National Park Service
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Natural Resource Stewardship and Science

Mountain Lake Non-native Fish Eradication Pretreatment Planning Reconnaissance Surveys of Kettling, Skymo, and Sourdough Lakes at North Cascades National Park Service Complex, Washington

2010 Data Summary

Natural Resource Data Series NPS/NOCA/NRDS—2013/446

ON THE COVER
East end of Sourdough Lake, September, 2010
Photograph courtesy of North Cascades National Park

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Abstract

Ninety- three naturally fishless mountain lakes found in the park complex have been stocked with non-native trout, and currently 33 of these lakes contain naturally reproducing populations. These self-sustaining fish populations have the ability to overpopulate with multiple age classes, effectively dominating many trophic levels and consuming excessive amounts of their prey base. In addition, non-native trout are dispersing downstream from lakes and competing or hybridizing with native fish.

NPS Natural Resource Preservation Program (NRPP) funds have been obligated for the period of 2012-2014 to eliminate naturally reproducing fish populations in five lakes. Fish eradication in three of these lakes (Sourdough, Kettling, and Skymo Lakes) will be accomplished by chemical treatment using rotenone. The inherent complexity of lake and stream restoration projects using piscicides requires a comprehensive examination of a large number of physical, chemical and biological parameters that are used in the planning, implementation, and evaluation phases of the project. To address these needs, the objectives of this project were:

1. Provide basic physical, chemical, and biological data required for development of the Treatment Plans (e.g., lake bathymetry and features, hydrology, water temperature, pH and dissolved oxygen profiles; characteristics of the non-native fish population; identification of non-target native species of concern and their distribution etc.)

2. Provide baseline biological data for evaluation of impacts of the rotenone treatment on native zooplankton, macroinvertebrate, and amphibian communities and recovery of these communities in the absence of fish predation.

Site descriptions, methods and results of these data collection efforts are summarized in this report.

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Introduction

The North Cascades National Park Complex (NOCA) covers 684,000 acres and includes North and South Units of the National Park, Lake Chelan National Recreation Area, and Ross Lake National Recreation Area. The rugged mountainous landscape of NOCA contains 245 mountain lakes potentially suitable for sustaining fish populations that were naturally fishless due to impassable waterfalls and cascades. Though naturally "barren" of fish, mountain lakes contain a diverse assemblage of native species including plankton, macroinvertebrates, frogs and salamanders.

One of the principal threats facing aquatic resources at NOCA can be attributed to the widespread introduction of non-native fishes. Settlers began stocking North Cascade lakes in the late 1800's with various species of non-native trout. By the 20th century, stocking had become a routine management practice. Ninety three of the 245 naturally fishless mountain lakes found in the park complex have been stocked with non-native trout, and currently 33 of these lakes contain naturally reproducing populations. These self-sustaining fish populations have the ability to overpopulate with multiple age classes, effectively dominating many trophic levels and consuming excessive amounts of their prey base. After NOCA was established in 1968, a conflict over fish stocking emerged between the National Park Service (NPS) and Washington Department of Fish and Wildlife (WDFW) and reached a high point in mid-1980. Shortly thereafter, the NPS initiated a decade-long research effort through Oregon State University and the USGS-Biological Resources Division to evaluate the ecological effects of non-native fish in NOCA mountain lakes. The research concluded that reproducing populations of non-native fish, established through past stocking of lakes with sufficient spawning habitat, can overpopulate a lake and measurably deplete or extirpate their food base. More specifically, long-toed salamanders, large crustacean zooplankton, and several nearshore macroinvertebrates appear to be at greatest risk in warmer, productive lakes with self-sustaining trout populations (Liss et al. 2002, Tyler et al. 1998).

However, the degree of impact on amphibian, zooplankton, and macroinvertebrate populations appears to be dependent on the density of fish. Researchers were not able to identify statistically significant effects to native species in lakes stocked with low-densities of fish incapable of reproducing. Reproducing fish populations may exert more predatory pressure because of the typically higher densities of fish. Large zooplankters, macroinvertebrates and amphibians demonstrate co-existence with non-reproducing populations of salmonid fish, especially if suitable habitat factors are present (Liss 1998, Hoffman and Pilliod 1999, Divens et al. 2001).

Other research and monitoring efforts have found that the impacts of non-native trout are not just confined to lakes. Non-native trout are dispersing downstream from lakes and competing or hybridizing with native fish. For example, hybridization between introduced Rainbow Trout (*Oncorhynchus mykiss*) and native Westslope Cutthroat Trout (*O. clarki lewisi*) has been well documented in the eastern side of the park in the Stehekin River drainage (Ostberg and Rodriguez 2006) where pure strains of Westslope Cutthroat are currently only found in the upper reaches of the watershed. Brook Trout (*Salvelinus fontinalis*) are also found in some NOCA lakes, and their presence has been identified by the U.S. Fish and Wildlife Service (USFWS) as posing a significant threat to the status and recovery of downstream populations of Federally-listed Bull Trout (*Salvelinus confluentus*) through competition, introgressive hybridization, and predation (USFWS 2004).

Removal of non-native fish from mountain lakes in various protected areas is yielding very promising results. In Sequoia-Kings Canyon National Park, mountain yellow-legged frogs are rapidly recolonizing lakes where populations of non-native trout were recently removed (Vredenberg 2004). Long-toed salamanders (*Ambystoma macrodactylum*) have recolonized a number of lakes in Montana's Bitterroot Mountains following the extinction of introduced trout populations, despite low levels of inter-population dispersal (Funk and Dunlap 1999). In the Canadian Rockies, large crustacean zooplankton assemblages have recovered following the elimination of fish from mountain lakes, although recovery has taken an average of almost two decades (Donald 1989). At Mount Rainier National Park, gill net removal of Brook Trout from a small lake resulted in significant changes in the behavior and abundance of northwestern salamanders (*Ambystoma gracile*), with adults actively feeding during the day (instead of hiding) and more widely distributed throughout the lake (Hoffman et al. 2004). These case studies demonstrate that fish removal can lead to recovery of native organisms even without further intervention, such as introductions of founding populations, although recovery for some species can take many years.

In light of recent and past scientific findings, and in response to a lawsuit over the General Management Plan for Lake Chelan National Recreation Area, a Mountain Lakes Fishery Management Plan /Environmental Impact Statement was prepared (NPS 2005). A Record of Decision for the NOCA Mountain Lakes Fishery Management Plan/EIS was signed in December, 2008, which calls for the removal of self-sustaining populations of non-native trout from NOCA's mountain lakes.

Objectives

Building on experience from fish control pilot projects conducted in seven NOCA lakes during FY 2008 – FY 2010, a plan has been developed to eliminate naturally reproducing fish populations in five more lakes, beginning in 2012. Fish eradication in three of these lakes will be accomplished by chemical treatment using rotenone. The inherent complexity of lake and stream restoration projects using piscicides requires a comprehensive examination of a large number of physical, chemical and biological parameters that are used in the planning, implementation, and evaluation phases of the project (Moore et al. 2008, Finlayson et al. 2010). The objectives of this project were to:

1. Provide basic physical, chemical, and biological data required for development of the Treatment Plan (e.g., lake bathymetry, volume, and depth); lake features including substrate, woody debris, and aquatic vegetation, locations and flows of inlet and outlet streams water temperature, pH and dissolved oxygen profiles; characteristics of the non-native fish population; identification of non-target native species of concern and their distribution etc.

2. Provide baseline biological data for evaluation of impacts of the rotenone treatment of native species communities and recovery of these communities in the absence of fish predation (e.g., changes in zooplankton, macroinvertebrate, and amphibian species composition and abundance)

Site Selection and Description

Based on the criteria established for prioritizing and conducting removal of non-native fishes, three lakes were selected for this project: Sourdough and Skymo in the Ross Lake watershed and Kettling in the Lake Chelan/Stehekin watershed (Table 1). All of these waters are considered to be a high priority for rehabilitation based on the potential for restoring salamander habitat and reducing the impacts of non-native fish on downstream populations of rare and threatened fishes, (i.e. native Westslope Cutthroat Trout in the Lake Chelan watershed and Federally-listed Bull Trout in the Ross Lake watershed). Benefits to other amphibian species and native invertebrate species would also be realized.

Table 1. Characteristics of lakes selected for rotenone pre-treatment study and treatment year.

Name/Code	Drainage/Sub-Drainage	Elev. (m)	Surf. Area (ha)	Max Depth (m)	Fish Species	Treat. Year
Sourdough PM-12-01	Ross Lake/Pierce Ck	1,409	11.2	32.6	Brook	2012
Kettling MR-05-01	Stehekin/Bridge Ck	1,638	4	7	Rainbow	2013
Skymo PM-03-01	Ross Lake/Skymo Ck	1,608	4.4	6.1	Cutthroat	2014

All of the lakes selected for fish eradication are expected to provide excellent salamander habitat. Re-colonization should be rapid following fish removal, as all of these waters either have some salamanders present in the lake or are close to ponds with breeding populations. Although other species of amphibians inhabit lakes in the Park complex, long-toed and northwestern salamanders are integral to the food web structure of fishless mountain lakes and are the focus of restoration concern at NOCA. Habitat for these two species overlaps much of the lake habitat suitable for sustaining fish populations. As a consequence, their distribution throughout the Park complex has been compromised. Other concerns include climate change (causing low water levels in shallower lakes and ponds), air pollutant deposition, and disease.

The following site descriptions and stocking histories are derived from historical survey data and stocking records documented between 1980 and 2000. Overall very few surveys have been conducted at each of these lakes.

Sourdough Lake

Sourdough Lake is a relatively large (11.2 ha) and deep lake (31 m max. depth) located in the north unit of the park at an elevation of 1,409 m. The lake is situated in the subalpine zone with tree species including whitebark pine (*Pinus albicaulis)*, Pacific silver fir (*Abies amablis*), subalpine fir (*Abies lasiocarpa*), mountain hemlock (*Tsuga mertensiana*), and Alaska cedar (*Callitropsis nootkatensis*). Sourdough Lake drains via Pierce Creek into Ross Lake, dropping over 900 m in 4.7 km. Land cover types adjacent to the lakeshore include steep talus slopes, rocky cliffs, shrub/meadows, and conifer forest. The lake bottom substrate includes a mixture of bedrock areas, boulders and cobble, overlain in places with silt and gravel patches. No other lakes are found in the vicinity of Sourdough Lake. Visitor use is low and access to the lake requires a 2-km cross country hike from the nearest maintained trail.

Sourdough Lake is a highly oligotrophic lake with a Secchi depth of 13 m or more, neutral pH and low specific conductivity. Several small (5 to 6) intermittent snowmelt streams provide the only inflowing surface water and are usually dry by late August. The lake outlet has a cobble and gravel substrate and follows a flat and even gradient for about 40 m before the stream drops down the valley wall to Ross Lake. Some suitable spawning gravel is found in the outlet and in spring seep areas around the shoreline.

An abundant population of small Brook Trout (<225 mm total length) has developed since their introduction sometime prior to 1935. Brook Trout in Sourdough appear to spawn in October to November based on a 1975 evaluation of egg size development. Two attempts (1993 and 1998) to introduce Mount Whitney strain Rainbow Trout using fixed wing aircraft were apparently unsuccessful. Sourdough Lake is within the range of long-toed salamanders, however no salamanders or other amphibians have been observed at the lake.

Kettling Lake

Kettling Lake is located in the South Unit of the park in the Bridge Creek watershed of the Stehekin River drainage. The lake is connected to the Kettling Creek tributary branch of Bridge Creek, is north-facing, and positioned at the edge of subalpine and high forest zones at an elevation of 1638 m. Kettling Lake has a surface area of 4.0 ha and maximum depth of 7.0 m. One smaller and shallower lake (MR-06-01, surface area 0.8 ha, max. depth of 3.0 m) is located at the head of Kettling Creek at 1,692 m elevation and approx 1.5 km upstream from Kettling Lake. The lake is surrounded by continuous forest; however 60% of the lakeshore is bounded by a narrow strip of boggy meadows that extend into the forest. Primary tree species include a mixture of Pacific silver fir, mountain hemlock, Engelmann spruce (*Picea engelmannii*), subalpine fir, and some whitebark pine and subalpine larch (*Larix lyallii*). Access to the lake requires a 2-km cross country hike from the nearest maintained trail.

Kettling Creek is the main inlet entering the lake from the north. Its main channel is 2-3 m wide breaking into 4 channels across a wet boggy fan at the lakeshore. A 3-4 m high falls and a 2-3 m high cascade are found about 125 m upstream and preclude upstream fish movement. Abundant woody debris in the shallow braided channels of the inlet fan would also make upstream fish movement difficult. Two other small intermittent inlet streams enter the lake from the east side.

The lake outlet stream is 3-6 m wide with a gentle gradient for approximately the first 50 m. The stream has a silt bottom with patches of sedge and equisetum and abundance of woody debris. Further downstream the gradient increases, with a series of falls and cascades (1-4 m high), and the stream narrows to 2-3 m. The substrate in this reach is primarily cobble and boulder and within this section the water disappears among the substrate at a few locations.

Kettling Lake is considered to be oligotrophic. The water is cold, clear, highly oxygenated, and very low in dissolved minerals. Summer surface water temperature is around 11^{o}C, the Secchi disk is visible to the bottom, pH is near neutral, and specific conductivity ranges between 15 and 30 µS/cm. The lake bottom substrate is mostly silt.

Historically, Kettling Lake was fishless like most of the mountain lakes in the park. Rainbow Trout, Westslope Cutthroat, and hybrid Rainbow x Cutthroat have all been documented to occur in the lake during the mid 1970s through 2000. Fish stocking records do not exist for Kettling

Lake. Fish were most likely introduced during the period between the mid-1930s and early 1940s when other lakes in the area were stocked with Cutthroat and Rainbow Trout. A fish population estimate was conducted by Oregon State University researchers (Liss et al. 1995) using mark and recapture methods in 1993. Fish density was estimated to be 333 fish/ha, considered as moderate when compared with other reproducing fish population estimates from park lakes. Adequate spawning gravels were only observed in the lower 20 m of the main inlet stream. Natural falls/cascade barriers in the inlet and outlet streams prevent any upstream fish movement. No fish are found in the upper lake.

Long-toed salamanders have been documented in Kettling Lake on two occasions and Western toads have also been observed there. The smaller upstream lake (MR-06-01) is known to contain a moderately abundant population of long-toed salamanders.

Skymo Lake

Skymo Lake is a subalpine lake with an ENE exposure and is located in the North Unit of the park complex. The nearest access trail to the lake is located about 4 km from the lake and cross country travel to the lake is very difficult. The catchment area around the lake is sparsely vegetated, primarily talus, with patches of shrub and meadow vegetation types. Small stands of conifers occur on adjacent slopes and include mountain hemlock, subalpine fir, and some Alaska cedar.

The lake has two basins and drains via Skymo Creek approximately 6 km into Ross Lake. The upper basin (PM-04-01, 1610 m elevation) is perched slightly above the lower basin (PM-03-01, 1,608 m elevation) and the two basins are connected by a short and shallow stream. A small glacier is located at the upper end of PM-04-01. In the past nearly a third of the lake was covered with glacial ice during the summer, however more recently the glacier has receded to the fringe of the upper end of the lake. The estimated size of the upper lake is approximately 1.0 ha and the lower lake is 4.4 ha. The outlet stream of the lower basin travels along a relatively low gradient approximately 300 m before steeply dropping off on its way to Ross Lake (1100 m below Skymo Lake). A small pond (PM-02-01, 0.17 ha, 1,591 m elevation), connected by a short intermittent outlet, joins Skymo creek 250 m downstream from the lake. Another small pond (PM-03-02, 0.04 ha) is located on a nearby ridge to the east of Skymo Lake at 1,658 m elevation. A group of 6 small ponds (PM-05 group, surface area ranging from 0.03 ha to 0.32 ha) are located approximately 2 km SE of Skymo Lake at an elevation of 1,386-1,395 m.

Maximum depth of the upper basin of Skymo Lake is approximately 4.5 m, and 6.1 m for the lower basin. Maximum depths for the adjacent small ponds range from 1 to 2 m. The lake bottom is predominantly bedrock, boulder and cobble with some patches of sand gravel and silt. The lake is oligotrophic and clear with Secchi visibility to the bottom. Dissolved oxygen is near saturation, pH is near neutral, and specific conductivity is generally 15 to 30 µS/cm. Summer surface water temperature of the upper basin (5 to 7^{o}C) is much colder than the lower basin and is attributed to a semi-permanent snowfield located on the shaded west end of the lake. Summer surface water temperature of the lower basin ranges from 11-13^{o}C.

Long-toed salamanders have not been documented in Skymo Lake; however the watershed is well within the distribution of long-toed salamanders and they have been observed in most of the nearby ponds, providing a likely source for recolonizaton of Skymo Lake. Western toads have also been observed along the Skymo Lake shoreline.

Skymo Lake was initially stocked in 1968 with Westslope Cutthroat Trout (non-native to the westside of the park complex). Mt. Whitney strain Rainbow Trout were stocked by fixed wing aircraft in 1993, 1994, and 1998. None of these Rainbow Trout introductions appeared to be successful. Predation by the existing Westslope Cutthroat Trout population and variable success of fixed wing aircraft plants were the likely cause of mortality. Currently an abundant population of Westslope Cutthroat Trout is found in the lower basin. Most fish are generally small ranging from 150 to 250 mm total length. Although spawning habitat appears to be very limited, reproduction is evident by the fish density and number of successive year classes captured in previous surveys. Fish have been observed in the connecting stream between the two basins and some were also observed in the upper basin during 2010. Colder water temperature may limit fish use of the upper basin and no spawning habitat has been observed in the upper basin or in its outlet stream.

Methods

Sampling sites were visited in August and September of 2010 to begin collection of physical, chemical, and fish population data necessary for developing piscicide treatment plans for each of the three lakes. In addition, biological data concerning native communities of amphibians, benthic macroinvertebrates, and zooplankton were collected to document the current condition of these communities; to document presence of native species of concern; and, to provide a baseline to assess changes in these communities in the absence of fish predation.

Sampling dates and tasks completed at each lake are shown in Table 2. For these initial investigations, sampling effort was focused on Sourdough and Kettling Lakes which are the first lakes scheduled to be treated (2012 and 2013; Table 1). At Skymo Lake, the combination of an adverse weather forecast and a search mission being conducted elsewhere in the Park shortened the sample period and consequently only bathymetry and biological data were collected.

Table 2. Sourdough, Kettling, and Skymo Lakes sampling dates and tasks.

	Lake (Sampling Dates)		
Tasks	**Sourdough (9/1-6/2010)**	**Kettling (8/9-13/2010)**	**Skymo (lower basin) (8/23-25/2010)**
Bathymetric data collection.	X	X	X
Lake bottom substrate, woody debris, aquatic vegetation.	X	X	
Inlet, outlet, seep information (location, channel dimensions, discharge, spawning gravel, fish barriers)	X	X	
Establish lake water level benchmarks and measure level.	X		
Water clarity.	X	X	
Deploy continuous air and water temperature data loggers.	X	X	X (water only)
Water column profiles for temperature, dissolved oxygen, specific conductivity, and pH.	X	X	
Water chemistry – nutrients, dissolved organic carbon, acid neutralizing capacity, anions and cations.	X	X	
Chlorophyll a samples.	X	X	
Zooplankton vertical tow samples.	X	X	X
Littoral zone benthic macroinvertebrate samples.	X	X	X
Inlet and outlet benthic macroinvertebrate samples.		X	X
Amphibian visual encounter surveys and observations.	X	X	X
Fish abundance – lake population estimate and gill net catch-per-effort.	X	X	X
Fish distribution in the project area (lake depth distribution, inlets and outlets).	X	X	X
Fish length frequency and condition.	X	X	X

Methods are summarized in the following sections. Most of the methods used for collection of physical, chemical, and biological data are taken from the following Standard Operating Procedures (SOPs) found in the Draft North Coast and Cascade Network (NCCN) Mountain Lake Monitoring Protocol (Glesne et al. 2012):

SOP #4: Lake features and bathymetric maps
SOP #5: Water level measurement
SOP #6: Water clarity measurement
SOP #7: Instrumented water column profiles
SOP #8: Continuous temperature measurement
SOP #9: General water chemistry: filtered and unfiltered
SOP #10: Chlorophyll-a concentration
SOP #11: Benthic macroinvertebrate collection and processing
SOP #12: Zooplankton collection and processing
SOP #13: Fish sampling
SOP #14: Aquatic amphibian sampling and processing

Physical and Chemical Data

A number of physical and chemical attributes of each lake and inlet/outlet streams was collected for the purposes of developing a detailed rotenone treatment plan. Treatment planning requires consideration of several physical and chemical attributes that influence the application or limit the effectiveness of the rotenone treatment and include:

- High pH (>8.5)
- Maximum depth >10m
- Sunlight penetration
- High alkalinity/acid neutralizing capacity
- Presence of thermocline
- Dissolved oxygen profile
- Water temperature range
- Dense aquatic vegetation and/or woody debris accumulations
- Measurement of lake volume or inlet/outlet discharge
- Inlet and outlet stream gradient, flow, and water travel time

High pH, alkalinity, high water temperature, and greater exposure to sunlight all increase the degradation rate of rotenone, requiring application of more of the chemical to compensate for the increased degradation rate. Dense accumulations of aquatic vegetation, algae and other organic matter will also require more rotenone for treatment. Treatment methods using rotenone and factors influencing treatment effectiveness are discussed in more detail in Finlayson et al. (2000).

Physical Characteristics

Bathymetric data were collected in the field to construct a contour map. Shoreline points that were evident on aerial photos were established as beginning and endpoints for cross-lake transects. GPS coordinates were recorded at these points. At Kettling Lake, a raft equipped with a depth finder was rowed from point to point, with depths and distance from the beginning point recorded at approximately 10- to 15-second intervals. At Sourdough and Skymo lakes, a depth finder equipped with GPS capabilities was used to record depth and position data to an SD magnetic storage card several times per second. Depth and position data were entered into a spreadsheet, and GIS was used to construct the depth contour map. Physical characteristics of the lake, including surface area, volume, and mean depth were derived from the bathymetric model.

Lake bottom substrate, aquatic plants and accumulations of woody debris were recorded by observations made at random plot locations around the entire shoreline. Lake water level was measured as the vertical distance from surface of the water to a level line taken at permanent benchmarks established at two shoreline locations. Water clarity was measured using a Secchi disk taken at the location of maximum lake depth.

Continuous water temperature loggers (Onset HOBO®) were deployed 1m below the lake surface, at mid-depth, and 1m above the bottom at Sourdough Lake, and at surface and bottom locations at Kettling and Skymo Lakes. A single air temperature logger was deployed at Sourdough Lake in a tree located on the outlet end of the lake. Water temperature profile data were collected at Sourdough and Kettling Lakes using YSI instrumentation. Temperature at Sourdough Lake was recorded at 1-m intervals from the surface to bottom at the deepest part of the lake. Temperature profile data at Kettling Lake were recorded near the surface, at mid-depth, and near the bottom.

The location of inlets, outlets, stream fish barriers and seeps were recorded by photographs and by GPS points transferred to high resolution aerial photos using GIS. Stream channel dimensions and flow were measured at representative cross-sections. Discharge was determined by taking the sum of discharge values for width, depth and velocity (Swoffer Mod. 2100) from at least 15 cells in a cross-section.

Chemical Characteristics

Water samples were collected in the field for analyses of nutrients, dissolved organic carbon (DOC), anions and cations, and acid neutralizing capacity (ANC). All samples were collected at the lake location of maximum depth. DOC samples were collected at 1 m below the surface and other samples were collected at mid-depth in the water column with some additional samples taken near the surface. With the exception of ANC, all other parameters were analyzed by contracted laboratories. ANC samples were processed in the NOCA laboratory using the Gran titration method (Rounds 2006, Glesne et al. 2012). Water chemistry samples were not collected at Skymo Lake. Chlorophyll a samples were collected from mid-depth in the water column at Sourdough and Kettling Lakes and analyzed by a contracted laboratory.

Dissolved oxygen (DO), specific conductivity, and pH depth profile data were collected at Sourdough and Kettling lakes using YSI instrumentation. Profile data at Sourdough Lake was recorded at 1 m intervals from the surface to bottom. Depth profile data at Kettling Lake were recorded near the surface, at mid-depth, and near the bottom.

Trophic status among NOCA alpine lakes in tends to be oligotrophic, although chlorophyll concentrations may vary widely among lakes classified as oligotrophic. The Trophic State Index (TSI) is a commonly used measure of trophic status that assumes a relationship between biomass and productivity, as well as between biomass, nutrients, and water clarity (Carlson 1977).

Trophic assessment is based on measures of chlorophyll a, total phosphorus, and Secchi depth, and if the assumptions are met, the resulting TSI for each parameter should be approximately equal to the other two. Values less than 30 are typical for lakes and reservoirs that exhibit oligotrophic traits (Wetzel 2001). Each seven TSI_{chla} units represent a doubling of chlorophyll concentrations. Since total phosphorus is not in the suite of water quality measurements, a TSI_{TP} value cannot be determined. Total phosphorus differs from total dissolved phosphorus, which is measured, in that samples are not filtered.

TSI values for Secchi depth (SD) and chlorophyll a (CHL) were calculated using the following simplified equations from Carlson and Simpson (1996):

$$TSI(SD) = 60 - 14.41 \ln(SD)$$

$$TSI(CHL) = 9.81 \ln(CHL) + 30.6$$

Where:
ln = natural logarithm
SD = Secchi depth in meters
CHL = Chlorophyll a in µg/L

Native Community Assemblage Characteristics

Zooplankton, littoral benthic macroinvertebrates (BMI), and amphibian data were collected to characterize pre-treatment conditions for use in evaluation of the success of the treatment, short-term impacts to native communities, and longer term recovery of the native communities in the absence of fish predation.

Zooplankton

Three replicate zooplankton samples were collected from each lake during 2010. Each sample consisted of three bottom-to-surface vertical tows, taken at the deepest point in the lake, and pooled together into one sample. Zooplankton samples were preserved in the field and delivered to contracted laboratories for enumeration and identification.

