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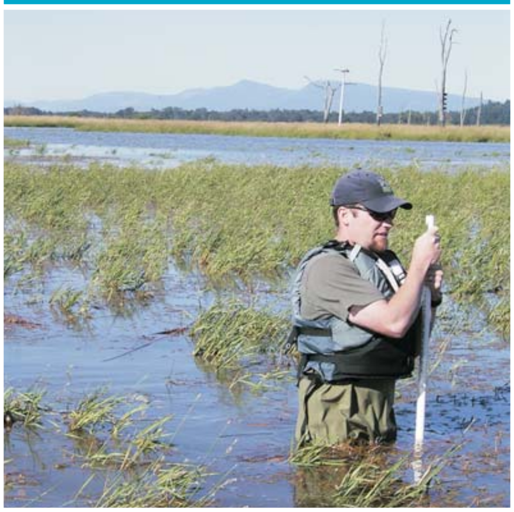
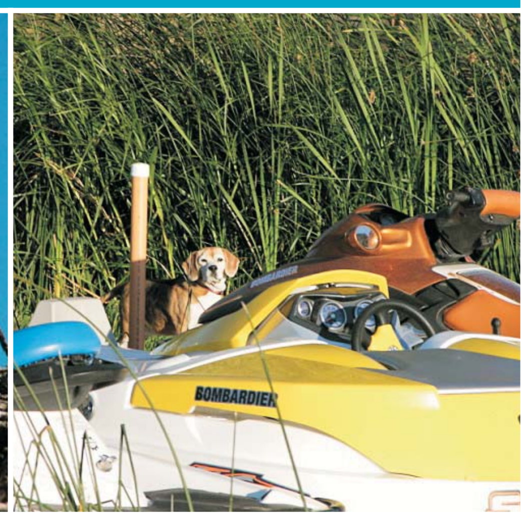
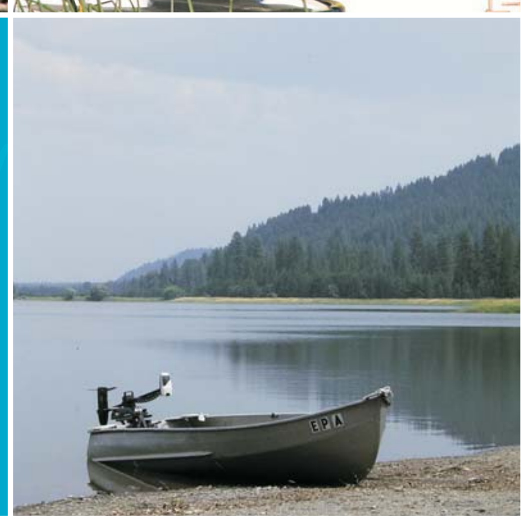


Ecological Condition of Lakes in Idaho, Oregon, and Washington





EPA Region 10
Office of Environmental Assessment

Ecological Condition of Lakes in Idaho, Oregon, and Washington
EPA Region 10 Report

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Abstract

The Environmental Protection Agency (EPA) in collaboration with state agencies conducts monitoring of various aquatic resources to answer questions on the condition of the Nation's waters. This series of surveys is conducted under EPA's National Aquatic Resources Surveys (NARS) program. These surveys employ a statistical design that makes it possible to describe the quality of the resource across the Nation in terms of good, fair or poor condition relative to a reference condition or numeric standards. In addition, the extent of human disturbance can be described in relation to geographic variations.

The NARS program initiated a survey of lakes called the National Lakes Assessment (NLA). Data were collected for this assessment from 1,028 lakes across the contiguous United States in summer 2007. This report uses a subset of the data from this larger project to assess the ecological condition of the lakes of the EPA Region 10 states of Idaho, Oregon, and Washington (subsequently referred to as Region 10). A total of 90 lakes were sampled in Region 10. In general, most lakes in the Region are in good or fair condition based on the results of the indicators analyzed. The most widespread stressors are physical habitat quality of the lakeshore and shallow areas, and nutrients.

Purpose

Lakes are an important aquatic resource in the Pacific Northwest Region. Monitoring of lakes by the states within EPA Region 10 is limited and there are no programs that survey lakes for the purpose of state-wide assessment. This ecological assessment of lakes in Region 10 has three purposes:

- Report on the ecological condition of lakes using direct measures of biological assemblages.

- Identify and rank the relative importance of stressors affecting lake condition by using measures of chemical, physical and biological habitat to determine how wide-spread/common these stressors are.

- Conduct preliminary analysis of landscape metrics derived from remotely sensed data that may be useful for assessing regional lake condition.

Introduction

The EPA conducts nation-wide ecological surveys of aquatic resources to evaluate their status and to examine associations between ecological condition and natural and anthropogenic influences. These National Aquatic Resource Surveys (NARS) are based on the premise that the condition of aquatic biota can be determined by examining biological response indicators and ecological indicators of stress. The long-term goal of NARS is to directly measure environmental resources to determine if they are in an acceptable or unacceptable condition relative to a set of environmental or ecological values. Two major features of these surveys are the use of ecological indicators and probability-based selection of sample sites.

An ecological assessment can be performed in a variety of ways ranging from a description of the extent of a resource to an enumeration of the abundance and distribution of biota in an ecosystem. The ecological assessment of lakes in Region 10 described in this report evaluates critical stressors related to water quality, biological condition, physical habitat condition, and recreation. Two critical components of aquatic ecosystems are: 1) the condition of the biota, and 2) the relative importance of human-caused stressors.

The first component of this ecological assessment is based on the fact that biological communities are adapted to local habitat (the combination of physical, chemical, and spatial elements) and therefore the ecological condition of lakes is reflected by the quality and health of the biotic communities. Essentially, the biotic communities integrate the many human disturbances that we are interested in assessing. Maintaining the biotic communities is also one of the pillars of the federal Clean Water Act "…. [S]upporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat."

The second component of this assessment evaluates ecological stressors. Stressors are defined as the pressures or disturbances exerted on aquatic systems. These are the chemical, physical, and biological components of the ecosystem that have the potential to degrade the biotic integrity of the aquatic system. This ecological assessment will identify stressors and describe their spatial extent.

The National Lakes Assessment (NLA) was a two-year effort to collect data from lakes across the United States and to report on their ecological condition at a national scale (USEPA 2010). Consistent field, lab, and data analysis methods were used across the country and across lake types. All sites were selected using a probabilistic design. Collectively, the sites are a statistical representation of the target population of lakes of the United States.

This Region 10 report uses a subset of the data analyzed for the NLA to describe the condition of the lakes in EPA Region 10. Region 10 has previously reported the ecological condition of other aquatic resources including rivers, streams and estuaries in Region 10 using this same approach (Hayslip et al. 2006, Herger et. al. 2007). This is the first time extensive data have been available for reporting on the ecological condition of lakes across Region 10.

Overview of Lakes Ecological Assessment

A. Survey Design

Assessing a very large and diverse area requires a study design that can adequately capture the variation across the landscape and be descriptive of the entire ecological resource of lakes in the Region. There are various options for collecting data to describe the ecological condition of this 'target population'. A census method, where data are collected from every lake, is impractical (if not impossible). This survey used a sample approach similar to a public opinion poll where data are collected from a subset of the target lakes. This information is then used to determine characteristics of the greater target population. The sample sites are selected using a probability-based sampling method to insure that they are statistically representative of the target population. In a probability sample, every lake of the target population has a known non-zero probability of being selected. This feature has two advantages in that it 1) prevents site selection bias and 2) allows statistically valid inferences describing characteristics of the entire target population to be made.

The target population was sampled in a spatially-restricted manner so that the distribution of the sample sites has approximately the same spatial distribution as the target population. This was achieved by using an unequal probability sample method to ensure distribution of samples of sites by size, State, and major ecoregion types (mountainous/humid v. xeric). For example, in this study large lakes were given higher probability of being selected for sampling than small lakes. This effectively increases the probability of having large lakes selected for the sample so that the sample is not dominated by the small lakes, which are much more common in the landscape. This variable selection probability by lake size is accounted for when making the regional estimates by using site weighting factors. Each site is assigned a weight, based on the occurrence of its type in the Region. Small lakes have a smaller weighting factor than large lakes. Therefore, any inferences based on the un-weighted set of sites to the entire target population are inaccurate.

B. Lake Selection and Extent of Evaluation

The sample frame for this study was all lakes, reservoirs, and ponds that are permanent waterbodies within Oregon, Idaho, and Washington that have the following characteristics:

- surface area > 4 ha (10 acres)
- ≥ 1000m^2 open, unvegetated, water surface area
- ≥ 1 meter depth
- excludes 'working' lakes meaning those used for aquaculture, tailings disposal, active borrow pits, sewage treatment, evaporation, etc.
- excludes saline coastal waterbodies and those under tidal influence
- excludes flowing waterbodies such as 'run of the river' reservoirs

The data used to generate this set of lakes was the National Hydrography Dataset (NHD), which is a set of GIS layers. For Region 10, this dataset consisted of 11,340 lakes, reservoirs and ponds with at least four hectares of surface area. This dataset was screened using the criteria described above which resulted in a set of 3,423 lakes considered the target population for Region 10.

Sample lakes were selected randomly from the target population in proportion to their occurrence within five size categories (Overton et al. 1990, Stevens and Olsen 2004). A final evaluation was conducted to ensure each lake was accessible and satisfied the criteria for inclusion as a target lake. For this project, accessible meant that 1) they did not have safety issues that would prohibit sampling, 2) they were not excessively remote, and 3) that landowners would grant access.

In Region 10, a total of 90 lakes were slated for sampling. As lakes were selected from the design list of eligible lakes (those meeting the target criteria), many were rejected due to access denial or inaccessibility. Almost 50% of the eligible lakes were rejected before the final 90 lakes were selected. These 90 lakes represent the "inference population" of 1,700 (49.7 % of the original target population). Results in this report are presented in relation to this inference population. For example, if an indicator has poor condition in 10% of the lakes this means that 170 lakes in the Region are in poor condition (**Figure 1**).

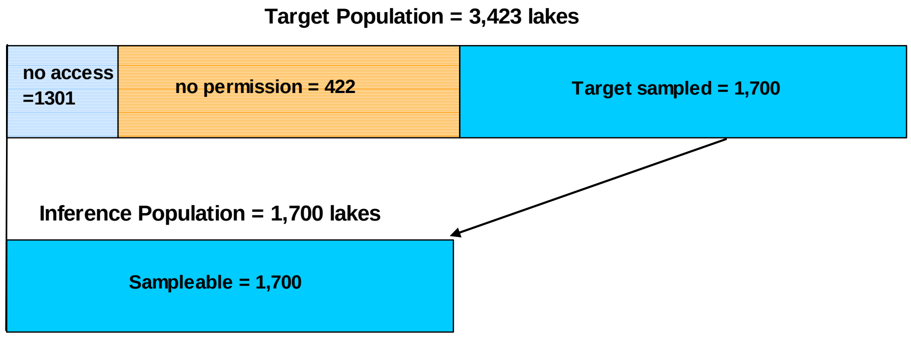


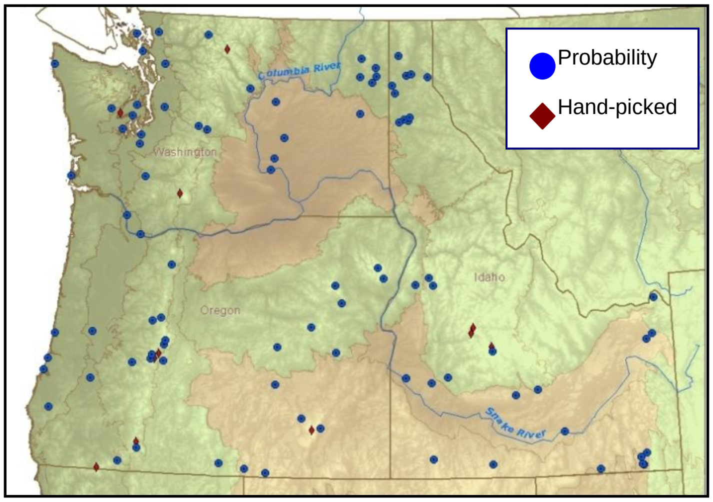
Figure 1. Fate of lakes available from NHD for use as target sample. Lake criteria requirements and screening for sampleablity yields inference population of 1,700 lakes.

The process used to select sites allows for unbiased estimates of condition indicators with known statistical confidence. Error bars on the graphs in this report express the uncertainty of the population estimates at the 95% confidence level. For example, an estimate of poor biological condition of 40% with an error bar of +/- 10% means there is 95% confidence that the true value is between 30% and 50%.

Error bars of 5-15% would be expected for this type of ecological assessment. However, In Region 10, error bars tended to be rather large (approximately 20%) depending on the indicator. One explanation for the large error bars in the Region is the heterogeneous landscape and lack of consistent lake size in the Region. Further, the variance is calculated spatially meaning that variances are all based on each site and its three closest “neighbors” in geographic space. If sites have neighbors with large site weights, meaning they are rare in terms of size (big lakes), then larger local variance estimates will result. If there are areas with no or very few lakes, nearest neighbors may be far apart, or at different elevations. The spatial variability in distance between lakes, elevation, and variation in lake size results in the increased error in the region compared to areas with more homogeneous lake size by elevation (e.g. Minnesota, Wisconsin) and compared to the nation-wide assessment error (USEPA 2009a).

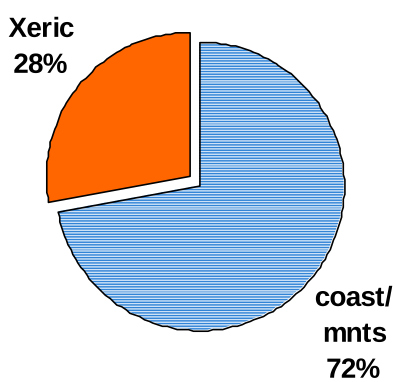
C. Description of Region 10 Sample Lakes

The Pacific Northwest ecosystem has diverse physiological, climatic, and floral and faunal characteristics as evident by the inclusion of all or portions of 11 different ecological regions (ecoregions) within its boundary (USEPA 2003, Omernik 1987). The diversity of the contiguous portion of Region 10 includes large expanses of high dry plateau, steep mountains, and forested areas. The Region has two major climatic regions, xeric and mountainous areas. The xeric portion of the basin is represented by the Columbia Plateau, North Basin Range, and Snake River Plain ecoregions. The land area categorized as xeric is a substantial portion of the PNW (shown in brown on **Map 1**). The remaining ecoregions comprise the mountainous climatic region (shown in green).



Map 1. Locations of sampled lakes in the Coastal/Mountain west (green) and Xeric (brown) ecoregions in Region 10 states of Oregon, Washington, and Oregon.

The location of the 90 randomly selected sample lakes used to represent the inference population of 1,700 lakes are shown on Map 1 and are listed in **Appendix 1**. Nearly three quarters of the sampled lakes are within the coastal/mountains ecoregions, and most are in public ownership (**Figure 2**).



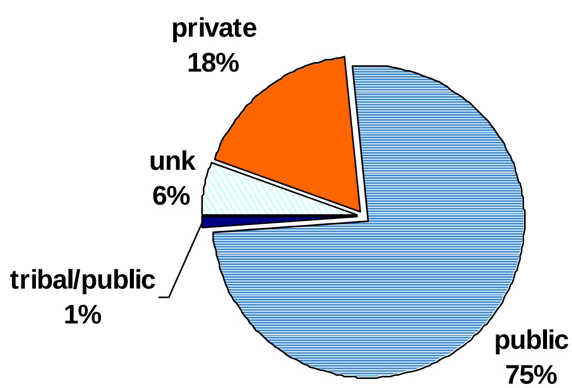


Figure 2. Description of sampled lakes by aggregated Level 3 Ecoregion and by Ownership.

Lakes from five size categories of open water surface area were included in the sample. The 90 sample lakes were relatively equally distributed between the three mid-sized categories (**Figure 3**).

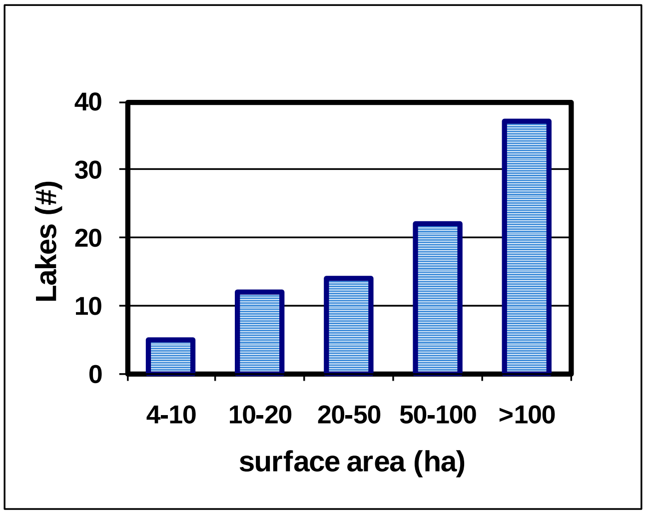


Figure 3. Sample lakes in each size category (N=90).

Each lake sampled in the smallest size class represents a proportionately larger number of lakes in the PNW states due to the far larger number of small lakes present in the three-state region relative to larger size classes. Thus, these small lakes carry a larger 'weight' in the survey. The sample design forced the inclusion of large sized lakes in the sample. Because of the proportionately larger number of small lakes a completely random sample without this 'forcing' would result in a dominance of small lakes in the sample, making it difficult to draw inferences for large lakes.

Applying the assigned weights to the sample lakes results alters the proportion of lakes within the man-made versus natural categories that will be represented by the assessment results. The inference population has 33% of lakes in the man-made categories (including reservoirs), versus 43% in the 90 lakes actually sampled (**Figure 4**). Similarly the proportion of lake distribution among ecoregions differs once weights are applied: about 8% (114 lakes) of the inference lakes are within the xeric portions of Region 10 compared to 28% of the 90 sampled lakes.

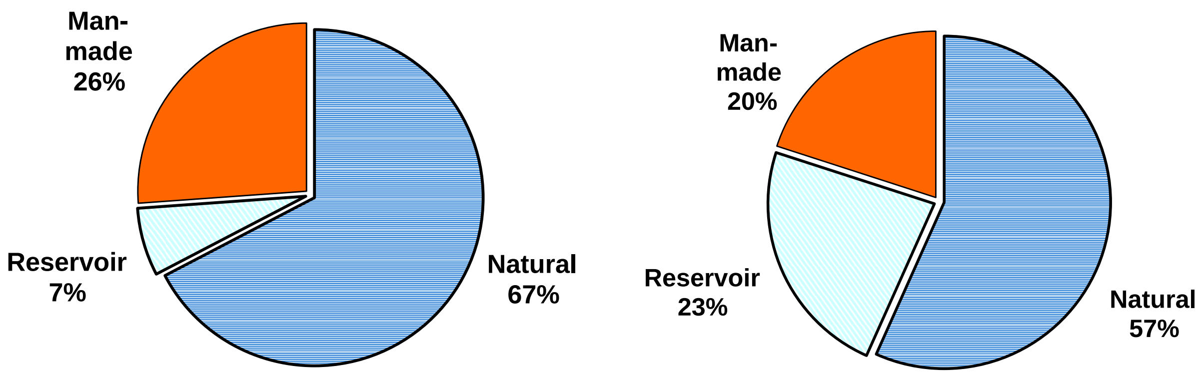


Figure 4. Proportion of inference lakes (1700) within each lake origin category compared to proportion when weighting is not applied (90 sampled lakes).

D. Aquatic Stressor Indicators

Characterizing the ecological condition of lakes is complex due to their dynamic nature. Ecological indicators must be carefully selected so that they robustly represent the important aspects of lake quality. In order to thoroughly characterize lakes, indicators were selected to assess four major aspects of lake ecological characteristics. These are biological condition, water quality and trophic state, physical habitat condition, and recreation suitability. This report examines the most relevant metrics for evaluating the stressors affecting the ecological condition. The four categories of lake condition indicators and the specific indicators examined in this assessment are summarized in **Table 1**.

Table 1. Description of Indicators used to evaluate lake condition.

Indicator	Why important	Metrics of assessment
	1. Biological Condition	
Plankton: floating microscopic rganisms includes: zooplankton (invertebrates) and Phytoplankton- algae	Responds to stressors of nutrient enrichment and turbidity. Responses can be quantified through changes in species composition and abundance.	Taxa loss (O/E) model develop for the combined presence of zooplankton and phytoplankton
Sediment diatoms—microscopic algae with silicon cell walls that are preserved in lake sediments	Diatom species have specific requirements of alkalinity, total P, conductivity, etc.	Diatom condition index (LDC) based on diatom assemblage in surface sediments
	2. Water Quality and Trophic State	
Nutrients: total phosphorus (P) and total nitrogen (N)	P and N are required for primary productivity. Excessive nutrients negatively affect lake function.	Reference condition comparisons and numeric thresholds
Dissolved oxygen	Essential for support of aquatic life. Organisms have differing requirements for optimal growth.	Numeric thresholds from the literature
Water clarity-Secchi transparency depth and turbidity measurement	Water clarity is an indirect measure of algal growth and suspended solids.	Reference condition comparisons and numeric thresholds.
Chlorophyll-a-- photosynthesizing pigment is a measurement of algal biomass	Indicates level of primary productivity and is used to estimate trophic State.	Comparison to reference condition
	3. Physical Habitat Condition	
Littoral habitat— forms the interface between terrestrial and aquatic environment. Metric of cover features	Important area of nutrient inputs and aquatic habitat. Area commonly altered by human activities.	Comparison to reference condition
Lakeshore habitat (terrestrial nearshore area and shoreline zone)–metric of vegetation structure and complexity	Area where human disturbance can have the most effect on a lake.	Comparison to reference condition
Physical habitat complexity—combines littoral and lakeshore habitat metrics	Used to assess overall habitat structural complexity and integrity.	Comparison to reference condition
Human disturbance- extent of human activities in proximity to the lakeshore	Alteration of habitat by humans can affect biological integrity.	Comparison to reference condition
	4. Recreation Suitability	
Cyanobacteria cell counts–class of algae that produce algal toxins	Indirect indicator of presence of algae that could produce toxins.	Numeric thresholds from the literature
Chlorophyll-a density- indicator of presence of all algae	Indirect indicator of presence of algae that could produce toxins.	Numeric thresholds from the literature
Microcystin –an algal toxin produced by some cyanobacteria	Direct measure of microcystin which is harmful to humans and wildlife.	Numeric thresholds from the literature
Enterococci-bacteria of animal intestinal tracts (including humans)	Direct measure of bacteria.	Relative ranking
Fish tissue contaminants	Bioaccumulative and persistent -- these are harmful to fish consumers.	Numeric thresholds from the literature

E. Landscape Indicators

Landscape metrics that describe the physical conditions of watersheds were calculated for the watersheds of each lake using a Geographic Information System (GIS). These indicators are useful for describing the type and quantity of human disturbance that can influence lake condition. We analyzed these indicators to explore which ones are most related to stressor indicators generated from the lakes data and to examine the buffer widths that were most useful for these various types of landscape indicators. This is an exploratory analysis of Region 10 data as landscape metrics were not used in the National Lakes Survey.

