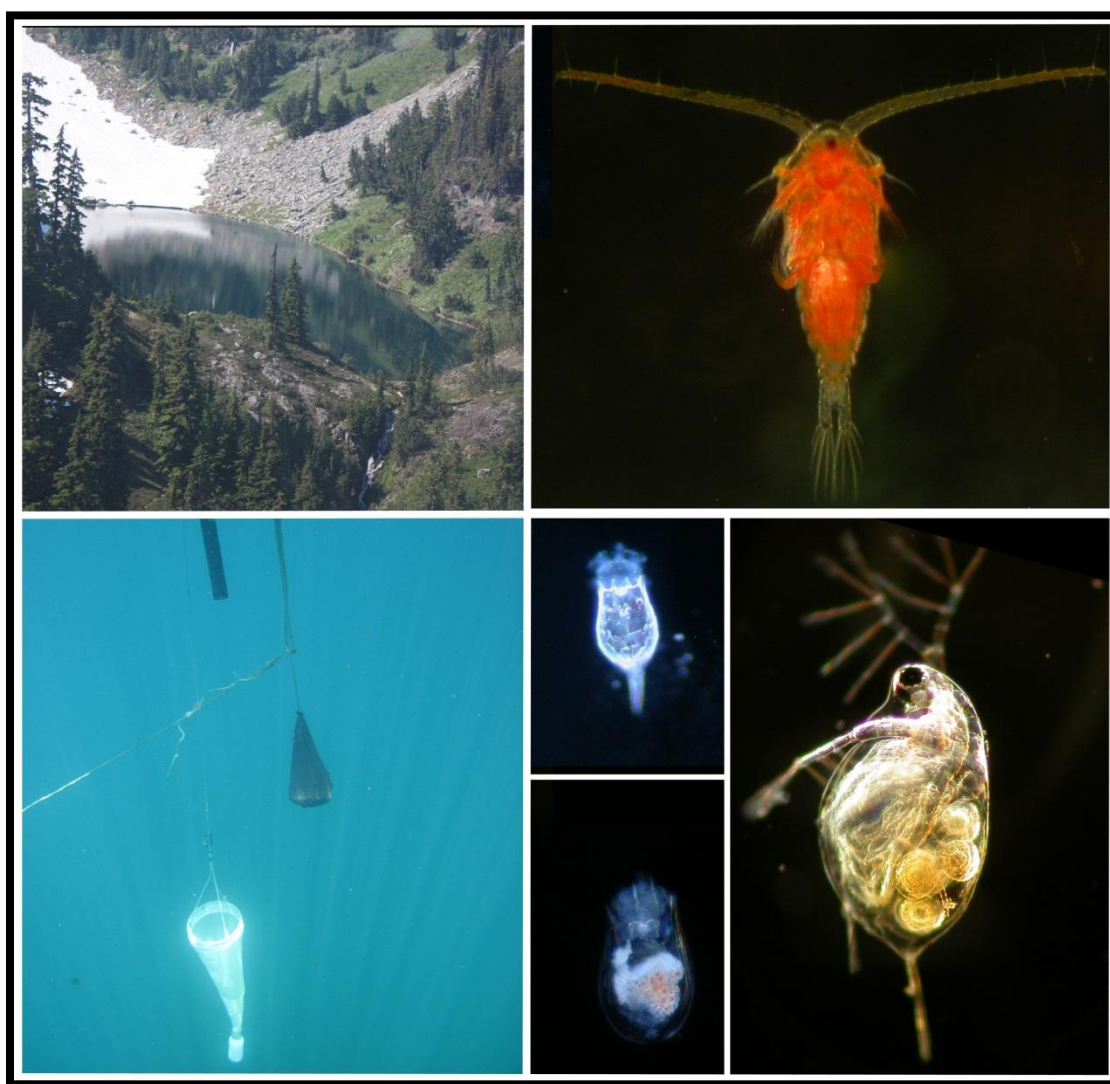




Zooplankton Assemblages from Mountain Lake Study Sites in the North Coast and Cascades Network

2009 Field Season Report

Natural Resource Technical Report NPS/NCCN/NRTR—2012/629



ON THE COVER

Zooplankton sampling and typical zooplankton found in NCCN mountain lakes. Clockwise from upper left: Crazy Lake (OLYM); *Hesperodiaptomus kenai*; *Daphnia rosea*; *Notholca michiganensis*; Zooplankton net sampling water column adjacent to deep water sampling buoy. Center: *Keratella cochlearis*

Photograph by: Steven C. Fradkin

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October 2012

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the North Coast and Cascades Network website (<http://science.nature.nps.gov/im/units/nccn/reportpubs.cfm>) and the Natural Resource Publications Management website (<http://www.nature.nps.gov/publications/nrpm/>).

Please cite this publication as:

Fradkin, S. C., W. Baccus, R. Glesne, C. Welch, B. Samora, and R. Lofgren. 2012. Zooplankton assemblages from mountain lake study sites in the North Coast and Cascades Network: 2009 field season report. Natural Resource Technical Report NPS/NCCN/NRTR—2012/629. National Park Service, Fort Collins, Colorado.

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Abstract

As part of the development of the draft North Coast and Cascades Network Mountain Lake Monitoring Protocol, the zooplankton communities of 18 subalpine lakes, 6 at Mount Rainier National Park, 6 at North Cascades National Park Service Complex, and 6 at Olympic National Park, were sampled during August through September of 2009. Samples were identified to the lowest possible taxonomic level and data were analyzed via multivariate community techniques. During the 2009 ice-free season, the zooplankton community structure of each park was distinctly different. Mount Rainier and North Cascades zooplankton communities were numerically dominated by rotifers, driven largely by the genera *Conochilus* and *Keratella*, while Olympic communities were numerically dominated by cladocerans. The cladoceran *Holopedium gibberum*, found almost ubiquitously across Mount Rainier lakes, was found only in Mount Rainier. Mount Rainier lakes had the most taxa (average of 11.2 ± 1.7), while Olympic lakes had the fewest (average of 7.2 ± 2.8). NOCA lakes had an average of 9.0 ± 2.3 taxa. These data suggest that there are regional differences within the NCCN in species pools and factors that structure zooplankton communities.

Acknowledgments

Zooplankton samples were identified and enumerated by the contract taxonomist Dr. A. Vogel. Samples were collected by field crews in each of three NCCN mountain lake parks. The MORA field crew included: J. Layman, A. McCulloch, G. Picayo. The NOCA field crew included H. Anthony, M. Eckmann, M. Parker, and A. Rawhouser. The OLYM field crew included: B. Downham, H. Levine, L. Loken. N. Antonova provided assistance with the composition of GIS maps. P. Crain and S. Hampton provided valuable review comments.

Introduction

This report presents zooplankton community assemblage data from the 2009 field season during the development of the draft Mountain Lakes Monitoring Protocol in the North Coast and Cascades Network (NCCN) as part of the Inventory and Monitoring Program of the National Park Service (NPS). The program focuses on “vital signs”, which are defined as information-rich attributes that are used to track the overall condition, or “health” of park natural resources to provide early warning of situations that require intervention” (Fancy et al. 2009). Monitoring has been implemented throughout the National Park system; for this purpose, 270 park units have been organized by ecoregion into 32 networks (Fancy et al. 2009). As one of these networks, the NCCN is composed of eight NPS units, including three with mountain lakes (Figure 1): Mountain Rainier National Park (MORA), North Cascades National Park Service Complex (NOCA), and Olympic National Park (OLYM). Mountain lakes were identified as a key vital sign at numerous workshops developing the NCCN Inventory and Monitoring Program (Weber et al. 2009).

