ECOLOGICAL FACTORS INFLUENCING FISH DISTRIBUTION IN A LARGE SUBARCTIC LAKE SYSTEM

By

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A

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By

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Abstract

The coastal climate and frequent wind storms in southwest Alaska create an atypical thermal environment (non-stratified in summer) in the remote Ugashik lakes. This study documents the distribution of lake trout *Salvelinus namaycush*, Arctic char *S. alpinus*, Dolly Varden *S. malma*, Arctic grayling *Thymallus arcticus*, round whitefish *Prosopium cylindraceum*, and pygmy whitefish *P. coulterii* relative to depth, substrate particle size, food habits, length, and age in the absence of strong thermal structure. Sample sites were randomly chosen within sampling strata and gill nets were set at each site. Lake trout and round whitefish were most abundant and had the oldest individuals in the catch. In more typical thermally stratified lake systems lake trout and Arctic char usually move to colder, deeper water in summer. In the Ugashik lakes, however, both species were abundant in shallow water all summer. Prior to this study pygmy whitefish were undocumented in this system. The fish examined in the Ugashik lakes were opportunistic feeders, consuming organisms such as isopods and amphipods. Fish in the Ugashik lakes were found in locations different from what one would expect from predominant literature. Fisheries managers may need to take this into account in their fisheries management.

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Introduction

Alaska has thousands of pristine lakes and ponds. Many of them are located in remote areas that are logistically difficult to access, leaving the fish communities in a majority of these lakes unstudied. There has been extensive research on limnology (LaPerriere 1996, 1997; Edmundson and Todd 2000), salmon (Mathisen et al. 1998; Young 2004), and other studies of individual salmonid species in Alaskan lakes (Adams 1990; Villegas 1993; Scanlon 2000) but very few studies on a fish community in a remote lake system.

Alaska Peninsula lakes offer unique circumstances to study freshwater fish populations. The coastal climate influence creates an atypical thermal habitat in Upper and Lower Ugashik Lakes, which are two relatively large lakes located in a remote area on the Alaska Peninsula National Wildlife Refuge (Figure 1 USFWS 2004). The geographic location of the Ugashik lakes results in high coastal winds, creating a longer ice-free season than more inland lakes (LaPerriere 1997; Mathisen et al. 1998; Edmundson and Todd 2000). The Ugashik lakes do not develop thermal stratification because of their exposure to coastal climate and strong winds from frequent storms. The lakes are classified as warm thereimictic, meaning they can circulate at any time during the ice-free season given sufficient winds and warm water temperatures above 4^{o} C (Cole 1994; LaPerriere 1996). Thermal instability allows heat energy to mix deeply into these lakes (LaPerriere 1996). The water mass mixing suggests that growth of aquatic organisms could be higher in these lakes compared to other lakes that stratify and maintain a cold (4°C) hypolimnion (LaPerriere 1996).

Compared to other lake systems in northern regions, the Ugashik lakes have been sparsely studied. Past studies have focused on species important to commercial and sport fisheries. They have documented the characteristics of sockeye salmon *Oncorhynchus nerka* and coho salmon *O. kisutch* in the Ugashik drainage (Edmundson and Todd 2000), and most of the sport fish studies completed were focused on Arctic grayling in the Ugashik Narrows and the