Assessment Thresholds

Numeric Thresholds

For some indicators, values in the literature were available to evaluate lake condition. These thresholds are well established and are widely used and accepted. Dissolved oxygen levels were compared to EPA national recommendations. Lake trophic state was determined by comparing lake water quality metrics to the Trophic State Index developed by Carlson (1977 and 1983). Finally, the survey results for recreation indicators are compared to recommendations from the World Health Organizations (WHO) that are used to rate lake quality.

Reference Condition

Numeric condition threshold values were either not available or applicable for determining many of the biological and physical habitat conditions, and some of the water quality conditions for this lakes survey. In order to describe the ecological condition of the lakes of Region 10, we must have an expectation of the ecological condition in a relatively ‘undisturbed’ state. This benchmark for determining ecological condition is commonly referred to as the ‘reference condition’. A reference condition can have many meanings. For instance, it could mean a ‘pre-settlement condition’, a ‘desired condition’, or an ‘acceptable current condition’ that implies some level of human disturbance. Setting reasonable expectations for each of the indicators of ecological condition is therefore a challenge. For this assessment, reference condition is developed from the analysis of carefully selected sites that represent the best attainable or ‘least disturbed’ watershed condition, habitat structure, water quality and biological parameters (Hughes 1995, Stoddard et al. 2006). Deviation from the reference condition is a measure of the effect of stressors on the ecosystem. A site is considered to be in ‘good’ condition if it is in the condition we would expect to see if it were minimally exposed to the stressors of concern (i.e., if it is equivalent to reference condition). Thus, ‘good’ condition is defined relative to our expectations for a particular system rather that against an absolute benchmark of ecosystem attributes (Bailey et al. 2004).

The diversity of physical, chemical, and biological characteristics of the lakes of the Pacific Northwest states must be considered when defining reference condition and calculating lake ecological condition. For example, a lake with finer-sized substrate and low shoreline vegetative structure may be typical of an undisturbed lake in one ecoregion while those same characteristics may represent a more disturbed condition in a forested/mountainous ecoregion. Because ecoregions have similar characteristics in terms of soil, climate, geology, and vegetation, it follows that the lakes of an ecoregion would have similar stressors as well as similar responses to those stressors. Thus, ecoregions provide a template for refining the expected condition of lakes throughout a broad and variable area.

Reference sites came from two sources: 1) a set of lakes that were handpicked for sampling based on input from the state resource managers and 2) a set of lakes from within the greater National Lakes Survey probability lakes dataset. The handpicked sites were selected as being lakes in a minimally disturbed condition based on best professional judgment of state lake survey coordinators. In Region 10, 11 of these handpicked lakes were sampled in the three states (see Map 1). After data were collected from all probability and hand-picked sites, the dataset was screened to select sites in a least disturbed condition based on landscape data interpretation. This subset of lakes was further screened to include only those where the water quality was considered to be in good condition based on phosphorus, nitrogen, chloride, and sulfate concentrations. From this two step process a subset of reference lakes were identified from the probability dataset.

The reference lakes were used by EPA's Office of Water and Office of Research and Development (ORD) to generate condition metrics for the various indicators. Technical details on the development of each of these condition indicators will not be discussed here but can be found in EPA's Technical Appendix (EPA 2010). The Technical Appendix details the data analysis and development of metrics and condition indicators that are reported in this assessment.

Methods

A. Quality Assurance

All data collected and generated for this report followed the Quality Assurance Project Plan (QAPP) developed for the NLA (USEPA 2009b). The QAPP addresses all levels of the program, from collection of field data and samples and the laboratory processing of samples to standardized/centralized data management. Numerous crews conducted field sampling. Consistency and adherence to the field protocols (USEPA 2007) was insured by crews participating in training sessions, and field audits conducted by EPA Region 10 personnel early in the field season. Also, 10% of the sites were re-sampled to provide estimates of the variability of the metrics.

B. Field Sample Collection

Field data were collected during the summer growing period ('index period'). In Region 10, the sites were sampled between June and August. Field sampling was conducted at both the deepest point in the lake and at stations along the shoreline (**Figure 5**). The deepest location, termed the X-site, is where most indicators were collected including water chemistry, chlorophyll-a, phytoplankton, zooplankton, sediment diatoms, and algal toxins samples. Ten 'physical habitat' stations were established along the shoreline equidistant from one another with the location of the first site selected randomly. Physical habitat and benthic macro-invertebrates were collected at each of the ten stations and the enterococci sample was collected at the last station. These physical habitat stations were not established at large lakes (greater than 5,000 hectares) and physical habitat data and benthic invertebrates were not collected at those water bodies. The enterococci sample was collected near the boat launch site for these big lakes. A summary of field sampling protocols is shown in **Table 2** and further details on field methods and sample preservation and handling can be found in the field operations manual (EPA 2007).

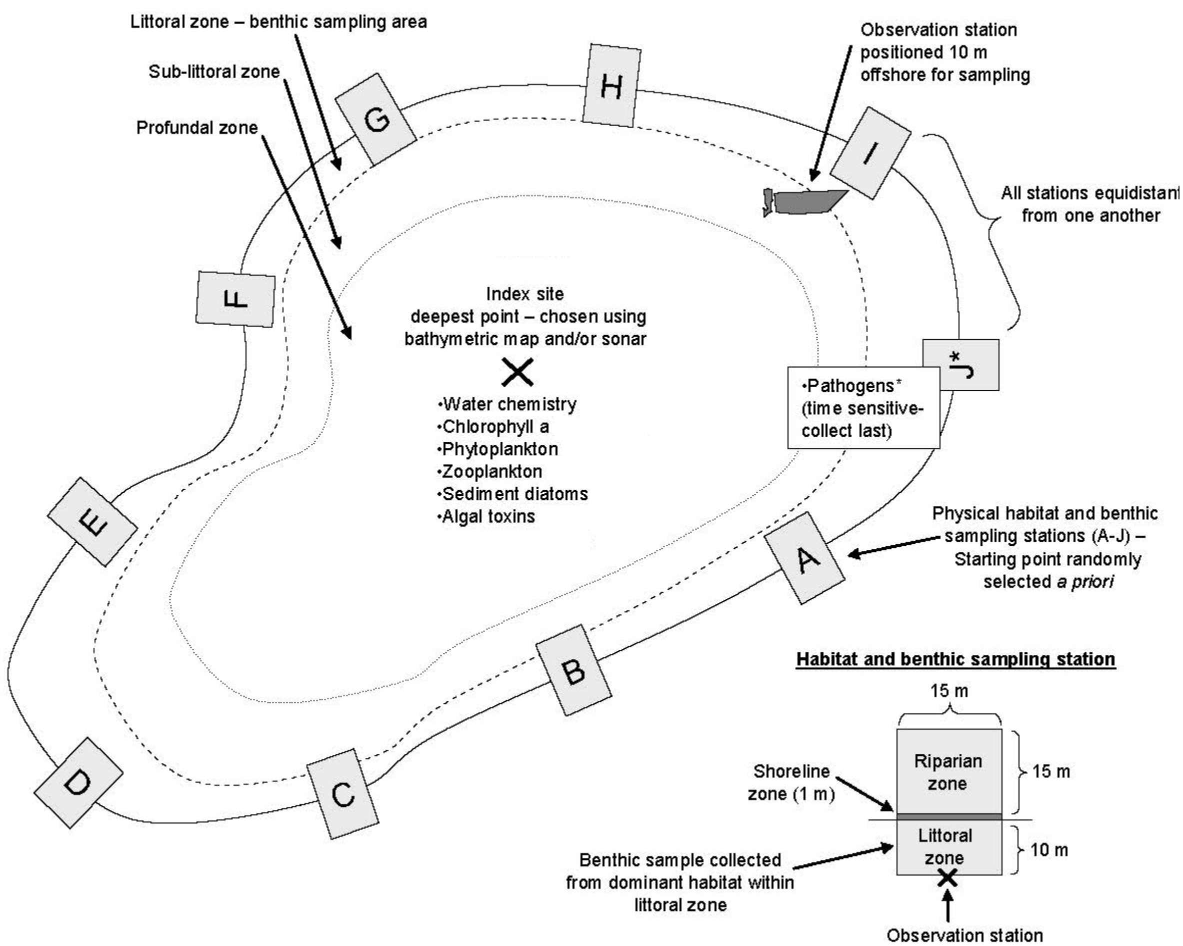


Figure 5. Diagram of sampling locations within each lake.

Table 2. Summary of field data collection protocols.

Metric Type	Field Method
	Sampling at X-site (deepest part of lake)
Secchi disc transparency	Deployed from shady side of boat. Depth of disappearance and reappearance were recorded. Secchi reading was used to define the euphotic zone for the water chemistry data collection procedures (2 times Secchi depth = total euphotic zone).
Water chemistry	Water sample collected with an integrated sampler so that water could be collected from the upper two meters of the water column, which encompasses the euphotic zone. When Secchi depth determined that the euphotic zone was < 2 meters the integrated sampler was only deployed to that depth.
Water quality profile	In situ DO, pH, water temperature, and conductivity were measured with an electronic meter at the surface and through the water column (DO value used in assessment was the mean value from the top 2 m).
Chlorophyll-a	Collected as part of water sample using the integrated sampler. Sample was filtered in the field and filter was submitted for analysis.
Phytoplankton	Collected as part of water sample using the integrated sampler.
Zooplankton	Conducted two vertical sampling tows through the entire water column, one using fine (80um) and one using coarse mesh (243um) Wisconsin nets.
Sediment diatoms	A 4in. diameter coring device was deployed to collect a sediment core with minimum length of 45 cm. A one-cm slice was removed from both the top and bottom of the core.
Algal toxin	Collected as part of water sample using the integrated sampler.
Sediment mercury*	Small plug of sediment from surface portion of sediment core was removed with a pipette prior to removal of the 1-cm slice for the diatom sample.
	Sampling at 10 physical habitat stations
Physical habitat	Recorded three types of visual (qualitative) observations made within the habitat station diagramed in Figure 5: 1) Littoral habitat cover and structure recorded from 10x15m littoral plot 2) Riparian/shoreline vegetative structure and cover complexity at three levels (tree canopy, understory, and ground cover) recorded from Riparian/shoreline plot. 3) Human influences within the riparian/shoreline/littoral portions were recorded.
Benthic Invertebrates*	A 500 um D-frame kick net was swept through a single 1 linear meter of the dominant habitat type at a maximum depth of 0.5m. Samples from all ten stations were composited into one sample.
Enterococci	Water sample collected in littoral zone of last physical habitat station where lake depth is one meter deep. Sample collected at 0.3 meters depth.

*=data not available for report

C. Landscape Data Methods

Basin area was delineated for each lake by EPA Office of Water using components of the NHDPlus system. The NHD flowline data was examined to determine the lowest Hydrologic sequence number. This number was selected as the lake outlet and its downstream measure was used as the point location of the pour point. This point and the flowline data associated with the waterbody was used to delineate the drainage basin using the NHDPlus Basin Delineation tool. A few lakes that were not found on the

NHDPlus Basin network had their basins delineated using the ArcGIS Spatial Analyst->Hydrology->Watershed tool. A sample watershed is in **Figure 6**.

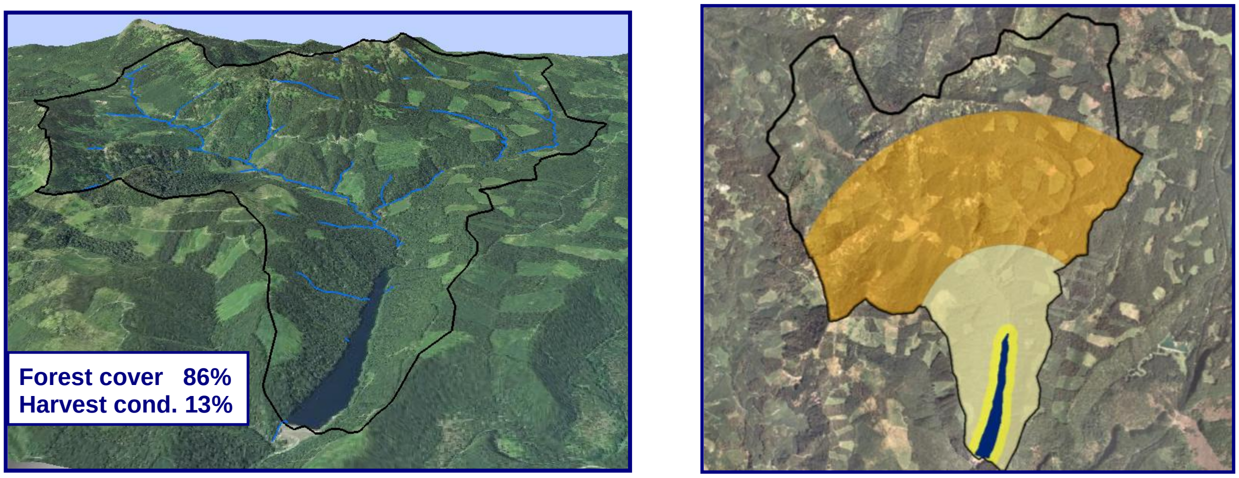


Figure 6. Example of lake contributing area with sample cover classes and illustration of four buffers distances, entire watershed, 5km, 2km and 200m, in which each cover attribute was calculated (Smith reservoir, Oregon).

Within each watershed polygon, landcover metrics such as percent forest and percent agriculture were calculated from National Land Cover Database (NLCD) Digital coverages. The Analytical Tools Interface for Landscape Assessments (ATtILA 3.x), an ArcView Software extension (Ebert et al. 2000), was used to calculate the metrics. In addition to these standard landcover metrics, EPA Region 10 generated a suite of other metrics that are relevant to human disturbance in the Pacific Northwest. These metrics relied on the use of higher resolution data available for the region and incorporated several models specific to the Western US. Landscape metrics used in this analysis are summarized in (**Table 3**). Additionally, landcover metrics were-calculated at three buffer distances from the lake, 5km, 2km, and nearshore 200m (Figure 6). These are used in the analysis to test for the optimum buffer that gives the best expression of landscape stressor metrics. Results of the analysis of these metrics are in **Appendix 2**.

Table 3. Summary of landscape metrics used for comparison to lake condition.

Metric Category	Metric Description	Source
Land cover	Percent cover of land types (% forest, shrub, agriculture, etc.)	NLCD
Forest disturbance	Attributes of “Transitional from Forest harvest’ and ‘Transitional from Forest Fire’ are more detailed forest vegetation conditions over the standard NLCD metrics which commonly interpret ‘disturbed’ forest harvest as either Grass or Shrub cover.	NW_GAP database
Agriculture on > 9% slope	Amount of agriculture on steep slopes. Calculated from slope grid, 9% threshold value, and agriculture coverage.	NHD and 30m NED slope database
Potential Unit Grazing	Indicator of the intensity of potential cattle/calf grazing. Calculated from county cattle census data, Potential Cow Habitat score which is in turn calculated from five inputs: land ownership, land cover, proximity to water, topographic position grid index, and slope.	NLCD, NHD and 30m NED slope database
Sediment delivery model	Estimate of basin average rates of soil erosion and total annual sediment delivery at the basin outlet. Calculated from empirical models ‘RUSLE (Renard et al. 1997) and SEDMOD (Fraser 1999).	GIS based modeling tool from USEPA Landscape Research Group (Van Remortel et al. 2005, 2006)
Roads	Road density and road stream crossing density from Tela-Atlas data layer	Region 10 SDE database
Human population	Population density calculated from 2000 Census Tiger File census layer.	Region 10 SDE database
Land ownership	Four attributes of ownership: Private, State, Federal, and Tribal.	ICEBEMP website
Elevation	Mean, minimum and maximum elevation of watershed.	USGS National Elevation Dataset (NED)
Precipitation	Mean, minimum, and maximum precipitation calculated from 18-year dataset.	Daymet website

1. Biological Condition

Lakes have many levels of interacting biological assemblages including primary producers such as algae and phytoplankton, intermediate assemblages such as benthic macro- invertebrates and zooplankton, and fish assemblages operating at various trophic levels (e.g. bottom-dwelling herbivores or pelagic predators). The overall condition of a lake is defined by its functioning biological community and the number and kinds of organisms in a lake is a direct measure of its health. The biotic community determines the response indicators because alterations and disturbances to lakes change the biotic community. Two biotic assemblages are evaluated in the survey, plankton assemblage and sediment diatoms. Although benthic macro-invertebrates were collected at the shore plots, the model of biological condition resulting from these data has not been finalized by EPA Office of Water and is not presented in this report.

Phytoplankton (floating algae) and zooplankton (free floating animals) are highly responsive to changes in lake ecosystems. They are useful response indicators because the effect of environmental changes can be detected through changes in species composition, abundance, and body size (for zooplankton). For the NLA, project researchers developed a combined phytoplankton-zooplankton “Observed versus Expected Index” (O/E Index). This type of index estimates biological condition by measuring the agreement between the taxonomic composition expected under reference conditions and that observed at the individual lakes and thus expresses taxa loss. The model is complicated by the fact that taxonomic composition varies with natural environmental factors. The O/E Index depends on models that predict how taxonomic composition varies and on calibration to the reference sites.

Diatoms are a group of algae that have silica based cell walls. When these organisms die, these cell walls (*valves*) are deposited on the substrate. Through time, subsequent sedimentation preserves these valves. Because the valves are unique to particular species, diatom valves present in sediment cores can be used to identify the diatom assemblage at various points in the history of the lake. Diatoms are useable as a biological condition indicator because many diatom species have well-defined optima and tolerances for environmental variables such as pH, nutrients, water salinity or color (Stoermer and Smol 1999). For this assessment, information on the environmental conditions that favor particular diatom species can be coupled with diatom assemblage data from reference lakes to develop a sediment ”lake diatom condition” Index (LDC). Diatom data from the surface sediments of each lake was compared to this index to estimate the condition of the diatom assemblage. Further details on the development of both the plankton community taxa loss model and the sediment LDC Index are discussed in the NLA Technical Document (EPA 2010).

Results of these two models applied to the Region 10 lakes data are in **Figure 7**. Results are shown as green (good), yellow (fair), red (poor) and stippled (no data). The plankton community taxa loss model indicates that 62% of Region 10 inference lakes are good, 10% fair, and 27% in the poor category. The sediment diatom LDC presents a similar view with 66% in the good category. A smaller proportion is in the poor category (3%).

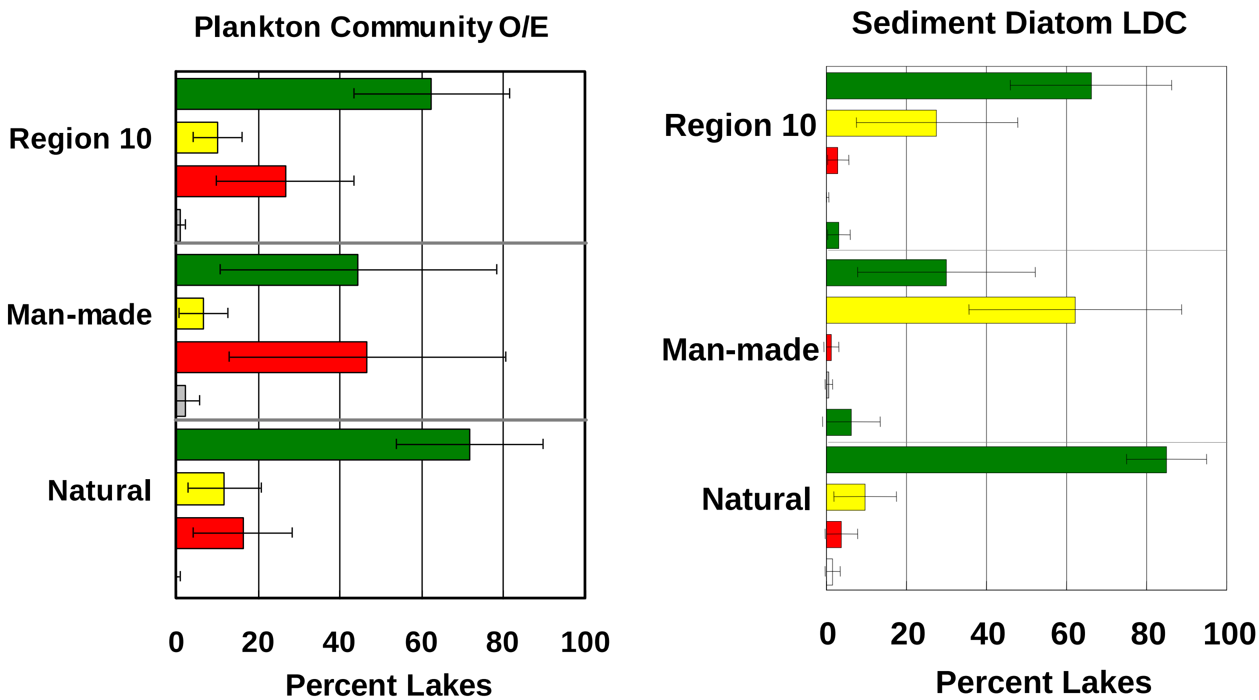


Figure 7. Region 10 lakes in good, fair, poor, no data, and not assessed condition classes for the plankton community O/E and sediment lake diatom condition (LDC) indicators of biological condition.

