 2 calibration and confirmation samples.

Difference (model minus panel consensus call)	**Calibration**		**Confirmation**	
	Number	**Percent**	**Number**	**Percent**
model - 1 better	0	0	0	0
model - 1/2 better	1	2.5	1	10
0 - exact match	32	80	9	90
model - 1/2 worse	7	17.5	0	0
model - 1 worse	0	0	0	0
Total # Samples	**40**	**100**	**10**	**100**

4 DECISION RULES AND BCG MODELS FOR LAKE GROUP 4

One BCG model was developed for all Group 4 lakes. During the calibration exercise, panelists made BCG level assignments on 37 samples. Panelists then made BCG level assignments on 10 additional samples to confirm the model. BCG level assignments for these 47 samples are summarized in Appendix F

4.1 Site Assignments and BCG Level Descriptions

Panelists assigned samples to 5 BCG levels (BCG levels 1-5). Locations of the assessed Group 4 lakes are shown in Figure 10. Of the 47 samples that were assessed, 18 represent very high quality waters (3 were assigned to BCG level 1 and 15 to BCG level 2). Most of the Group 4 samples were assigned to BCG levels 2, 3 and 4 (Table 8). The 2 lakes that were assigned to BCG level 5 are located in the western part of the state (Figure 10).

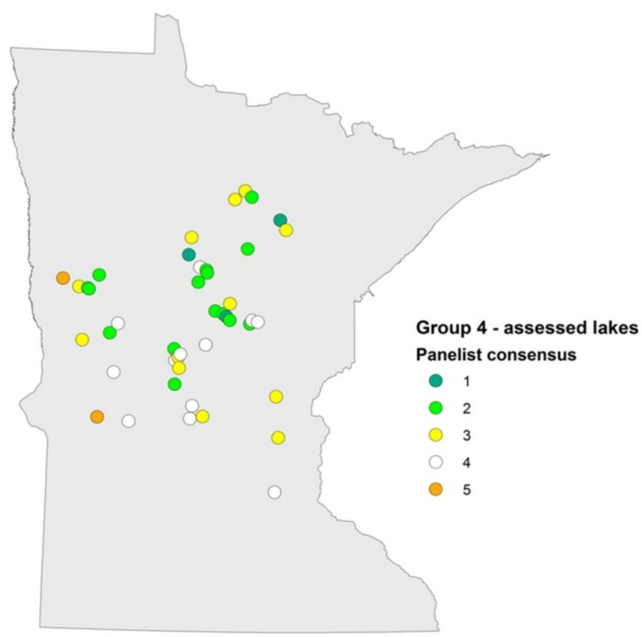

Figure 10. Locations of Group 4 lakes that were assessed during the BCG exercise, coded by panelist BCG level assignment.

Table 8. Number of Group 4 calibration and confirmation samples that were assessed, organized by BCG level (group consensus).

BCG level	Calibration	Confirmation
1	3	0
2	13	2
3	10	3
4	9	5
5	2	0
6	0	0
Total	***37***	***10***

4.2 BCG Attribute Metrics

The total taxa richness metric and taxonomic attribute metrics related to sensitive (Attribute I, II, III) and tolerant (Attribute V, Va, VIt) organisms were useful in distinguishing between BCG levels in the Group 4 samples. This is consistent with patterns seen in the other lake groups. The sensitive taxa richness metric shows the strongest monotonic pattern, decreasing from one BCG level to the next as conditions degrade. The total taxa, percent sensitive individuals and percent weight of extra tolerant (Attribute Va+VIt) metrics show relatively monotonic patterns as well, but are less distinct (Figure 11). The percent weight of extra tolerant taxa is particularly effective at discriminating between BCG levels 4 and 5. Box plots for all metrics that were considered during the Group 4 calibration process can be found in Appendix G.

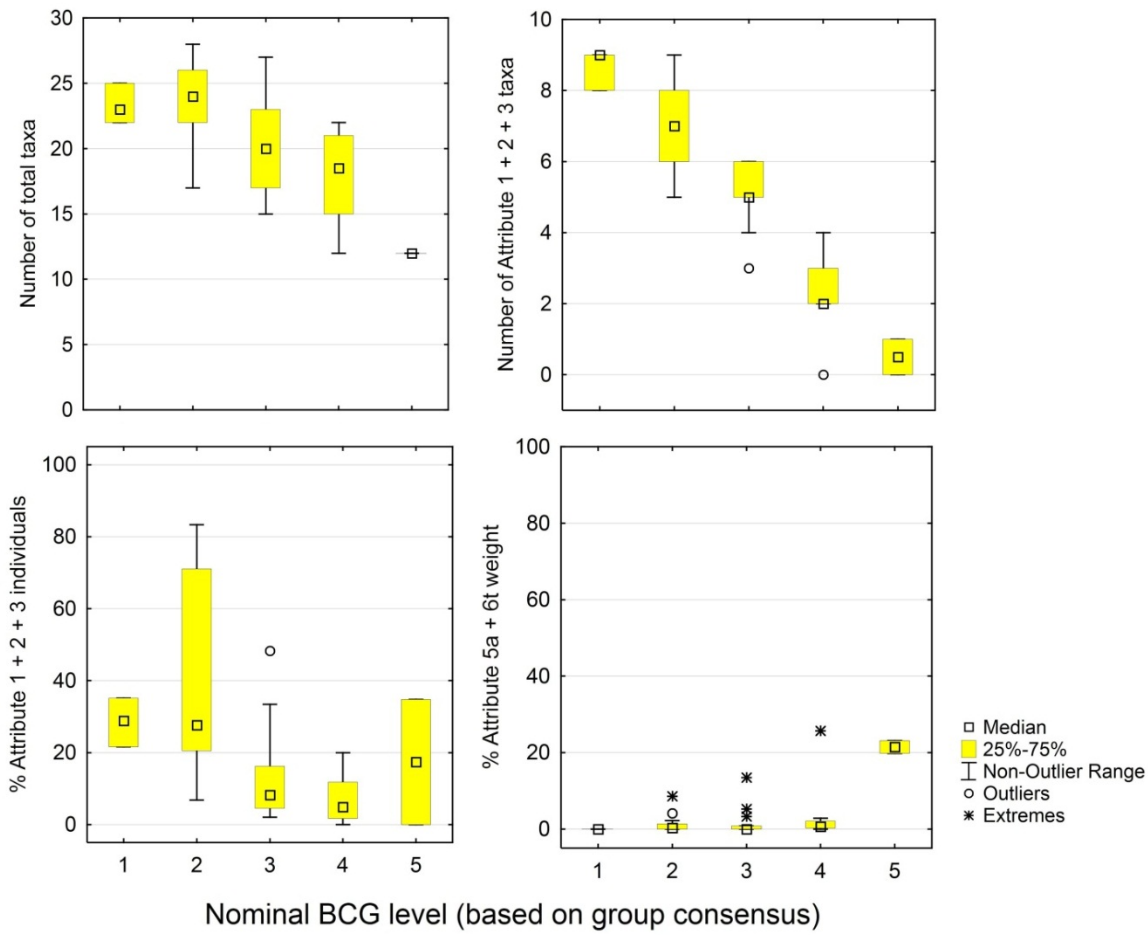

Figure 11. Box plots of a subset of metrics that comprise the Group 4 BCG model, grouped by nominal BCG level (group median choice). These include richness, abundance and biomass metrics for sensitive (Attribute I,II,III) and tolerant (Attribute Va & VI) taxa. Sample sizes for each BCG level are summarized in Table 8.

4.3 BCG Rule Development

The rules in Table 9 were developed for distinguishing BCG levels for fish assemblages in Group 4 lakes. The panel considered both lake size and lake connectivity (streams flowing in and out) in making assessments, but neither were important in the final rule set, so one BCG model was developed for all Group 4 lakes. The rules were calibrated and confirmed with the 47 fish samples rated by the group, and were adjusted so that the model would replicate the panel's decisions as closely as possible. The general pattern of decreasing richness of sensitive taxa and increasing relative abundance of tolerant individuals as biological condition degrades (Figure 11) forms the basis of the decision rules (Table 9).