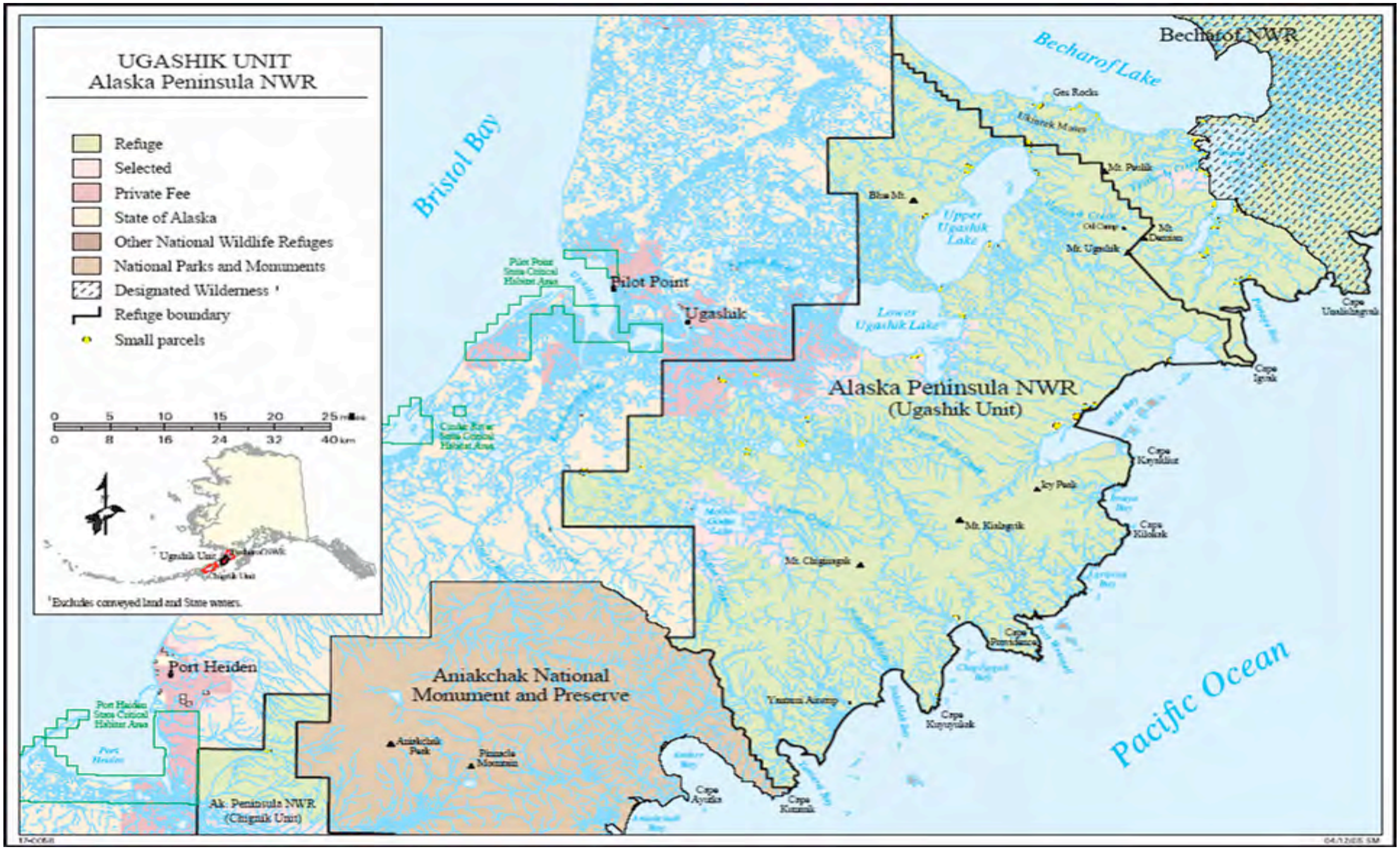


Figure 1. Location of study area, Upper and Lower Ugashik Lake, Alaska Peninsula. The Ugashik lakes are two relatively large lakes located in a remote area within the Ugashik Unit of the Alaska Peninsula National Wildlife Refuge, approximately 120 km southwest of King salmon. (U.S. Fish and Wildlife Service 2004)

Lower Ugashik Lake Outlet (Meyer 1990, Villegas 1993, Jaenicke and Squibb 2000), and lake trout in the lower lake (Jaenicke et al. 1996, Margraf and Valliere 2005).

There has never been a comprehensive study on the ecological processes of the resident fish in the Ugashik lakes system. The general deficiency of information on resident fish distribution and abundance was identified in the Alaska Peninsula National Wildlife Fishery Management Plan (USFWS 1994). Past studies documented lake trout *Salvelinus namaycush*, Arctic char *S. alpinus*, Dolly Varden *S. malma*, Arctic grayling *Thymallus arcticus,* round whitefish *Prosopium cylindraceum*, sockeye salmon, and coho salmon in the Ugashik lakes (Meyer 1990, Villegas 1993, Edmundson and Todd 2000). The species just mentioned as well as lake whitefish *Coregonus.clupeaformis,* pygmy whitefish *P. coulterii,* least cisco *C. sardinella,* ninespine stickleback *Pungitius pungitius*, threespine stickleback *Gasterosteus aculeatus,* northern pike *Esox lucius,* and slimy sculpin *Cottus cognatus* were found in Becharof Lake, just north of Upper Ugashik Lake on the Alaska Peninsula (Scanlon 2000) and were assumed to be found in the Ugashik lakes. This study focused on the salmonid species, excluding Pacific salmon, in the Ugashik lakes.

The fish species assemblage found in the Ugashik Lakes during the first field season included Arctic char, lake trout, Dolly Varden, round whitefish, and pygmy whitefish (an undocumented species in the lakes prior to 2003). Other species found were sockeye salmon, coho salmon, chum salmon *O. keta*, ninespine stickleback *Pungitius pungitius,* slimy sculpin *Cottus cognatus,* starry flounder *Platichthys stellatus*, northern pike *Esox lucius*, and Alaska blackfish *Dallia pectoralis*.

Determination of species composition, seasonal distribution, catch per unit effort, and length frequencies that are representative of fish communities in large lakes has been extensively researched, but little has been done in lakes without thermal stratification such as the Ugashik lakes. Normally, salmonids in lakes are distributed according to temperature preference, lake thermal structure, and often by availability of prey (Martin 1970; Johnson 1972; Dahlberg 1981; Sellers et al. 1998; Nowak and Quinn 2002; Klemetsen et al. 2003a; Dux 2005). The resident salmonid distribution in the Ugashik lakes could be influenced by the homogenous thermal structure of the lakes, depth, substrate particle size, or food availability.

This study describes and compares the distribution and diet of six salmonids (three char, two coregonids, and Arctic grayling) by depth of capture, length, age, and substrate type during the summers of 2003 and 2004. Specific objectives were to determine their summer depth distribution, describe the relationship between depth, length, and age, to determine the substrate type used by these six species, and to determine the association between salmonid summer depth distribution and feeding habits.

Study Area

The Ugashik lakes are two relatively large lakes located in a remote area within the Ugashik Unit of the Alaska Peninsula National Wildlife Refuge, approximately 120 km southwest of King Salmon (Figure 1 USFWS 2004). These lakes are remnants of larger glacial lakes that were dammed by glacial moraines from the glacier advance of the late Wisconsin age (Detterman 1986). The Ugashik Lake system is comprised of two distinct basins, an upper lake (199.4 km^2) and a lower lake (182.3 km^2). The two lakes are joined by the Ugashik Narrows, a relatively fast-flowing channel that is 0.5-km long (Edmundson and Todd 2000). The Ugashik lakes are highly oligotrophic and do not develop consistent thermal stratification (Edmundson and Todd 2000). Average depth of the upper lake is 28.6 m, and recent reports have documented the maximum depth at 180 m (Edmundson and Todd 2000; Hartman, West Virginia University, personal communication). The lower lake has a mean depth of 35.7 m, and a maximum depth of 120 m (Edmundson and Todd 2000). Lower

Ugashik Lake has an outlet that forms the beginning of the Ugashik River. The elevation at the outlet is approximately 4 m above sea level. The headwaters of the Ugashik drainage originate in the volcanic Aleutian Range east of the lakes, from 1340 to 2525 m elevation. To the west of the lakes is the Bristol Bay coastal plain, which is mostly flat, treeless, low-profile tundra with remnants of glacial moraines. The Alaska Peninsula has a moderate, polar maritime climate characterized by high winds, mild temperatures, and frequent precipitation. Fog and drizzle are common in the summer, while severe storms occur year round, often with intense winds (USFWS 1994, 2004).

The lakes are accessible by floatplane or by boat from the village of Ugashik, located about 40 km downstream from the outlet of the lower lake. In addition to resident fish species, the Ugashik lakes support significant runs of coho and sockeye salmon.