The current status of zooplankton communities related to fish predation in Sourdough, Kettling, and Skymo Lakes were evaluated by comparisons with NOCA reference lake data summaries representing a gradient of fish density (R. Glesne, NOCA files). Zooplankton community structure is particularly useful for evaluating impacts of non-native fish stocking in NOCA mountain lakes. Reference lake zooplankton samples were collected from 25 NOCA mountain lakes between 2006 and 2010. These samples represent a range in fish predation intensity as indicated by fish density derived from statistical estimates of their population size and represent characteristics of zooplankton communities that occur in lakes with high fish density (≥200 fish/ha, N=10) and those with low density (0 to <200 fish/ha, N=15). Zooplankton samples were replicated at most lakes, with an average of 2.5 samples collected for each of the 25 reference lakes. Twenty-one candidate metrics (Appendix 1) representing zooplankton abundance (no/m^3), taxa richness, and taxonomic group composition were evaluated for use in interpreting differences among zooplankton communities found in each of these reference groups. The 21 candidate metrics were narrowed down to eight metrics that showed significant differences (Mann-Whitney, $p<0.05$) among reference lakes grouped by high and low fish density (Table 3).

Table 3. Zooplankton metrics useful for interpretation of fish predation impacts based on results from Mann-Whitney significance tests comparing 10 NOCA lakes with high fish density (≥200 fish/ha) and 15 lakes with low fish density or no fish present.

Zooplankton Metrics	Mann-Whitney Two-tail Probability	Trend with Increasing Fish Density
Abundance Metrics (no./m^3)		
Large-bodied Crustacean Abundance (>1 mm)	<0.001	(-)
Rotifer Abundance	0.002	(+)
Composition Metrics		
%Crustaceans	<0.001	(-)
%Copepoda	<0.001	(-)
%Calanoid Copepods	<0.001	(-)
%Large-bodied Crustaceans (>1 mm)	<0.001	(-)
%Rotifers	<0.001	(+)
Taxa Number Metrics		
Large-bodied Crustacean Taxa (>1 mm)	<0.001	(-)

Littoral Benthic Macroinvertebrates (BMI)

Duplicate BMI pooled samples were collected at each lake. Each pooled sample consisted of five kick samples that were time and area constrained and taken from randomly selected locations around the lake shoreline.

Semi-quantitative BMI samples were also collected from inlet and outlet streams at Kettling and Skymo lakes. Very low flows in the inlet and outlet streams at Sourdough Lake precluded sampling in these areas. Duplicate stream BMI samples consisted of standard area constrained kick (500 µm mesh) samples; three 0.186 m^2 samples pooled into a single sample. Qualitative BMI multi-habitat kick samples were also taken from the outlet streams at Kettling and Skymo lakes.

Macroinvertebrate samples were preserved in the field and delivered to contracted laboratories for sorting, enumeration and identification. All samples were randomly sorted (SOP 11, Glesne et al. 2012) to obtain an approximate sample of 500 specimens for analyses.

As with zooplankton, the current status of BMI communities related to fish predation in Sourdough, Kettling, and Skymo lakes were evaluated by comparisons with NOCA reference lake data summaries representing a gradient of fish density (R. Glesne, NOCA files). BMI community structure is also useful for evaluating impacts of non-native fish stocking in NOCA mountain lakes. Reference lake BMI samples were collected from 30 NOCA mountain lakes between 2006 and 2010. These samples represent a range in fish predation intensity as indicated by fish density derived from statistical estimates of their population size and represent characteristics of zooplankton communities that occur in lakes with high fish density (≥200 fish/ha, N=10) and those with low density (0 to <200 fish/ha, N=20). BMI samples were replicated at most lakes, with an average of 2 samples collected for each of the 30 reference lakes. Thirty-three candidate metrics (Appendix 2) representing BMI taxa richness and taxonomic group composition were evaluated for use in interpreting differences among BMI communities found in each of these reference groups. The 33 candidate metrics were narrowed down to 14 metrics that showed significant differences (Mann-Whitney, $p<0.05$) among reference lakes grouped by high and low fish density (Table 4).

Table 4. Benthic macroinvertebrate metrics useful for interpretation of fish Predation impacts based on results from Mann-Whitney significance tests comparing 10 NOCA lakes with high fish density (≥200 fish/ha) and 20 lakes with low fish density or no fish present.

Metrics	Mann-Whitney Two-tail Probability	Trend with Increasing Fish Density
Taxa Number Metrics (ave. no. of taxa/replicate)		
Trichoptera		(-)
Limnephilidae (Trichoptera)		(-)
Diptera		(+)
Composition Metrics		
%*Psidium* (Mollusca: Bivalvia)		(+)
%Trichoptera		(-)
%Limnephilidae (Trichoptera)		(-)
%*Desmona mono* (Limnephilidae)		(-)
%*Ecclisomyia* (Limnephilidae)		(-)
%Coleoptera		(-)
%Dytiscidae (Coleoptera)		(-)
%Ceratopogoninae (Diptera)		(+)
%*Coryoneura* (Chironomidae)		(+)
%*Paratanytarsus* (Chironomidae)		(+)
%EPTOC*		(-)

*%EPOTC– Combined composition of Ephemeroptera, Plecoptera, Trichoptera, Odonata, and Coleoptera taxa.

Amphibians

Amphibian sampling consisted of shoreline visual encounter surveys (VES) and general observations within the project area (inlets, outlets, nearby ponds, etc.). VES surveys covered the entire shoreline and included intensive plot searches at 50 m intervals with observations between plots. During the survey, hand nets were used to capture amphibians to aid in identification, obtain length measurements and for photographic documentation.

Fish Population Assessment

Fish Sampling Gear

Gill nets, electrofishing, angling, and visual observations were used to collect information about the fish populations in the project area to establish a pre-treatment baseline condition for fish density, biomass, distribution, fish length and weight structure, and physiological condition.

Gill nets were made out of monofilament with polycore float line and weighted lead core line at the bottom of the net. Monofilament used in these nets was of a fine diameter ranging from 0.12 mm for the smallest mesh size to 0.17 mm for the largest mesh size. All nets were 36 m long and

1.8 m deep, consisting of six 6-m panels configured as shown in the following diagram. The fine

12.5 mm bar mesh 0.12 mm dia	18.5 mm bar mesh 0.15 mm dia	25.0 mm bar mesh 0.15 mm dia	18.5 mm bar mesh 0.15 mm dia	25.0 mm bar mesh 0.15 mm dia	33.0 mm bar mesh 0.17 mm dia

diameter of the monofilament used in the net minimizes the weight (<3 lbs.) for backpacking and reduces their visibility in the water resulting in increased sampling effectiveness over nets using larger monofilament diameter sizes.

Gill nets were generally set horizontally from the shoreline out towards the center of the lake with the small mesh panels located near shore. Net depths were controlled by the length of cord attached to the weight and float secured to the end of the net. A single gill net was oriented vertically in the water column to determine if fish were using the deeper waters of Sourdough Lake. Most nets were set overnight and gill net catch-per-effort (CPE; fish/net-hr) data were recorded to provide a baseline to evaluate the success of fish eradication efforts during and after treatment. Battery operated backpack electrofishing equipment was used to determine relative abundance of fish in the inlet and outlet streams and their upstream and downstream limits of distribution. Fish capture by angling was accomplished using light spinning and fly fishing gear.

Fish Size Structure

The size structure of the population was represented by length frequency histograms, developed using total lengths (mm) from all fish captured. To evaluate differences in fish size-selectivity between angling and gill net capture methods, separate histograms were constructed for both gear types to aid in visual interpretation of differences in their length distributions. In addition, the distribution of sizes captured by angling was statistically compared to those collected by gill nets using the Kolmogorov-Smirnov two-sample test. Significant differences among median lengths of fish caught by angling and gill nets were tested using the Mann-Whitney U-test.

Fish Weight and Condition

Up to ten fish in each 10-mm length group were weighed, and examined for determination of sex and maturity, length/weight regressions, and physiological condition. To develop the log-linear relationship between length and weight, individuals were grouped by sex, and linear regression was performed to derive the parameter coefficients

Physiological condition of individual fish based on individual lengths and weights was assessed using condition factor and relative weight index. Condition factor (K) is a ratio of weight to length. A constant scaling factor is applied so that the value is typically between 0.1 and 10. It is typically viewed as a measure of the relative plumpness of a fish, with plumpness being directly related to nutritional status. The scale for K is relative to the species and interpretation is based on comparison to other populations and time periods. It also may show a trend with size due to allometric growth. Generally, higher values indicate plumper fish relative to a given length. The formula incorporates weight and the cubed value of total length to reflect the relation to volume (i.e., weight):

$K_{TL} = (W/TL^3) \times 100{,}000$

Where:
K_{TL}= condition factor using total length measurements
W= weight in grams
TL= total length in millimeters

The relation of the K values in a fish population to perception of the quality of the fish and the fishery by recreational anglers has been assessed through studies conducted in New Zealand on Brown Trout and Rainbow Trout waters (Barnham and Baxter 1998). These are presented as the range of K values and the typical comments attributed to fish that demonstrate that condition:

K_{TL} value:	Comments:
1.60	Excellent condition, trophy class fish
1.40	A good, well proportioned fish
1.20	A fair fish, acceptable to many anglers
1.00	A poor fish, long and thin
0.80	Extremely poor fish, resembling a barracuda; big head and narrow, thin body

The relative weight index (W_r) was developed to better express the relationship of weight to length for a given population of fish and to enhance the ability to compare this relationship among different size groups and among species. The index is based on a comparison of an individual's weight to a standard weight as a direct proportion and is expressed as a percent. The standard weight is based on length and is developed from comparable population(s). The 75th percentile of weight for a given length in the populations used for comparison is established as the standard weight. This is then developed as an equation by which one converts the lengths of the sample to the corresponding standard weight. Then the weight of each sampled fish is divided by the standard weight and expressed as a percent to provide the relative weight value. Conceptually, a W_r of 100 would characterize a population that demonstrates an optimal relationship among physiological needs, habitat characteristics, and suitability to anglers. This index differs from the condition factor (K) in that the inherent change that can be caused by allometric growth is factored out since standard weight is relative to a given length. However, consideration must be given to the sources of the populations that are used to establish the standard for standard weights. North Cascade Range alpine lakes may have attributes that cause growth characteristics to differ from those used to establish the standard weight, and this could affect the interpretation of this metric.

The standard weight equation used for W_r calculations of Brook Trout found in Sourdough Lake was generated from a compendium of length and weight values representing 113 populations of Brook Trout from throughout North America (Hyatt and Hubert 2001):

$\log_{10}$ standard weight [g] = -5.186 + (3.103 * $\log_{10}$ total length [mm])

The standard weight equation used for W_r calculations of Westslope Cutthroat Trout found in Skymo Lake was generated from a compendium of length and weight values representing 48 lentic populations of Cutthroat Trout from their interior range in western North America (Kruse and Hubert 1997):

$\log_{10}$ standard weight [g] = -5.192 + (3.086 * $\log_{10}$ total length [mm])

The standard weight equation used for W_r calculations of Rainbow Trout in Kettling Lake was generated from a compendium of length and weight values for 50 lentic populations of Rainbow Trout from throughout North America (Simpkins and Hubert 1996):

$\log_{10}$ standard weight [g] = -4.898 + (2.990 * $\log_{10}$ total length [mm])

Fish Population Estimation

Mark and recapture fish population estimates were used to establish the initial density and biomass of the fish populations in all three lakes. Fish density and biomass information is particularly useful for interpreting the intensity of existing fish predation impacts on the native communities in lakes (Liss et al. 1998, 2002). The population estimate method calls for different gear to be used in the marking and recapture efforts in the attempt to avoid sampling gear bias. To estimate population size, angling activities were conducted first, in order to introduce marked fish into the population. These fish were measured, the dorsal tip of the caudal fin was clipped off, and fish were released near the site of capture. Recapture efforts using experimental gill nets began the day after fish marking was completed. Experimental gill nets were set overnight at up to ten locations that were roughly evenly spaced around the lake. These nets were pulled the next day; fish were removed, and reset another day at Sourdough and Kettling lakes.

Population size was estimated using Petersen's mark and recapture single census approach with Chapman's modification to correct for statistical bias (Ricker 1975) according to the following equation:

$N = ((M+1)*(C+1))/(R+1)$

Where:
N = population estimate
M = total number of fish marked
C = total fish caught by gillnetting
R = marked fish recaptured by gillnetting.

The coefficient of variation of the population estimate was calculated by the equation given by Seber (1982) and converted to percent as follows;

$\%CV = (1/(\mathrm{sqrt}((M*C)/N)))*100$

Upper and lower confidence limits were calculated with Poisson approximations to the hypergeometric distribution (Appendix II, in Ricker 1975). Table values representing upper and lower limits for recaptures (95% confidence) are found either by locating the observed number of recaptures (*x*) in the appendix table or by using the formulae provided with the table for larger numbers of recaptures. Each of these values is inserted into the population estimation formula to come up with upper and lower limits for the estimate.

Based on the population estimate for the number of fish, the number and sizes of fish removed by gillnetting and angling mortality, and the relationship of length to weight that was established from a subsample of the removed fish, estimations of the remaining number and biomass of fish were made. Biomass was determined by using the length-weight relationship to estimate a weight for each fish captured by gillnetting. These weights were averaged, and the mean weight per fish was multiplied by the estimated population size to derive estimated total biomass of fish in the lake. Total biomass is likely underestimated because gill nets are less effective at catching small fish; however, the smallest size groups of fish also represent a disproportionately small proportion of biomass in relation to their numbers.

Results: Sourdough Lake

Physical Characteristics

The lake is notably deep and has complex bottom topography (Table 5). Its 11.2-ha surface is oval-shaped on an east-west long axis with steep slopes surrounding it. The central portion of the lake exhibits a sharp drop around the lake to a flat bottom in the center at 25-30 m (Figure 1). Shallow ridges occur at both the east end and west end of the lake that partially enclose deeper areas behind them.

Table 5. Physical characteristics of Sourdough Lake.

Parameter	Sourdough Lake
Length (m)	587
Fetch (m)	579
Breadth (m)	276
Perimeter (m)	1,671
Area (m^2)	112,495
Shoreline development	1.41
Maximum depth (m)	31.13
Volume (m^3)	1,374,448
Volume (ac-ft)	1,114

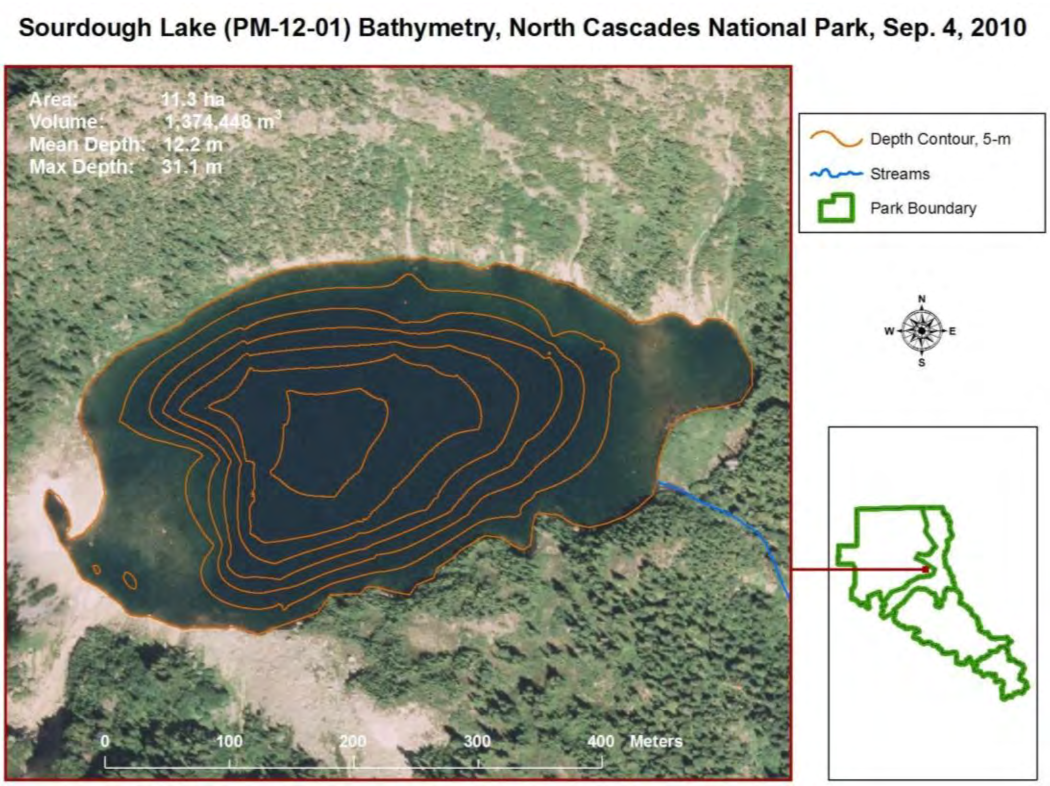

Figure 1. Bathymetric map of Sourdough Lake.

At the west end a smaller pond has as small, shallow connection to the main body of the lake. Nearshore the bottom is largely bedrock outcroppings, boulders, and rubble. No islands or peninsulas are present, and the shoreline is shrubby to the north and east, tree-lined to the southwest, and has bare rocky slopes to the southwest and west. No perennial inlet streams were evident. An outlet stream drains the lake on the southeast end where discharge was measured in an incised slot through a bedrock outcrop (Table 6). Snow in the basin was represented by a patch that was less than 2 m diameter, and discharge at the outflow (0.41 cfs) reflected the lack of surface water sources.

Table 6. Sourdough Lake outlet stream wetted width and discharge, September 4, 2010.

Location	Stream Width		Discharge	
	ft	m	ft^3/s	m^3/s
Outlet	0.85	0.26	0.41	0.01

Water Chemistry and Depth Profiles

The water chemistry in Sourdough Lake is similar to other lakes that were sampled in NOCA in 2010 (Table 7). In comparison with three other lakes, nutrient concentrations are higher, which appears to be reflected in a higher chlorophyll a concentration, but overall these lakes all exhibit low primary productivity. Total ionic concentration, as reflected in specific conductance, is higher near the bottom than at the surface, and the water is more acidic in the bottom stratum, suggesting that vertical circulation is restricted at least during the summer. Specific anion concentrations are similar to surface waters of other lakes, but among the cations ammonia and potassium are higher than the other lakes (Table 8). Six of the eight cations and anions that were analyzed showed the highest concentrations in the bottom stratum, again indicating that circulation between bottom and surface water is inhibited during the summer sampling period.

A TSI value was determined for Secchi depth and chlorophyll a for Sourdough Lake (Table 9). The chlorophyll a TSI value indicated that the lake was the most productive among those that were sampled in summer, 2010, but indicated that all of these lakes are well within the limits of what are recognized as oligotrophic lakes (TSI <40). The TSI Secchi depth value indicated that the lake was more productive than the chlorophyll a TSI value indicated, but this value can be affected by non-phytoplankton determinants of water clarity, such as humic materials and suspended silt. Therefore, chlorophyll a is used as the best indicator of trophic state.

A vertical profile of temperature, specific conductance, and pH was measured at 1-m intervals from surface to bottom on September 5, 2010 (Figure 2). A thermocline was evident between 7 and 8 m; above this temperatures were 12 ^{o}C and higher while bottom temperatures were near 4 ^{o}C. This indicates that strong seasonal stratification is present, and this pattern of stratification was also evident in a vertical thermal profile measured down to 15 m on September 11, 1975. The thermocline was also where pH became more acidic and ionic concentration increased from that of surface waters.

Dissolved oxygen increased in the metalimnion where the temperature change occurred and then showed a trend of decreasing concentrations throughout the hypolimnion. The increase in the metalimnion may be caused by a deep chlorophyll maximum such that phytoplankton are

Table 7. Water chemistry including nutrients for Sourdough Lake, September 3, 2010, and other North Cascades mountain lakes sampled in the summer, 2010.

Lake	Total dissolved nitrogen (mg/L)	NH_3-N (mg/L)	Total dissolved phosphorus (mg/L)	Soluble reactive phosphorus (orthophosphate) (mg/L)	Total dissolved solids (mg/L)	Dissolved organic carbon[1] (mg/L)	Specific conductance (µS/cm)	Mean Chlorophyll a (µg/L)	pH	Acid neutralizing capacity (meq/L)
Sourdough[2]	0.05	*0.001	*0.002	*0.001	16	2.58	13.86	0.105	6.50	0.12
Sourdough[3]	-	-	-	-	-		23.20	-	6.17	0.15
Kettling[4]	0.04	*0.001	*0.001	*0.000	20	266.27	19.37	0.092	6.88	0.15
Middle Blum[4]	0.03	*0.001	0.007	*0.000	13	67.21	16.60	0.058	6.80	0.09
Lower Blum[4]	0.02	*0.001	0.006	*0.000	12	2.60	14.96	0.051	6.74	0.08

[1] Dissolved organic carbon samples taken at 1 m below surface at all sites.

[2] Sample taken at 1 m below surface.

[3] Sample taken at 1 m above bottom.

[4] Sample taken at mid-depth.

* Below detection limits

Table 8. Anion/cation content for Sourdough Lake, September 6, 2010, and other North Cascades mountain lakes sampled in the summer, 2010.

Lake Name	Chloride Cl µeq/L	Nitrate NO_3 µeq/L	Sulfate SO_4 µeq/L	Sodium Na µeq/L	Ammonium NH4 µeq/L	Potassium K µeq/L	Magnesium Mg µeq/L	Calcium Ca µeq/L
Sourdough[1]	2.52	0.10	17.11	17.64	4.58	5.66	23.92	123.27
Sourdough[2]	4.31	1.28	22.17	28.96	7.82	9.85	37.59	198.63
Kettling Lake[3]	2.03	0.04	19.99	21.50	1.13	4.89	20.01	170.75
Skymo Lake	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Middle Blum[3]	3.00	0.02	48.52	35.20	1.55	3.96	23.28	133.86
Lower Blum[3]	2.91	*	36.95	26.14	1.91	3.72	23.72	121.84

[1] Sample taken at 1 m below surface.

[2] Sample taken at 1 m above bottom.

[3] Sample taken at mid-depth.

* Below detection limit

Table 9. Carlson's Trophic State Index determinations based on Secchi depth and chlorophyll a for Sourdough Lake, September 6, 2010, and other North Cascades mountain lakes sampled in the summer, 2010.

Lake	Chlorophyll a[1] (μg/L)	TSI_{chla}	Secchi depth (m)	TSI_{SD}
Sourdough	0.1050	8.5	11.8	24.4
Kettling	0.0920	7.2	Bottom (6.9)	
Middle Blum	0.0580	2.7		
Lower Blum	0.0510	1.4		

[1] Sample taken at mid-depth.

concentrated in the metalimnion where inorganic nutrients are more abundant than in surface waters but light is still sufficient for photosynthesis. The decrease in oxygen below this region to less than 2 mg/L mirrors the increase in ionic concentration below 16 m where specific conductance increased from 10 to 16 μmhos/cm. Although this was not likely enough difference to chemically stratify the lake, the chemical gradient may inhibit wind-induced mixing and provide concentration stability to the bottom layers as indicated by the lack of oxygen and higher ionic concentration at that depth (Wetzel 2001).

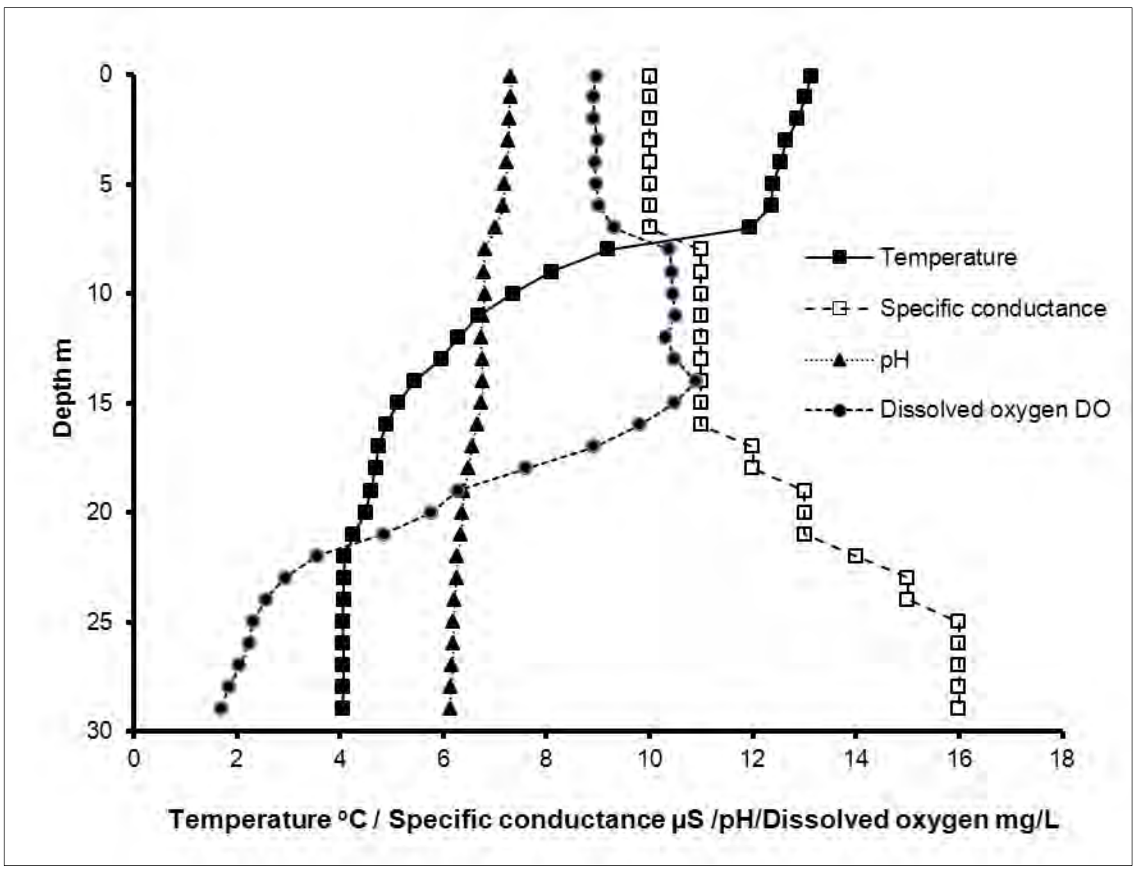

Figure 2. Vertical temperature, specific conductance, pH, and dissolved oxygen profiles at the deepest location in Sourdough Lake, September 5, 2010.