There are 9 quantitative rules for BCG level 1 samples, including a rule that requires the presence of cisco in lakes with maximum depths greater than 40 feet (Table 9). Rules for BCG level 2 are similar to Level 1, with some exceptions (e.g., the cisco rule is dropped, Attribute I taxa are not required, thresholds for total taxa and sensitive taxa are reduced and tolerant taxa can comprise a slightly higher proportion of the assemblage). There is one set of alternate rules for BCG level 2 which require the presence of a certain percentage of sensitive taxa or a certain percentage of sensitive individuals in the nearshore sample (Table 9). Rules for BCG level 3 have the same threshold for total taxa richness as BCG level 2 samples and still require the presence of highly sensitive (Attribute I, II) taxa, but allow higher proportions of tolerant taxa. The alternate set of rules from BCG level 2 are carried over to BCG level 3 but have reduced thresholds for the sensitive taxa. BCG level 4 samples have a slightly lower threshold for total taxa richness than BCG level 3 samples and have no requirements for sensitive taxa, but restrict the proportions of tolerant and extra tolerant organisms. Rules for BCG level 5 are characterized by decreased taxa richness and greater presence of tolerant taxa. Samples that fail to meet minimum BCG level 5 requirements are assigned to BCG level 6.

Table 9. BCG quantitative decision rules for fish assemblages in Group 4 lakes. The numbers in parentheses represent the lower and upper bounds of the fuzzy sets.

BCG Level 1	
Metrics	**rule**
# Total taxa	≥ 20 (15-25)
# Attribute I taxa	> 1 (0-2)
# Attribute I+II taxa	≥ 4 (2-5)
% Attribute I+II+III taxa	≥ 30% (25-35)
% Attribute I+II+III individuals in NS catch	≥ 20% (15-25)
% Attribute V+Va+VIt individuals in NS catch	< 7% (5-10)
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	≤ 50% (45-55)
# Attribute VI taxa (includes VIi, VIm or VIt)	absent (0-1)
Cisco	> 0 if max depth > 40 ft

Table 9 continued…

BCG Level 2		
Metrics	**rule**	**alt rule**
# Total taxa	≥ 15 (10-20)	
# Attribute I+II taxa	≥ 2 (1-3)	
# Attribute I+II+III taxa	≥ 5 (3-7)	
% Attribute I+II+III taxa	≥ 25% (20-30)	--
% Attribute I+II+III individuals in NS catch	--	≥ 25% (20-30)
% Attribute V+Va+VIt individuals in NS catch	≤ 10% (5-15)	
% Attribute Va+VIt weight in TN+GN catch	≤ 10% (5-15)	
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	≤ 70% (65-75)	
BCG Level 3		
Metrics	**rule**	**alt rule**
# Total taxa	≥ 15 (10-18)	
# Attribute I+II taxa	> 0 (0-1)	
% Attribute I+II+III taxa	≥ 15% (10-20)	--
% Attribute I+II+III individuals in NS catch	--	≥ 15% (10-20)
% Attribute V+Va+VIt individuals in NS catch	≤ 20% (15-25)	
% Attribute Va+VIt weight in TN+GN catch	≤ 15% (10-20)	
BCG Level 4		
Metrics	**rule**	
# Total taxa	≥ 12 (8-16)	
% Attribute V+Va+VIt individuals in NS catch	≤ 45% (40-50)	
% Attribute Va+VIt weight in TN+GN catch	≤ 25% (20-30)	
% Attribute V+Va+VIt taxa	≤ 20% (15-25)	
% Attribute VIt weight in TN+GN catch	< 3% (0-5)	
BCG Level 5		
Metrics	**rule**	**alt rule**
# Total taxa	≥ 10 (5-15)	
% Attribute V+Va+VIt taxa	≤ 50% (45-55)	
% Attribute V+Va+VIt individuals in NS catch	≤ 90% (85-95)	--
% Attribute V+Va+VIt weight in TN+GN catch	--	≤ 90% (85-95)

4.4 Model Performance

To evaluate the performance of the 37-sample calibration dataset and the 10-sample confirmation dataset, we assessed the number of samples where the BCG decision model's nominal level exactly matched the panel's majority choice and the number of anomalous samples, or samples where the model predicted a BCG level that differed from the majority expert opinion. Ties were taken into account as described in Section 3.4.

The Group 4 BCG model performs well. It assigns scores that are within a half BCG level or better on 100% of the samples in both the calibration and confirmation datasets (Table 10). When half levels are considered, the BCG model rates 8 of the calibration samples a half level worse than the panelists and assigns 4 samples a rating that is a half level better. In the confirmation dataset, the model rated 1 sample a half level better than the panel consensus, and the rest were exact matches (Table 10). Three samples in the calibration dataset were assigned to BCG level 1 by panelists, but were rated as BCG level ½ ties by the model. This was because only one Attribute 1 taxon was present in these samples; for full membership in BCG level 1, the model requires the presence of more than 1 Attribute 1 taxon.

Table 10. Model performance for Group 4 calibration and confirmation samples.

Difference (model minus panel consensus call)	**Calibration**		**Confirmation**	
	Number	**Percent**	**Number**	**Percent**
model - 1 better	0	0.0	0	0
model - 1/2 better	4	10.8	1	10
0 - exact match	25	67.6	9	90
model - 1/2 worse	8	21.6	0	0
model - 1 worse	0	0	0	0
Total # Samples	**37**	**100**	**10**	**100**

5 DECISION RULES AND BCG MODELS FOR LAKE GROUP 5

BCG models for Group 5 lakes were calibrated for 2 lake area-based size classes: small: ≤ 300 acres; and medium to large: > 300 acres. During the calibration exercise, panelists made BCG level assignments on 46 samples. In order to confirm the model, panelists made BCG level assignments on 9 additional samples. BCG level assignments for these 55 samples are summarized in Appendix H.

5.1 Site Assignments and BCG Level Descriptions

Panelists assigned samples to 4 BCG levels (BCG levels 2-5). Samples were evenly distributed across the two size classes (Table 11). Locations of the assessed Group 5 lakes are shown in Figure 12. Of the 55 samples that were assessed, none were assigned to BCG levels 1 or 6. Most were assigned to BCG levels 2 through 4 (Table 11).

Table 11. Number of Group 5 calibration and confirmation samples that were assessed, organized by BCG level (group consensus).

BCG level	Calibration		Confirmation	
	Small	Medium to Very Large	Small	Medium to Large
1	0	0	0	0
2	4	5	1	1
3	6	11	2	3
4	9	8	1	1
5	2	1	0	0
6	0	0	0	0
Totals	***21***	***25***	***4***	***5***

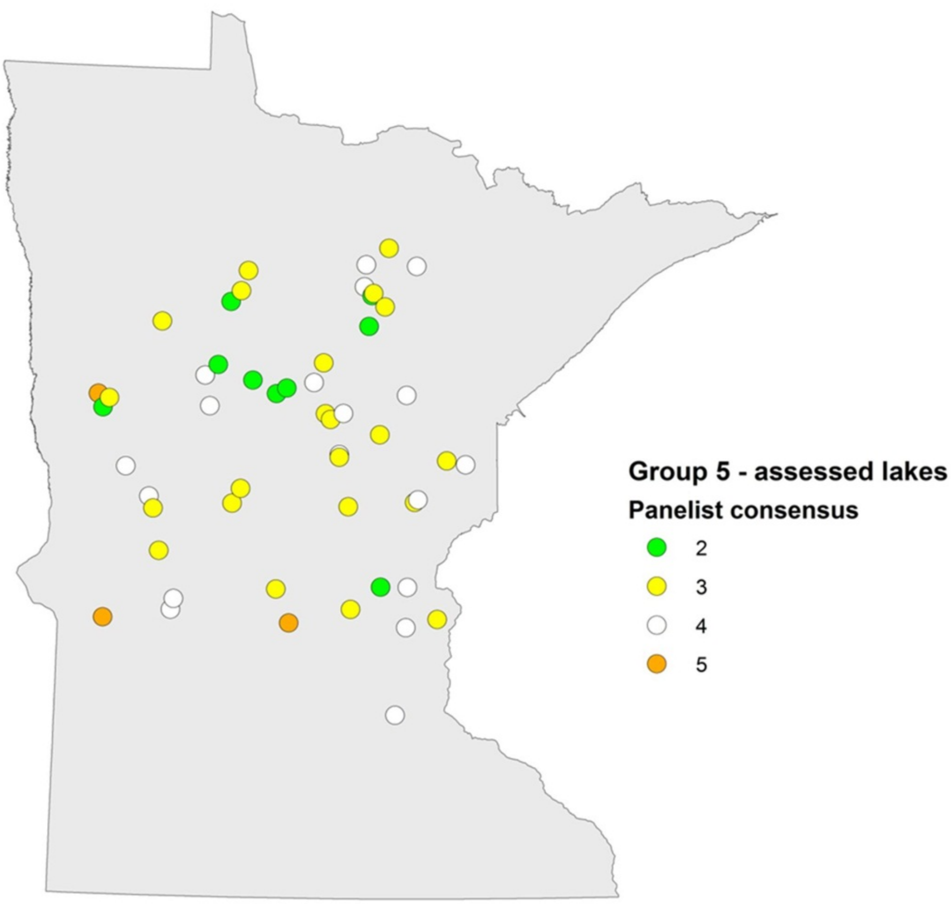

Figure 12. Locations of Group 5 lakes that were assessed during the BCG exercise, coded by panelist BCG level assignment.

