Report

The 2007 Survey of Oregon Lakes

By: Shannon Hubler and Lesley Merrick

June 2010

Last Updated: 06/30/2010
By: Shannon Hubler
10-LAB-012

This report prepared by:
Oregon Department of Environmental Quality
Laboratory and Environmental Assessment Division
Watershed Assessment Section
3150 NW 229th, Suite 150, Hillsboro, Oregon 97124 U.S.A.
1-800-452-4011
www.oregon.gov/deq

Contact:
Shannon Hubler
(503) 693-5728
hubler.shannon@deq.state.or.us

Table of Contents

Acknowledgements 4
Executive Summary 5
Key Findings 5
Future lake assessments in Oregon 5
The National Aquatic Resource Surveys 6
Why probabilistic surveys? 7
Ecological focus 7
Objectives 8
Survey Design and Indicators 9
Probabilistic Design 10
Site Weighting Factors 10
Lakes resource in Oregon 10
Comparisons of the random draw with NHD 11
Field sampling 13
Watershed Analyses 14
Setting Expectations: The Reference Condition Approach 16
Biological reference sites 17
Physical habitat reference sites 19
Nutrient reference sites 19
Benchmarks to determine condition classes 20
Ecological Condition of Oregon's Lakes 21
Plankton 22
Index development and benchmarks 22
Results: Plankton O/E 23
Macroinvertebrates 25
Index development 25
Preliminary results 25
Physical Habitat Condition of Oregon's Lakes 27
Index conditions and benchmarks 28
Shoreline human disturbance 28
Riparian, Littoral, Littoral+Riparian 28
Shoreline Human Disturbances 29
Riparian Vegetative Cover 31
Littoral Cover 33
Littoral and Riparian Cover 35
Water Quality Condition of Oregon's Lakes 37
Nutrient Condition 39
Total Nitrogen 39
Total Phosphorus 40
Chlorophyll-a 43
Chemistry 45
Turbidity 45
Dissolved Oxygen 47
Trophic State of Oregon's Lakes 48
Nitrogen 49

Phosphorus 49
Chl-a 49
Secchi transparency 50
Inferring past nutrient conditions 52
Inference model development 53
Inferred Total Nitrogen 54
Inferred Total Phosphorus 54
Recreational Indicators 55
Algal toxins 56
Microcystin 56
Cyanobacteria 56
Enterococci 57
Sediment Mercury 57
Relationships Among Indicators 58
Correlations of indicators 59
Biological relationships 59
Habitat relationships 60
Water chemistry relationships 61
Summary of Findings 63
Ranking of Stressors 64
Extent of Stressors 64
Relative Risk 65
Setting lake management priorities 65
The utility of probabilistic monitoring 66
Considerations for the 2012 National Lakes Assessment 67
Study design 67
Sampling procedures, indicators, and analyses 68
Additional indicators 70
Next steps 71
References 72
Appendix. A History of DEQ Lake Monitoring in Oregon 74
Lake Monitoring Eras 74
1960’s - 1970’s 74
1980’s – 1990’s 74
2000’s on 76

Acknowledgements

The funding for this research was provided by the USEPA Office of Water. USEPA and their contractors (Great Lakes Environmental and Tetra Tech) provided training, equipment, laboratory processing, data management, and analytical support. USEPA Region 10 staff provided support in field audits, GIS support, and coordination with the national planning and assessment teams.

Excellent reviews of this report were provided by Andy Schaedel and Roger Edwards of the Oregon Lakes Association (OLA). Andy also graciously provided a history of lake monitoring and assessments at DEQ. Additionally, OLA board members provided critical feedback in the early stages of data assessments.

Finally, and most importantly, the field crew of Greg Coffeen, Lesley Merrick, and Jessica Vogt did a fantastic job. Special thanks to Greg and Lesley for taking on leadership and project management roles at the beginning of the field season.

The ODEQ Lakes field crew (clockwise from top-left): Greg Coffeen, Lesley Merrick, Shannon Hubler, and Jessica Vogt.

Executive Summary

How to Use This Report

This report provides results for 30 randomly selected lakes and reservoirs throughout Oregon. The study was part of a larger assessment to describe the status of biological, chemical and habitat conditions in lakes and reservoirs across the United States, the National Lakes Assessment (NLA; USEPA 2009a). While the 30 lakes and reservoirs (hereafter referred to as "lakes") in Oregon were selected at random to represent the population of Oregon's lakes, our analysis of the physical attributes of Oregon's lakes suggests that the small sample size was inadequate to accurately describe the population. For example, the random sites over-represented reservoirs and under-represented natural lakes. Smaller lakes are over-represented compared to larger lakes. Additionally, error estimates in the results were quite large. Due to these factors, we chose to present the results of the conditions of Oregon's lakes in a more qualitative manner (percent of lakes surveyed, rather than percent of all Oregon lakes).

The study was not designed for assessing the condition of individual lakes. Individual lakes sampled as part of this project were intended as replicates of the population of Oregon lakes. This is an important distinction, and requires caution when interpreting the results of these surveys on an individual lake basis. All field surveys were conducted on a single day and thus represent a snapshot of current conditions for any given lake. The data from individual lakes should be examined in context with existing information for the lake.

Key Findings

Assessments of lake conditions in Oregon showed many similarities to lake conditions observed nationally. Poor biological conditions, as measured by plankton assemblages, were observed for 23% of the lakes surveyed in Oregon. Nationally, 22% (+/- 5%) of lakes showed poor biological conditions (USEPA 2009a). Riparian and shallow water (littoral) habitat conditions and excessive nutrients were the most common stressors to the biology in Oregon. This same pattern was observed nationally and across the Western United States.

Nationally, there was a 2-3 times greater risk of observing poor biological conditions when nutrients or riparian/littoral habitat were also in poor condition (USEPA 2009a). The small sample size in Oregon precluded our ability to perform these same analyses. In general, poor biological conditions were observed most often in lakes with higher levels of nutrients and greater disturbance of near-shore habitat.

Future lake assessments in Oregon

Several new tools are now available for assessing lake conditions in Oregon. We now have a model for plankton that can assess biological conditions across the state. A macroinvertebrate model should be available in the near future. Additionally, several models are now available to assess riparian and littoral lake conditions. Biological and habitat assessments are useful because they are integrative in nature, reflecting the stresses to lakes throughout time. They are particularly effective when a single sampling visit to a lake is required.

How to obtain the data: http://www.epa.gov/owow/lakes/lakessurvey/web_data.html

The National Aquatic Resource Surveys

Van Patten Lake (Baker Co.)

The National Aquatic Resource Surveys

In the summer of 2007, crews from the Oregon Department of Environmental Quality (ODEQ) surveyed 30 lakes across the state. (Unless specifically stated otherwise, from here on out "lakes" is used to refer to both natural lakes and man-made reservoirs.) These lake surveys were funded as part of the Environmental Protection Agency's (EPA) National Lakes Assessment (NLA). The NLA is one part of the National Aquatic Resource Surveys (NARS) which are designed to provide a statistically valid assessment of the condition of the nation's lakes and reservoirs. The second goal was to determine the relative importance of stressors in impacting lake conditions. The 30 lakes were selected as a statistical representation of all lakes in Oregon (at least those lakes meeting certain requirements on size, permanence, maximum depth, etc.). Oregon's lakes were assessed for ecological, recreational, water chemistry, and physical habitat indicators. More than 1,000 lakes were sampled across the country as part of the NLA.

Why probabilistic surveys?

Under the federal Clean Water Act (CWA), the EPA is mandated to report to Congress on the conditions of the nation's surface waters. States are required under Section 305(b) of the CWA to report on conditions of surface waters to EPA every two years. A variety of approaches and different levels of monitoring efforts by states made it difficult to report on the status of the nation's waters to Congress in a scientifically defensible way (GAO 2002).

Following this critique of monitoring and reporting approaches, the EPA amended its guidelines to states, agencies, and tribes for the award of CWA Section 106 monitoring funds. The objective was to increase the capacity of states and tribes to effectively and accurately monitor and report to EPA on the conditions of surface waters. Under these guidelines, states are expected to develop and implement statistically valid strategies to monitor and report on surface water conditions at the state-scale. An additional requirement for the award of 106 monitoring funds is the participation in the statistically valid National Aquatic Resource Surveys (NARS). The NARS cover four different surface water types: lakes, streams and rivers, coastal (bays and estuaries), and wetlands.

The ODEQ has opted for full participation in the NARS, including monitoring and state-wide assessments. We have a long history of working with EPA staff on probabilistic monitoring, dating back to stream surveys in the Coast Range ecoregion in 1994. Since then we have completed surveys of wadeable streams at multiple ecoregions, basins, and statewide (Hubler 2007); as well as surveys of coastal bays and estuaries. We have since expanded our probabilistic monitoring efforts from only wadeable streams to lakes (NARS in 2007) and large rivers (NARS in 2008-2009). In 2011, we plan to fully participate in the national survey of wetlands.

Ecological focus

One major difference that the NARS has over traditional water monitoring in Oregon (and nationally) is the focus on ecological conditions. Most of our monitoring at ODEQ tracks acceptable levels of water chemistry parameters are set to protect the most sensitive beneficial use (e.g., salmon, fish tissue for human health consumption, recreation use, and drinking water). The assumption behind this traditional approach is that if water chemistry meets these acceptable levels, then the beneficial use will be protected. However, the actual condition to be protected is frequently not monitored leaving the actual condition of the beneficial use unknown.

With NARS the emphasis is placed on the ecological condition of Oregon's lakes. The condition of biological *assemblages* was used as a direct measure of beneficial use support. By looking at the relationships among biological condition and water quality and physical habitat indicators it is possible to determine the most important ecological stressors in any given lake.

Assemblages are a part of a community of organisms within an ecosystem. For example, a lake biological community contains phytoplankton, zooplankton, macroinvertebrate, and fish assemblages (among others).

A historical view of ODEQ's role in lake monitoring in Oregon is described in the Appendix. Past lake monitoring efforts were not random, as in this study. Instead, specific lakes were targeted for monitoring, especially larger lakes with higher recreational uses or suspected trophic (excess nutrients) issues. Most recently lake monitoring performed by ODEQ focused on specific objectives such as developing TMDLs (CWA section 303(d)); hydropower relicensing (CWA section 401); drinking water protection, etc).

Objectives

Our primary objective in this assessment is to present the results of our surveys of 30 randomly selected lakes in Oregon. The focus of this report is on the population of lakes surveyed, not individual lakes. Data from each lake surveyed can be found in a companion document: The 2007 Survey of Oregon Lakes: Individual Lake Summaries (Merrick 2010).

Secondarily, we intended to introduce the purpose, strengths, and weaknesses of probabilistic monitoring to lake managers in Oregon. Our goal was to open a dialogue with lake managers about how to improve monitoring and assessment of Oregon's lakes. We anticipate these discussions will result in improvements to the next round of lake sampling under the NARS in 2012, hopefully with participation from a wide array of agencies, researchers, and monitoring groups.

Big Lake (Linn Co.)

Survey Design and Indicators

Moon Reservoir (Harney Co.)

Probabilistic Design

Since sampling all Oregon's lakes and reservoirs is not feasible, the NLA used a random sampling design to select lakes throughout Oregon. The idea behind probabilistic sampling is that each site has a known chance (probability) of being selected, and collectively the randomly selected sites are a statistically valid representation of the entire population. The probabilistic design is similar to an opinion poll, where each person polled represents a certain proportion of the total population (Stoddard et. al 2005). This type of environmental sampling is not meant to be used for site specific assessments, but rather as a tool to define the quality of a population of water bodies.

Site Weighting Factors

As with a political opinion poll, where population density demographics can skew results, lake area and geographic density can bias the results of the population. For example, in Oregon a simple random sampling of lakes could over-represent small lakes in Oregon as there are a higher number of them throughout the state. In this assessment, lake area and geographic density bias was eliminated by applying differential site weighting factors. Site weights are the amount of lakes each site in our poll represents of the total population of [target] lakes in Oregon. For example, large lakes like Waldo Lake or Beulah Reservoir had small weights, where the results from these lakes represented 1.8 and 4.4 of Oregon's target lakes, respectively. The smallest lakes, like Powers Pond or Van Patten Lake, each represented 168 of Oregon's target lakes because there are more small lakes in Oregon than large lakes.

Lakes resource in Oregon

The random sample draw of lakes in Oregon was selected from the USGS/EPA National Hydrography Dataset (NHD). The NHD is a series of digital maps which reveal topography, area, flow, location, and other attributes of the nation's surface waters (USEPA 2009a). The NHD classified 3,193 water bodies as potential lakes or ponds, ranging from less than 1 hectare (2.4 acres) up to the largest lake in Oregon (Upper Klamath 26,705 hectares). The target lake population for this assessment was defined by EPA to include any lake, pond, or reservoir greater than 4 hectares, at least 1 meter deep, and have a minimum of 0.1 hectare open water. Additionally, commercial treatment and/or disposal ponds, brackish lakes, and ephemeral lakes were eliminated from the target population (Table 1) (USEPA 2009a).

Table 1. Criteria used in the 2007 NLA to determine which lakes comprised the target population.

NLA Target Lake Criteria	
Lake Characteristics	Greater Than 4 Hectares in Area
	At Least One Meter Deep
	Minimum of 0.1 Hectares Open Water
Lake Type	Not a Treatment or Disposal Pond
	Non Brackish
	Non Ephemeral

Under these criteria, the target population of lakes Oregon was reduced to 1,159 (36% of the NHD defined lakes or ponds) (Figure 1). The bulk of the lakes removed (1,494) were less than 4 hectares. Through office-based reconnaissance and field visits, we determined that 24% (276 lakes) of the 1,159 lakes were non-target: 20% not a lake, 1% less than 1 meter deep, 2% less than 4 hectares, and 1% saline. Therefore, the Oregon assessment was based on a target population of 883 lakes. We were unable to sample three of the randomly selected lakes due to denial from private landowners. These three lakes represented 21% of the target population (189 lakes); however, this was mostly driven by denial of access to one site with a high weight (representing 168 lakes). Ultimately, this means that the 30 lakes ODEQ sampled represents 79% of the total target population of lakes in Oregon (weighted value of 694, non-weighted value of 30 lakes) (Figure 1).

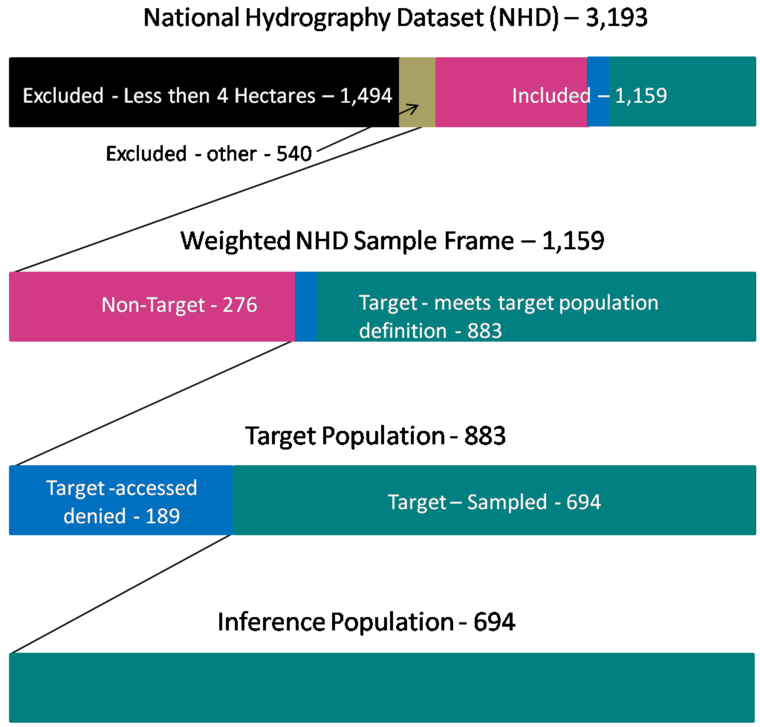


Figure 1. The National Hydrography Dataset (NHD) was used as the source of potential lakes for inclusion in the 2007 National Lakes Assessment. The final population of lakes represented by the thirty random sites surveyed, following various screens for inclusion criteria and access to privately owned lands, was 694 lakes.

Comparisons of the random draw with NHD

Typically, a minimum of fifty sites are used in statewide probabilistic surveys in order to obtain higher confidence intervals. In Oregon only 30 surveys were conducted due to a lack of funding (Table 3). We analyzed our randomly sampled sites to understand how representative they were of the EPA original sample draw from the NHD. Five separate characteristics of the two populations were compared: reservoir vs. lake, area category, elevation, Level III ecoregion, and NLA ecoregion (Figure 2).

These comparisons reveal that the weights of the 30 random survey sites (Table 3) over-represented the extent of the lake resource that are reservoirs, in the smallest area class (4-10 HA), located in the highest elevation category, in the Blue Mountains Level III ecoregion, and in the Western Mountains NLA ecoregion. Conversely, lakes in the Northern Basin and Range and Willamette Valley Level III ecoregions, and Xeric NLA ecoregion were under represented.

Because of these findings, we moved away from reporting our findings using site weights and percent of Oregon lakes. Instead we focused on reporting the range of conditions observed and a percent of lakes surveyed approach.

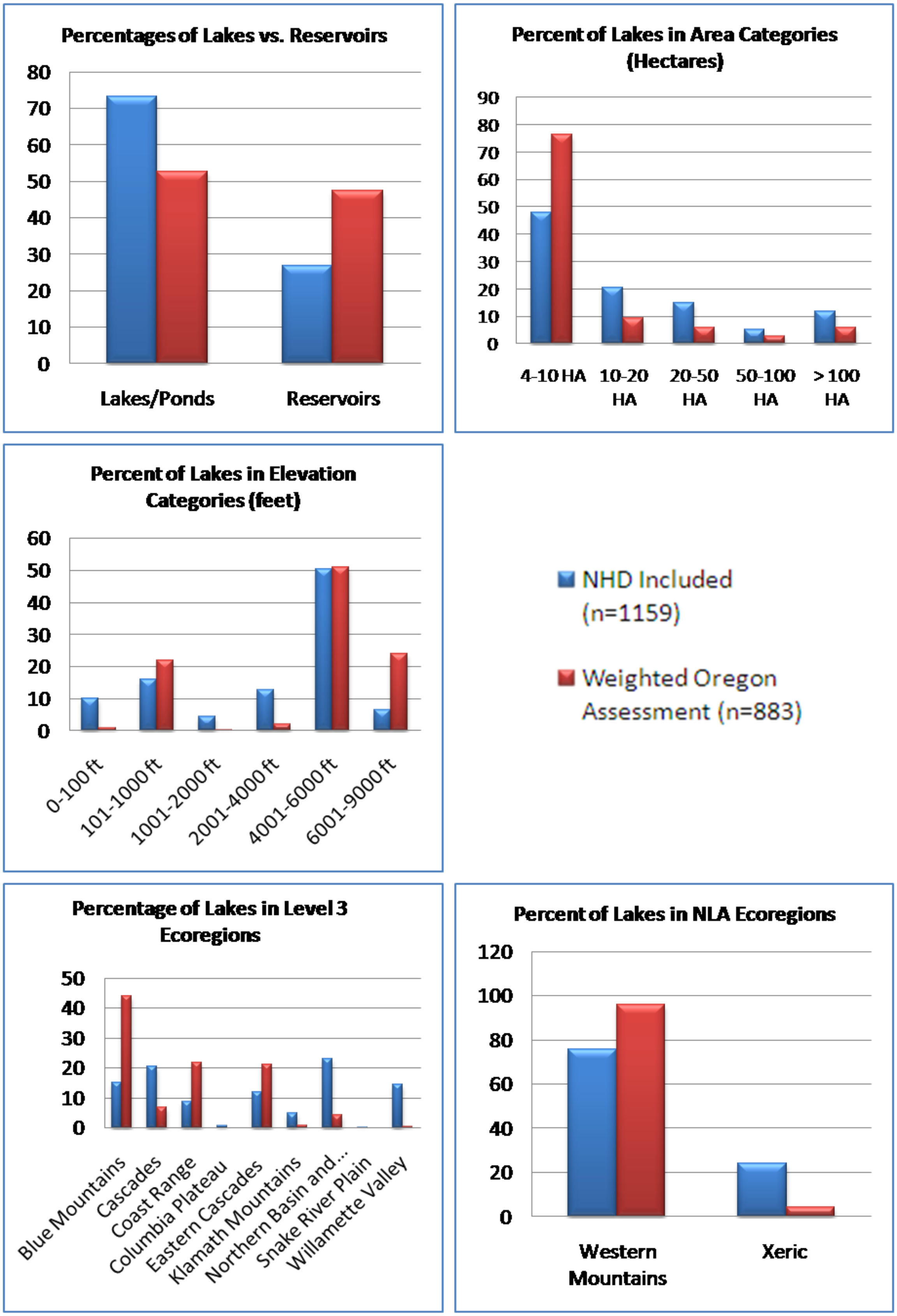


Figure 2. Various ways of examining the degree of similarity between the source pool of target lakes in Oregon (NHD Included) and the random draw of 30 lakes in Oregon (Weighted Oregon Assessment).

Field sampling

The field surveys divided each lake into two zones (Figure 3). A single station at the deepest point of the lake ("Z") was established to collect water chemistry, lake profile, algal toxins, sediment cores, and plankton tows. The second zone included ten equally spaced stations around the perimeter of the lake ("A" through "J"). Sampling at these perimeter stations included littoral benthic macroinvertebrate samples and littoral and riparian physical habitat observations. At one predetermined littoral station a single *Enterococci* sample was collected. Littoral zone plots extended 10 m from shore into the lake and were 15 m wide. Riparian zone plots extended 15 m away from the water's edge and were 15 m wide.

Indicators that were assessed for this report are shown in Table 2.

For detailed descriptions of field methods, refer to the field operations manual (USEPA 2007).

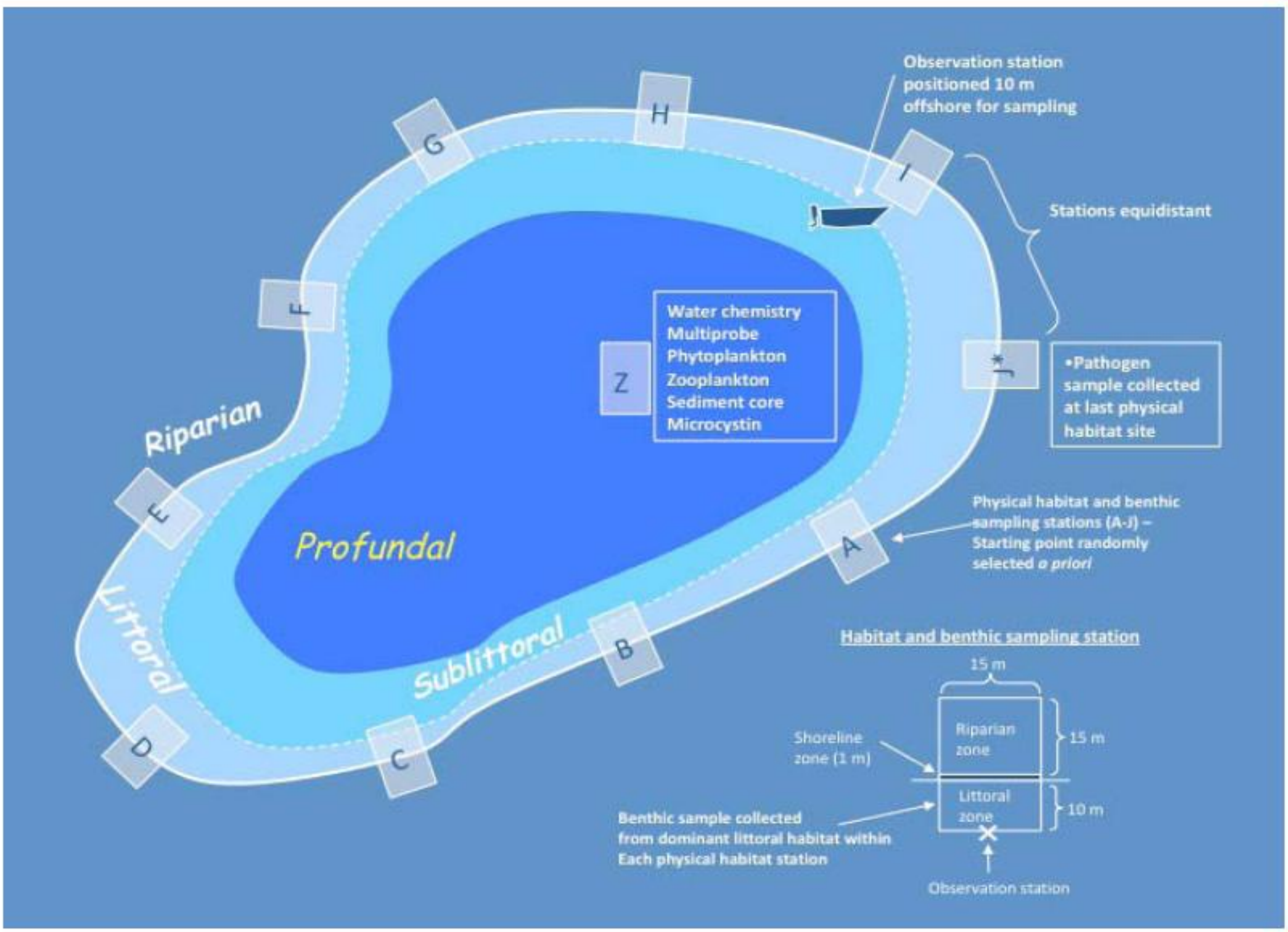


Figure 3. Sampling zones and indicators collected at 30 random lakes throughout Oregon as part of the 2007 National Lakes Assessment. (Figure courtesy of USEPA 2009a.)