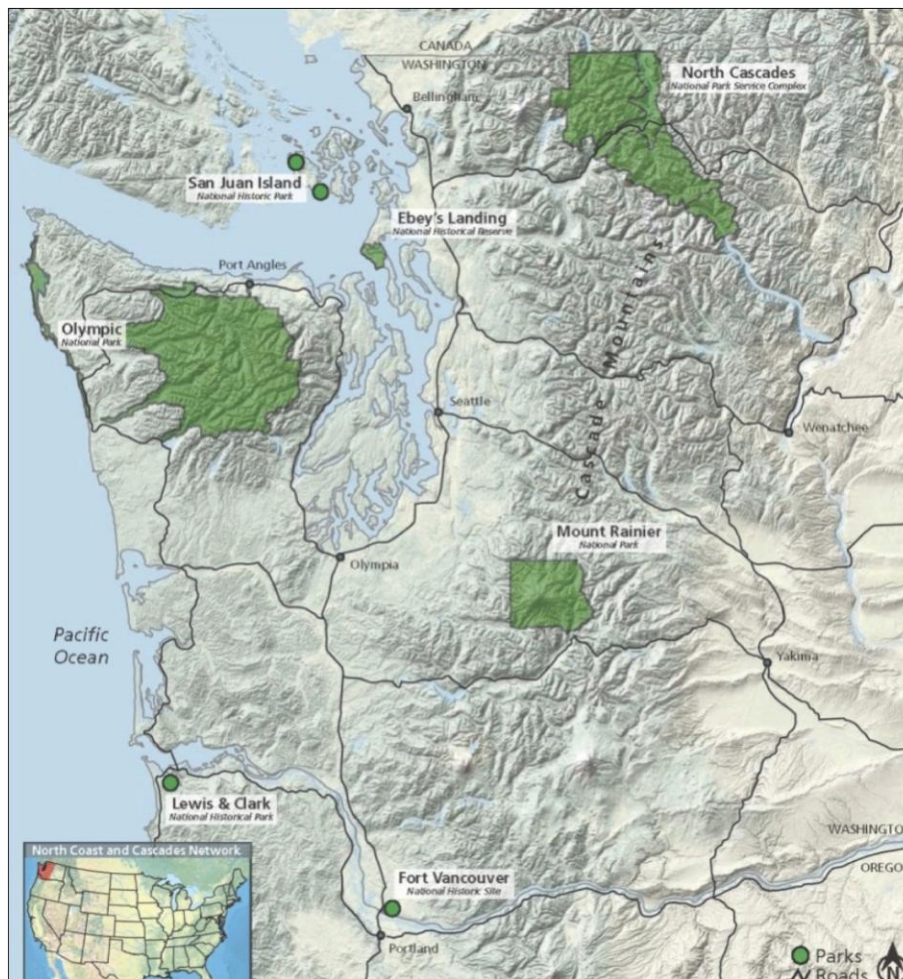


Figure 1. Map illustrating locations of parks within the North Coast and Cascades Network. The three parks with mountain lakes that make up the Mountain Lakes Protocol parks are Mount Rainier National Park (MORA), North Cascades National Park Service Complex (NOCA), and Olympic National Park (OLYM).

Mountain lakes are essential park ecosystems in the NCCN, both culturally and ecologically. The NCCN contains over 1608 mountain lakes and ponds. These lakes are enormously popular visitor destinations due to their esthetic and natural characteristics. Mountain lakes are tightly linked to their neighboring terrestrial environments, as critical breeding sites for many amphibian and insect species, and water sources and feeding grounds for park wildlife. These sensitive ecosystems have in-lake physical and biological processes that respond to and integrate a suite of key environmental stressors (Thompson et al. 2005, Vinebrooke and Leavitt 2005, Christensen et al. 2006). Mountain lakes function as “petri dishes in the sky”, by integrating the effects of global climate change, atmospheric deposition, visitor impacts, amphibian declines, and exotic species introductions. As a broad-spectrum monitoring program that is sensitive to each of the identified stressors, the NCCN Mountain Lakes Monitoring Protocol addresses a range of regional and park-specific management issues that are relevant both now and into the future.

The mountain lake parks of the NCCN span a gradient of urban influence, from the highly populated greater Puget Sound region (MORA, NOCA), to the sparsely populated Olympic Peninsula (OLYM). These parks also span a west-east precipitation gradient, from the very wet OLYM, to the drier MORA and NOCA. This precipitation gradient is also present in each park with the western areas being relatively wetter than the eastern areas. Because of these gradients, network parks and areas within may respond differently to certain stressors (i.e., atmospheric deposition of contaminants), while responding similarly to others (i.e., global climate change) (Eilers et al. 1989, Cole and Landres 1996). Lake ecosystems have a rich history of ecological research and have provided fundamental ecological concepts, mechanistic explanations, and demonstrations of anthropogenic change (i.e., Goldman 2000). The NCCN Mountain Lakes Monitoring Program utilizes a cost efficient comprehensive approach (multiple indicators representing key physical, chemical, and biological attributes) which will serve to address current issues as well as future emerging issues.

Pelagic zooplankton are important constituents of mountain lake food webs. They transfer energy between primary producers and secondary consumers (i.e., fish, salamanders, etc.). Changes in zooplankton species richness, community composition, and abundance provide insight into the effects of environmental perturbations that can alter lake productivity, water quality, competitive interactions, predator-prey interactions, and the introduction of non-native species (e.g., Edmonson and Litt 1982, Arnott et al. 1998, Hampton 2005, Frost et al. 2006). This report covers solely the zooplankton component of the NCCN Mountain Lakes Protocol. In particular, this report focuses on the taxonomic structure of the NCCN mountain lake zooplankton communities. More detailed analyses of trends in zooplankton community structure and associated environmental variables will be presented in an upcoming 5-year synthesis report.

Study Areas

Mount Rainier National Park (MORA)

Mount Rainier National Park, established in 1899, is located in the Southern Cascades physiographic province, in western Washington and is surrounded mostly by national forest lands, of which approximately 147,000 hectares are designated wilderness. MORA encompasses 95,354 ha and is located about 100 kilometers southeast of the Seattle-Tacoma metropolitan area. Designated wilderness encompasses 97 percent of the park and developed areas make up 3 percent including a National Historic Landmark District that encompasses park roads and some

developed areas. At 4392 m, Mount Rainier, an active volcano that last erupted about 150 years ago, is the most prominent peak in the Cascade Range. The park contains 26 named glaciers across 9 major watersheds, with approximately 405 lakes and ponds, and 470 rivers and streams and over 1214 ha of other wetland types. Vegetation is diverse, reflecting the varied climatic and environmental conditions encountered across the park's 3900 m elevation gradient. Approximately 58 percent of the park is forested, 23 percent is subalpine parkland, and the remainder is alpine, half of which is vegetated and the other half consists of permanent snow and ice.

North Cascades National Park Service Complex (NOCA)

North Cascades NPS Complex, (North Cascades National Park, Ross Lake National Recreation Area, and Lake Chelan National Recreation Area), established in 1968, covers 276,901 ha of the Cascade Range from the Canadian border south approximately 80 km to the head of Lake Chelan. The Stephen Mather Wilderness encompasses approximately 93% of the Complex. The park complex is located in the North Cascade physiographic province, in northwestern Washington. It is surrounded on the west, south and east by 1.9 million hectares of national forest lands, of which 763,890 hectares are designated wilderness. NOCA shares its northern boundary with the Canadian province of British Columbia. The park complex is characterized by deep, forested valleys between high, glaciated mountain peaks. The North Cascades NPS Complex spans the Cascade crest, placing within its boundary two major biogeographic zones: temperate marine and semi-arid continental. Precipitation varies across elevation gradients and the crest of the North Cascade Range, with a maximum average of about 400 cm/year on the western peaks to a minimum average of 50 cm/year in the Lake Chelan corridor. There park contains 318 glaciers, 554 lakes and ponds, and approximately 6,500 kilometers of perennial rivers and streams. NOCA watersheds eventually flow into four major river systems: Columbia River, Fraser River, Skagit River and Nooksack River. There are three reservoirs within Ross Lake NRA, all behind dams built to provide hydroelectric power. Lake Chelan, which developed within a deep, glacial trough, is the third deepest natural lake in the United States.

Olympic National Park (OLYM)

Olympic National Park, established in 1938, protects 373,384 ha of three distinctly different, yet interwoven ecosystems – rugged glacier-capped mountains, more than 100 km of wild Pacific coastline, and magnificent stands of old-growth temperate rain forest. Olympic encompasses one of the largest wilderness areas in the contiguous United States with 95% of its area in congressionally designated wilderness. Bounded by the Strait of Juan de Fuca to the north, the Hood Canal extension of Puget Sound to the east, and the Pacific Ocean to the west, the Olympic Mountains are geographically isolated from other Washington mountain ranges and are characterized by glaciated peaks and steep elevation gradients (0-2428 m). A marked precipitation gradient characterizes the Olympics where the wettest location in the conterminous United States is less than 60 km from the driest west coast site north of southern California. The mean annual precipitation ranges from around 48 centimeters per year on the dry northeastern part of the peninsula to 600 centimeters per year at the crest of the Olympic range. There park contains 266 glaciers, 649 lakes and ponds, and approximately 5,600 kilometers of rivers and streams. The park is almost entirely roadless, with trails largely confined to valley bottoms along with some leading up steep ascents to ridges and glacial basins. Access off of established trails is difficult and time-consuming.