When natural and man-made lakes are compared, plankton taxa loss model indicates a relatively high proportion of man-made lakes in the poor category (47%) compared to natural lakes (16%) (Figure 7). The sediment LDC index shows that most man-made lakes are in the fair category (62%) while natural lakes are mostly of good condition for this indicator (85%).

2. Water Quality and Trophic State

A. Water Quality

Chemical stressors have the potential to affect biota of lakes by altering their basic environment so that required tolerable ranges are no longer present. Key chemical stressors in this assessment are nutrients (nitrogen and phosphorus), turbidity, and dissolved oxygen.

The nutrients nitrogen and phosphorus control algal production in lakes. These are important because algae are the primary production that drives the biology of lakes. Phosphorus is often the ‘limiting nutrient’ in lakes of the Pacific Northwest as it controls the pace at which algae are produced. When phosphorus is exhausted by the growing algae, the nutrient will be essentially gone from the lake and further algal growth will be limited. Likewise, small increases in phosphorus can cause rapid algal growth in lakes that are limited by phosphorus. Excess nutrients in lakes can have negative effects on lake biological communities, recreation, and aesthetics.

Turbidity is a measure of light scatter that is often described as murkiness or lack of clarity. Suspended sediment or high concentrations of algae cause turbidity in lakes. Although turbidity is a natural characteristic of lakes, human activities can decrease water clarity by increasing sediment or nutrient levels. Nitrogen, phosphorus and turbidity condition classes are based on regionally determined condition class thresholds that were generated from an evaluation of reference site conditions. Details of cut-offs and how these were calculated are available in the Technical Document (EPA 2010). Summary statistics of relevant water quality and trophic state metrics are in **Table 4**.

Table 4. Water quality summary statistics for Region 10 lakes' inference population (~1700 lakes).

Metric	units	Inference N	Mean	Median	Minimum	Maximum	Std.Dev.
Total Phosphorus	ug/L	1694	62.22	9.00	1.00	2670.00	186.03
Total Nitrogen	mg/L	1694	0.65	0.40	0.01	7.68	0.96
Turbidity	NTU	1694	12.18	0.73	0.24	574.00	58.70
Chlorophyll-a	ug/L	1694	12.37	1.91	0.07	194.40	25.82
Secchi depth*	M	1604	3.89	4.03	0.04	36.71	2.65
Dissolved Oxygen**	mg/L	1694	7.72	8.04	1.00	11.72	1.55

* Lakes that were clear to bottom excluded from Secchi depth summary statistics.

** Dissolved oxygen value is mean of multiple measurements in the euphotic zone.

About half of the inference lakes are in good condition for nutrients, 57% of the lakes for phosphorus and 41% of the lakes for nitrogen (**Figure 8**). A substantial portion of the lakes are in the poor category for these nutrients (39% and 49%). Most man-made lakes were in the poor category for both phosphorus and nitrogen.

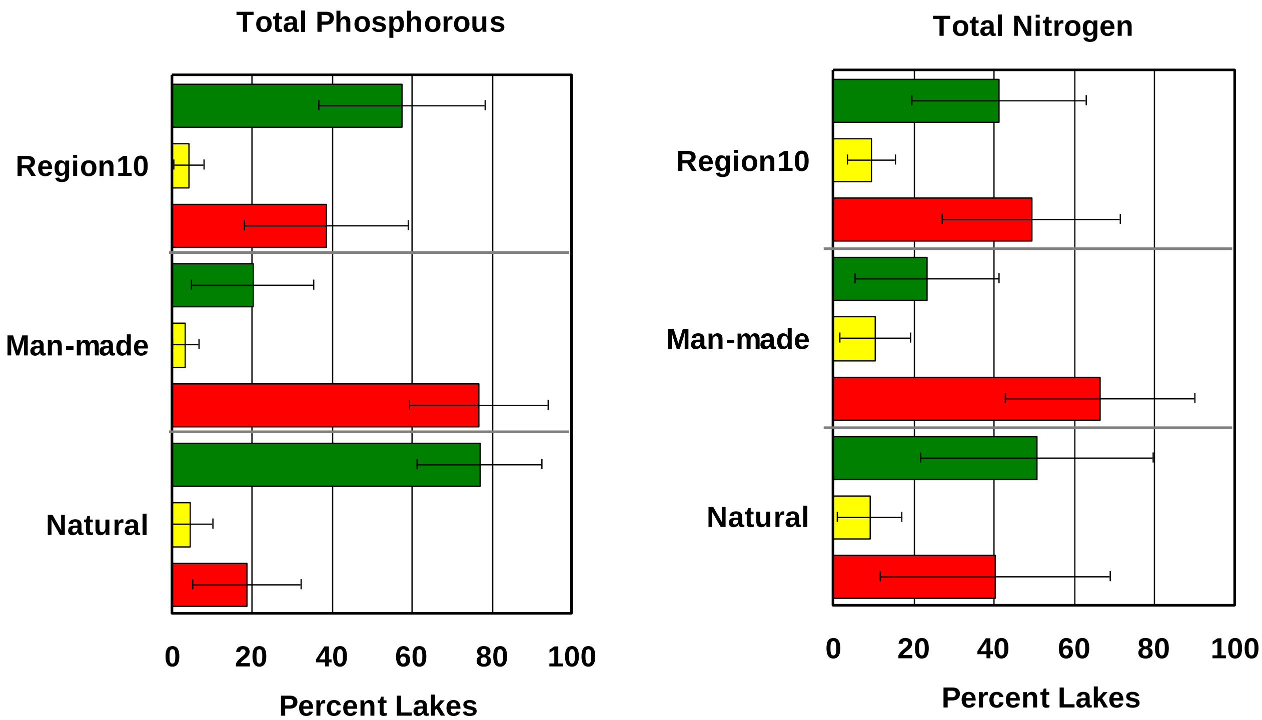


Figure 8. Lakes in good, fair, poor condition classes for total phosphorus and nitrogen.

Turbidity condition results are similar to those for phosphorus (**Figure 9**). Most of the Region 10 inference lakes are in good condition for turbidity (58%). The man-made lakes have a much higher proportion of lakes in the poor category compared to the natural lakes.

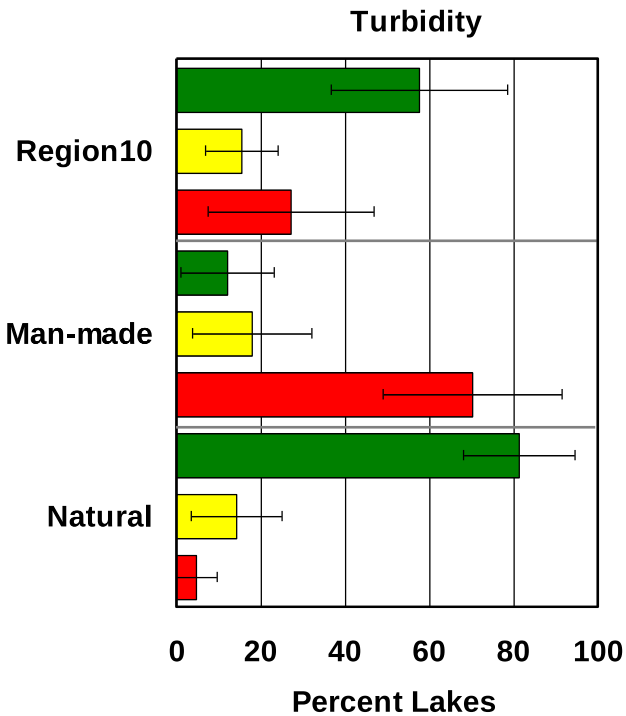


Figure 9. Lakes in good, fair, poor condition classes for turbidity.

Dissolved oxygen is a direct indicator of a lake's ability to support aquatic life and aquatic organisms have specific DO requirements. In general, levels below 3 mg/L are considered low and those below 1mg/L do not support aquatic life. For this survey, the following EPA-recommended thresholds for DO concentration were applied: good ≥ 5 mg/L, fair >3 to <5 and poor ≤3. Region-wide, dissolved oxygen measured in the euphotic zone was high with a mean of 7.7 mg/L (Table 4). Almost all lakes are in the good category (97%). High dissolved oxygen in the euphotic zone is an expected result. Depths below the euphotic zone (e.g. the hypolimnion) are where low DO concentrations are more likely to first occur. Low DO in the hypolimnion is a natural process and is not unexpected.

B. Trophic State

The trophic state of a lake is the description of its biological productivity. Chlorophyll-a is a measure of primary productivity of the lake and is therefore the most straightforward indicator of lake biological productivity. Levels of nutrients and Secchi transparency depth are indirect indicators that also give insight into the trophic state of a lake. As described above, nutrients are often correlated to algal production as their levels can range from very low, resulting in limiting algal production, or high, resulting in high algal production. Secchi transparency is another measure of lake clarity. Very clear water can indicate low levels of algal productivity while low transparency can indicate high algal presence. Thresholds of phosphorus, nitrogen, chlorophyll-*a*, and Secchi transparency are used to characterize trophic condition. The thresholds used in this assessment were selected based on input from states and are similar to those determined by Carlson's Trophic State Index (Carlson 1977 and Carlson 1983). **Table 5** shows the breakdown of parameter thresholds related to each of the four levels of productivity.

Table 5. Carlson Trophic State Index (TSI) parameter thresholds.

Trophic State	Chlorophyll-a (µg/L)	Total Phosphorus (µg/L)	Total Nitrogen (mg/L)	Secchi Transparency (M)
Oligotrophic	<2	< 10	<0.35	>4
Mesotrophic	2 - < 7	10 - <25	0.35 - <0.75	4 - >2
Eutrophic	7 - <30	25 - <100	0.75 - <1.4	2 - 0.7
Hypereutrophic	≥30	>100	≥1.4	<0.7

Eutrophication, the process of moving to a more biologically productive state, is a natural progression in the life of most natural lakes. The trophic conditions of lakes range from highly productive (hypereutrophic) to very low productivity (oligotrophic). In the Region 10 inference lake population, the chlorophyll-a measures indicate that most of the lakes are oligotrophic (62%) followed by a relatively even distribution of the more productive categories (**Figure 10**). The other three TSI thresholds for nutrients and Secchi transparency depth also indicate dominance of oligotrophic lakes in Region 10.

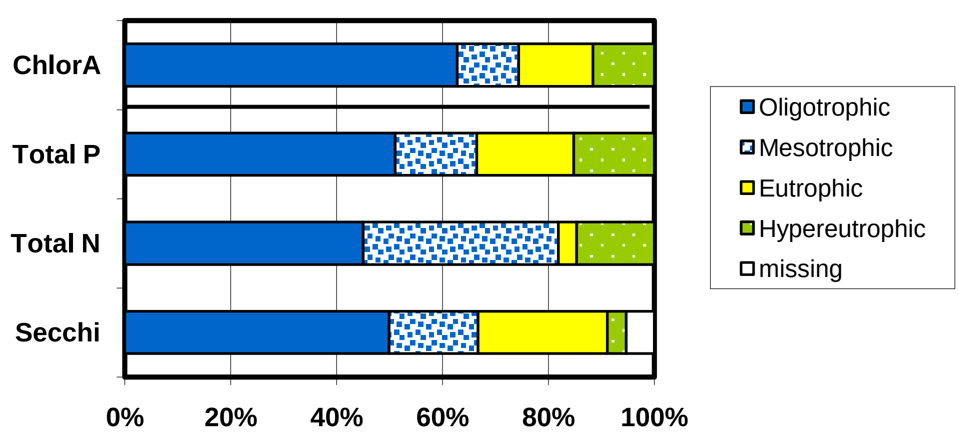


Figure 10. Percentage of inference lakes in each of four trophic categories based on TSI thresholds for four trophic state indicators.

Comparing TSI thresholds for chlorophyll-a between the natural and the man-made lakes, we see a large difference in the proportion of oligotrophic lakes (**Figure 11**). The natural lakes tend to be oligotrophic while the man-made lakes are more productive and have higher levels of eutrophication.

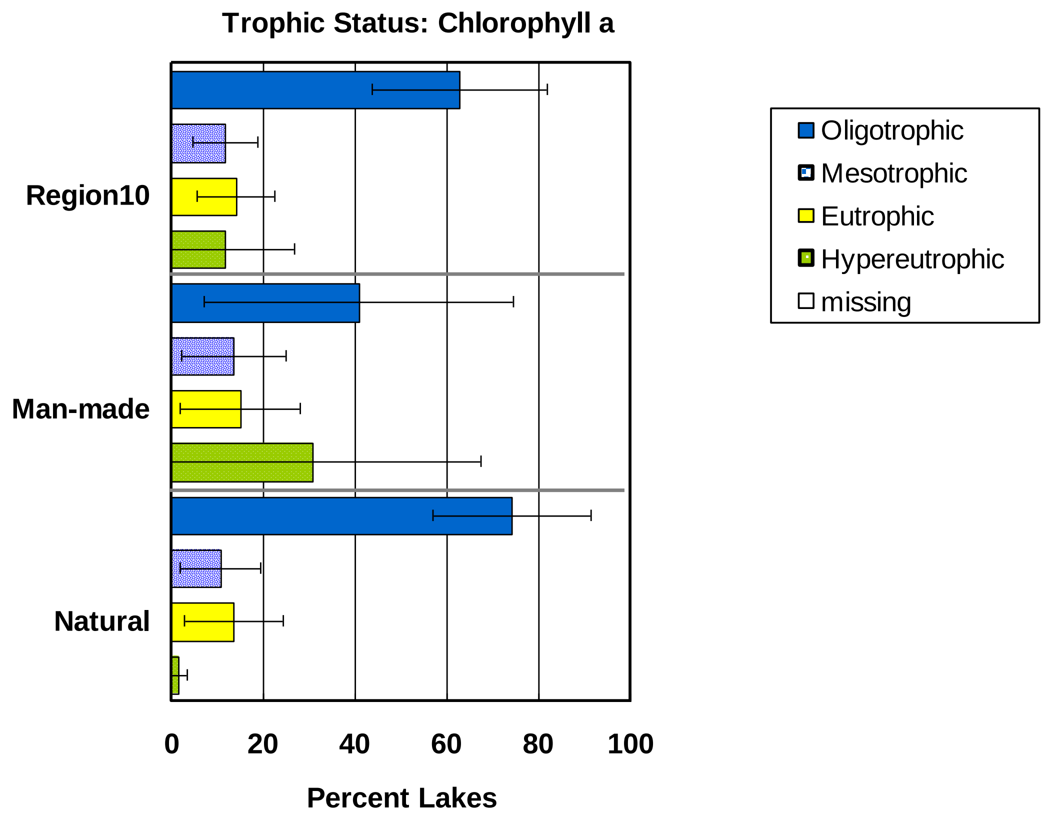


Figure 11. Percent of lakes in four trophic classes based on TSI thresholds for chlorophyll-a.

Generally the poor classification of the lakes by trophic state is related to high nutrient levels resulting in increased primary production. However, this relationship is more complex as 'high' nutrients may not necessarily be responsible for a negative biological response. **Appendix 3** examines the factors that may be affecting lake production. The possible biological response to the observed nutrient levels within Region 10 lakes is evaluated.

3. Physical Habitat Stressors

Lakeshore and littoral habitat are important characteristics of lake ecological condition. These habitats support the biological community by supplying food, refuge from predators, and conditions suitable for reproduction and rearing. Shore areas also influence nutrient cycling, production and sedimentation rates. The interface between the lakes and human disturbance often occurs at the lakeshore where human activities can adversely affect the lake by reducing habitat complexity. Physical habitat indicators are useful for diagnosing likely causes of ecological degradation in lakes and can be used as benchmarks to compare future habitat changes that may result from anthropogenic activities.

Field data collected in the terrestrial, shoreline, and littoral zones results in hundreds of individual measurements and observations describing an array of characteristics including bank morphology, substrate, fish concealment features, aquatic macrophytes, terrestrial vegetative structure, and human land use and disturbance. EPA researchers evaluated and summarized these data into four integrative physical habitat indicators of lake condition. These four stressor indicators are described as follows:

- Littoral (shallow water zone)—metric that combines cover and structure features used by biotic assemblages in the littoral zone. These include large woody debris, snags, brush, overhanging vegetation, aquatic macrophytes, boulders, and ledges.
- Lakeshore cover and structure—metric that combines structure and cover characteristics of three layers of vegetation (tree canopy, understory, and ground cover) present in the lakeshore zone (terrestrial and shoreline plot)
- Physical habitat complexity--metric that combines data from the littoral zone cover estimates and the vegetation structure of the lakeshore plot.
- Human disturbance- distribution, extent, of human land use activities in the lakeshore area and the proximity of these activities.

Condition ratings of good, fair, poor were established relative to the reference conditions that exist within the region. Details on how these metrics were calculated and how the condition classes were determined and assigned are described in the NLA Technical Document (EPA 2010).

Across Region 10, 35% of the inference lake population had good lakeshore habitat where lakeshore vegetation is complex and intact as expected by the comparisons to the reference condition (**Figure 12**). An equal proportion of the lakes were in the poor category, indicating loss of lakeshore complexity. Man-made lakes had a very high occurrence of poor lakeshore condition as indicated by this metric. The condition of shallow water areas was substantially better (Figure 12). Overall, the quality of the littoral zone is good, indicating there is usually adequate quantity of shallow habitat and that this habitat has adequate complexity to support biological assemblages. Over 68% of the inference lakes have shallow water habitat that has structure and complexity consistent with the reference condition.

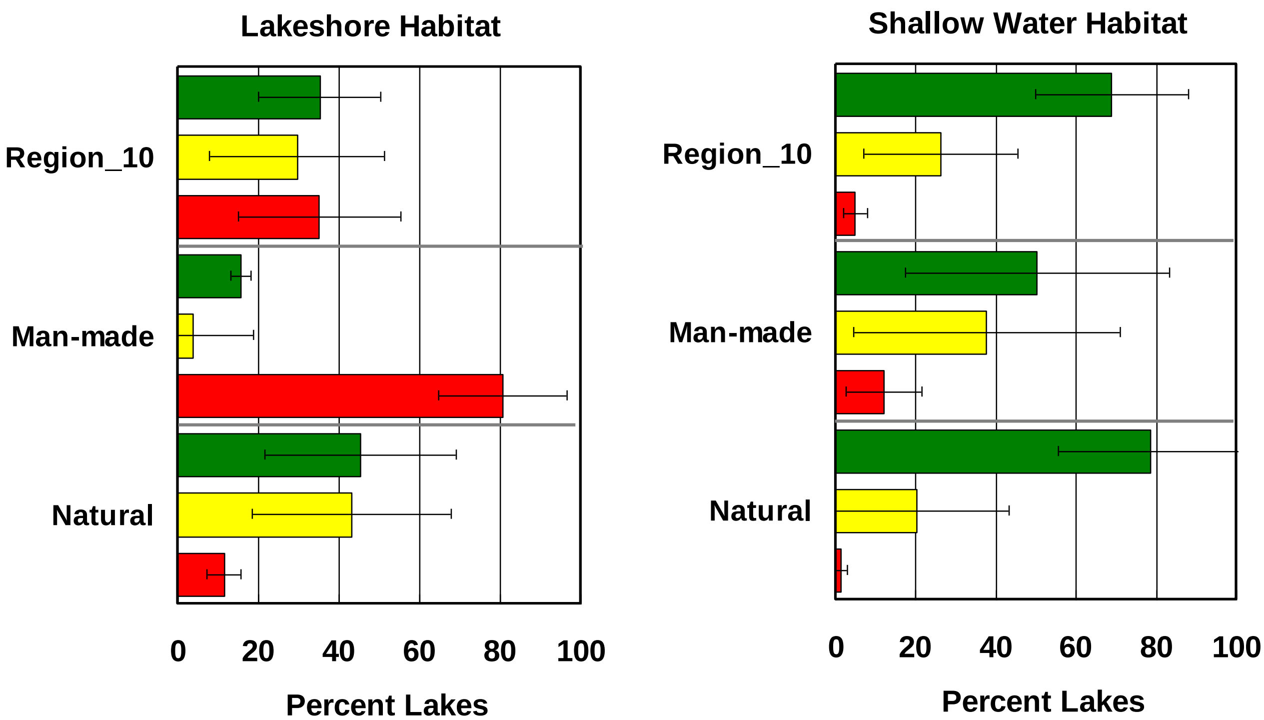


Figure 12. Lakes in good, fair, poor condition classes for lakeshore habitat and shallow water habitat.

The physical habitat complexity indicator is the arithmetic mean of the lakeshore and shallow water habitat metrics and provides a more generalized view of habitat conditions (**Figure 13**). About 50% of the inference lakes have good habitat vegetative cover and complexity with good structure and cover in the littoral zone. Over 50% of the man-made lakes are poor for overall physical habitat. The signature of human disturbance results in fair-to poor-rating in 80% of the man-made inference lakes (Figure 13). Less than 2% of the man-made lakes were in the good condition class for disturbance in the lakeshore area.