Table 2. Indicators collected for the 2007 National Lakes Assessment and which ones were reported on in this report.

	Water Quality	Physical Habitat	Biological	Recreational
REPORTED	**Water Column Chemistry** - pH, DO, Temp, Turbidity, ANC, Conductivity, Ions	**Shoreline Human Disturbance**	**Plankton (O/E model)** - Zooplankton - Phytoplankton	**Algal Toxins** - Microcystin - Cyanobacteria
	Nutrients - Phosphorus - Nitrogen	**Riparian Vegetation Cover**	**Macroinvertebrates (O/E model)**	
	Chlorophyll-a Density	**Littoral Habitat Cover**	**Sediment Diatom Cores** - Lake Diatom Condition - Inference Model	
	Secchi Depth	**Littoral and Riparian Habitat Complexity**		
NOT REPORTED			**Invasive Species**	
			Sediment diatom IBI	**Pathogens** - *Enterococci*
				Sediment Mercury

Watershed Analyses

Geographic Information System (GIS) data layers were used to characterize the effects of land use, human stressors, and natural physical attributes on the condition of surveyed lakes. GIS metrics were calculated for three different spatial scales: within 200 m from the lake, within 2-kilometers from the lake, and for the entire lake basin. The layer used to define the land use in the lake watersheds was generated in GIS by combining land ownership layers, zoning layers, and the National Land Cover Dataset (NLCD). The process yielded nine land use categories, which were then aggregated into four groups: Agricultural, Forest, Urban, and Other. The USEPA GIS based tool ATtILA was used to obtain physical characteristics, slope, elevation, stream density, and average annual precipitation of the watersheds. Attila was also used to generate human stressor metrics: number of roads crossings over streams, road density, road length, and population density.

Table 3. Thirty randomly selected lakes throughout Oregon were sampled by the Oregon Department of Environmental Quality in 2007.

Site ID	Lake name	Longitude	Latitude	County	Ecoregion	Area (hectares)	Site Weight
NLA06608-0049	Clear Creek Reservoir	-117.15336	45.06233	BAKER	Western Mountains	10 - 20	16.4
NLA06608-0290	Junipers Reservoir	-120.52569	42.19565	LAKE	Western Mountains	50 - 100	4.0
NLA06608-0306	Moon Reservoir	-119.41335	43.41788	HARNEY	Xeric	>100	4.1
NLA06608-0402	Powers Pond	-124.07809	42.88975	COOS	Western Mountains	4 - 10	168.5
NLA06608-0406	Clear Lake	-121.70443	45.18038	WASCO	Western Mountains	>100	4.4
NLA06608-0614	Cooper Creek Reservoir	-123.26862	43.37864	DOUGLAS	Western Mountains	50 - 100	4.0
NLA06608-0625	Van Patten Lake	-118.18599	44.95429	BAKER	Western Mountains	4 - 10	168.5
NLA06608-0658	Clear Lake	-124.07961	44.02384	LANE	Western Mountains	50 - 100	4.0
NLA06608-0677	Mann Lake	-118.44684	42.77239	HARNEY	Xeric	50 - 100	3.7
NLA06608-0678	Hosmer Lake	-121.78048	43.96359	DESCHUTES	Western Mountains	>100	4.4
NLA06608-0870	Smith Reservoir	-122.04638	44.31669	LINN	Western Mountains	50 - 100	4.0
NLA06608-0881	Phillips Reservoir	-118.04564	44.68030	BAKER	Western Mountains	>100	4.4
NLA06608-0933	Beulah Reservoir	-118.15043	43.92763	MALHEUR	Western Mountains	>100	4.4
NLA06608-0934	Waldo Lake	-122.03825	43.73613	LANE	Western Mountains	>100	1.8
NLA06608-1058	Lake of the Woods	-122.21421	42.36492	KLAMATH	Western Mountains	>100	4.4
NLA06608-1073	Ice Lake	-117.27237	45.22936	WALLOWA	Western Mountains	20 - 50	10.8
NLA06608-1190	Fern Ridge Lake	-123.30008	44.08794	LANE	Western Mountains	>100	4.4
NLA06608-1266	Lucky Reservoir	-119.99761	42.11998	LAKE	Xeric	10 - 20	15.2
NLA06608-1426	Horsfall Lake	-124.24600	43.45220	COOS	Western Mountains	>100	4.4
NLA06608-1445	Baca Lake	-118.85217	42.91835	HARNEY	Xeric	>100	4.1
NLA06608-1446	Torrey Lake	-122.01754	43.79630	LANE	Western Mountains	20 - 50	10.8
NLA06608-1638	Big Lake	-121.87321	44.37178	LINN	Western Mountains	50 - 100	4.0
NLA06608-1894	Sparks Lake	-121.74563	44.02665	DESCHUTES	Western Mountains	20 - 50	10.8
NLA06608-1958	Hills Creek Reservoir	-122.42161	43.66298	LANE	Western Mountains	>100	1.8
NLA06608-2082	Emigrant Lake	-122.60082	42.15140	JACKSON	Western Mountains	>100	4.4
NLA06608-2438	Piute Reservoir	-119.56340	42.06681	LAKE	Xeric	20 - 50	10.0
NLA06608-2450	Lake Edna	-124.17904	43.63164	DOUGLAS	Western Mountains	10 - 20	16.4
NLA06608-2481	Officers Reservoir	-119.39276	43.98863	GRANT	Western Mountains	4 - 10	168.5
NLA06608-2673	Strawberry Lake	-118.68504	44.30658	GRANT	Western Mountains	10 - 20	16.4
NLA06608-2726	South Twin Lake	-121.76654	43.71379	DESCHUTES	Western Mountains	20 - 50	10.8

Setting Expectations: The Reference Condition Approach

Ice Lake (Wallowa Co.)

In order to assess the ecological, chemical, and physical habitat conditions of Oregon's lakes, we need some measure of what acceptable conditions are for each indicator. This is relatively simple for indicators with existing water quality standards. However, standards have been established for relatively few indicators—especially for biological or habitat indicators. The NLA used the reference condition approach to identify *least-disturbed* lakes to establish benchmarks for indicators (Stoddard et. al 2006) Least-disturbed conditions represent "the best of what's left" for any given region. In some parts of the United States much of the landscape is relatively undisturbed, while in other regions the landscape has been altered more extensively by human activities.

Unlike streams and rivers assessments, ODEQ doesn't have a set of previously sampled reference sites to rely upon for establishing indicator benchmarks. To this end, our assessments of lake condition rely entirely upon the reference populations established for the national assessment. More detailed descriptions of the reference selection process can be found in the NLA technical appendices (USEPA 2010).

Multiple sets of reference sites were used to assess different indicator types. Each separate set of reference sites was used to establish benchmarks for determining condition classes for the various indicators, and the methods by which benchmarks were determined also varied.

Biological reference sites

One set of reference sites was used to assess the condition of plankton and macroinvertebrate assemblages. Prior to screening for reference sites, all lakes were grouped based on similarities in nine environmental variables covering geography (longitude, latitude, and elevation), geology (calcium content), climate (air temperature and precipitation), lake size (area and depth) and extent of shoreline development. Three larger regions and nine smaller ecoregions were identified. Oregon lakes were part of the West region and two ecoregions (Western Mountains and Xeric) (Figure 4).

Screening criteria to identify reference sites used water chemistry and physical habitat data collected as part of the lake surveys (USEPA 2010). Data screened included seven chemical variables (total nitrogen, total phosphorus, chloride, sulfate, turbidity, dissolved oxygen, acid-neutralizing capacity) and three physical habitat variables relating to shoreline disturbances (agricultural, non-agricultural, intensity and extent of disturbances). To avoid circularity, biological data was excluded from the reference screening process.

Screening criteria were established for each of the nine ecoregions. Only sites that passed all nine screening criteria were accepted as reference sites. In the West, a total of 50 biological reference sites were identified (Figure 5). The majority of these were located in the Mountains ecoregion (n = 46) and only four reference sites were located in the Xeric ecoregion. Thirty sites were natural lakes and twenty were reservoirs. Eight reference lakes were located in Oregon (Table 4).

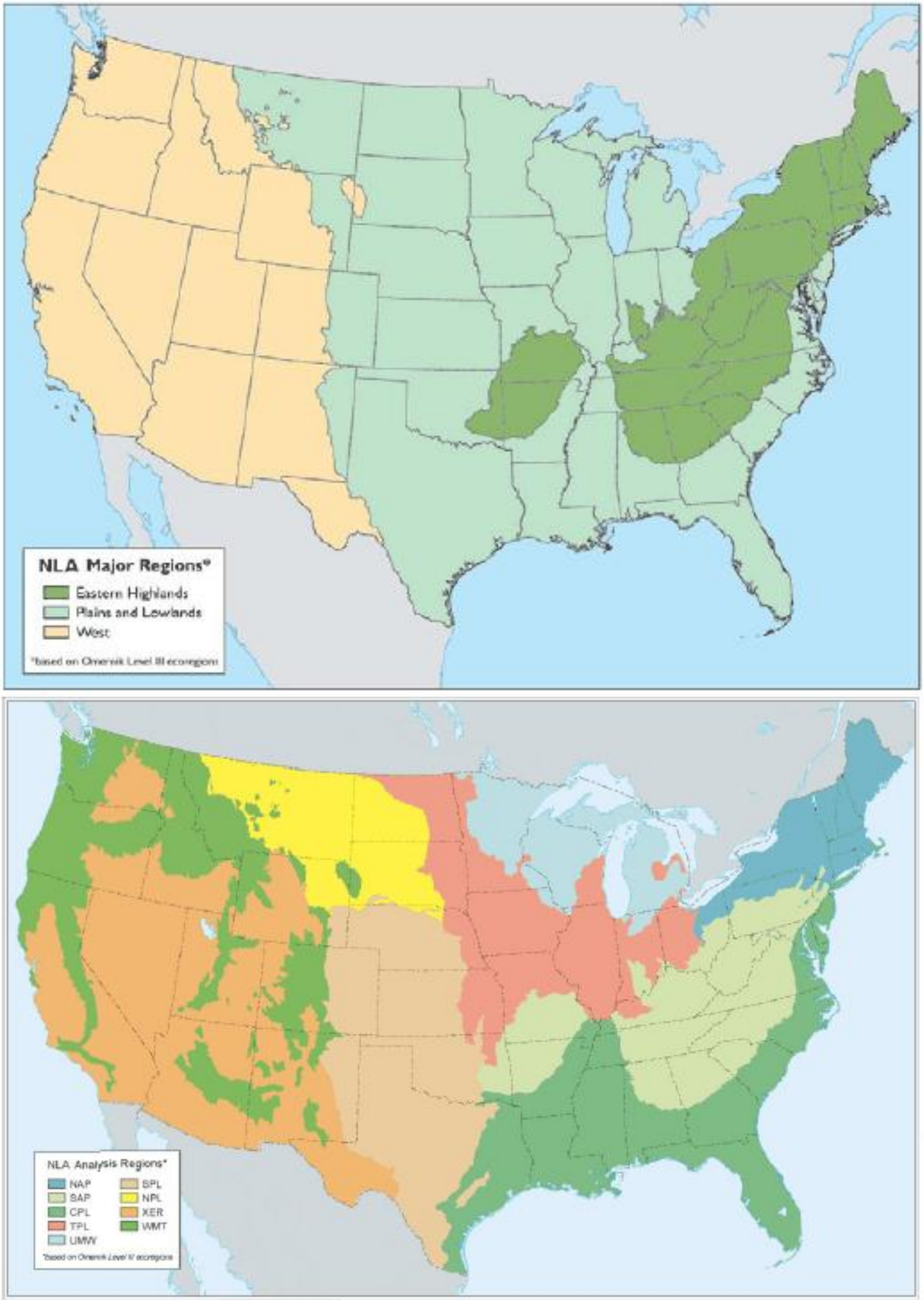


Figure 4. Assessment regions and ecoregions in the 2007 NLA. Oregon lakes were located in the West region (top panel) and Western Mountains (WMT) and Xeric (XER) ecoregions (bottom panel). (Figure courtesy of USEPA 2009aa)

Table 4. Oregon lakes designated as reference sites for use in assessing lake conditions.

Lake name	County	Ecoregion	Selection	Biological	Habitat	Water Chemistry
Van Patten Lake	Baker	Western Mts.	Random	√	√	√
Waldo Lake	Lane	Western Mts.	Random	√	√	
Ice Lake	Wallowa	Western Mts.	Random	√	√	
Torrey Lake	Lane	Western Mts.	Random	√	√	
Strawberry Lake	Grant	Western Mts.	Random			√
Charlton Lake	Deschutes	Western Mts.	Hand-picked	√	√	
Squaw Lakes	Jackson	Western Mts.	Hand-picked	√	√	
Deer Lake	Deschutes	Western Mts.	Hand-picked	√	√	√
Four Mile Lake	Klamath	Western Mts.	Hand-picked	√	√	√
Fish Lake	Harney	Xeric	Hand-picked			√

Physical habitat reference sites

The same ten screening variables and criteria were applied to all sampled lakes as was used to screen for biological reference sites. Additionally, one more screen was added that removed lakes with large lake level fluctuations (determined from aerial photos and field measurements). This removed nine lakes from the 50 lakes in the West used for assessment of biological condition, leaving 41 total habitat reference lakes. The final number of reference sites identified in the Mountains ecoregion was 38 and there were three in the Xeric ecoregion (Figure 5). There were eight Oregon lakes used as physical habitat reference sites (Table 4).

Nutrient reference sites

A third set of reference sites was used to assess nutrients, chlorophyll-a, and turbidity. Screening criteria were developed for 11 nutrient ecoregions across the U.S. (USEPA 2009a), but in the West covered the same two ecoregions as for biological reference sites (Xeric and Western Mountains). The identification of nutrient reference sites required dropping nutrients from the screening process; just as the biological reference screening process avoided the use of biological information. Data screened included chemical (chloride, sulfate), shoreline disturbance (agricultural, non-agricultural, disturbance intensity), and landuse in the watershed (agricultural, industrial, and residential). Chloride was not used for lakes in the Coast Range level III ecoregion, because of the potential for naturally high values due to marine sources.

If a lake exceeded any one of the reference screening criteria, the lake was removed from the reference pool. A total of 37 lakes were identified as nutrient reference sites for the West, 14 from the Xeric and 23 from the Mountains ecoregions (Figure 5). Seventeen lakes were identified as both biological and nutrient reference sites. Four lakes in Oregon were identified as reference sites for nutrients (Table 4).

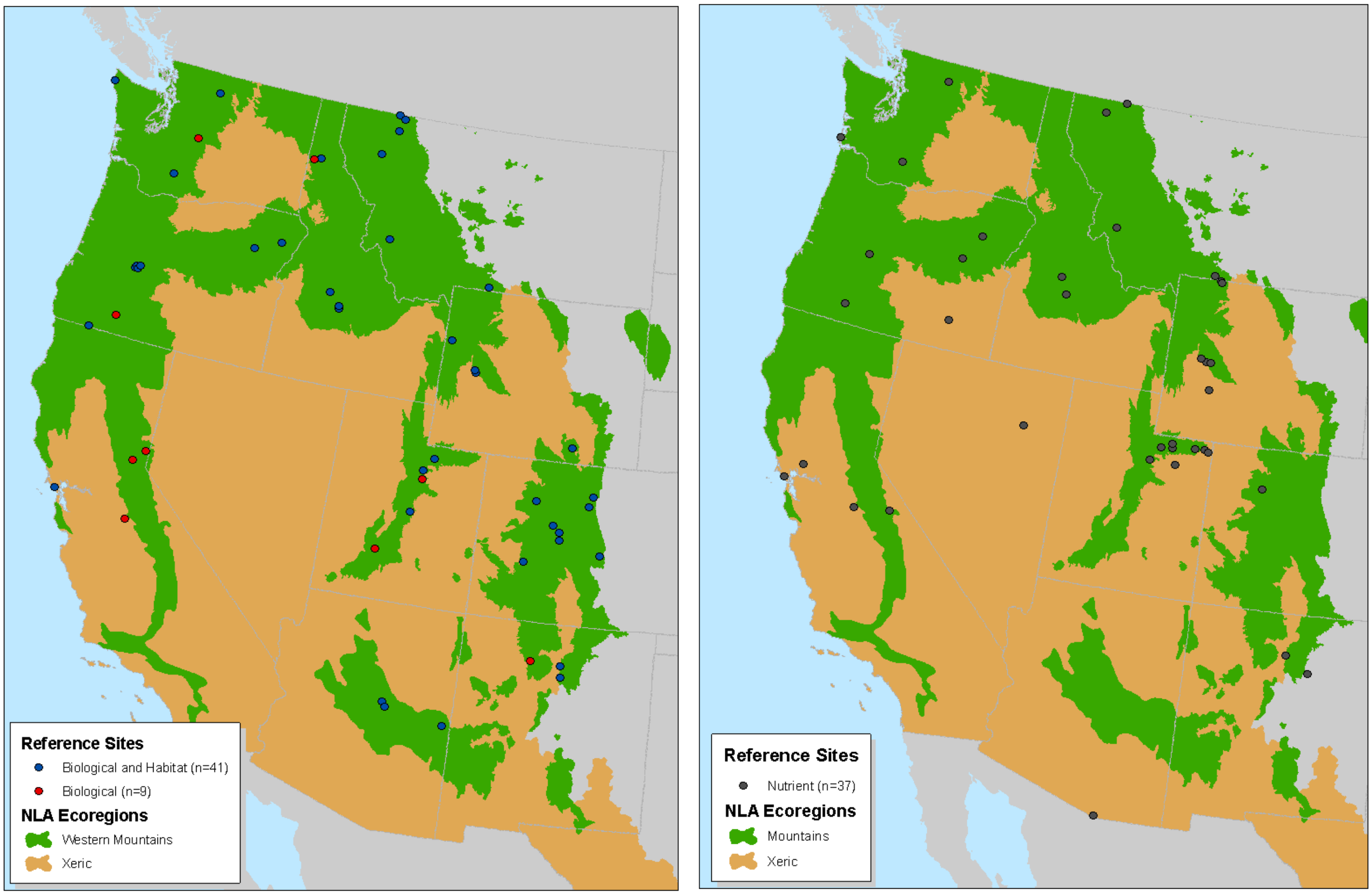


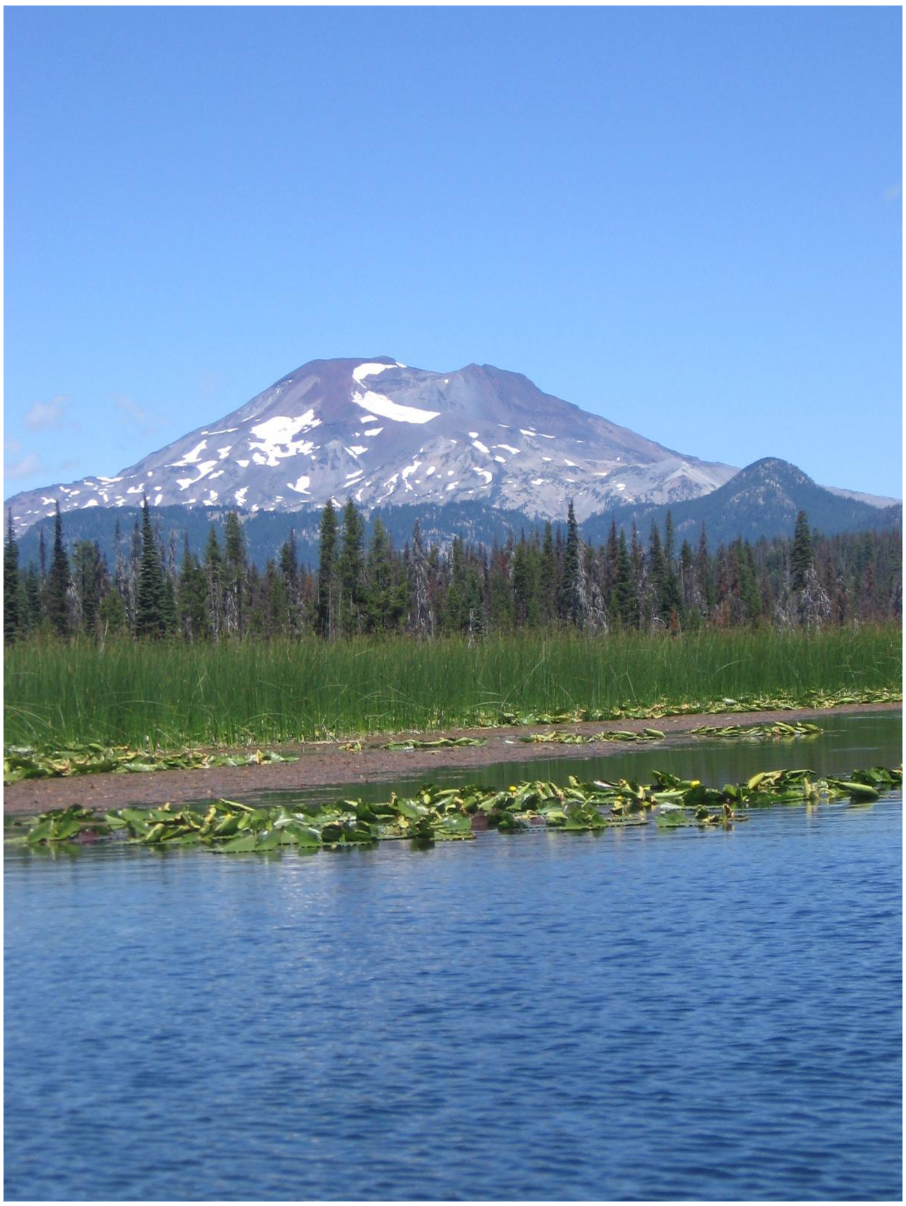
Figure 5. Reference sites used for assessing biological and physical habitat condition (left panel) and nutrient and water quality condition (right panel).

Benchmarks to determine condition classes

We used the same benchmarks for determining lake conditions as were used for the NLA. The distributions of values observed at reference sites were used to determine the conditions of all indicators at a lake, except for recreational indicators and shoreline human disturbance. For indicators where increasing values were associated with improved conditions, the 5th and 25th percentiles of reference values were used as benchmarks separating condition classes. For indicators where increasing values were associated with decreasing conditions, the upper 75th and 95th percentiles were used as benchmarks.

Access to Ice Lake required hiring a professional outfitter with horses and mules to carry the field crew and gear.