Fish Population Assessment

Fish Captures and Length Distribution

Brook Trout was the only fish species found in Sourdough Lake. Backpack electrofishing was used to assess the distribution of fish in the outlet stream, and Brook Trout were found in pool habitat in the outlet stream as far downstream as was possible to access.

During the first four days at the site 614 fish were captured by angling, and of these 591 were fin-clipped, and released near the site of capture (Table 10). Catch per angler hour averaged 16.6 fish. Five mortalities occurred during sampling, and eighteen marked fish were recaptured and released. An additional seven fish were captured by electrofishing along the east shore, and these were also marked, bringing the total number of marked fish to 598.

Table 10. Capture of Brook Trout by angling in Sourdough Lake, September 1-4, 2010, that were marked for population estimation.

No. of anglers	Hours fished (range)	No. caught	Catch per angler-hour	Recaptures & mortalities	No. marked by angling	Total No. marked
5	37 (5.0-10.5)	614	16.6	18 & 5	591	598[1]

[1] Seven fish caught by electrofishing included in total number marked.

Using 10-mm groups to portray the length-frequency distribution, the primary modal length of the 591 Brook Trout captured by angling from Sourdough Lake and marked by fin-clipping was 180-189 mm (Figure 3). The smallest fish was in the 90-99 mm group and the largest in the 240-249 mm group.

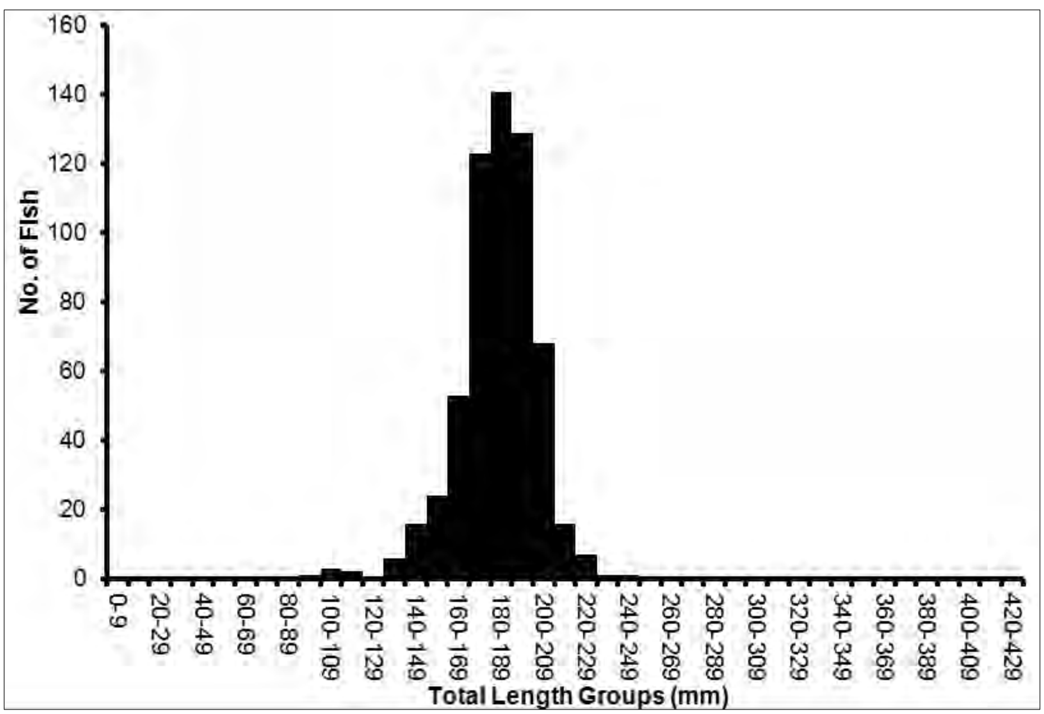

Figure 3. Distribution of total lengths of 591 Brook Trout captured by angling in Sourdough Lake in September 1-4, 2010.

Gillnetting captured 718 Brook Trout in an overnight set using 10 nets September 4-5, and 3 fish were caught in the experimental vertical gill net set September 5-6 for a total of 721 fish (Table 11). Mean catch per net-hour ranged from 3.2 to 5.4 for the 10 nets. The experimental vertical gill net captured three fish from depths ranging from 10.5 to 17.0 m.

Table 11. Capture of Brook Trout by gill nets in Sourdough Lake, September 4-6, 2010, to determine fish population estimate and assess population characteristics.

Gill net no.	Net hrs.	No. caught	Catch per net-hour	Marked fish recaptures
1	18.7	71	3.8	1
2	19.1	75	3.9	6
3	16.7	70	4.2	5
4	8.8	41	4.6	4
5	16.9	92	5.4	10
6	20.0	83	4.2	7
7	20.5	80	3.9	11
8	15.4	49	3.2	10
9	17.0	81	4.8	8
10	20.0	76	3.8	9
Vertical net	NA	3	NA	1
Totals	173.1	721	4.2	72

The primary modal length group of Brook Trout collected by gillnetting was 180-189 mm (Figure 4), identical to those captured by angling. The smaller secondary mode at 110-119 mm also occurs in the group of fish captured by angling. Two extraordinarily large fish were caught, one in the 320-329 mm length group and the other in the 410-419 mm length group.

Both the angling and the gill net size distributions show a similar rapid truncation for smaller fish. The cumulative distribution of sizes captured by angling was statistically compared to those collected by gillnetting. Angling collected a significantly larger proportion of smaller fish based on the proportional cumulative frequency distributions (Kolmogorov-Smirnov two-sample test, $P \leq 0.05$; Figure 5). However, the difference results from the large proportion of fish in the 160 to 210 mm range in both of the samples causing steep cumulative frequency curves. The difference in the two curves is actually one length group. The median total lengths of both the gillnetted fish and the angled fish was identical at 184 mm (Mann-Whitney U-test, $P > 0.05$).

The steep topography of the nearshore habitat caused gill nets to extend to deeper depths that were not accessible to angling efforts, which were mostly conducted from shore. If the fish were assorting by size in these habitats, the deeper habitat sampled by gill nets may have captured more larger fish, and angling may have captured more smaller fish in the shallower water near shore.

The size difference likely had minimal effect on the population estimate. In applying this technique to population estimation, if either the marking or the subsequent recapture is done randomly, the estimate is not biased. In addition, anticipated bias can be remediated by using different gear types for initial capture and for recapture (Ricker 1975), and the sampling protocol we used conformed to both of these conditions.

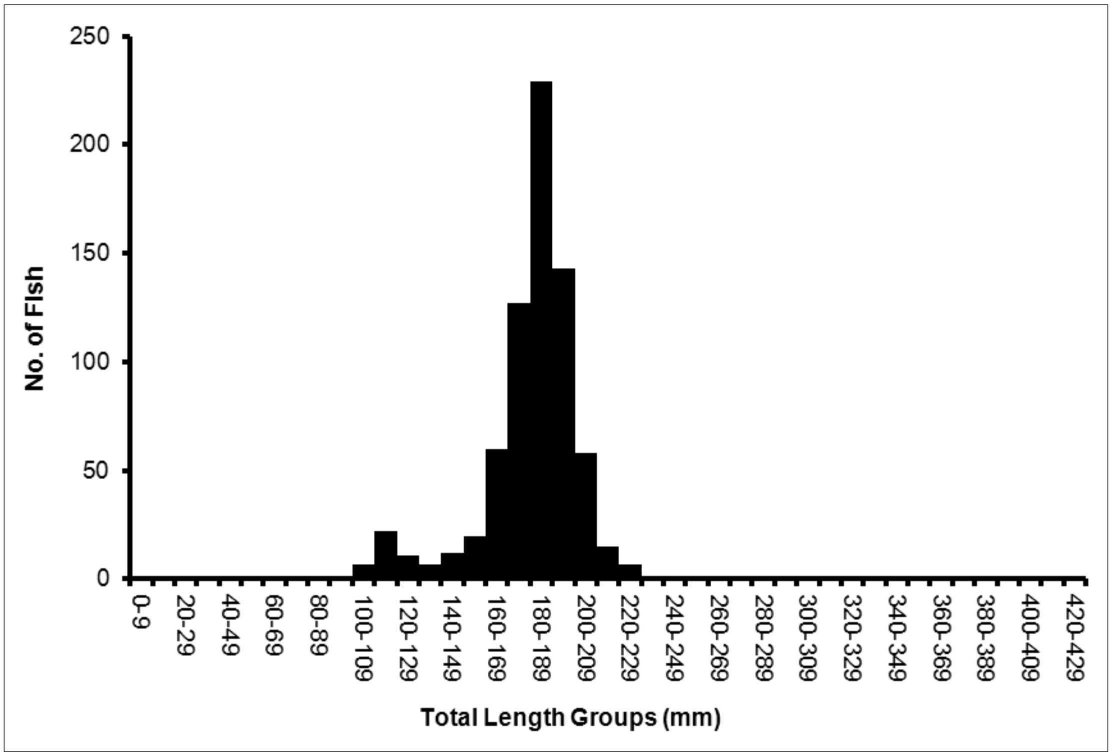

Figure 4. Distribution of total lengths of 721 Brook Trout captured by gillnetting in Sourdough Lake, September 4-6, 2010.

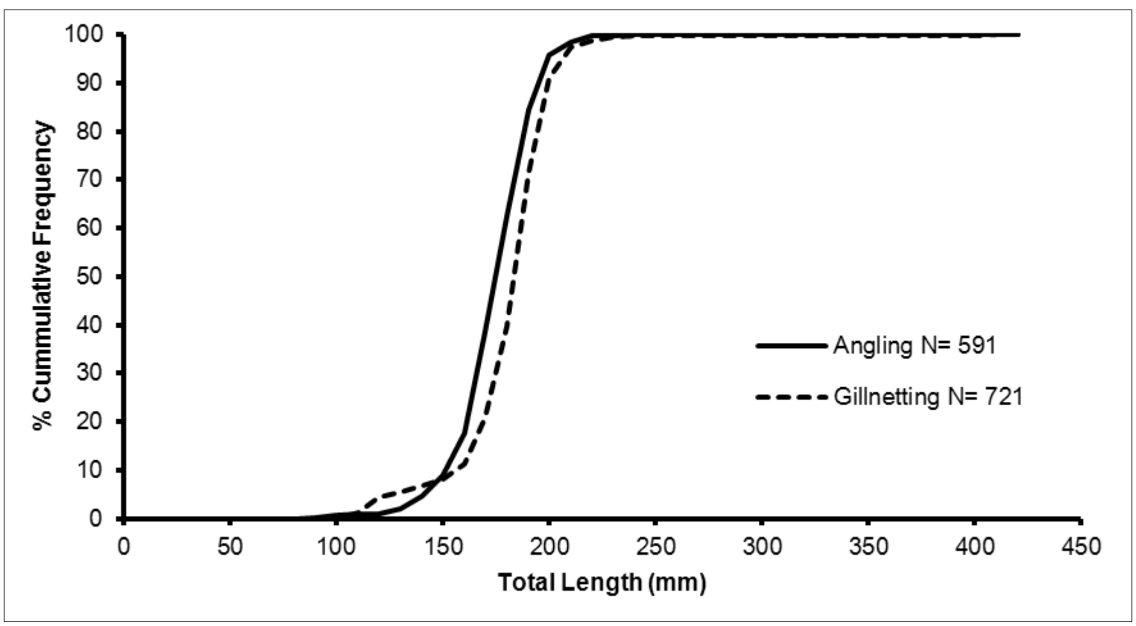

Figure 5. Relative cumulative length frequency distributions comparing Brook Trout captured by angling versus gillnetting from Sourdough Lake, September 1-6, 2010 (Kolmogorov-Smirnov D statistic=22.9; critical value at P≤0.05=19.2).

Sex and maturity were assigned in 71 of the fish collected by gillnetting (Table 12). The proportion of males and females was biased toward females with 1.6 females per male. Proportion of adults ranged from 60% in females to 78% in males, but no males and only 7% of females showed signs of being in spawning condition. Brook Trout are fall spawners, so spawning must occur later in September, October, and possibly November prior to ice up.

Table 12. Sex distribution and sexual maturity of Brook Trout collected by gillnetting from Sourdough Lake, September 4-6, 2010.

Maturity	**Females**		**Males**	
	N	**%**	**N**	**%**
Adult	27	61.36	21	77.78
Ripe	3	6.82	0	0
Juvenile	14	31.82	6	22.22
Total	44	61.97	27	38.03

Fish Weight and Condition

To develop the log-linear relationship between length and weight, these were recorded for ten fish in each 10 mm length group. Individuals were grouped by sex, and linear regression was performed to derive the parameter coefficients (Figure 6). The R-squared values were 0.97 for males and 0.98 for females, indicating that weights for the remaining portion of the sample in which only lengths were recorded could be reasonably estimated.

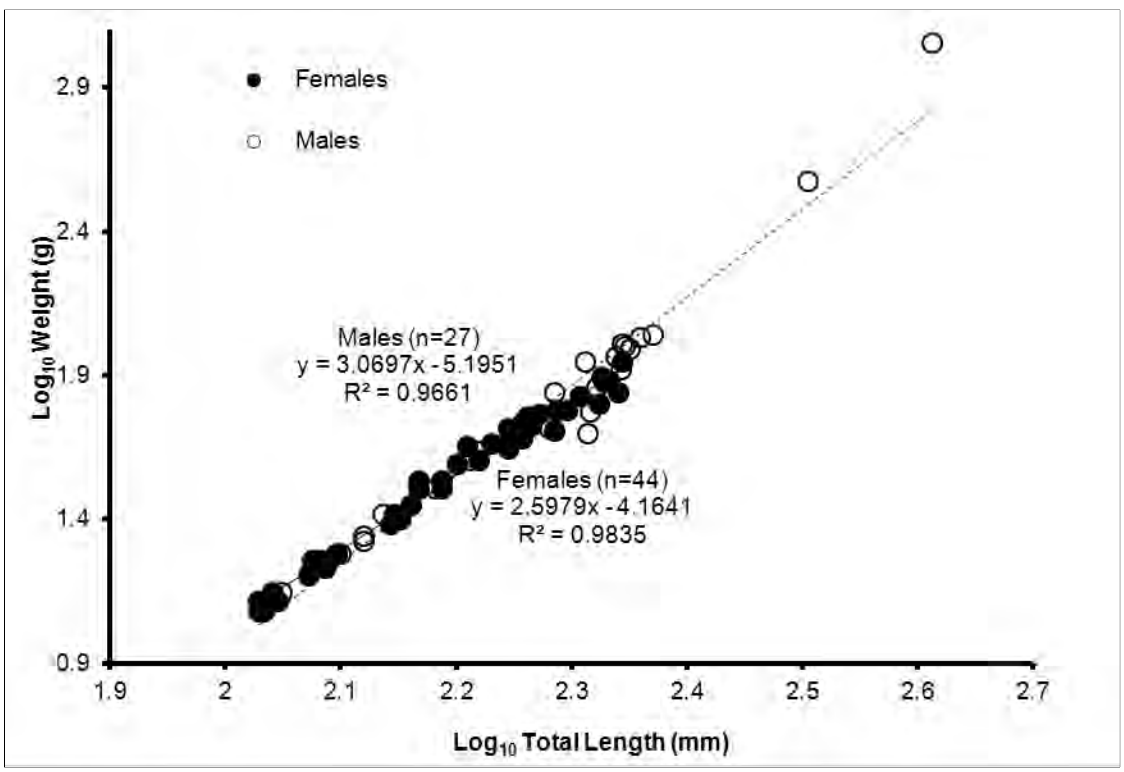

Figure 6. Linear regression by sex of $\log_{10}$ transformed total lengths and weights for Brook Trout captured by gill nets from Sourdough Lake, September 4-6, 2010.

Physiological condition of individual fish based on individual lengths and weights was assessed using condition factor and relative weight index. Condition factor (K) values for male and female Brook Trout are shown in Figure 7. All but one individual Brook Trout in Sourdough Lake were less than ―fair.‖ (K <1.2; Barnum and Baxter 1998). Approximately, 20% were ―extremely poor‖ (K <0.8). The largest fish in the sample at 410 mm had a K value >1.6 representing ―excellent condition,‖ which might be attributable to this specimen's larger size (>400 mm) allowing it to effectively forage on the abundance of small Brook Trout. Interpretation using the categories developed by Barnham and Baxter (1998) could be constrained by the applicability of the relationship to fishes other than Rainbow Trout and Brown Trout. However, the body conformation based on the length weight log linear relationship appears similar to Rainbow Trout in Kettling Lake based on the slope coefficient for length.

Condition factor does not appear to differ between males and females with values for both sexes across the range of K values at each size. A group of eight males between 190 and 230 mm were plumper than corresponding sizes of females, which may reflect long-term effects in resource allocation and the energetic costs of producing eggs.

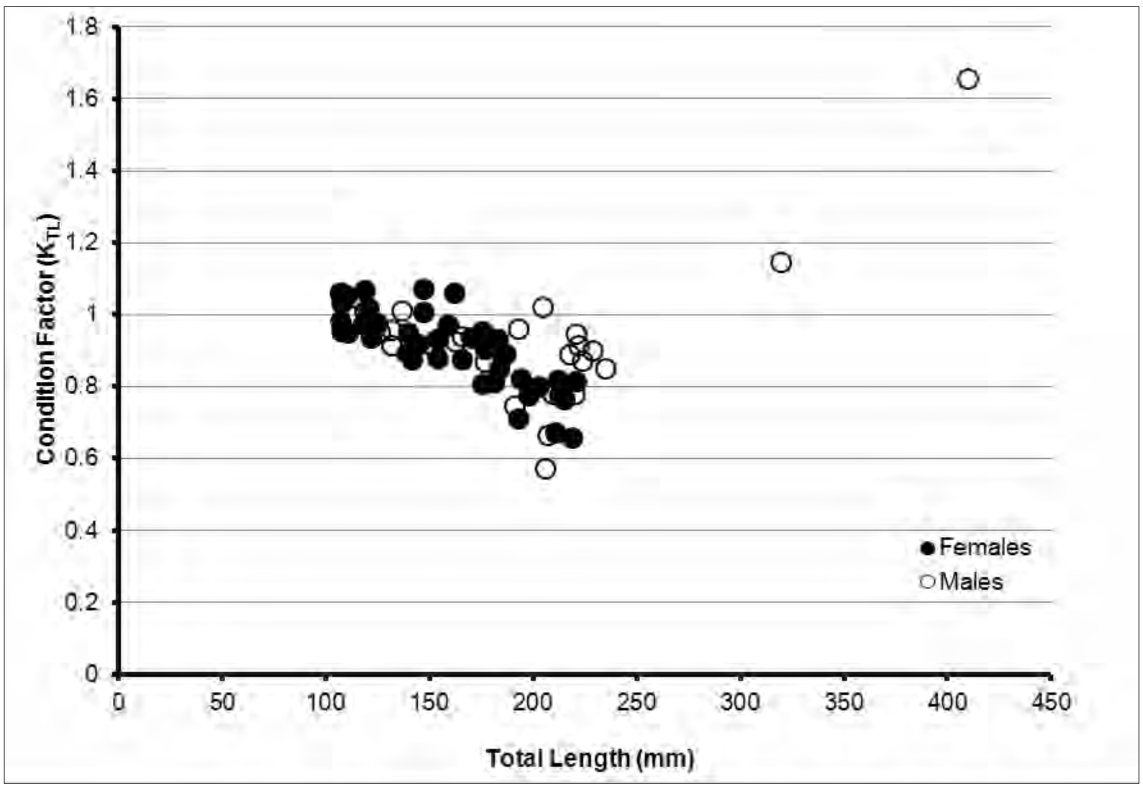

Figure 7. Relative plumpness (condition factor, K_{TL}) across total length by sex for Brook Trout from Sourdough Lake, September 4-6, 2010.

The population demonstrates a downward trend in K with increasing length, which is opposite of the trend expected to be caused allometric growth wherein changes in shape as a result of increases in size increase the relative plumpness of a fish. This downward trend with increasing size would be expected in a population that is limited by food abundance, particularly the availability of larger food items. The Sourdough Lake population likely subsists on aquatic macroinvertebrates and zooplankton so the larger fish have reached a size where availability and ability to capture and consume them result in a diet that increasingly does not support energetic storage in the form of body lipids. This translates to a loss of plumpness, or girth, with increasing length. The two largest, and highest condition, fish have reached a size where diet likely consists of a substantial portion of fish.

The relative weight index (W_r) was developed to better express the relationship of weight to length for a given population of fish and to enhance the ability to compare this relationship among different size groups and among species. Conceptually, a W_r of 100 would characterize a population that demonstrates an optimal relationship among physiological needs, habitat characteristics, and suitability to anglers. The array of values for relative weight (Figure 8) appears similar to those for condition factor (Figure 8). The highest values occurred at both ends of the length spectrum. The smallest fish, from 100 to110 mm, had W_r values of approximately 100 with larger fish showing a decreasing trend in values. However, the two exceptionally large fish, which were 320 and 410 mm, showed higher values with the 410-mm fish having the highest W_r value at 137. Again, the size and condition of this fish is likely attributable to its ability to consume smaller Brook Trout. The relative weight was consistent between males and females across the range of lengths.

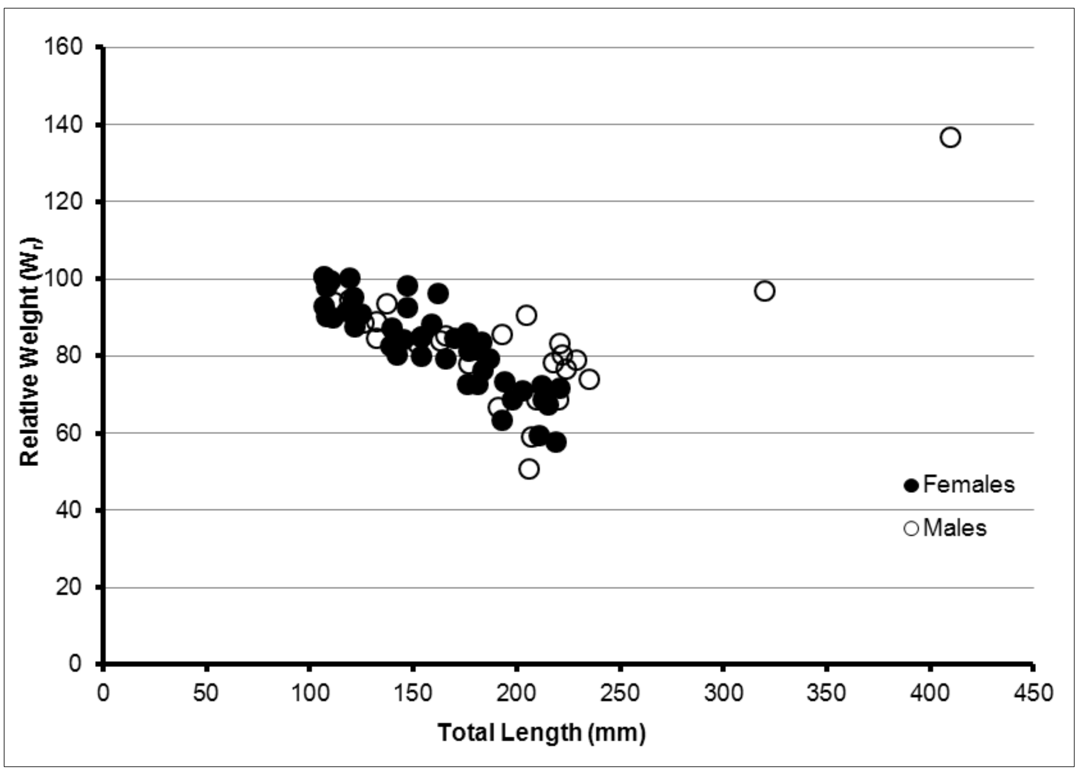

Figure 8. Relative weights (Wr) across total length by sex for Brook Trout from Sourdough Lake, September 4-6, 2010 (Hyatt and Hubert 2001).

Fish Population Estimation

The number of Brook Trout in the population in Sourdough Lake was estimated using Petersen's mark and recapture single census approach with Chapman's modification to correct for statistical bias. All crew members participated in angling using spinning rods and fly rods during the first four days on the site to capture fish for marking. Anglers were haphazardly distributed around the lake on the shore or in a raft, and marked fish were released in the vicinity of capture. Recapture was conducted by gill netting overnight on days four and five. An experimental gill net was devised to be hung vertically so depth of Brook Trout distribution could be assessed overnight on days 5 and 6.

Gill netting efforts resulted in capture of 72 of the 598 fish that were marked. The estimated population size was 5,924 fish with a coefficient of variation of 11.7% (Table 13). The 95% confidence interval for this estimate is 4,718-7,434, based on a Poisson distribution of the number of recaptured marked fish. This results in a range of 2,716 fish around the estimate.

Table 13. Population estimate of Brook Trout in Sourdough Lake, Ross Lake watershed September 1-6, 2010, using Chapman's modification of Petersen's single census mark and recapture method.

Population Estimate Parameters	No.
Marked fish - M	
Angling catch	591
Electrofishing catch	7
Total marked	598
Captured fish - C	
Captured by gill net	718
Captured by vertical net	3
Total captured	721
Recapture of marked fish - R	
Captured by gill net	71
Captured by vertical net	1
Total recaptured	72
Population estimate – N (95% CI)	5,924 (4,718-7,434)
%Coefficient of variation - %CV	11.7

Biomass of Brook Trout in Sourdough Lake prior to and subsequent to sampling was estimated based on the estimated population size, the relationship of length to weight that was established from a subsample of the removed fish, and the number and sizes of fish removed by gillnetting and angling mortality. The length-weight relationship was used to estimate a weight for each fish captured by gill nets. These weights were averaged to derive mean weight per fish. The mean weight per fish was multiplied by the population size to arrive at the estimation of 325 kg of fish in the lake prior to sampling. Gill netting and angler-induced mortality totaled 40 kg so the resulting biomass was 286 kg after sampling.

Total biomass may be underestimated because gill nets are less effective at catching small fish, as indicated by the size truncation of smaller size groups in the length distribution based on gill net samples (Figure 5). However, the smallest sized fish likely were a small proportion of the total biomass relative to their numbers, and fish smaller than those that were gill netted were not observed along the shoreline.

Gill netting and angling reduced the estimated population size and biomass by 12.3%, assuming that the size distribution captured by the gill nets reflects the actual size distribution of fish in the lake (Table 14). Fish density was reduced from 529 to 464 fish per hectare, and biomass decreased from 29.1 to 25.5 kg per hectare.