5.2 BCG Attribute Metrics

As with the other lake groups, the total taxa richness metric and taxonomic attribute metrics related to sensitive (Attribute I, II, III) and tolerant (Attribute V, Va, VIt) organisms were most effective at distinguishing between BCG levels in the Group 5 samples. The patterns in these metrics are relatively monotonic, with the total taxa and sensitive taxa metrics generally decreasing as conditions degrade, while the tolerant taxa metrics increase. The drop in sensitive taxa is most evident between BCG levels 2 and 3, while the increase in tolerant taxa is most noticeable between BCG levels 3, 4 and 5 (Figure 13). The total richness metric increased with lake size, consistent with known species-area relationships (Figure 14). Box plots for all metrics that were considered during the Group 5 calibration process can be found in Appendix I.

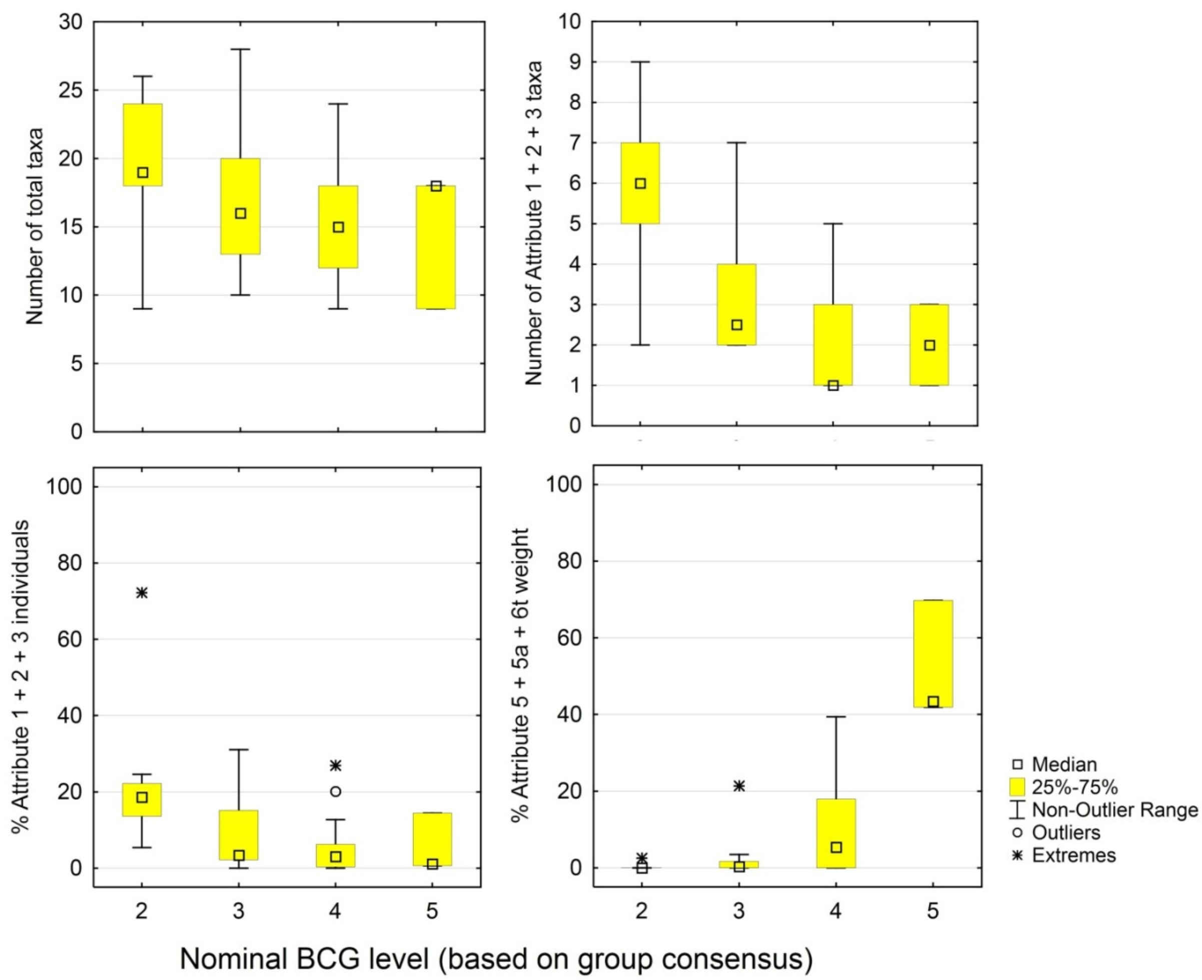

Figure 13. Box plots of a subset of metrics that comprise the Group 5 BCG model, grouped by nominal BCG level (group median choice). These include richness, abundance and biomass metrics for sensitive (Attribute I,II,III) and tolerant (Attribute V, Va & VIt) taxa. Sample sizes for each BCG level are summarized in Table 11.

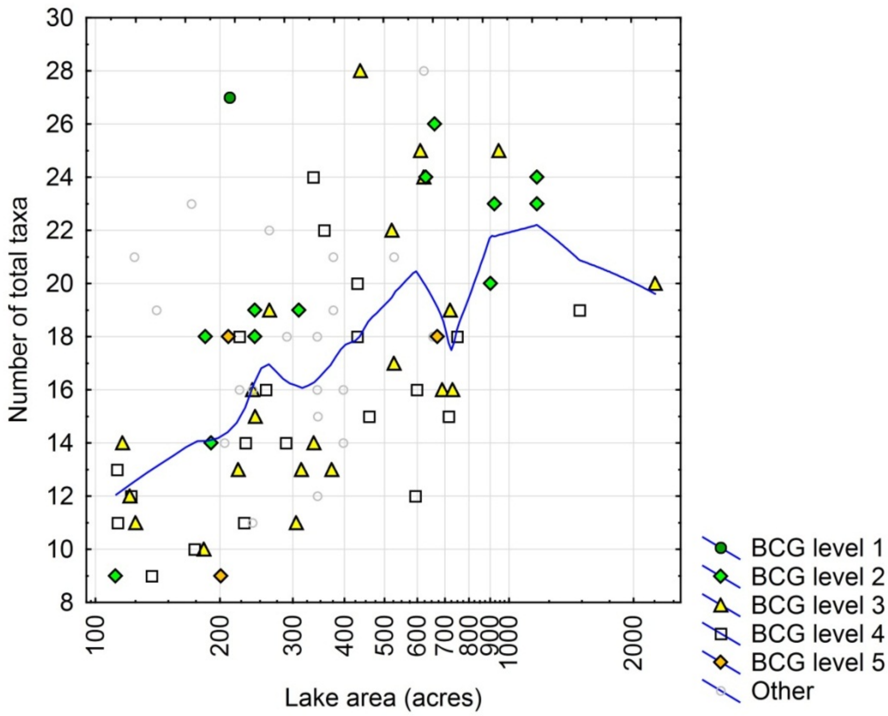

Figure 14. Relationship between total taxa metric values and lake area for Group 5 samples, fit with a Lowess trend line. Samples are coded by nominal BCG level (group median choice). The x-axis is log-transformed.