Ecological Condition of Oregon's Lakes

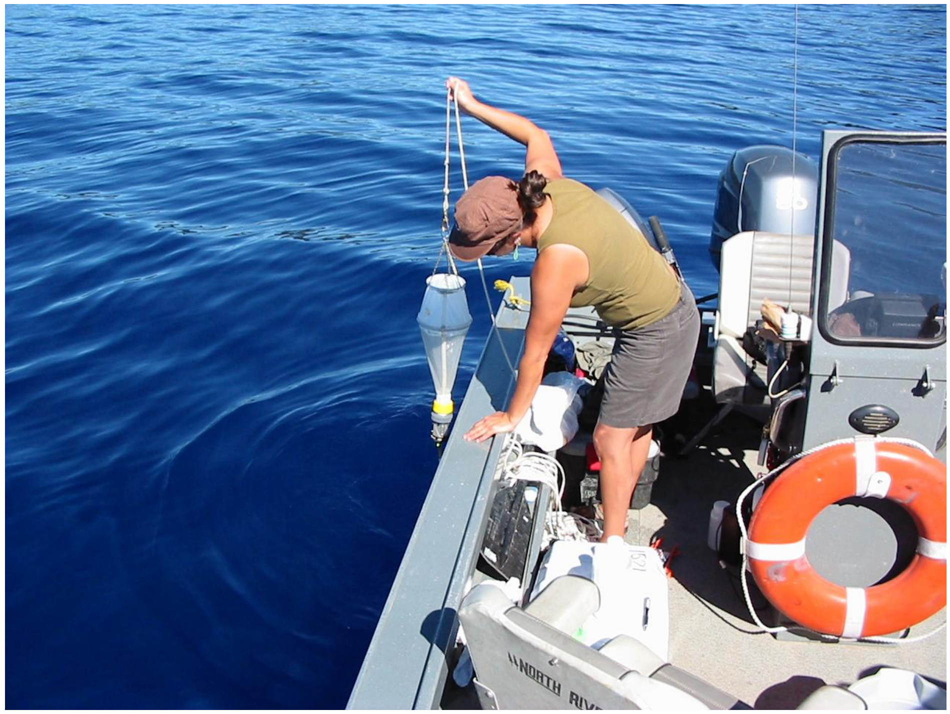


Hosmer Lake (Deschutes Co.)

Ecological Conditions

Plankton

Lake plankton assemblages were assessed using both phytoplankton and zooplankton. At the index site (the deepest point in the lake), zooplankton were collected with vertical tows of a Wisconsin net. Two separate tows were taken from the bottom of the lake to the top of the lake. One tow was with a fine mesh net (80 um) and the other tow was with a coarse mesh net (243 um). For shallow lakes with high clarity (clear to bottom), two tows of each mesh size were collected. Following tows, plankton within each net were rinsed into sample containers where they were then narcotized and preserved. Phytoplankton samples were taken from the top two meters of the water column at the index site.



Collecting plankton with a Wisconsin net. (Waldo Lake)

Sample processing in the laboratory involved slightly different procedures for phytoplankton and zooplankton. Phytoplanktons were subsampled to 300 natural algal units. For zooplankton, separate subsamples were taken for microcrustaceans and rotifers. For each zooplankton group, a minimum of 200 and a maximum of 400 individuals were counted. All plankton were identified to lowest practical taxonomic resolution.

Index development and benchmarks

A combined phyto- and zooplankton predictive model was created to assess the ecological condition of lake plankton assemblages. This model predicts the types of plankton taxa expected to occur at a given lake, assuming the lake was in least disturbed reference condition. The number of reference taxa that were observed (O) at a lake was compared to expected reference taxa (E). The ratio of O/E provides an indication of taxonomic completeness—did we see the types of plankton commonly found at reference sites with similar environmental conditions? Another way to think of O/E is that it represents taxa loss. Values of O/E less than 1.0 suggest that there are fewer reference taxa at a lake than would be expected if the lake were in least disturbed conditions.

The 50 sites in the West identified as biological reference sites were used to make estimates of E at each lake in Oregon. Predictions of expected taxa at a given lake were made from reference sites that had similar environmental characteristics. Environmental predictors for the West model included water holding capacity, soil permeability, depth to water table, longitude, and calcium oxide content. A more thorough description of Plankton O/E model development can be found in the NLA Technical Appendix (USEPA 2010).

Following the benchmarks used in the NLA, lakes with Plankton O/E values greater than or equal to the 25th percentile of reference site O/E values (>= 0.88) were considered to be in good condition. An O/E between the 5th and 25th percentile of reference O/E values (0.69 – 0.87) were classified in fair condition. O/E values at a lake less than or equal to the 5th percentile of reference O/E values (0 – 0.68) were considered to be in poor condition.

Results: Plankton O/E

Good conditions were observed for 50% of surveyed lakes. Fair conditions in the plankton assemblage were observed at 20% of lakes. Most disturbed (poor) conditions were observed at 23% of surveyed lakes. Plankton condition was unavailable for 2 lakes (7%) (Table 5). Cumulative distribution frequencies (CDFs) of the Oregon sites and the populations of West and Region 10 lakes show very similar distributions of plankton O/E (Figure 6).

Reservoirs in Oregon showed lower ecological condition compared to natural lakes. Sixty percent of plankton assemblages from surveyed natural lakes were in good condition, compared to 40% of surveyed reservoirs. Natural lakes showed only 13% in poor condition, compared to 33% of reservoirs (Table 5). This same pattern was observed across the West, where the distribution of reservoirs was shifted to the left, representing higher percentages of lakes in the poor condition class (Figure 6).

Oregon-Mountains lakes showed 60% of lakes in good condition and 16% in poor condition. Only three out of the five Oregon-Xeric lakes had adequate plankton samples—all three were in poor condition (Table 5). Across the West, a pattern of higher disturbance was observed for plankton in Xeric lakes (Figure 6). The Oregon-Mountains sites follow the distribution of the West-Mountains fairly closely, but did show a lower percentage in fair and higher percentage in good conditions.

Table 5. Plankton conditions observed in Oregon lakes.

Plankton Condition					
		Good	Fair	Poor	N/A
Statewide	Oregon (n=30)	50%	20%	23%	7%
Regional	Mountains (n=25)	60%	24%	16%	
	Xeric (n=5)	-	-	60%	40%
Lake Origin	Natural (n=15)	60%	20%	13%	7%
	Reservoirs (n=15)	40%	20%	33%	7%

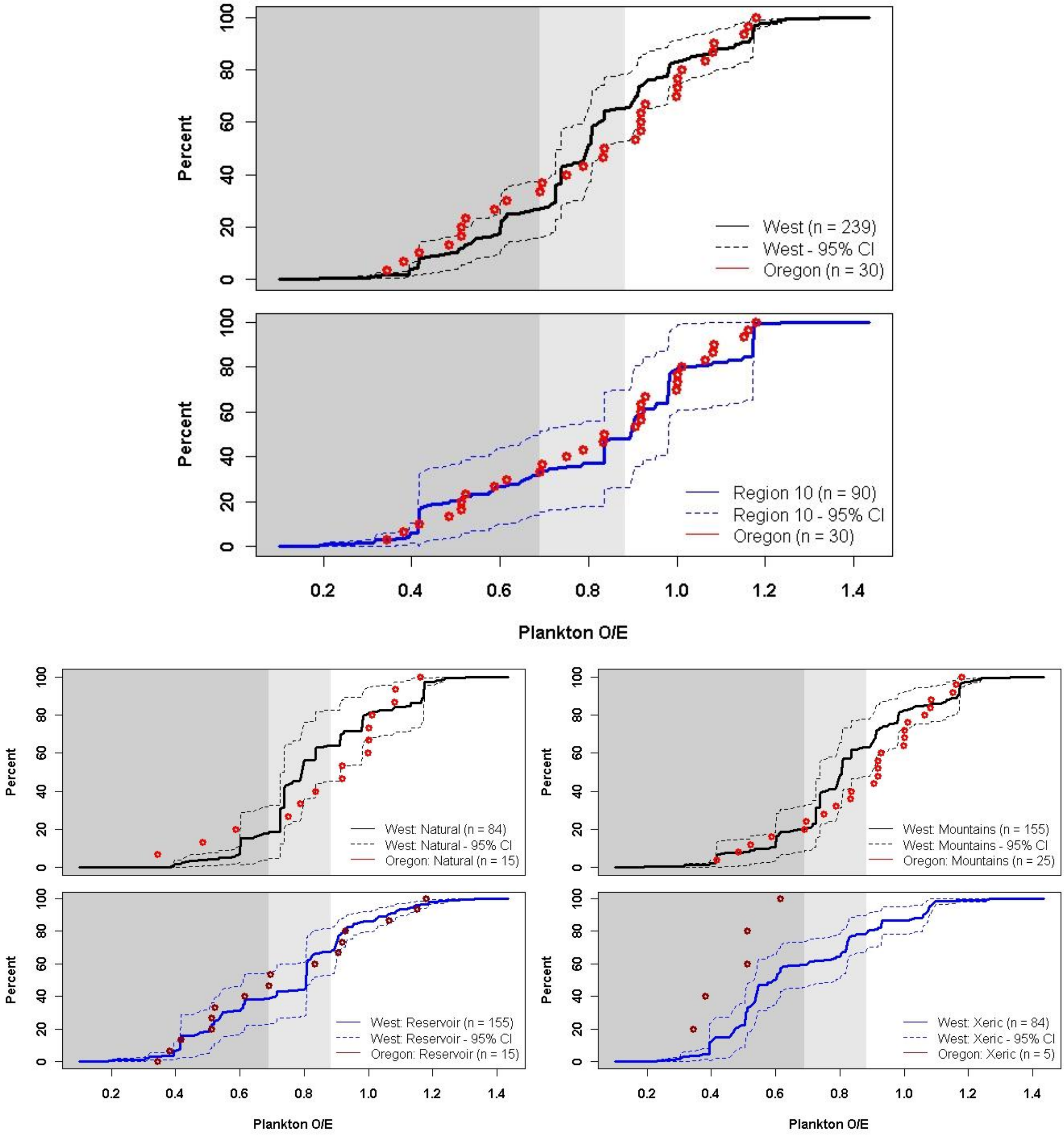


Figure 6. Cumulative distribution frequencies (CDFs) of the plankton O/E index at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. "O/E" = observed to expected ratio of reference plankton taxa. Condition classes based on reference benchmarks show improving biological conditions from left to right (poor = dark grey, fair = light grey, good = white).

Macroinvertebrates

Macroinvertebrate collection in the littoral plot, using a D-frame kick-net. (Moon Reservoir)

Benthic macroinvertebrates were collected from ten separate 10m x 15m plots located in the littoral zone. (These same plots were also used for physical habitat observations.) Within each littoral plot, the dominant substrate was identified as rocky/large woody debris, macrophyte beds, or mud/sand. Samples were collected by taking one meter sweeps of the dominant substrate using a D-frame dip net (500 um mesh). The ten individual sweeps were all composited into a single sample and preserved in the field with 95% ethanol. Laboratory processing of macroinvertebrate samples involved subsampling a minimum of 500 individuals and identification to lowest practical taxonomic resolution.

Index development

A macroinvertebrate predictive model was created in much the same way as the plankton model. The model was constructed only for sites in the West. The same 50 reference sites used in the plankton O/E model were examined for modeling suitability. Only 41 reference sites were used, though, due to low macroinvertebrate abundances (less than 200 individuals) at eight reference sites.

The macroinvertebrate O/E model was constructed by ODEQ—not the national assessment team. The results presented from the macroinvertebrate O/E model should be viewed as a preliminary exploration of the potential utility of macroinvertebrates to assess lake conditions in Oregon. A more thorough modeling of macroinvertebrates is planned for the national dataset and the models developed from that process will be preferred over this exploratory model.

Preliminary results

Macroinvertebrates were in good condition at 40% of the lakes surveyed in Oregon. Fair and poor conditions were each observed for 30% of the Oregon lakes (Table 6). Similar results were observed for all lakes across the West with 50% in good condition, 20% in fair condition, and 30% in poor condition.

Just as for plankton, natural lakes in Oregon showed better macroinvertebrate conditions than reservoirs (Table 6). Over half of natural lakes sampled in Oregon (53%) were in good condition, compared to 27% of Oregon reservoirs. Only 13% of sampled natural lakes were in poor condition, compared to almost half (47%) of reservoirs. Similar conditions were observed for natural lakes and reservoirs across the West.

Table 6. Macroinvertebrate conditions observed at Oregon lakes.

Macroinvertebrate Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	40%	30%	30%
Regional	Mountains (n=25)	44%	28%	28%
	Xeric (n=5)	20%	40%	40%
Lake Origin	Natural (n=15)	53%	33%	13%
	Reservoirs (n=15)	27%	27%	47%

Forty-four percent of Oregon—Mountains lakes were in good condition, while fair and poor conditions each were observed for 28% of surveyed lakes. One Oregon—Xeric lake was in good condition and two lakes each were in fair and poor condition. West—Mountains lakes showed a higher percentage in good condition and lower percentage in poor condition than was observed for West—Xeric lakes.

Although these are preliminary results they show the potential these study methods have for assessment of lake conditions in Oregon.

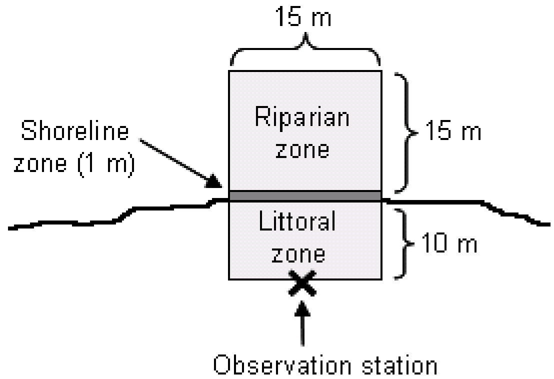
Ten separate 1 meter long sweeps were made through the dominant littoral substrate habitat and composited into one sample.

Physical Habitat Condition of Oregon's Lakes

Strawberry Lake (Grant Co.)

Physical Habitat Conditions

Habitat measurements and observations covered two distinct lake zones: the littoral and the riparian. The littoral zone was surveyed within plots with dimensions of 10 m perpendicular from the shore into the lake and 15 m wide. Within the littoral plot we recorded depth, visual estimates of substrate composition, visual estimates of aquatic macrophyte cover, and visual estimates of fish cover. The riparian plot extended 15 m perpendicular from the shoreline away from the lake and 15 m wide. Within the riparian plot we visually estimated cover within three vertical vegetation zones, visual estimates of shoreline substrate composition, and human influences.



Layout of physical habitat sampling zones. (Figure from USEPA 2007.)

Based on the observations in the littoral and riparian plots, four physical habitat indices were used to assess the condition of Oregon's lakes.

Index conditions and benchmarks

Shoreline human disturbance

The same benchmarks to determine good, fair, and poor condition classes were applied to all lakes in the NLA (Table 7). Lakes with shoreline human disturbance values ≤ 0.20 were classified as good. Shoreline human disturbance values from 0.21 to 0.75 were classified as fair. Poor conditions were assigned to any lake with shoreline human disturbance values greater than 0.75.

Riparian, Littoral, Littoral+Riparian

Reference sites were grouped together across the Xeric and Western Mountains sub-regions, due to both low sample sizes and high variability within sub-regions. Site-specific expected values (E) were determined by multiple linear regression models for each index. The model of the riparian vegetative cover index factored out elevation, latitude, and sub-region. The littoral cover index modeled elevation. The littoral+riparian index factored out differences in elevation, latitude, and sub-region.

The ratio of observed values for the habitat indices (O) to site-specific expected values (E) were used to establish reference benchmarks for determining condition classes (Table 7). Lakes with O/E values greater than the 25^{th} percentile of reference sites in the West were categorized as in good condition. O/E values between the 5^{th} and 25^{th} percentiles of reference scores were considered to be in fair condition. O/E values less than or equal to the 5^{th} percentile of reference O/E values were in poor condition.

Table 7. Reference benchmarks for assessing physical habitat condition.

Habitat - West	Good	Fair	Poor
Shoreline Human Disturbance	≤ 0.20	0.20 to ≤ 0.75	> 0.75
Riparian Vegetative Cover	> 0.86	0.86 to 0.57	< 0.57
Littoral Cover	> 0.59	0.59 to 0.27	< 0.27
Littoral Cover and Riparian Cover	> 0.86	0.86 to 0.58	< 0.58

Shoreline Human Disturbances

This index summarizes the extent and intensity of human activities within 15m from the wetted edge and 10 m into the near shore littoral zone (USEPA 2010). Extent was calculated as the proportion of habitat sampling stations with at least one type of human activity. Intensity calculations were means of weighted counts of agricultural and non-agricultural activities observed at each of the habitat sampling stations. Activities observed outside of the shoreline plots were given half the weight of activities observed closer to the lake.

Assessment of shoreline disturbance levels showed 20% of surveyed lakes in Oregon in good condition, 57% in fair condition, and 23% in poor condition (Table 8). The Oregon sites follow the distribution of the Region 10 population of lakes closely (Figure 7). However, Oregon and Region 10 lakes showed lower condition compared to the West population of lakes, which showed almost 50% of lakes in good condition.

Oregon's reservoirs showed higher levels of shoreline human disturbances than natural lakes. One-third of reservoirs in Oregon were in poor condition for shoreline disturbance and 67% were in fair condition (Table 8). Oregon's natural lakes showed 40% of sites in good condition, 47% in fair condition, and 13% in poor condition. West reservoirs also showed higher levels of disturbance compared to West natural lakes (Figure 7). Mann Lake, a natural lake in southeastern Oregon, showed the greatest shoreline human disturbance in the West.
Approximately 40% of the reservoirs in the West had shoreline disturbance levels below the lowest level observed in Oregon reservoirs.

Shoreline human disturbance at Lucky Reservoir was high.

One-quarter (24%) of Oregon-Mountains sites were in good condition, 60% were in fair condition, and 16% were in poor condition (Table 8). Of the five Xeric lakes in Oregon, two were in fair condition and three were in poor condition. Oregon-Mountains lakes showed a lower percent of sites in good condition, compared to West-Mountains lakes (Figure 7). Approximately 30% of West-Xeric lakes had shoreline human disturbance levels lower than observed at any of the five Oregon-Xeric lakes.

Table 8. Shoreline Human Disturbance conditions observed in Oregon lakes.

Shoreline Human Disturbances				
		Good	Fair	Poor
Statewide	Oregon (n=30)	20%	57%	23%
Ecoregion	Mountains (n=25)	24%	60%	16%
	Xeric (n=5)	-	40%	60%
Lake Origin	Natural (n=15)	40%	47%	13%
	Reservoirs (n=15)	-	67%	33%

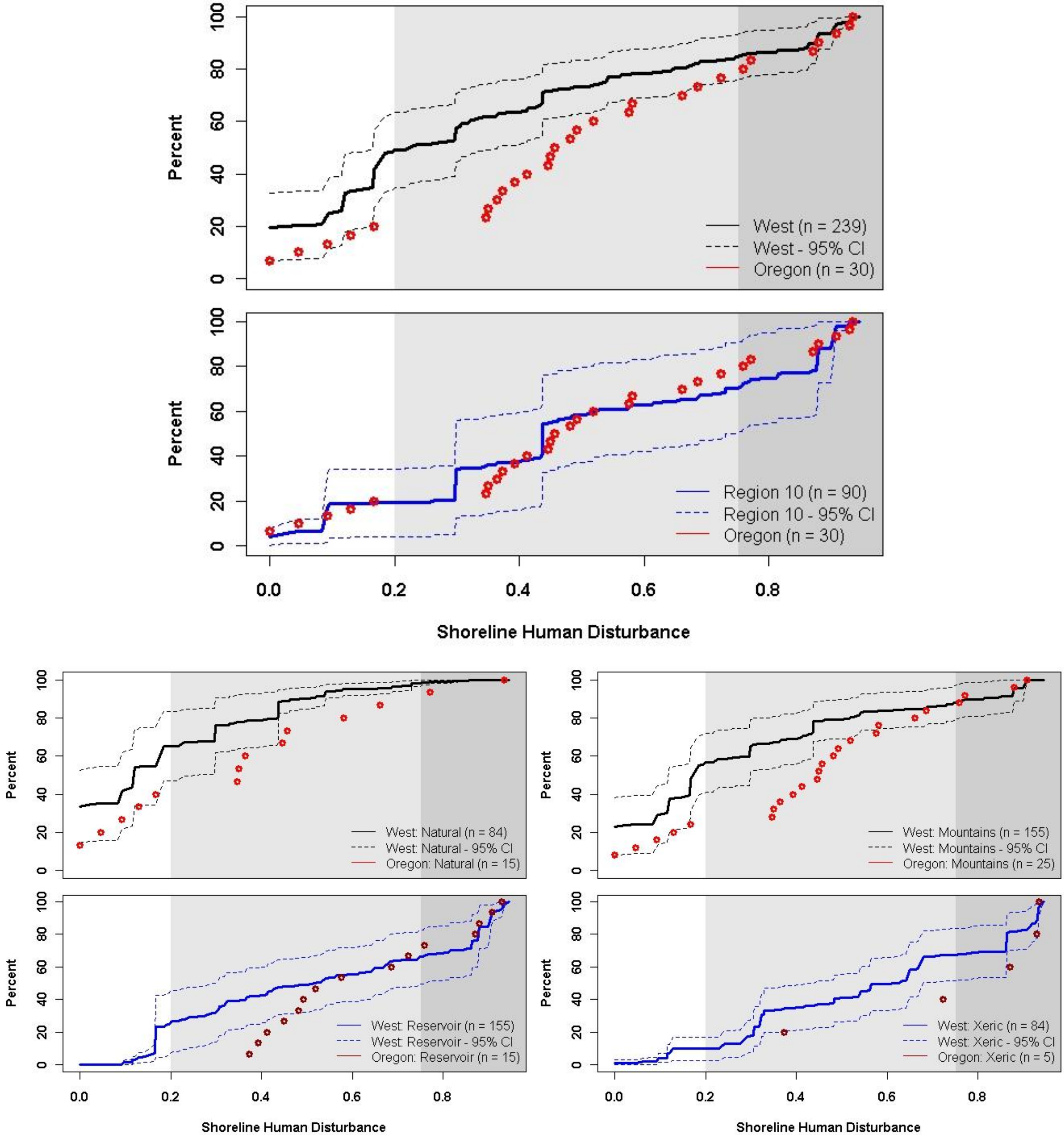


Figure 7. Cumulative distribution frequencies (CDFs) of shoreline human disturbance at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. Condition classes based on reference benchmarks show improving shoreline disturbance conditions from right to left (poor = dark grey, fair = light grey, good = white).

Riparian Vegetative Cover

This index summarizes the cover and structural complexity of vegetation within three separate layers (vertical heights) across the habitat sampling stations. Vegetation layers included ground cover (vertical height < 0.5 m), understory (0.5 – 5 m), and canopy (> 5 m). Visual estimates of aerial coverage in five percentage classes (0%, 1-10%, 10-40%, 40-75%, and > 75%) were made for different vegetation types (large diameter woody, small diameter woody, non-woody, inundated, and barren). Riparian vegetation structure and complexity determinations in the lakes assessment were quite similar to those made for streams and rivers surveys.

Three separate riparian cover indices were used in the NLA, one for each of the West, Plains and Lowlands, and Eastern Highlands regions (Figure 4). The riparian cover index summarizes the woody cover in the three height layers, presence of large diameter trees, inundated vegetation (under water), and bedrock and boulders. Boulders and bedrock were included to account for the natural potential for lakes to have relatively barren riparian areas (USEPA 2010).

Half (50%) of the surveyed lakes in Oregon showed riparian vegetative cover in poor condition (Table 9). Thirteen percent of Oregon sites were in fair condition and 37% were in good condition. There was a higher percent of Oregon sites in poor condition than was observed for the West and Region 10 populations (Figure 8).

Natural lakes in Oregon showed 60% of sites in good condition, compared to only 13% in good condition for reservoirs (Table 9). Twenty percent of Oregon natural lakes were in poor condition, compared to 80% of reservoir sites. Oregon natural lakes showed a slight trend towards lower riparian cover than West natural lakes (Figure 8). Oregon reservoir sites showed a much higher percent of lakes with lower riparian cover than expected, compared to the West reservoirs population. Mann Lake and Clear Lake (Wasco Co.) were among the lakes with the lowest riparian cover of any natural lakes in the West. Beulah Reservoir, Emigrant Lake, and Hills Creek Reservoir were among those with the lowest riparian cover of any reservoirs in the West.