The Brook Trout in Sourdough Lake have established a self-sustaining population largely consisting of small, thin fish. Social trails stemming from the established trail traveling from the town of Diablo to Sourdough Lookout provide a route to the ridge south of and 400 m above the lake, but gaining access down to the lake is challenging, given the steepness of the terrain and lack of a trail. Therefore, recreational angling has likely been minimal at most. This appears to have been the case in 1975 as well when the surveying fish biologists included remarks in their field notes to the effect that perhaps a Boy Scout troop could be brought in to reduce the population numbers by angling so as to increase the size of the remaining fish. If so, the estimated fish biomass of 29.1 kg per hectare reflects the carrying capacity of the lake with respect to fish, with reproduction and growth offset by natural mortality.

Table 14. Population parameters for Brook Trout in Sourdough Lake, Ross Lake watershed September 1-6, 2010.

Parameter	No.	%
Estimated original population size	5,924	100.0
Removed by gill nets	721	12.2
Removed by angling mortality	5	0.1
Total removed	726	12.3
Estimated remaining population size	5,198	87.8
Previous no. of fish/ha	529	
Current no. of fish/ha	464	
Estimated original biomass (kg)	325	100.0
Estimated reduction in biomass (kg)	40	15.7
Estimated remaining biomass (kg)	286	88.0
Previous density (kg/ha)	29.1	
Current density (kg/ha)	25.5	
Captured once by angling & released	591	10.0
Captured by electrofishing & released	7	0.1
Total no. of fish captured by angling	598	10.1

Zooplankton

Average values for zooplankton density (no/m^3) by taxa from three replicate samples collected at Sourdough Lake in September, 2010, are shown in Table 15. Ten taxa (excluding copepod intermediate nauplii and copepodid life stages) were observed in the three samples. Rotifers were represented by six of the 10 taxa. The average total density was 2,219 organisms/m^3. *Polyarthra vulgaris* (Rotifera) was the most abundant taxon (842/m^3) followed by cyclopoid copepods (copepodids and *Diacyclops thomasi*).

Zooplankton metric values are compared with those from the NOCA fish density reference groups in Table 16. The absence of large-bodied crustacean taxa (>1 mm) and calanoid copepods is indicative of lakes with high fish densities (>200 fish/ha). Larger calanoid copepods (*Hesperodiaptomus kenai* and *H. arcticus*) and the cladoceran, *Daphnia pulex*, are commonly found in lakes with low fish densities but rarely found in lakes with high density fish populations. These taxa are more vulnerable to predation because of their larger body size. Metrics representing percent composition of all crustacean taxa, copepods, and rotifers fell between the mean metric values of the low and high fish density reference groups.

Table 15. Average density (no/m3) of zooplankton samples collected at Sourdough Lake, September 3, 2010.

Taxa	Division	Sourdough Lake no./m^3 (n=3)
Bosmina coregoni	Cladocera	144.9
Holopedium gibberum	Cladocera	23.5
copepodid, Cyclopoida	Copepoda:Cyclopoida	448.6
Diacyclops thomasi	Copepoda:Cyclopoida	469.1
Microcyclops varicans	Copepoda:Cyclopoida	0.8
copepod nauplii	Copepoda	91.5
Conochilus unicornis	Rotifera	4.4
Kellicottia longispina	Rotifera	4.4
Keratella cochlearis var. cochlearis	Rotifera	3.0
Polyarthra vulgaris	Rotifera	841.6
Synchaeta sp.	Rotifera	47.6
Notholca foliacea	Rotifera	139.8
Total Density:		2219
Total Taxa:		10

Table 16. Comparison of zooplankton metric values for Sourdough Lake, 2010, with average, minimum, and maximum metric values from 15 low fish density and 10 high fish density NOCA reference lakes sampled between 2006 and 2010. Selected metrics represent a subset of 21 candidate metrics that show significant differences (Mann Whitney, p<0.05, two-tail) among NOCA lakes grouped by low and high density fish populations (see Appendix 1 and Table 3).

Metrics (Predicted trend with fish density +/-)	Sourdough	Low Density/No Fish (n=15)			High Density (n=10)		
	(n=3)	Mean	Min	Max	Mean	Min	Max
Large-bodied Crustacean no/m^3 (-)	0	599	0	2,476	0	0	0
Rotifer no/m^3 (+)	1041	3,367	14	30,040	61,158	759	495,667
%Crustaceans (-)	46.6	73.8	3.8	99.3	13.1	0.5	46.6
%Copepoda (-)	45.5	68.8	2.1	99.3	10.2	0.2	45.5
%Calanoid Copepods (-)	0.0	58.7	0.0	97.5	2.5	0.0	11.1
%Lg.-bodied Crustaceans (>1mm) (-)	0.0	16.7	0.0	57.0	0.0	0.0	0.0
%Rotifers (+)	46.9	26.2	0.7	96.2	86.1	46.9	99.5
No. Large-bodied Crustacean Taxa (-)	0	1.1	0.0	2.0	0.0	0.0	0.0

Benthic Macroinvertebrates (BMI)

A total of 27 taxa were collected from replicate samples collected on September 4, 2010 (Table 17). Chironomid species (Diptera) represented the majority of taxa collected (n=17) and collectively accounted for 83% of the total number of specimens in the samples (Figure 9). *Paratanytarsus* and *Psectrocladius* were the most abundant taxa collected in the samples, representing 20.3 and 16.8%, respectively, of the total number of specimens in the samples. The combined percent composition of taxonomic groups mostly sensitive to fish predation (Odonata, Ephemeroptera, Trichoptera, and Coleoptera) was low (3.3%).

Table 17. Average number (n=2), percent composition, and total BMI taxa collected at Sourdough Lake, September 4, 2010.

			Sourdough Lake (n=2)	
Taxon	**Phyla/class/subclass/etc**	**Family**	**Ave No.**	**%**
Nematoda	Nematoda		13.5	2.3
Oligochaeta	Annelida: Oligochaeta		15	2.6
Pisidium	Mollusca: Bivalvia	Pisidiidae	19.5	3.4
Acari	Arthropoda: Acari		0.5	0.1
Somatochlora	Insecta: Odonata	Corduliidae	0.5	0.1
Callibaetis	Insecta: Ephemeroptera	Baetidae	4	0.7
Ecclisomyia	Insecta: Trichoptera	Limnephilidae	0.5	0.1
Polycentropus	Insecta: Trichoptera	Polycentropodidae	13	2.3
Hydroporinae	Insecta: Coleoptera	Dytiscidae	1	0.2
Ceratopogoninae	Insecta: Diptera	Ceratopogonidae	1.5	0.3
Brillia	Insecta: Diptera	Chironomidae	1.5	0.3
Chironomus	Insecta: Diptera	Chironomidae	2.5	0.4
Cladotanytarsus	Insecta: Diptera	Chironomidae	2.5	0.4
Corynoneura	Insecta: Diptera	Chironomidae	38	6.6
Cricotopus	Insecta: Diptera	Chironomidae	1	0.2
Heterotrissocladius	Insecta: Diptera	Chironomidae	2.5	0.4
Orthocladius Complex	Insecta: Diptera	Chironomidae	1	0.2
Paratanytarsus	Insecta: Diptera	Chironomidae	120	20.8
Phaenopsectra	Insecta: Diptera	Chironomidae	1	0.2
Polypedilum	Insecta: Diptera	Chironomidae	59.5	10.3
Procladius	Insecta: Diptera	Chironomidae	51	8.8
Psectrocladius	Insecta: Diptera	Chironomidae	97	16.8
Psilometriocnemus	Insecta: Diptera	Chironomidae	1.5	0.3
Synorthocladius	Insecta: Diptera	Chironomidae	21	3.6
Tanytarsus	Insecta: Diptera	Chironomidae	59.5	10.3
Thienemannimyia Complex	Insecta: Diptera	Chironomidae	19	3.3
Zavrelimyia	Insecta: Diptera	Chironomidae	29	5.0
		Ave Total No:	576.5	
		Total Taxa:	27	

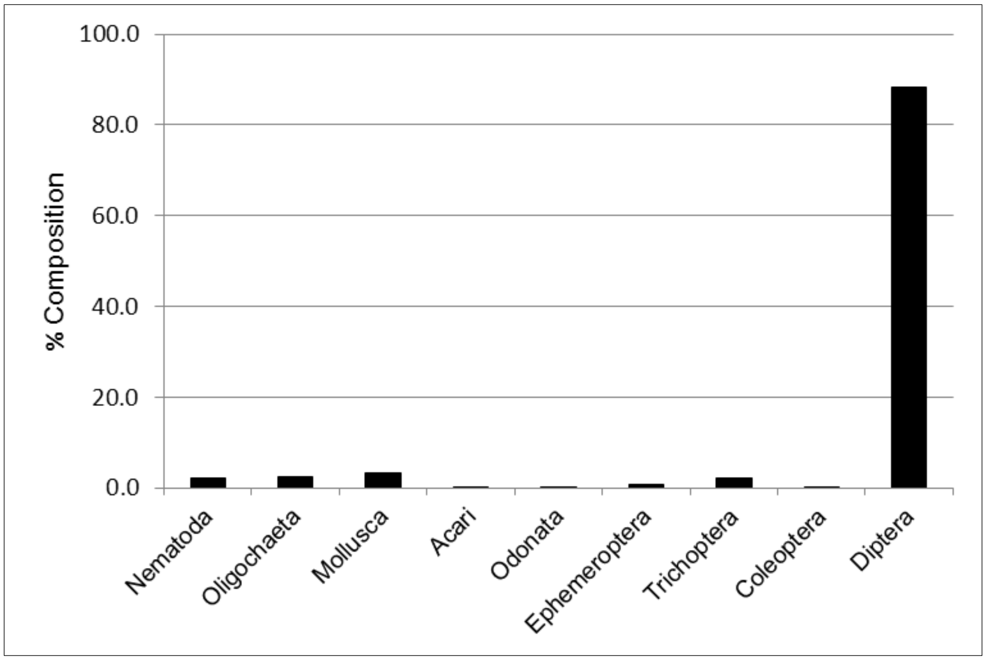

Figure 9. Composition of major BMI taxonomic groups, Sourdough Lake, September 4, 2010.

BMI metric values are compared with those from the NOCA fish density reference site groups in Table 18. The 14 metrics selected for evaluation represent a subset of 33 candidate metrics (Appendix 2) that exhibited significant differences (among 30 NOCA lakes grouped by low and high fish density (≥200 fish/ha). Only one limnephilid (Trichoptera) taxon was found in Sourdough Lake and is consistent with what is expected for NOCA lakes with high fish density fish populations (mean = 0.94, Table 18). Total number of Trichoptera and Diptera taxa fell between the mean values for low and high fish density site groups.

All of the composition metrics in Table 18 that predict a decreasing trend with increasing fish density (-) appear to be consistent with expectations for lakes with high densities of fish, with the exception of %Trichoptera taxa. Values for these metrics either reflected the absence of a taxon (%*Desmona mono* - a limnephilid trichopteran, and %Dytiscidae - Coleoptera) or exhibited very low values (%Limnephilidae, %Ecclisomyia - another limnephilid, %Coleoptera, and %EPTOC) when compared to what is expected in NOCA lakes with low fish density populations. Feeding strategies of these mobile taxa make them more vulnerable to predation in the presence of fish. Because of their vulnerability, fish predation has resulted in a large disparity between their distribution among NOCA lakes with low and high fish densities, particularly for *Desmona mono* and dytiscid beetles (present in approximately 75% of lakes with low fish densities and only found in 20% of the lakes with high fish densities; R. Glesne, NOCA files). Composition metrics for %*Coryoneura* and %*Paratanytarsus* (Chironomidae genera) were consistent with the expected values for NOCA lakes with high fish density populations.

Table 18. Comparison of BMI metric values for Sourdough Lake, 2010, with average, minimum, and maximum metric values from 20 low fish density and 10 high fish density NOCA reference lakes sampled between 2006 and 2010. Selected metrics represent a subset of 33 candidate metrics that show significant differences (Mann Whitney, p<0.05, two-tail) among NOCA lakes grouped by low and high density fish populations (see Appendix 2 and Table 4).

		Reference Lake Fish Density			
		Low Density		High Density	
Metrics (Predicted trend with fish density +/-)	**Sourdough Lake Values**	**Mean**	**Range**	**Mean**	**Range**
Taxa Number Metrics (ave. no. of taxa from replicates)					
Trichoptera (-)	2	2.53	1.0-4.3	1.11	0-2.5
Limnephilidae (Trichoptera) (-)	1	2.21	0-3.7	0.94	0-2.5
Diptera (+)	12	9.74	5.2-15.5	12.72	8.8-17.2
Composition Metrics (ave. %composition from replicates)					
%*Pisidium* (Mollusca: Bivalvia) (+)	3.4	3.01	0-16.8	6.57	0.5-16.1
%Trichoptera (-)	2.3	2.69	0.3-16.1	0.70	0-2.3
%Limnephilidae (Trichoptera) (-)	0.1	2.50	0-16.1	0.45	0-2.1
%*Desmona mono* (Limnephilidae) (-)	0	0.45	0-2.6	0.07	0-0.6
%*Ecclisomyia* (Limnephilidae) (-)	0.1	1.14	0-11.9	0.02	0-0.1
%Coleoptera (-)	0.2	6.08	0-35.8	1.85	0-10.4
%Dytiscidae (Coleoptera) (-)	0	4.16	0-35.8	0.01	0-0.1
%Ceratopogoninae (Diptera) (+)	0.3	0.45	0-3.6	12.25	0.1-71.4
%*Coryoneura* (Chironomidae) (+)	6.7	0.61	0-3.5	2.13	0-7.3
%*Paratanytarsus* (Chironomidae) (+)	20.8	0.85	0-6.4	13.93	0-60.7
%EPTOC* (-)	3.3	13.73	2.8-49.9	4.45	0.2-14.0

*%EPOTC – Ephemeroptera, Plecoptera, Trichoptera, Odonata, and Coleoptera.

Amphibians

No amphibians were observed during the survey around the perimeter of Sourdough Lake and in the outlet stream. The lake and the outlet provided the only aquatic habitat at this site, and these locations were all inhabited by Brook Trout. Steep slopes around the lake contributed to the lack of aquatic habitat beyond the shore of the lake overall. A dried-up vernal pond approximately 50 m by 10 m was present adjacent to the treeline north of the outflow on the east end of the lake, and this could provide breeding and temporary rearing habitat in the spring and early summer.

Summary for Sourdough Lake

1. Limnology: area 11.2 ha; volume 1,374,448 m^3; maximum depth 31 m; thermocline depth 8 m; hypolimnion hypoxic; trophic state oligotrophic
2. Lake chemistry: pH profile 6.1-7.4; TDS 16 mg/L; ANC 0.12-0.15 meq/L
3. Zooplankton: The absence of large-bodied zooplankton (calanoid copepods and cladocerans) and dominance of smaller cladocerans, cyclopoid copepods, and rotifers is typical for NOCA lakes with high density fish populations.
4. Benthic Macroinvertebrates: Diptera taxa dominated the samples, both in number of taxa and percent composition. Coleoptera, Ephemeroptera, Odonata, and Trichoptera taxa, known to be vulnerable to fish predation, were either absent or observed in very low abundance as expected for NOCA lakes with high density fish populations.
5. Amphibians: none
6. Fishes: Eastern Brook Trout were captured in Sourdough Lake and its outlet stream.
7. Fish spawning habitat: Typical spawning habitat for Brook Trout was not identified in locations accessible to fish. No perennial inlet streams were present, and the outlet stream passed over a barrier. Downstream passage to Ross Lake via Pierce Creek appears feasible.
8. Fish recruitment: No evidence of recent recruitment was found. Fish that were visually observed in the water corresponded in size to the smallest fish that were gillnetted with none smaller than 90 mm.
9. Fish condition: Most fish in the population are not attractive to anglers, being short and thin. Also, the proportion of thin fish increases with increasing length. The lake does not have established trail access so angling pressure is likely low.
10. Fish population size: Population estimation was conducted in a manner that provided a robust estimate of 5,924 fish (95% CI: 4,718-7,434). This was reduced to an estimated 5,198 fish by gillnetting and other mortality.
11. Fish biomass and fish removal: Initial fish density was estimated at 29.1 kg/ha; this was reduced 12.3% by gillnetting to 25.5 kg/ha. The initial density likely reflected carrying capacity.
12. Risk to native fish species: Native ESA-listed Bull Trout in Ross Lake, the upper Skagit River watershed, and the downstream reservoirs and lower Skagit River are at risk of introgressive hybridization with non-native Brook Trout that may move downstream from Sourdough Lake and Pierce Creek. Large Brook Trout were collected in Sourdough Lake and have been collected during previous fish surveys of the Ross Lake.
13. Feasibility of restoration: Although some reduction of the fish population occurred through gillnetting, the complexity of the nearshore habitat and the depth and size of the lake precludes gillnetting as the sole means of restoring the lake. Amphibians were not observed around the lake and there are no nearby colonization sources, so this aspect of restoration may require intervention. Recovery of zooplankton and macroinvertebrates is likely to take some time because of their limited dispersion capability and the absence of nearby colonization sources.

Results: Kettling Lake

Physical Characteristics

The surface of the lake is a 4.1-ha oval with a bowl-shaped bottom and a regular shoreline (Table 19; Figure 10). Maximum depth is 6.9 m, and occasional sunken boulders, rubble, and sunken and emergent logs were visible throughout the lake.

Table 19. Physical characteristics of Kettling Lake.

Parameter	Measurement
Length (m)	293
Fetch (m)	293
Breadth (m)	201
Perimeter (m)	851
Area (m^2)	40,918
Shoreline development	1.19
Maximum depth (m)	6.90
Volume (m^3)	159,436
Volume (ac-ft)	129
Mean Depth (m)	3.90

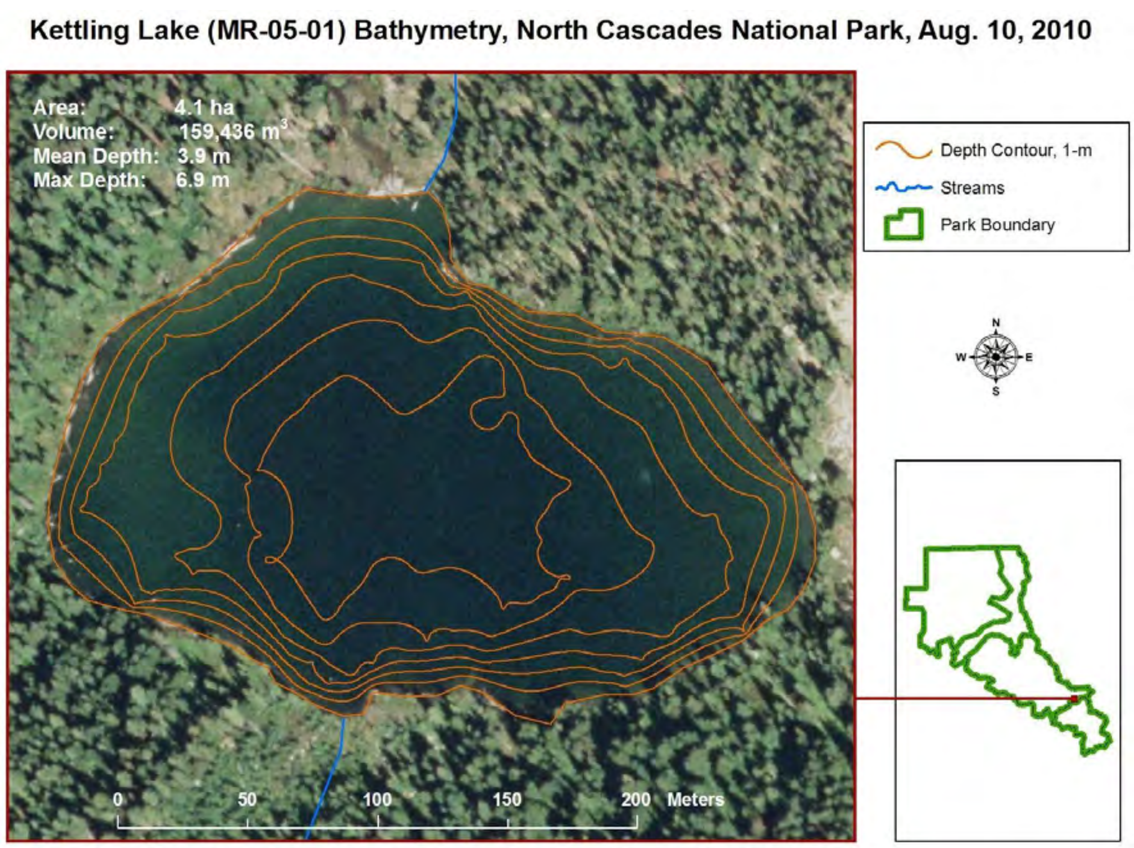

Figure 10. Bathymetric map of Kettling Lake; inlet from the south side and outlet to the north.

No islands or peninsulas are present, and the shoreline is forested with the exception of a slide area on the east end. An inlet stream is present on the south side, which has a braided channel in the boggy area where it enters the lake. Similar to observations from the survey conducted in 1975, the stream becomes braided into a few distributaries as it enters the lake over the last 20 m. Approximately 125 m upstream from the lake a 2-3 m waterfall occurs. The stream appears passable to fish in the reach below the falls to the lake. An outlet stream drains the lake on the north side. Discharge was measured near the lake at the inlet and the outlet. Snow was not evident in the upper watershed, and flows were similar, between 0.2 and 0.3 cfs (Table 20). The outlet stream traverses through ponded areas and then falls steeply down the drainage. At the flow level during this survey, two likely barriers to upstream fish passage were identified and these appeared likely to remain impassable during higher flows. These occurred approximately 150 m downstream. Seeps were also present along the east, south, and west sides of the lake. Generally, these were 10-15 cm wide and deep. Those along the east side were perched 1 to 2 m above the lake level, draining steeply to the lake at the shore. The seep channels along the south shore drained the boggy slope on the west side of the inlet stream and only contained water where shallow depressions were present. Similarly, seep channels along the west shore wound through grass and shrub habitat. These also had intermittent pools of water. The shorelines on the south and the west were perched 0.5 m above the water's edge so these seeps drained steeply to the lake at their outfalls.

Table 20. Kettling Lake inlet and outlet stream wetted width and discharge, August 10, 2010.

Location	Stream width		Discharge	
	ft	m	ft^3/s	m^3/s
Inlet	2.00	0.60	0.22	0.0062
Outlet	2.10	0.64	0.29	0.0082

Water Chemistry and Depth Profiles

With the exception of (DOC), the water chemistry in Kettling Lake is similar to other lakes that were sampled in North Cascades National Park in 2010 (Table 21). DOC was greater by at least a factor of four in comparison to Lower Blum, Middle Blum, and Sourdough lakes.

DOC arises from a variety of sources, but the most evident one for alpine lakes is coniferous forest. Aerobic fungi degrade celluloses, hemicelluloses, and lignins contained in needles and other coniferous tree litter, and these compounds are readily leached of organic acids (Wetzel 2001). Casual visual examination of aerial photographs of the watersheds of these lakes indicates that the highest proportion of coniferous forest occurs at Kettling Lake among the lakes used for comparison. In addition, Kettling Lake is smaller, shallower, and lacks thermal stratification so these factors may also contribute to higher concentrations of DOC. The presence of oxygen and relatively warm temperatures on the bottom may facilitate the breakdown of coniferous tree parts by aerobic fungi, yielding the high DOC value that was reported. The water appeared slightly stained brown, suggesting that tannins may contribute to the higher DOC.

Anion and cation concentrations were consistent with other mountain lakes (Table 22). The concentrations were within the range of values from the other four lakes used for comparison for

Table 21. Water chemistry including nutrients for Kettling Lake sampled on August 11, 2010 and other NOCA lakes sampled in the summer of 2010.

Lake	Total dissolved nitrogen (mg/L)	NH_3-N (mg/L)	Total dissolved phosphorus (mg/L)	Soluble reactive phosphorus (orthophosphate) (mg/L)	Total dissolved solids (mg/L)	Dissolved organic carbon[1] (mg/L)	Specific conductance (µS/cm)	Mean Chlorophyll a (µg/L)	pH	Acid neutralizing capacity (meq/L)
Kettling[2]	0.04	*0.001	*0.001	*0.000	20	266.27	19.37	0.092	6.88	0.15
Sourdough[3]	0.05	*0.001	*0.002	*0.001	16	2.58	13.86	0.105	6.50	0.12
Sourdough[4]	-	-	-	-	-	-	23.20	-	6.17	0.15
Middle Blum[2]	0.03	*0.001	0.007	*0.000	13	67.21	16.60	0.058	6.80	0.09
Lower Blum[2]	0.02	*0.001	0.006	*0.000	12	2.60	14.96	0.051	6.74	0.08

[1] Dissolved organic carbon samples taken at 1 m below surface at all sites.

[2] Sample taken at mid-depth.

[3] Sample taken at 1 m below surface.

[4] Sample taken at 1 m above bottom.

* Below detection limits.

Table 22. Anion/cation content for Kettling Lake sampled on August 11, 2010 and other NOCA lakes sampled in the summer of 2010.

Lake Name	Chloride Cl µeq/L	Nitrate NO_3 µeq/L	Sulfate SO_4 µeq/L	Sodium Na µeq/L	Ammonium NH4 µeq/L	Potassium K µeq/L	Magnesium Mg µeq/L	Calcium Ca µeq/L
Kettling Lake	2.03	0.04	19.99	21.50	1.13	4.89	20.01	170.75
Sourdough	2.52	0.10	17.11	17.64	4.58	5.66	23.92	123.27
Sourdough	4.31	1.28	22.17	28.96	7.82	9.85	37.59	198.63
Middle Blum	3.00	0.02	48.52	35.20	1.55	3.96	23.28	133.86
Lower Blum	2.91	*	36.95	26.14	1.91	3.72	23.72	121.84

* Below detection limit

all three anions and three of the five cations. Kettling Lake was only distinguished by having the lowest ammonium and lowest magnesium concentrations, but these do not appear exceptionally low.

A TSI value could only be determined for chlorophyll a for Kettling Lake; Secchi depth was undetermined because the bottom was visible at the deepest location and total phosphorus, which requires an unfiltered sample, was not measured because water samples are filtered prior to analysis for measurement of total dissolved phosphorus (Table 21). The TSI value for chlorophyll a of 7.2 indicates that the lake is very oligotrophic. Compared to other North Cascades National Park alpine lakes that were sampled for chlorophyll a in 2010, it is similar to Sourdough and more productive than Middle Blum and Lower Blum.