Methods

Biological Sampling

Gear. – Four types of floating and sinking multifilament nylon experimental gill nets were used. Two gill nets were 120-m long made up of six 20 m panels. The panels of one net were composed of: 10, 12.5, 16, 19, 22, and 25 mm bar mesh sizes. The panels of the other 120-m net were composed of: 10, 19, 33, 45, 55, and 60 mm bar mesh sizes. Two gill nets were 60-m long made up of six 10 m panels. The panels of one net were composed of: 10, 12.5, 16, 19, 22, and 25 mm bar mesh sizes. The panels of the other 60-m net were composed of: 10, 19, 33, 45, 55, and 60 mm bar mesh sizes. All gill nets were 1.8 m deep.

Experimental design. – This study was conducted over two summer field seasons in 2003 and 2004. It included both Upper and Lower Ugashik lakes but excluded the Ugashik Narrows to minimize conflicts with sport fish users.

Preliminary data analysis using chi square tests for independence, suggested there was no significant difference in catch per unit effort (CPUE) in the Upper and Lower lakes, with a few minor exceptions. For this reason we chose to consider the Ugashik lakes as a single system. Minor exceptions, only found in the lower lake, included very few pygmy whitefish and Arctic grayling, and in the eastern area fewer fish were caught which was possibly due to the island geography specific only to that section of the two lakes.

To better understand the distribution of the fish in the Ugashik system, the lakes were divided into two strata. Areas located within 60 m of the shoreline were designated as "shoreline", because the gill nets used for these sites were 60-m long. Areas 60 m from shore and greater were categorized as “offshore”. These divisions were made arbitrarily to ease logistical concerns and were based upon proximity to the shoreline and depth. The offshore stratum was further divided into two strata for allocation of sampling effort. These were also based on the coarse scale bathymetric maps available for the lakes at the onset of this study (Mathisen 1996). After sampling began the bathymetric maps were found to be imprecise, and post sampling analysis indicated that the offshore strata were not significantly different so they were combined to make one offshore stratum.

The locations of all sample sites were determined using a systematic sampling design with a random starting point. Sampling sites within the shoreline strata were determined by choosing a random start point and systematically choosing sample sites along the shoreline of each lake. The random start point was selected using a random number generator. One number was selected from the total number of meters along the shoreline for each lake. Sampling sites for the offshore strata were determined by choosing a random start point and systematically choosing sample sites from a grid (Figure 2). The grids marking latitude and longitude distances for each lake were separated into 1-kilometer increments. Once a random point from the grid was chosen, the sample site was randomly chosen from the immediate area (plus/minus 0.5 km east-west and north-south from the chosen point) surrounding that point. Selected sampling locations for strata were plotted on maps using topographic mapping software

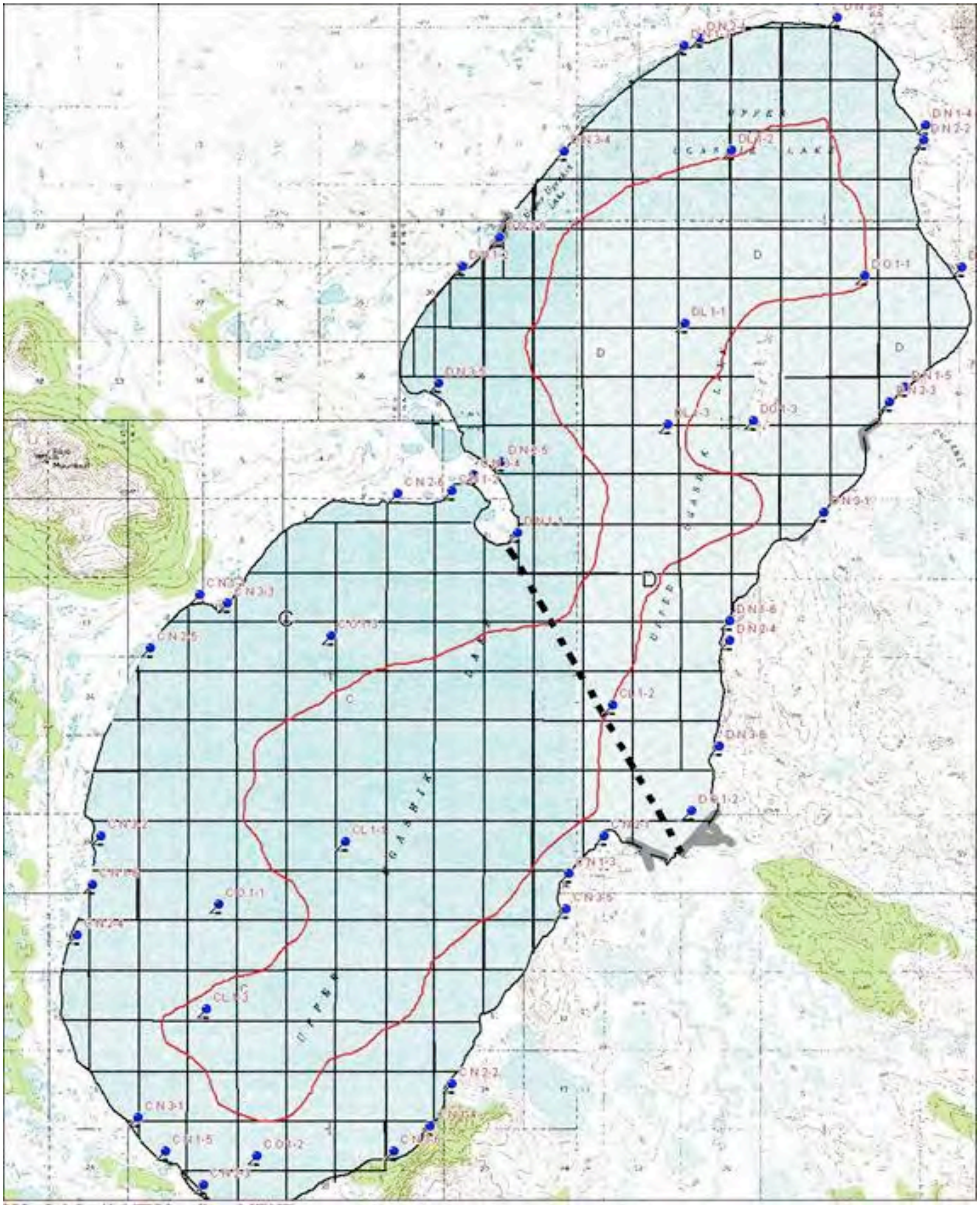


Figure 2. An example of the one kilometer grid system that was used to provide a framework for randomly selecting sample sites in the Upper and Lower Ugashik Lakes, 2003-2004. The dark dots on the map are examples of sample sites. The shoreline strata is represented by the black outline of the lake. The contour line in the middle of the lake represents 30 m depth which was taken from bathymetric maps (Mathisen 1996) that were used to separate the original two offshore strata.