Oregon-Mountains lakes showed a nearly even mix of good (44% of sites) and poor (40%) riparian conditions (Table 9). Sixteen percent of Oregon-Mountains sites were in fair condition for riparian vegetative cover. All five of the Oregon-Xeric sites were in poor riparian cover condition. Oregon-Mountains sites showed a higher percentage in poor condition than the West-Mountains population (Figure X). The five Oregon-Xeric sites fell within the bottom 40% of riparian cover values observed in the West-Xeric population.

Table 9. Riparian Vegetative Cover conditions observed in Oregon lakes,

Riparian Vegetative Cover Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	34%	13%	50%
Ecoregion	West (n=25)	44%	16%	40%
	Xeric (n=5)	-	-	100%
Lake Origin	Natural (n=15)	60%	20%	20%
	Reservoirs (n=15)	13%	7%	80%

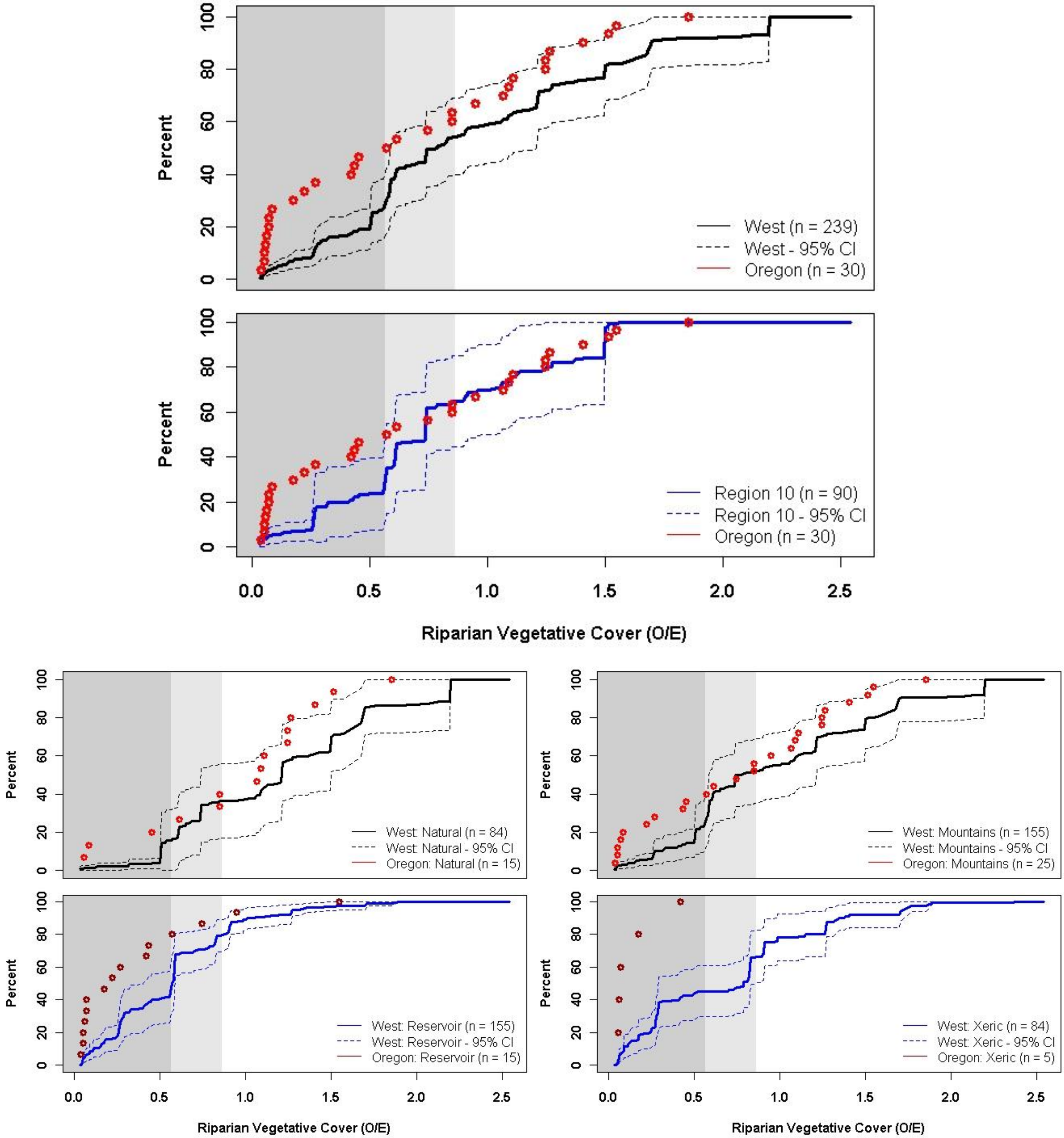


Figure 8. Cumulative distribution frequencies (CDFs) of riparian vegetative cover at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. "O/E" = observed to expected ratio. Condition classes based on reference benchmarks show improving riparian cover conditions from left to right (poor = dark grey, fair = light grey, good = white).

Littoral Cover

This index summarizes cover and complexity within the 15 x 10 m littoral plot at each habitat sampling station. Types of cover included woody snags, woody brush, inundated live-trees, inundated herbaceous vegetation (both aquatic and terrestrial), overhanging vegetation, rock ledges, boulders, human structures. Separately, estimates of cover from floating, emergent, and submerged macrophytes were made.

Three separate littoral cover indices were used in the NLA, one for each of the West, Plains and Lowlands, and Eastern Highlands regions (Figure 4). The index covering Oregon lakes (West region) included estimates of cover provided by woody snags, woody brush, boulders, rock ledges, inundated live trees, overhanging vegetation, plus emergent and floating macrophytes. Cover provided by submerged macrophytes was excluded (USEPA 2010).

The majority of sampled Oregon lakes showed good condition (53%) for littoral cover (Table 10). Just over one-quarter of sites (27%) were in fair condition and 20% of sites in Oregon had poor littoral cover condition. Lakes across Region 10 and the West showed slightly higher littoral conditions than observed at Oregon sites (Figure 9). Sixty-nine percent of Region 10 lakes were in good condition and 26% were in fair condition. Only 5% of Region 10 lakes were in poor condition.

As was observed for many other indicators, there was a discrepancy between littoral conditions in reservoirs and natural lakes. One-third (33%) of Oregon reservoir sites were in poor littoral condition, compared to only 7% of natural lakes (Table 10). About one-quarter of reservoirs were in good littoral condition, while the majority (80%) of natural lakes sampled in Oregon were in good condition. Reservoirs in the West showed a similar extent of lakes in poor condition (29%) as was observed for Oregon reservoirs (Figure 9). Natural lakes in the West were almost entirely in good condition (90%), with only 1% in poor condition.

A low percentage of sampled Oregon-Mountains lakes were in poor condition (12%) (Table 10). The majority of Oregon-Mountains lakes were in good condition (64%), with the remaining 24% in fair condition. Two Oregon-Xeric lakes were in fair condition, while three lakes were in poor condition. The population of West-Mountains lakes showed a higher extent of lakes in good condition (76%) and the same extent in poor condition (12%), compared to sampled sites in Oregon (Figure 9). Littoral condition in West-Xeric lakes was slightly lower than observed for West-Mountains lakes. Sixty-eight percent of West-Xeric lakes were in good condition, with 10% in fair and 20% in poor condition.

Table 10. Littoral Cover Condition observed in Oregon lakes.

Littoral Cover Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	53%	27%	20%
Ecoregion	Mountains (n=25)	64%	24%	12%
	Xeric (n=5)	-	40%	60%
Lake Origin	Natural (n=15)	80%	13%	7%
	Reservoirs (n=15)	20%	40%	33%

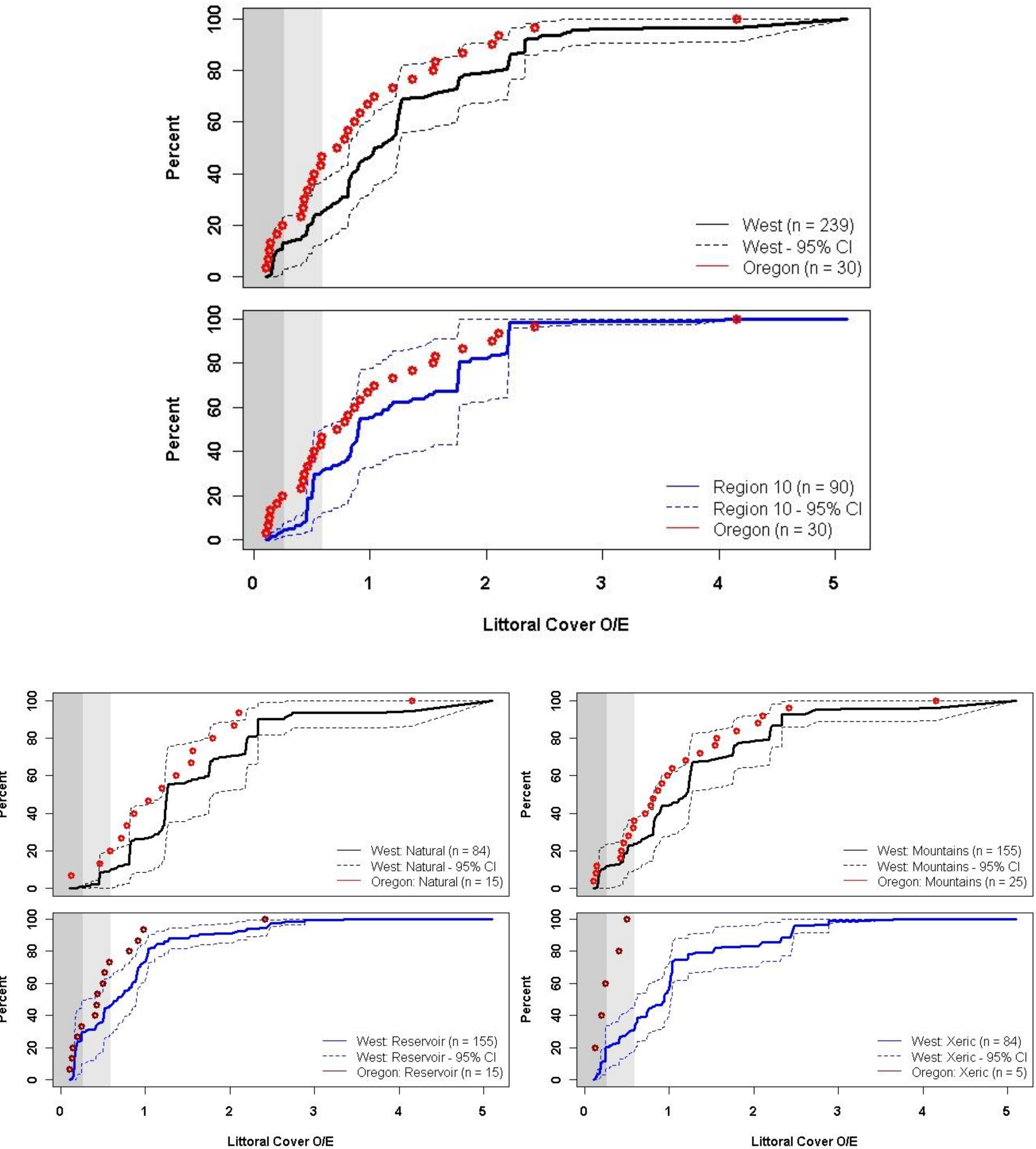


Figure 9. Cumulative distribution frequencies (CDFs) of littoral cover at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. "O/E" = observed to expected ratio. Condition classes based on reference benchmarks show improving littoral cover conditions from left to right (poor = dark grey, fair = light grey, good = white).

Littoral and Riparian Cover

The combined littoral and riparian cover index is simply the mean of the separate littoral and riparian indices.

Conditions in both the littoral and riparian zones were poor for nearly half (47%) of sampled Oregon lakes. Ten percent of Oregon lakes were in fair conditions, with only 43% in good condition (Table 10). The sampled Oregon lakes showed a higher percentage in poor condition compared to Region 10 and West populations (Figure 10).

The percent of lakes in good conditions was much higher for Oregon natural lakes (73%) than Oregon reservoirs (13%) (Table 11). Twenty percent of Oregon natural lakes were in poor condition, compared to 73% of Oregon reservoirs. Both Oregon natural and reservoir sites tended to fall to the left (lower cover) of corresponding West populations, with Oregon reservoirs showing the greater departure (Figure 10). Reservoirs across the West also showed a majority of lakes to be in poor condition (58%) with 20% in good condition. For natural lakes across the West, though, the majority were in good condition (75%), with 20% in poor condition.

Littoral cover included floating emergent macrophytes.

For Oregon-Mountains sites, 52% were in good condition. About one-third (36%) of Oregon-Mountains lakes were in poor condition (Table 11). All five Oregon-Xeric lakes sampled were in poor condition for riparian and littoral cover. The distribution of West-Mountains lakes matched the Oregon sites fairly closely (Figure 10). Half of West-Xeric lakes were in poor condition (51%), compared to 31% in good condition.

Table 11. Combined littoral and riparian cover conditions observed in Oregon lakes.

Littoral and Riparian Cover Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	43%	10%	47%
Ecoregion	Mountains (n=25)	52%	12%	36%
	Xeric (n=5)	-	-	100%
Lake Origin	Natural (n=15)	73%	7%	20%
	Reservoirs (n=15)	13%	13%	74%

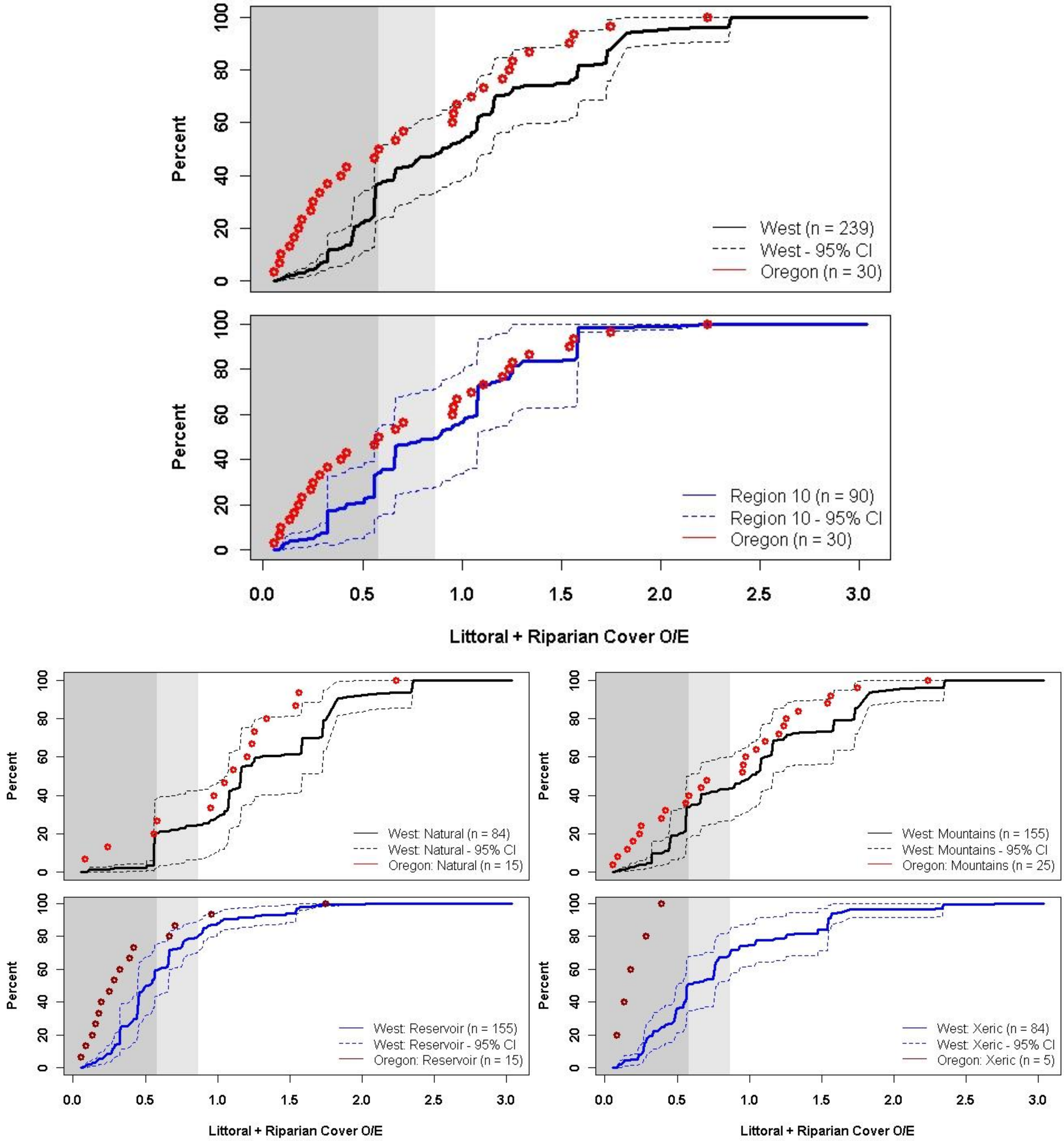
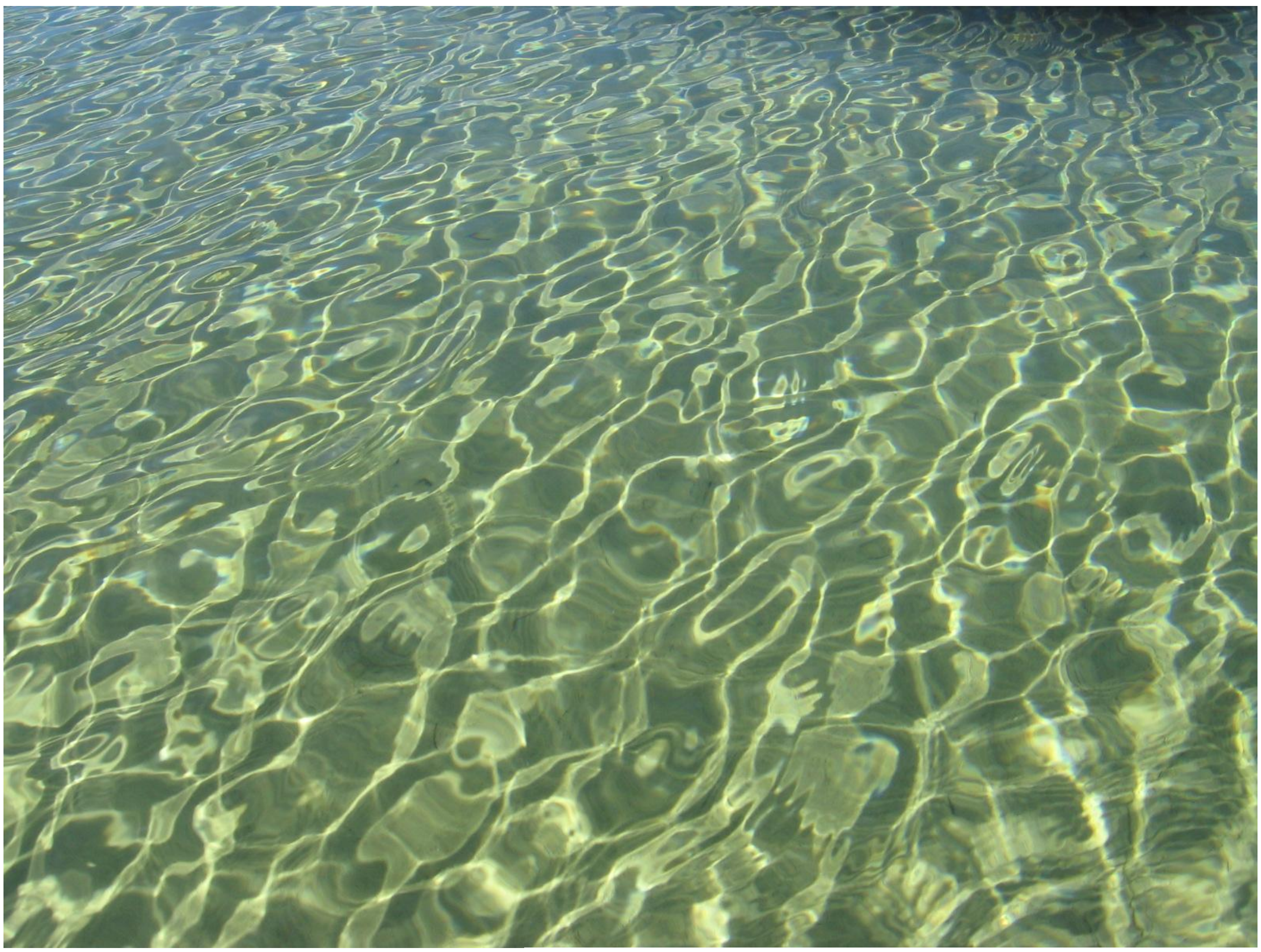


Figure 10. Cumulative distribution frequencies (CDFs) of littoral and riparian cover at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. "O/E" = observed to expected ratio. Condition classes based on reference benchmarks show improving littoral and riparian cover conditions from left to right (poor = dark grey, fair = light grey, good = white).

Water Quality Condition of Oregon's Lakes

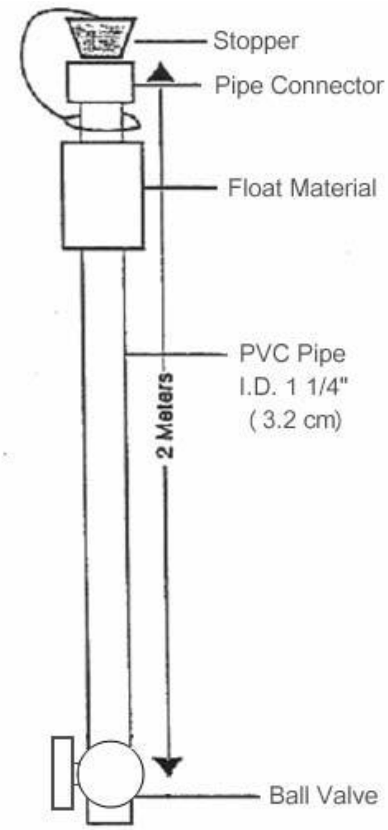


Hosmer Lake (Deschutes Co.)

Water Quality Conditions

At the index site, or deepest point of the lake, chemistry samples were collected from an integrated sample of the top two meters of lake water. Two liters were collected for chlorophyll-a samples and four liters were collected for chemical analyses. The chemical parameters measured included physical variables (pH, color, conductivity, turbidity), nutrients (total nitrogen, total phosphorus, chlorophyll-a), ions (ammonia, nitrate, chloride, sulfate, magnesium, potassium, etc.), and organic carbon content. Results from water chemistry samples were used to assess lake condition for individual parameters, determine trophic status (nutrients, chl-a, Secchi depth), and used to establish screening criteria for reference lakes.

Additionally, water chemistry profiles for dissolved oxygen, temperature, pH, and conductivity were collected at each lake. While not discussed in this report, water profiles are shown for individual lakes in a separate document with results presented on a lake-by-lake basis (Merrick 2010). Additionally, profile information can be downloaded from the National Lakes Survey webpage: http://www.epa.gov/owow/lakes/lakessurvey/web_data.html



The integrated sampler used to collect water samples in the NLA. (Figure from USEPA 2007.)

Reference condition benchmarks for water quality parameters were established separately for the Western Mountains and Xeric ecoregions (Table 12).

Table 12. Reference benchmarks for water quality parameters were developed independently from reference sites in the Western Mountains and Xeric ecoregions.

Water Quality – Western Mountains	Good	Fair	Poor
Total Nitrogen (mg/L)	≤ 0.278	> 0.278 to 0.380	> 0.380
Total Phosphorus (mg/L)	≤ 0.015	> 0.015 to 0.019	> 0.019
Chlorophyll-a (ug/L)	≤ 1.81	> 1.81 to 2.74	> 2.74
Turbidity (NTU)	≤ 1.44	> 1.44 to 5.47	> 5.47

Water Quality – Xeric	Good	Fair	Poor
Total Nitrogen (mg/L)	≤ 0.514	> 0.514 to 2.286	> 2.289
Total Phosphorus (mg/L)	≤ 0.048	> 0.048 to 0.130	> 0.130
Chlorophyll-a (ug/L)	≤ 7.79	> 7.79 to 29.5	> 29.5
Turbidity (NTU)	≤ 3.69	> 3.69 to 24.9	> 24.9

Nutrient Condition

Total Nitrogen

More than half of the lakes sampled in Oregon (57%) were in good condition for nitrogen levels. Most of the remaining lakes were in poor condition (30%), with of the fewest lakes (13%) in fair condition (Table 13). Region 10 lakes showed a similar but less dramatic pattern, with 49% of lakes in good condition and 41% in poor condition. There was a slight tendency for Oregon lakes to show a higher percent of sites in lower nitrogen concentrations (up to about 350 ug/L) compared to the percent of lakes across the West and Region 10 (Figure 11).