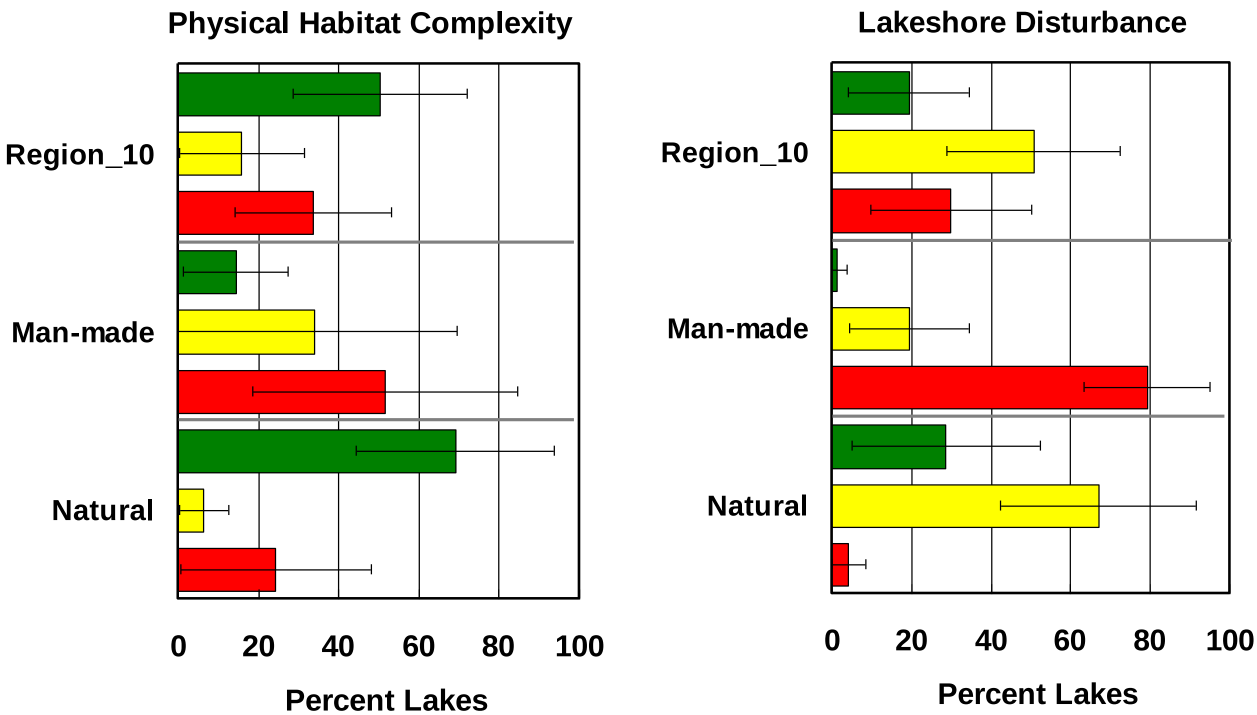


Figure 13. Lakes in good, fair, poor condition classes for habitat complexity and lakeshore disturbance.

4. Suitability for Recreation

Recreation indicators address the ability of lakes to support human activities such as boating, swimming, and fishing, which are protected uses under the federal Clean Water Act. Many factors affect the recreational quality of lakes, from aesthetic characteristics such as water clarity and quantity of macrophytes to the quality of the fish community that supports sport fishing. Safety for recreation is increasingly of concern to the public. Algal toxins, pathogenic microbial organisms, and contaminants in fish tissue are the three areas of concern for health hazards to people, pets, and wildlife. Of these, the National Lakes Survey focuses primarily on algal toxins as indicators of recreation suitability. The bacteria of the genus *Enterococcus* were measured as an indicator of the potential for pathogens. .

A. Algal toxins

Cyanobacteria (i.e. blue-green algae) are naturally occurring algae that can produce algal toxins. Cases of wildlife fatalities, off-flavor water and fish, and human skin rashes have been attributed to blue-green algae exposure. Eutrophic conditions can result in periodic cyanobacteria blooms that appear on the lake's surface as unsightly layers of odiferous scum. Although cyanobacteria may be present, the actual production of algal toxins cannot be implied as not all cyanobacteria produce algal toxins. Determining the presence/hazard of algal toxins is complicated by the fact that their presence is both spatially and temporally erratic. Algal blooms are not uniform on the lake surface, but tend to concentrate on the windward shore. Similarly, physical and chemical conditions that promote algal blooms are ephemeral. Determining presence/hazard of algal toxins in a one-day data collection event is therefore challenging. Three indicators were used to assess algal toxin risk: microcystin presence – a common algal toxin, cyanobacteria cell counts – bacteria that can produce algal toxins, and chlorophyll-a concentration – a general measure of algal presence. Note that the last two indicators are not direct measures of algal toxins but are surrogates for their presence. The World Health Organization established risk thresholds that we use to assess risk to recreation suitability (**Table 6**).

Table 6. World Health Organization's recreation indicator thresholds of risk associated with potential exposure to algal toxins.

Indicator	Low	Moderate	High
Microcystin (µg/L)	<10	10- ≤20	>20
Chlorophyll-a (µg/L)	<10	10 - < 50	>50
Cyanobacteria (#/L)	< 20,000	20,000- <100,000	≥ 100,000

Microcystins, along with anatoxin-a and saxitoxins are among the most common cyanotoxins (Graham et al. 2010). Microcystin is a liver toxin that is known to cause tumors and is likely carcinogenic to humans. The presence of microcystin was low in the inference lake population and only 12% of lakes had levels of microcystin above the detection limit of 0.1 ug/L. All lakes of the inference population (100%) were rated as having low risk to recreation suitability due to microcystin presence. The other two measures of cyanotoxin exposure risk indicate that the inference lakes have an overall low level of risk (**Figure 14**). Region-wide, the proxy indicators show over 80% of inference lakes having low risk. For the chlorophyll-a indicator, a higher proportion man-made lakes had high risk (30%) than for natural lakes (<2%).

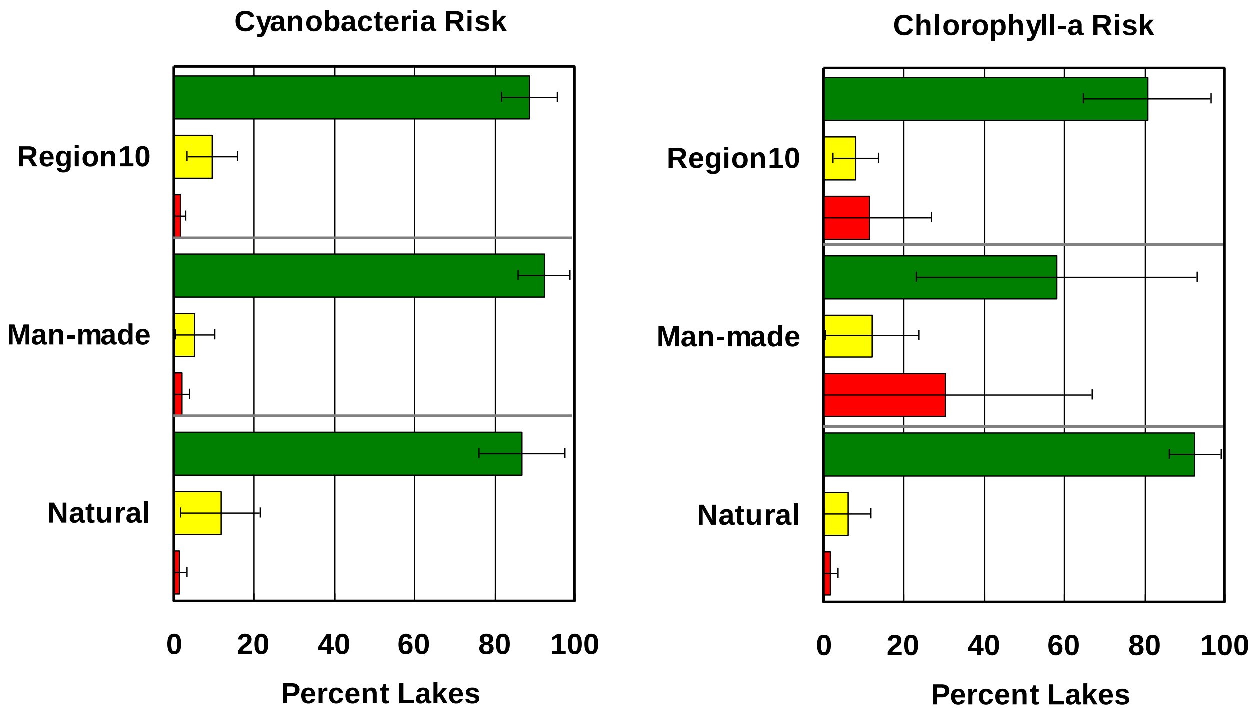


Figure 14. Lakes within low, medium and high risk categories for algal toxin exposure based on cyanobacteria cell counts and chlorophyll-a concentration.

B. Pathogens

Enterococci are bacteria found in soil, vegetation, and surface water that have been contaminated by animal excrement. Most species of enterococci are not harmful to humans, however their presence can indicate disease causing agents carried by fecal material. Currently there are no water quality criteria or recommended thresholds for evaluating the enterococci data collected as part of the survey. Thus, the results are limited in their value as an indicator of the condition of lakes. For this survey, a simple ranking of the enterococci data from all lakes of the survey was developed by EPA. Four category rankings were determined by reviewing the data for clustering and professional judgment. This ranking provides a relative indication of the presence of bacteria in lakes (**Table 7**).

Table 7. Results of ranking Region 10 data by Enterococcus concentration categories. Samples collected from 88 sites (inference population =1694).

Ranking (CCE/100mL)*	% R10 inference sites	R10 results range
1 : <500	96	Non detects- 497
2 : 500-1,000	1	515-786
3 : 1,000-5,000	2	1,698-2486
4 : >5,000	1	6127

*Data are expressed as Calibrator Cell Equivalents (CCE) per volume.

In Region 10, most lakes are in the lowest ranking category of enterococci presence and many of the sample lakes were below the detection limit. All of the reference lakes sampled in Region 10 were also in the lowest category. These results add to the consistent picture that condition of the Region's lakes is good for recreation suitability.

C. Contaminants in Fish Tissue

Fish tissue used to examine contaminant exposure was not collected as part of this assessment. However, in the early 2000s, EPA Office of Science and Technology conducted a National Lake Fish Tissue Study which evaluated the condition of the nation's lakes for this important indicator of recreational suitability. This study used similar survey design and results were applicable to the entire contiguous United States. The Region 10 portion of this study is presented in **Appendix 4**. Mercury, DDTs, and PCBs results are reported.

Summary of Findings: ranking stressors

The relative extent calculation shows the stressors that have the greatest effect on the target population. A stressor with high relative extent is both widespread and common among lakes while stressors with low relative extent occur over a small area or infrequently over a wide area. The relative extent for this survey is simply a ranking of the 'poor' category results for each stressor indicator, ordered according to their magnitude by percent of lakes. Looking across all of the stressor indicators, those associated with water quality and trophic state had slightly higher impact on lakes of the region followed by physical habitat indicators (**Figure 15**). The following are overall summary statements of indicator results.

- Evaluation of the biological condition of Region 10 lakes relied on the combined zooplankton/phytoplankton O/E scores. The results showed that 62% are good, 10% fair, and 27% poor condition.

- Chlorophyll-a concentrations indicate that 12% of the lakes are hypereutrophic with the rest having progressively lower states of eutrophication.

- Nutrients were the most extensive stressors in the region with 49% of the lakes classified as being in poor condition for nitrogen and 39% for phosphorus.

- Three habitat stressors related to lakeshore condition (lakeshore habitat, lakeshore disturbance and habitat complexity) were similar in their extent, ranging from 30% to 35% in poor condition.

- Three indicators of recreational suitability support that there is a low risk of algal toxin exposure in lakes of Region 10.

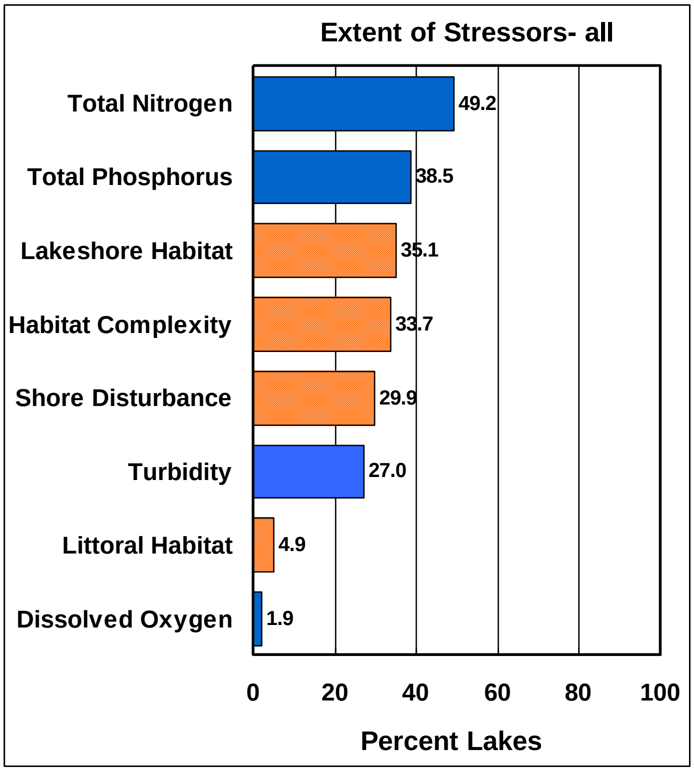
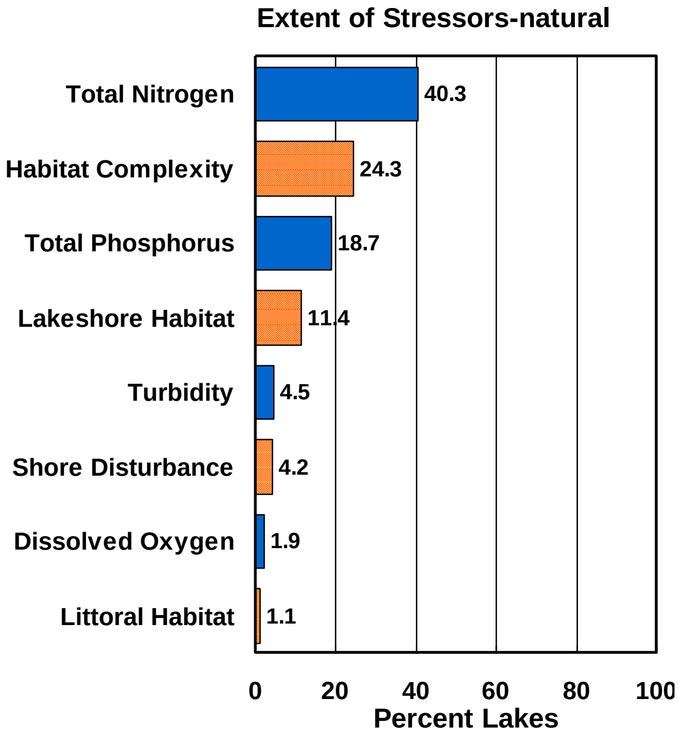


Figure 15. Relative extent of poor stressor condition across all stressor metrics for all Region 10 lakes.

As shown throughout this report, the man-made lakes have generally poorer condition than the natural lakes (**Figure 16**). Both habitat and water quality indicators were substantial stressors for man-made lakes. More than 50% the man-made lakes were classified as being in poor condition for all but two of the indicators. Also, only 45% of man-made lakes were in the good category for biological condition compared to 72% of the natural lakes. Natural lakes were predominantly in the good category except for the total nitrogen indicator (40% in poor category).



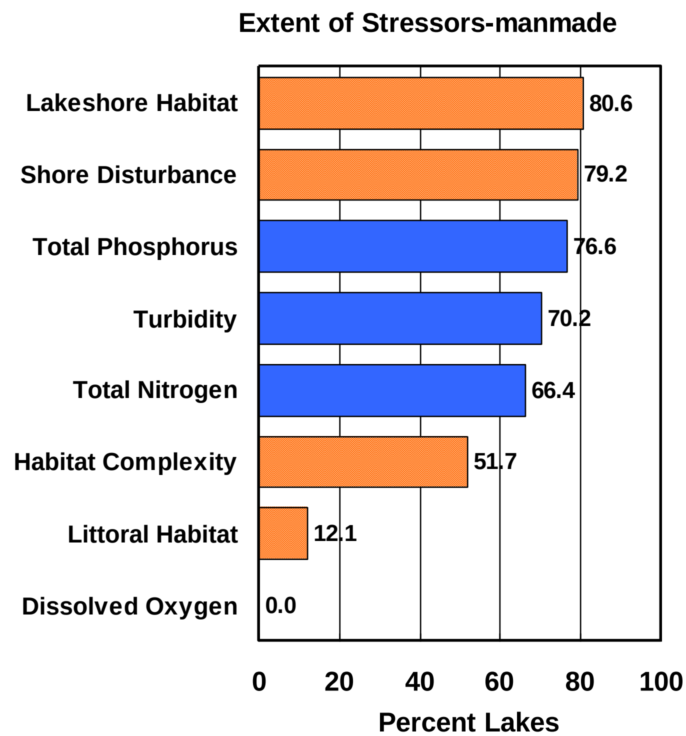


Figure 16. Relative extent of poor stressor condition across all stressor metrics for natural lakes and man-made lake categories.

Recommendations

Several recommendations for improving the survey came to light during the course of this analysis and from discussions with state collaborators:

- Improve site selection design to insure more reasonable error bounds in the western ecoregions.

- Develop GIS landscape condition indicators. Our analysis of landscape metrics in Appendix 2 shows several metrics that have good potential as indicators of lake watershed condition. Further development of landscape indicators using larger datasets would provide another dimension to the overall description of lake condition.

- Add fish tissue contaminants as a recreation suitability indicator. Although some states have monitoring programs for the tracking of toxins in fish tissue, data in the Region 10 states is limited. Having data collected as part of this survey would be a significant contribution to understanding this important aspect of human health in Northwest lakes. Information on metals (mercury, arsenic, selenium), PBDEs, and legacy pesticides, are specifically needed.

- Improve ability to assess recreation suitability by sampling areas that are more likely used for recreation. Sampling for this indicator would be more relevant at sites adjacent to the shore rather than the center of the lake. Also, improve ability to interpret data by collecting pathogen data that can be used to classify the condition. Many states use E. coli. If problems with holding times can be overcome, this would be a more useful metric for pathogens.

- Sample an adequate number of sites to allow determination of relative risk. Although methods are available for determining relative risk, the low number of sites in each cell of the contingency table that are used to compute the ratings prohibits this calculation for Region 10. More sample sites would thus yield a more meaningful analysis.

- Include a more comprehensive analysis of the diatom core in order to provide good information on past conditions. This information would be a useful long-term indicator.

- Research a more effective way to include invasive species assessment into the survey. These data were included as qualitative observational information that is not rigorously analyzed. This is a very important aspect of lake condition.

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Appendix 1. Sampled Lakes in Region 10

Appendix 1. List of sampled probability lakes including design coordinates (90 total).

SITE_ID	State	Weight	Longitude (dd)	Latitude (dd)	Area (ha)	Major ecoregion	Level III ecoregion
NLA06608-0005	ID	15.010328	-114.840386	43.929209	19.5	WMT	16
NLA06608-0085	ID	9.195787	-116.141432	43.460454	33.4	XER	12
NLA06608-0241	ID	3.738934	-111.729262	42.291543	170.2	XER	80
NLA06608-0277	ID	3.738934	-113.400612	42.678174	3395.5	XER	12
NLA06608-0497	ID	9.195787	-111.815938	42.107653	34.2	XER	13
NLA06608-0561	ID	2.425646	-116.089322	44.948436	2018.4	WMT	16
NLA06608-0581	ID	2.425646	-114.382789	43.252639	1443.3	XER	12
NLA06608-0597	ID	2.425646	-116.665495	43.547058	3571.2	XER	12
NLA06608-0650	ID	4.030970	-111.396362	44.642099	2459.2	WMT	17
NLA06608-0769	ID	4.030970	-116.602150	47.465617	399.6	WMT	15
NLA06608-0837	ID	3.395574	-113.923741	43.325359	81.3	XER	12
NLA06608-0961	ID	3.660791	-116.686557	47.489395	91.9	WMT	15
NLA06608-1281	ID	233.572732	-116.155618	48.135006	6.2	WMT	15
NLA06608-1329	ID	4.030970	-116.169740	45.068128	148.1	WMT	16
NLA06608-1473	ID	2.425646	-116.893380	47.890852	370.3	WMT	15
NLA06608-1521	ID	3.395574	-111.853579	42.233175	61.5	XER	13
NLA06608-1537	ID	15.010328	-116.638410	48.161727	17.4	WMT	15
NLA06608-1793	ID	4.030970	-116.564348	47.520730	201.8	WMT	15
NLA06608-1930	ID	3.738934	-111.473476	44.100512	144.2	XER	12
NLA06608-1985	ID	2.425646	-116.798693	47.448688	11029.2	WMT	15
NLA06608-1989	ID	3.738934	-114.891000	42.202900	393.0	XER	80
NLA06608-2005	ID	3.395574	-116.112474	42.297374	56.6	XER	80
NLA06608-2305	ID	9.914039	-116.527985	48.184430	39.3	WMT	15
NLA06608-2497	ID	3.660791	-116.970121	48.008220	54.5	WMT	15
NLA06608-2801	ID	3.395574	-112.689224	42.085663	50.2	XER	13
NLA06608-2954	ID	13.922860	-111.603733	44.023613	19.1	XER	12
NLA06608-3121	ID	4.030970	-116.462359	44.964527	211.4	WMT	11
NLA06608-3157	ID	4.030970	-115.798714	43.549425	332.4	WMT	16
NLA06608-3313	ID	3.395574	-111.836249	42.123193	52.3	XER	13
NLA06608-3329	ID	3.660791	-116.824496	48.457411	70.5	WMT	15
NLA06608-0049	OR	16.398147	-117.153355	45.062327	12.9	WMT	11
NLA06608-0290	OR	3.999259	-120.525686	42.195652	59.2	WMT	9
NLA06608-0306	OR	4.084627	-119.413348	43.417883	107.8	XER	80
NLA06608-0402	OR	168.547626	-124.078093	42.889749	7.5	WMT	1
NLA06608-0406	OR	4.403663	-121.704430	45.180381	141.9	WMT	4
NLA06608-0614	OR	3.999259	-123.268618	43.378645	52.7	WMT	78
NLA06608-0625	OR	168.547626	-118.185992	44.954294	6.8	WMT	11
NLA06608-0658	OR	3.999259	-124.079610	44.023835	60.6	WMT	1
NLA06608-0677	OR	3.709520	-118.446839	42.772394	89.8	XER	80

Appendix 1 continued. List of sampled probability lakes including design coordinates (90 total).