A vertical profile of temperature was measured at 1-m intervals from surface to bottom on August 12, 2010 (Figure 11). Temperature was uniform throughout the water column, indicating that no seasonal thermal stratification was present. Since the warmest water temperatures tend to occur in August, it is likely that this lake seldom, if ever, stratifies on a seasonal basis. However, on warm, sunny days it may exhibit temporary diurnal stratification. Historical temperature data from September 14, 1976 also indicate that the lake was unstratified.

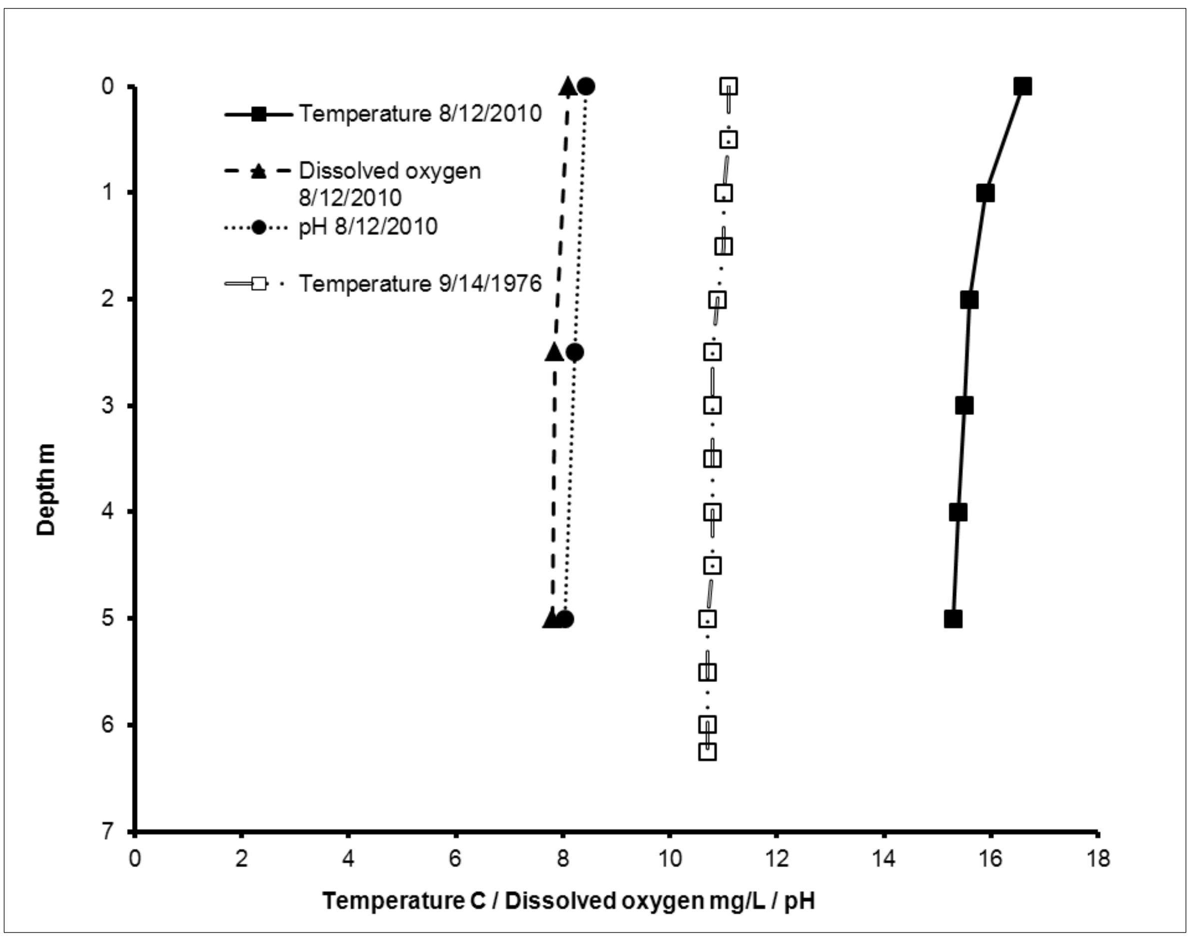

Figure 11. Vertical temperature, dissolved oxygen, and pH profiles for August 12, 2010 and September 14, 1976 in Kettling Lake.

As a result of the lack of stratification, dissolved oxygen can be circulated freely within the water column, and the surface mid-depth, and near bottom measurements show that it is uniformly high throughout (Figure 11).

Fish Population Assessment

Fish Captures and Length Distribution

Fish in Kettling Lake most closely resembled Rainbow Trout, and this was the only fish species found in the lake. Some of these fish exhibited aberrant spotting patterns and had very faint pink to orange pigmentation in the skin folds of the mandible that suggested that some degree of hybridization with Westslope Cutthroat Trout had occurred in the past. At the inlet stream on the south side of the lake Rainbow Trout were captured up to the first waterfall, approximately 125 m upstream, but no fish were found above the falls; it has a vertical drop of 2 to 3 m so it is likely a barrier to upstream movement. At the mouth of the inlet five or six larger, spawning fish were present. Smaller spawning fish were observed upstream to the falls. Angling effort and visual observations in the smaller, shallower lake (MR-06-01) above Kettling Lake and the source of its inlet yielded no evidence of fish presence. At the outlet stream fish were visually observed in the series of pools at its inception where a series of low-gradient meanders occurred before the stream began dropping more steeply 85 m from the lake. Presence was not assessed in the steeper section downstream to its confluence with Bridge Creek, a distance of 1.75 km from the outlet and a drop of 570 m. No fish were present in the first meander pool, but smaller fish were found in the riffles below it. In the second meander pool five to six medium-sized fish that appeared to have finished spawning were noted. Further downstream, larger fish in spawning colors were present. The seeps around the south and west sides of the lake, described above in Physical Characteristics, were either inaccessible to fish or of insufficient size to support fish.

During the first two days at the site 103 fish were captured by angling, fin-clipped, and released near the site of capture to meet the assumption that marked fish used in the population estimate are randomly distributed among unmarked fish (Table 23). Catch per angler hour averaged 3.0 fish. One mortality was noted during sampling, and six fish were recaptured and released.

Table 23. Capture of Rainbow Trout by angling in Kettling Lake, August 9-10, 2010, that were marked for population estimation.

No. of anglers	Hours fished (range per angler)	No. caught	Catch per angler-hour	Recaptures & mortalities	No. marked
5	47.5 (8.5-10.5)	110	3.0	6 & 1	103

Using 10-mm groups to portray the length-frequency distribution, the primary modal length of Rainbow Trout captured by angling from Kettling Lake was 210-219 mm (Figure 12). A secondary mode appears at 260-269 mm. The smallest fish was in the 120-129 mm group and the largest in the 280-289 mm group. We collected 330 Rainbow Trout by gill netting (Table 24). Mean catch per net-hour ranged from 0.8 to 1.4 for the first day of sampling with ten nets (#1-10), but the second day it dropped to 0.2 to 0.5 for three nets (#11-13) that were re-set, likely as a result of the reduction of the number of fish. Also, experience with gill netting in other alpine lakes suggests that fish become less susceptible to capture after the initial effort and resulting mortality.

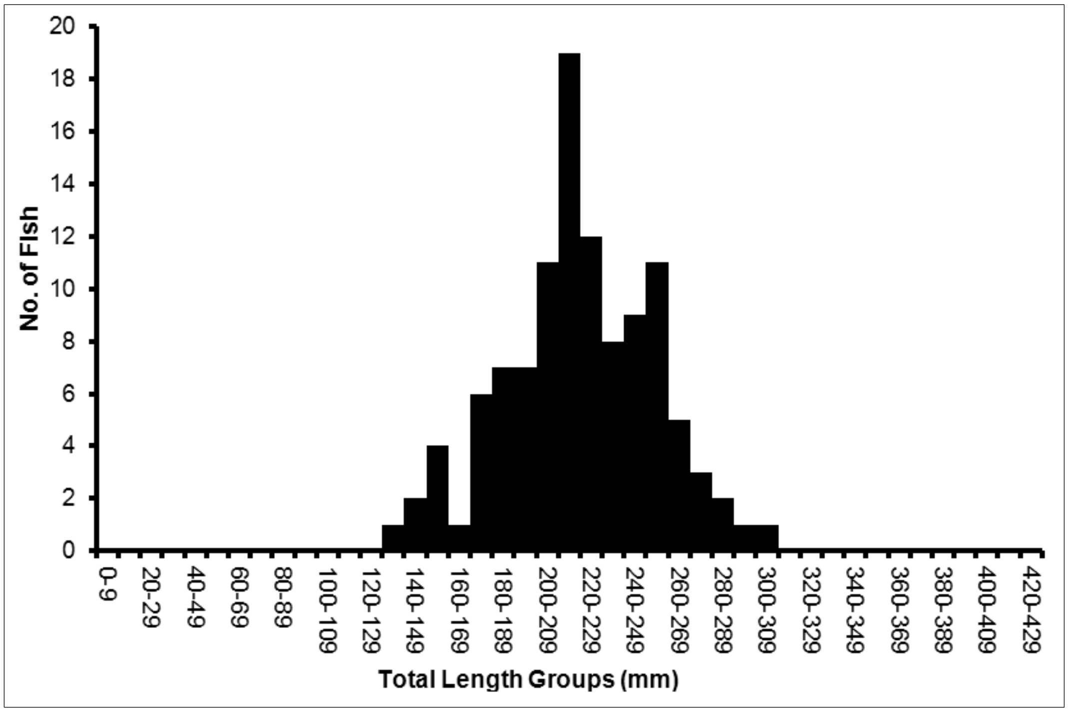

Figure 12. Distribution of total lengths of 110 Rainbow Trout captured by angling in Kettling Lake, August 9-10, 2010.

Table 24. Capture of Rainbow Trout by gill nets in Kettling Lake, August 11-13, 2010, to assess marked fish and assess population characteristics.

Gill net	Net hrs.	Tot. no. caught	Catch per net-hour	Marked fish recaptures
1	23.1	33	1.4	2
2	23.3	33	1.4	6
3	23.5	34	1.4	2
4	24.0	40	1.7	11
5	24.3	34	1.4	4
6	27.2	28	1.0	5
7	27.3	22	0.8	2
8	27.5	21	0.8	2
9	28.3	30	1.1	3
10	28.5	29	1.0	1
11	26.3	13	0.5	2
12	26.2	5	0.2	2
13	26.1	8	0.3	1
Totals	335.4	330	1.0	43

The primary modal length group of Rainbow Trout collected by gill netting was 170-189 mm (Figure 13), which is three 10-mm size groups smaller than those captured by angling (Figure 12). A secondary mode appears at 230-239 mm, again smaller than the 260-269 mm for angled fish. The smallest fish was in the 80-89 mm group and the largest in the 310-319 mm group, and this range encompassed that of fish collected by angling.

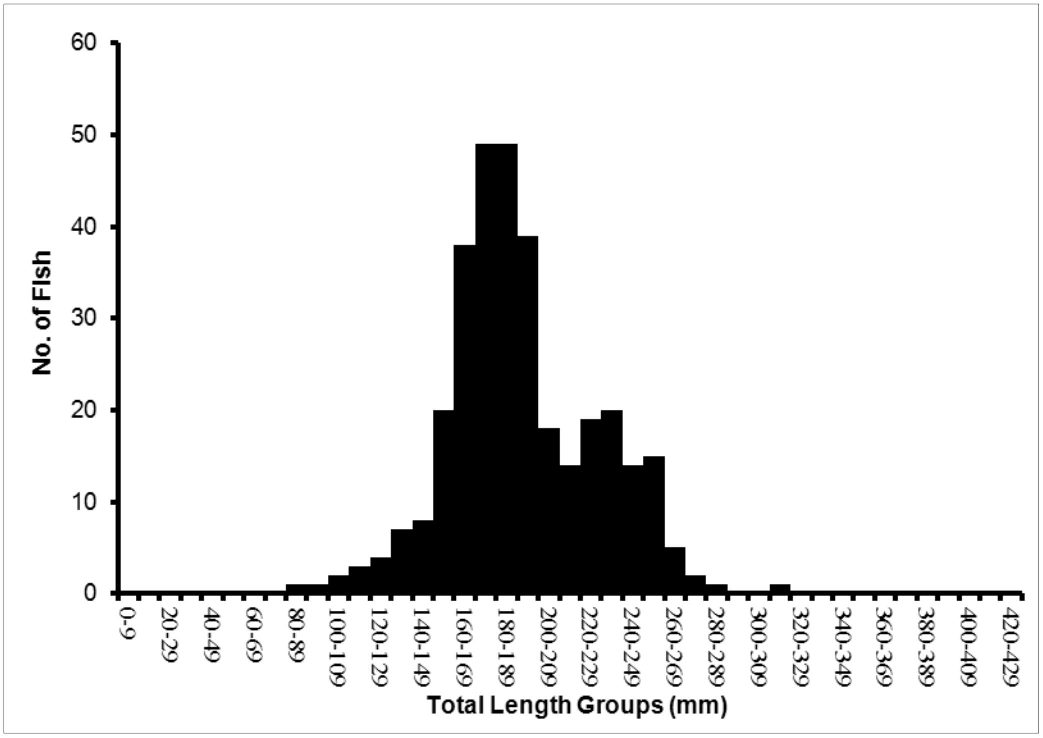

Figure 13. Distribution of total lengths of 330 Rainbow Trout captured by gillnetting in Kettling Lake, August 11-13, 2010.

The distribution of sizes captured by angling was statistically compared to those collected by gill nets. Gillnetting collected a significantly larger proportion of smaller fish (Kolmogorov-Smirnov two-sample test, $P \leq 0.001$; Figure 14). The median total length of gill netted fish was 185 mm versus 215 mm for angled fish (Mann-Whitney U-test, $P \leq 0.0001$), but the size range of fish collected by gillnetting encompassed those captured by angling. The size difference likely had minimal effect on the population estimate. In applying this technique to population estimation, if either the marking or the subsequent recapture is done randomly, the estimate is not biased. In addition, anticipated bias can be remediated by using different gear types for initial capture and for recapture (Ricker, 1975), and the sampling protocol we used conformed to both of these conditions.

Both the angling and the gill net size distributions show rapid truncation for smaller fish. This may be a reflection of size selectivity by the gear, particularly for angled fish. Hook size was not accounted for during sampling, and since the smallest angled fish were in the 130-139 mm range and the smallest gillnetted fish were in the 80-89 mm range, one explanation is that the smaller fish were not susceptible to angling because the hooks were too large. However, fishing effort may not have been directed to areas where the smallest fish occur during the day or small fish may have been less inclined to attack a lure in open water during the day.

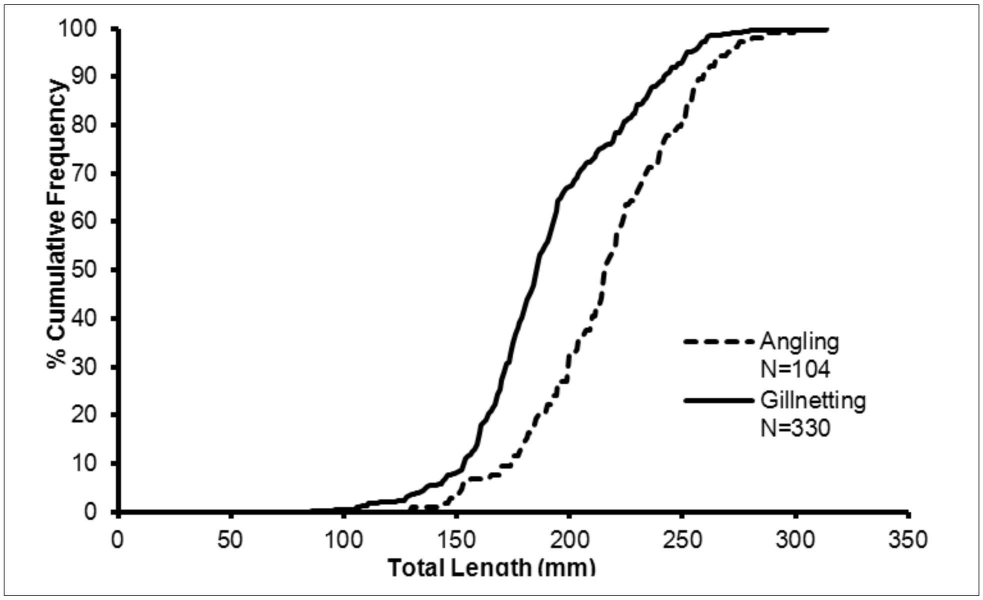

Figure 14. Relative cumulative length frequency distributions comparing Rainbow Trout captured by angling versus gillnetting from Kettling Lake, August 9-13, 2010 (Kolmogorov-Smirnov D statistic=40.0; critical value at P≤0.05=19.2).

Sex and maturity were assigned in 329 of 330 fish collected by gillnetting (Table 25). The proportion of males and females was biased toward males with 1.2 males per female. More than 95% of the fish of both sexes were mature adults. Among the mature adult females about 8% had eggs that were ready to be released or had just released most of the eggs. In 1% of the males milt was readily expressed during examination.

Table 25. Sex distribution and sexual maturity of Rainbow Trout collected by gill nets from Kettling Lake, August 11-13, 2010.

Maturity	Females		Males	
	N	%	N	%
Adult	144	96.6	180	98.9
Ripe	11	7.6	2	1.1
Juvenile	3	2.0	2	1.1
Total	147	44.5	182	55.2

Fish Weight and Condition

To develop the log-linear relationship between length and weight, these were recorded for ten fish in each 10-mm length group. Individuals were grouped by sex, and linear regression was performed to derive the parameter coefficients (Figure 15). The R-squared values were 0.94 for males and 0.97 for females, indicating that weights for the remaining portion of the sample in which only lengths were recorded could be reasonably estimated.

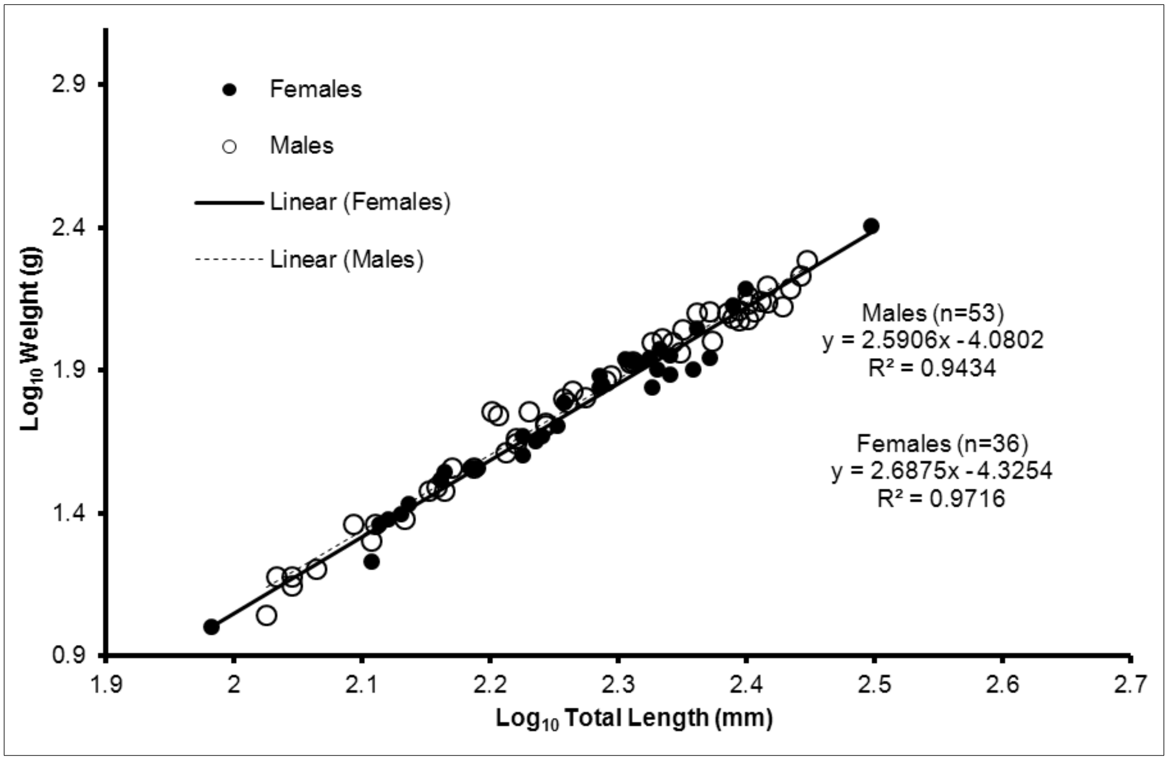

Figure 15. Linear regression by sex of $\log_{10}$-transformed total lengths and weights for Rainbow Trout captured by gillnetting from Kettling Lake, August 11-13, 2010.

Physiological condition of individual fish based on individual lengths and weights was assessed using condition factor and relative weight index. Condition factor (K) values for male and female Rainbow Trout are shown in Figure 16. Rainbow Trout in Kettling Lake range from extremely poor to fair (65% - K <1.2; Barnum and Baxter 1998). Condition factor does not appear to differ between males and females. Values for both sexes occur across the range, although a few males less than 200 mm TL have the highest condition factors. The population demonstrates a downward trend with increasing length, which is opposite of the trend typically caused by allometric growth wherein changes in shape as a result of increases in size increase the relative plumpness of a fish. The downward trend with increasing size would be expected in a population that is limited by food abundance, particularly the availability of larger food items. This population likely subsists on aquatic macroinvertebrates so the larger fish have reached a size where availability and ability to capture and consume them result in a diet that increasingly does not support energetic storage in the form of body lipids. This translates to a loss of plumpness, or girth, with increasing length.

The array of values for relative weight (W_r) appears similar to those for condition factor (Figure 17). Only 3.4% of the fish (three males,159-170 mm) have W_r values of 100 or more. Relative weight generally does not differ between sexes across the entire range of lengths. As also shown by K values, the decreasing condition with increasing length is again evident.

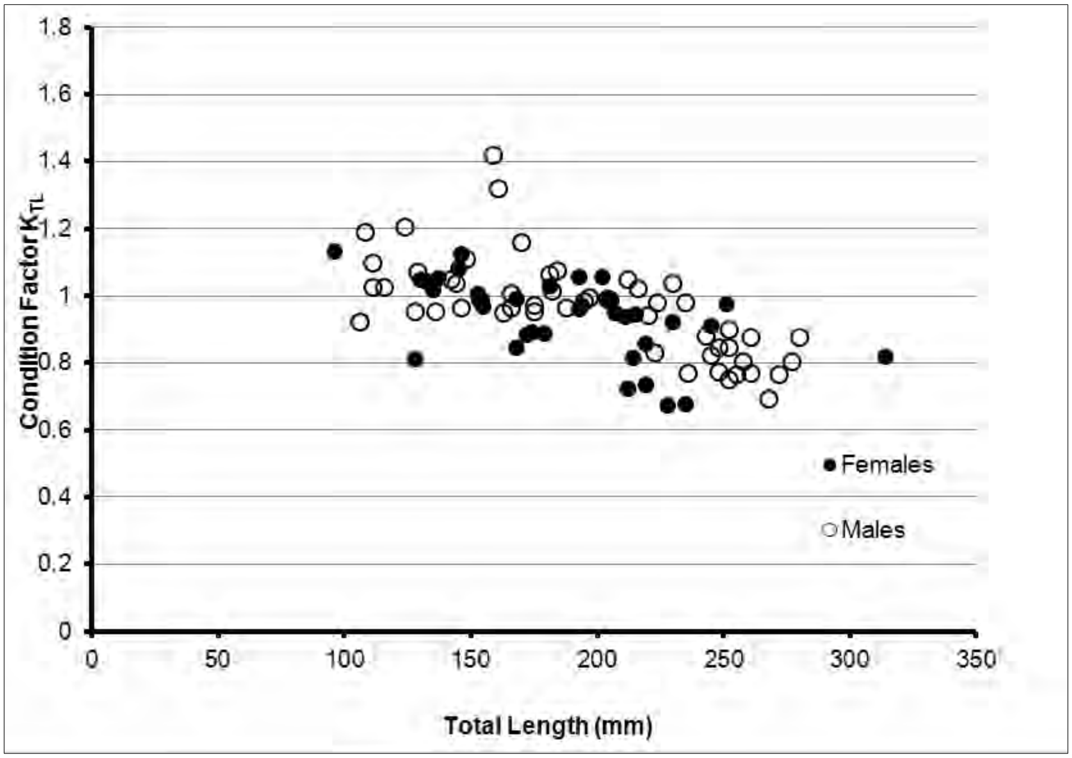

Figure 16. Relative plumpness (condition factor, K_{TL}) by total length and by sex for Rainbow Trout captured by gillnetting from Kettling Lake, August 11-13, 2010.

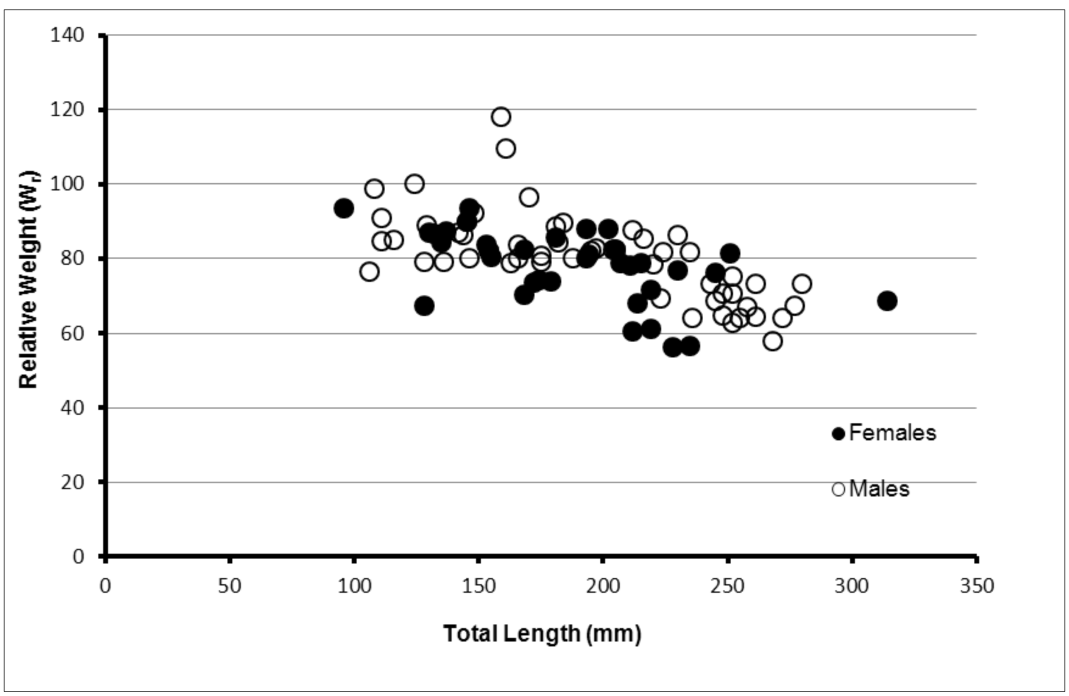

Figure 17. Relative weights (W_r) by total length and by sex for Rainbow Trout captured by gillnetting from Kettling Lake, August 11-13, 2010 (Simpkins and Hubert, 1996).