Natural lakes and reservoirs in Oregon differed in their nitrogen conditions. Most of the natural lakes sampled (73%) were in good condition and a low percentage (20%) of natural lakes were in poor condition. Oregon reservoirs showed 40% (n =6) in good nitrogen conditions and 40% in poor nitrogen conditions (Table 13). Similar patterns were observed across the West, where reservoirs showed a higher percent of lakes in poor condition (41%) compared to natural lakes (26%). The population of natural lakes in the West and in Oregon tended towards lower nitrogen levels (Figure 11).

Nitrogen levels for Oregon-Mountains lakes showed a similar pattern to that observed for all of Oregon lakes, with 68% (n =17) in good condition and 32% (n =8) in poor condition. Four of the Oregon-Xeric lakes were in fair condition and one lake was in poor condition (Table 13). Oregon-Mountains sites showed a slight tendency toward lower nitrogen concentrations, up to approximately 400 ug/L. Nitrogen concentrations in Oregon-Xeric sites fell into the upper 30% of the distribution of West-Xeric sites.

Table 13. Total nitrogen conditions observed at Oregon lakes.

Nitrogen Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	57%	13%	30%
Ecoregion	Mountains (n=25)	68%	-	32%
	Xeric (n=5)	-	80%	20%
Lake Origin	Natural (n=15)	73%	7%	20%
	Reservoirs (n=15)	40%	20%	40%

Total Phosphorus

Half of the Oregon sites (50%) exceeded reference benchmarks and were designated in poor condition for phosphorus. Almost all other lakes in Oregon were in good phosphorus condition (47%), with only 3% in fair condition (Table 14). In contrast, at the Region 10 scale, the majority of lakes were in good condition (57%) and a little more than one-third of lakes were in poor condition (39%). The distribution of phosphorus concentrations at Oregon sites was similar to both West and Region 10 lake populations (Figure 12). At concentrations above approximately 30 ug/L, Oregon sites showed a slight tendency towards higher total phosphorus compared to West lakes.

Two-thirds of sampled reservoirs in Oregon were in poor phosphorus condition (n = 10), with 27% (n = 4) in good condition. The opposite was true of natural lakes sampled in Oregon, where 67% (n = 10) were in good condition and 33% (n = 5) were in poor condition for phosphorus (Table 14). The trend across the West was similar, although less dramatic, with reservoirs showing 33% in good condition and 51% in poor condition. Natural lakes across the West had 70% in good condition and 18% in poor condition. The distributions of natural lakes show a shift to the left, or lower phosphorus levels (Figure 12). The majority of natural lakes had total phosphorus concentrations below 10 ug/L, while approximately 20% of reservoirs showed similar concentrations. Compared to natural lakes in the West, Oregon natural lakes showed slightly lower phosphorus levels up to approximately 5-7 ug/L. Oregon natural lake and reservoir sites showed a small divergence from the West populations at approximately 30-40 ug/L, with a tendency toward slightly higher phosphorus levels.

Most Oregon-Mountains sites were in good phosphorus condition (56%, n = 14), with 40% of sites (n = 10) in poor condition. All five of the Oregon-Xeric lakes sampled were in poor condition (Table 14). The distribution of Oregon-Mountains sites followed the distribution of the West-Mountains population closely (Figure 12). Just as for nitrogen, phosphorus concentrations at Oregon-Xeric sites fell into the upper 30% of concentrations observed among West-Xeric lakes.

Table 14. Total phosphorus conditions observed at Oregon lakes.

Phosphorus Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	47%	3%	50%
Ecoregion	Mountains (n=25)	56%	4%	40%
	Xeric (n=5)	-	-	100%
Lake Origin	Natural (n=15)	67%	-	33%
	Reservoirs(n=15)	27%	6%	67%

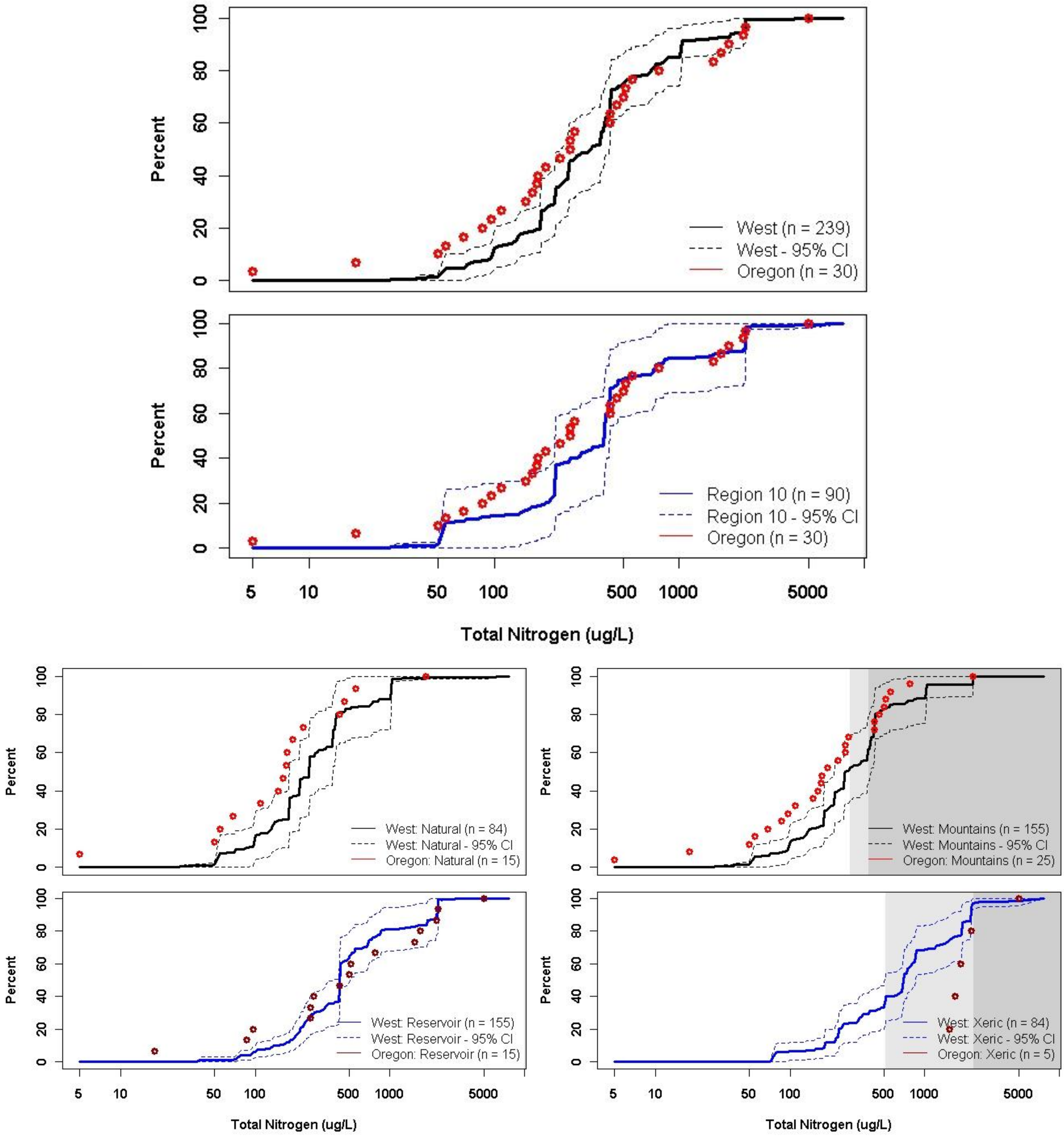


Figure 11. Cumulative distribution frequencies (CDFs) of total nitrogen at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. Because water quality benchmarks were developed separately for each ecoregion, condition classes are only shown in the bottom right panel. Condition classes based on reference benchmarks show improving total nitrogen conditions from right to left (poor = dark grey, fair = light grey, good = white).

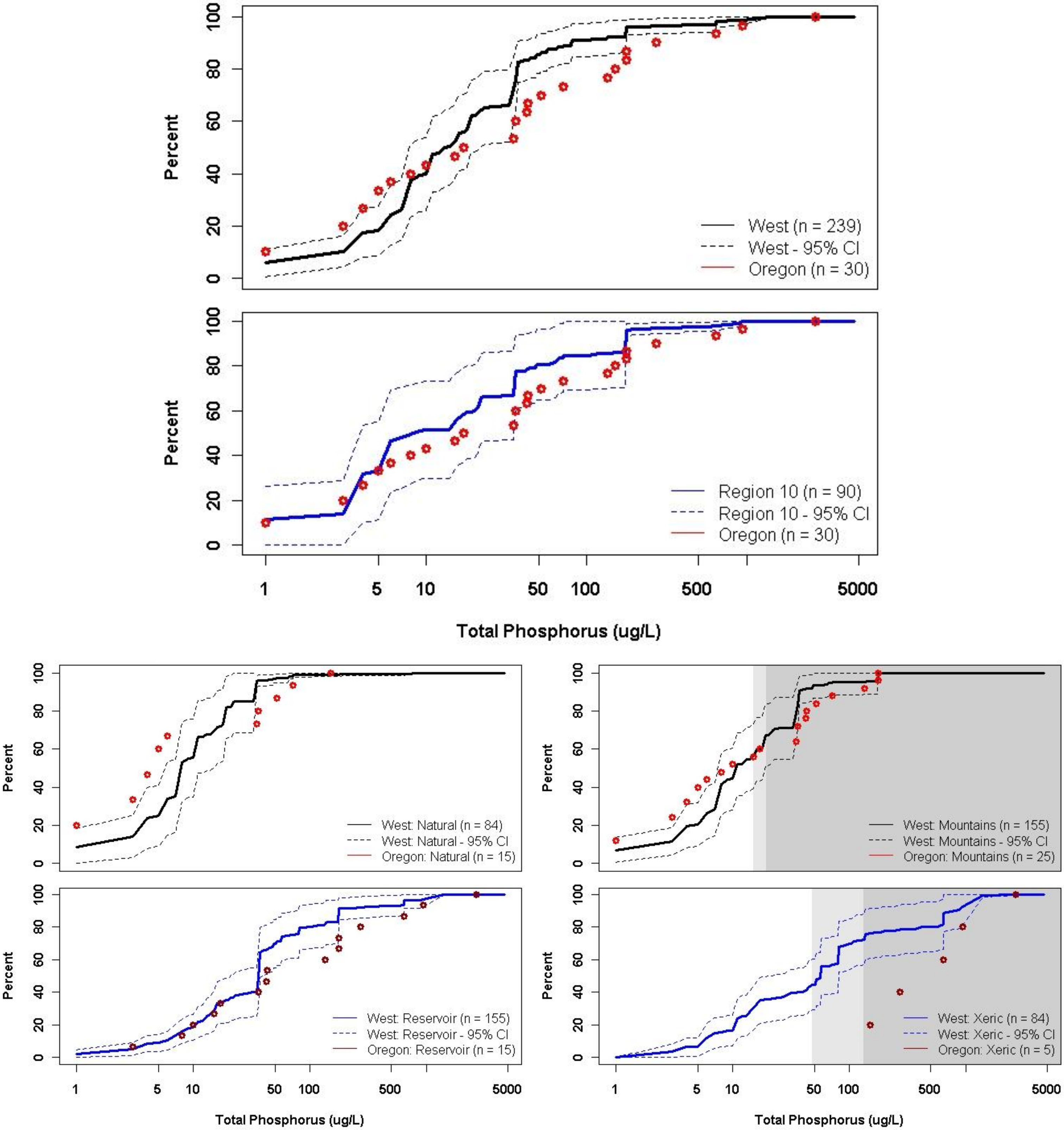


Figure 12. Cumulative distribution frequencies (CDFs) of total phosphorus at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. Because water quality benchmarks were developed separately for each ecoregion, condition classes are only shown in the bottom right panel. Condition classes based on reference benchmarks show improving total phosphorus conditions from right to left (poor = dark grey, fair = light grey, good = white).

Chlorophyll-a

Comparisons of chlorophyll-a (chl-a) to levels observed at reference sites showed 63% (n = 19) of Oregon's sampled lakes in good condition and 30% (n = 9) in poor condition (Table 15). A similar extent of Region 10 lakes was in poor condition (31%), but the extent in good condition (53%) was less than observed across Oregon lakes. The distribution of chl-a observed at Oregon sites was very similar to the distributions of West and Region 10 lakes populations (Figure 13). In Oregon lakes, the percentage of sites with chlorophyll-a concentrations less than 2 ug/L was slightly higher than the percent of lakes observed for the West and Region 10 populations.

Natural lakes and reservoirs showed differing chlorophyll-a quality. Most of the natural lakes sampled in Oregon were in good condition (80%, n = 12), with 13% (n =2) in poor condition. Reservoirs, however, showed equivalent good (46%, n = 7) and poor (46%) chlorophyll-a conditions (Table 15). Across the West, natural lakes (59% good, 21% poor) also displayed higher chlorophyll-a quality than reservoirs (35% good, 51% poor). CDF plots show Oregon's natural lakes and reservoirs with slightly left-shifted distributions, indicating slightly lower chl-a levels across the range of conditions (Figure 13).

Chlorophyll conditions for Oregon-Mountains lakes showed 68% (n = 17) in good condition and 32% (n = 8) in poor condition. Two Oregon-Xeric lakes were in good condition, two were in fair condition, and one site was in poor condition (Table 15). The distribution of Oregon-Mountains sites was similar to the West-Mountains population of lakes. Chl-a concentrations in Oregon-Xeric sites fell along most of the range of the distribution of West-Xeric lakes.

Table 15. Chlorophyll-a conditions observed at Oregon lakes.

Chlorophyll-a Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	63%	7%	30%
Ecoregion	Mountains (n=25)	68%	-	32%
	Xeric (n=5)	40%	40%	20%
Lake Origin	Natural (n=15)	80%	7%	13%
	Reservoirs (n=15)	47%	6%	47%

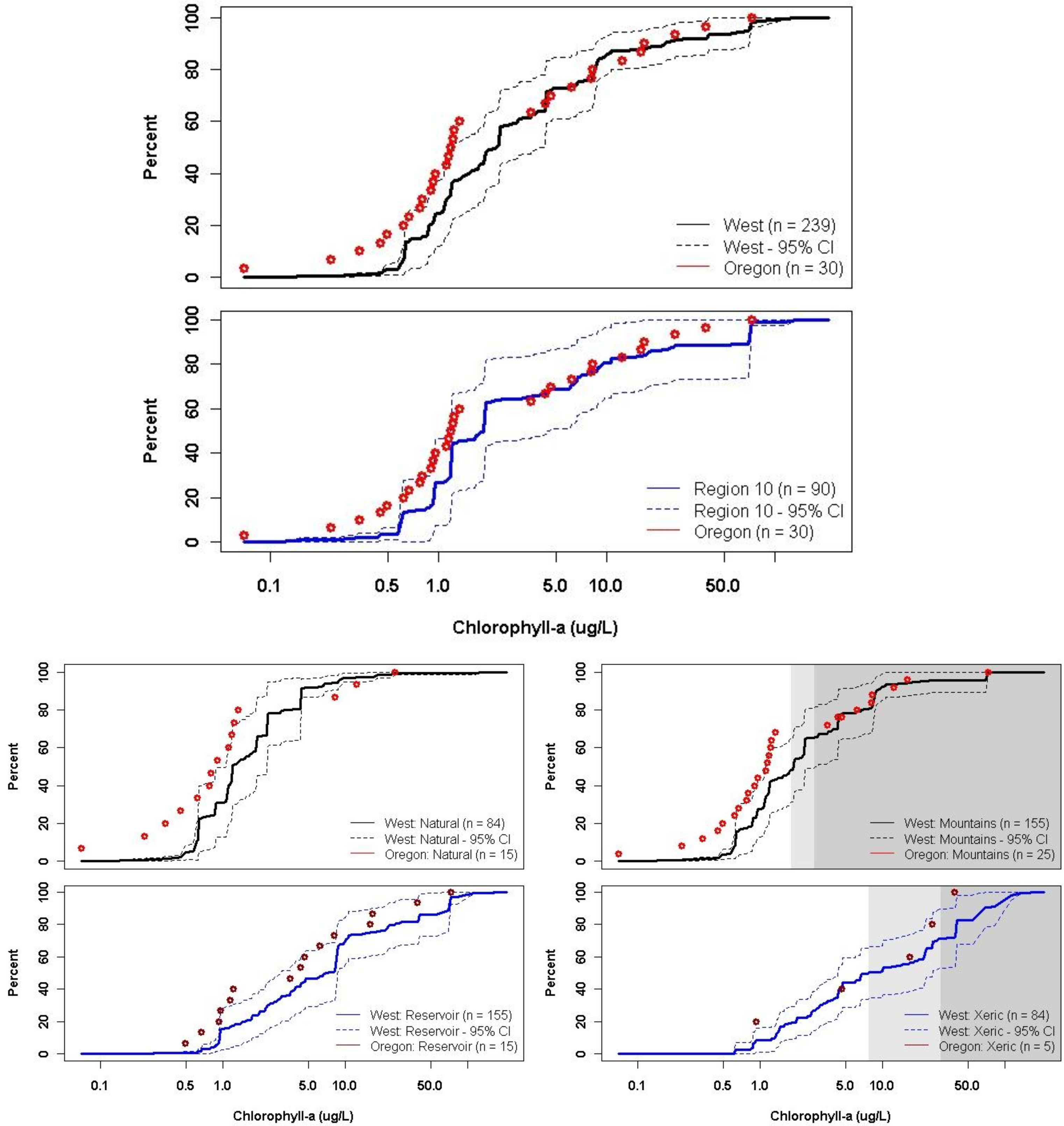


Figure 13. Cumulative distribution frequencies (CDFs) of chlorophyll-a at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. Because water quality benchmarks were developed separately for each ecoregion, condition classes are only shown in the bottom right panel. Condition classes based on reference benchmarks show improving chlorophyll-a conditions from right to left (poor = dark grey, fair = light grey, good = white).

Chemistry

Turbidity

Nearly half (47%) of sampled lakes in Oregon were in good condition for turbidity. Thirty percent of sampled lakes in Oregon showed poor turbidity conditions (Table 16). The Oregon sites fell closely along the West and Region 10 population distributions up to approximately 2 NTU (Figure 14). Above 2 NTU, Oregon sites tended to shift more to the right, suggesting higher turbidities. Several Oregon lakes showed among the highest turbidities observed in the West and nationally. Piute Reservoir had the fourth highest turbidity (152 NTU) in the West and Junipers Reservoir had the third highest turbidity (194 NTU) in the West. Lucky Reservoir had the highest turbidity in the country (574 NTU), 145 NTU higher than any other lake in the West. Field observations noted high cattle use and minimal riparian cover at each of these Oregon lakes.

Poor turbidity conditions in Oregon were more frequently associated with reservoirs (53%) than natural lakes (7%) (Table 16). Twenty percent of reservoirs were in good condition, compared to 73% of sampled natural lakes in Oregon. A similar pattern was observed for natural lakes compared to reservoirs across the West (Figure 14). Approximately 90% of natural lakes in the West had turbidities of 3 or less, while only about half of West reservoirs had turbidities as low. Mann Lake, located in southeastern Oregon, had the third highest turbidity (36 NTU) of any natural lake in the West.

Over half (56%) of the Oregon-Mountains lakes showed good condition for turbidity. Almost one-quarter (24%) were in fair condition and 20% were in poor condition (Table 16). Four of five Oregon-Xeric sites were in poor condition for turbidity.

Table 16. Turbidity conditions observed at Oregon lakes.

Turbidity Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	47%	23%	30%
Ecoregion	Mountains (n=25)	56%	24%	20%
	Xeric (n=5)	-	20%	80%
Lake Origin	Natural (n=15)	73%	20%	7%
	Reservoirs (n=15)	20%	27%	53%