(Delorme 1999), and the coordinates were downloaded to a GPS receiver that was used to locate sample sites in the field. All sampling sites were randomized and selected prior to the commencement of sampling in the field.

Shoreline Sites. – Two sinking nets (60 m each) were set at the bottom at each of the randomly selected sample sites because there were two categories of mesh sizes. One collection refers to two nets. Nets were monitored continuously to minimize adult salmon capture. The “soak time,” or duration of fishing time, for shoreline collections was two hours.

Offshore Sites. – Two sinking gill nets (120 m each) were set at the bottom at each of the randomly selected sample sites because there were two different configurations of mesh sizes. The sinking nets were tied together with the connected ends chosen randomly. This configuration of nets was defined as one collection. The soak time for offshore collections was four hours, unless shortened by weather. If collections had to be aborted, the duration of the set was recorded, and data was collected on all fish caught.

Data Collection. – Location, depth, water temperature at depth of capture using an 8-L Van Dorn water bottle, and time of each collection were recorded. Fork length (nearest mm) was measured from all targeted fish. Number of fish and which species caught by each mesh size was recorded.

Otoliths and stomachs were taken from target fish mortalities. Mortality included any fish that died prior to removal from the gill net. Sagittal otoliths were extracted using the cranio-caudal mid-sagittal cut and stored in 95% ethanol. One otolith from each fish sampled was prepared for aging by thin-sectioning transversely through the core (Secor et al. 1991; R. Brown, USFWS personal communication). Two readers independently estimated ages of otoliths based on annuli from hyaline (active growth) and opaque (slow growth) bands. One hyaline and one opaque band represent one year of growth (Jearld 1983; R. Brown, USFWS, personal communication).

Stomach contents were stored in 85% ethanol. If possible, invertebrates in the samples were identified to the ordinal taxonomic level, and fish taken from stomachs were identified to species.

Substrate type was categorized by visual assessment of the substrate particle size of the area where a net was set, using a technique similar to the Modified Wentworth classification (Cummins 1962). Categories included silt (< 0.059 mm), sand (0.06 – 1 mm), gravel (2 – 63 mm), cobble (64 – 256 mm), and boulder (>256 mm). The use of an underwater video camera with lighting aided in documenting the substrate particle size found at each sample site.

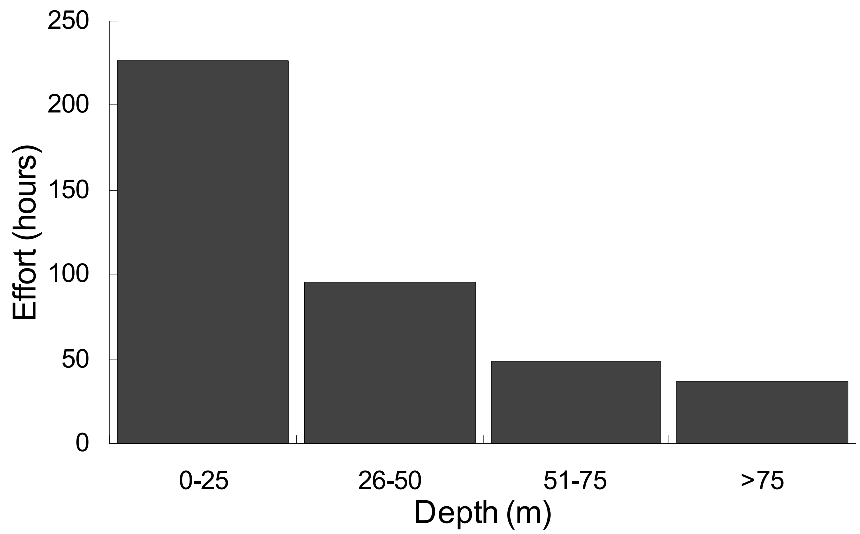
Environmental data were recorded for each collection. These data included weather conditions, wind speed and direction, wave height, air temperature, water surface temperature, and orientation of net.

Data Analyses

The analyses of depth, time, and substrate used log transformed CPUE due to non-normally distributed data, and the analyses of length, age, and diet used observed catch. Catch is the number of fish caught standardized by soak time and net length. Effort is one gill net set, or collection, equal to a four-hour soak time. CPUE was calculated by dividing catch by the number of gill net collections per day. It was then log transformed.

The stratified random sampling method resulted in the gill net effort mostly allocated to the 0-5 m water depth (Figure 3). The most effort was in the 0-5 m area due to our expectation that most fish would be in this area because species richness is usually the highest in littoral areas (Randall et al. 1996).

Time. – A one-way nonparametric analysis was used, with the Kruskal-Wallis test (SAS Institute Inc. 2004), to test the null hypothesis that there is no statistically significant difference in CPUE among the three months (June, July, and August) for each species ($\alpha = .05$). To find which time periods were different, an analysis of variance (ANOVA) two-sample test was used to test the



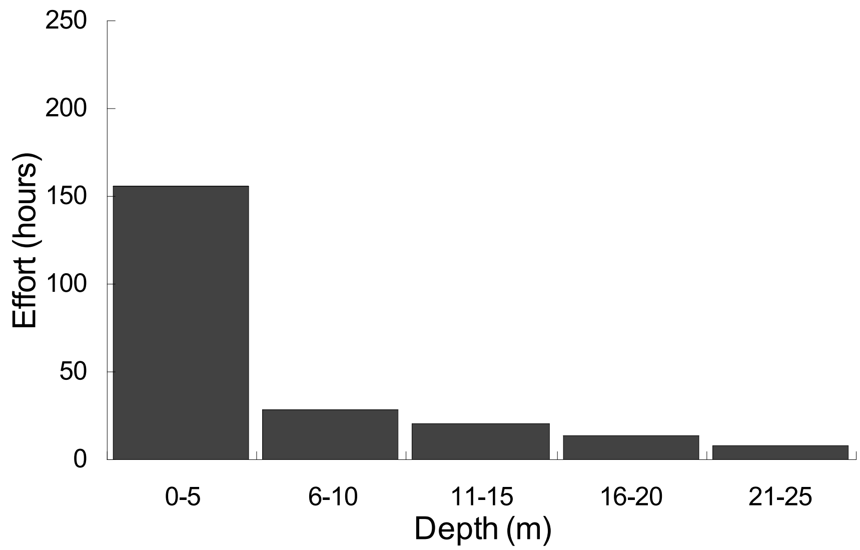


Figure 3. Allocation of gill net effort by depth in the Ugashik lakes, 2003-2004.

null hypothesis that the CPUE distributions were statistically identical for pairs of months.