Sampling Design

The study site lakes included in this report are reference lakes selected to be sampled annually for the duration of the NCCN Mountain Lakes long-term monitoring program (Glesne et al. 2012). The NCCN Mountain Lakes Protocol identifies a total of 20 NCCN reference lakes, six in MORA, six in NOCA, and eight in OLYM. During the 2009 protocol development season, only six reference lakes had been established in OLYM. Thus, this report examines only the zooplankton communities from 18 NCCN lakes.

Study site lakes were randomly selected from target populations of NCCN lakes that meet certain criteria in an attempt to standardize the type of lake sampled. Study lakes for each park are illustrated in Figures 2-4. These criteria are:

- Lakes are entirely within park boundaries
- Lakes have surface areas ranging from 0.4 to 6.0 ha
- Lakes ranging in elevation from 1220m to the upper limit of the subalpine zone
- Lakes are not heavily influenced by glacial runoff
- Lakes are safely accessible on foot by trail or off trails during August and September
- Lakes have maximum depths >2.5m
- Lakes do not have high densities of fish.

Study site lakes were visited once for sampling during mid-summer and early fall (August through September), to approximate the middle of the ice-free plankton growing season. A variety of physical, chemical and biological parameters were sampled during each visit. Water chemistry, chlorophyll-a, zooplankton, Secchi depth and water column profiles (dissolved oxygen, temperature, pH, specific conductivity) were sampled at a permanent sampling buoy located at the deepest point in each lake. Air temperature and water temperature at the surface, mid-depth and bottom depth was recorded continuously throughout the year by temperature dataloggers deployed at the sampling buoy. Water level was measured at two stations located on each lake shoreline. Complete shoreline surveys were used for recording observations of amphibians. Details related to the sampling design can be found in the draft protocol (Glesne et al. 2012).

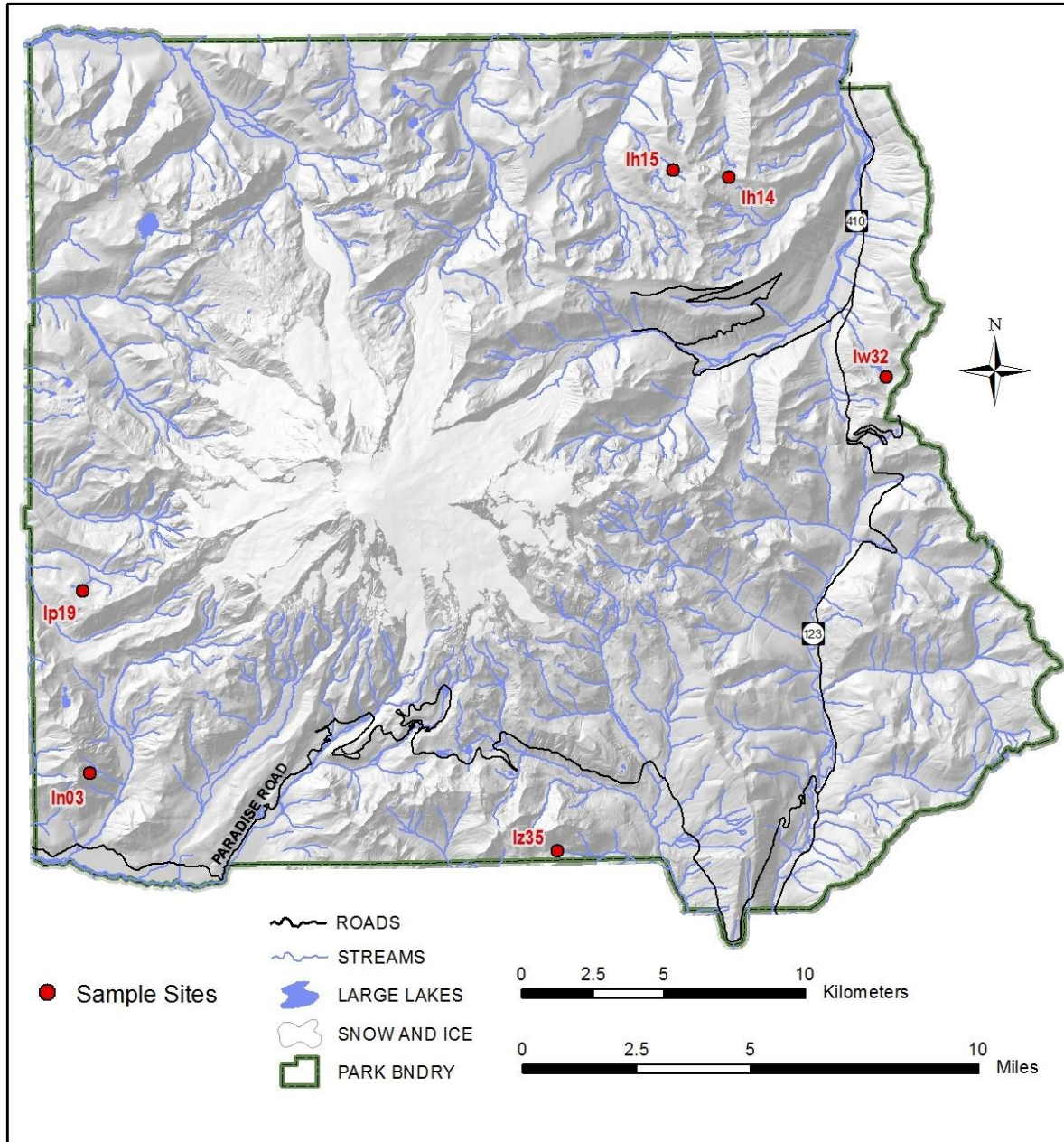


Figure 2. Map of the MORA study site mountain lakes. Lake Allen (ln03), Upper Palisades Lake (lh14), Deadwood Lake (lw32), Blue Lake (lz35), lh19 and lh15.