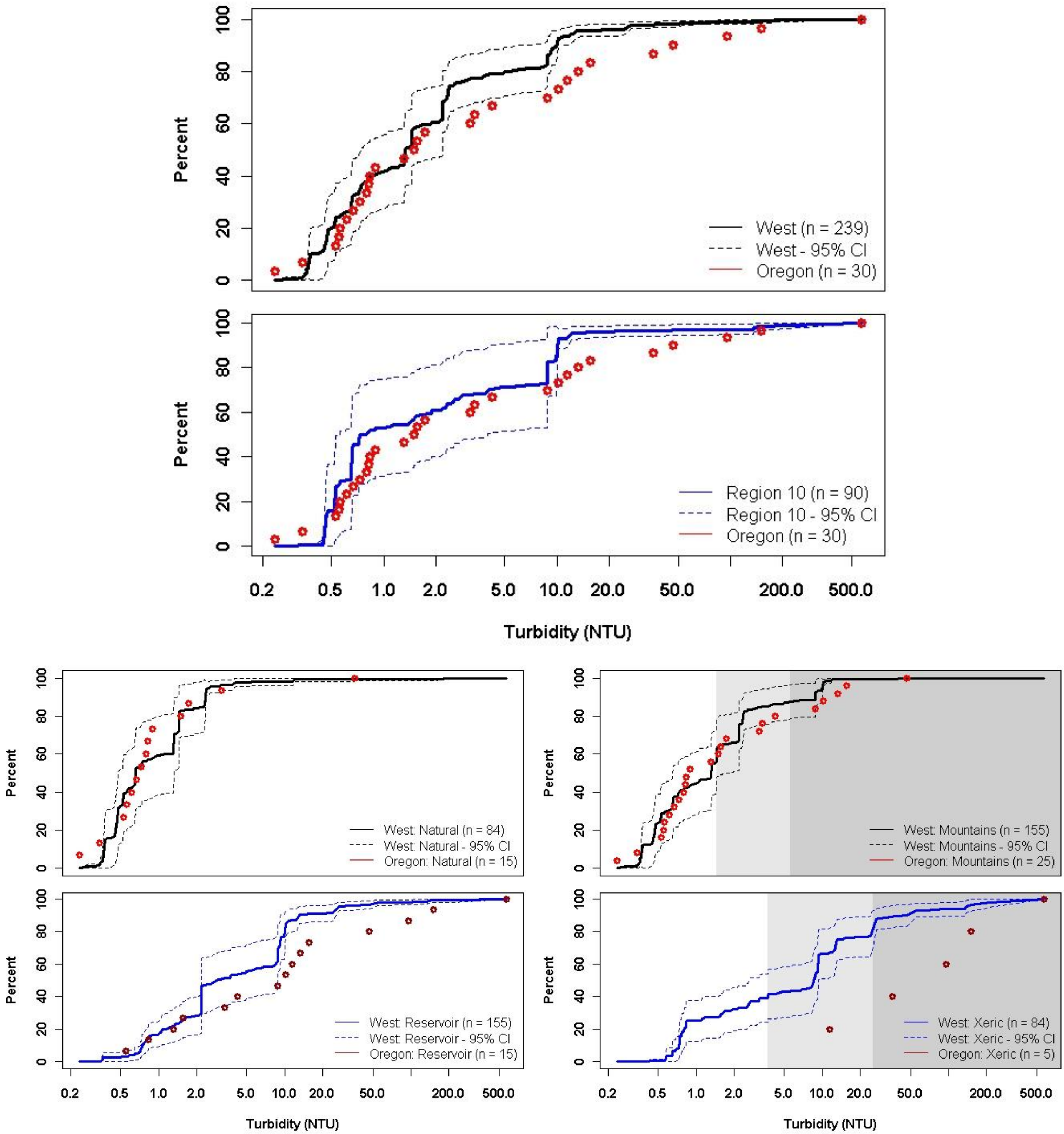


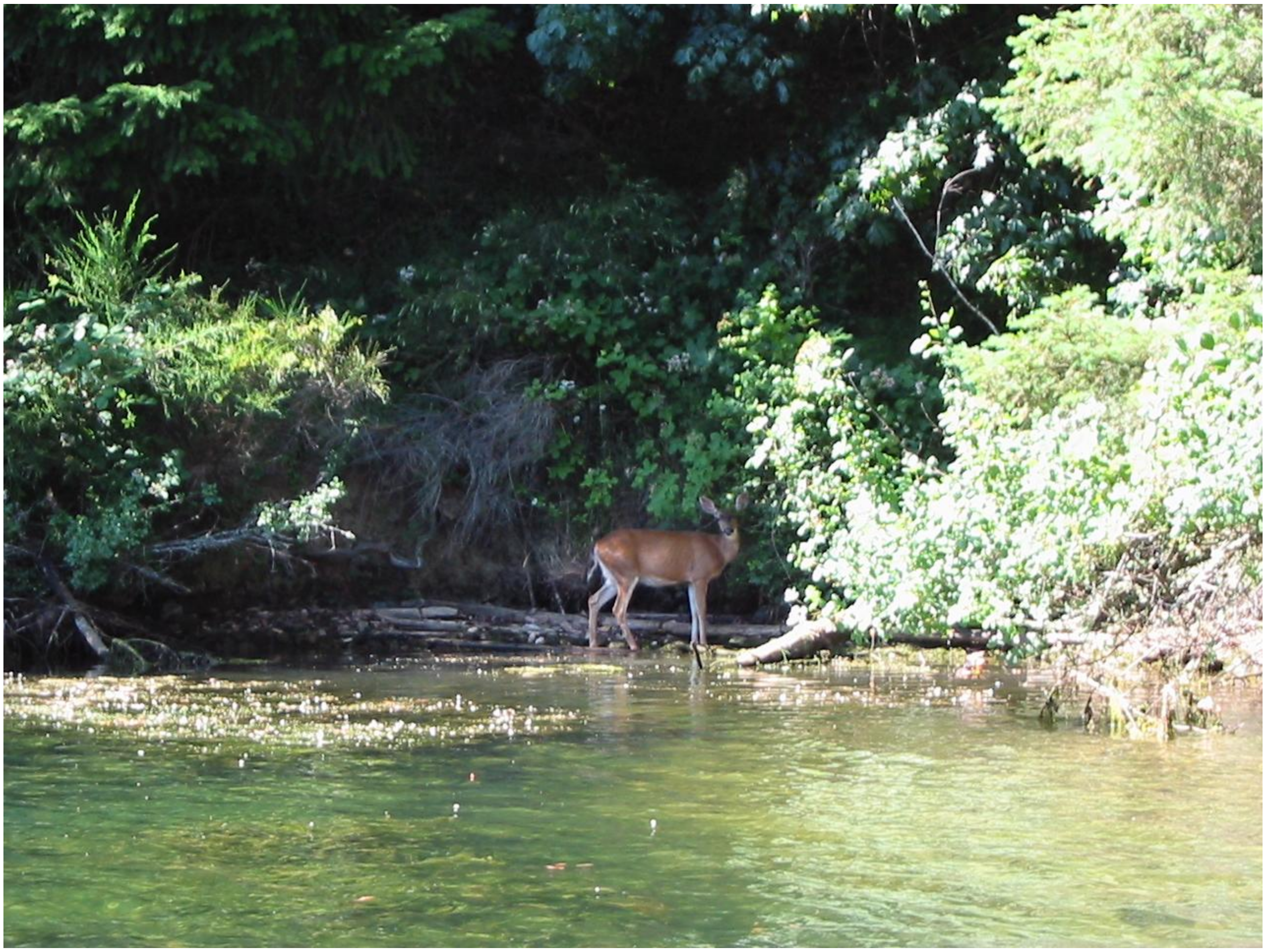
Figure 14. Cumulative distribution frequencies (CDFs) of turbidity at various geographic (top panel), origin (bottom left panel), and ecoregion (bottom right panel) scales. Because water quality benchmarks were developed separately for each ecoregion, condition classes are only shown in the bottom right panel. Condition classes based on reference benchmarks show improving turbidity conditions from right to left (poor = dark grey, fair = light grey, good = white).

Dissolved Oxygen

Nearly all of Oregon's lakes were in good condition (97%) for dissolved oxygen (D.O.) concentrations in the top two meters. One site, Baca Lake, in Oregon was in fair condition for D.O., representing 3% of surveyed Oregon lakes (Table 17). Baca Lake was a reservoir and located in the Xeric ecoregion and was very shallow, less than one meter in most locations. Across the West, only one lake (out of 239) showed poor D.O. conditions. This one lake was located in the Mountains ecoregion in Washington, representing 2% of Region 10 lakes.

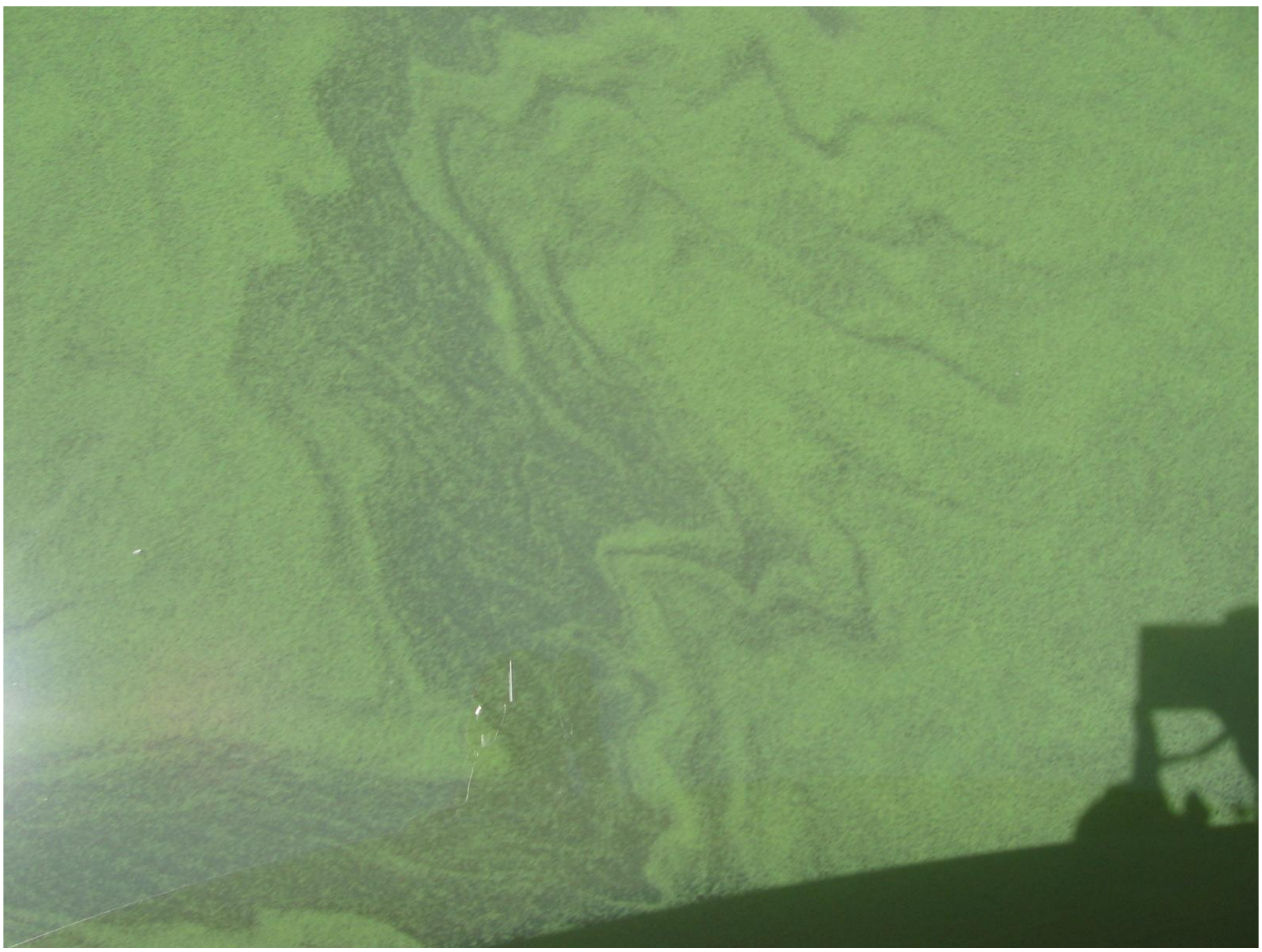
Table 17. Dissolved oxygen conditions observed at Oregon lakes.

Dissolved Oxygen Condition				
		Good	Fair	Poor
Statewide	Oregon (n=30)	97%	3%	-
Ecoregion	Mountains (n=25)	100%	-	-
	Xeric (n=5)	80%	20%	-
Lake Origin	Natural (n=15)	100%	-	-
	Reservoirs (n=15)	80%	20%	-



Cooper Creek Reservoir (Douglas Co.)

Trophic State of Oregon's Lakes



Algal bloom at Beulah Reservoir (Malheur Co.)

Trophic State

Trophic state is a measure of a lake's algal biomass, or primary productivity potential. Several water quality parameters can be used to estimate trophic state. The trophic state of lakes was determined separately for each of four parameters; total nitrogen, total phosphorus, chlorophyll-a, and depth of the photic zone measured by Secchi disk. The thresholds used to define trophic status, based on values from the literature, were used nationwide (USEPA 2010).

Nitrogen

Assessments of nitrogen concentrations in sampled Oregon lakes showed 57% to be oligotrophic, 20% mesotrophic, 3% eutrophic, and 20% hypereutrophic (Table 18). Oregon showed a higher percentage of sites in oligotrophic state than the West (46%) and Region 10 (45%) lake populations.

Nitrogen trophic states were different between Oregon's reservoirs and natural lakes. Natural lakes in Oregon were almost entirely oligotrophic (73%) or mesotrophic (20%). One natural lake was hypereutrophic (7% of natural lake sites). Reservoirs showed 40% of sites in oligotrophic state, with 20% in mesotrophic state. One reservoir was eutrophic (7%) and five were hypereutrophic (33%) (Table 18). Nearly two-thirds (63%) of natural lakes in the West were oligotrophic, compared to 35% of reservoirs across the West.

For Oregon-Mountains lakes, 68% of sites were oligotrophic and 24% were mesotrophic. One site (4%) was classified as eutrophic and one site was deemed hypereutrophic (4%). All five of Oregon's Xeric lakes were considered hypereutrophic (Table 18). West-Mountains lakes (55%) were more oligotrophic than West-Xeric lakes (29%).

Phosphorus

For all of the lakes sampled in Oregon, 43% of sites showed an oligotrophic phosphorus state. Six percent were mesotrophic, 23% were eutrophic, and 27% were hypereutrophic (Table 18). Half of Region 10 lakes (51%) Were oligotrophic, compared to 35% of West lakes.

Oregon's reservoirs showed higher phosphorus trophic states than natural lakes. Nearly half of Oregon's reservoirs (47% of sites) were hypereutrophic and another 20% were considered eutrophic. Twenty percent were oligotrophic and 13% were mesotrophic. Natural lakes in Oregon showed an opposite pattern, with 67% oligotrophic, 26% eutrophic, and only 7% hypereutrophic (Table 18). Across the West, 61% of reservoirs were eutrophic or hypereutrophic, similar to the 67% of sites in Oregon. A little more than half of Western natural lakes were considered oligotrophic (55%) and another 30% were mesotrophic, while for Oregon 67% were oligotrophic and none were mesotrophic.

About half of Oregon-Mountains lakes (52%) were oligotrophic, 8% were mesotrophic, 28% were eutrophic, and 12% were hypereutrophic, based on phosphorus levels. All five Oregon-Xeric lakes were considered hypereutrophic (Table 18). Over two-thirds (36%) of West-Xeric lakes were either oligotrophic or mesotrophic. West-Mountains lakes were 44% oligotrophic and 26% mesotrophic.

Chl-a

The third method by which trophic state was assessed was by using chlorophyll-a concentrations. Sixty percent of Oregon lakes sampled were considered oligotrophic for chlorophyll-a and 13%

were mesotrophic. Eutrophic chlorophyll-a conditions were observed at 20% of sampled lakes, while hypereutrophic state was observed at 7% of sites (Table 18). Sixty percent of West lakes and 74% of Region 10 lakes were either oligotrophic or mesotrophic.

Just as for nitrogen and phosphorus, chlorophyll-a derived trophic status showed large differences between natural lakes and reservoirs. Oregon reservoirs showed 40% of sites to be oligotrophic, 27% of sites to be mesotrophic, 20% eutrophic, and 13% hypereutrophic (Table 18). Natural lakes, on the other hand, were mostly oligotrophic (80% of sites), with the remainder eutrophic (20%). Reservoirs across the West were more evenly split among the various trophic states (oligotrophic = 26%, mesotrophic = 24%, eutrophic = 32%, and hypereutrophic = 19%). Chlorophyll-a concentrations in natural lakes across the West resulted primarily in oligotrophic (66%) and mesotrophic (28%) states.

Two-thirds (68%) of Oregon-Mountains lakes surveyed were considered oligotrophic, 12% were mesotrophic, 16% of sites were eutrophic, and 4% were hypereutrophic (Table 18). West-Mountains lakes were most often oligotrophic (54%), with 26% mesotrophic, 16% eutrophic, and 4% hypereutrophic. Percentages of Xeric lakes across the West were nearly evenly split among the four trophic states for chlorophyll-a (22% - 29%), as were the five Oregon-Xeric sites.

Secchi transparency

Transparency, measured by Secchi disk, was the fourth method for assessing lake trophic state. Across Oregon, 40% of surveyed lakes were considered oligotrophic, 7% were mesotrophic, 23% were eutrophic, and 17% were hypereutrophic. Thirteen percent of Oregon lakes were not assessed for trophic state with Secchi disk because they were either clear to the bottom or the data was not collected (Table 18). Half (50%) of the West and Region 10 lake populations were in oligotrophic state,, One-quarter (25%) of lakes across the West and 29% of Region 10 lakes were eutrophic or hypereutrophic. Waldo Lake, at 36.7 m, had the highest Secchi depth of any lake surveyed in the entire nation. Big Lake, with a Secchi depth of 15.1 m, was the second highest of any lake in the West.

Just as observed with other variables, secchi trophic state suggests large differences between natural lakes and reservoirs. Twenty percent of reservoirs sampled in Oregon were considered oligotrophic, compared to 60% of natural lakes (Table 18). Two-thirds of reservoirs in Oregon had shallow secchi depths, with designations of eutrophic and hypereutrophic. In contrast, only 13% of natural Oregon lakes sampled were eutrophic or hypereutrophic. Secchi trophic state was not assessed for four (27%) natural lakes in Oregon. The distributions of natural lakes and reservoirs show the same patterns for West lakes. Several Oregon lakes had high secchi depths. Smith Reservoir (upper McKenzie River basin) had the second highest secchi depth (12.5 m) of any reservoir in the West.

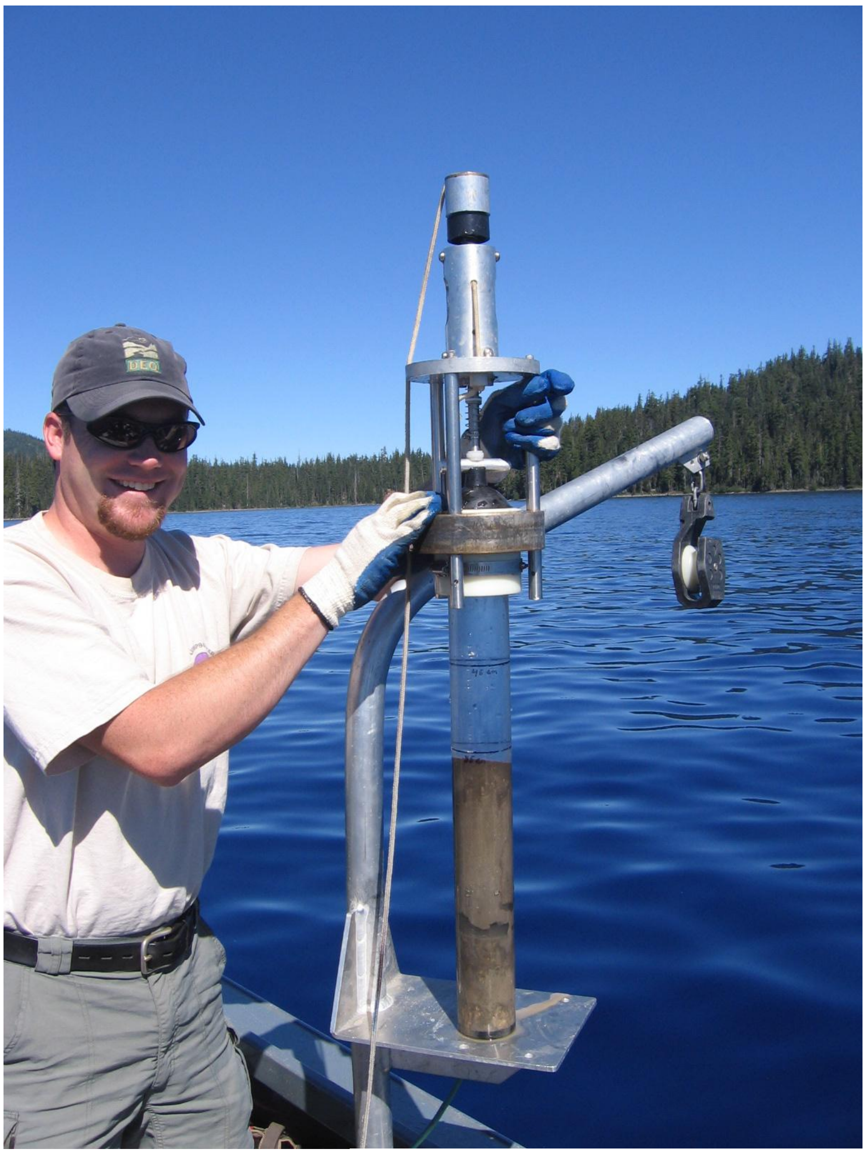
Oregon-Mountains showed 48% of sites in oligotrophic state for secchi, with 8% mesotrophic, 24% eutrophic, and 4% hypereutrophic. Sixteen percent (n = 4) of Oregon-Mountains lakes were not assessed (Table 18). One Oregon-Xeric site was eutrophic and four sites were hypereutrophic for secchi depth. The Oregon lakes mentioned above with some of the highest secchi depths in the West were from the Mountains ecoregion.

Table 18. Trophic status for Oregon lakes as determined by four water quality parameters.

Trophic Status by Indicator				
	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Nitrogen (n=30)	57%	20%	3%	20%
Total Phosphorus (n=30)	43%	7%	23%	27%
Chlorophyll-a (n=30)	60%	13%	20%	7%
Secchi transparency (n=30)	40%	7%	23%	17%

Waldo Lake (Lane Co.) had the highest Secchi depth of any lake in the nation.

Inferring past nutrient conditions



Waldo Lake (Lane Co.)

Inferring Past Conditions

Sediment diatoms were sampled from the index site at each lake. A modified KB corer was used to collect sediments, with a target depth of 35 - 45 cm. Once brought to the surface, the top 1 cm section of the core was collected. Then all but the bottom 3 cm of the core was discarded. A final 1 cm slice of the core was collected and placed into a separate sample container from the surface sediments. The bottom 2 cm of the core was discarded. Diatoms from the surface section of the core were used to develop an index of biological integrity. Due to a lack of information on index development, we have chosen not to report on lake conditions in Oregon using the diatom assemblage. Diatoms from both the surface and bottom core slices were used in the development of inference models.

Inference model development

Sediment diatom data were also used to assess current and past lake conditions for total nitrogen and total phosphorus. This technique has been employed in paleolimnological studies across the world since the 1980s (Christie and Smol 1993, Ter Brakk and Juggins 1993, Birks 1998). The general ecological concept is that any given diatom will show maximum abundances in lakes with environmental conditions close to its optimal conditions. Diatoms collected from the top 1 cm of the sediment core were used to calculate optimal environmental conditions for each taxon. The optimum nutrient conditions for each plankton taxon were identified as those nutrient concentrations were the taxon achieved maximum abundances.

Retrieving a sediment core from Hosmer Lake (Deschutes Co.)

Once the optimal conditions for surface diatoms are known, the diatoms observed in the bottom of the core can be used to “reconstruct” what past conditions in any given lake were like. In brief, the inferred past environmental conditions in the lake will be closest to the optima of the most abundant diatom taxa in the bottom sediments. Specifics about the development of the diatom inference models can be found in the NLA Technical Appendix (USEPA 2010).

Sediment cores were not dated, so we do not know how far back in time each core goes. at each lake, bottoms of cores were presumed to be representative of pre-European conditions if they were long enough and/or known to come from lakes with lower sedimentation rates. Bottom core samples were not collected for reservoirs, meaning bottom core samples were collected only at the 15 natural lakes in Oregon. Additionally, four of the cores collected at natural lakes were of insufficient length or from lakes with high sedimentation rates. Inferences of past nutrient conditions were available for only 11 natural lakes in Oregon. We report on the number of lakes showing significant increases, significant decreases, or insignificant changes in nutrients.

Core samples were collected at natural lakes only. Four natural lakes did not have associated core data or the core was of insufficient length, leaving 11 lakes with inferred nutrients.

Inferred Total Nitrogen

Five natural lakes in Oregon showed no significant difference in nitrogen levels, based on top and bottom layer diatoms (Table 19). Two natural lakes showed significant increases in nitrogen and four sites showed significant decreases in nitrogen levels. For all Western natural lakes, no significant changes in diatom inferred nitrogen conditions were observed at 25% of sites. About one-third (34%) of the West population of natural lakes exhibited positive changes and 27% exhibited negative changes in nitrogen levels (based on diatom inferences). Fourteen percent of natural lakes in the West were unable to be assessed for inferred nitrogen conditions.

Inferred Total Phosphorus

Two natural lakes in Oregon showed no significant difference in phosphorus levels. Three natural lakes showed significant increases in phosphorus and six sites showed significant decreases in phosphorus levels (Table 19). Current phosphorus levels showed a greater degree of fluctuation from historic to current levels than was observed for nitrogen. For all Western natural lakes, no significant changes in diatom inferred phosphorus conditions were observed at 8% of sites. Half (50%) of the West population of natural lakes exhibited positive changes and 28% exhibited negative changes in phosphorus levels (based on diatom inferences). Fourteen percent of natural lakes in the West were unable to be assessed for inferred phosphorus conditions.

Table 19. Diatoms from sediment cores were used to infer past nutrient conditions and make comparisons to nutrient levels observed in this study. "Increasing" means diatom inferred nutrient levels from the bottom of the core were less than inferred nutrients from the top of the core. "Decreasing" means diatom inferred nutrient levels from the bottom of the core were higher than inferred nutrients from the top of the core.

Inferred Chemistry			
	Increasing	Decreasing	No Change
Big Lake		N, P	
Hosmer Lake	N, P		
Ice Lake		N, P	
Lake of the Woods		N	P
Mann Lake		N, P	
South Twin Lake		N, P	
Sparks Lake		N	P
Strawberry Lake	N, P		
Torrey Lake			N, P
Van Patten Lake			N, P
Waldo Lake	N		P

Recreational Indicators

Beulah Reservoir (Malheur Co.)

Recreational Indicators

Results from the assessment of recreational conditions as part of the NLA should be interpreted with caution. The collection of algal toxins data occurred at the deepest point of the lake. In many cases, algal blooms are concentrated in the near-shore area (see picture of Beulah Reservoir on the preceding page). For many lakes, the near-shore area also has the highest recreational or livestock use, and thus the highest risk of toxic algae exposure.

Algal toxins

Algal toxins samples were collected from an integrated sample of the top 2 m of water at the index site. A total of 500 ml of water was collected for algal toxins analyses. Immediately after collection, the sample was placed on wet ice. Within 6 hours, the samples were frozen on dry ice and remained frozen until analyzed at the processing laboratory.

Cyanobacteria densities were used to categorize lakes into one of three condition classes: low risk (< 20,000 cells/ml), moderate risk (20,000-100,000 cells/ml), and high risk (> 100,000 cells/ml).