5.3 BCG Rule Development

The rules in Table 12 were developed for distinguishing BCG levels for fish assemblages in Group 5 lakes. The rules were calibrated and confirmed with the 55 fish samples rated by the group, and were adjusted so that the model would replicate the panel's decisions as closely as possible. The panel considered both lake size and lake connectivity (streams flowing in and out) in making assessments. Rules taking into account lake connectivity were not important in the final rule sets, but there were some differences in expectations related to lake size, so BCG models were calibrated for 2 lake area-based size classes (small: ≤ 300 acres; and larger: > 300 acres).

The basis of the decision rules (Table 12) is a general pattern of decreasing richness of sensitive taxa and increasing relative abundance of tolerant individuals as biological condition degrades (Figure 13). There are 7 quantitative rules for BCG level 1 samples. Because no BCG level 1 samples from Group 5 were assessed during this exercise, these rules are provisional. The provisional rules are based on Level 1 rules from Group 2 that were then customized for Group 5 lakes based on input from the panelists. Compared to the BCG level 1 rules, the thresholds for the sensitive and tolerant taxa metrics in BCG level 2 samples are generally less stringent, such that slightly fewer sensitive taxa are required and higher proportions of tolerant taxa are allowed. There are some differences in the BCG level 2 rules for small versus larger lakes (e.g., small BCG level 2 lakes do not have a total taxa richness rule and have slightly lower thresholds for sensitive and highly sensitive taxa) (Table 12).

Thresholds are further relaxed in the BCG level 3 rules, which require slightly fewer sensitive taxa and allow higher proportions of tolerant and extra tolerant taxa (Table 12). The total taxa richness rule is applied to both small and larger BCG level 3 lakes, with smaller lakes having a slightly lower threshold. Highly sensitive (Attribute I,II) taxa are dropped from the BCG level 3 rules, as they disappear with increasing biological degradation. A new metric, the percent weight of Centrarchidae in trap net samples, is applied only to BCG level 3 lakes (Table 12). In BCG level 4 lakes, thresholds for total taxa richness and sensitive taxa are further reduced, while thresholds for tolerant and extra tolerant organisms continue to increase. Rules for BCG level 5 are characterized by decreased taxa richness, absence of sensitive taxa, and greater abundance of tolerant taxa (Table 12). Samples that fail to meet minimum BCG level 5 requirements are assigned to BCG level 6.

Table 12. BCG quantitative decision rules for Group 5 fish assemblages in small (**≤ 300 acres) and larger** lakes (> 300 acres). The numbers in parentheses represent the lower and upper bounds of the fuzzy sets. Cells are highlighted in orange if bounds differ across size classes. BCG Level 1 rules are provisional (in gray).

BCG Level 1	**Small (≤ 300 acres)**		**Medium-Large (> 300 acres)**	
Metrics	**rule**		**rule**	
# Total taxa	≥ 20 (15-25)		≥ 20 (15-25)	
# Attribute I+II taxa	≥ 4 (3-5)		≥ 4 (3-5)	
% Attribute I+II+III taxa	≥ 30% (25-35)		≥ 30% (25-35)	
% Attribute I+II+III individuals in NS catch	≥ 10% (5-15)		≥ 10% (5-15)	
% Attribute V+Va+VIt individuals in NS catch	≤ 5% (4-6)		≤ 5% (4-6)	
% Most dominant taxon in NS catch	≤ 55% (50-60)		≤ 55% (50-60)	
# Attribute VI taxa (includes VIi, VIm or VIt)	absent (0-1)		absent (0-1)	
BCG Level 2	**Small (≤ 300 acres)**		**Medium-Large (> 300 acres)**	
Metrics	**rule**	**alt rule**	**rule**	**alt rule**
# Total taxa	--		≥ 15 (10-20)	
# Attribute I+II taxa	> 0 (0-1)		≥ 2 (1-3)	
# Attribute I+II+III taxa	≥ 4 (2-6)	--	≥ 6 (4-8)	--
% Attribute I+II+III individuals in NS catch	--	≥ 20% (15-25)	--	≥ 20% (15-25)
# Attribute V+Va+VIt taxa	--	absent (0-1)	--	
% Attribute V+Va+6t taxa	≤ 15% (10-20)		≤ 15% (10-20)	
% Attribute Va+VIt individuals in NS catch	≤ 1% (0-2)		≤ 1% (0-2)	
% Attribute Va+VIt weight in TN+GN catch	≤ 5% (0-10)		≤ 5% (0-10)	

Table 12 continued…

BCG Level 3	**Small (≤ 300 acres)**		**Medium-Large (> 300 acres)**	
Metrics	**rule**	**alt rule**	**rule**	**alt rule**
# Total taxa	≥ 9 (6-12)		≥ 12 (8-15)	
# Attribute I+II+III taxa	≥ 2 (0-3)		≥ 2 (0-3)	
% Attribute I+II+III taxa	≥ 12% (8-15)	--	≥ 12% (8-15)	--
% Attribute I+II+III individuals in NS catch	--	≥ 1% (0-2)	--	≥ 1% (0-2)
% Attribute Va+VIt individuals in NS catch	< 3% (0-5)		< 3% (0-5)	
% Attribute V+Va+VIt weight in TN+GN catch	≤ 5% (0-10)		≤ 5% (0-10)	
% Centrarchidae weight in TN catch	> 12% (10-15)		> 12% (10-15)	
BCG Level 4	**Small (≤ 300 acres)**		**Medium-Large (> 300 acres)**	
Metrics	**rule**		**rule**	
# Total taxa	≥ 8 (6-10)		≥ 8 (6-10)	
# Attribute I+II+III taxa	> 0 (0-1)		> 0 (0-1)	
% Attribute Va+VIt individuals in NS catch	≤ 10% (5-15)		≤ 10% (5-15)	
% Attribute V+Va+VIt weight in TN+GN catch	≤ 40% (35-45)		≤ 40% (35-45)	
% Attribute V+Va+VIt taxa	≤ 30% (25-35)		≤ 30% (25-35)	
BCG Level 5	**Small (≤ 300 acres)**		**Medium-Large (> 300 acres)**	
Metrics	**rule**	**alt rule**	**rule**	**alt rule**
# Total taxa	> 7 (5-10)		> 7 (5-10)	
% Attribute V+Va+VIt taxa	≤ 50% (45-55)		≤ 50% (45-55)	
% Attribute V+Va+VIt individuals in NS catch	≤ 75% (70-80)	--	≤ 75% (70-80)	--
% Attribute V+Va+VIt weight in TN+GN catch	--	≤ 75% (70-80)	--	≤ 75% (70-80)

5.4 Model Performance

To evaluate the performance of the 46-sample calibration dataset and the 9-sample confirmation dataset, we assessed the number of samples where the BCG decision model's nominal level exactly matched the panel's majority choice and the number of anomalous samples, or samples where the model predicted a BCG level that differed from the majority expert opinion. Ties were taken into account as described in Section 3.4.

The Group 5 BCG models performed fairly well, but not as well as the models for the other lake groups. The Group 5 models assign scores that are within a half BCG level or better on 93.5% of the samples in the calibration dataset and on 89% of the samples in the confirmation dataset (Table 13). In the calibration dataset, there are 3 samples that differ by 1 BCG level (Samp043, Spitzer, collection year 2010; Samp052, Lawrence, collection year 2007; Samp162, Shakopee, collection year 2007). In 2 cases, the model assignment was 1 BCG level better than the panelist consensus. The majority of panelists assigned Samp043/Spitzer to BCG level 4 and the model assigned it to BCG level 3, while the majority of panelists assigned Samp052/Lawrence to BCG level 3 and the model assigned it to BCG level 2. The model assignment for Samp162/Shakopee was 1 BCG level worse than the panelist consensus (4 versus a 3). The model places this sample into BCG level 4 because it fails the BCG level 3 rule requiring the percent weight of tolerant and extra tolerant taxa in the trap and gill net samples to be less than or equal to 5% (in this sample, the metric value = 21.4%).

In the confirmation dataset, there was 1 anomalous sample (Samp600, Wolf, collection year = 2012). The model assigned this sample to BCG level 5, while panelists assigned it to BCG level 4. The model assigns this sample to BCG level 5 because it fails the BCG level 4 rule requiring the percent of extra tolerant individuals in the nearshore sample to be less than or equal to 10% (the metric value = 29.7%).