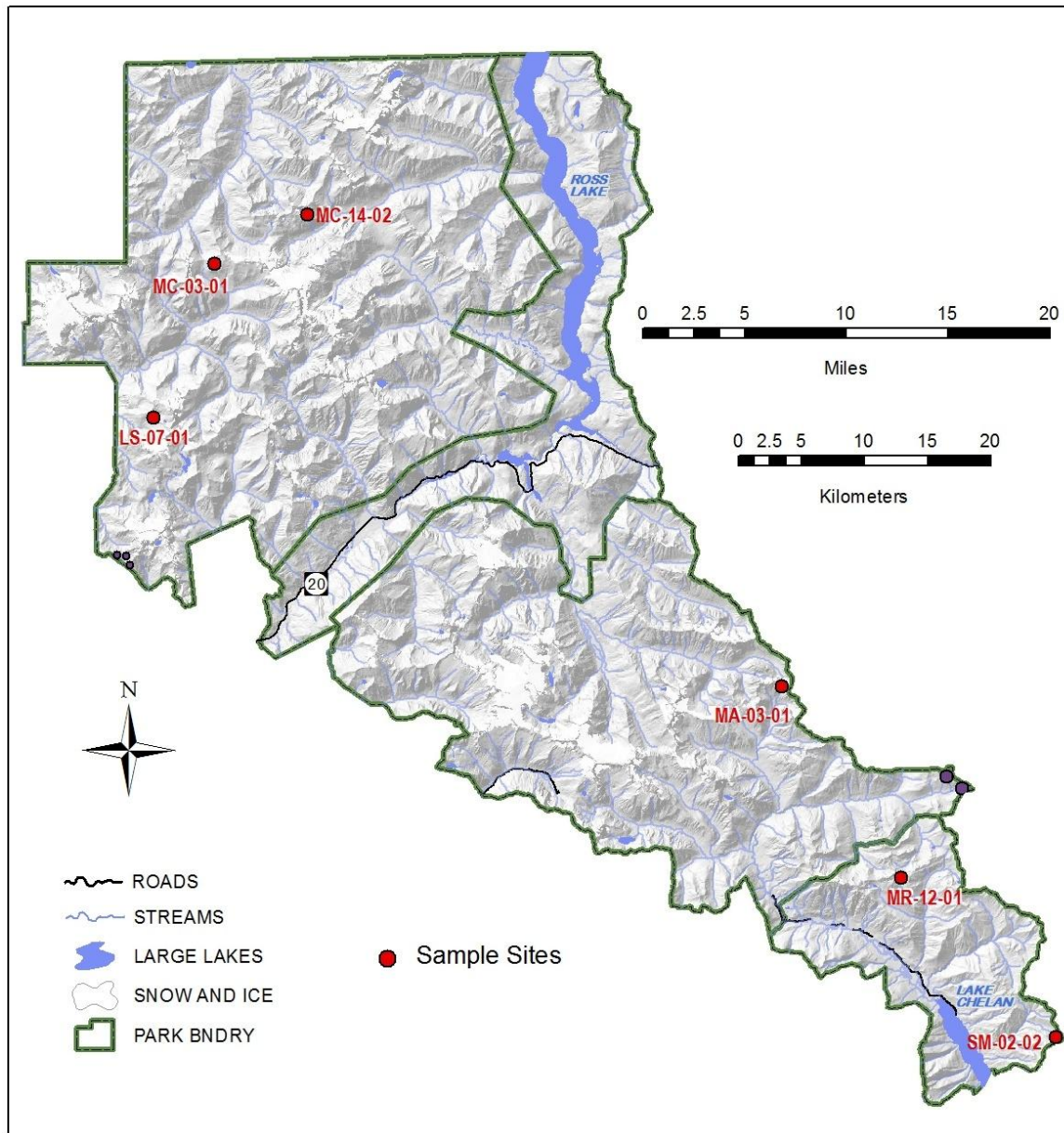


Figure 3. Map of the NOCA study site mountain lakes. Bowan Lake (MR-12-01), Lower Silent Lake (MA-03-01), Lower East Lake (MC-14-02), Upper Triplet Lake (SM-02-02), Easy Ridge Lake (MC-03-01), Lower Blum Lake (LS-07-01).

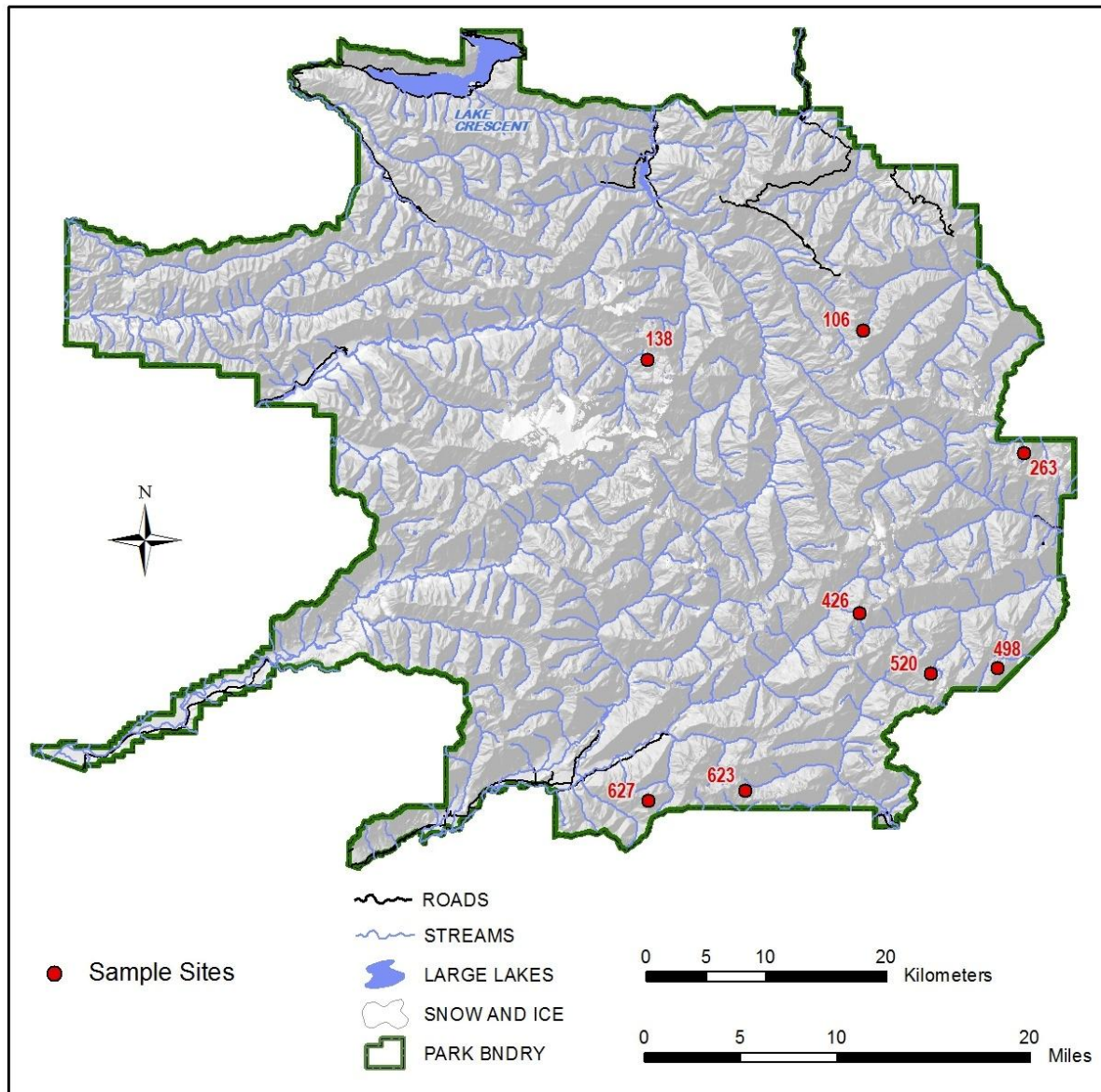


Figure 4. Map of OLYM study site mountain lakes. Ferry lake (138), Gladys lake (106), Heather lake (263), Lake LaCrosse (426), Crazy Lake (520), Milk Lake (498), Lake Sunup (623), and Lake Connie (627). In the 2009 sample season, Lakes LaCrosse and Crazy were not sampled.

Methods

Zooplankton samples were collected from the deep water sampling station using a 20 cm diameter (64- μ m mesh) Wisconsin-type zooplankton net towed vertically at approximately 0.5 m/sec from 1.0 m off the lake bottom to the surface. Three replicate tows were sampled at each lake. Net filtration efficiency was assumed to be 100%. Samples were preserved with either 95% Ethanol or with acid Lugol's solution. Samples were shipped to contractor Dr. Allen Vogel (ZP's Taxonomic Services, Lakewood, WA) who counted and identified zooplankton to the lowest possible taxonomic level. Pooled zooplankton samples were subsampled so that a minimum of at least 100 of the most abundant zooplankton species was counted. Zooplankton counts were conducted on a minimum of three subsamples of each sample using standard methods under a dissecting microscope (32x). Zooplankton abundance data for each NCCN park are presented in Appendix A.

Zooplankton community analyses were conducted using the multivariate methods in PRIMER-v6 (Clarke and Gorley 2006). Zooplankton species abundances were 4th root transformed to deemphasize the most abundant organisms (*sensu* Clarke and Warwick 2001). Bray-Curtis similarities were generated and represented with non-metric multidimensional scaling (MDS). Similarity percentage analyses (SIMPER) were used to identify zooplankton taxa contributing the most to the average similarity within parks, and analysis of similarity (ANOSIM) was used to test for significance of differences in community structure between parks. An analysis of taxonomic distinctness of each lake was conducted using the TAXTDEST procedure and a master taxa list for all parks. Diversity measures for each lake were also computed using the DIVERSE procedure. Differences in diversity measures between parks were analyzed via one-way ANOVAs and pairwise comparisons using JMP 7.0 (SAS 2007).

Results and Discussion

NCCN Zooplankton Community Structure

Zooplankton assemblage structure between parks in 2009 was significantly different ($P = 0.001$), and pairwise comparisons of each park show each park's assemblage structure to be distinctly different (Table 1). These differences are apparent in the clustering of park zooplankton assemblages in an MDS plot (Figure 5). More detail about these relationships among lake assemblages is displayed in a dendrogram in Figure 6.