Microcystin concentrations were used to categorize lakes into three classes identifying risk of exposure to algal toxins: low risk (< 10 ug/l), moderate risk (10 – 20 ug/l), and high risk (> 20 ug/l). The algal condition benchmarks come from the World Health Organization (USEPA 2009a). An additional measure of risk to algal toxins was simply presence of microcystin in a sample. If detected above 0.1 ug/L, then a lake was considered in poor condition for microcystin presence. If not detected above 0.1 ug/L, the lake was considered in good condition for microcystin presence.

Microcystin

All sites sampled in Oregon showed good condition (low risk) for Microcystin concentrations (Table 20). The maximum concentration observed in Oregon was 1.2 ug/L. Across the West, only one site was considered to be in fair condition (moderate risk), with a concentration of 15 ug/L. The highest observed concentration in Region 10 was 6.1 ug/L.

Four of the Oregon lakes surveyed (13%) had detectable microcystin concentrations (Table 20). Three of the lakes were from southeastern Oregon: Junipers Reservoir (first visit only), Mann Lake, and Baca Lake. Powers Pond had detectable microcystin on both visits, the first of which was concurrent with a fish kill. Recreational use is moderate to high in both Mann Lake (primarily fishing) and Powers Pond (fishing, boating).

Cyanobacteria

The assessment of health risks due to cyanobacteria was similar to the results for microcystin concentration. All sites with cyanobacteria densities were considered in good condition (low risk) (Table 20). Two sites in Oregon did not have cyanobacteria data available. Less than 2% of lakes across the West and Region 10 were considered to be in poor condition (high risk) for cyanobacteria density. All of the high risk occurrences were observed in the West-Xeric ecoregion, where 7% of lakes showed a poor condition for cyanobacteria.

Table 20. Recreational condition of sampled Oregon lakes for toxic algae.

Recreational Condition				
		Good	Fair	Poor
Microcystin (ug/L)	Oregon (n=30)	100%	-	-
Microcystin (presence)	Oregon (n = 30)	87%	-	13%
Cyanobacteria	Oregon (n=28)	100%	-	-

Enterococci

Enterococci samples were used to provide an assessment of human health risk due to fecal contaminants. A single 500 ml sample of lake water was collected at the final habitat and littoral sampling station at each lake. Immediately following collection the samples were placed on ice. Within 6 hours of collection, samples were filtered, placed on dry ice and frozen. Samples were processed in the laboratory using polymerized chain reaction methods (q-PCR).

Because of data quality concerns, we did not report on the bacterial results.

Enterococci samples were collected from the littoral plot at the last of the stations surveyed along the perimeter of the lake to facilitate meeting holding times.

Sediment Mercury

Sediment mercury samples were collected from the surface sediments of the sediment core used for development of the diatom index and models (see above). Prior to slicing off the top 1 cm of core sediments, a 1 cm^3 sample was collected from the middle of the core. Once transferred to the sterile collection jar, samples were placed on dry-ice until they were shipped to the processing laboratory.

These results were not available at the time this report was completed.

Relationships Among Indicators

Horsfall Lake (Coos Co.)

Correlations of indicators

We examined relationships among the various indices and metrics for biological, chemical, habitat, and landscape indictors. We used Spearman rank correlation to measure the degree that ranks of two variables co-vary, examining results only from Oregon's lakes. We chose Spearman rank correlation because it is not affected by departures from normality, effects from outliers, and does not assume a linear relationship between variables. Many of the variables used in this analysis were not able to meet normality, even following transformations. Additionally, given the low sample size (n = 30), outliers were frequently encountered.

Correlation coefficients (Spearman's rho, or ρ) range from -1.0 to 1.0. Positive ρ values indicate that as the ranked values of one variable increase, so too do the values of the second variable. Negative ρ values indicate that as one variable increases, the other variable decreases. To interpret correlations among variables, we classified ρ values into one of four categories representing the strength of the relationship among the two variables (Table 21). The coefficient of determination (ρ^2) can be interpreted as the proportion of variability in one variable that is explained by the variability in the second variable (Sokal and Rohlf 1995). The lowest benchmark for moderate correlations (ρ +/- 0.33) was chosen because we can interpret the ρ^2 (0.1) to represent a minimum of 10% of the variability in one indicator to be explained by variability in another indicator.

Table 21. Categories used to represent the strength of correlations between two indicators.

Correlation Indicators			
	Variability explained (ρ^2)	Positive relationship	Negative relationship
Moderate	10-25%	0.33 to 0.50	-0.33 to 0.50
Strong	26-56%	0.51 to 0.75	-0.51- to - 0.75
Very Strong	57-100%	0.76 to 1.0	-0.76 to -1.0

Biological relationships

Water chemistry--Plankton biological condition showed a negative relationship with all chemical indicators (Table 22). As concentrations or values of chemical parameters increased, Plankton O/E decreased. Moderate to strong relationships were observed with nutrients (total phosphorus and total nitrogen), organic carbon (total and dissolved), ammonia and nitrate, alkali metals (sodium and potassium), alkaline earth metals (magnesium and calcium), turbidity and color.

Habitat--Plankton O/E was moderately correlated with three out of the four habitat indicators. As conditions in the littoral and riparian improved, so too did plankton condition. Relationships were slightly higher for O/E and littoral condition than for riparian condition. A weak negative relationship was observed between plankton condition and the shoreline human disturbances.

Landuse--The percentage of forest and agricultural landuses in a lake basin had moderate, but opposite, correlations with plankton condition. Higher amounts of forest in a basin were positively related to higher plankton conditions (rho = 0.49). Conversely, higher amounts of agriculture in a basin were negatively related to higher plankton conditions (rho = -0.49).

Natural factors--Plankton O/E showed a positive relationship to precipitation. As the maximum precipitation in a lake basin increased, so too did plankton condition (rho = 0.38).

Preliminary macroinvertebrate correlations—In general, macroinvertebrates showed similar directionality (positive or negative) but weaker correlations to stressors as were observed for plankton. Macroinvertebrate condition showed a moderate negative relationship to total phosphorus and silica. Weak negative correlations were observed with other water chemistry parameters. Macroinvertebrates showed a similar response (moderate positive correlations) to habitat conditions as was observed for plankton. As riparian and littoral condition improved, so too did macroinvertebrate conditions.

Habitat relationships

Water chemistry—As shoreline human disturbances increased, water chemistry values increased. Strong positive relationships were observed among riparian disturbance and acid neutralizing capacity (ANC), magnesium, turbidity, conductivity, and total organic carbon. Moderate positive relationships were observed with calcium, dissolved organic content, sodium, nutrients, chlorophyll-a, chloride, pH, and nitrate/nitrite.

Higher riparian and littoral cover index values were associated with lower water chemistry concentrations (negatively associated). For nutrients, total nitrogen showed a strong relationship to both the riparian and littoral zone conditions (rho = -0.55 to -0.60). Total phosphorus showed a moderate relationship with riparian conditions (rho = -0.45) and strong relationship to littoral conditions (rho = -0.56). Both habitat zones showed strong negative relationships with turbidity, alkaline earth metals (magnesium and calcium), ANC, organic content (DOC and TOC), ammonia, and chlorophyll-a. The highest correlation was observed between ammonia concentration and the littoral cover index.

Habitat— The shoreline human disturbance metric was negatively and moderately correlated with the littoral and riparian indices (rho = -0.45 to -0.48). The riparian cover and littoral cover indices showed a strong correlation (rho = 0.78).

Landuse— Shoreline human disturbance showed a moderate negative relationship with the percentage of forest landuse in a basin (rho = -0.48) and a strong positive relationship with percent agriculture in a basin (rho = 0.53). Percent forest in a basin showed a strong positive correlation with riparian and littoral cover indices (rho = 0.63 – 0.65). Higher levels of agricultural landuse showed strong to very strong relationships to cover indices (rho = -0.67 to -0.76), with a slightly stronger relationship to littoral cover.

Natural factors— Shoreline human disturbance showed moderate negative relationships to latitude and maximum precipitation in the basin. In general, lakes located in wetter climates and further north in Oregon showed lower levels of human disturbance in the riparian. Riparian and littoral cover indices showed a strong positive relationship with mean precipitation (rho = 0.51 to 0.61) and a moderate to strong positive relationship with longitude (rho = 0.37 to 0.56). In general, lakes located in wetter climates and further west in Oregon showed higher levels of riparian and littoral cover.

GIS Human Stressors—Road density and number of road crossings in a basin showed moderate positive correlations with shoreline human disturbance. Road length and density showed moderate negative relationships with both the riparian and littoral indices. However, the number of road crossings over streams in a basin showed moderate negative relationships only with the riparian cover index.

Water chemistry relationships

Almost all water chemistry parameters showed moderate to very strong correlations to all other water chemistry parameters. Nitrate and nitrate/nitrite showed the fewest number of correlations to other water chemistry parameters. Given this consistency among chemistry parameters, we will highlight only a few.

Chlorophyll-a showed very strong positive relationships with organic carbon and total nitrogen. Relationships were also observed between chl-a and several GIS metrics. Strong correlations were observed for percent agriculture, road density, and total population. Moderate correlations were observed for population density, road crossings, and road length.

Nutrients (total phosphorus and total nitrogen) were mostly correlated to the same things, but nitrogen typically showed slightly higher ρ values. This was true across almost all variables, but notably plankton O/E showed a stronger correlation to phosphorus than to nitrogen. The strongest correlations with other chemical variables were organic carbon, chl-a, turbidity, and color. Percent forest in a lake basin showed a strong negative relationship to phosphorus and very strong to nitrogen. Percent agriculture showed a strong positive relationship to both nutrients.

Turbidity was lower in sites with higher amounts of forest in the basin, riparian and littoral cover, precipitation, and plankton O/E. Turbidity was typically higher in lakes with high levels of agriculture in the basin, nutrients, conductivity, and chlorophyll-a.

Clear Creek Reservoir (Baker Co.)

Table 22. Results of Spearman rank correlations among selected field measured and remote sensing indicators for thirty lakes surveyed in Oregon.

	Plankton O/E	Macroinvertebrate O/E	Riparian Disturbance	Riparian Vegetative Cover	Littoral Cover	Littoral + Riparian Cover	% Forest	% Agriculture	Maximum Precipitation	Road density	Road Crossings	Population density	Conductivity	Turbidity	Total Nitrogen	Total Phosphorus
Macroinvertebrate O/E	0.05															
Riparian Disturbance	-0.19	-0.14														
Riparian Vegetative Cover	0.30	0.38	-0.46													
Littoral Cover	0.44	0.33	-0.48	0.78												
Littoral + Riparian Cover	0.39	0.34	-0.45	0.96	0.89											
% Forest	0.49	0.15	-0.48	0.54	0.51	0.52										
% Agriculture	-0.49	-0.19	0.53	-0.67	-0.76	-0.71	-0.84									
Maximum Precipitation	0.38	0.05	-0.32	0.51	0.61	0.56	0.54	-0.68								
Road density	0.01	-0.07	0.43	-0.35	-0.22	-0.31	-0.43	0.34	0.03							
Road Crossings	-0.16	-0.30	0.35	-0.48	-0.33	-0.48	-0.30	0.36	0.09	0.48						
Population density	-0.11	0.22	0.18	-0.07	-0.07	-0.05	-0.43	0.27	-0.01	0.49	0.22					
Conductivity	-0.34	0.04	0.54	-0.53	-0.51	-0.53	-0.71	0.79	-0.72	0.41	0.15	0.31				
Turbidity	-0.58	-0.18	0.55	-0.67	-0.66	-0.67	-0.84	0.84	-0.53	0.33	0.45	0.35	0.72			
Total Nitrogen	-0.56	-0.10	0.42	-0.55	-0.58	-0.60	-0.78	0.75	-0.66	0.24	0.19	0.23	0.72	0.76		
Total Phosphorus	-0.61	-0.40	0.39	-0.45	-0.56	-0.52	-0.65	0.70	-0.51	0.13	0.24	0.07	0.62	0.73	0.81	
Chlorophyll-a	-0.55	0.02	0.35	-0.53	-0.51	-0.58	-0.69	0.60	-0.39	0.52	0.39	0.40	0.65	0.69	0.80	0.62

Summary of Findings

Ice Lake (Wallowa Co.)

Ranking of Stressors

Extent of Stressors

We have a list of indicators and the percent of sites in Oregon in good, fair, or poor condition for each indicator. What can we do with this information? Our first efforts to summarize this information involved ranking the stressors according to those with the highest degree of poor conditions. Figure 15 shows that riparian cover, total phosphorus, and littoral + riparian cover resulted in the highest percent of lakes failing to meet reference benchmarks--each with nearly 50% of surveyed lakes in poor condition. Turbidity, chlorophyll-a, and total nitrogen showed the next highest percent of sites in poor condition (30% each).

There are a few interesting patterns in this list of most extensive stressors. All of the stressors, except for Microcystin presence, showed moderate to strong correlations with plankton O/E (Table 20). The physical habitat cover indices showed a positive relationship to plankton condition—with increasing riparian and littoral cover, biological condition improved. As nutrients, chlorophyll-a, or turbidity increased, biological condition decreased.

All four of the habitat indicators made the list of most extensive stressors in Oregon. Habitat conditions in the riparian and littoral were observed to be among the most extensive stressors at the national scale, as well as for the two ecoregions of the West (Mountains and Xeric) (USEPA 2009a). Additionally, all of the most extensive water quality stressors showed moderate (total phosphorus) or strong correlations (turbidity, chlorophyll-a, total nitrogen) to riparian conditions. This is an important finding, as it illustrates the connection between ecological condition, water quality, and the condition of the surrounding landscape. To effectively manage water quality in a lake, riparian conditions should also be managed to limit disturbances and improve vegetative cover.

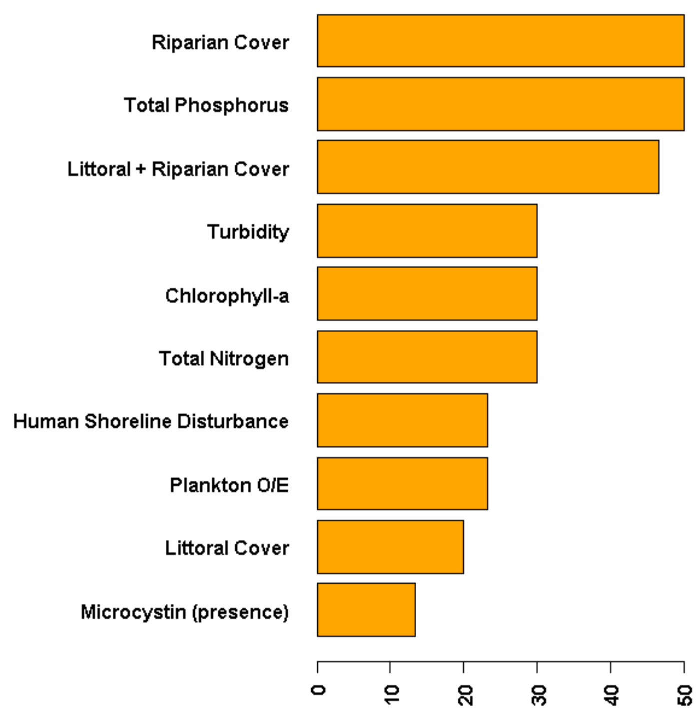


Figure 15. Ranking of stressors from highest to lowest percent of Oregon lakes surveyed that were in poor condition for each indicator.

Relative Risk

This method is used to identify the severity that a stressor has on biological condition. It has been utilized widely in the human health field. One common example of this is the risk associated with smoking. According to health research, the risk of developing lung cancer is 23 times more likely in a smoking male than a non-smoking male, and 13 times more likely for a smoking female than a non-smoking female (U.S. Department of Health and Human Services 2004). Within the context of ecological assessments of lake conditions, relative risk represents the likelihood of poor biological conditions being associated with poor conditions for a specific chemical or habitat stress factor.

Unfortunately, with only 30 lakes sampled in Oregon, estimating the risk any particular stressor has on the biological assemblage is quite difficult. We can look at the results of the national survey to get some indication of the stressors most likely to impact plankton condition. At the national scale, poor plankton condition was most often associated with poor riparian and littoral condition, poor nutrient condition, and poor turbidity condition (USEPA 2009a). In our study of Oregon lakes, these parameters also show the highest percent of lakes in poor condition.

The national report also identified some differences between natural lakes and reservoirs in regards to the risk of certain stressors. For natural lakes, the highest risks to biological condition (Plankton O/E) were observed for total nitrogen and turbidity, followed by riparian cover and total phosphorus. For reservoirs, the highest risks to plankton assemblages were associated with riparian and littoral cover, with water quality stressors showing insignificant risks. Given a large enough sample size, it would be interesting to see if relative risk differs between natural lakes and reservoirs in Oregon.

Setting lake management priorities

We can utilize extent and risk analyses to prioritize future lake monitoring and management. Given the relationships observed between near-shore and shallow water habitats and ecological and water quality measures, one example might be to perform intensive habitat monitoring at candidate reference sites to develop a more accurate expectation of riparian and littoral conditions. From a regulatory perspective, we might use this list of most pervasive stressors to set priorities for water quality standards development, establish TMDL implementation benchmarks, or set forth shoreline modification and development restrictions.

Additionally, we should begin to examine the relationship between biota and stressors. In this study we have observed strong relationships among plankton communities and nutrient concentrations, as well as moderate relationships with riparian and littoral conditions. More effort should go into determining which specific plankton taxa are more closely related to desirable or undesirable conditions for specific stressors. These relationships can be used as an effective screening tool for an array of stressors. This can be a cost effective and sensitive method of monitoring, as a single biological sample can be used to identify multiple stressors (Huff et. al 2006).

The utility of probabilistic monitoring

This report represents the first attempt to assess the conditions of lakes in Oregon as a whole. As with any new venture, there were successes and failures. The key to making improvements in our understanding of the conditions of Oregon's lakes is to expand on the successes and learn from our failures.

The probabilistic monitoring survey design provides the ability to make an unbiased assessment of the conditions of Oregon's lakes. To utilize probabilistic monitoring, though, we needed to define what constituted a lake (Table 1). Size, depth, and permanence constraints limited our population of potential lakes (3,193) to a smaller target population (n = 883) (Figure 1). Additionally, when a target lake is unable to be sampled, we lose the ability to represent conditions of another subset of the target population. In this study, the three privately owned lakes where we were denied access to sample resulted in estimates of conditions representing a total of 694 lakes. The number of lakes we were actually able to assess represents only 22% of all lakes identified in the NHD. When reviewing the results of this study, it is very critical to remember that we had a fairly narrow view of what constitutes a lake. Extrapolation to lakes outside of the target constraints used in this study would be inappropriate.

The power of probabilistic surveys comes from utilizing the conditions of surveyed lakes to represent the conditions of the resource as a whole. A key component of probabilistic designs is that individual survey sites represent replicates of the sampled population. The main objective of the national lakes assessment (and other national aquatic resource surveys)—as well as this assessment of Oregon lakes—was to determine the extent of lakes in good, fair, or poor condition for a suite of indicators. The assessment of individual lake conditions is not an objective. We caution against using the results from individual lakes outside of this context. The methods of the surveys called for sampling many different indicators, but all within a single visit to a lake. Thus, any indicator with considerable temporal variability is less likely to be adequately characterized for a single lake. Also, those indicators which were assessed from only a single location in the lake will not adequately represent spatial variability.

To take advantage of probabilistic monitoring design a sufficient sample size must be surveyed. When too few sites are sampled the ability to make accurate and precise estimates of resource conditions is reduced. This was apparent in this study, where we observed large errors in our estimates of good, fair, and poor conditions for most indicators. For example, if we presented the information from the 30 lakes sampled in Oregon as a population estimate, 32% of target lakes in Oregon have poor plankton condition (compared to the 23% of sites surveyed). However, our 95% confidence intervals range from 0-65% of target lakes. The utility of such broad population estimates is questionable, which is why we opted to represent conditions of Oregon lakes in terms of percent of sites. In doing so, we lose the ability to make statements about the population of target lakes in Oregon (883 lakes). Given the new nature of this type of monitoring design for lakes, we decided to take a conservative approach to describing the conditions of Oregon's lakes. Our goal is to learn from this round of sampling and make improvements for the next surveys in 2012.

Considerations for the 2012 National Lakes Assessment

The most apparent success of Oregon's participation in the NLA was the completion of a comprehensive survey of ecological conditions for 30 lakes across Oregon. Given the logistics of sample collections on one day and over-night shipment of samples to laboratories the next day, plus the remote location of many of Oregon's lakes, this was a challenge. The result of these surveys is a baseline view of the range of conditions for various water quality, habitat, and biological indicators. We can use this information to help prioritize future monitoring needs, as well as to speak on potential management improvements for lakes in Oregon.

Study design

The probabilistic design applied in this study was ultimately intended to summarize the status of lakes at a national scale. Secondarily, the random approach provided the ability to describe conditions at larger ecoregion scales, as well as partition the resource into natural lakes and reservoirs. Random sites within each state were selected separately, allowing state agencies to make assessments of lakes within their jurisdictions. However, the number of sites—and thereby funds—to survey provided to each state varied considerably. States with low sample sizes needed to find funding sources outside of the NLA if they wanted to increase the number of lakes surveyed. Given limited monitoring resources within ODEQ, we decided to assess lake conditions in Oregon with the funding provided by EPA for 30 lakes. Idaho and Washington both added additional random sites, beyond those supplied by EPA as part of the NLA, to reach 30 sites (the recommended minimum number of sites to do a population estimate).

EPA suggests that the magnitudes of errors are routinely associated with sample size; however, this was not observed within Region 10. All three Region 10 states sampled the same number of lakes (30 in each state). When we assessed lake conditions in Oregon probabilistically (not included in this report), we observed maximum errors of approximately +/- 30% for most indicators. For Washington lakes, maximum errors were typically around +/- 20-25%; while for Idaho, error estimates were less, typically around +/- 15%. The likely cause of these discrepancies in errors was a greater imbalance in site weights in Oregon's lakes, compared to Idaho or Washington lakes. Prior to the next round of the NARS lake assessments, ODEQ will work with EPA study design staff to examine this issue of varying error rates. This may help us determine the appropriate sample size needed to achieve desired maximum error rates.

Another consideration related to sample size is to ask which additional strata in Oregon's lakes are important to assess. We observed substantial differences in conditions between natural lakes and reservoirs. If we want to statistically describe the conditions of each of these types of lakes, we will need to survey more lakes and include this stratum in the design process. Ecoregions may be another stratum that lake managers in Oregon feel are important to assess. While some differences were noted between Western Mountains and Xeric lakes in the national report (USEPA 2009a), we surveyed too few Oregon lakes in the Xeric ecoregion to make any meaningful comparisons. Also, we need to determine if these larger aggregate ecoregions are sufficient. An additional potential stratum is landuse. We observed some patterns in lake condition between forest and agricultural landuse. These are important questions to consider, and the answer mostly depends on three things: sample size required, cost, and consensus that these are important questions.

Sampling procedures, indicators, and analyses

Perhaps the greatest success of the NLA was the development of new indicators for use in assessing lake conditions. The large number of samples taken and inclusion of reference lakes allowed for development of assessment tools that can be applied across the nation, allowing for standardized assessments and communication among lake managers.

Reference condition

In the absence of existing water quality criteria or standards, the reference condition approach can be used to establish benchmarks for biological, water quality, and habitat indicators. The NLA relied heavily on reference sites to establish lake conditions. The development of regional reference benchmarks for nutrients and other water quality parameters should be useful in opening a dialogue with lake managers across Oregon. Do these condition benchmarks align with your expectations for lakes in Oregon? Are there more appropriate values to use? Do the trophic state benchmarks derived from reference sites sampled as part of the NLA match the levels you use in your program?

Since so much relies on reference sites in the assessment of lake conditions, it is obvious that small reference sample sizes represent the greatest risk to inaccurate assessments. Only 50 reference sites were used in the development of the West plankton O/E model. Forty-one sites were used in the development of habitat and macroinvertebrate O/E models for all lakes in the West. A total of 38 reference sites were used to develop condition benchmarks for nutrients and other water quality parameters. The next round of sampling for the NLA should help improve upon these numbers, although funding is always a limiting factor. We feel that this area is where lake managers in Oregon can help themselves the most in developing assessment capabilities. Partnering with other agencies, research groups, etc. to increase the number of reference lakes in Oregon would improve lake assessments considerably. The key issue would be to prioritize the indicators needed to be sampled. Given their resilience and lack of existing information, our recommendation would be to focus on biological and habitat indicators first—at least for lakes monitored with a single visit.