Depth. – Diagnostic analyses of log CPUE residuals resulted in the creation of four depth strata (0 – 25 m, 26 – 50 m, 51 – 75 m, and > 75 m). Diagnostic analyses also revealed non-normally distributed CPUE data. Due to the prevalence of zeros for CPUE in water greater than 25-m deep because of less species caught in deeper water, the shallow water of 0 – 25 m was analyzed separately from the deeper water. A one-way nonparametric analysis (SAS Institute Inc. 2004) was used to test for statistically significant differences ($\alpha = .05$) in CPUE between depths for the shoreline and offshore strata.

Length and Age. – Descriptive statistics (mean, 95% confidence interval, mode, and range) were used to separately analyze length and age. Pearson correlation was used to test for any associations between various combinations of length, depth, and time. ANOVA was used to assess the statistical significance of length and depth for comparison for the three different months (SAS Institute Inc. 2004). Fork lengths of lake trout and Arctic char were used with simple linear regression analyses to address the null hypothesis that size distribution of these salmonids is not related to depth. Pygmy whitefish were not in these analyses because they were only found in deep water, and Arctic grayling, Dolly Varden, and round whitefish were only found close to the shoreline.

Substrate. – To evaluate how the distribution of each species was related to the substrate type over which they were collected the Vanderploeg and Scavia (1979) electivity index (E*) was used:

$$E^* = \frac{W_i - (1/n)}{W_i + (1/n)},$$

$$W_i = \frac{r_i / p_i}{\sum r_i / p_i};$$

where r is the proportion of the substrate particle size used by the species, p is the proportion of that substrate type available in the environment (data for p were collected concurrently at the time of fish collections), and n is the number of substrate types. This electivity index, E*, which is traditionally used to examine selectivity in diets, is considered to be the best of the available electivity indices (Lechowicz 1982). This index ranges between -1.00 and +1.00, with higher proportional use (E*> 0) of a particular substrate type and lower proportional use (E*< 0) of a particular substrate type, respectively. From Vanderploeg and Scavia (1979), an index of E* = 0 denotes neutrality, or random use; here a broader range of neutrality, 0.1≥E*≥-0.1 was chosen (Zekeria and Videler 2003).

This electivity index, E*, was used to assess substrate type that the five species (pygmy whitefish were not used in the substrate analysis) were frequently captured over in 0 – 20 m of water. Silt was the only substrate particle size found below 20 m so it was deemed unnecessary to analyze the substrate type at greater depths. All fish captured in > 20 m of water were caught over silt. Subsequently, E* was used to analyze size-dependent relationships of fish distribution over substrate type. For all fish species included in this analysis length data was divided into three length groups (with the exception of lake trout, which only had two length groups). The length distribution of each species was divided into equally numbered size groups (Table 1.)

Food habits. – Fish stomach contents were quantified using frequency of occurrence. This describes the uniformity with which species select food items in their diet but it does not indicate importance of the food types selected (Bowen 1996). Differences in food habits by time period, depth, substrate, and size groups were described for each fish species. Size groups for food habits were determined using fish captured at all depths (Table 2).

Table 1. Small, medium, and large length groups for analyses of substrate type and length in 0 – 20 m depth, in Upper and Lower Ugashik lakes, 2003-2004.

	Small (mm)	Medium (mm)	Large (mm)
Arctic char	91 – 330	331 – 434	435 – 710
Dolly Varden	84 – 280	281 – 385	386 – 602
Arctic grayling	111 – 300	301 – 400	401 - 495
Round whitefish	126 – 340	341 – 400	401 - 480
Lake trout*	152 – 449		450 - 573

* only two length groups

Table 2. Size groups for analyses of food and length at all depths. Small, medium, and large length groups for each salmonid species in Upper and Lower Ugashik lakes.

	Small (mm)	Medium (mm)	Large (mm)
Lake trout	152 – 260	261 – 390	391 - 530
Arctic char	112 – 270	271 – 375	376 – 710
Dolly Varden	84 – 270	271 – 315	316 – 585
Arctic grayling	111 – 350	351 – 415	416 - 475
Round whitefish	126 – 360	361 – 400	401 - 460
Pygmy whitefish*	89 – 104		105 - 120

* only two length groups

Results

Time

In the 0 – 25 m depth range there was a statistically significant difference for the CPUE of Dolly Varden between June and July; more fish were caught in July than in June. There was also a statistically significant difference in CPUE for Arctic char, Dolly Varden, and lake trout between July and August; more fish were caught in July than in August for each species (Figure 4). No statistically significant difference of CPUE and time was found for any of the species captured in water greater than 25 m.

Depth

Lake trout and Arctic char were captured at all depths sampled (Figure 5). Forty-two percent of lake trout were caught in less than 10 m. Ninety percent of Arctic char were found shallower than 10 m. Ninety-nine percent of Dolly Varden char were found in less than 10 m. All Arctic grayling were caught in 0 to 10 meters of water. All round whitefish were caught in less than 20 m, with 88 % caught in less than 10 m of water. Pygmy whitefish are only found in water greater than 20 m deep, with 86% caught between 35-60 m.