Lake Fish Population Estimation

Population size of Rainbow Trout in Kettling Lake was estimated using Petersen's mark and recapture single census approach with Chapman's modification to correct for statistical bias. All crew members participated in angling using spinning rods and fly rods for two days to capture fish for marking. Anglers were haphazardly distributed around the lake on the shore and in two rafts, and marked fish were released in the vicinity of capture. Recapture was conducted by gillnetting for the two subsequent days. We recaptured 43 of the 103 fish that were marked, resulting in a population estimate of 782 fish with a coefficient of variation of 15.2% (Table 26). The 95% confidence interval for this estimate is 584-1,046 based on a Poisson distribution of the number of recaptured marked fish, resulting in a range of 461 fish around the estimate.

Based on the population estimate for the number of Rainbow Trout in Kettling Lake, the number and sizes of fish removed by gillnetting and angling mortality, and the relationship of length to weight that was established from a subsample of the removed fish, estimations of the remaining number and biomass of fish were made. Total biomass is likely underestimated because gill nets are not very effective at catching small fish, as indicated by the size truncation at the 80-89 mm group (Figure 13); however, the smallest size groups of fish also represent a disproportionately small proportion of biomass in relation to their numbers.

Table 26. Population estimate of Rainbow Trout in Kettling Lake, August 9-13, 2010, using Chapman's modification of Petersen's single census mark and recapture method.

Population Estimate Parameters	No.
Marked fish - M	
Angling catch	103
Total marked	103
Captured fish - C	
Captured by gill net	330
Total captured	330
Recapture of marked fish - R	
Captured by gill net	43
Total recaptured	43
Population estimate – N (95% CI)	782 (584-1,046)
%Coefficient of variation - %CV	15.2

Gillnetting and angling reduced the estimated population size and biomass by 42%, assuming that the size distribution captured by the gill nets reflects the actual size distribution of fish in the lake (Table 27). Fish density was reduced from 191 to 110 fish per hectare, and estimated biomass decreased from 13.4 to 7.7 kg per hectare.

No stocking has occurred in Kettling Lake in recent years. The isolated location relative to trail networks and to other lakes and the difficulty in accessing it overland suggest that recreational angling has little effect on the population. If so, the estimated original biomass of 13.4 kg per hectare likely reflects the carrying capacity of the lake with respect to fish, wherein reproduction and growth are offset by natural mortality.

Table 27. Population parameters for Rainbow Trout collected from Kettling Lake, August 9-13, 2010.

Parameter	No.	%
Estimated original population size	782	100.0
Removed by netting	330	42.2
Removed by angling	1	0.1
Total removed	331	42.3
Estimated remaining population size	451	57.7
Previous no. of fish/ha	191	
Remaining no. of fish/ha	110	
Estimated original biomass (kg)	55	100.0
Estimated reduction in biomass (kg)	23	42.3
Estimated remaining biomass (kg)	32	57.7
Previous biomass density (kg/ha)	13.4	
Remaining biomass density (kg/ha)	7.7	

Zooplankton

Average values for zooplankton density (no/m^3) by taxa from three replicate samples collected at Kettling Lake in August, 2010, are shown in Table 28. Seven taxa (excluding copepod intermediate nauplii and copepodid life stages) were observed in the three samples. The average total density was 30,424 organisms/m^3. *Kellicottia bostonensis* (Rotifera) was by far the most abundant taxon (22,827/m^3) followed by two cladoceran taxa, *Holopedium gibberum* (3,165/m^3) and *Daphnia ambigua* (3,043/m^3).

Table 28. Average density (no/m^3) of zooplankton samples collected at Kettling Lake, August 11, 2010.

Taxa	Division	Kettling no/m^3 (n=3)
Holopedium gibberum	Cladocera	3,165.7
Daphnia ambigua	Cladocera	3,043.0
Polyphemus pediculus	Cladocera	10.7
copepodid, Cyclopoida	Copepoda:Cyclopoida	10.7
copepodid, Calanoida	Copepoda:Calanoida	1206.5
Leptodiaptomus tyrrelli	Copepoda:Calanoida	10.7
copepod nauplii	Copepoda	42.7
Keratella cochlearis var. cochlearis	Rotifera	106.8
Kellicottia bostonensis	Rotifera	22,827.6
Total Density:		30,424.4
Total Taxa:		7

Zooplankton metric values are compared with those from the NOCA fish density reference groups in Table 29. All of the metric values for Kettling Lake were consistent with values expected for NOCA lakes with high density fish populations. The absence of large-bodied crustaceans and high densities and %composition of rotifers are particularly significant indicators of high fish predation intensity.

Table 29. Comparison of zooplankton metric values for Kettling Lake, 2010, with average, minimum, and maximum metric values from 15 low fish density and 10 high fish density NOCA reference lakes sampled between 2006 and 2010. Selected metrics represent a subset of 21 candidate metrics that show significant differences (Mann Whitney, p<0.05, two-tail) among NOCA lakes grouped by low and high density fish populations (Appendix 1 and Table 3).

Metrics (Predicted trend with fish density +/-)	**Kettling**	**Low Density/No Fish (n=15)**			**High Density (n=10)**		
	(n=3)	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Large-bodied Crustacean no/m^3 (-)	0	599	0	2,476	0	0	0
Rotifer no/m^3 (+)	22,934	3,367	14	30,040	61,158	759	49,5667
%Crustaceans (-)	24.6	73.8	3.8	99.3	13.1	0.5	46.6
%Copepoda (-)	4.2	68.8	2.1	99.3	10.2	0.2	45.5
%Calanoid Copepods (-)	4.0	58.7	0.0	97.5	2.5	0.0	11.1
%Lg.-bodied Crustaceans (>1mm) (-)	0.0	16.7	0.0	57.0	0.0	0.0	0.0
%Rotifers (+)	75.4	26.2	0.7	96.2	86.1	46.9	99.5
No. Lg.-bodied Crustacean Taxa (-)	0	1.1	0.0	2.0	0.0	0.0	0.0

Benthic Macroinvertebrates (BMI)

A total of 31 taxa were collected from two replicate samples collected on August 16, 2010 (Table 30). Diptera taxa were represented by 20 taxa and collectively all Diptera accounted for 82% of the total number of specimens in the samples (Figure 18).

Chironomid species represented the majority of Diptera taxa collected (n=16). *Tanytarsus* and *Procladius* were the most abundant taxa collected in the samples, representing 27.9 and 16.8%, respectively, of the total number of specimens in the samples. Percent composition of all other taxonomic groups was low (Figure 18). The combined percent composition of taxonomic groups, mostly sensitive to fish predation (Odonata, Ephemeroptera, Trichoptera, and Coleoptera), was 6.8%.

BMI metric values are compared with those from the NOCA fish density reference site groups in Table 31. The 14 metrics selected for evaluation in Table 31 represent a subset of 33 candidate metrics (Appendix 2) that exhibited significant differences (among 30 NOCA lakes grouped by low and high fish density (>200 fish/ha). Taxa number metrics for Trichoptera/Limnephilidae were low and similar to what is expected for lakes with high density fish populations. Number of Diptera taxa was high as predicted (+) for lakes with high density fish populations.

Similar to Sourdough Lake (Table 18), all of the composition metrics for Kettling Lake BMI (Table 31) that predict a decreasing trend (-) with increasing fish density appear to follow this trend. Taxa vulnerable to fish predation were either absent (*Desmona mono*, *Ecclisomyia* sp., and dytiscid beetles) or only found in low abundance (%Trichoptera/Limnephilidae, %Coleptera, and %EPTOC).

Table 30. Average number (n=2), percent composition, and total BMI taxa collected at Kettling Lake, August 16, 2010.

			Kettling Lake (n=2)	
Taxon	**Phyla/class/subclass/etc**	**Family**	**Ave No.**	**%**
Nematoda	Nematoda		14.0	2.7
Oligochaeta	Annelida: Oligochaeta		8.5	1.7
Helobdella stagnalis	Annelida: Hirudinea	Glossiphoniidae	1.5	0.3
Pisidium	Mollusca: Bivalvia	Pisidiidae	11.5	2.3
Hyalella	Crustacea: Amphipoda	Hyalellidae	12.0	2.3
Acari	Arthropoda: Acari		9.5	1.9
Aeshna	Insecta: Odonata	Aeshnidae	2.5	0.5
Somatochlora	Insecta: Odonata	Corduliidae	6.5	1.3
Callibaetis	Insecta: Ephemeroptera	Baetidae	24.5	4.8
Sialis	Insecta: Megaloptera	Sialidae	0.5	0.1
Unknown Limnephilidae	Insecta: Trichoptera	Limnephilidae	0.5	0.1
Hydrophilidae	Insecta: Coleoptera	Hydrophilidae	0.5	0.1
Ceratopogoninae	Insecta: Diptera	Ceratopogonidae	19.0	3.7
Dasyhelea	Insecta: Diptera	Ceratopogonidae	4.0	0.8
Tabanidae	Insecta: Diptera	Tabanidae	2.5	0.5
Ablabesmyia	Insecta: Diptera	Chironomidae	6.5	1.3
Cladopelma	Insecta: Diptera	Chironomidae	8.5	1.7
Corynoneura	Insecta: Diptera	Chironomidae	9.0	1.8
Heterotrissocladius	Insecta: Diptera	Chironomidae	1.0	0.2
Limnophyes	Insecta: Diptera	Chironomidae	2.0	0.4
Metriocnemus	Insecta: Diptera	Chironomidae	1.0	0.2
Microtendipes Pedellus Grp	Insecta: Diptera	Chironomidae	14.0	2.7
Pagastiella	Insecta: Diptera	Chironomidae	72.0	14.1
Paramerina	Insecta: Diptera	Chironomidae	13.0	2.5
Paratanytarsus	Insecta: Diptera	Chironomidae	1.0	0.2
Polypedilum	Insecta: Diptera	Chironomidae	10.0	2.0
Procladius	Insecta: Diptera	Chironomidae	94.0	18.4
Psectrocladius	Insecta: Diptera	Chironomidae	17.0	3.3
Tanytarsus	Insecta: Diptera	Chironomidae	142.5	27.9
Thienemannimyia Complex	Insecta: Diptera	Chironomidae	1.0	0.2
Zavrelimyia	Insecta: Diptera	Chironomidae	1.0	0.2
		Ave Total No:	511.0	77.0
		Total Taxa:	31	

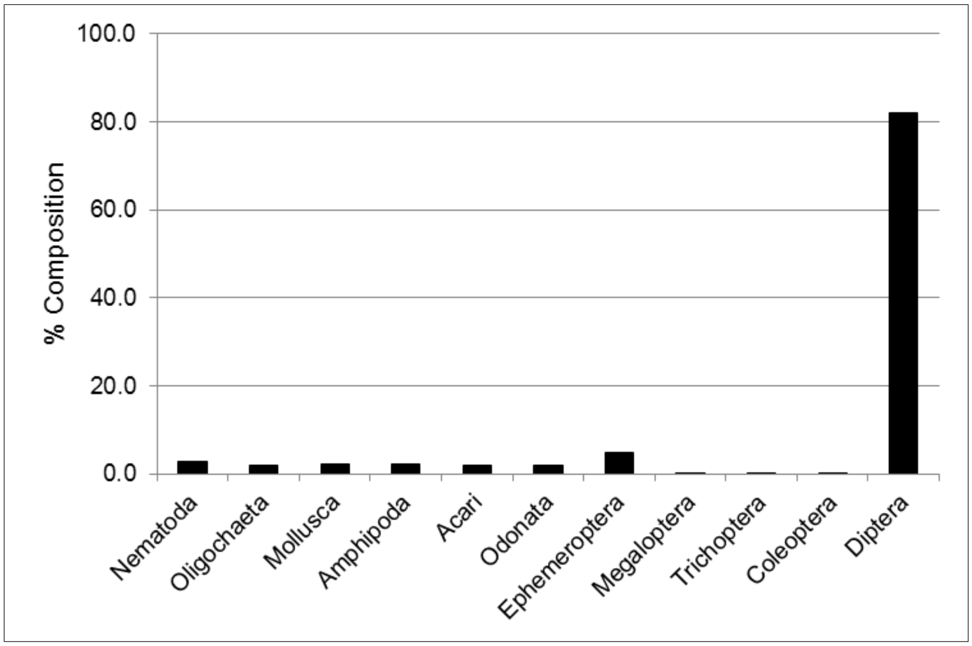

Figure 18. Composition of major BMI taxonomic groups, Kettling Lake, August 16, 2010.

Table 31. Comparison of BMI metric values for Kettling Lake, 2010, with average, minimum, and maximum metric values from 20 low fish density and 10 high fish density NOCA reference lakes sampled between 2006 and 2010. Selected metrics represent a subset of 33 candidate metrics that show significant differences (Mann Whitney, p<0.05, two-tail) among NOCA lakes grouped by low and high density fish populations (see Appendix 2 and Table 4).

		Reference Lake Fish Density			
		Low Density		High Density	
Metrics (Predicted trend with fish density +/-)	**Kettling Lake Values**	**Mean**	**Range**	**Mean**	**Range**
Taxa Number Metrics (ave. no. of taxa from replicates)					
Trichoptera (-)	1	2.53	1.0-4.3	1.11	0-2.5
Limnephilidae (Trichoptera) (-)	1	2.21	0-3.7	0.94	0-2.5
Diptera (+)	16	9.74	5.2-15.5	12.72	8.8-17.2
Composition Metrics (ave. %composition from replicates)					
%*Pisidium* (Mollusca: Bivalvia) (+)	2.3	3.01	0-16.8	6.57	0.5-16.1
%Trichoptera (-)	0.1	2.69	0.3-16.1	0.70	0-2.3
%Limnephilidae (Trichoptera) (-)	0.1	2.50	0-16.1	0.45	0-2.1
%*Desmona mono* (Limnephilidae) (-)	0	0.45	0-2.6	0.07	0-0.6
%*Ecclisomyia* (Limnephilidae) (-)	0	1.14	0-11.9	0.02	0-0.1
%Coleoptera (-)	0.1	6.08	0-35.8	1.85	0-10.4
%Dytiscidae (Coleoptera) (-)	0	4.16	0-35.8	0.01	0-0.1
%Ceratopogoninae (Diptera) (+)	3.7	0.45	0-3.6	12.25	0.1-71.4
%*Coryoneura* (Chironomidae) (+)	1.8	0.61	0-3.5	2.13	0-7.3
%*Paratanytarsus* (Chironomidae) (+)	0.2	0.85	0-6.4	13.93	0-60.7
%EPTOC* (-)	6.8	13.73	2.8-49.9	4.45	0.2-14.0

*%EPOTC – Ephemeroptera, Plecoptera, Trichoptera, Odonata, and Coleoptera.

Amphibians

No amphibians were observed during the visual encounter survey around Kettling Lake. Observations made around the area at the north end of the upper lake (MR-06-01, upstream from Kettling), which was shallow and mud-bottomed with emergent grass, had several small pockets where the water's surface indicated an underlying disturbance. We were able to identify 20 long-toed salamander larvae (*Ambystoma macrodactylum*) and one adult from this habitat. Based on the multitude of locations where we could see subsurface activity, we surmised that this species was abundant in this water body.

Summary for Kettling Lake

1. Limnology: area 4.1 ha; volume 159,436 m^3; maximum depth 6.9 m; thermocline not present; trophic state oligotrophic
2. Lake chemistry: pH profile 8.0-8.5; TDS 20 mg/L; ANC 0.15 meq/L
3. Zooplankton: The community structure and composition is similar to what is expected for NOCA lakes with high density fish populations; rotifers dominate in abundance and composition and large-bodied crustaceans are absent.
4. Benthic Macroinvertebrates: The number of Diptera taxa observed was high and the numbers of Trichoptera, Ephemeroptera, Odonata, and Coleoptera taxa were low, as expected for lakes with high density fish populations. Similar to Sourdough Lake, all of the composition metrics for Kettling Lake macroinvertebrates that predict a decreasing trend with increasing fish density appear to follow this trend. Taxa vulnerable to fish predation were either absent (*Desmona mono*, *Ecclisomyia* sp., and dytiscid beetles) or only found in low abundance (%Trichoptera/Limnephilidae, %Coleptera, and %EPTOC).
5. Amphibians: long-toed salamanders are abundant in upper watershed.
6. Fish species: Only Rainbow Trout were captured. The physical appearance of individual fish suggests that Westslope Cutthroat Trout may have hybridized with Rainbow Trout in the past. The higher proportion of male Rainbow Trout could be the result of hybridization.
7. Fish spawning habitat: Rainbow Trout may spawn in the vicinity of the inlet and the outlet. Upstream dispersal is limited by a waterfall near the lake. Downstream passage to Bridge Creek appears feasible.
8. Fish recruitment: No evidence of recent recruitment was found. Fish that were visually observed in the water corresponded in size to the smallest fish that were gillnetted with none smaller than 80 mm. However, ripe males and females were captured in the gill nets, and spawning fish were observed in the streams.
9. Fish condition: Most fish in the population are not attractive to anglers, being small and thin. Also, the proportion of thin fish increases with increasing length.
10. Fish population size: Population estimation was conducted in a manner that provided a robust estimate of 782 fish. This was reduced to 451 fish by gillnetting.
11. Fish biomass and fish removal: Initial fish density was estimated at 13.4 kg/ha; this was reduced 42.3% by gillnetting to 7.7 kg/ha. The initial density likely reflected carrying capacity Carrying capacity based on estimated fish biomass is low, which reflects the trophic status of the lake.
12. Risk to native species: Native Westslope Cutthroat Trout in Bridge Creek are at risk of introgressive hybridization with non-native Rainbow Trout, as has occurred below tributary barriers in the Stehekin River watershed. Historical introgressive hybridization of Rainbow Trout when Westslope Cutthroat Trout were present in Kettling Lake may increase the likelihood of hybridization in Bridge Creek and below.
13. Feasibility of restoration: An abundant population of long-toed salamanders is present in the lake upstream of Kettling Lake that would facilitate re-colonization. The presence of stream connected upper basin fishless lake will also likely facilitate recovery of zooplankton and benthic macroinvertebrate communities.

Results: Skymo Lake

Physical Characteristics

The lake is oval-shaped on a southwest-northeast long axis (Table 32). Its 4.4-ha surface is oval-shaped, and the bottom is flat and strewn with boulders. The northwest shore falls steeply to the edge of the lake while the southeast shore consists of a rocky ledge for several meters back to the steep slope. Maximum depth is 6.1 m (Figure 19).

Table 32. Physical characteristics of Skymo Lake.

Parameter	Measurement
Length (m)	479
Fetch (m)	433
Breadth (m)	133
Perimeter (m)	1,220
Area (m^2)	44,109
Shoreline development	1.64
Maximum depth (m)	6.10
Volume (m^3)	159,436
Volume (ac-ft)	110
Mean Depth (m)	3.1

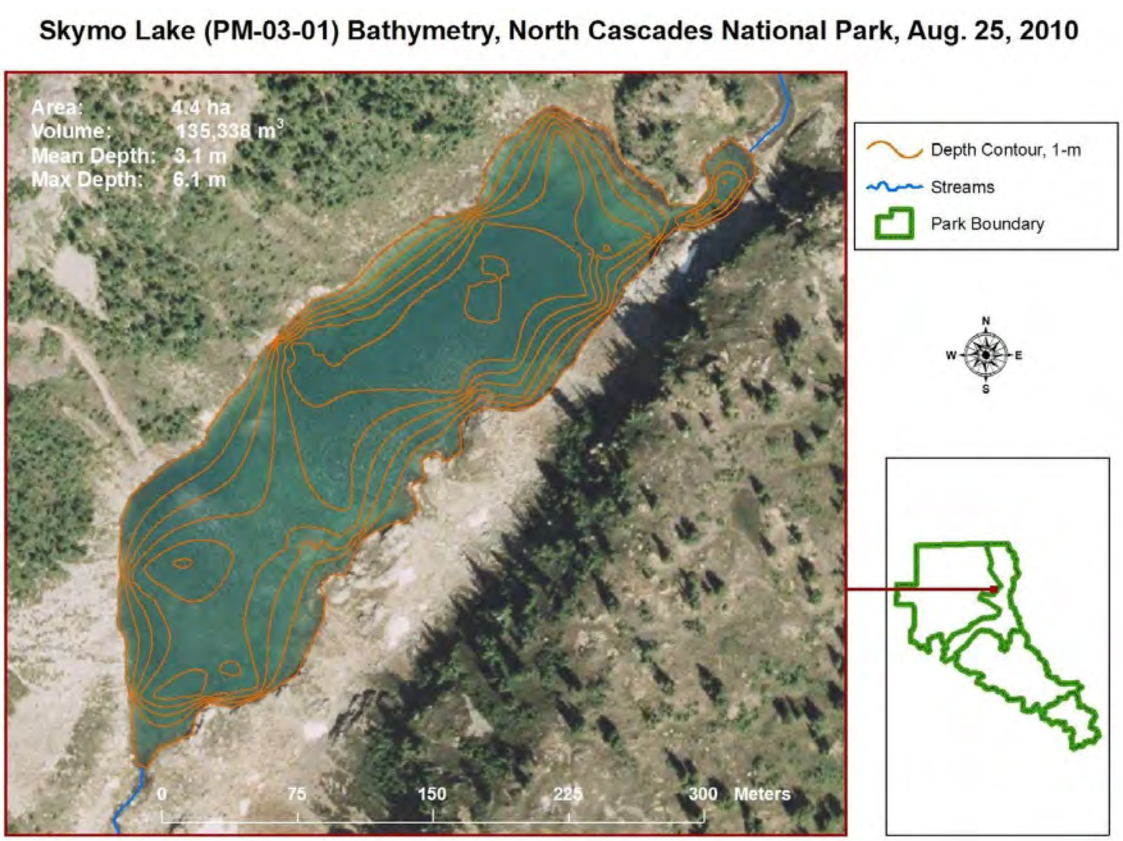

Figure 19. Bathymetric map of Skymo Lake.

The bottom was visible throughout, with occasional boulders, rubble, and sunken and emergent logs encountered. No islands or peninsulas are present, and the shoreline is mostly rocky with shrubby growth. An inlet stream is present on the southwest end, which drains a smaller lake referred to as Upper Skymo Lake (PM-04-01). Upper Skymo Lake was not surveyed. The Skymo Lake outlet stream drains the lake on the northeast end through a pond, over a log jam downstream and into another pond. Skymo Creek then falls steeply through a gorge as a series of cascades and small pools. Approximately 0.16 km downstream of the log jam at the lake outlet, a 0.5-ha off-channel pond is present 10 m from the left bank. Discharge was not measured at the inlet or outlet of the lake.

Water Chemistry and Depth Profiles

We did not collect water samples for chemical analysis from Skymo Lake because of the imposed time constraint. However, historical data for vertical temperature profiles, collected in August, 1985, were available and are included in this report (Figure 20). The profiles indicate that Skymo Lake was not seasonally thermally stratified, with only a 0.8 ^{o}C temperature difference between the surface and the bottom at 6.1 m. Upper Skymo Lake was also unstratified at its deepest point of 4.8 m. However, temporary daily thermal stratification may occur on warm, sunny days with no wind, as is suggested by the small vertical gradient from surface to bottom in both lakes.

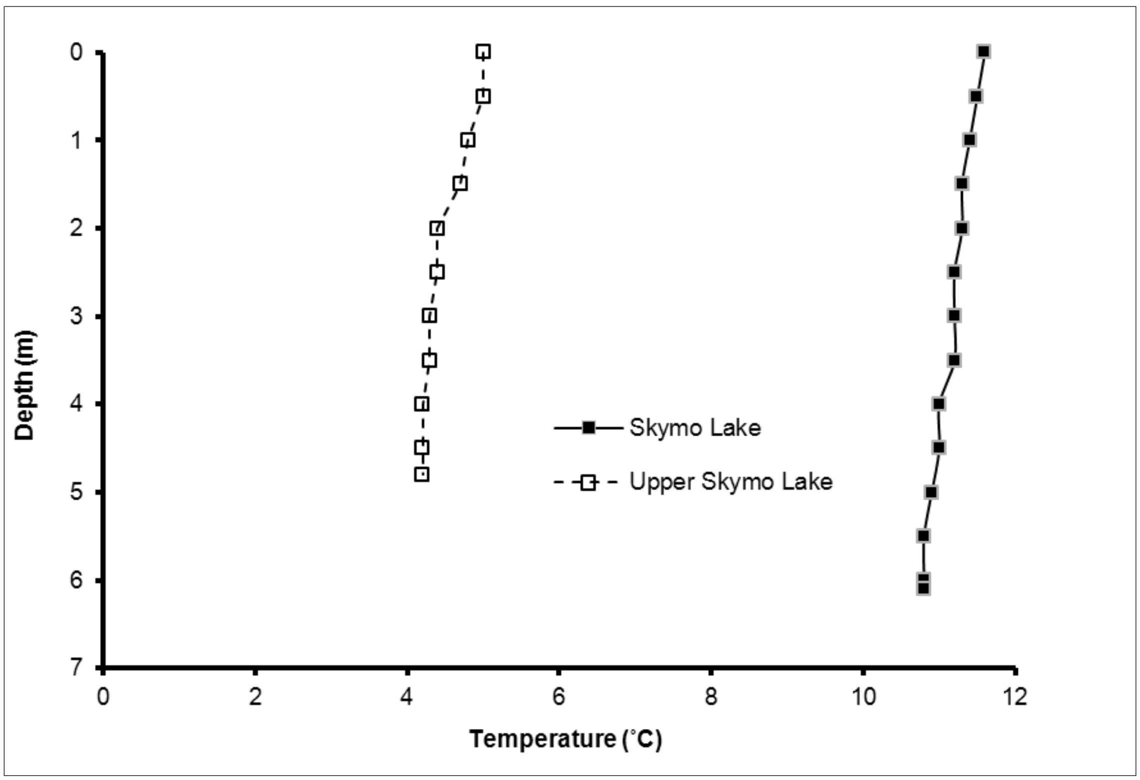

Figure 20. Historical vertical temperature profiles for August 21, 1986 for Skymo Lake and Upper Skymo Lake.