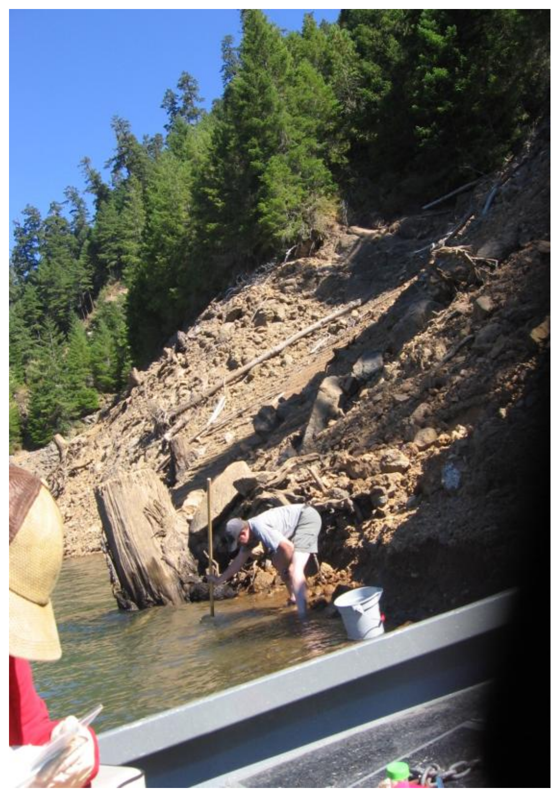
Biological indices

The development of the plankton O/E model may prove to be one of the most beneficial developments to come out of the NLA. The plankton O/E model appears to be sensitive to a wide array of stressors, as indicated by the correlations analysis (Table 20). The model performance is adequate, with a standard deviation (SD) in reference lakes' O/E values of 0.19. (For comparison, ODEQ's O/E models for macroinvertebrates have SD's of 0.14 and 0.17.) Considering the scale at which the NLA plankton model was developed (West) and the low sample size of reference lakes, this is good news. Further refinements, such as increased reference lake sample sizes allowing for development of smaller regional models, should result in a sensitive and highly useful lake assessment tool.

When state and federal partners were developing the list of indicators and sampling methods, there were concerns that a single sample of plankton assemblages, which vary considerably in composition and abundance throughout the summer, would be of little use. The results of the NLA seem to indicate otherwise. Much as we have observed with other biological indices in streams (macroinvertebrates, aquatic vertebrates), one-time sampling of plankton assemblages in lakes appears to be effective in spite of high degrees of seasonal variability. The plankton assemblages in any one sample can be viewed as integrating the effects of various stressors through time. These integrative assessment tools are especially important in context with the one-time sampling involved in this and other probabilistic monitoring studies (e.g., the NARS).

It was disappointing that only one biological assemblage index was used to assess lake conditions. The Lake Diatom Condition index (LDC) did not seem to perform well. It made almost no distinction of the condition of lakes in Oregon (22 good, 5 fair, and 3 poor). Also, it showed weak correlations to all other potential stressors except total phosphorus (rho = -0.39). And the ultimate reason for not including this index in this report was the lack of documentation concerning final metrics and reference benchmarks. Another disappointment was the lack of macroinvertebrate data available for a full assessment of Oregon lakes. Macroinvertebrates occupy a central role in aquatic ecosystems and thus are sensitive to a wide array of stressors. We did explore the potential of the macroinvertebrate data from the West, finding model performances similar to the plankton O/E model. ODEQ staff will continue to work with national experts to examine this data with the intent of developing regional predictive models that can be applied to Oregon's lakes.

The development of models to assess past lake nutrient conditions was intriguing, but from a perspective of all of Oregon's target lakes it was of little use given the low sample sizes. Results presented here may be of more use to individual lake managers. However, we do feel that this is an important assessment tool with unique capabilities. The sediment cores allow us to make an assessment of historical lake conditions—this means that reference conditions (at least for these indicators) are built into the lake itself. We don't need to rely upon a small set of lakes spread out across the Western U.S. to determine previous nutrient conditions. Additionally, reference conditions (at least for the inferred indicators) are determined on a lake-by-lake basis. This is a very alluring and potentially powerful assessment tool. Future lake surveys as part of the NLA should incorporate diatom-core dating, at least for a subset of lakes, to gain an understanding of the time-frame involved between surface and bottom core slices.



Sampling in the littoral and riparian zones at Hills Creek Reservoir. The barren area shown represents the majority of the riparian plot.

Physical habitat indices

The development of indicators of riparian condition for lakes may also prove to be quite beneficial to lake management in Oregon. The riparian cover index appeared to perform well, despite small numbers of reference sites and a large spatial scale. It showed moderate to strong correlations to many water quality, landuse, and human disturbance variables. Other monitoring projects on streams throughout the state have shown riparian cover and human disturbances in the riparian to be among the stressors with the greatest extent and risk (Mulvey et. al 2009, Hubler 2007). In these studies, even the major stressors that were not direct measures of riparian condition can be indirectly related to riparian conditions (e.g., temperature, excess fine sediments).

The riparian and littoral indices are more integrative measures of lake condition. The information was collected across 10 systematically random locations around the lake, thus the indices are representative of whole lake conditions. The indices should be more robust throughout the sampling season than many of the other variables. However, this assumes level fluctuations are not too large, which is not always the case. At several reservoirs we observed large level fluctuations, resulting in riparian plots located on barren muddy shores. Drawdown didn't have much of a bias on estimates of riparian cover at reservoirs such as Junipers Reservoir and Moon Reservoir, where little vegetative cover exists within close proximity to the lakes. Lake fluctuation did have a major bias at sites with extensive forest along the high water line. Both Clear Creek Reservoir and Hills Creek Reservoir were rated as having poor riparian cover, despite moderate to heavy vegetative cover above the high water line. More discussion needs to go into the potential effects of level fluctuations on riparian and littoral indices for the next round of sampling.

Recreational indicators

In our opinion, not much worked well in regards to recreational indicators. We collected sediment mercury samples from the surface layer of the diatom cores. However, the data was unavailable at the time of writing this report. Bacteria samples were also collected and the data were not available until late in the analysis stage, of unknown quality, and no regional benchmarks were provided for assessment via the national assessment. Those most disappointed in the lack of bacteria information were the field crews, who spent hours filtering the samples following long days in the field. (Or perhaps they will be relieved to not have to think of the samples again?) The bacteria sample was collected from one littoral plot at the end of the day in an effort to meet holding times. Some have questioned the need for a composite sample to be more representative of lake Enterococci concentrations, however this will result in many samples not meeting the 6 hour holding times prior to filtration and freezing.

Two toxic algae indicators were collected, Microcystin and cyanobacteria concentrations. Both of these indicators were collected from a 500 mL composite of water in the top two meters of the lake, at the lake's deepest point. The results from this survey suggest very low risk of harmful algal blooms in Oregon lakes and reservoirs. This information is counter to current lake monitoring efforts in Oregon, where harmful algal blooms have become a hot topic. A workshop on harmful algal blooms for lake managers in Oregon occurred in the spring of 2010. In 2009, 21 separate toxic algae advisories were reported for 17 different lakes and reservoirs (DHS 2009). One of these lakes, Hills Creek Reservoir, was one of the random lakes surveyed by ODEQ crews, but we collected algal samples after the harmful algal bloom advisory was lifted. There is room for considerable debate on the methods utilized in sampling toxic algae as part of the NLA. First, collecting toxic algae samples from the deepest point in the lake may miss higher concentrations when the algae have been blown towards the shoreline. Perhaps locating algal samples in the littoral plots would be more effective? The near shore areas are also more likely to be locations for more intensive recreational contact by humans or use by livestock and pets. Also, algal blooms are highly seasonal, potentially arguing against relying too heavily on a one-time grab sample to characterize lakes. Again, though, we must be careful to remember the goal of the probabilistic approach is to characterize a population, not a single site. This is certainly an issue with a lot of public interest and support—this should be an important discussion topic for planning the next stage of the national lakes assessment.

Additional indicators

There were many potential indicators that were discussed in the planning stages of the NLA, but not included in the surveys. With limited funding and limited time to perform an individual survey (one day maximum), it was necessary to exclude some very important indicators. For example, we did not assess fish assemblages (the top of the food chain) or fish tissue for human consumption. The key issue was that to collect information for these indicators would have been too costly and time consuming. However, a national fish tissue study was performed from 2000-2003 and followed probabilistic survey design (USEPA 2009b). Mercury and PCBs were detected in every sample from 500 lakes and reservoirs. Additionally, dioxins and furans, DDT, and chlordane were frequently detected in the tissue samples. The probabilistic design allowed estimates of the percent of lakes (out of a total of approximately 77,000 lakes in the lower 48 states) exceeding human health criteria. Mercury concentrations were exceeded for 49% of lakes, PCB concentrations were exceeded at 17% of lakes, and dioxin and furan concentrations were exceeded at 8% of lakes. The ability to report similarly for Oregon lakes would be very powerful.

Invasive species information was collected as part of the 2007 NLA, but the data was unavailable at the time of writing this report. Additionally, the methods were not intensive and the species lists were not well developed for western lakes. This is an area of high concern among lake (and rivers) managers and the public. More discussion needs to occur at the national scale for development of this indicator at the national scale. However, Oregon lake managers should actively discuss this in the context of developing appropriate species lists, sampling methods, and identification guides prior to the 2012 round of sampling.

Collecting a sediment diatom core often required multiple attempts. When it worked well, it really made the crew happy.

Next steps

ODEQ's role in lake monitoring has diminished tremendously since the loss of the Clean Lakes Program in 1994 (see Appendix) and we have lost the experience and insight of staff critically involved in monitoring Oregon's lakes. We plan to present the findings presented in this report at the Oregon Lakes Association annual meeting in September 2010. We hope this will result in increased awareness of the utility of probabilistic monitoring for lakes, as well as the potential for individual lake managers to utilize the new assessment tools developed from the 2007 NLA. Our highest objective, though, is to open a dialogue among lake managers and researchers with much more experience and knowledge of Oregon's lakes.

We expect the feedback from these discussions to be critical in strengthening the next round of lakes sampling in 2012. At a minimum, we hope to begin developing a network of reference lakes for more accurate assessments of Oregon's lakes. We also hope to build the capacity for lake managers to utilize indicators that are more integrative in nature, such as biological and habitat indicators.

References

Birks, H. J. B. 1998. Numerical tools in quantitative palaeolimnology – progress, potentialities and problems. Journal of Palaeolimnology 20: 307-332.

Christie, C. E. and J. P. Smol. 1993. Diatom assemblages as indicators of lake tropic status in Southeastern Ontario lakes. Journal of Phycology 29:575-586.

DHS. 2009. Oregon Harmful Algae Bloom Program: 2009 Bloom Season Recap. Oregon Department of Human Services. http://www.oregon.gov/DHS/ph/hab/2009_Bloom_Season_Recap.pdf

GAO. 2002. Inconsistent State Approaches Complicates Nation's Efforts to Identify Its Most Polluted Waters. Government Accountability Office. GAO-02-186.

Hubler, S. 2007. Wadeable Stream Conditions in Oregon. Oregon Department of Environmental Quality. DEQ07-LAB-0081-TR. http://www.deq.state.or.us/lab/techrpts/docs/DEQ07-LAB-0081-TR.pdf

Huff, D., S. Hubler, D. Drake, Y. Pan. 2006. Detecting Shifts in Macroinvertebrate Assemblage Requirements: Implicating Causes of Impairment in Streams. Oregon Department of Environmental Quality. DEQ06-LAB-0068-TR. http://www.deq.state.or.us/lab/techrpts/docs/10-LAB-005.pdf

Merrick, L. 2010. The 2007 Survey of Oregon Lakes: Individual Lake Summaries. Oregon Department of Environmental Quality. 10-LAB-013. http://www.deq.state.or.us/lab/techrpts/bioreports.htm

Mulvey, M., A. Borisenko, R. Leferink. 2009. WILLAMETTE BASIN RIVERS & STREAMS ASSESSMENT. Oregon Department of Environmental Quality. DEQ 09-LAB-016, http://www.deq.state.or.us/lab/wqm/docs/WillametteBasinAssessment2009.pdf

Stoddard, J.L., D. V. Peck, S. G. Paulsen, J. Van Sickle, C. P. Hawkins, A. T. Herlihy, R. M. Hughes, P. R. Kaufmann, D. P. Larsen, G. Lomnicky, A. R. Olsen, S. A. Peterson, P. L. Ringold, and T. R. Whittier. 2005. An Ecological Assessment of Western Streams and Rivers. U.S. Environmental Protection Agency, Washington, DC. EPA. 620/R-05/005

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson, and R.H. Norris. 2006. Setting Expectations for the Ecological Condition of Streams: The Concept of Reference Condition. Ecological Applications, 16(4), pp. 1267–1276

Ter Braak, C.J.F. and S. Juggins. 1993. Weighted averaging partial least squares regression (WA-PLS): an improved method for reconstructing environmental variables from species assemblages. Hydrobiologia. 269/270:485-502.

U.S. Department of Health and Human Services. 2004. The Health Consequences of Smoking: A Report of the Surgeon General. Atlanta: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, Office on Smoking and Health. http://www.cdc.gov/tobacco/data_statistics/sgr/2004/complete_report/index.htm

USEPA. 2007. Survey of the Nation's Lakes: Field Operations Manual. U.S. Environmental Protection Agency, Washington, DC. EPA841-B-07-004.

USEPA. 2009a. National Lakes Assessment: A Collaborative Survey of the Nation’s Lakes. U.S. Environmental Protection Agency, Washington, DC. EPA 841-R-09-001.

USEPA. 2009b. The National Study of Chemical Residues in Lake Fish Tissue. U.S. Environmental Protection Agency, Washington, DC. EPA 823-R-09-006.

USEPA. 2010. National Lakes Assessment: Technical Appendix. U.S. Environmental Protection Agency, Washington, DC. EPA 841-R009-001a.

Boreal toad (Torrey Lake, Lane Co.)

Appendix. A History of DEQ Lake Monitoring in Oregon

By Andy Schaedel (Oregon Department of Environmental Quality and Oregon Lakes Association)

Lake Monitoring Eras

There have been roughly three “eras” of programs that addressed lake water quality which have been conducted by DEQ and its predecessor, the Oregon State Sanitary Authority:

1960’s – 1970’s – pre-Clean Lakes Program.

1980’s – 1990’s – Programs run under the Clean Lakes Program (Section 314 of the Clean Water Act).

2000’s on – Integration of lakes into various programs.

1960’s - 1970’s

During the 1960’s and early 1970’s, the Department’s focus was on characterizing the water quality of lakes in Oregon and determining their suitability for supporting beneficial uses – primarily recreation. Much of the characterization of lakes was done by collecting limited nutrient, bacteriological and algal data. Lakes were categorized using the Saprobic System, which is similar to the trophic characterization of lakes that is currently used.

This information was summarized in two reports:

McHugh, Bob. January 3, 1972. <u>An Interim Study of Some Physical, Chemical and Biological Properties of Selected Oregon Lakes</u>; Oregon Department of Environmental Quality. Portland, OR. 130 pp.

This report was submitted to the Environmental Quality Commission and to Governor McCall. “The indications from this report are that a variety of situations exist in different lakes in the state but the trend is toward a recreational-use oriented deterioration of many of the lakes.”

McHugh, Bob. June 1979. <u>Some Highly Eutrophic Oregon Lakes, with Recommendations for the Restoration of their Quality</u>; McHugh, Bob; June 1979. Oregon Department of Environmental Quality. Portland, OR. 33 pp.

This paper was developed in response to the Section 314 Clean Water Act (CWA) requirement that each state: “identify and classify according to eutrophic condition all publicly owned fresh water lakes in the state; procedures, processes and methods to control sources of pollution of such lakes; and methods and procedures to restore the quality of such lakes”. Twenty two lakes were identified as candidates for restoration.

1980’s – 1990’s

During this period of time, the Department focused its lake related activity mainly on use and administration of the Section 314 Clean Lakes Funding. A program called the Clean Lakes Program (Section 314) was established in 1972 as part of the CWA. The program was created to provide financial and technical assistance to States in restoring publicly-owned lakes. The DEQ administered this program in Oregon, under direction of the Environmental Protection Agency (EPA). Clean Lakes Program funding occurred from 1976 – 1994 but the program has not been funded since that time.

The program was set up as a multiple-part program:

Classification surveys and Lake Water Quality Assessments: where states were to identify and rate their lakes according to trophic conditions in order to be eligible for further funding. The Atlas of Oregon Lakes (OSU Press, 1985) was funded using this grant and further statewide assessments (including Citizen Lake Watch – a volunteer monitoring program) were done in the early 1990s under this funding (for more history on lake classification and related work, see Attachment 1).

Phase I - Diagnostic/Feasibility Studies: Funds were awarded for studies which would analyze a lake's condition, determine the causes of problems and identify procedures necessary to protect and restore its quality.

Phase II – Restoration and Protection Implementation: Funds were awarded to implement procedures recommended in the Phase I study for restoring and protecting the lake. Most of the federal funding went into this category.

Phase III – Post Restoration Monitoring: Limited funding was available to monitor and document the implementation.

The program, under the direction of EPA, funded approximately $145 million in grant activities since 1976 to address lake problems. There have been no general appropriations for the program since 1994. The program provided a widely varying amount of funding to States, ranging from $2.7 - $20 million per year but was typically in the $4 - $9 million range. Oregon received approximately $2 million of funding. DEQ administered the program and most of the work was done under contract.

DEQ had a staff person who, as part of their job duties, oversaw administration of the Clean Lakes program and was available to provide technical assistance to lake associations. This position was phased out in 1997 as a result of state budget shortfalls and lack of continued Clean Lake funding.

Highlights of the Clean Lakes Program

Lake Classification: DEQ received the last $100,000 Section 314 Lake Classification Grant awarded in 1981. A partnership was formed with Portland State University to pull together an inventory of information on 202 of Oregon's larger lakes (greater than 50 acres) and reservoirs (greater than 100 acres). This work was published as: Johnson, Daniel, R. Petersen, D. Lycan, J. Sweet, M. Neuhaus and A. Schaedel. 1985. Atlas of Oregon Lakes. Oregon State University Press. Corvallis, OR. 317 PP

Phase I and II Studies: A list of the Phase 1 and 2 projects that were funded under this program is in Table 1.

Lake Water Quality Assessments: Additional Section 314 Clean Lake requirements, along with additional funding opportunities, were made in the reauthorization of the CWA in 1987. Biennial reporting (as part of the 305(b) report) of the status and trends of water quality in lakes was now required, starting in April 1988. Particular focus was to be given to reporting on lakes affected by acid deposition and toxic pollutants. Congress realized that many states had limited lake monitoring data available to assess status and trends and much of this was funded with the Lake Classification funds that were available in the 1970's. This was the case in Oregon as the Atlas of Oregon Lakes was funded with those funds. Additional funding, in the form of Lake Water Quality

Assessment Grants, was made available to each state to help develop statewide water quality assessments.

Citizen Lake Watch Program: DEQ initiated a volunteer monitoring program on lakes, named the Citizen Lake Watch Program, in 1988. The program was conceived as follows: a consulting limnologist was to initially visit a lake and do a more comprehensive assessment of a lake to establish its baseline condition. A volunteer monitor then would do selective monitoring to help establish trends. The comprehensive survey was to be repeated every 10 years.

Initially, consultants carried out this work as state agencies were under restrictions for adding staff. Aquatic Analysts initiated the work in 1988-1989 and developed reports for 19 lakes. Scientific Resources, Inc ran the program in 1990. DEQ assumed the management of the program in 1991 during which time it developed a contract with Portland State University to take over the program. Portland State ran the program from 1991 – 2001. A series of annual reports and lake specific reports are available on the program.

While the program was useful for gathering data on Oregon Lakes as well as providing a means to train and educate local volunteers, funding was an issue. The program was supported by Section 314 CWA funds through 1997, at which point that source of funding ended. It continued under Section 319 CWA funding until 2001 at which point in time the Center for Lakes and Reservoirs was established at Portland State University and state funding supported the program for a few more years. Under ORS 352.068, the purpose of the Center for Lakes and Reservoirs is to assist state and federal agencies in researching and mitigating non-native, invasive aquatic species in this state and to work with communities in developing effective management of lakes and reservoirs. The Center (http://www.clr.pdx.edu/) has taken on a number of broader issues and is a great resource, especially for development of Vegetation Management Plans and for addressing invasive species.

More detail on the work funded under the Lake Water Quality Assessment grants can be found in DEQ's 305(b) reports for 1988, 1990, 1992 and 1994.

2000's on

Lake work has become integrated with other on-going or recently developed programs. Some of the key DEQ programs that are being used to address lake water quality include:

- Lake Monitoring –Survey of Nation's Lakes and Volunteer Monitoring
- 303(d) List and Total Maximum Daily Load (TMDL) Program
- 401 Hydroelectric Recertification Program
- Point Source Control Program
- 319 Nonpoint Source Grant Program
- Drinking Water Protection Program

Table A. Summary of Section 314 Phase 1 and 2 Lakes Studies in Oregon

Lake (Basin)	Phase	Date of Project	314 Funding	Total Cost	Summary
Mirror Pond (Deschutes)	1 2	1980-82 1983-84	$21,376 $150,000	$30,480 $150,000	Pond was filled with sediment and rooted vegetation. Study recommended dredging and stormwater sediment controls. Pond was dredged in 1983-1984.
Upper Klamath Lake (Klamath)	1	1980-83	$71,120	$101, 600	Lake experienced algal blooms, dense beds of macrophytes, high pH and low DO. Restoration plan recommended maintaining lake level and selected dredging, weed harvesting and use of aquascreen to provide for recreational use.
Fern Ridge Res (Willamette)	1	1980-82	$70,612	$101,088	Reservoir experienced seasonally high turbidity, bacteria, and algal blooms. Study recommended alum application to precipitate phosphorus, dredging, sand dispersal to cover clay bottom, delayed drawdown and addressing sources of bacteria in watershed.
Devils Lake (Mid Coast)	1 2	1980-82 1985-94	$99,670 $311,170	$143,643 $510,830	Lake experienced excessive algae and macrophyte growth that interfered with uses. Study recommended weed harvesting or herbicides to control plant growth and sewering. A Water Improvement District was formed to promote watershed and lake management and Grass Carp were introduced to control macrophyte growth. Educational and monitoring programs have been implemented.
Sturgeon Lake (Willamette)	1 2	1980-82 1984-94	$58,224 $376,767	$83,220 4983,534	Lake was filling in with sediment due to flood control dikes which reduced its natural flushing and was affecting water fowl habitat. Dredging of Dairy Creek to reestablish its connection with the Columbia River was carried out. Further maintenance work is needed.
Blue Lake (Willamette)	1	1981-83	$97,042	$145,543	Algae blooms and Eurasian Milfoil were interfering with recreational uses. Study recommended herbicide use, alum to precipitate phosphorus, dilution from Portland's water supply, and lake drawdown to kill weeds. Drawdown was unsuccessful but herbicide use and dilution have been used.
Garrison Lake (South Coast)	1	1987-90	$74,900	$107,000	Algal blooms forced Port Orford to abandon its water supply from the lake and macrophytes interfered with recreation. Study recommended diverting sewage effluent from the lake, forming a lake management district, addressing any failing septic systems, selective harvesting and improving wetland biofiltration of Mill Creek. Outfall has been relocated from the lake.
Lake Notasha (Klamath)	1	1991-94	$38,765	$54,520	Lake Notasha is a small, extremely pure wilderness lake that would be sensitive to anthropogenic change. Study determined that it has remained relatively unchanged and recommended various practices to protect it including not stocking fish into the lake.
Lake Lytle (North Coast)	1	1992-1994	$100,000	$142,664	Lake is heavily infested with Eurasian milfoil. The study determined that nutrient control would not address the milfoil concern (loadings were not excessive or linked to nutrients to the lake) and recommended control of the invasive species through herbicides. A management plan was developed.
Smith & Bybee Lakes (Willamette)	1	1993-95	$46,000	$70,740	The lakes have experienced infestation of Reed Canary Grass and loss of other natural vegetation since a water-level control was installed to address avian botulism concerns in 1982. The study recommended removal of the structure and to manage the lakes to mimic natural hydrologic conditions.