Length

Lake trout (n = 477) sizes ranged from 152 mm to 573 mm (Figure 7). The mean length was 367 mm (Figure 6). Arctic char (n = 260) length ranged from 91 mm to 710 mm (Figure 7). The mean length was 369 mm (Figure 6). Dolly Varden (n = 76) sizes ranged from 84 mm to 602 mm (Figure 7). The mean length was 363 mm (Figure 6). Arctic grayling (n = 136) length ranged from 111 mm to 495 mm (Figure 7). The mean length was 390 mm (Figure 6). Round whitefish (n = 271) sizes ranged from 126 mm to 480 mm (Figure 7). The mean length was 359 mm (Figure 6). Pygmy whitefish (n = 91) sizes ranged from 84 mm to 128 mm (Figure 7). The mean length was 104 mm (Figure 6).

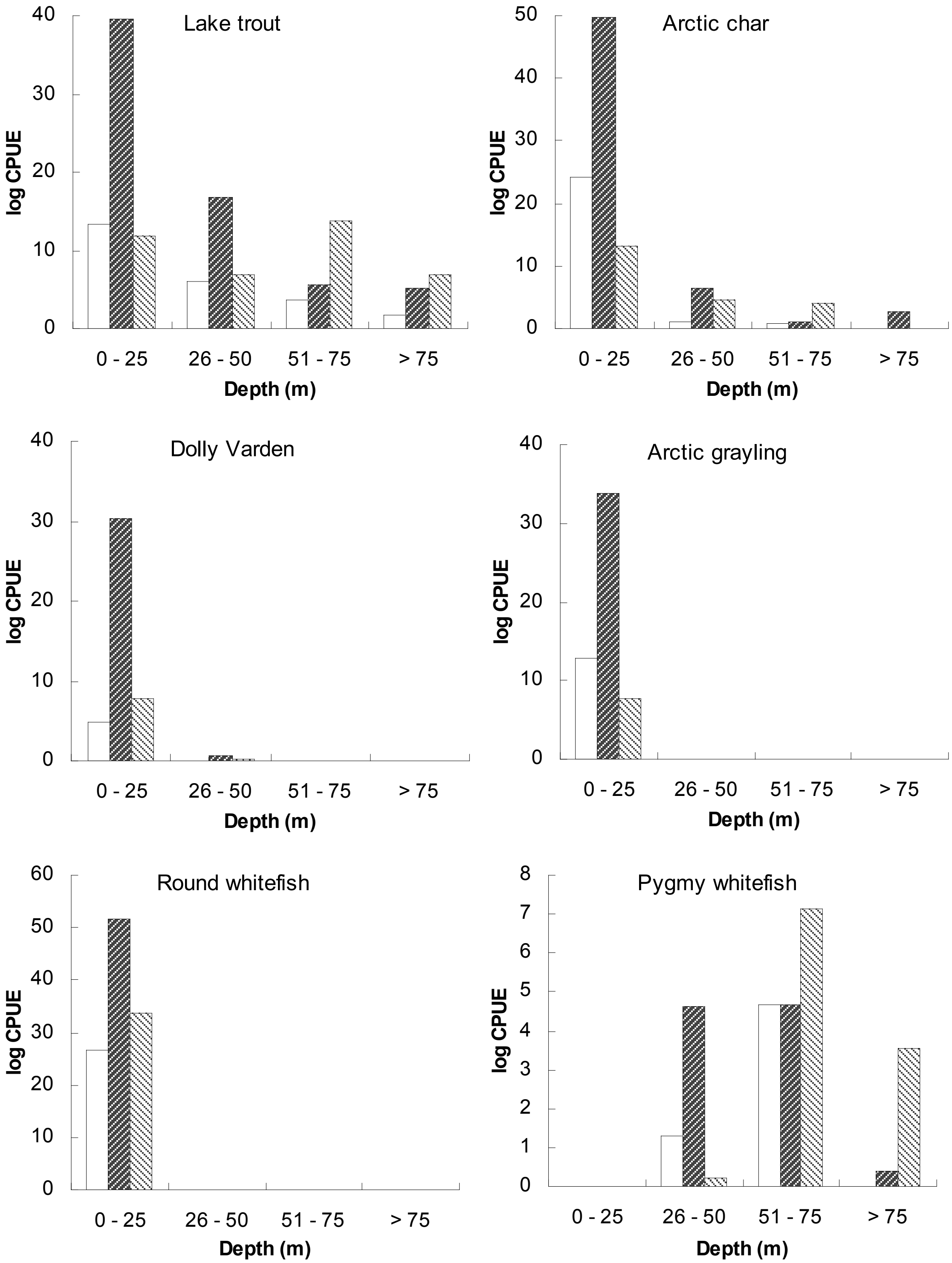


Figure 4. Log transformed catch per unit effort (CPUE) of each species sampled separated by depth and month of capture. Light bars at left = June; middle dark bars = July; gray bars at right = August.