Table 1. Analysis of similarities (ANOSIM) pairwise tests of 2009 zooplankton assemblage structure between NCCN Mountain Lake parks. The Global Test of a park difference was significant ($P = 0.001$, $R = 0.422$ based on 999 permutations).

Groups	R Statistic	P value	Possible Permutations	Actual Permutations	Number Observed
MORA, NOCA	0.415	0.006	462	462	3
MORA, OLYM	0.476	0.002	462	462	1
NOCA, OLYM	0.357	0.006	462	462	3

Taxonomic Distinctness

Average taxonomic distinctness is defined as the average taxonomic distance apart (phylogenetically) of all species pairs within a species list (Clarke and Gorley 2006). This is a measure of the taxonomic breadth of a sample. Figure 7 displays a funnel plot with simulated 95% probability limits for average taxonomic distinctness based on 999 taxa sublists drawn randomly from a master list of 131 taxa previously identified from lakes within the NCCN (A. Vogel, personal communication). OLYM study site lakes had fewer species, and generally lower average taxonomic distinctness values (i.e. narrower taxonomic breadths relative to NOCA and MORA lakes). One OLYM lake (Ferry) had significantly reduced average taxonomic distinctness (i.e., the point falls just outside of the 95% probability limit).

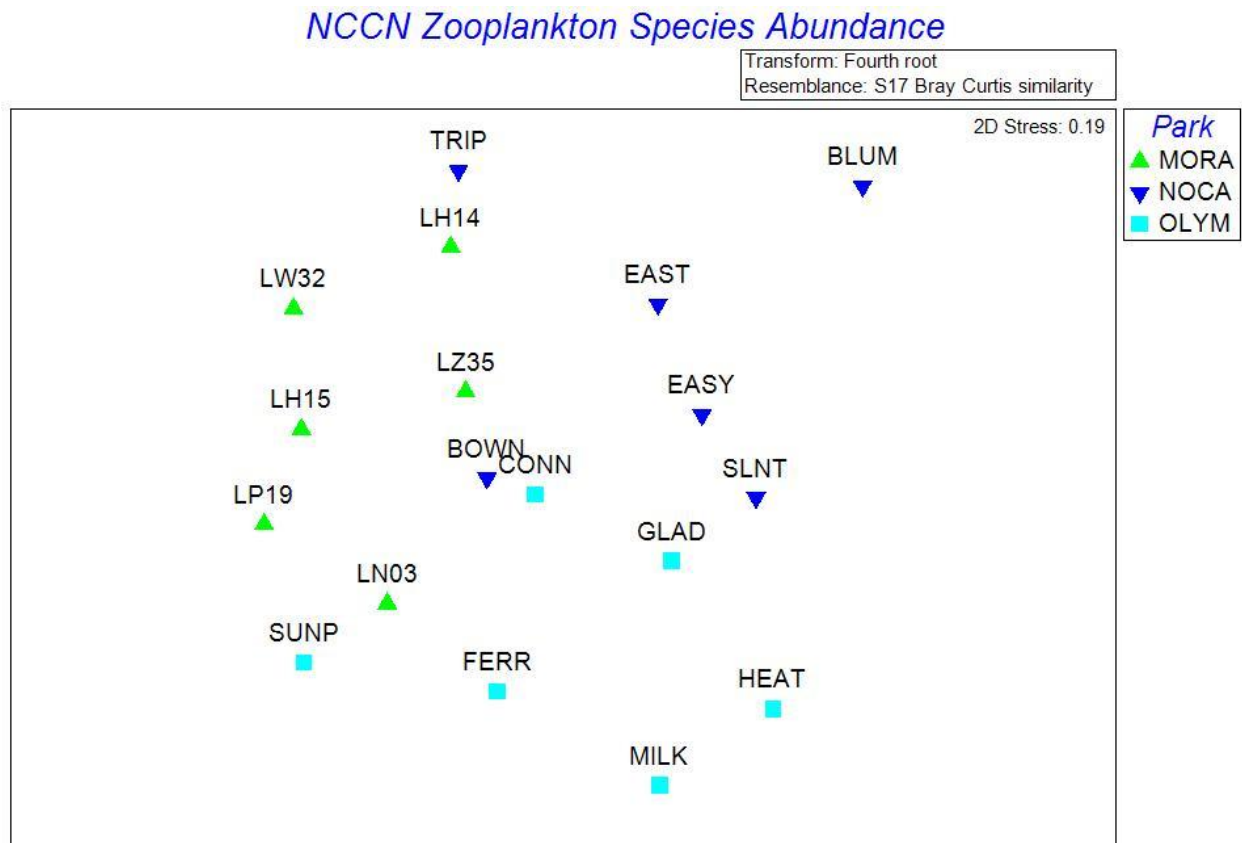


Figure 2. Zooplankton assemblages from NCCN study site mountain lakes. MDS plot for 4th root transformed species counts of 55 taxa from 18 lakes (6 lakes per park).

Diversity measures

Zooplankton taxonomic diversity appears to differ between parks, with an apparent diversity gradient; it is highest at MORA and lowest at OLYM (Table 2, Figure 8). Taxa richness (S), measured by the overall number of taxa observed between the six lakes at each park was significantly different (ANOVA $F(2,15) = 4.5393$, $p = 0.0289$) while the taxa richness measured by the Margelef index (d) and Shannon diversity index (H') was not. However, pairwise comparisons consistently showed that MORA had a significantly greater number of taxa, taxa richness, and Shannon diversity than OLYM (t-tests, $p = 0.0089$, 0.0593 , 0.018 respectively). The NOCA diversity measures were not significantly different from either OLYM or MORA.

Table 2. Average, Standard Deviation and lake specific diversity measures of NCCN study site mountain lakes. S= Total taxa, d = Taxa richness, H' = Shannon diversity index.

Park	Lake	S	d	H'
MORA	Average	11.2	2.55	2.21
	Std. Dev.	1.7	0.49	0.16
	LH15	11	2.32	2.20
	LN03	11	2.64	2.14
	LP19	9	1.90	2.07
	LW32	12	2.92	2.22
	LZ35	14	3.26	2.50
	LH14	10	2.25	2.11
NOCA	Average	9.0	2.32	2.03
	Std. Dev.	2.3	0.51	0.21
	BLUM	12	3.17	2.22
	BOWN	11	2.65	2.28
	EAST	9	2.28	2.10
	EASY	7	1.96	1.85
	SLNT	6	1.84	1.73
	TRIP	9	2.01	1.99
OLYM	Average	7.2	1.92	1.79
	Std. Dev.	2.8	0.59	0.38
	CONN	8	1.92	1.95
	FERR	11	2.94	2.27
	GLAD	7	1.86	1.81
	HEAT	4	1.42	1.34
	MILK	4	1.28	1.34
	SUNP	9	2.12	2.06

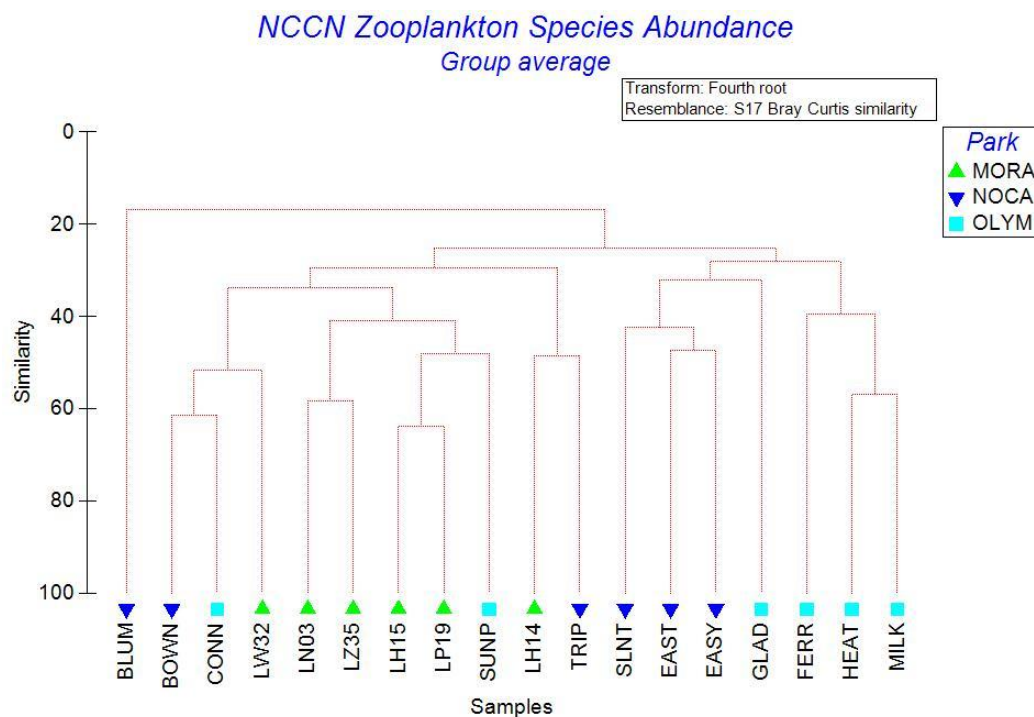


Figure 3 Dendrogram using group-average linking on Bray-Curtis species similarities from standardized abundance data. Lake codes are described in Figures 2, 3 and 4.