When half levels are considered, the BCG model rates 4 of the calibration samples a half level worse than the panelists and assigns 2 samples a rating that is a half level better. In the confirmation dataset, the model rated 2 samples a half level better than the panel consensus, 2 samples a half level worse, and the remaining 4 were exact matches (Table 13).

Table 13. Model performance for Group 5 calibration and confirmation samples.

Difference (model minus panel consensus call)	Calibration		Confirmation	
	Number	Percent	Number	Percent
model - 1 better	2	4.3	0	0.0
model - 1/2 better	2	4.3	2	22.2
0 - exact match	38	82.6	4	44.4
model - 1/2 worse	4	6.5	2	22.2
model - 1 worse	1	2.2	1	11.1
Total # Samples	**46**	**100**	**9**	**100**

6 DECISION RULES AND BCG MODELS FOR LAKE GROUP 7

One BCG model was developed for all Group 7 lakes. During the calibration exercise, panelists made BCG level assignments on 35 samples. Eight additional samples were assessed to confirm the model. BCG level assignments for these 43 samples are summarized in Appendix J.

6.1 Site Assignments and BCG Level Descriptions

Panelists assigned samples to 5 BCG levels (BCG levels 2-6). Locations of the assessed Group 7 lakes are shown in Figure 15. Of the 43 samples that were assessed, none were assigned to BCG level 1. Most were assigned to BCG levels 4 and 5 (Table 14). Three lakes were assigned to BCG level 6 (Table 11).

Table 14. Number of Group 7 calibration and confirmation samples that were assessed, organized by BCG level (group consensus).

BCG level	Calibration	Confirmation
1	0	0
2	2	1
3	5	1
4	11	1
5	16	3
6	1	2
Total	***35***	***8***

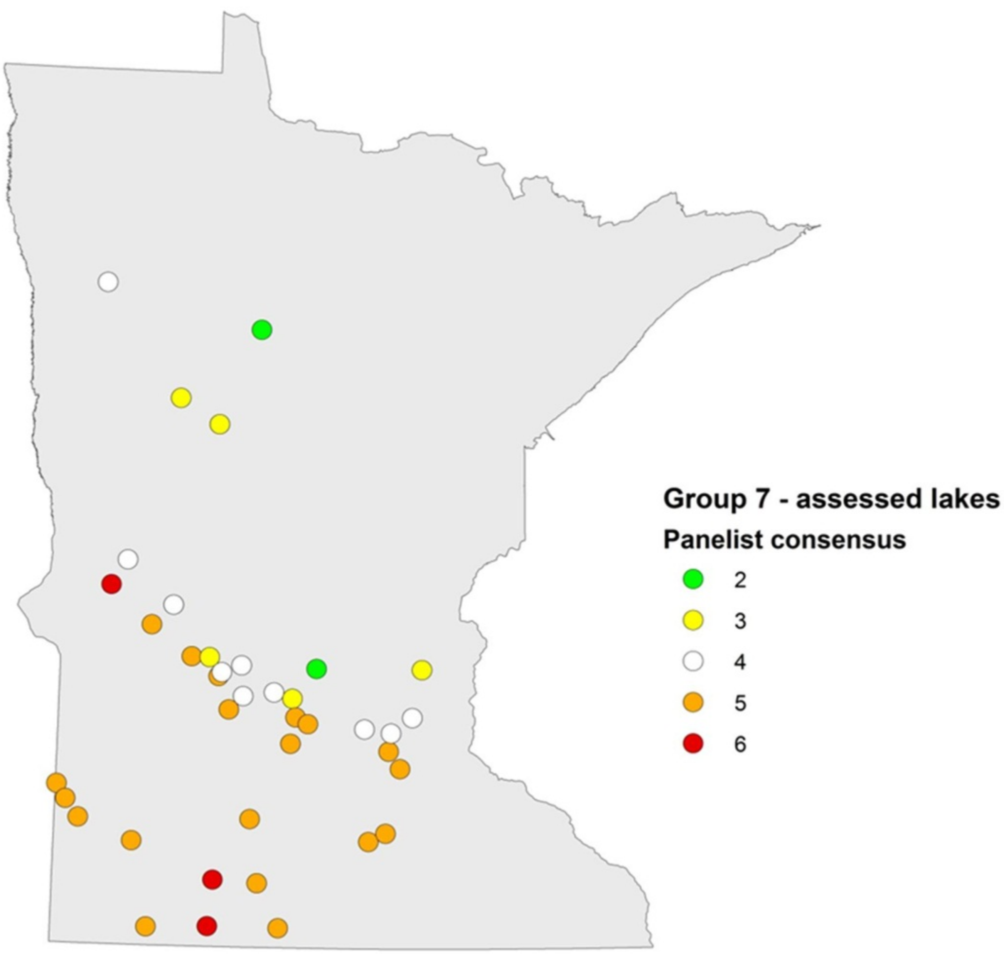

Figure 15. Locations of Group 7 lakes that were assessed during the BCG exercise, coded by panelist BCG level assignment.

6.2 BCG Attribute Metrics

The total taxa richness metric and taxonomic attribute metrics related to sensitive (Attribute I, II, III) and tolerant (Attribute V, Va, VIt) organisms were most effective at distinguishing between BCG levels in the Group 7 samples. As with the patterns seen in the other lake groups, these metrics are relatively monotonic, with the total taxa and sensitive taxa metrics generally decreasing as conditions degrade, while the tolerant taxa metrics increase. The number of sensitive taxa metric discriminates particularly well between BCG levels 2, 3 and 4, and the percent weight of tolerant and extra tolerant taxa in gill and trap nets metric discriminates well between BCG levels 2 and 3 and also between BCG levels 4 and 5 (Figure 16). Box plots for all metrics that were considered during the Group 7 calibration process can be found in Appendix K.