SITE_ID	State	Weight	Longitude (dd)	Latitude (dd)	Area (ha)	Major ecoregion	Level III ecoregion
NLA06608-0678	OR	4.403663	-121.780483	43.963587	102.2	WMT	4
NLA06608-0870	OR	3.999259	-122.046378	44.316686	63.7	WMT	4
NLA06608-0881	OR	4.403663	-118.045641	44.680299	911.8	WMT	11
NLA06608-0933	OR	4.403663	-118.150427	43.927628	716.8	WMT	11
NLA06608-0934	OR	1.750362	-122.038246	43.736127	2443.7	WMT	4
NLA06608-1058	OR	4.403663	-122.214210	42.364916	477.1	WMT	4
NLA06608-1073	OR	10.830667	-117.272370	45.229364	24.3	WMT	11
NLA06608-1190	OR	4.403663	-123.300076	44.087941	3230.3	WMT	3
NLA06608-1266	OR	15.210134	-119.997611	42.119982	13.8	XER	80
NLA06608-1426	OR	4.403663	-124.246005	43.452205	132.3	WMT	1
NLA06608-1445	OR	4.084627	-118.852169	42.918354	273.1	XER	80
NLA06608-1446	OR	10.830667	-122.017536	43.796302	27.7	WMT	4
NLA06608-1638	OR	3.999259	-121.873209	44.371781	90.7	WMT	4
NLA06608-1894	OR	10.830667	-121.745625	44.026655	32.9	WMT	4
NLA06608-1958	OR	1.750362	-122.421606	43.662976	1062.1	WMT	4
NLA06608-2082	OR	4.403663	-122.600822	42.151396	256.5	WMT	78
NLA06608-2438	OR	10.046007	-119.563401	42.066805	27.1	XER	80
NLA06608-2450	OR	16.398147	-124.179044	43.631644	14.5	WMT	1
NLA06608-2481	OR	168.547626	-119.392762	43.988628	5.9	WMT	11
NLA06608-2673	OR	16.398147	-118.685037	44.306582	12.7	WMT	11
NLA06608-2726	OR	10.830667	-121.766543	43.713787	40.9	WMT	9
NLA06608-0033	WA	32.549373	-121.299060	47.311084	15.2	WMT	77
NLA06608-0081	WA	32.549373	-122.124168	48.226120	10.0	WMT	2
NLA06608-0086	WA	8.741017	-122.426035	45.616571	101.3	WMT	3
NLA06608-0193	WA	7.938297	-121.175840	48.704386	81.4	WMT	77
NLA06608-0209	WA	2.337088	-122.083679	47.576010	1934.3	WMT	2
NLA06608-0337	WA	7.938297	-122.656243	48.393824	51.9	WMT	2
NLA06608-0449	WA	21.498248	-117.691524	48.135804	48.2	WMT	15
NLA06608-0529	WA	2.337088	-119.363985	47.184414	2575.6	XER	10
NLA06608-0593	WA	32.549373	-122.327709	48.708678	10.3	WMT	2
NLA06608-0641	WA	21.498248	-117.664050	48.418773	27.0	WMT	15
NLA06608-0721	WA	7.938297	-122.405638	46.497287	84.0	WMT	4
NLA06608-0785	WA	7.363184	-119.570872	46.871389	50.9	XER	10
NLA06608-0849	WA	2.337088	-124.632527	48.090401	3036.2	WMT	1
NLA06608-1041	WA	7.363184	-119.592605	47.728697	75.2	XER	10
NLA06608-1057	WA	8.741017	-121.094003	47.266902	1816.3	WMT	77
NLA06608-1217	WA	8.741017	-117.332380	48.273757	194.6	WMT	15
NLA06608-1297	WA	8.107748	-119.648323	46.693467	219.3	XER	10
NLA06608-1425	WA	32.549373	-122.972559	47.192047	14.5	WMT	2
NLA06608-1489	WA	21.498248	-122.569031	46.986303	22.2	WMT	2
NLA06608-1617	WA	7.938297	-122.705033	47.571772	93.2	WMT	2
NLA06608-1873	WA	8.741017	-123.264720	47.487995	1551.9	WMT	1
NLA06608-2134	WA	21.498248	-122.743569	45.892663	31.8	WMT	3
NLA06608-2193	WA	32.549373	-124.035496	46.419506	17.6	WMT	1

Appendix 1 continued. List of sampled probability lakes including design coordinates (90 total).

SITE_ID	State	Weight	Longitude (dd)	Latitude (dd)	Area (ha)	Major ecoregion	Level III ecoregion
NLA06608-2241	WA	8.741017	-117.318999	48.154021	120.4	WMT	15
NLA06608-2257	WA	225.045285	-122.784397	47.409308	7.2	WMT	2
NLA06608-2513	WA	2.337088	-122.561921	47.132856	441.5	WMT	2
NLA06608-2753	WA	2.337088	-117.688988	47.570687	49.6	XER	10
NLA06608-2833	WA	7.363184	-120.164879	47.918804	76.7	XER	10
NLA06608-3153	WA	7.938297	-122.816780	48.660289	73.9	WMT	2
NLA06608-3265	WA	21.498248	-117.408610	48.056480	28.2	WMT	15

Appendix 2. Analysis of Landscape Metrics

Introduction

GIS was used to generate landscape indicators that integrate conditions over the broader watershed contributing to lake condition. Landscape metrics were generated uniformly for all sample sites, which is useful when lake size prohibits adequate field collection of physical habitat data from lake shoreline zones. Our goal is to identify and test landscape metrics as indicators of lake watershed condition.

Objectives

1) Evaluate a large group of available landscape metrics to identify a shorter list of those with the most potential for estimating lake watershed condition.

2) Using the candidate indicators from the short list that perform best, describe lake watershed condition for the Western Mountains portion of Region 10 NLA sites.

Landscape metrics calculated at the scale of the entire basin may not be closely tied to nearshore habitat condition, which has been found to have a greater influence on lake condition. We calculated landscape metrics at various buffer distances from the lake shore to find the most useful scale for each metric.

Physical habitat indicators used in the NLA will be used to evaluate the landscape indicators. Generally, we expect a relationship between physical habitat indicators and landscape indicators. Lakes within watersheds with extensive watershed-scale disturbance are likely to have higher lakeshore disturbance as well as reduced lake condition. Conversely, lakes within watersheds with low levels of human disturbance are likely to have lower levels of human disturbance in proximity to the lakeshore with natural/intact lakeshore vegetation and littoral cover complexity that result in higher lake condition.

Identifying Best Metrics

<u>Methods</u>

This analysis uses watersheds from the 101 lakes sampled for the Region 10 portion of the NLA (90 probability and 11 handpicked sites). The initial list of landscape metrics included about 60 basin-scale variables within the categories shown on Table 3. The landcover type metrics were also calculated at three buffer widths (5km, 2km, and 200m) for each sample lake. Landscape metrics with the best potential to be used as indicators of lake watershed condition have the following characteristics:

1) an obvious relation to human disturbance (e.g. land use v. geomorphic metrics)

2) a logical relation to lake disturbance/response indicators
3) A reasonable range of values are represented in the data set. For example metrics that have many zero values such as %wetlands are not useful.
4) Limited autocorrelation so that each metric included is informative and not redundant.

Based on these desired characteristics the following steps were taken to winnow the list of landscape metrics:

--Check strength of association between landscape metrics generated at the basin-wide scale with lake indicators (physical habitat, water quality, biology response) using non-parametric Spearman rank correlation. Also, plot and review scatter diagrams for data distribution. Identify candidate list of metrics based on strength and pattern of the associations.
--Review the candidate metrics for logical relationships with lake disturbance/response indicators.
--Review the candidate metrics for autocorrelation to avoid redundancy.
--Recalculate the candidate metrics at the three buffer distances and re-check strength of association (non-parametric Spearman rank correlation) of each. From these results evaluate the best buffer distance for each of the candidate metrics.
--Review the modified candidate metrics for their adequacy of describing ecological condition and determine final list of metrics to carry forward into indicator development.

Results

Following these steps, a short list of the best landscape metrics in terms of relation to lake disturbance/response indicators was determined (**Table A1**). The results of the correlations to disturbance/response indicators are in **Table A2**. Other correlations used for data exploration are at the end of this appendix.

Table A1. Final list of best landscape metrics based on analysis of 101 Region 10 watersheds from the NLA.

Metric	***Units***	***buffer width***
Forest cover	% total cover	200m
Scrub-shrub cover	% total cover	2Km
Potential Unit Grazing	unitless	Basin-wide
RUSLE Cover Factor	unitless	Basin-wide

Table A2. Spearman rank correlation r values between best landscape metrics and chemical, biological, and physical habitat lakes metrics. Significant (p<.05) yet weak relationships are in bold blue <|0.5| and moderate to high correlations in bold italic red >|0.5|.

	***Epi. DO**	***Cond***	***Turb***	***N total***	***P total***	***Chl-a***	***Secc depth***	***Phyto OE***	***shore Dis.***	***shore cover***	***Lit. Cov.***	***Habitat complex.***
Forest Cover (200m)	**0.41**	***-0.59***	***-0.75***	***-0.53***	***-0.62***	***-0.54***	***0.70***	**0.43**	**-0.28**	***0.65***	***0.50***	***0.64***
Scrub-shrub Cover (2km)	**-0.44**	***0.52***	***0.54***	**0.43**	***0.54***	**0.28**	**-0.47**	-0.18	0.12	***-0.66***	***-0.57***	***-0.68***
Potential Unit Grazing (basin)	-0.04	**0.41**	**0.36**	**0.39**	**0.34**	**0.50**	**-0.42**	**-0.28**	**0.34**	-0.01	0.00	0.00
RUSLE Cover Factor (basin)	**-0.24**	**0.38**	***0.51***	**0.33**	**0.42**	**0.23**	**-0.38**	**-0.33**	-0.01	**-0.46**	**-0.30**	**-0.44**

Metric abbreviations: dissolved oxygen mean of values collected in upper 2m of water column, conductivity, turbidity, total nitrogen, total phosphorous, chlorophyll-a, Secchi depth, phytoplankton O/E, shoreline disturbance (RDIS), lakeshore cover (LITCVR), littoral cover (LITCVR), habitat complexity (LITRIPCVR).

Two other metrics, total agriculture cover and agriculture on slopes >9%, had reasonably good correlations but data were dominated by zero values. Likely that a more robust data set that included more sites in the xeric cluster would show these to be more useful. The results of the Sediment Model run for each watershed was tested but it had an inconsistent relation to lake response /distribution metrics. The model incorporates geomorphic metrics (slope) which effectively swamps out the effect of the actual sediment load delivered to the lake. Thus, this metric is not useful for this application. However, the cover component of the Model 'RUSLE Cover Factor' was identified as a useful metric. The four retained metrics are described below.

Forest Cover:

Forest cover areas are characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover. This cover class includes the following cover codes of the NLCD:
41. Deciduous Forest - areas dominated by trees where 75% or more of the tree species shed foliage simultaneously in response to seasonal change.
42. Evergreen Forest - areas dominated by trees where 75% or more of the tree species `maintain their leaves all year. Canopy is never without green foliage.
43. Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the cover present.

This metric is calculated for the portion of the basin within 200m of the lakes shoreline and is expressed as percent of the total cover. The forest cover metric is positively correlated to lake physical habitat, water clarity, and biological response indicators.

Scrub-shrub Cover:

Shrublands are areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included. This cover class includes code 51 of the NLCD coverage defined as: Areas dominated by shrubs; shrub canopy accounts for 25-100% of the cover. Shrub cover is generally greater than 25% when tree cover is less than 25%. Shrub cover may be less than 25% in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25% and shrubs cover exceeds the cover of the other life forms.

The scrub-shrub metric is calculated for the 2km buffer area adjacent to the lakeshore and is expressed as percent of the total cover. As expected, this metric has a negative correlation to lake physical habitat, water clarity, and biological response indicators.

Potential Unit Grazing:

The Potential Unit Grazing (PUG) is an indicator of the intensity of potential cattle/calf grazing. This metric is based on estimations of cattle usage coupled with estimations of 'cow habitat' and requires calculation of several grids. The following is a brief description of how this metric is calculated.

1) A Cow Density grid is generated using USDA agriculture census data reported by counties on the total number of grazing cow-calves.
2) A Potential Cow Habitat grid is generated from methods developed by EPA Region 10 (Pers. Comm. Peter Leinenbach) using five inputs: land ownership, land cover, proximity to water, topographic position grid index, and slope.
3) A relative risk weighting factor is developed for the Potential Cow Habitat grid to define the relative intensity of the habitat weights in each habitat grid cell. Applying these weights to the grid results in a new 'Potential Cow Habitat Usage' grid.
4) The final metric Potential Unit Grazing (PUG) grid calculated as the Cow Density Grid multiplied by the Potential Cow Habitat Usage grid.

This metric is calculated for the entire basin and is unitless. The Potential Unit Grazing indicator has a negative correlation to lake physical habitat, water clarity, and biological response indicators. In general, areas with the highest potential for water quality impacts due to grazing are flat non-protected grasslands, within 90 meters of a water source, within counties with high cattle densities and low available potential cow habitat.

RUSLE Cover Factor:

The RUSLE (Revised Universal Soil Loss Equation) model predicts potential surface soil erosion across the landscape. One input to this model is the RUSLE Cover Factor (i.e., RUSLE C), which is used to reflect the effect of agricultural cropping and landcover management practices on erosion rates. Specifically, RUSLE C represents the effects of plants, soil cover, soil biomass, and soil disturbing activities on erosion. Although no specific reference is available to obtain these values for landscape scale modeling, various references can provide estimates established at the plot scale (listed at the end of this Appendix). USING the SEDMOD model, RUSLE C plot scale measurements obtained from literature were applied across the landscape and estimates of weighted average watershed RUSLE C conditions were calculated.

The RUSLE Cover Factor is unitless and is calculated at the basin scale. It is negatively correlated to lake physical habitat, water clarity, and biological response indicators in the data set of Region 10.

Indicator Development

The four landscape metrics identified as having the most substantial relation to lake watershed condition were carried forward into the indicator development phase.

Methods

Data for the indicator development analysis were restricted to sites within the Western Mountains cluster. This was necessary as there were insufficient numbers of reference sites from the Xeric cluster in Region 10 to include sites from this portion of the Region. A total of 17 reference sites (10 handpicked and 7 from probability site dataset) were available for determining condition thresholds for the Western Mountains cluster in Region 10. Recall, all probability and hand-picked sites in the NLA are evaluated for chemical and lakeshore characteristics and qualified as reference or non-reference. Because we are developing thresholds with only the Western Mountains reference sites the final analysis of the condition was only applied to the probability sites from this same cluster. Of the 90 probability sites in Region 10, 65 sites are within the Western Mountains cluster.

Thresholds were based on the distribution of values in the set of 17 reference sites and whether the correlation with the indicator is positive or negative. For indicators where high values indicate a better condition (e.g. forest cover), we used the 25th percentile of the distribution of the reference sites values to distinguish between “least disturbed” (similar to reference site condition) and “somewhat disturbed” (somewhat different from set of reference condition values). The 5th percentile was used to distinguish between “somewhat disturbed” and “disturbed” (very different from the set of reference sites). For indicators where high values indicate disturbance or poorer condition (e.g. scrub-shrub cover), the thresholds were reversed. The 75th percentile of the distribution of the reference site values was used to distinguish between “least disturbed” and “somewhat disturbed” condition, and the 95th percentile was used to distinguish between “somewhat disturbed” and “disturbed” condition. This scoring was conservative to account for the fact that, although minimally disturbed, reference sites may have some level of human disturbance. The thresholds determined for each of the four landscape metrics are in **Table 3A** and box plots showing the range of values in the reference data for each metric are in **Figure1A**.

Table 3A. Data range percentiles (calculated directly) used to define thresholds between Least, Intermediate, and Most disturbed for four landscape metrics based on Western Mountain region reference sites.

Indicator	***buffer extent***	***ref site n***	***Correlation type***	***5%***	***25%***	***75%***	***95%***
Forest cover	200m	17	positive	33.36	65.19	93.91	97.35
Scrub-shrub cover	2 Km	17	negative	0.00	0.28	17.54	25.28
Potential Unit Grazing	basin-wide	17	negative	0.00	0.03	0.15	0.43
*RUSLE Cover Factor	basin-wide	15	negative	0.02	0.03	0.06	0.09

*Two extreme values omitted before calculation of thresholds for the RUSLE Cover Factor.

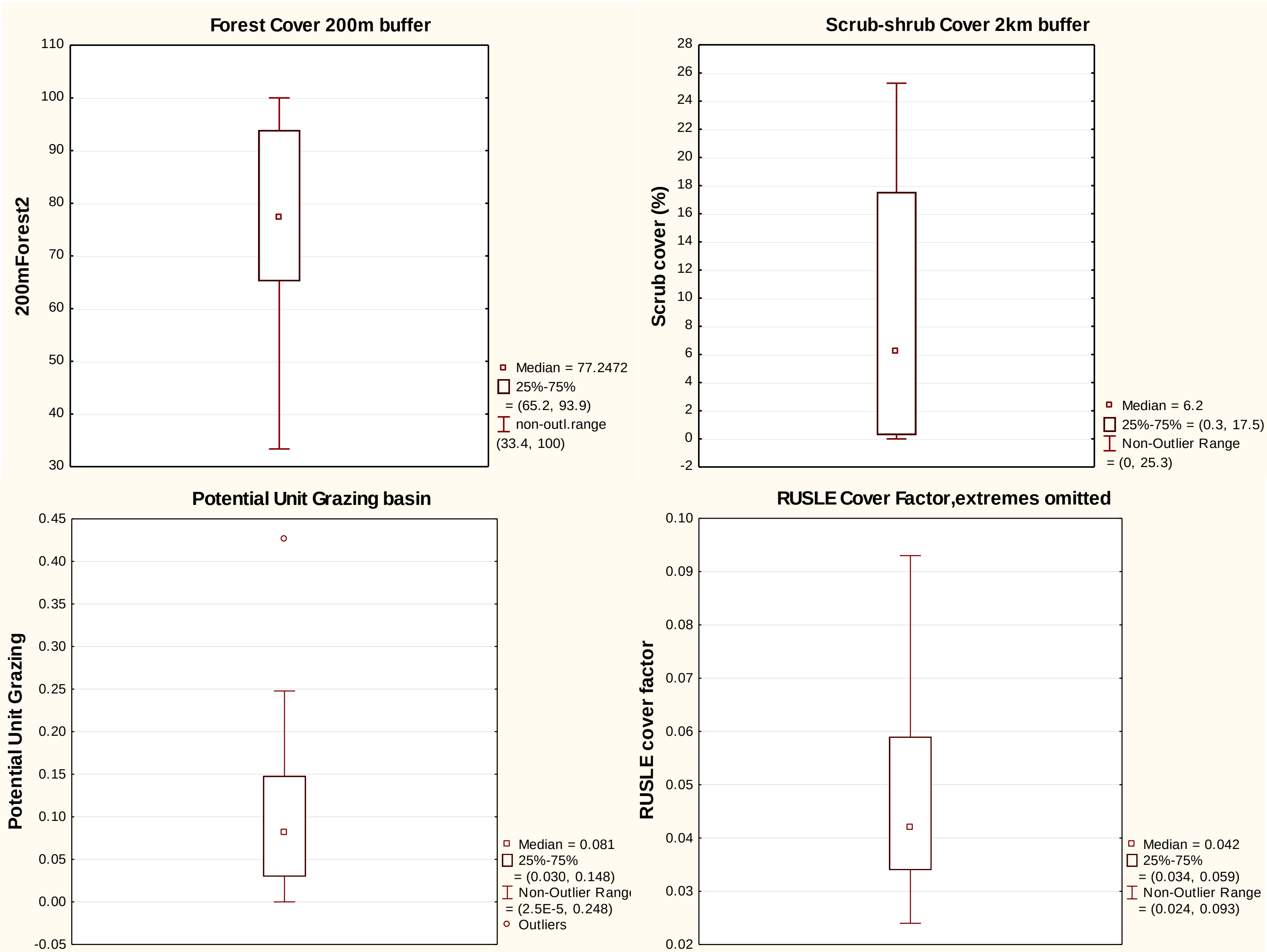

Figure 1A. Range of values across 17 Western Mountain region reference sites for four best landscape metrics. RUSLE C factor presented without extreme values (N=15).

Results

The thresholds calculated for the four landscape metrics were applied to the western mountain Region 10 data yielding the relative percents of least disturbed, somewhat disturbed, and most disturbed sites for the 65 sites (**Figure 2A**). These results were compared to the physical habitat indicator results (**Figure 3A**) for the same western mountain sites. The best performing landscape indicator was forest cover calculated at the 200m buffer. This buffer yielded similar results for the 65 sites as did the habitat complexity indicator (combined metric of littoral/lakeshore cover) where about 55% of the sites are in the least disturbed category. The scrub-shrub and the RUSLE C factor indicators show a similar pattern, with a large majority of sites classified in the least disturbed category.