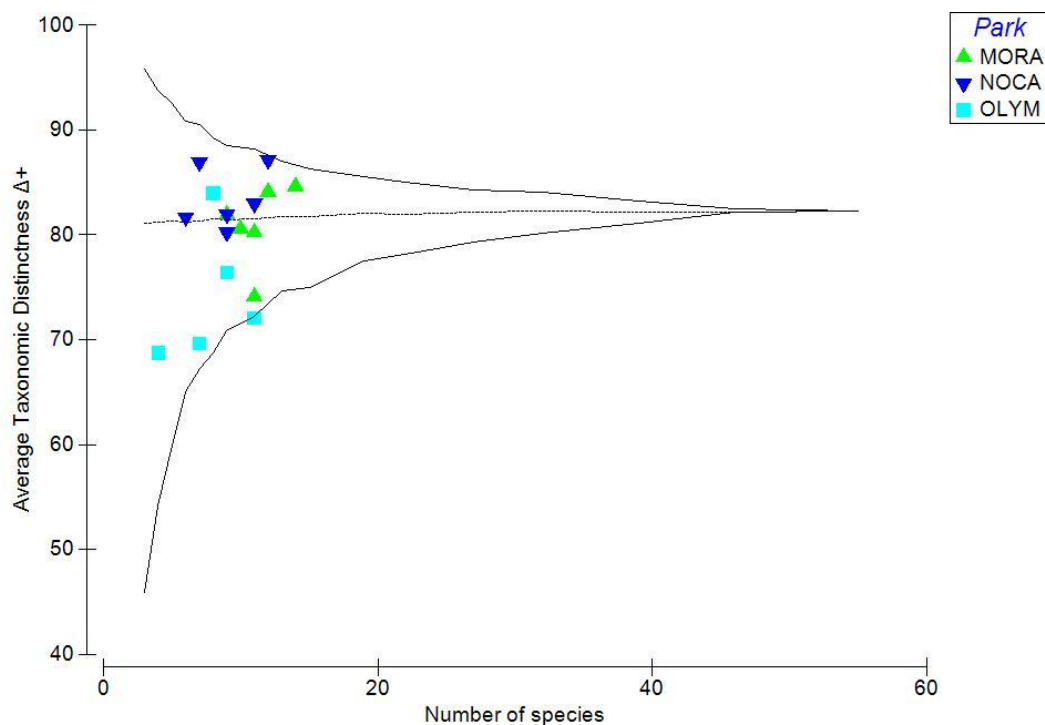


Figure 7. Funnel plot of average taxonomic distinctness (Δ^+) versus number of species in taxonomic sublist for zooplankton assemblages in each NCCN park. Thick lines indicate 95% probability limits for simulated Δ^+ values. The dotted line denotes the Δ^+ for the entire taxa list. Symbols denote actual Δ^+ values for the park/lake 2009 sample combinations.

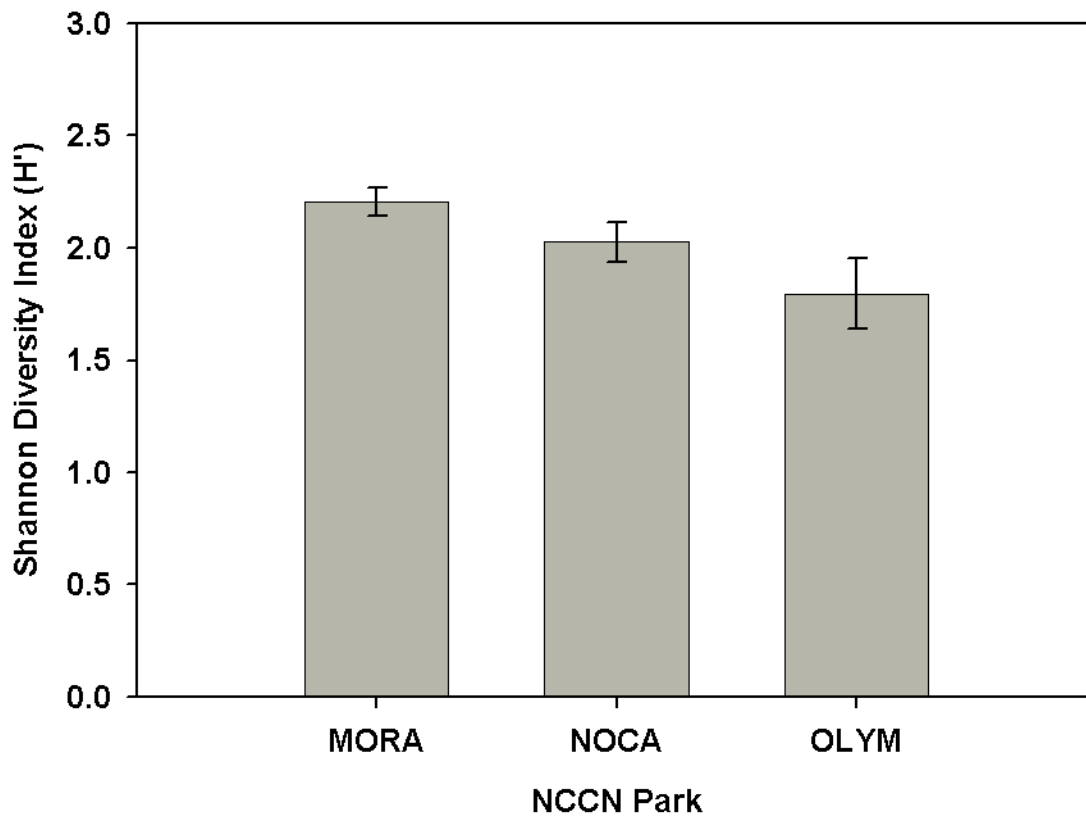


Figure 8. Average Shannon Diversity Index (H') values ($\pm$ SE) for 6 study site lakes in each NCCN mountain lake park. Overall park diversity measures are not significantly different (one-way ANOVA, $F=3.5465$, $P=0.0548$). Student's t pairwise comparison show MORA/OLYM diversity to be significantly different ($p=0.018$), while MORA/NOCA and NOCA/OLYM diversity are not significantly different ($p=0.1552$ and $p=0.2645$ respectively).

Species contributions to community structure

The community structure at each park was dominated by a different number and set of species (Table 3). At MORA, 7 taxa contributed most to community structure (i.e., those contributing up to 80% cumulative similarity). Of these, the colonial rotifer *C. unicornis*, the cladoceran *H. gibberum*, and juvenile copepods had the most consistent presence across MORA lakes (i.e. with Similarity/Standard Deviation ratios >1). It is interesting to note that *H. gibberum* was found only in MORA in 2009, and was fairly ubiquitous, being found at 5 of the 6 lakes (Appendix A1). At NOCA, 4 taxa contributed the most to community structure. Of these, juvenile copepods and the rotifer *K. cochlearis* had the most consistent presence across NOCA lakes. At OLYM, 3 taxa contributed the most to community structure. Of these, juvenile copepods and the adult calanoid copepod *H. kenai* had the most consistent presence across OLYM lakes.

Table 3. Zooplankton taxonomic contribution to similarity of community structure within MORA, NOCA, and OLYM as determined by SIMPER analysis. Taxa shown are only those contributing up to a cut-off of ~80% cumulative percent contribution.