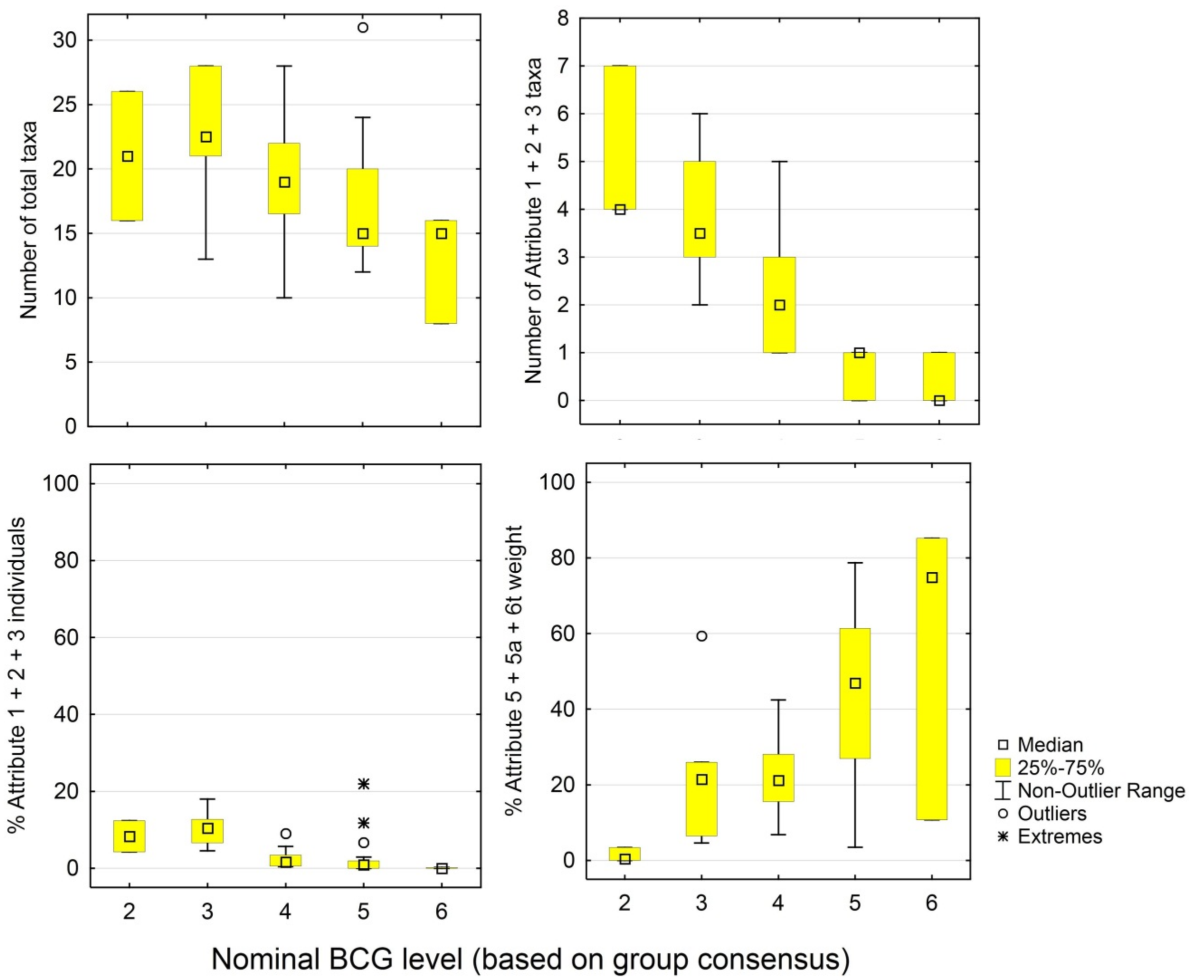

Figure 16. Box plots of a subset of metrics that comprise the Group 7 BCG model, grouped by nominal BCG level (group median choice). These include richness, abundance and biomass metrics for sensitive (Attribute 1, 2 & 3) and tolerant (Attribute 5, 5a & 6t) taxa. Sample sizes for each BCG level are summarized in Table 14.

6.3 BCG Rule Development

The rules in Table 15 have been developed for distinguishing BCG levels for fish assemblages in Group 7 lakes. The panel considered both lake size and lake connectivity (streams flowing in and out) in making assessments, but neither were important in the final rule set, so one BCG model was developed for all Group 7 lakes. The rules were calibrated and confirmed with the 43 fish samples rated by the group, and were adjusted so that the model would replicate the panel's decisions as closely as possible. The basis of the decision rules (Table 15) is a general pattern of decreasing richness of sensitive taxa and increasing relative abundance of tolerant individuals as biological condition degrades (Figure 16).

There are 7 quantitative rules for BCG level 1 samples. Because no BCG level 1 samples from Group 7 were assessed during this exercise, these rules are provisional. The provisional rules are based on Level 1 rules from Group 2 that were then customized for Group 7 lakes based on input from the panelists. Compared to the BCG level 1 rules, the thresholds for the sensitive and tolerant taxa metrics in BCG level 2 lakes are less stringent, such that fewer sensitive taxa are required and more tolerant taxa are allowed. This trend continues in the rules for BCG level 3 lakes, which allow slightly lower proportions of sensitive taxa and higher abundances of tolerant and extra tolerant organisms (Table 15). There is a set of alternate rules for BCG level 3 that require either the presence of at least 3 sensitive taxa or limit the proportions of tolerant or extra tolerant organisms (Table 15). BCG level 4 lakes have the same threshold for total taxa richness (10) as BCG level 3 lakes, but thresholds for sensitive taxa are further reduced and thresholds for tolerant and extra tolerant organisms continue to increase. Two new metrics, the number of top predators (northern pike, smallmouth bass, largemouth bass, rock bass or bowfin) and the percent of tolerant sunfish (green sunfish, orangespotted sunfish and hybrid sunfish), are applied only to BCG level 4 lakes (Table 15). Rules for BCG level 5 are characterized by decreased taxa richness, absence of sensitive taxa, and greater abundance of tolerant taxa (Table 15). Samples that fail to meet minimum BCG level 5 requirements are assigned to BCG level 6.

Table 15. BCG quantitative decision rules for fish assemblages in Group 7 lakes. The numbers in parentheses represent the lower and upper bounds of the fuzzy sets. BCG Level 1 rules are provisional (in gray).

BCG Level 1		
Metrics	**rule**	
# Total taxa	≥ 20 (15-25)	
# Attribute I+II taxa	> 4 (3-6)	
% Attribute I+II+III taxa	≥ 30% (25-35)	
% Attribute I+II+III individuals in NS catch	≥ 10% (5-15)	
% Attribute V+Va+VIt individuals in NS catch	≤ 5% (4-6)	
% Most dominant taxon in NS catch	≤ 55% (50-60)	
# Attribute VI taxa (includes VIi, VIm or VIt)	absent	
BCG Level 2		
Metrics	**rule**	
# Total taxa	≥ 15 (10-20)	
# Attribute I+II+III taxa	> 3 (2-5)	
% Attribute I+II+III individuals in NS catch	> 3% (2-6)	
% Attribute V+Va+VIt taxa	≤ 15% (10-20)	
% Attribute V+Va+VIt individuals in NS catch	≤ 10% (5-15)	
% Attribute V+Va+VIt weight in TN+GN catch	≤ 10% (5-15)	
BCG Level 3		
Metrics	**rule**	**alt rule**
# Total taxa	≥ 10 (5-15)	
# Attribute I+II+III taxa	> 3 (2-5)	--
% Attribute I+II+III taxa	> 7% (5-10)	
% Attribute I+II+III individuals in NS catch	≥ 4% (2-6)	
% Attribute V+Va+VIt taxa	--	≤ 25% (20-30)
% Attribute V+Va+VIt individuals in NS catch	--	≤ 5% (2-8)
% Attribute Va weight in TN+GN catch	--	≤ 15% (10-20)
% Attribute VIt weight in TN+GN catch	--	≤ 20% (15-25)
BCG Level 4		
Metrics	**rule**	
# Total taxa	≥ 10 (5-15)	
# Attribute I+II+III taxa	> 0	
% Attribute V+Va+VIt individuals in NS catch	≤ 45% (40-50)	
% Attribute V+Va+VIt weight in TN+GN catch	≤ 45% (40-50)	
% Attribute V+Va+VIt taxa	≤ 35% (30-40)	
% Attribute Va weight in TN+GN catch	≤ 25% (20-30)	
% Attribute VIt weight in TN+GN catch	≤ 25% (20-30)	
Number of top predator taxa*	≥ 1 (0-2)	
% Tolerant sunfish** individuals in NS catch	≤ 25% (20-30)	

Table 15 continued…

BCG Level 5		
Metrics	**rule**	**alt rule**
# Total taxa	≥ 9 (5-13)	
% Attribute V+Va+VIt taxa	≤ 50% (45-55)	
% Attribute V+Va+VIt individuals in NS catch	≤ 80% (75-85)	--
% Attribute V+Va+VIt weight in TN+GN catch	--	≤ 65% (60-70)

*Top predators = northern pike, smallmouth bass, largemouth bass, rock bass and bowfin
** Tolerant sunfish = green sunfish, orangespotted sunfish and hybrid sunfish

6.4 Model Performance

To evaluate the performance of the 35-sample calibration dataset and the 8-sample confirmation dataset, we assessed the number of samples where the BCG decision model's nominal level exactly matched the panel's majority choice and the number of anomalous samples, or samples where the model predicted a BCG level that differed from the majority expert opinion. Ties were taken into account as described in Section 3.4.

The Group 7 BCG model performs well. It assigns scores that are within a half BCG level or better on 100% of the samples in the calibration dataset and on 75% of the samples in the confirmation dataset (Table 16). In the confirmation dataset, there are 2 samples that differ by 1 BCG level (Samp676, Calhoun, collection year = 2012; Samp103, Okabena, collection year = 2008). In both cases, the model assignment is 1 BCG level better than the panelist consensus. The majority of panelists assigned Samp076/Calhoun to BCG level 4, but it meets all the BCG level 3 requirements so the model assigned it to BCG level 3. Samp103/Okabena meets all the BCG level 4 requirements so the model placed it in BCG level 4, but the panelist consensus was a 5.

When half levels are considered, the BCG model rates 1of the calibration samples a half level worse than the panelists. The rest are exact matches (Table 13).

Table 16. Model performance for Group 7 calibration and confirmation samples.