The Potential Unit Grazing results were most similar to the shoreline disturbance indicator of the physical habitat indicators. Recall that the indicator of shoreline disturbance is based on evidence of human disturbance in proximity to the shore. Both of these indicators estimate a much lower portion of the sites in the least disturbed condition category.

Future Work

The four indicators identified in this appendix yielded results similar to the physical habitat indicators for the Western Mountain cluster of the Region 10 portion of the NLA. It would be useful to further test these indicators with a larger dataset of reference sites and in different ecoregions. These have the potential to be used for the upcoming lakes survey with further refinement. They may also serve as a reasonable substitution for field data from lakes that are too large to reasonably collect field data on physical habitat.

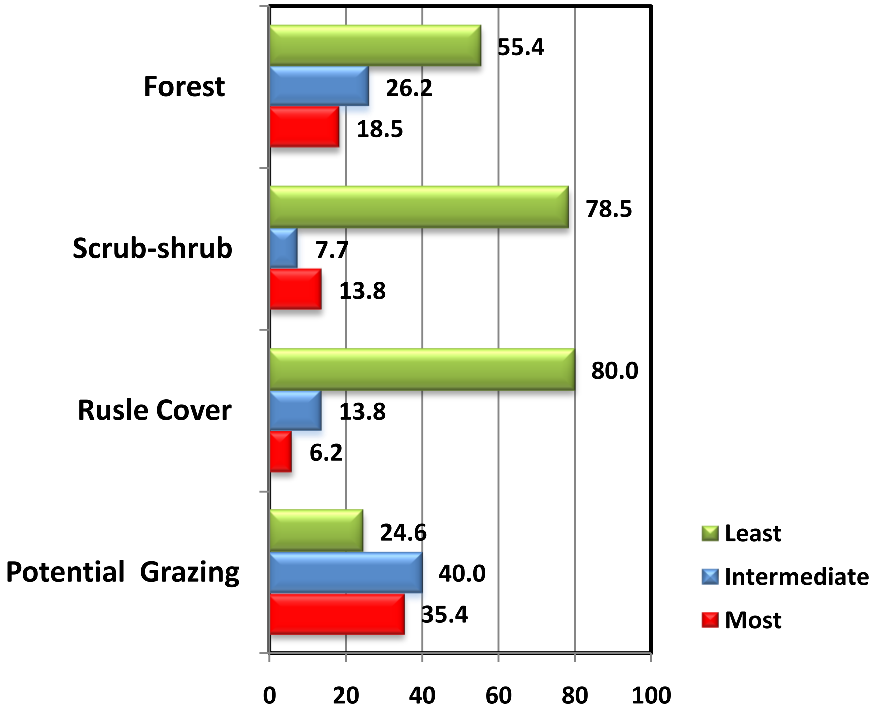

Figure 2A. Percent of least, intermediate, and most disturbed condition for sites of the Western Mountain cluster of the Region 10 NLA based on landscape condition indicators (n=65).

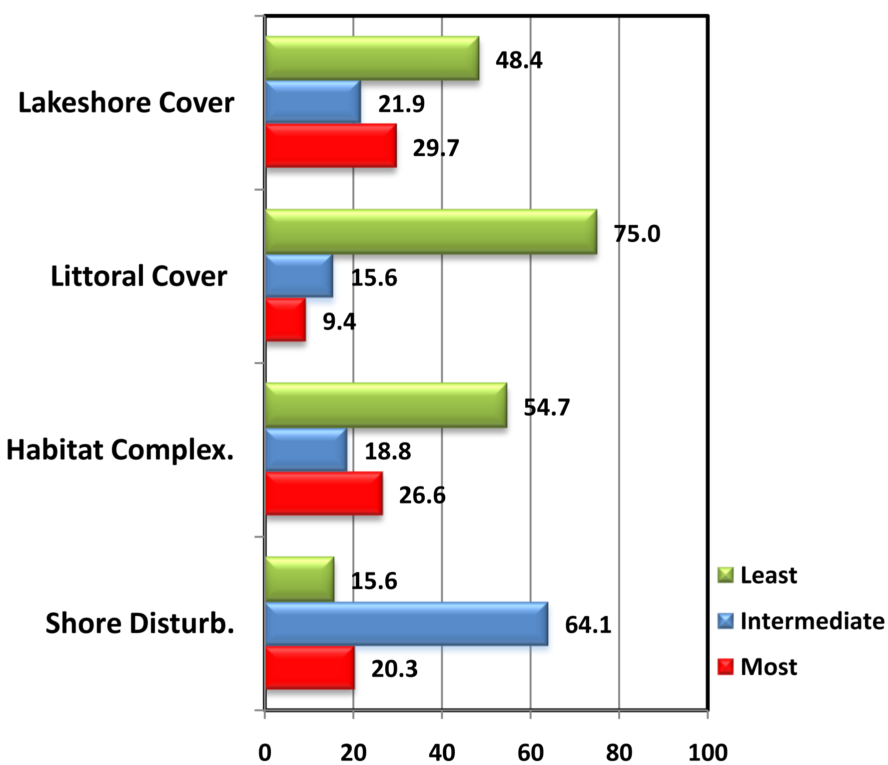

Figure 3A. Percent of least, intermediate, and most disturbed condition for sites of the Western Mountain cluster of the Region 10 NLA based on four physical habitat condition indicators (n=64).

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Spearman Correlation results for landscape and lakeshore condition metrics to lake condition metrics. Significant correlations (p<.05) are red bold.

	EpiDO	Cond.	Turb.	N total	P total	Chl-a	Secchi mean	Phyto.OE
Total Ag. Cover (200m)	**-0.27**	**0.42**	**0.53**	**0.33**	**0.43**	**0.47**	**-0.51**	**-0.30**
Forest Cover (200m)	**0.41**	**-0.59**	**-0.75**	**-0.53**	**-0.62**	**-0.54**	**0.70**	**0.43**
Scrub-shrub Cover (2km)	**-0.44**	**0.52**	**0.54**	**0.43**	**0.54**	**0.28**	**-0.47**	-0.18
Agr. on >9% slope (basin)	-0.16	**0.59**	**0.45**	**0.34**	**0.34**	**0.39**	**-0.40**	**-0.23**
Sediment Model (basin)	0.14	**-0.37**	**-0.29**	**-0.45**	**-0.38**	**-0.32**	**0.40**	**0.27**
Potential Unit Grazing (basin)	-0.04	**0.41**	**0.36**	**0.39**	**0.34**	**0.50**	**-0.42**	**-0.28**
RUSLE Cover Factor (basin)	**-0.24**	**0.38**	**0.51**	**0.33**	**0.42**	**0.23**	**-0.38**	**-0.33**
Shoreline disturbance	-0.08	**0.25**	**0.31**	**0.25**	**0.30**	**0.24**	**-0.29**	**-0.23**
Lakeshore Cover Index	**0.51**	**-0.35**	**-0.59**	**-0.41**	**-0.48**	**-0.32**	**0.57**	**0.21**
Littoral Cover Index	**0.41**	**-0.28**	**-0.43**	**-0.32**	**-0.39**	-0.19	**0.45**	**0.23**
Lit.-Rip. Cover Index	**0.50**	**-0.34**	**-0.57**	**-0.40**	**-0.49**	**-0.31**	**0.57**	**0.24**

Spearman correlation results for landscape and lakeshore condition metrics to geophysical characteristic metrics

	W.S. Area	Lake Polygon Area	Lake Surface Proport.	Elev. mean	Slope mean	Precip. max.	Precip. mean
Total Ag. Cover (200m)	**0.36**	**0.30**	**-0.25**	0.03	-0.06	**-0.35**	**-0.48**
Forest Cover (200m)	**-0.40**	**-0.27**	**0.32**	-0.08	**0.22**	**0.49**	**0.64**
Scrub-shrub Cover (2km)	**0.43**	0.13	**-0.58**	**0.47**	0.12	**-0.59**	**-0.74**
Agr. on >9% slope (basin)	**0.54**	**0.40**	**-0.37**	-0.04	-0.09	**-0.32**	**-0.56**
Sediment Model (basin)	-0.06	-0.01	0.11	0.07	**0.71**	**0.55**	**0.56**
Potential Unit Grazing (basin)	0.06	0.09	-0.01	**-0.41**	**-0.44**	-0.16	**-0.23**
RUSLE Cover Factor (basin)	**0.29**	**0.20**	**-0.25**	0.19	-0.19	**-0.30**	**-0.41**
Shoreline disturbance	0.14	0.14	-0.08	-0.17	-0.18	-0.17	**-0.23**
Lakeshore cover	**-0.32**	-0.18	**0.32**	**-0.37**	-0.09	**0.44**	**0.55**
Littoral Cover	**-0.31**	-0.18	**0.30**	**-0.33**	-0.03	**0.42**	**0.49**
Habitat complexity	**-0.34**	-0.19	**0.35**	**-0.39**	-0.10	**0.44**	**0.55**

Spearman correlation results to check for autocorrelation for landscape and lakeshore metrics.

	Total Ag.	Forest	Scrub	Ag>9	Sed.Mod.	PUG	RUSLE c	Shore Distrub	Shore cover	Lit.Cov.	Habitat compl.
Total Ag. Cover (200m)	1.00	**-0.60**	**0.36**	**0.62**	-0.17	**0.24**	**0.31**	**0.25**	**-0.40**	**-0.38**	**-0.41**
Forest Cover (200m)	**-0.60**	1.00	**-0.67**	**-0.62**	**0.35**	**-0.34**	**-0.67**	**-0.28**	**0.65**	**0.50**	**0.64**
Scrub-shrub Cover (2km)	**0.36**	**-0.67**	1.00	**0.47**	**-0.22**	0.06	**0.55**	0.12	**-0.66**	**-0.57**	**-0.68**
Agr. on >9% slope (basin)	**0.62**	**-0.62**	**0.47**	1.00	**-0.22**	**0.41**	**0.43**	**0.21**	**-0.32**	**-0.30**	**-0.33**
Sediment Model (basin)	-0.17	**0.35**	**-0.22**	**-0.22**	1.00	**-0.32**	-0.10	-0.16	0.10	0.11	0.10
Potential Unit Grazing (basin)	**0.24**	**-0.34**	0.06	**0.41**	**-0.32**	1.00	0.14	**0.34**	-0.01	0.00	0.00
Rusle Cover Factor (basin)	**0.31**	**-0.67**	**0.55**	**0.43**	-0.10	0.14	1.00	-0.01	**-0.46**	**-0.30**	**-0.44**
Shoreline disturbance	**0.25**	**-0.28**	0.12	**0.21**	-0.16	**0.34**	-0.01	1.00	-0.17	**-0.21**	-0.19
Lakeshore cover	**-0.40**	**0.65**	**-0.66**	**-0.32**	0.10	-0.01	**-0.46**	-0.17	1.00	**0.66**	**0.96**
Littoral Cover	**-0.38**	**0.50**	**-0.57**	**-0.30**	0.11	0.00	**-0.30**	**-0.21**	**0.66**	1.00	**0.81**
Habitat Complexity	**-0.41**	**0.64**	**-0.68**	**-0.33**	0.10	0.00	**-0.44**	-0.19	**0.96**	**0.81**	1.00

Appendix 3. Additional Nutrient Analysis for Region 10 NLA Lakes

Recall that elevated nitrogen and phosphorus levels (categorized as "poor" in **Figure 8**) were observed in many of the Region 10 lakes. Despite the "poor" classification for some of the lakes, it is possible that these high nutrient levels are not resulting in increased primary productivity (i.e., excessive algal growth) and therefore they might not be resulting in a negatively impacted biological response. This appendix evaluates the possible biological response to the observed nutrient levels within Region 10 lakes.

Background Information

The Concept of the Limiting Nutrient

Research has shown that algal growth in a lake will be limited if at least one of the nutrients (typically either nitrogen or phosphorus) is at or below the literature values for the Michaelis-Menten half-saturation constants. Specifically, the relationship between the algal growth rate and concentration of a substrate (nutrients) can be described by the following empirical model:

where G_N is the algal growth rate depending on nutrient supplies, G_{max} is algal growth rate at optimum temperature, light and nutrient conditions, N is the substrate (nutrient) concentration, and Ks is the nutrient concentration at which the algal growth rate is one half (0.5) the maximum rate and is referred to as the Michaelis-Menten half-saturation constant. As can be inferred from this equation, where in-lake nutrient concentrations are low, algal growth is inhibited, while at high concentrations algal nutrient demands are fully met and growth is limited by other factors (i.e., light availability and temperature) (Thomann and Mueller 1987). While algal growth will still occur at low concentrations, algal growth will be drastically reduced.

Algal growth will not be limited by nitrogen or phosphorus, however, if water column nutrients are present in concentration exceeding five times the respective Michaelis-Menten half-saturation constants (Thomann and Mueller 1987). Typical half-saturation constants for phosphorus and nitrogen are 8 ug/l and 25 ug/l, respectively (EPA/600/3-85/040). Accordingly, nutrient concentrations that should saturate algal growth demands are defined as 40 ug/l and 125 ug/l, phosphorus and nitrogen, respectively. There are several ways that the nutrient limitation term can be expressed (i.e., Multiplicative, Minimum, and Harmonic Mean) (Chapra 1997). The most common approach used is where the nutrient in shortest supply is expected to control growth:

Nitrogen to Phosphorus Ratios

Algae incorporate inorganic nutrients from the water in proportion to their cellular stoichiometry (Chapra 1997). Specifically, the Redfield ratio is often used to judge the requirements of algae:

Oxygen:Carbon:Nitrogen:Phosphorus = 109:41:7.2:1 (by weight)

As can be seen in the equation above, algal cell stoichiometry is well represented by a Nitrogen to Phosphorus (N/P) ratio of 7. Thomann and Mueller (1987) reported that nitrogen could cause algal grown limitations when the N/P ratio is less than 5, with co-limitation likely when the ratio is between 5 and 20, and that phosphorus could cause algal growth limitations at N/P ratios greater than 20. The N/P ratio does not directly affect algal productivity. Rather it only identifies the nutrient that could be limiting growth.

Carlson Trophic State Indices (TSI)

A lake's trophic condition is a measure of abiotic and biotic relationships. Carlson (1977) and Havens (1995) introduced a set of lake trophic state indices (TSI), which use algal biomass as the basis for trophic state classification and reflects a continuum of "states" based on a base-2 logarithmic transformation of Secchi Disk Depth (SD) in meters, chlorophyll-a (CHL) in ug/l, total phosphorus (TP) in ug/l and total nitrogen (TN) in mg/l:

$$\begin{aligned} \mathrm{TSI(SD)} &= 10*(6-(\ln SD/\ln 2)) \\ \mathrm{TSI(CHL)} &= 10*(6-((2.04-(0.68*\ln CHL))/\ln 2)) \\ \mathrm{TSI(TP)} &= 10*(6-((\ln(48/TP))/\ln 2)) \\ \mathrm{TSI(TN)} &= 10*(6-((\ln(1.47/TN))/\ln 2)) \end{aligned}$$

Calculated TSI values represent continuum from 1 to 100, with a value of "1" representing the "least productive" possible condition and "100" representing the "most productive" possible condition. Because of the logarithmic scale, a doubling in the response occurs at each 10 unit increase of the TSI value. For example, a TSI(CHL) of 32 would have three orders of magnitude less productivity than a TSI(CHL) of 62. Of the four TSI indices listed above, chlorophyll-a (i.e. TSI(CHL)) is the index of choice for representing the trophic state of the lake because chlorophyll best reflects the actual amount of algal biomass in the water (Carlson 1983).

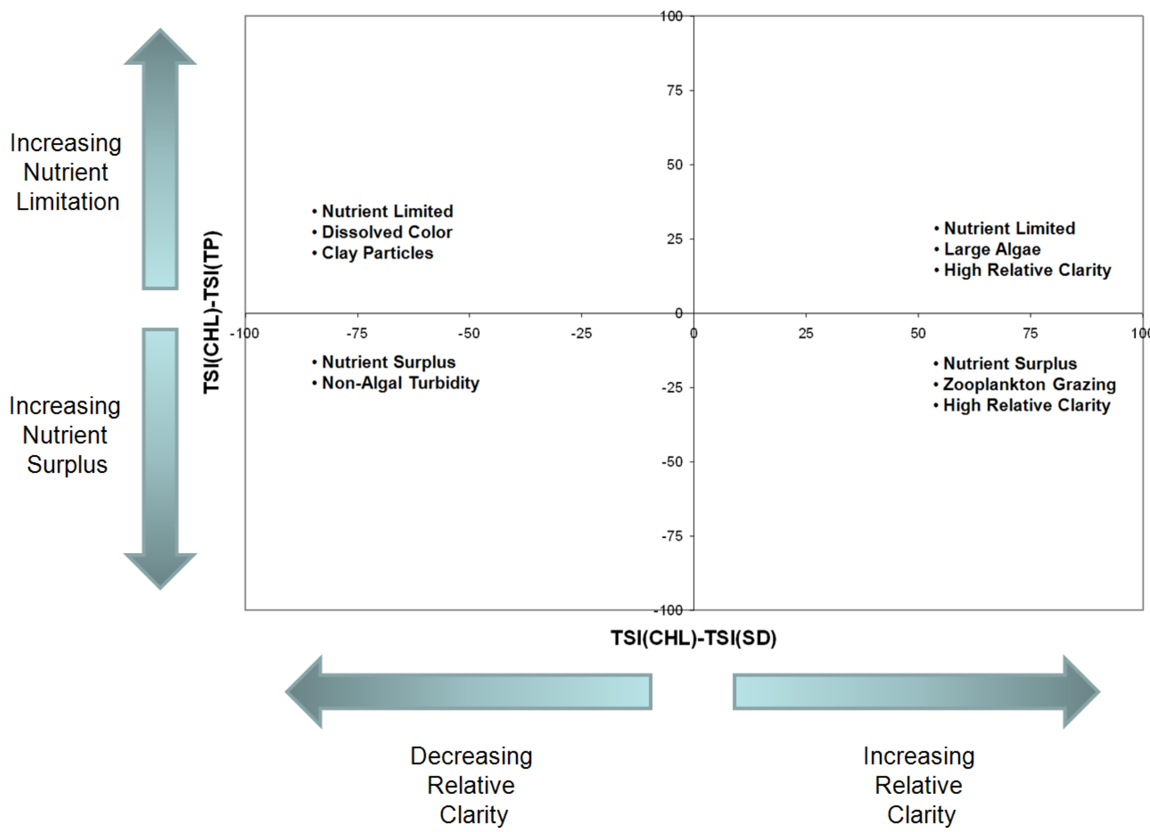
TSI Graphical Method to Identify Limiting Factors on Lake Productivity

As a general model, the TSIs adequately describe the relationship between nutrient availability, algal productivity, and lake transparency. In theory, TSI values should result in the same value regardless of which measurement is used, but in practice, TSI values vary. Fortunately, these metrics often vary in predictable ways that provide insight into chemical and biological features that are unique for each lake (Carlson and Havens

2005). For example, Secchi depth will not correlate well with chlorophyll if the major light scattering or attenuation substance in the water were clay particles or dissolved humic color, nor would TP correlate well with chlorophyll where phosphorus was not limiting algal growth. Deviations of the indices can therefore be used to identify such situations (Carlson 1991).

Accordingly, Carlson and Havens (1995) proposed a Graphical Method to identify limiting factors on lake algal biomass based on a comparison between the TSI indices. The basis for this method is the premise that an observed deviation of chlorophyll TSI from the nutrient TSI indicate the magnitude of nutrient limitation, while deviations of TSI(CHL) from TSI(SD) indicates the degree of light penetration relative to the number and size of sestonic particles (**Figure A-1**). Specifically, positive values associated with the y-axis of this Figure (i.e., “TSI(CHL)-TSI(TP)”) indicated a potential nutrient limiting condition, and negative numbers indicate a potential nutrient surplus condition. Similarly, positive values associated with the x-axis of this Figure (i.e., “TSI(CHL)-TSI(SD)”) indicated that the algae are packaged in large colonies resulting in greater transparencies than expected, and negative numbers indicate that light is scattered or absorbed by very small particles, such as suspended clays or by dissolved solids.

Figure A-1. Example of possible interpretation of deviation in Trophic State Index (TSI) values using the Graphical Method.



Results

Measured nutrient levels in the “inference” NLA lakes showed that primary productivity was primarily influenced by phosphorus concentrations (**Figure A-2**). Specifically, algal productivity was less than expected when phosphorus concentrations were greater than the Michaelis-Menten saturation cutoff of 40ug/l. In addition, most lakes with water concentrations below this limit showed a high level of potential phosphorus limitations. Alternatively, the bottom image in **Figure A-2** illustrates that there was not a discernable pattern of algal productivity associated with nitrogen concentrations, indicating that nitrogen is less influential factor affecting lake productivity.

Similarly, calculated nitrogen to phosphorus ratios (N/P) indicated a strong productivity response to water column phosphorus concentrations (**Figure A-3**). For example, when N/P ratio was greater than 20, most lakes had a TSI(CHL)-TSI(TP) value of greater than zero (Indicating phosphorus limitations for these lakes). Lakes with a N/P ratio less than 5 clearly showed that nitrogen was limiting (i.e., TSI(CHL)-TSI(TP) <0). The bottom image associated with **Figure A-3** illustrates that nitrogen did not have a clear relationship between productivity (i.e., y axis) and the N/P ratio, indicating that nitrogen is less influential factor affecting lake productivity.

Figure A-4 indicates that primary productivity within many of the lakes (those located in the top left and right corners of the figure) is potentially limited by phosphorus. In addition, this figure shows that many of the “man-made” lakes (those created through dams or impoundments) had reduced productivity levels resulting from high turbidity levels. Examples are the lakes located in the bottom left corner of the figure.