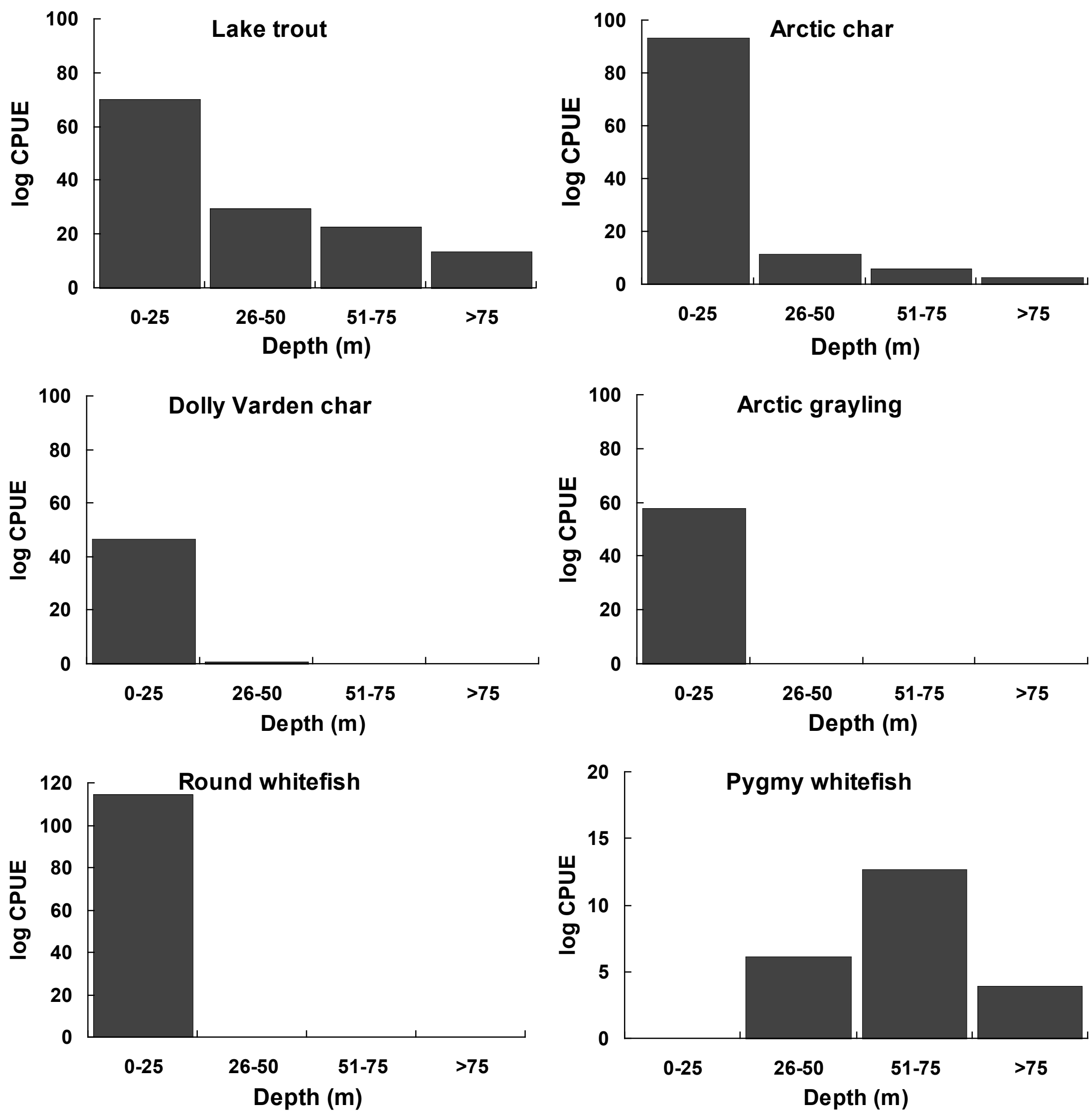


Figure 5. Log transformed catch per unit effort (CPUE) by depth of six salmonid species in the Upper and Lower Ugashik lakes, 2003-2004.

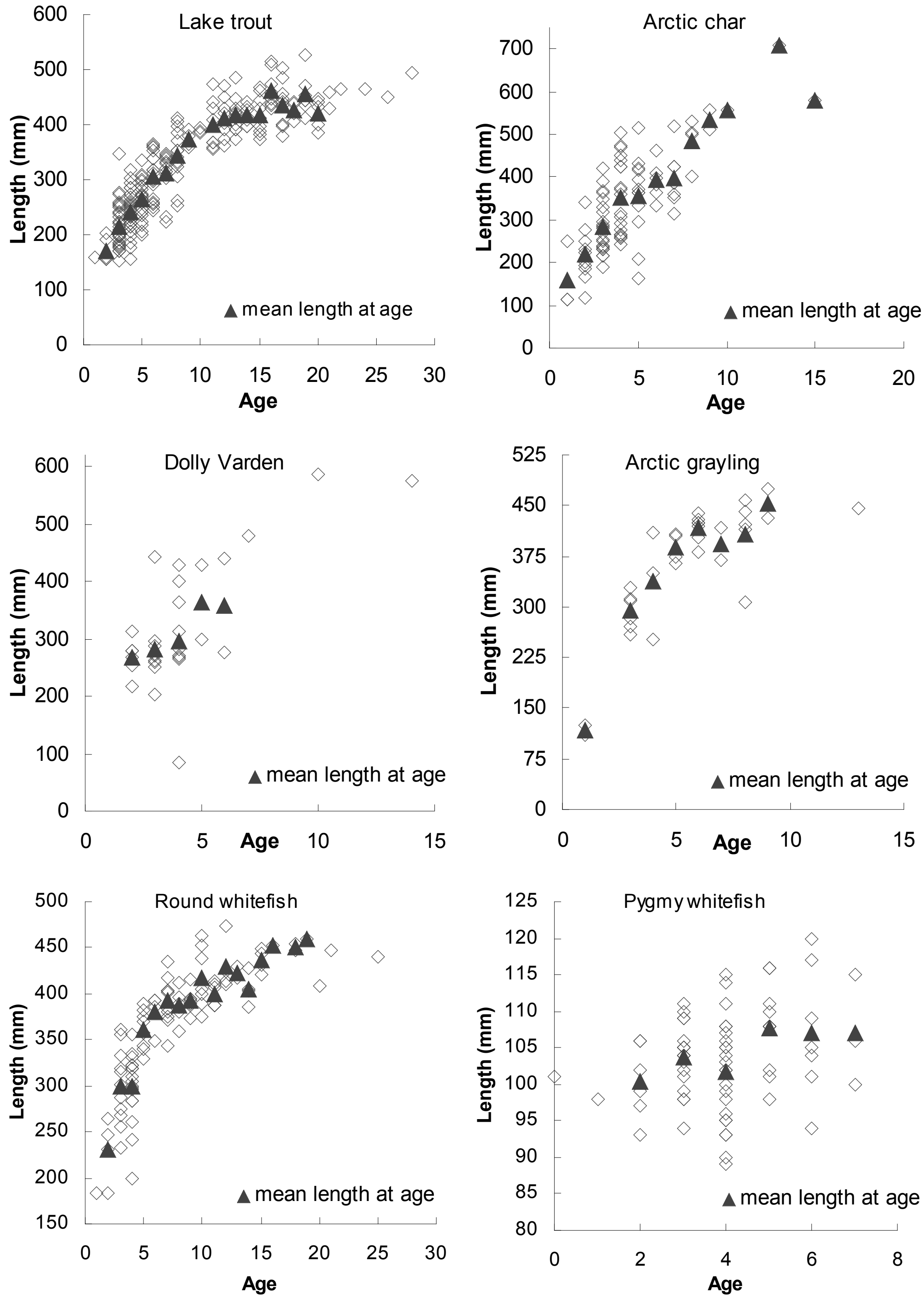


Figure 6. Lengths at age for each species sampled in the Ugashik lakes, 2003-2004. (◊ = individual)