Difference (model minus panel consensus call)	Calibration		Confirmation	
	Number	**Percent**	**Number**	**Percent**
model - 1 better	0	0.0	2	25
model - 1/2 better	0	0.0	0	0
0 - exact match	34	97.1	6	75
model - 1/2 worse	1	2.9	0	0
model - 1 worse	0	0	0	0
Total # Samples	**35**	**100**	**8**	**100**

7 COMPARISON OF RULES ACROSS LAKE GROUPS

Table 17 shows the similarities and differences in BCG rules and thresholds across the lake groups. Most metrics are used in more than one BCG model. Thresholds are not exactly the same across all models but are generally similar. Examples of metrics that are part of multiple models include total taxa richness, the percent tolerant and extra tolerant (Attribute 5+5a+6t) taxa metric, which is used in the BCG level 5 rules for all the models, and the percent sensitive (Attribute 1+2+3) taxa metric, which is used in the BCG level 1 rules for all of the models. The thresholds for the sensitive taxa metrics tend to be slightly higher for Group 2 lakes, since this lake group includes some of the highest quality waters in the state. Some metrics are unique to one model. These include: the cisco metric, which is applied only in Group 4 lakes with maximum depths greater than 40 feet; the percent weight of highly sensitive (Attribute 1+2) taxa in trap and gill nets, which is part of the Group 2 models; the percent weight of Centrarchidae in trap nets, which is used in the Group 5 models; and the number of top predator taxa and the percent of tolerant sunfish, which are used in Group 7 model (Table 17).

Table 17. Comparison of BCG model rules across the different lake groups. The numbers represent the mid-points between the lower and upper bounds of the fuzzy sets. Colored text denotes alternate rules (alternate 1 rules are shown in green text and alternate 2 rules are shown in blue text).

BCG Level 1	Group 2	Group 4	Group 5	Group 7
# Total taxa	> 22	≥ 20	≥ 20	≥ 20
# Attribute I taxa	> 0	> 0	--	--
# Attribute I+II taxa	≥ 5	≥ 4	≥ 4	> 4
% Attribute I+II weight in TN+GN catch	> 0%	--	--	--
% Attribute I+II+III taxa	≥ 35%	≥ 30%	≥ 30%	≥ 30%
% Attribute I+II+III individuals in NS catch	≥ 20%	≥ 20%	≥ 10%	≥ 10%
% Attribute V+Va+VIt individuals in NS catch	≤ 5%	< 7%	≤ 5%	≤ 5%
% Most dominant taxon in NS catch	< 60%	--	≤ 55%	≤ 55%
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	--	≤ 50%	--	--
# Attribute VI taxa (includes VIi, VIm or VIt)	0	0	0	0
Cisco	--	> 0 if max depth > 40 ft	--	--

*MAX metric membership value (% Attribute 1+2+3 individuals in NS catch ≥ 10 (2-18)) or (% Attribute 1+2+3 weight in TN+GN catch ≥ 5 (0-10))
**Top predators = northern pike, smallmouth bass, largemouth bass, rock bass and bowfin
*** Tolerant sunfish = green sunfish, orangespotted sunfish and hybrid sunfish

Table 17 continued…

BCG Level 2	Group 2	Group 4	Group 5	Group 7
# Total taxa	≥ 20	≥ 15	≥ 15 in lakes > 300 acres	≥ 15
# Attribute I+II taxa	≥ 4 in lakes ≤ 2500 acres; ≥ 5 in lakes > 2500 acres	≥ 2	> 0 in lakes ≤ 300 acres; ≥ 2 in lakes > 300 acres	--
% Attribute I+II weight in TN+GN catch	> 0	--	--	--
# Attribute I+II+III taxa	--	≥ 5	alt 1 ≥ 4 in lakes ≤ 300 acres; ≥ 6 in lakes > 300 acres OR	> 3
% Attribute I+II+III taxa	≥ 30%	alt 1 ≥ 25% OR	--	--
% Attribute I+II+III individuals in NS catch	> 14%	alt 2 ≥ 25%	alt 2 ≥ 20% AND	> 3%
# Attribute V+Va+VIt taxa	--	--	alt 2 = 0 in lakes ≤ 300 acres	--
% Attribute V+Va+VIt taxa	≤ 20%	--	≤ 15%	≤ 15%
% Attribute Va+VIt individuals in NS catch	< 5%	--	≤ 1%	--
% Attribute V+Va+VIt individuals in NS catch	--	≤ 10%	--	≤ 10%
% Attribute V+Va+VIt weight in TN+GN catch	< 20%	--	--	≤ 10%
% Attribute Va+VIt weight in TN+GN catch	--	≤ 10%	≤ 5%	--
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	≤ 55%	≤ 70%	--	--

Table 17 continued…

BCG Level 3	**Group 2**	**Group 4**	**Group 5**	**Group 7**
# Total taxa	≥ 15	≥ 14	≥ 9 in lakes ≤ 300 acres, ≥ 12 in lakes > 300 acres	≥ 10
# Attribute I+II taxa	> 0 in lakes > 700 acres	≥ 1	--	--
# Attribute I+II+III taxa	--	--	> 1 in lakes ≤ 300 acres, ≥ 2 in lakes > 300 acres	alt 1 > 3 OR
% Attribute I+II+III taxa	≥ 20%	alt 1 ≥ 15% OR	alt 1 ≥ 12% OR	> 7%
% Attribute I+II+III individuals in NS catch	> 0*	alt 2 ≥ 15%	alt 2 ≥ 1%	≥ 4%
% Attribute I+II+III weight in TN+GN catch	> 0*	--	--	--
% Attribute V individuals in NS catch	≤ 20%	--	--	--
% Attribute V+Va+VIt taxa	≤ 15%	--	--	alt 2 ≤ 25% AND
% Attribute V+Va+VIt individuals in NS catch	--	≤ 20%	--	alt 2 ≤ 5% AND
% Attribute Va+VIt individuals in NS catch	< 8%	--	< 3%	--
% Attribute V+Va+VIt weight in TN+GN catch	≤ 20%	--	≤ 5%	--
% Attribute Va+VIt weight in TN+GN catch	--	≤ 15%	--	--
% Attribute Va weight in TN+GN catch	--	--	--	alt 2 ≤ 15% AND
% Attribute VIt weight in TN+GN catch	--	--	--	alt 2 ≤ 20%
% Centrarchidae weight in TN catch	--	--	> 12%	--
% Most dominant Attribute IV taxon in NS catch (minus bluegill)	≤ 55%	--	--	--

*MAX metric membership value (% Attribute I+II+III individuals in NS catch ≥ 10 (2-18)) or (% Attribute I+II+III weight in TN+GN catch ≥ 5 (0-10))

Table 17 continued…

BCG Level 4	**Group 2**	**Group 4**	**Group 5**	**Group 7**
# Total taxa	≥ 15	≥ 12	≥ 8	≥ 10
# Attribute I+II+III taxa	> 2	--	> 0	> 0
% Attribute I+II+III individuals in NS catch	≥1%	--	--	--
% Attribute V+Va+VIt individuals in NS catch	≤ 40%	≤ 45%	--	≤ 45%
% Attribute Va+VIt individuals in NS catch	--	--	≤ 10%	--
% Attribute V+Va+VIt weight in TN+GN catch	--	--	≤ 40%	≤ 45%
% Attribute Va+VIt weight in TN+GN catch	--	≤ 25%	--	--
% Attribute V+Va+VIt taxa	≤ 25%	≤ 20%	≤ 30%	≤ 35%
% Attribute Va weight in TN+GN catch	≤ 20%	--	--	≤ 25%
% Attribute VIt weight in TN+GN catch	≤ 50%	< 3%	--	≤ 25%
Number of top predator taxa**	--	--	--	≥ 1
% Tolerant sunfish*** individuals in NS catch	--	--	--	≤ 25%
BCG Level 5	**Group 2**	**Group 4**	**Group 5**	**Group 7**
# Total taxa	≥ 10	≥ 10	> 7	≥ 9
% Attribute V+Va+VIt taxa	≤ 50%	≤ 50%	≤ 50%	≤ 50%
% Attribute V+Va+VIt individuals in NS catch	alt 1 ≤ 90% OR	alt 1 ≤ 90% OR	alt 1 ≤ 75% OR	alt 1 ≤ 80% OR
% Attribute V+Va+VIt weight in TN+GN catch	alt 2 ≤ 90%	alt 2 ≤ 90%	alt 2 ≤ 75%	alt 2 ≤ 65%

**Top predators = northern pike, smallmouth bass, largemouth bass, rock bass and bowfin
*** Tolerant sunfish = green sunfish, orangespotted sunfish and hybrid sunfish

8 DESCRIPTION OF ASSEMBLAGES IN EACH BCG LEVEL

When panelists assess samples, they often associate particular taxa (and abundances of these taxa) with certain BCG levels. In Table 18, we provide narrative descriptions of each of the BCG levels that were assessed during this exercise, as well as lists of fish taxa that were commonly found in samples from each BCG level.