Park	Species	Average Abundance	Average Similarity	Similarity SD ratio	Percent Contribution	Cumulative Percent
MORA	<i>Conochilus unicornis</i>	10.2	9.3	1.1	23.6	23.5
	Calanoid copepodid	5.6	7.3	2.1	18.5	42.1
	<i>Holopedium gibberum</i>	4.6	4.3	1.1	10.8	52.8
	<i>Keratella cochlearis</i>	6.1	4.2	0.6	10.6	63.4
	copepod nauplii	3.1	3.0	1.2	7.6	70.9
	Cyclopoid copepodid	2.1	2.0	0.8	5.0	76.0
	<i>Daphnia rosea</i>	2.5	1.9	0.5	4.7	80.6
	<i>Hesperodiaptomus arcticus</i>	2.9	1.9	0.5	4.7	85.3
	<i>Microcyclops varicans</i>	1.6	1.4	0.8	3.5	88.8
	Diaptomid copepodites	3.3	1.3	0.5	3.2	92.0
NOCA	Calanoid copepodid	4.5	9.9	1.2	30.7	30.7
	<i>Keratella cochlearis</i>	5.1	7.6	5.5	23.5	54.1
	<i>Keratella hiemalis</i>	3.1	4.7	0.8	14.7	68.9
	Copepod nauplii	3.2	4.1	1.2	12.6	81.5
	Cyclopoid copepodid	1.3	2.0	0.8	6.2	87.6
	Chironomid larvae	1.3	1.7	0.8	5.2	92.8
OLYM	Calanoid copepodid	3.4	11.0	2.2	32.9	32.9
	Copepod nauplii	3.3	9.3	2.5	27.6	60.5
	<i>Hesperodiaptomus kenai</i>	3.3	8.0	1.2	23.8	84.3
	Chaoborus larvae	1.4	2.1	0.5	6.3	90.5

Between parks community structure differences are driven largely by the abundance and presence of rotifers and cladocerans (Table 4). MORA zooplankton differs from NOCA and OLYM zooplankton mainly by the presence and abundance of *C. unicornis*, *K. cochlearis*, *H. gibberum*, and *D. rosea*. NOCA and OLYM zooplankton differ mainly by the presence and abundance of *Keratella* species and calanoid copepods.

In summary, the zooplankton communities in each park had distinctly different structure in 2009. MORA had the highest taxonomic diversity and number of taxa, while OLYM has the lowest. Rotifers numerically dominated the zooplankton of MORA and NOCA lakes, while copepods and cladocerans dominated the OLYM zooplankton (Figure 9). These data suggest that regional differences in the factors that structure zooplankton communities exist within the NCCN. Analysis of data from future years will be critical to determine how robust this pattern is over time.

Table 4: Pairwise comparisons of zooplankton taxonomic contribution to differences in community structure between parks as determined by SIMPER analysis. Taxa shown are only those contributing up to a cut-off of ~40% cumulative percent contribution.

Park	Species	Park1 Avg. Abund.	Park2 Avg. Abund.	Avg. Dissimilarity	Dissimilarity SD ratio	Percent Contribution	Cumulative Percent
MORA & NOCA	<i>Conochilus unicornis</i>	10.2	0.5	10.8	1.5	14.8	14.8
	<i>Keratella cochlearis</i>	6.1	5.1	6.9	1.3	9.5	24.3
	<i>Holopedium gibberum</i>	4.6	0.0	5.1	1.3	7.0	31.4
	<i>Daphnia rosea</i>	2.5	1.3	3.6	1.0	4.9	36.3
NOCA & OLYM	<i>Conochilus unicornis</i>	10.2	2.1	11.0	1.4	4.8	14.8
	<i>Keratella cochlearis</i>	6.1	1.5	7.8	1.0	10.6	25.4
	<i>Holopedium gibberum</i>	4.6	0.0	5.6	1.3	7.6	33.0
	<i>Daphnia rosea</i>	2.5	1.4	4.0	1.0	5.4	38.4
	Sm. diaptomid copepodites	3.3	1.3	4.0	1.0	5.4	43.8
OLYM & MORA	<i>Keratella cochlearis</i>	5.1	1.5	8.5	1.5	11.4	11.4
	<i>Keratella hiemalis</i>	3.1	0.0	6.1	1.1	8.3	19.7
	<i>Hesperodiaptomus kenai</i>	1.8	3.3	5.3	1.4	7.2	26.9
	Calanoid copepodid	4.5	3.4	4.7	1.6	6.4	33.3

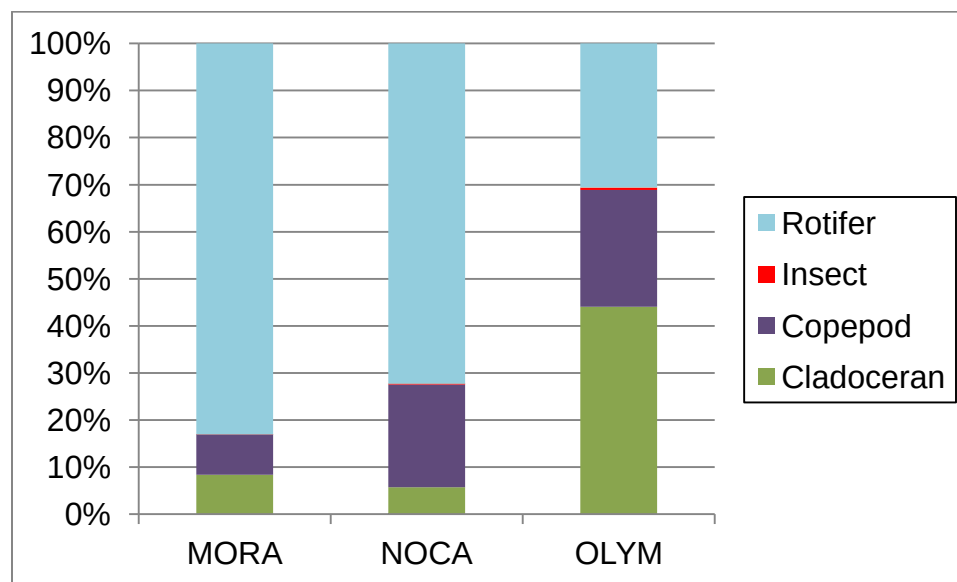


Figure 9: Average percent of major zooplankton taxonomic groups in study site lakes for each NCCN Mountain Lake park.

Literature Cited

- Arnott, S. E., J. J. Magnuson, and N. D. Yan. 1998. Crustacean zooplankton species richness: single- and multiple-year estimates. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1573-1582.
- Christensen, M. R., M. D. Graham, R. D. Vinebrooke, D. L. Findlay, M. J. Paterson, and M. A. Turner. 2006. Multiple anthropogenic stressors cause ecological surprises in boreal lakes. *Global Change Biology* 12:1-7.
- Clarke, K. R., and R. M. Warrick. 2001. Change in marine communities: an approach to statistical analyses and interpretation. 2nd Ed. Primer-3, Plymouth, UK.
- Clarke, K. R., and R. N. Gorley. 2006. PRIMER v6: User manual/tutorial. Primer-e, Plymouth, UK.
- Cole, D. N., and P. B. Landres. 1996. Threats to wilderness ecosystems: impacts and research needs. *Ecological Applications* 6:168-184.
- Edmondson, W. T., and A. H. Litt. 1982. Daphnia in Lake Washington. *Limnology and Oceanography* 27:272-293.
- Eilers, J. M., D. F. Brakke, D. H. Landers, and W. S. Overton. 1989. Chemistry of wilderness lakes in the Western United States. *Environmental Monitoring and Assessment* 12:3-21.
- Fancy, S. G., J. E. Gross, and S. L. Carter. 2009. Monitoring the condition of natural resources in US national parks. *Environmental Monitoring and Assessment* 151:161-174.
- Frost, T. M., J. M. Fisher, J. L. Klug, S. E. Arnott, and P. K. Montz. 2006. Trajectories of zooplankton recovery in the Little Rock Lake whole-lake acidification experiment. *Ecological Applications* 16:353-367.
- Glesne, R. S., S. C. Fradkin, B. A. Samora, J. R. Boetsch, R. E. Holmes, and B. Christoe. 2012. Protocol for long-term monitoring of mountain lakes in the North Coast and Cascades Network: Version July 3, 2012. Natural Resource Report NPS/NCCN/NRR—2012/549. National Park Service, Fort Collins, Colorado.
- Goldman, C. R. 2000. Four decades of change in two subalpine lakes. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie* 27:7-26.
- Hampton, S. E. 2005. Increased niche differentiation between two *Conochilus* species over 33 years of climate change and food web alteration. *Limnology and Oceanography* 50:421-426.
- SAS. 2007. JMP 7 statistics and users guide. SAS Institute Inc. Cary, North Carolina.
- Thompson, R., C. Kamenik, and R. Schmidt. 2005. Ultra-sensitive alpine lakes and climate change. *Journal of Limnology* 64:139-152.