Fish Population Assessment

Fish Captures and Length Distribution

Westslope Cutthroat Trout was the only species found in Skymo Lake and in the outlet stream. Backpack electrofishing was used to assess the distribution of fish in the inlet and outlet streams. In the inlet stream, which exits from Upper Skymo Lake along the southwestern shore, no Westslope Cutthroat Trout were captured; however, we observed what appeared to be Westslope Cutthroat Trout in Upper Skymo Lake. The previous survey conducted in August, 1985 indicated that no fish were present in Upper Skymo, but there are no falls or cascades present in the stream connecting the two lakes that would prevent upstream movement during high water periods. At the outlet from Skymo Lake, fish were present in the two larger pools at the outflow, and they were present throughout the downstream section into the gorge. Presence was not assessed in the steeper sections downstream to its confluence with Ross Lake, a distance of 5.7 km along Skymo Creek from the outlet and a drop of 1120 m. The pond located 0.16 km downstream of the outlet from the lake was not assessed for the presence of fish. The seeps that occurred along the northwest side of the lake were both inaccessible and too small to support fish.

During the first two days at the site 191 Westslope Cutthroat Trout were captured by angling, fin-clipped, and released near the site of capture to meet the assumption that marked fish are randomly distributed among unmarked fish (Table 33). Catch per angler hour averaged 5.3 fish. One mortality occurred during sampling, and four fish were recaptured and released.

Table 33. Capture of Cutthroat Trout by angling in Skymo Lake, August 23-24, 2010, for marking fish for population estimation.

No. of anglers	Hours fished (range)	No. caught	Catch per angler-hour	Recaptures & mortalities	No. marked
7	31.5 (2.5-6.0)	196	5.3	4 & 1	191

Using 10-mm groups to portray the length-frequency distribution, the primary modal length of fish captured by angling from Skymo Lake was 220-229 mm (Figure 21). A secondary mode appears at 180-189 mm, with smaller peaks on either side of these. These are suggestive of different year classes. The smallest fish was in the 110-119 mm group and the largest in the 300-309 mm group. Fish that were captured more than once were only counted as single marks.

We collected 757 Westslope Cutthroat Trout by gill netting. Mean catch per net-hour ranged from 2.2 to 4.1 for the 13 nets set for one day of sampling (Table 34). The primary modal length group of Westslope Cutthroat Trout collected by gillnetting was 180-189 mm (Figure 22), which is three 10-mm size groups smaller than those captured by angling, but it corresponds to the secondary peak in the angling length distribution. However, the smallest fish captured by angling was in the 110-119 mm group and by gillnetting in the 90-99 mm group. Gillnetting also captured larger fish than were taken by angling, such that the size distribution captured by gillnets encompassed that taken by angling. The sharp curtailment in the small-sized fish collected by gillnetting may reflect the limits of the susceptibility of small fish to the smaller mesh or it may reflect a population with limited and sporadic recruitment resulting in missing year classes.

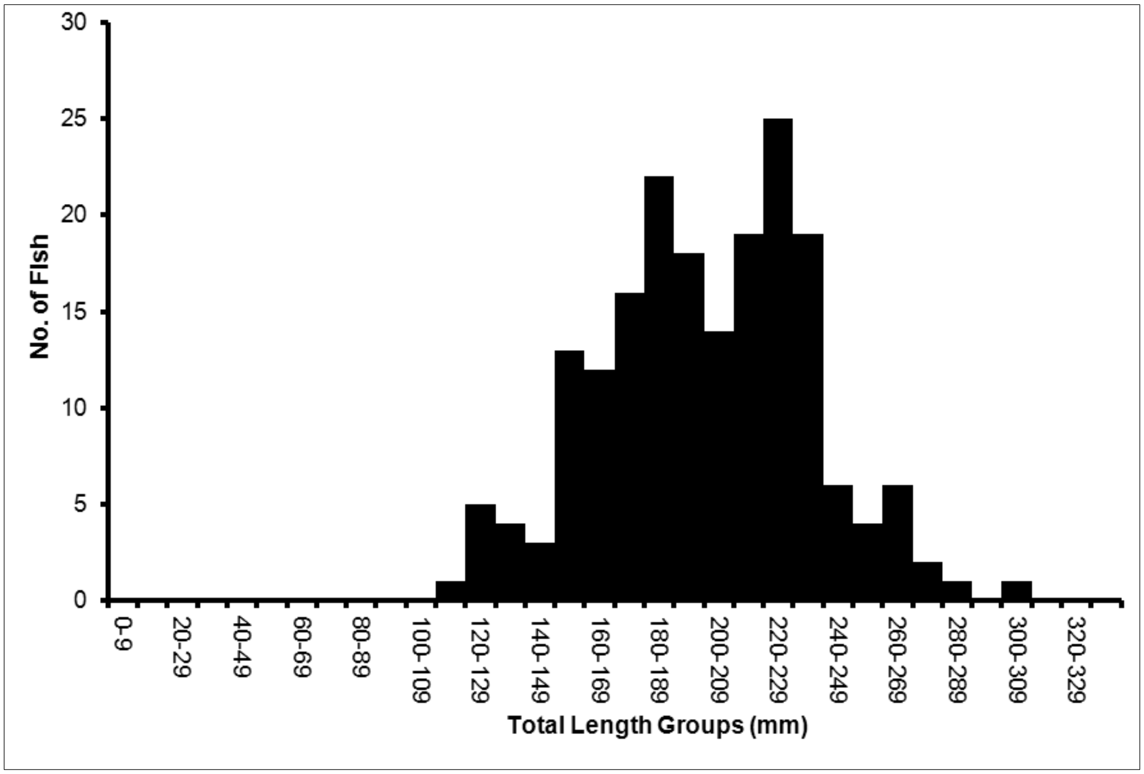

Figure 21. Distribution of total lengths of 191 Westslope Cutthroat Trout captured by angling in Skymo Lake, August 23-24, 2010.

Table 34. Capture of Westslope Cutthroat Trout by gill nets in Skymo Lake, August 24-25, 2010, to recapture marked fish and assess population characteristics.

Gill net no.	Net hrs.	No. caught	Catch per net-hour	Marked fish recaptures
1	17.3	52	3.0	8
2	17.4	71	4.1	7
3	19.7	51	2.6	6
4	19.3	64	3.3	10
5	20.7	53	2.6	2
6	21.6	57	2.6	13
7	20.8	55	2.7	6
8	20.1	73	3.6	7
9	21.2	46	2.2	3
10	21.0	58	2.8	6
11	21.2	62	2.9	7
12	21.3	58	2.7	6
13	22.2	57	2.6	6
Totals	263.7	757	2.9	87

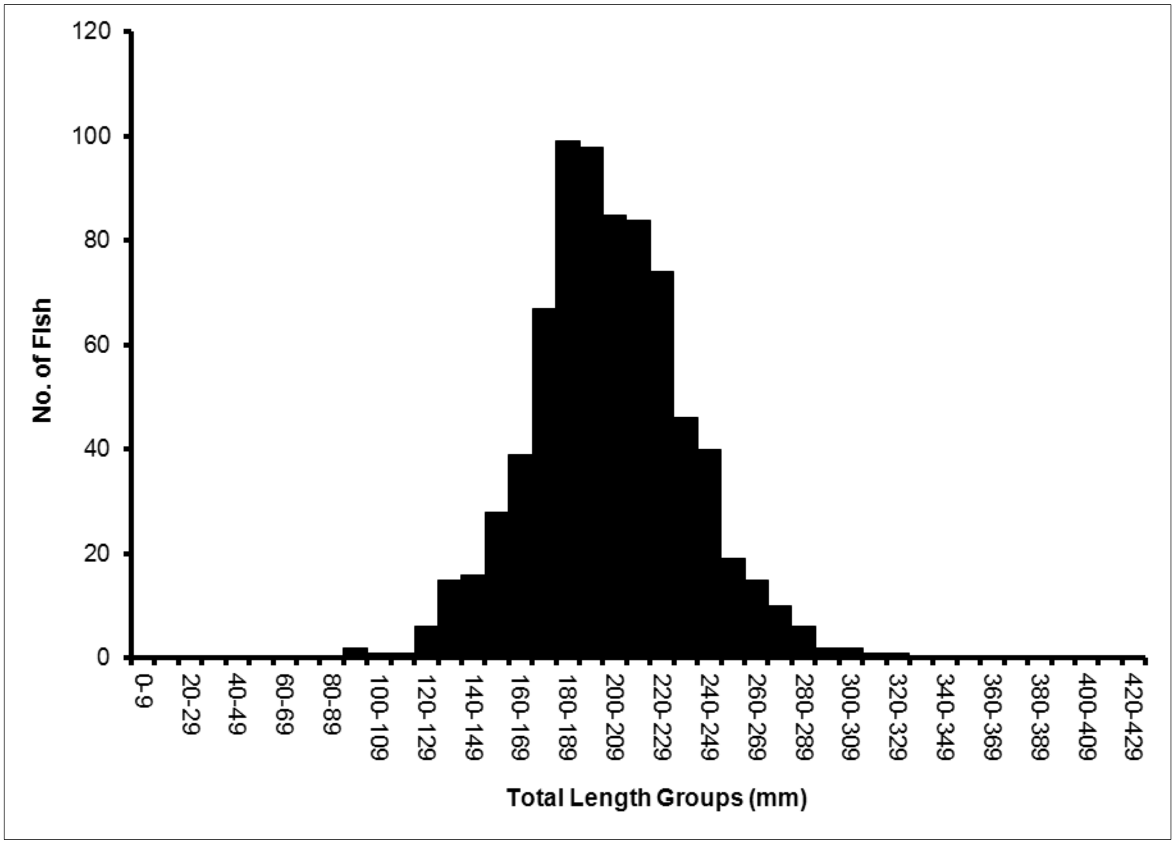

Figure 22. Distribution of total lengths of 757 Westslope Cutthroat Trout captured by gillnetting in Skymo Lake, August 24-25, 2010.

The overall distribution of sizes captured by angling was statistically compared to those collected by gillnetting. Gillnetting collected the same proportion of fish in each size group as angling across the range of sizes (Kolmogorov-Smirnov two-sample test, $P \leq 0.001$; Figure 23). The median total length group 190-199 mm corresponded for the two types of sampling gear (Mann-Whitney U-test, $P \leq 0.0001$), but the size range of fish collected by gill nets was larger at both ends of the distribution such that it encompassed fish captured by angling. The size difference likely had minimal effect on the population estimate. In addition, both the marking and the subsequent recapture were done randomly, and different gear types were used for the initial capture and the recapture so the estimate should not be biased (Ricker, 1975).

Both the angling and the gill net size distributions show rapid truncation for smaller fish. This may be a reflection of size selectivity by the gear, particularly for angled fish. Since the smallest angled fish were in the 110-119 mm range and the smallest gillnetted fish were in the 90-99 mm range, the smaller fish may have not been as susceptible to angling because the hooks were too large. Fishing effort may not have been directed to areas where the smallest fish occur during the day or small fish may have been less inclined to attack a lure in open water during the day. However, the size distributions based on the two capture techniques may reflect actual size distributions wherein successful spawning does not occur on an annual basis because of habitat or other environmental limitations or where food limitations result in slower growth as fish get larger, compressing the size-distinctions among age classes.

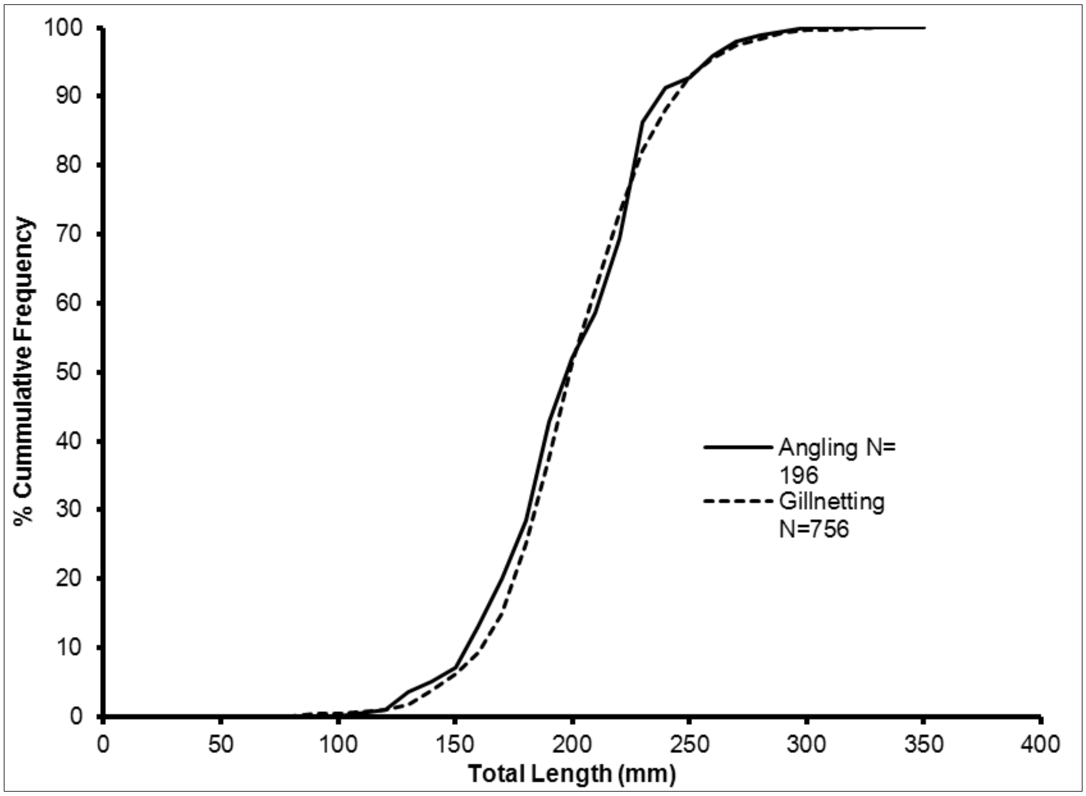

Figure 23. Relative cumulative length frequency distributions comparing Westslope Cutthroat Trout captured by angling versus gill nets from Skymo Lake, August 23-25, 2010 (Kolmogorov-Smirnov D statistic=5.3; critical value at P≤0.05=19.2).

Sex and maturity were assigned in 329 of 330 fish collected by gillnetting (Table 35). The proportion of males and females was biased toward males with 1.3 males per female. More than 95% of the fish of both sexes were mature adults. The low number of juvenile fish suggests that recruitment of year classes may be sporadic. Among the mature adult females about 8% had eggs that were either were ready to be released or had just released most of the eggs. In 1% of the males milt was readily expressed during examination.

Table 35. Sex distribution and sexual maturity of Westslope Cutthroat Trout collected by gillnetting from Skymo Lake, August 24-25, 2010.

Maturity	Females		Males	
	N	%	N	%
Adult	54	94.7	41	91.1
Juvenile	3	5.3	4	8.9
Total	57	55.9	45	44.1

Fish Weight and Condition

The log-linear relationship between length and weight was limited to fish for which sex could be determined and was analyzed by sex (Figure 24). The correlation coefficient (R^2) for each sex was typically good, being 0.94 for males and 0.98 for females, and appeared to be consistent between sexes despite the presence or recent presence of eggs. This indicates this relationship can be used to more accurately estimate weights of individual fish based on length. Since weights were recorded for a set number of fish within each length category and lengths were recorded for all remaining fish, the resulting regression equations were used to estimate individual weights for the group of unweighed fish.

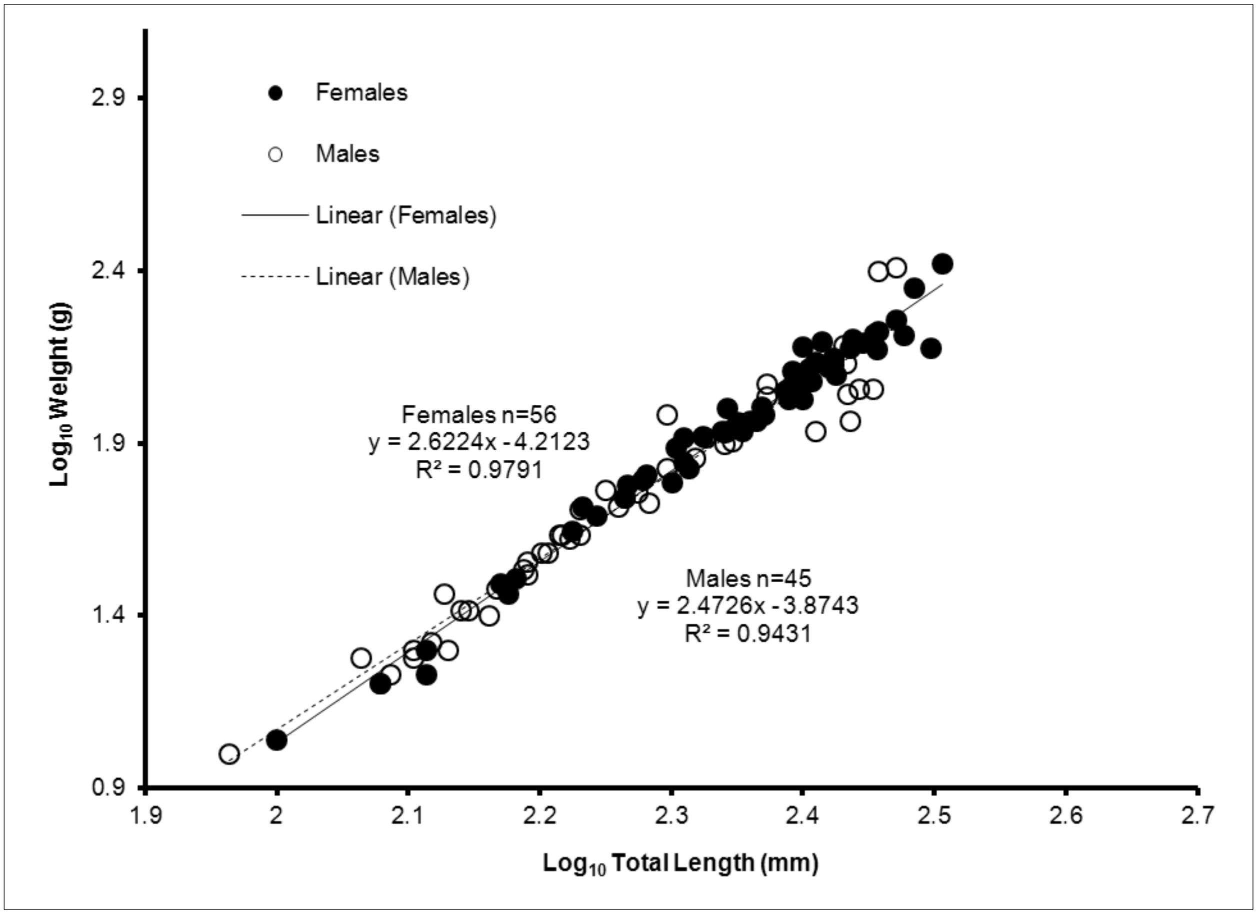

Figure 24. Linear regression by sex of $\log_{10}$-transformed total lengths and weights for Cutthroat Trout captured by gillnetting from Skymo Lake, August 24-25, 2010.

Calculation of Condition Factor (K_{TL}) indicated 96% of the sampled Westslope Cutthroat Trout had a K value less than 1.2, and K ranged down to as low as 0.45 (Figure 25). According to interpretation by Barnham and Baxter (1998) for trout, 1.2 represents a fair fish, acceptable to anglers. However, 91% of the sample had a K value of 1 or less, and these fish are characterized as poor, being long and thin. The highest K value was 1.3, still less than that for fish described as good and well proportioned.

Condition factor values for given size groups ranged more widely in males, with both the highest and lowest values occurring in a few individuals, though the sexes do not appear to differ across the range of sizes. The population demonstrates a downward trend in K with increasing length. Typically, larger fish exhibit higher K values as girth increases disproportionately to length. The decreasing trend in K with length indicates that food becomes more limiting for larger fish. In this environment the lack of larger food items in particular would be expected. Based on casual observations while fish are being examined, aquatic insects, especially midges (Family

Chironomidae), dominate the diet. Larger fish may have reached a size where the energy exerted to forage and capture these is just offset by the nutrition derived. This translates to a trend of loss of plumpness, or girth, with increasing length.

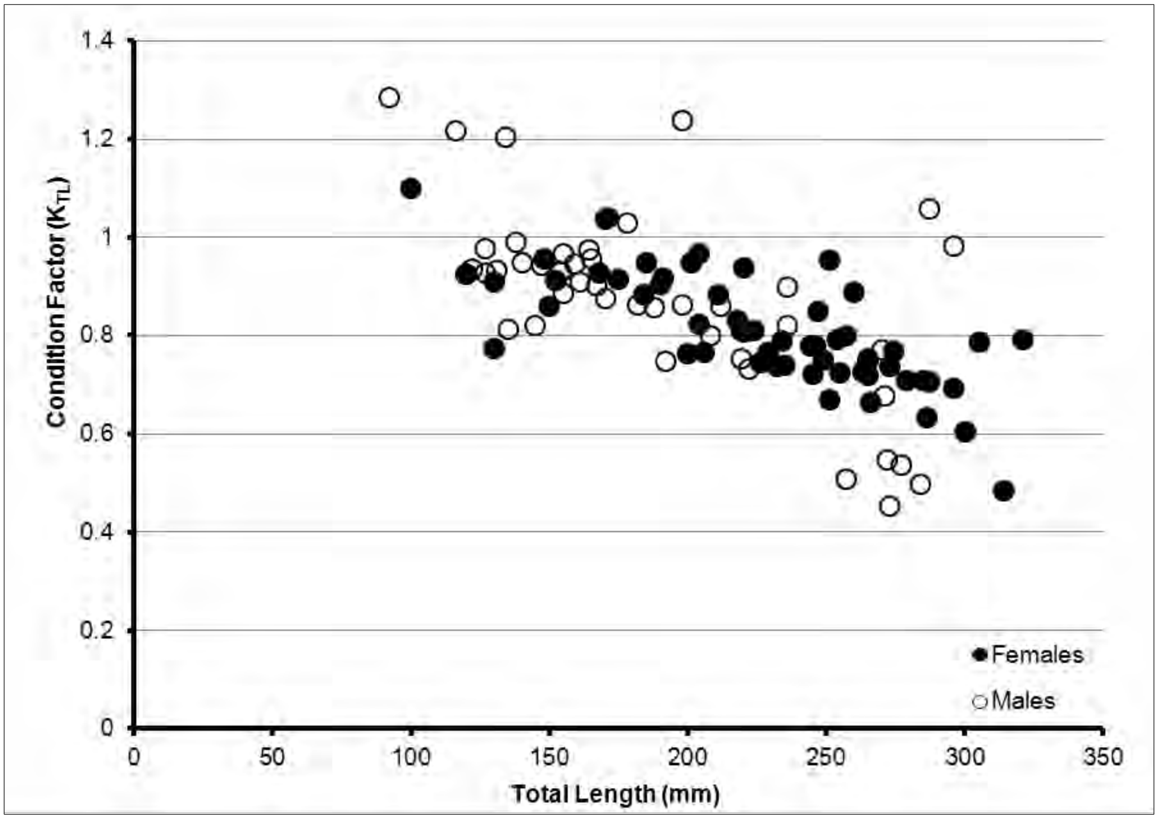

Figure 25. Relative plumpness (condition factor, K_{TL}) by total length and by sex for Westslope Cutthroat Trout captured by gillnetting from Skymo Lake in August 24-25, 2010.

To assess the health of the population with the relative weight index (W_r), standard weights were established using a standard weight equation for Cutthroat Trout taken from a compendium of length and weight values for 48 lentic populations of Cutthroat Trout from their interior range in western North America (Kruse and Hubert 1997). Relative weights were calculated by dividing actual individual weight by standard weight for a given length of fish and multiplying by 100.

The array of values for relative weight appears similar to those for condition factor (Figure 26). Only three fish have values of 100 or more (3.4%), identifying them as the plumpest fish, but these values occur in three of the smaller males (90-135 mm). However, the relative weight does not differ between genders across the entire range of lengths. As also shown by condition factors, the decreasing plumpness with increasing length is again evident. Since relative weight is irrespective of allometric growth, and, conceptually, a Wr of 100 characterizes a population that demonstrates an optimal relationship among physiological needs, habitat characteristics, and suitability to anglers, this assessment also supports the contention that larger fish are more food-limited. Broader interpretation would have to consider that the applicability of the standard weight equation to fish from North Cascade Range alpine lakes. These populations may have attributes that result in body conformations that differ from those that were used to establish the standard weight.