The bottom image in **Figure A-4** illustrates these lakes grouped into Michaelis-Menten half-saturation classes. The group called “P < 5 times Michaelis-Menten half-saturation constant” (shown by blue diamonds in the figure) was the most centrally located around the origin of this figure (i.e., 0,0), indicating a close relationship between observed and expected productivity. This result could be expected because phosphorus is present at potentially limited concentrations and the model used to evaluate these lakes (i.e., TSI Difference Graph) was derived for phosphorus conditions. Similarly, lakes associated with the group called “N&P < 5 times Michaelis-Menten half-saturation constant” (shown by green squares in the figure) were located around the origin. However, they were much more scattered around the origin, indicating less precision in the model. The one site associated with the group called “N < 5 times Michaelis-Menten half-saturation constant” indicated that productivity levels were much lower than expected based on phosphorus concentrations, a result that would be expected for a nitrogen limited system.

Alternatively, lakes associated with the group named “”Excessive” N&P, TSI(CHL)-TSI(TP)<-10) (shown by red circles in the figure) were very deviant from the origin of the figure, with most lakes located in the bottom left quadrant of the figure. This result indicates that, despite high levels of nutrients, the primary production response (i.e., chlorophyll) is less than expected, and that the water column transparency is higher than expected based on level of observed chlorophyll in the water, indicating that non-algal turbidity is reducing potential primary productivity in these lakes. Lakes associated with the group named “”Excessive” N&P, TSI(CHL)-TSI(TP)>-10) (shown by orange triangles in the figure) were shown to have productivity levels slightly below expected conditions based on measured phosphorus concentrations.

As mentioned in the main body of the document, a phytoplankton-zooplankton observed versus expected index (O/E index) was developed for the NLA lakes. This type of index estimates biological condition by measuring the agreement between the expected taxonomic composition under reference conditions with that observed at the individual lakes, thus expressing taxa loss. Comparing O/E results of the 90 Region 10 sample lakes to the 11 hand-picked reference lakes, measured O/E index conditions were statistically (p=0.01) less than reference conditions for lakes with “excessive” levels of both nitrogen and phosphorus (i.e., concentration exceed five times the respective Michaelis-Menten half-saturation constants) (**Figure A-5**).

Recall that lake productivity for lakes associated with the group “”Excessive” N&P, TSI(CHL)-TSI(TP)>-10” (the orange triangles in **Figure A-4**) was at expected levels based on nutrient concentrations, indicating that the low O/E index values for these sites is a result of high productivity. Alternatively, lakes associated with the group “”Excessive” N&P, TSI(CHL)-TSI(TP)<-10” had very suppressed primary productivity. It can be concluded that low O/E index results for these sites is a result of high non-algal turbidity levels. Finally, biological conditions associated with other three groups were not statistically different than reference conditions, indicating that nutrient limitation could be occurring within these lakes.

Summary

- Despite high observed nitrogen concentrations in R10 “inference” lakes (see **Figure 8**), phosphorus is the nutrient shown to be the primary nutrient influencing lake productivity (see **Figures A-2** and **A-3**).

- Algal growth was lower than expected in many lakes with high nitrogen and phosphorus concentrations, potentially indicating the effects of high turbidity (see **Figure A-4**). This conclusion applies primarily to sites at man-made lakes.

- The biological response (i.e., O/E index) was statistically lower for lakes with “excessive” nutrient levels (see **Figure A-5**). This trend was not observed for lakes with one or both nutrients below a threshold concentration (i.e., 5 times the Michaelis-Menten half-saturation concentration).

- Low O/E index values appear to be a results of either high productivity (for the group named ”Excessive” N&P, TSI(CHL)-TSI(TP)>-10) or high turbidity (for the group named ”Excessive” N&P, TSI(CHL)-TSI(TP)<-10).

Figure A2. Potential nutrient limitations and nutrient concentrations for R10 NLA lakes. [Positive numbers on the y-axis indicate potential nutrient limitations, and negative numbers indicate potential nutrient surplus. The dashed red line represents potential nutrient surplus concentrations based on five (5) times Michaelis-Menten half-saturation concentrations (i.e., 40 and 125 ug/l for phosphorus and nitrogen, respectively.)]

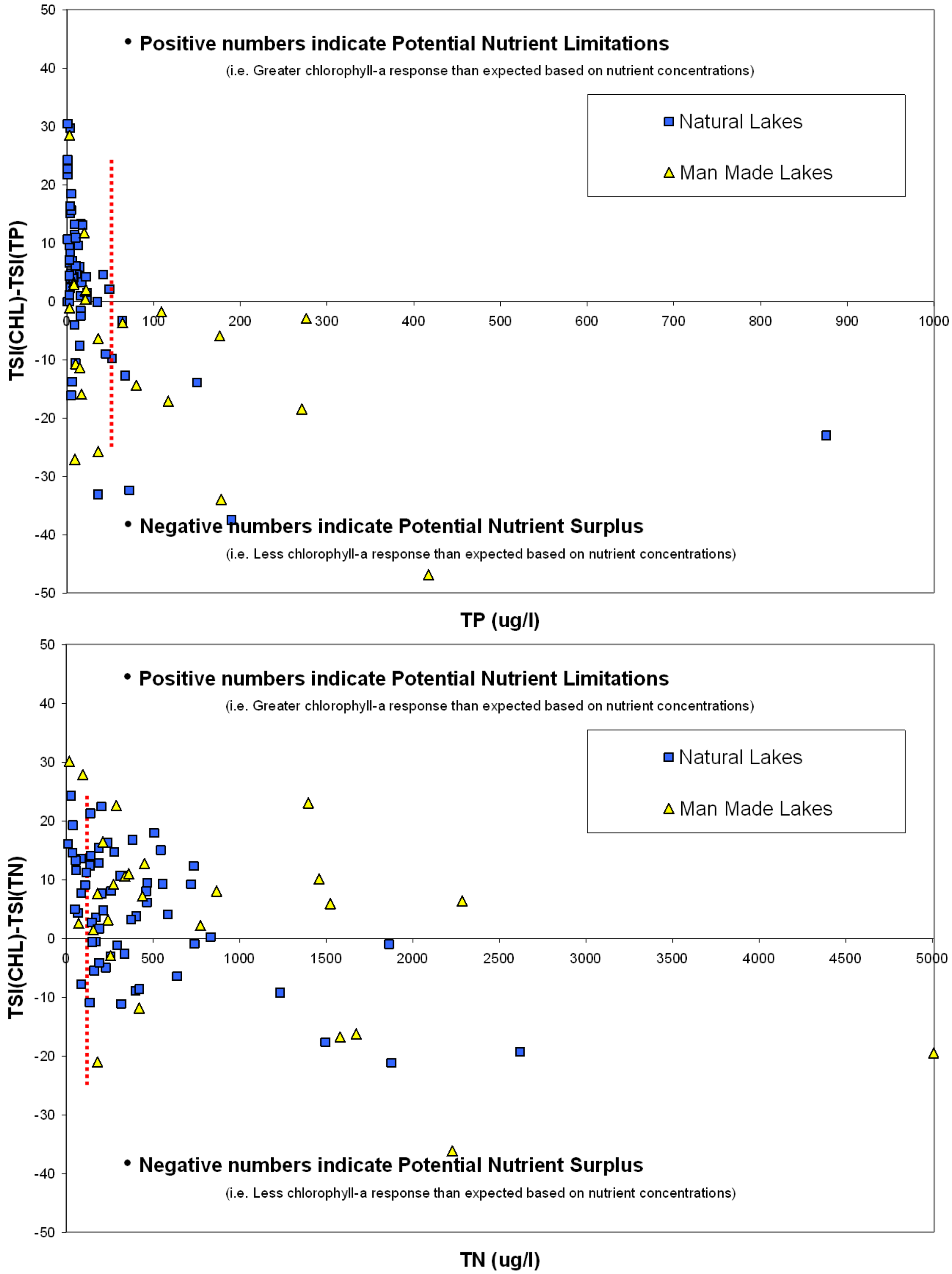
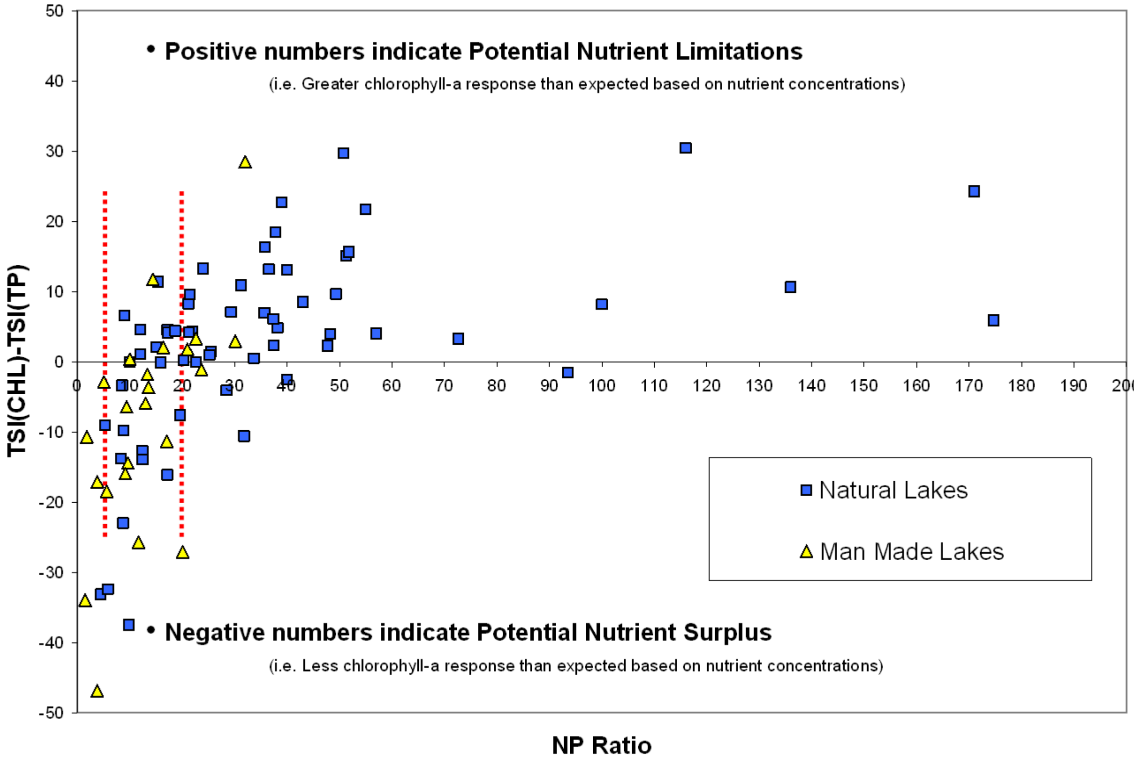


Figure A-3. Potential nutrient limitations and N/P ratios for Region 10 NLA lakes. [Positive numbers on the y-axis indicate potential nutrient limitations, and negative numbers indicate potential nutrient surplus. The left dashed red line represents the approximate N/P ratio cut-off below which nitrogen is the limiting nutrient, and the right dashed line represents the N/P ratio above which phosphorus is a limiting nutrient. The area between these two dashed lines represents the N/P ratio where either nitrogen or phosphorus could be limiting algal growth.]



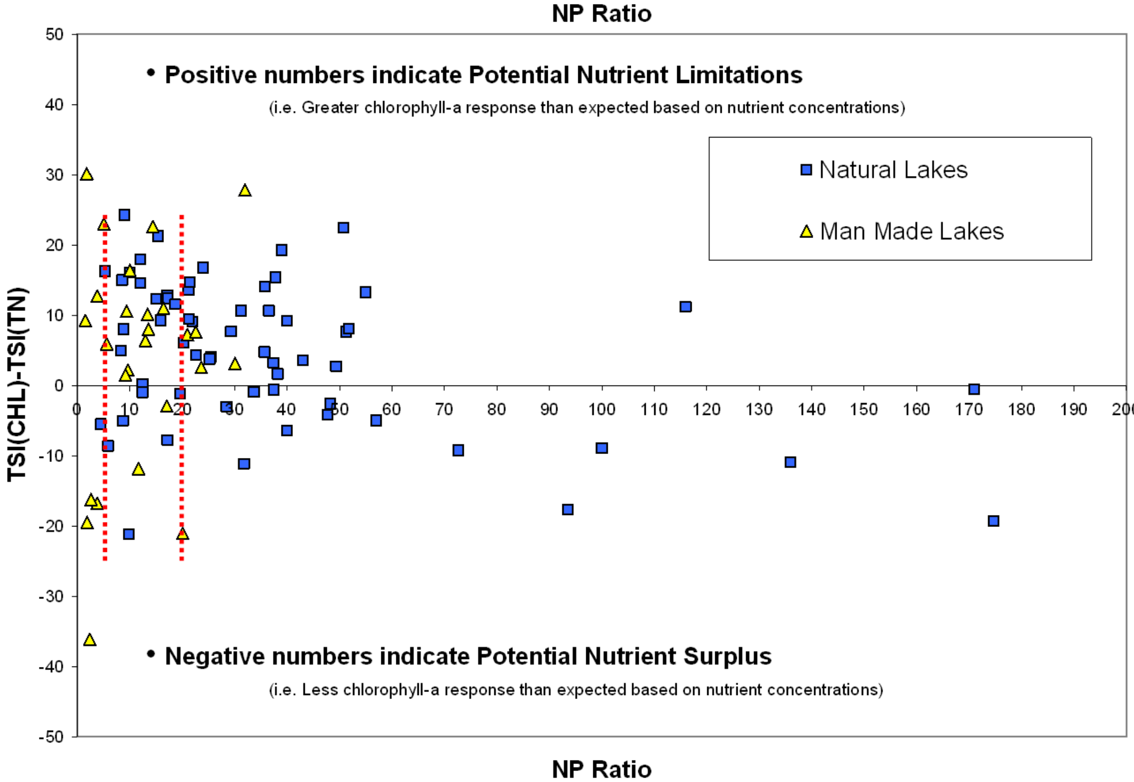
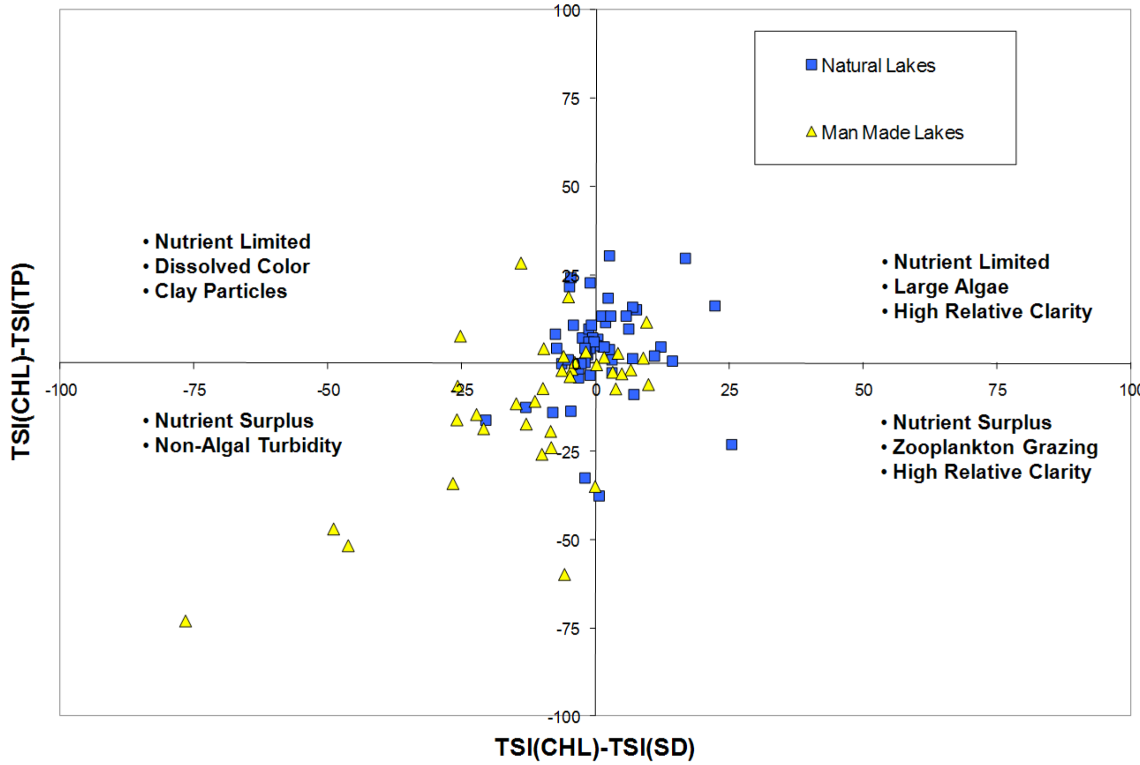


Figure A-4. TSI Difference Graph for Region 10 NLA lakes.
[Positive numbers on the y-axis indicate potential nutrient limitations, and negative numbers indicate potential nutrient surplus. Positive numbers on the x-axis occurs indicates that chlorophyll is packaged in large filamentous or colonial groups, and negative numbers indicate potential non-algal turbidity.]



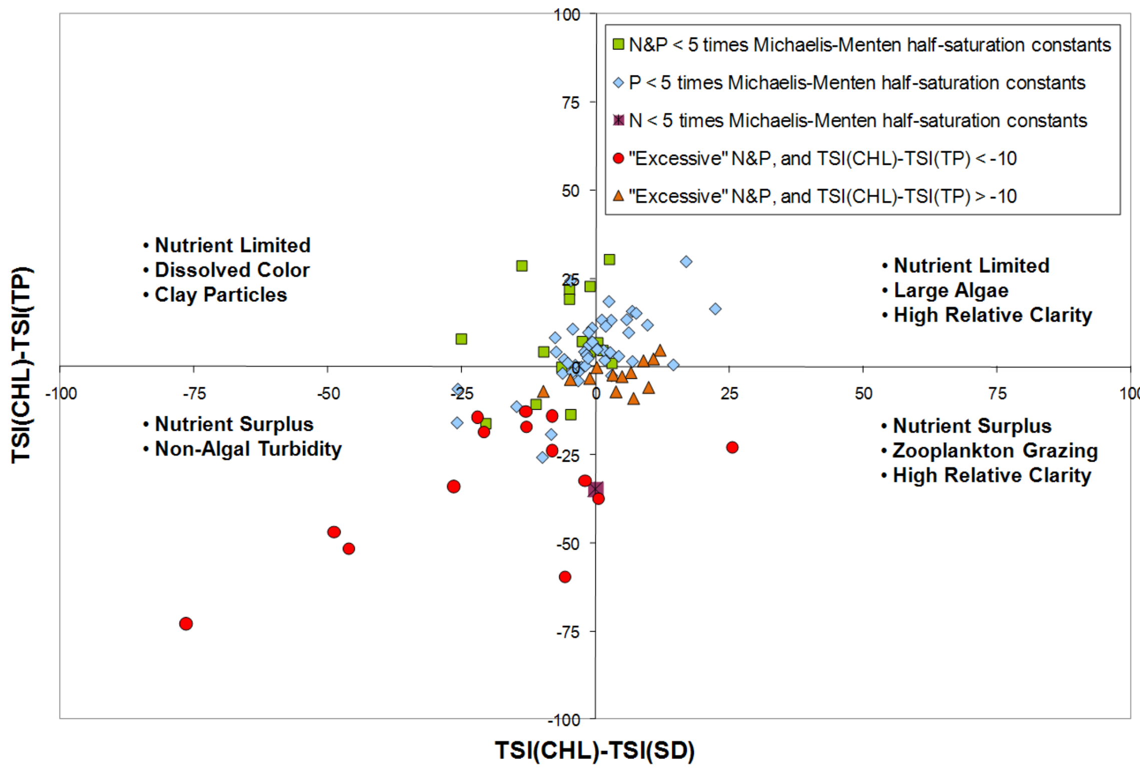
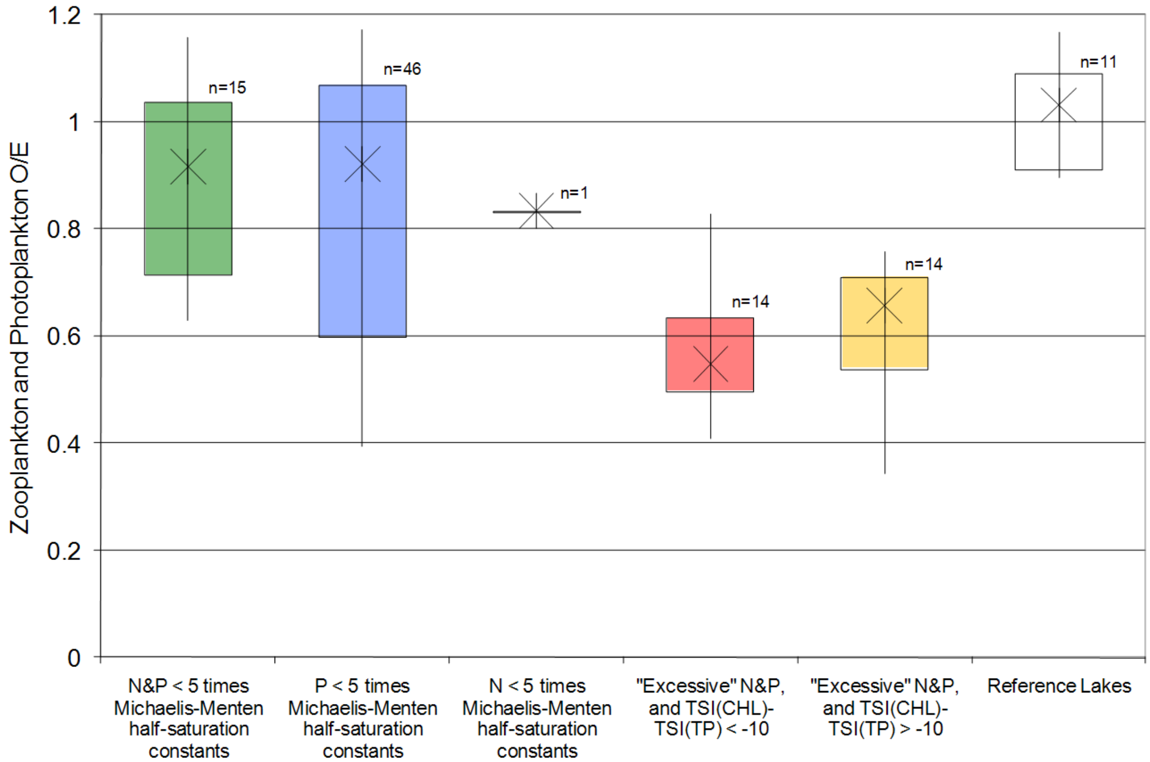


Figure A-5. Comparison between calculated Zooplankton and Phytoplankton Observed/Expected Values (O/E) and TSI Analysis Groups for Region 10 NLA lakes.