Table 18. Narrative descriptions of fish assemblages in each BCG level. Definitions are modified after Davies and Jackson (2006).

BCG level 1	**Definition:** Natural or native condition - *native structural, functional and taxonomic integrity is preserved; ecosystem function is preserved within the range of natural variability*
	Narrative: Endemic or rare species are likely present (e.g., pugnose shiners, least darters, greater redhorse, lake whitefish, longear sunfish). Some rare species have limited distributions, for example, greater redhorse and lake whitefish are limited to large, deep lakes (Lake Group 2). Non-native taxa are absent. During this exercise, no BCG level 1 samples were assessed in Lake Groups 5 or 7.
BCG level 2	**Definition:** Minimal changes in structure of the biotic community and minimal changes in ecosystem function - *virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability*
	Narrative: Highly sensitive (Attribute II) and intermediate sensitive (Attribute III) taxa are present (e.g., blackchin and blacknose shiners, cisco, banded killifish, mimic shiners, Iowa darters, and pumpkinseed), as are native top predators and taxa of intermediate tolerance (rock bass and smallmouth bass). Tolerant taxa like green sunfish, black bullhead and fathead minnow may occur, but if they do, their presence does not displace native fish or alter structure and function.
BCG level 3	**Definition**: Evident changes in structure of the biotic community and minimal changes in ecosystem function - *Some changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa but intermediate sensitive taxa are common and abundant; ecosystem functions are fully maintained through redundant attributes of the system*
	Narrative: Sensitive (Attribute II & III) taxa are common or abundant (e.g., blackchin and blacknose shiners, Iowa darters, pumpkinseed). Taxa of intermediate tolerance (Attribute IV) (e.g., black crappie, bluegill, bluntnose minnow, largemouth bass, northern pike, walleye, yellow bullhead, and yellow perch) are present in greater numbers than in BCG level 2 samples. Tolerant (Attribute V or Va) taxa (e.g., green sunfish, black bullhead and common carp) are present in greater numbers as well, but alterations to the structure and function of the fish community are minimal.

BCG level 4	**Definition**: Moderate changes in structure of the biotic community and minimal changes in ecosystem function **-** *Moderate changes in structure due to replacement of some intermediate sensitive taxa by more tolerant taxa, but reproducing populations of some sensitive taxa are maintained; overall balanced distribution of all expected major groups; ecosystem functions largely maintained through redundant attributes*
	Narrative: Sensitive (Attribute II or III) taxa (e.g., banded killifish, Iowa darters, pumpkinseed) are still present but occur in lower numbers. Taxa of intermediate tolerance (Attribute IV) (e.g., black crappie, bluegill, brown bullhead, hybrid sunfish, largemouth bass, northern pike, walleye, white sucker, yellow bullhead and yellow perch) are common, as are tolerant taxa (e.g., green sunfish, black bullhead). Non-native tolerant taxa (e.g., common carp) are more prevalent.
BCG level 5	**Definition**: Major changes in structure of the biotic community and moderate changes in ecosystem function **-** *Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*
	Narrative: Overall richness and abundance declines. Sensitive species are reduced or absent. Taxa of intermediate tolerance (Attribute IV) such as black crappie, bluegill, largemouth bass, northern pike, walleye, and yellow bullhead are common, as are tolerant (Attribute V or Va) taxa like green sunfish and black bullhead. Common carp occur more frequently and in greater numbers.
BCG level 6	**Definition**: Major changes in structure of the biotic community and moderate changes in ecosystem function **-** *Sensitive taxa are markedly diminished; conspicuously unbalanced distribution of major groups from that expected; organism condition shows signs of physiological stress; system function shows reduced complexity and redundancy; increased build-up or export of unused materials*
	Narrative: Overall richness and abundance declines further. Sensitive (Attribute II or III) taxa are absent.

9 DISCUSSION

Aquatic biologists from MPCA, MNDNR, MBI and an independent contractor partnered to develop a common assessment system based on the BCG for fish assemblages in Minnesota lakes. This was a collective exercise among the biologists to develop consensus on assessments of samples. We elicited the rules that the biologists used to assess the samples, and developed quantitative decision criteria for assigning samples to BCG levels for four different lake groups.

The BCG models performed well. The BCG models for the different lake groups correctly assessed anywhere from 93 to 100% of the calibration samples, and 75 to 100% of the confirmation samples. A number of lakes were assigned to BCG levels 1 or 2, which, based on participants' input, represent the present-day highest quality waters in this region.

As new data are collected, BCG model outputs can be generated using the Access database that will accompany this report. If the BCG models are utilized, users should consider the limitations of the models. Results should be interpreted with caution if any of the following apply:

- Concerns about identifications based on vouchered specimens.
- Sites with a history of winterkill within the last 10 years prior to the survey. However, winterkill is often undetected and may be an important structuring force in shallow-water lake assemblages.
- Staff did not complete seining or backpack electrofishing sampling on at least 5 stations.
- Nearshore survey work was done before June 10 or after September 20.
- Lakes less than 100 acres.
- Although all lakes in MNDNR's survey set are stocked, any unusual management, or very small stocked lakes may have an unusual fish assemblage due to management.
- Lakes that function more as reservoirs or riverine lakes.
- Small lakes with a direct open-water connection to a larger lake.
- Lakes in Schupp lake classes 1 – 19
- Lakes in parts of the state that were not assessed during this exercise (e.g., far north and northeast (Northern Minnesota wetlands), northwest (Lake Agassiz Plain), southeast (Driftless Area)

The BCG provides a powerful approach for an operational monitoring and assessment program, for communicating resource condition to the public and for management decisions to protect or remediate water resources. It allows practical and operational implementation of multiple aquatic life uses in a state's water quality criteria and standards. The levels of the BCG are biologically recognizable stages in condition of lakes. As such, they can form a biological basis for criteria and regulation of a state's waterbodies. Current thresholds of narrative biocriteria in many states (usually an IBI score, or something similar) are relatively low (e.g., level 4-level 5), and fail to protect outstanding condition waters (levels 1 and 2), or even good condition waters (level 3). Thus, biocriteria set at a lower BCG level will allow incremental degradation of waterbodies to the regulatory level.

Moving ahead, MPCA and MNDNR could potentially use the BCG models to supplement the IBI measures that they currently use to assess lake health. Preliminary analyses have shown good correspondence between the IBI and BCG (Jacquelyn Bacigalupi, personal communication, March 2014). If the BCG models are used to supplement IBI measures, the BCG, as developed conceptually in Davies and Jackson (2006), addresses several limitations of existing biotic indexes. Advantages of the BCG include:

- The BCG is based on ecological considerations with wide expert agreement, rather than on empirical analysis of a particular data set. The resulting index is calibrated using a data set, but the result is intended to be more general than a regression analysis of biological response to stressors.

- The BCG uses universal attributes (Attributes I to VI) that are intended to apply in all regions. Specifics of the attributes (taxon membership, attribute levels indicating good, fair, poor, etc.) do vary across regions and stream types, but the attributes themselves and their importance are consistent.

- The BCG requires descriptions of the classes or levels, from pristine to degraded. While requiring extra work, this ensures that future information and discoveries can be related back to the baseline level descriptions. Levels are not perfect or static—they will be altered by increase in knowledge.

With the calibrated lake BCG models, MPCA can extend the TALU framework that it has developed for rivers and streams to assessment and criteria for lakes. As with the rivers and streams, criteria could be expressed as IBI scores, using thresholds that are developed based on BCG levels corresponding to points that would be protective of the tiered uses (MPCA 2014). The calibration of the lake BCG models represents an important step as Minnesota revises its Water Quality Standards and Criteria. The BCG models can be used to express goals and criteria for classes of water bodies in terms of their biological condition or response, including, for example, setting criteria for exceptional waters of the state, as well as defining attainable restoration goals for impaired waters.

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