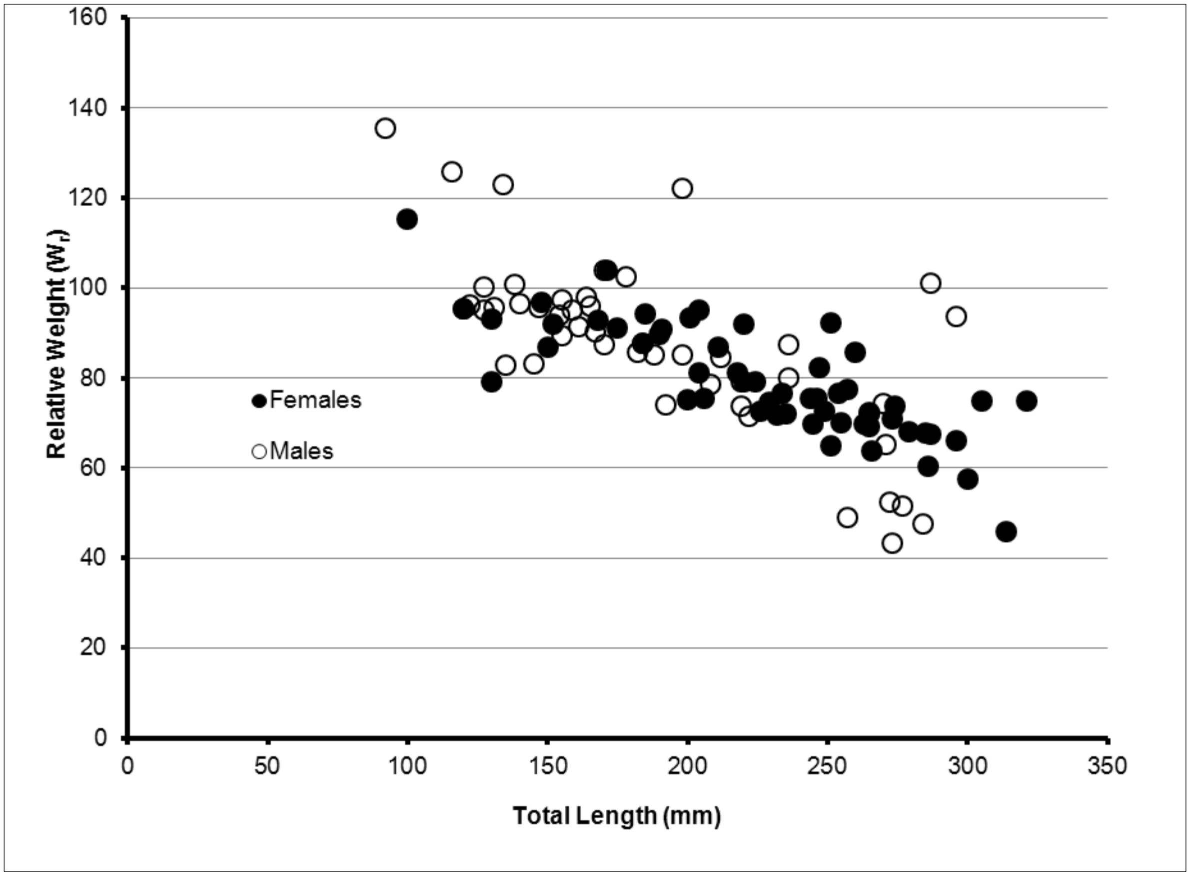

Figure 26. Relative weights (W_r) by total length and by sex for Westslope Cutthroat Trout captured by gillnetting from Skymo Lake, August 24-25, 2010 (Kruse and Hubert 1997).

Lake Fish Population Estimation

The number of Westslope Cutthroat Trout in Skymo Lake was estimated using Petersen's mark and recapture single census approach with Chapman's modification to correct for statistical bias. All crew members participated in angling using spinning rods and fly rods for two days to capture fish for marking. Anglers haphazardly distributed themselves around the lake on the shore or fished from the raft, and marked fish were released in the vicinity of capture. An additional five fish were captured by backpack electrofishing, and these were also marked and released in the vicinity of capture. Recapture was conducted by gillnetting overnight beginning on the day that angling efforts were terminated.

The thirteen gill nets captured 757 fish including 87 of the 195 fish that were marked. This resulted in a population estimate of 1,688 fish with a coefficient of variation of 10.7% (Table 36). The 95% confidence interval for this estimate is 1,442-2,183 based on a Poisson distribution of the number of recaptured marked fish. This results in a range of 741 fish around the estimate.

Table 36. Population estimate of Westslope Cutthroat Trout in Skymo Lake, August 23-25, 2010, using Chapman's modification of Petersen's single census mark and recapture method.

Population Estimate Parmenters	No.
Marked fish - M	
Angling catch	190
Electrofishing catch	5
Total marked	195
Captured fish - C	
Captured by gill net	757
Total captured	757
Recapture of marked fish - R	
Captured by gill net	87
Total recaptured	87
Population estimate – N (95% CI)	1,688 (1,442-2,183)
%Coefficient of variation - %CV	10.7

Based on the estimated number of Westslope Cutthroat Trout in Skymo Lake, the number and sizes of fish removed by gillnetting, and the relationship of length to weight that was established from a subsample of the removed fish, estimations of the remaining number and biomass of fish were made. Biomass was determined by using the length-weight relationship to estimate a weight for each fish captured by gillnetting that was measured but not weighed. The sum of these weights represents the biomass that was removed from the lake. The weights were averaged to derive a mean weight per individual fish. The mean weight was multiplied by the estimated population size to derive estimated total biomass of fish in the lake. Total biomass is likely underestimated because gill nets are less effective at catching small fish, as suggested by the truncation of the length frequency distribution for fish less than 100 mm (Figure 23); however, the smallest size groups of fish also represent a disproportionately small proportion of biomass in relation to their numbers and may not be present in the lake since they were neither captured by any of the three methods nor visually observed. Gillnetting reduced the estimated population size and biomass by 55%, assuming that the size distribution captured by the gill nets reflects the actual size distribution of fish in the lake (Table 37). Fish density was reduced from 304 to 211 fish per hectare, and biomass decreased from 28.0 to 12.6 kg per hectare.

Skymo Lake has not been stocked in recent years, and no part of the established trail network leads to the lake. No evidence of recent encampments was found, likely due to the difficulty in accessing it. Thus recreational angling as a potential source of mortality likely plays little role in the population dynamics of the lake has little effect on the population. If so, the estimated biomass of 28.0 kg per hectare prior to the removal of fish by gillnetting was probably a good approximation of the carrying capacity of the lake with respect to this species and size distribution of fish. The downward trend in ponderal indices suggests a population that has reproduction and growth balanced by natural mortality.

Table 37. Population parameters for Westslope Cutthroat Trout in Skymo Lake, Ross Lake watershed August 23-25, 2010.

Parameter	No.	%
Estimated original population size	1,688	100.0
Removed by netting	757	44.8
Removed by angling	1	0.1
Total removed	758	44.9
Estimated remaining population size	930	55.1
Previous no. of fish/ha	384	
Remaining no. of fish/ha	211	
Estimated original biomass (kg)	123.7	100.0
Estimated reduction in biomass (kg)	55.5	44.9
Estimated remaining biomass (kg)	68.2	55.1
Previous biomass density (kg/ha)	28	
Remaining biomass density (kg/ha)	15.5	

Zooplankton

Average values for zooplankton density (no/m^3) by taxa from three replicate samples collected at Skymo Lake in August, 2010, are shown in Table 38. Seven taxa (excluding the copepod intermediate nauplii life stage) were observed in the three samples. The average total density was 791.4 organisms/m^3, which was the lowest density of the three lakes sampled (2219/m^3, Sourdough, Table 15; and 30,424/m^3, Kettling, Table 28). *Polyarthra vulgaris* (Rotifera) was the most abundant taxon (731.7/m^3) followed by *Kellicottia bostonensis* (Rotifera, 21.2/m^3). The combined total density for all crustacean zooplankters at Skymo Lake (32.2/m^3) was also much lower than at Sourdough Lake (1178.4/m^3, Table 15) and Kettling Lake (7490/m^3, Table 28).

Table 38. Average density (no/m^3) of zooplankton samples collected at Skymo Lake, August 23, 2010.

Taxa	Division	Kettling no/m^3 (n=3)
Daphnia ambigua	Cladocera	7.1
copepodid, Calanoida	Copepoda:Calanoida	11.0
copepod nauplii	Copepoda	13.3
Harpacticoida	Copepoda:Harpacticoida	0.8
Keratella cochlearis var. cochlearis	Rotifera	4.7
Polyarthra vulgaris	Rotifera	731.7
Keratella serrulata	Rotifera	1.6
Kellicottia bostonensis	Rotifera	21.2
Total Density:		791.4
Total Taxa:		7

Zooplankton metric values are compared with those from the NOCA fish density reference groups in Table 39. All of the metric values for Skymo Lake were consistent with values expected for NOCA lakes with high density fish populations. The absence of large-bodied crustaceans, limited abundance of other crustacean taxa, and high %composition of rotifers are significant indicators of high fish predation intensity.

Table 39. Comparison of zooplankton metric values for Skymo Lake, 2010, with average, minimum, and maximum metric values from 15 low fish density and 10 high fish density NOCA reference lakes sampled between 2006 and 2010. Selected metrics represent a subset of 21 candidate metrics that show significant differences (Mann Whitney, $p<0.05$, two-tail) among NOCA lakes grouped by low and high density fish populations (Appendix 1 and Table 3).

Metrics (Predicted trend with fish density +/-)	**Skymo**	**Low Density/No Fish (n=15)**			**High Density (n=10)**		
	(n=3)	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Large-bodied Crustacean no/m^3 (-)	0	599	0	2476	0	0	0
Rotifer no/m^3 (+)	759	3,367	14	30,040	61,158	759	495,667
%Crustaceans (-)	4.1	73.8	3.8	99.3	13.1	0.5	46.6
%Copepoda (-)	3.2	68.8	2.1	99.3	10.2	0.2	45.5
%Calanoid Copepods (-)	1.4	58.7	0.0	97.5	2.5	0.0	11.1
%Lg.-bodied Crustaceans (>1mm) (-)	0.0	16.7	0.0	57.0	0.0	0.0	0.0
%Rotifers (+)	95.9	26.2	0.7	96.2	86.1	46.9	99.5
No. Lg.-bodied Crustacean Taxa (-)	0	1.1	0.0	2.0	0.0	0.0	0.0

Benthic Macroinvertebrates (BMI)

In general, the impact of fish predation on BMI communities in Skymo Lake (PM-03-01) appears to be less severe than in other lakes with high density fish populations. It is probable that the much colder (Figure 20) upper basin (PM-04-01), with a short and shallow stream connection to Skymo Lake, serves as somewhat of a refuge for some taxa. Although fish are present in the upper basin, visual observations indicate that their density is much lower than in Skymo Lake.

A total of 38 BMI taxa were collected from two replicate samples collected at Skymo Lake (Table 40), compared to 27 taxa collected at Sourdough Lake (Table 17) and 31 taxa collected at Kettling Lake in 2010 (Table 30). Diptera taxa at Skymo Lake were represented by 26 taxa. Collectively, Diptera accounted for 48.9% of the total number of specimens in the samples (Figure 27), much less than Sourdough and Kettling Lakes (83.3 and 82.0%, respectively, Figures 9 and 18). Chironomid species represented the majority of Diptera taxa collected (n=24). *Tanytarsus* (Chironomidae) was the most abundant taxon collected in the samples, representing 17.8% (Table 40) of the total number of specimens in the samples.

Table 40. Average number (n=2), percent composition, and total BMI taxa collected at Skymo Lake (PM-03-01), August 24, 2010.

			Skymo Lake (n=2)	
Taxon	**Phyla/class/subclass/etc**	**Family**	**Ave No.**	**%**
Nematoda	Nematoda		42.5	7.2
Oligochaeta	Annelida: Oligochaeta		68.5	11.6
Pisidium	Mollusca: Bivalvia	Pisidiidae	103	17.5
Acari	Arthropoda: Acari		3.5	0.6
Ameletus	Insecta: Ephemeroptera	Ameletidae	0.5	0.1
Callibaetis	Insecta: Ephemeroptera	Baetidae	8.5	1.4

Table 40. Average number (n=2), percent composition, and total BMI taxa collected at Skymo Lake (PM-03-01), August 24, 2010 (continued).

			Skymo Lake (n=2)	
Taxon	**Phyla/class/subclass/etc**	**Family**	**Ave No.**	**%**
Sweltsa	Insecta: Plecoptera	Chloroperlidae	1	0.2
Desmona mono	Insecta: Trichoptera	Limnephilidae	3	0.5
Dicosmoecus atripes	Insecta: Trichoptera	Limnephilidae	1	0.2
Ecclisocosmoecus scylla	Insecta: Trichoptera	Limnephilidae	0.5	0.1
Halesochila taylori	Insecta: Trichoptera	Limnephilidae	7.5	1.3
Hydrophilidae	Insecta: Coleoptera	Hydrophilidae	61	10.4
Ceratopogoninae	Insecta: Diptera	Ceratopogonidae	0.5	0.1
Rhabdomastix	Insecta: Diptera	Tipulidae	0.5	0.1
Brillia	Insecta: Diptera	Chironomidae	1.5	0.3
Chaetocladius	Insecta: Diptera	Chironomidae	0.5	0.1
Corynoneura	Insecta: Diptera	Chironomidae	1	0.2
Diamesa	Insecta: Diptera	Chironomidae	0.5	0.1
Eukiefferiella Claripennis Grp	Insecta: Diptera	Chironomidae	0.5	0.1
Eukiefferiella cf. tirolensis	Insecta: Diptera	Chironomidae	2	0.3
Heterotrissocladius	Insecta: Diptera	Chironomidae	10.5	1.8
Hydrobaenus	Insecta: Diptera	Chironomidae	0.5	0.1
Macropelopia	Insecta: Diptera	Chironomidae	30	5.1
Monodiamesa	Insecta: Diptera	Chironomidae	0.5	0.1
Orthocladius Complex	Insecta: Diptera	Chironomidae	2	0.3
Paracladopelma	Insecta: Diptera	Chironomidae	18	3.1
Parametriocnemus	Insecta: Diptera	Chironomidae	1.5	0.3
Paratanytarsus	Insecta: Diptera	Chironomidae	0.5	0.1
Polypedilum	Insecta: Diptera	Chironomidae	0.5	0.1
Procladius	Insecta: Diptera	Chironomidae	36	6.1
Prodiamesa	Insecta: Diptera	Chironomidae	1.5	0.3
Psectrocladius	Insecta: Diptera	Chironomidae	32.5	5.5
Stempellinella	Insecta: Diptera	Chironomidae	0.5	0.1
Synorthocladius	Insecta: Diptera	Chironomidae	4.5	0.8
Tanytarsus	Insecta: Diptera	Chironomidae	104.5	17.8
Thienemannimyia Complex	Insecta: Diptera	Chironomidae	1.5	0.3
Tvetenia Bavarica Group	Insecta: Diptera	Chironomidae	0.5	0.1
Zavrelimyia	Insecta: Diptera	Chironomidae	35.5	6.0
		Ave Total No:	588.5	
		Total Taxa:	38	

Percent composition of other taxa commonly found in the two replicate samples included *Pisidium* (Mollusca, 17.5%), Oligochaeta (11.6%), and Hydrophilidae (Coleoptera, 10.4%) which are more commonly found in lakes with high fish densities than the dytiscid beetles. The combined percent composition of taxonomic groups mostly sensitive to fish predation at Skymo Lake (Odonata, Ephemeroptera, Plecoptera, and Trichoptera) was 3.8%. Odonata specimens were not collected from Skymo Lake.

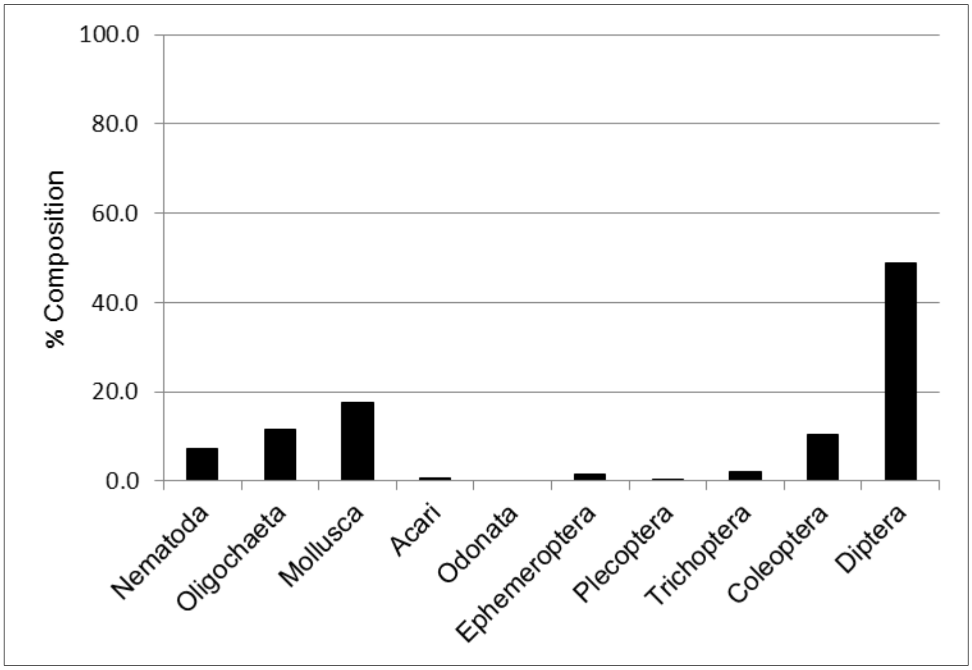

Figure 27. Composition of major BMI taxonomic groups, Skymo Lake (PM-03-01), August 24, 2010.

BMI metric values are compared with those from the NOCA fish density reference site groups in Table 36. The 14 metrics selected for evaluation in Table 41 represent a subset of 33 candidate metrics (Appendix 2) that exhibited significant differences among 30 NOCA lakes grouped by low and high fish density (≥200 fish/ha).

BMI metric evaluation produced mixed results regarding interpretation of fish predation impacts. Taxa number metrics for Trichoptera/ Limnephilidae were similar to what is expected for lakes with low density fish populations. However, the number of Diptera taxa was high as predicted (+) for lakes with high density fish populations.

Composition metrics in Table 41 also showed mixed results. Some metrics that were predicted to decrease with increasing fish density such as %Trichoptera, %Limnephillidae, and %*Desmona mono* had values that were similar to the mean values of the low fish density reference lakes while %*Ecclisomyia* and %Dytiscidae values were similar to the mean values of lakes with high fish density. Similarly, some metric values for Skymo Lake that were predicted to increase with increasing fish density were more indicative of lakes with low fish density (e.g., %*Coryoneura*, %*Paratanytarsus*, and %Ceratopogoninae) while the %*Pisidium* value for Skymo Lake was more similar to values of lakes with high fish densities.

Table 41. Comparison of BMI metric values for Skymo Lake (PM-03-01), 2010, with average, minimum, and maximum metric values from 20 low fish density and 10 high fish density NOCA reference lakes sampled between 2006 and 2010. Selected metrics represent a subset of 33 candidate metrics that show significant differences (Mann Whitney, p<0.05, two-tail) among NOCA lakes grouped by low and high density fish populations (see Appendix 2 and Table 4).

		Reference Lake Fish Density			
		Low Density		High Density	
Metrics (Predicted trend with fish density +/-)	**Skymo Lake Values**	**Mean**	**Range**	**Mean**	**Range**
Taxa Number Metrics (ave. no. of taxa from replicates)					
Trichoptera (-)	3	2.53	1.0-4.3	1.11	0-2.5
Limnephilidae (Trichoptera) (-)	3	2.21	0-3.7	0.94	0-2.5
Diptera (+)	16	9.74	5.2-15.5	12.72	8.8-17.2
Composition Metrics (ave. %composition from replicates)					
%*Pisidium* (Mollusca: Bivalvia) (+)	16.1	3.01	0-16.8	6.57	0.5-16.1
%Trichoptera (-)	2.1	2.69	0.3-16.1	0.70	0-2.3
%Limnephilidae (Trichoptera) (-)	2.1	2.50	0-16.1	0.45	0-2.1
%*Desmona mono* (Limnephilidae) (-)	0.5	0.45	0-2.6	0.07	0-0.6
%*Ecclisomyia* (Limnephilidae) (-)	0.1	1.14	0-11.9	0.02	0-0.1
%Coleoptera (-)	10.4	6.08	0-35.8	1.85	0-10.4
%Dytiscidae (Coleoptera) (-)	0	4.16	0-35.8	0.01	0-0.1
%Ceratopogoninae (Diptera) (+)	0.1	0.45	0-3.6	12.25	0.1-71.4
%*Coryoneura* (Chironomidae) (+)	0.2	0.61	0-3.5	2.13	0-7.3
%*Paratanytarsus* (Chironomidae) (+)	0.1	0.85	0-6.4	13.93	0-60.7
%EPTOC* (-)	14.0	13.73	2.8-49.9	4.45	0.2-14.0

*%EPOTC – Ephemeroptera, Plecoptera, Trichoptera, Odonata, and Coleoptera.

Amphibians

Two replicate amphibian visual surveys were conducted around the perimeter of Skymo Lake and one visual survey was conducted around the pond that is 0.16 km below the outlet. The Skymo Lake surveys detected only one amphibian, a western toad (*Bufo boreas*). At the pond downstream of Skymo Lake adjacent to Skymo Creek, three egg masses and four larvae of salamanders were found. These were likely long-toed salamanders (*Ambystoma macrodactylum*) as these had been previously documented in this area.

Summary for Skymo Lake

1. Limnology: area 4.1 ha; volume 135,338 m^3; maximum depth 6.1 m; no thermocline (historical data); trophic status oligotrophic (historical data)
2. Lake chemistry: not available
3. Zooplankton: Densities of zooplankton at Skymo Lake were much lower than at Kettling and Skymo lakes, with the exception of one species of Rotifer. All of the metric values for Skymo Lake were consistent with values expected for NOCA lakes with high density fish populations. The absence of large-bodied crustaceans, limited abundance of other crustacean taxa, and high %composition of rotifers are significant indicators of high fish predation intensity.
4. Benthic Macroinvertebrates: Diptera specimens dominated both the number of taxa and %composition of the samples. A few taxa of Ephemeroptera and Trichoptera, normally not present in lakes with high density fish populations, may persist in the nearby colder, Upper Skymo basin, where few fish are found. Taxa number and %composition metrics showed mixed results. Some metrics that were predicted to decrease with increasing fish density had values that were similar to the mean values of the low fish density reference lakes while other metric values were similar to the mean values of NOCA lakes with high fish density.
5. Amphibians: Western toads were observed along the lakeshore and long-toed salamanders were observed in the pond adjacent to the lake outlet stream.
6. Fishes: Only Westslope Cutthroat Trout were captured in Skymo Lake. Fish were also present in Upper Skymo Lake.
7. Fish spawning habitat: Westslope Cutthroat Trout may spawn in the vicinity of the inlet stream from Upper Skymo Lake and the outlet stream to Ross Lake. Upstream dispersal is limited by lack of perennial streams. Downstream passage to Ross Lake via Skymo Creek appears feasible.
8. Fish recruitment: No evidence of recent recruitment was found, fish smaller than 80 mm were not collected or observed.
9. Fish condition: Most fish in the population are not attractive to anglers, being noticeably thin across the size range. Also, the proportion of thin fish increases with increasing length. The lake does not have established trail access so angling pressure is likely low.
10. Fish population size: Population estimation was conducted in a manner that provided a robust estimate of 1,688 fish. This was reduced to 930 fish by gillnetting.
11. Biomass and fish removal: Initial fish density was estimated at 28.0 kg/ha; this was reduced 55.1% by gillnetting to 12.6 kg/ha. The initial density likely reflected carrying capacity.
12. Risk to native species: Native Rainbow Trout in Ross Lake and the upper Skagit River watershed are at risk of introgressive hybridization with non-native Westslope Cutthroat Trout that may move downstream from Skymo Lake. However, few Westslope Cutthroat Trout have been collected during previous fish surveys of the lake, and Cutthroat Trout are also abundant in the Big Beaver Creek watershed.
13. Feasibility of restoration: Substantial reduction of the fish population appears feasible through use of gill nets, however complete eradication may require many years, based on previous experience at NOCA. A population of long-toed salamanders was present in a pond adjacent to Skymo Creek near the lake. Western toads were present around the lake. The proximity of these would facilitate re-colonization. Additional zooplankton and

macroinvertebrate samples should be collected from the nearby ponds and Upper Skymo Lake to assess the feasibility of recovery of taxa sensitive to fish predation.

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Appendix 1. Candidate zooplankton metrics for assessment of fish predation impacts in NOCA mountain lakes.

Zooplankton Metrics	Predicted Trend with Increasing Fish Density
Abundance Metrics (no./m^3)	
Total Abundance	(+/-)
Crustacean Abundance	(-)
Large-bodied Crustacean Abundance (>1mm)	(-)
Cladoceran Abundance	(+/-)
Copepod Abundance	(-)
Copepod nauplii Abundance	(-)
Calanoid copepods/copepodid Abundance	(-)
Cyclopoid copepods/copepodid Abundance	(+/-)
Rotifer Abundance	(+)
Composition Metrics	
%Crustaceans	(-)
%Cladocera	(+/-)
%Copepoda	(-)
%Calanoid Copepods	(-)
%Large-bodied Crustaceans (>1mm)	(-)
%Rotifers	(+)
%Dominant Taxon	(+)
Taxa Number Metrics	
Total Taxa	(+/-)
Copepod Taxa	(-)
Cladoceran Taxa	(+/-)
Rotifer Taxa	(+)
Large-bodied Crustacean Taxa (>1mm)	(-)

Appendix 2. Candidate littoral benthic macroinvertebrate metrics for assessment of fish predation impacts in NOCA mountain lakes.

Metrics	Predicted Trend with Increasing Fish Density
Taxa Number Metrics	
Total Taxa	(+/-)
Odonata (O)	(-)
Ephemeroptera (E)	(-)
Plecoptera (P)	(-)
Trichoptera (T)	(-)
Limnephilidae (Trichoptera)	(-)
Diptera	(+)
Chironomidae (Diptera)	(+)
EPT	(-)
EPO	(-)
EPTOC	(-)
Composition Metrics	
%Oligochaeta (Annelida)	(+/-)
%*Pisidium* (Mollusca: Bivalvia)	(+/-)
%Odonata	(-)
%Ephemeroptera	(-)
%*Ameletus* (Ephemeroptera)	(-)
%Plecoptera	(-)
%Trichoptera	(-)
%Limnephilidae (Trichoptera)	(-)
%*Desmona mono* (Limnephilidae)	(-)
%*Ecclisomyia* (Limnephilidae)	(-)
%Coleoptera*	(-)
%Dytiscidae (Coleoptera)	(-)
%Diptera	(+)
%Ceratopogoninae (Diptera)	(+)
%Chironomidae (Diptera)	(+)
%*Coryoneura* (Chironomidae)	(+)
%*Paratanytarsus* (Chironomidae)	(+)
%EPT	(-)
%ETO	(-)
%EPTOC	(-)
%Dominant 3 Taxa	(+)