- Vinebrooke, R. D., and P. R. Leavitt. 2005. Mountain lakes as indicators of the cumulative impacts of ultraviolet radiation and other global stressors. Pages 497-509 in U. M. Huber, K. M. Bugmann and M. A. Reasoner, eds. *Global change and mountain regions: A state of knowledge overview*. Springer-Verlag, New York, New York.
- Weber, S., A. Woodward, and J. Freilich. 2009. North Coast and Cascades Network vital signs monitoring report (2005). Natural Resource Report NPS/NCCN/NRR—2009/098. National Park Service, Fort Collins, Colorado.

Appendix A: Zooplankton Density Data

Table A1. Zooplankton abundance data (number/m³) by taxon for the 6 study site mountain lakes in Mount Rainier National Park.

Taxon	MORA Lakes					
	LH15	LN03	LP19	LW32	LZ35	LH14
Cladoceran						
<i>Chydorus sphaericus</i>	0	0	0	4.2	0	25.2
<i>Daphnia ambigua</i>	1061	0	848.8	0	0	125.8
<i>Daphnia rosea</i>	0	358.6	0	1443	364.9	0
<i>Holopedium gibberum</i>	297.1	0	123.5	59.4	3680.9	7343.9
<i>Pleuroxus aduncus</i>	0	7.3	0	0	0	0
<i>Polyphemus pediculus</i>	0	0	0	4.2	0	0
Copepods						
<i>Calanoid copepodid</i>	636.6	995.2	5000.4	4.2	2443.4	1131.8
<i>Copepod nauplii</i>	42.4	7.3	1605.1	0	349.1	251.5
<i>Cyclopoid copepodid</i>	127.3	65.9	0	0	43.6	176.1
<i>harpacticoid copepod</i>	0	0	0	0	0	25.2
<i>Hesperodiaptomus arcticus</i>	806.4	2092.8	0	0	745.7	0
<i>H. franciscanus</i>	0	7.3	0	0	0	0
<i>H. kenai</i>	0	0	771.7	84.9	0	0
<i>Leptodiaptomus signicauda</i>	0	0	0	0	0	1307.8
<i>Microcyclops varicans</i>	127.3	14.6	0	4.2	79.3	0
<i>Diaptomid copepodites</i>	15406.2	102.4	1034	0	0	0
Rotifers						
<i>Conochilus unicornis</i>	159579	25406.3	84450.5	339.5	2871.7	0
<i>Kellicottia longispina</i>	1697.7	0	17285.2	0	0	0
<i>Keratella cochlearis</i>	3395.3	0	0	18368.6	47.6	47886.4
<i>Keratella hiemalis</i>	0	0	0	0	15.9	0
<i>Keratella quadrata</i>	0	0	0	0	0	100.6
<i>Keratella serrulata</i>	0	0	0	0	15.9	0
<i>Keratella taurocephala</i>	0	0	0	0	15.9	0
<i>Polyarthra vulgaris</i>	0	0	493.9	1358.1	0	0
Insects						
<i>Chaoborus larvae</i>	0	7.3	0	0	0	0
<i>Chironomid larvae</i>	0	0	0	8.5	15.9	0
<i>mosquito larvae</i>	0	0	0	0	0	0
<i>mosquito pupae</i>	0	0	0	17	0	0
Protozoa						
<i>Diffugia sp.</i>	0	0	0	0	15.9	0

Table A2. Zooplankton abundance data (number/m³) by taxon for the 6 study site mountain lakes in North Cascades National Park Service Complex.

Taxon	NOCA Lakes					
	BLUM	BOWN	EAST	EASY	SLNT	TRIP
Cladoceran						
<i>Bosmina longirostris</i>	0	0	10.6	0	0	0
<i>Camptocercus rectirostris</i>	29.7	0	0	0	0	0
<i>Ceriodaphnia dubia</i>	0	0	0	0	0	167.2
<i>Daphnia ambigua</i>	0	0	201.6	0	0	1003.2
<i>Daphnia pulex</i>	0	0	53.1	0	0	0
<i>Daphnia rosea</i>	0	3887.6	0	0	0	0
<i>Scapholeberis armata</i>	0	0	0	0	0	60
Copepods						
<i>Calanoid copepodid</i>	0	2079.6	2164.5	673.8	355.4	257.2
<i>Copepod nauplii</i>	7.2	59.4	10.6	0	102.1	9337.1
<i>Cyclopoid copepodid</i>	5.6	17	53.1	5.3	0	0
<i>harpacticoid copepod</i>	1.5	0	0	0	0	0
<i>Hesperodiaptomus arcticus</i>	0	212.2	0	0	0	0
<i>H. kenai</i>	0	1510.9	0	397.9	0	0
<i>Leptodiaptomus sicilis</i>	0	0	1220.2	0	0	0
<i>Leptodiaptomus tyrrelli</i>	0	0	0	0	0	2152.1
<i>Microcyclops varicans</i>	4.6	0	0	0	0	0
<i>Ostracoda</i>	3.1	0	0	0	0	0
Rotifers						
<i>Conochilus unicornis</i>	0	93.4	0	0	0	0
<i>Keratella cochlearis</i>	39	432.9	127.3	37.1	9.3	60018
<i>Keratella hiemalis</i>	3362.5	0	488.1	249.3	15.9	0
<i>Lecane luna</i>	0	17	0	0	0	0
<i>Polyarthra vulgaris</i>	0	34	0	0	6.6	0
<i>Synchaeta sp.</i>	3329.7	0	0	0	0	0
<i>Trichocerca longiseta</i>	12.3	0	0	0	0	0
Insects						
<i>Chironomid larvae</i>	3.6	17	0	5.3	0	51.4
<i>mosquito larvae</i>	0	0	0	0	26.5	0
Arachnid						
<i>water mite</i>	0	0	0	0	0	25.7
Protozoa						
<i>Diffugia sp.</i>	12.3	0	0	37.1	0	0

Table A3. Zooplankton abundance data (number/m³) by taxon for the 6 study site mountain lakes in Olympic National Park.

Taxon	OLYM					
	CONN	FERR	GLAD	HEAT	MILK	SUNP
Cladoceran						
<i>Alona costata</i>	0	0	0	0	0	43.9
<i>Ceriodaphnia dubia</i>	0	0	811.7	0	0	0
<i>Chydorus sphaericus</i>	0	0	8	0	0	0
<i>Daphnia ambigua</i>	0	0	0	0	0	9329.8
<i>Daphnia pulex</i>	0	461.9	0	0	0	0
<i>Daphnia rosea</i>	4293.5	0	0	0	0	0
Copepods						
<i>Calanoid copepodid</i>	473.8	62.4	1074.3	38.6	30.7	22
<i>Copepod nauplii</i>	281.3	9.4	143.2	62.7	4.7	1646.4
<i>Cyclopoid copepodid</i>	0	3.1	8	0	0	0
<i>Diaptomus hesperus</i>	0	28.1	0	0	0	0
<i>harpacticoid copepod</i>	0	3.1	0	0	0	0
<i>Hesperodiaptomus. franciscanus</i>	0	0	1138	0	0	22
<i>H. kenai</i>	725.5	365.1	0	4.8	183.9	592.7
<i>Microcyclops varicans</i>	14.8	9.4	8	0	0	0
<i>Diaptomid copepodites</i>	0	6.2	0	0	0	1448.9
Ostracoda	14.8	0	0	0	0	0
Rotifers						
<i>Conochilus unicornis</i>	0	1160.9	0	0	0	2283.1
<i>Keratella cochlearis</i>	6884.4	0	0	0	0	0
<i>Polyarthra dolichoptera</i>	0	0	0	0	0	43.9
Insects						
<i>Chaoborus larvae</i>	74	37.4	0	0	70.7	0
Amphipods						
<i>Hyalella azteca</i>	0	0	0	4.8	0	0

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NPS 963/117181, October 2012

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