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Appendix 4. Fish Tissue—Region 10 results from 2004 National Lakes Fish Tissue Survey

Overview

The National Lake Fish Tissue Study was completed in 2004. This was the first time contaminants in lake fish tissue were estimated across the nation. The study assessed fish from natural and man-made lakes in the lower 48 states for the following purposes: 1) to estimate the distribution of persistent, bioaccumulative, and toxic chemical residues in freshwater fish tissue and 2) to define a national baseline for assessing progress of pollution control activities.

Sample lakes were selected using an uneven random design similar to that of the National Lakes Survey (Olsen et al. 2009). Sample lakes were drawn from six size-categories ranging from 1 to > 5,000 ha with varying probabilities of selection. The sample design ensured the sampling of rare (i.e. large) lake size classes and the spatial distribution of sites across states.

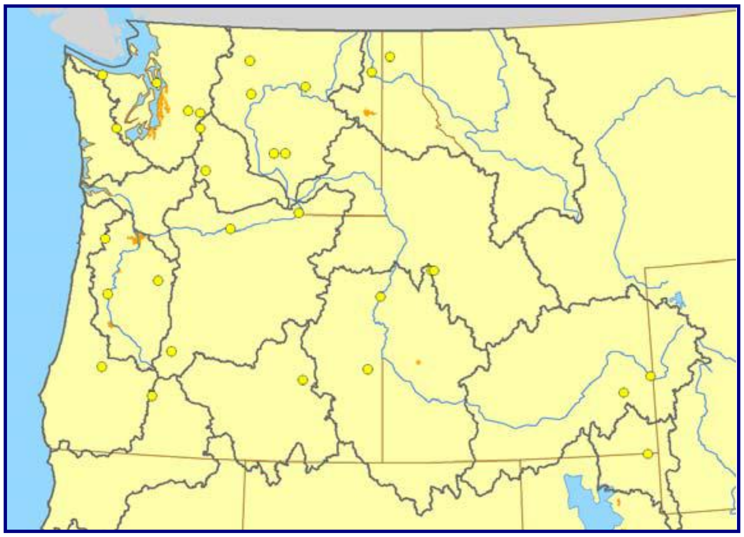
Fish tissue was collected from 500 lakes in the summers of 2000-2003 by the EPA and state agencies following field protocol and quality assurance directives developed for the survey (USEPA 2002, USEPA 2004). At each lake, crews attempted to collect two fish species composites of 5 similar-sized adults per site: one for the human health endpoint -predator species analyzed as fillets and one for the ecological endpoint analysis – bottom-dweller analyzed as whole fish tissue. The study analyzed fish tissue for 268 chemicals:

- 2 metals (mercury and 5 forms of arsenic)
- 17 dioxins and furans
- 159 PCB measurements (out of 209 congeners)
- 46 pesticides
- 40 other semi volatile organics (e.g., phenols)

Results for several important chemicals are in Stahl et al. 2009 and comprehensive information on the survey is available at
http://water.epa.gov/scitech/swguidance/fishshellfish/techguidance/study/index.cfm.

Region 10 Fish Tissue Study

The Region 10 portion of the national lakes survey consisted of 30 sample lakes in the three contiguous states of Region 10 (excludes Alaska). Sample lakes were distributed across the region (**Map 1**) with seven in Idaho, nine in Oregon and 14 in Washington. Sites were distributed among all lake size categories of the survey design but most were over 500 ha in surface area (**Figure A1**). The sample also represents a range of elevations with both large and small lakes distributed in range of elevations (**Figure A2**). This set of 30 lakes across Region 10 resulted in a very diverse group of sample lakes ranging from pristine high elevation lakes to low elevation working reservoirs. The lakes included in the Region 10 sample are listed at the end of this Appendix.



Map A1. Locations of 30 lake samples in Region 10.

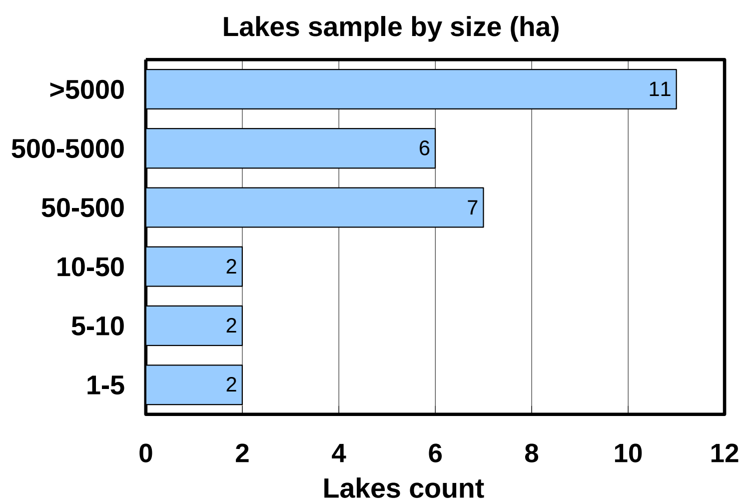


Figure A1. Count of lakes sampled by size category.

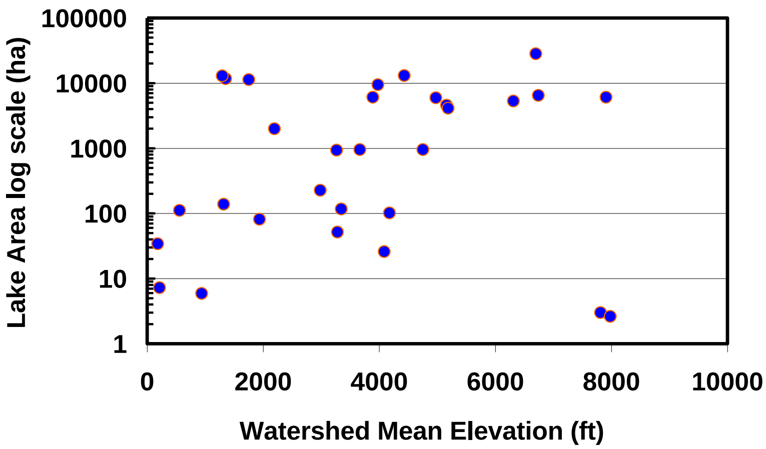


Figure A2. Distribution of lakes by size and elevation.

Each of the 30 lakes was fished for both a predator and bottom-dwelling species Samples were successfully collected at 28 of the lakes for predators and at 19 of the lakes for bottom-dwellers. We opted not to extrapolate these results to a greater inference population because of this small sample size and the great difference in 'weights' among lakes (see Lake List table). The data presented thus expresses only the results of these sample lakes. We report the results of total mercury, total PCBs (the sum of the congeners analyzed), and total DDTs (sum of DDTs, DDEs, and DDDs). These are important pollutants present in fish tissue in Region 10 as well as nation-wide.

- **Mercury** is an elemental metal that is toxic at low levels, affecting the nervous system and brain. The methylated form bioaccumulates in the food chain. Atmospheric deposition is the largest source of mercury in the environment (84%). Other basin scale sources are runoff, point discharges, and mining.
-
- **DDT:** Organochlorine pesticides including DDT were widely used in agriculture of the Columbia Basin. DDT is highly persistent in the environment, bioaccumulates in the food chain, and is linked to neurological and developmental disorders in birds and other animals. It was banned in 1972, but DDT and its breakdown products (DDD, DDE) still persist in the environment.
-
- **PCBs:** Polychlorinated biphenyls are synthetic compounds that were widely used in electrical equipment. These persistent, hydrophobic chemicals bioaccumulate in body fat and biomagnify in the food chain. PCBs have many congeners and vary in degree of toxicity. PCB manufacture was banned in 1979 as they are carcinogenic and pose environmental and human health risk.

Data were evaluated by comparing results to screening thresholds from the literature (Table A1). The human health threshold for mercury is a tissue based Water Quality Criterion (USEPA 2001). Threshold values for PCBs and DDTs are from EPA's guidance for assessing chemical contaminants and are risk-based thresholds (USEPA 2000). The ecological health screening values are wildlife toxicity thresholds based on risk to bald eagles and mink as cited in Hinck et al. 2008.

Table A1. Summary of screening value exceedances.

Chemical	Human Health Screening Value*	Ecological Health Screening Value**
Mercury	300 ppb	100-300 ppb
PCBs	12 ppb	110-480 ppb
DDTs	69 ppb	150-3,000 ppb

*from EPA national reporting
** from Hinck et al. 2008

Results

Summaries of results are presented as cumulative percent graphs with the threshold exceedance value shown in red for predators (human health endpoint) and bottom-dweller samples (ecological endpoint). Summary statistics are in the following table (**Table A2**).

Table A2. Summary statistics for fish tissue contaminants (units in ppb).

Variable	Mean	Std. Err.	Median	Std. Dev.	Skew.	Range	Min.	Max.	N
				Predators					
Mercury	198.18	34.85	133.00	184.39	1.30	577.80	23.20	601.00	28
Total PCBs	7.01	2.20	4.18	11.64	135.68	57.19	.533	57.72	28
Total DDTs	62.84	52.62	3.48	278.44	5.27	1481.40	0.00	1481.40	28
				Bottom-dwellers					
Mercury	153.92	33.01	93.60	143.90	1.86	581.50	14.50	596.00	19
Total PCBs	27.02	6.54	13.33	28.51	.85	83.27	.794	84.07	19
Total DDTs	151.65	62.61	10.49	272.92	2.20	955.91	0.00	955.91	19

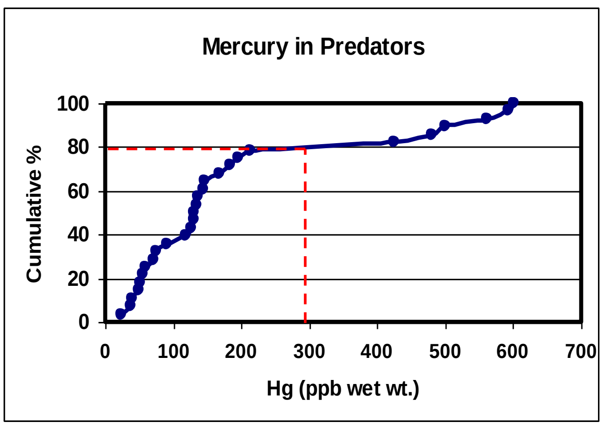
The three types of contaminants were commonly detected in the regional samples (**Table A3**). As with the National Tissue Survey results, mercury and PCBs were detected in 100% of the samples for both predators and bottom-dwellers. The region was consistent with the national detection for DDT as well.

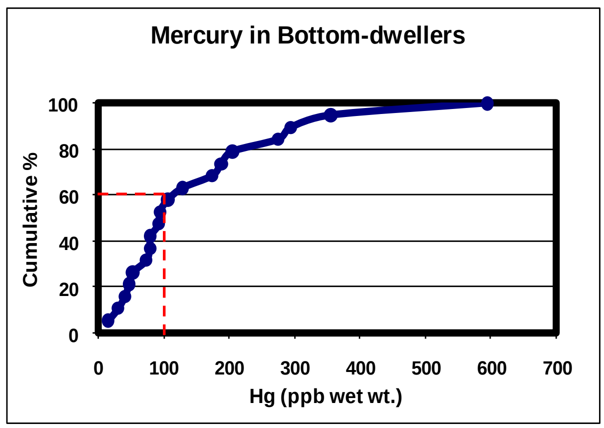
Table A3. Percent samples above detection limits.

Chemical	Predators	Bottom Dwellers
Mercury	100%	100%
Total PCBs	100%	100%
Total DDTs	83% (78% nationwide)	90% (98%nationwide)

Mercury

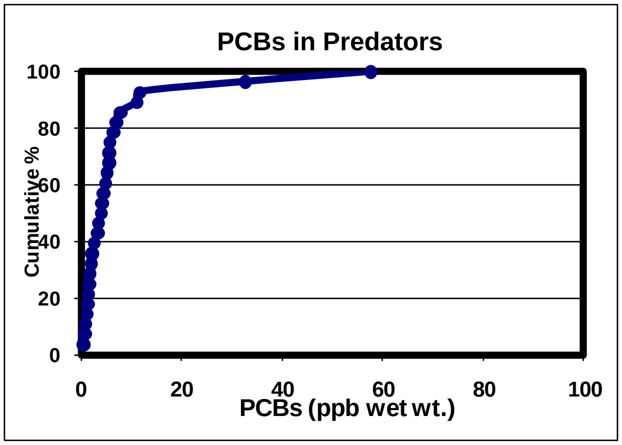
- Mercury levels were generally higher in predator fillet than in bottom-dweller whole fish composites.
- The human health screening level of 300ppb was exceeded in 20% (6) of predator composites.
- The low range of ecological endpoint screening value of 100ppb was exceeded in 50% (9) of bottom-dweller composites.

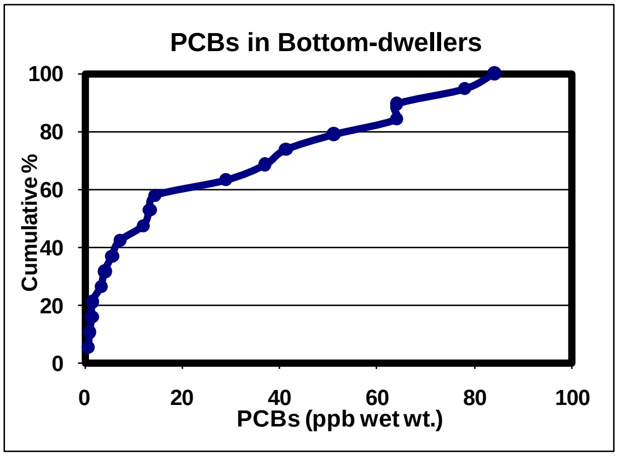




PCBs

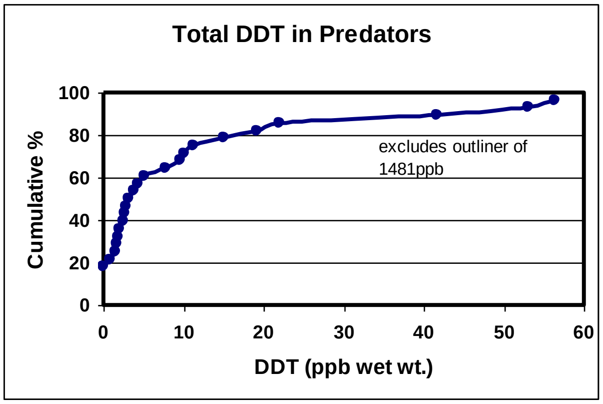
- PCBs were detected in all composites but levels were substantially higher in bottom-dweller whole fish than in predator fillet composites.
- The human health screening level of 12ppb was exceeded in 7% (2) of the predator composites.
- The ecological screening level of 110ppb was not exceeded.
- Fish of both categories had more PCBs in the larger lakes.

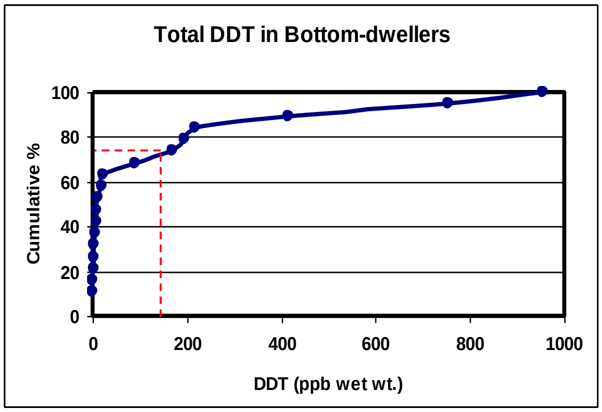




DDTs

- Except for one lake, DDTs in predator composites were below the human health screening level.
- The one outlier sample with very high levels of DDTs for predators was lake Chelan in eastern Washington. This is an area of intense long-term agriculture where accumulation of these legacy pollutants would not be surprising.
- DDTs in bottom-dweller whole-fish composites were generally higher than the predator fillet samples.
- The lower ecological screening value of 150 ppb was exceeded in 32% (6) of the bottom-dweller composites.
- Levels in neither sample type were substantially related to lake size.





Of the three types of contaminants, the human health threshold for mercury was exceeded for the most lakes in the Region 10 sample (**Table A4**). In general, the lakes sampled in the Region were in somewhat better condition based on human health thresholds for these contaminants compared to the nationwide results.

Table A4. Percent of lakes exceeding human health thresholds.

Chemical	Region 10	National Survey
Mercury	20%	49%
Total PCBs	7%	17%
Total DDTs	<4%	2%

Recommendations:

The following are recommendations for future national-scale fish tissue studies:

- Combine the effort needed to collect fish for a national fish tissue study with the efforts of the National Lakes Survey. The primary areas of overlap would be sample design and lake selection/evaluation. Collection of fish can be very time consuming, plus it requires specialized equipment and expertise. This task could not simply be added to the sample day for Lake Survey crews.
- Add analyses for selenium and zinc, which would be very useful for fish tissue monitoring in the western states.
- Increase sample size across the range of lake sizes. This is necessary to ensure the ability to make inferences to the greater population of lakes at a regional scale with reasonable statistical confidence.

References for Appendix 4.

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Table A4. Sites sampled in EPA Region 10 as part of National Lakes Fish Tissue Survey 2000-2004.

SiteID	Lake Name	State	Longitude (DD)	Latitude (DD)	County	Design Wgt.	Sample Year	Lake Area (ha)
OWOW99-0079	Brownlee Reservoir	ID	-117.0784	44.6758	WASHINGTON	1.97	2000	6070.5
OWOW99-0127	Palisades Reservoir	ID	-111.1113	43.2436	BONNEVILLE	1.97	2000	6061.6
OWOW99-0554	Priest Lake	ID	-116.8576	48.5679	BONNER	1.97	2000	9453.8
OWOW99-0627	Bear Lake	ID	-111.3329	42.0037		1.97	2000	28329.0
OWOW99-0904	Loon Cr. Lk #1	ID	-115.9208	45.0938	VALLEY	904.43	2002	2.6
OWOW99-1028	Enos lk #1	ID	-115.8469	45.0996	VALLEY	904.43	2002	3.0
OWOW99-1452	Blackfoot Reservoir	ID	-111.5860	42.9042	CARIBOU	1.97	2002	6475.2
OWOW99-0076	noname gravel pit	OR	-123.2389	44.5527	LINN	233.14	2002	7.2
OWOW99-0326	Malheur lake	OR	-118.7936	43.3098	HARNEY	1.97	2003	5961.7
OWOW99-0451	Crater Lake	OR	-122.0948	42.9494	KLAMATH	1.97	2001	5318.0
OWOW99-0629	Lake Umatilla	OR	-120.5315	45.7258	KLICKITAT	1.97	2002	11697.9
OWOW99-0901	Elk Lake	OR	-122.1189	44.8230	MARION	236.78	2002	26.0
OWOW99-1001	Denley Reservoir	OR	-123.2441	43.3729	DOUGLAS	233.14	2002	5.9
OWOW99-1353	lk Owyhee, elbow	OR	-117.3510	43.4992	MALHEUR	9.74	2003	4576.9
OWOW99-1454	Barney Reservoir	OR	-123.3889	45.4452	WASHINGTON	72.44	2003	81.1
OWOW99-1501	Wickiup Reservoir	OR	-121.7221	43.6916	DESCHUTES	9.74	2003	4110.4
OWOW99-0004	Keechelus Lake	WA	-121.3595	47.3342	KITTITAS	9.74	2001	955.4
OWOW99-0179	Frenchman Hills lk	WA	-119.5883	46.9819	GRANT	72.44	1999	138.3
OWOW99-0202	Cresent Lake	WA	-123.7674	48.0848	CLALLAM	9.74	1999	1995.2
OWOW99-0279	Nahwatzel Lake	WA	-123.3324	47.2432	MASON	72.44	2003	111.2
OWOW99-0304	Patterson Lake	WA	-120.2445	48.4589	OKANOGAN	72.44	2003	51.6
OWOW99-0504	Lake Chelan	WA	-120.3321	48.0261	CHELAN	1.97	2000	13091.0
OWOW99-0529	Rimrock Lake	WA	-121.1618	46.6403	YAKIMA	9.74	2000	952.0
OWOW99-0654	Lake Dorothy	WA	-121.3833	47.5843	KING	72.44	2000	101.9
OWOW99-0979	Lone Lake	WA	-122.4597	48.0215	ISLAND	236.78	2001	34.2
OWOW99-1054	Potholes Reservoir	WA	-119.3222	46.9868	GRANT	1.97	2001	11333.0
OWOW99-1354	Pend Oreille River	WA	-117.2925	48.4300	PEND_OREILLE	9.74	2002	935.8
OWOW99-1379	Buffalo Lake	WA	-118.8874	48.0631	OKANOGAN	72.44	2002	226.2
OWOW99-1479	Lake Wallula	WA	-118.9817	46.0048	BENTON	1.97	2002	12960.9
OWOW99-1554	Calligan Lake	WA	-121.6659	47.6052	KING	72.44	2002	117.0