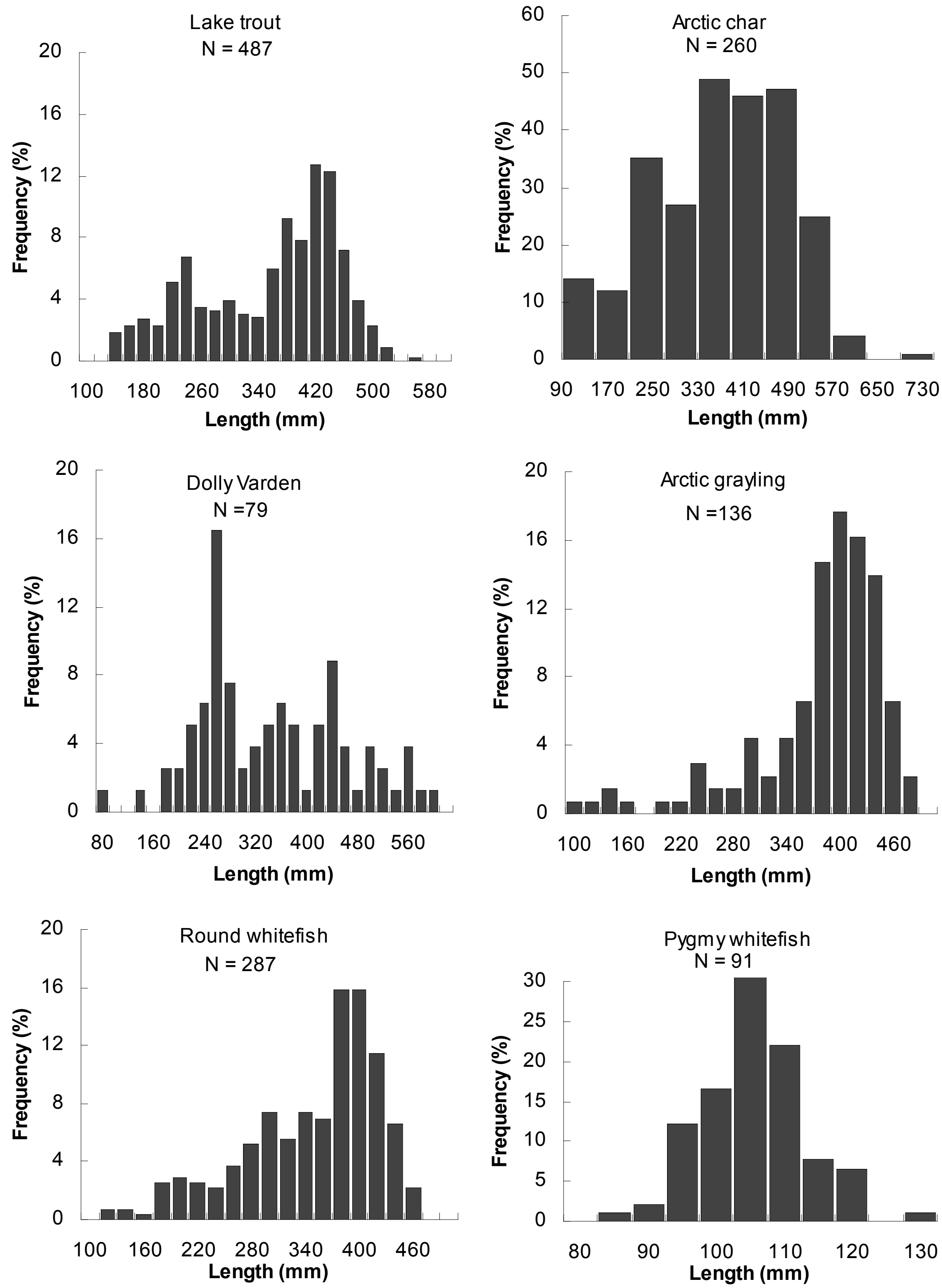


Figure 7. Length frequency graphs for each species sampled in the Ugashik lakes in 2003-2004.

Arctic char were caught at all depths, but length did not have a significant relationship to depth (*p*-value .38). Lake trout found in less than 25 m were significantly ($p < .0001$) larger than those at greater depths. Smaller lake trout (< 325 mm) were in water 25 m or deeper and larger fish (> 325 mm) were found at all depths. 39% of lake trout larger than 325 mm were in less than 20 m of water.

Length had a significant relationship to round whitefish depth in the 0 – 25 m water ($p < .0001$) during July. Figure 8 shows that, with the exception of one or two fish, all small (≤ 250 mm) fish stayed in water five meters deep or shallower. Larger fish were as deep as 20 m but most were in water less than 12-m deep.

Age

Age estimates of lake trout (n = 239) ranged from 1 to 28 years. The mean age was 9, and the most frequently caught was age 4 (Figure 9). Arctic char (n = 90) ages ranged from 1 to 15. The mean age was 5 and the most frequently caught was age 3 (Figure 9). Dolly Varden (n = 32) age ranged from 2 to 14. The mean age was 4 and the most frequently caught was age 3 (Figure 9). Arctic grayling (n = 32) ages ranged from 1 to 13. The mean age was 6 and the most frequently caught was also age 6 (Figure 9). Round whitefish (n = 104) ages ranged from 1 to 25. The mean age was 8 and the most frequently caught was age 4 (Figure 9). Pygmy whitefish (n = 73) ages ranged from 0 to 7. The mean age was 4 and the most frequently caught was also age 4 (Figure 9).

Length-at-age was highly variable (Figure 6). The oldest fish were not always the longest fish. If viewed in 100 mm length groups, lake trout 300-399 mm length group were composed of ages between 4 and 20 years, and 400-499 mm were composed of ages between 8 and 28 years. Round whitefish also had a great range in ages for the 300-399 mm and 400-499 mm length groups. These groups were composed of ages between 3 and 14, and 7 to 25 years, respectively. None of the other fish species had such wide ranges of ages for 100 mm length groups.

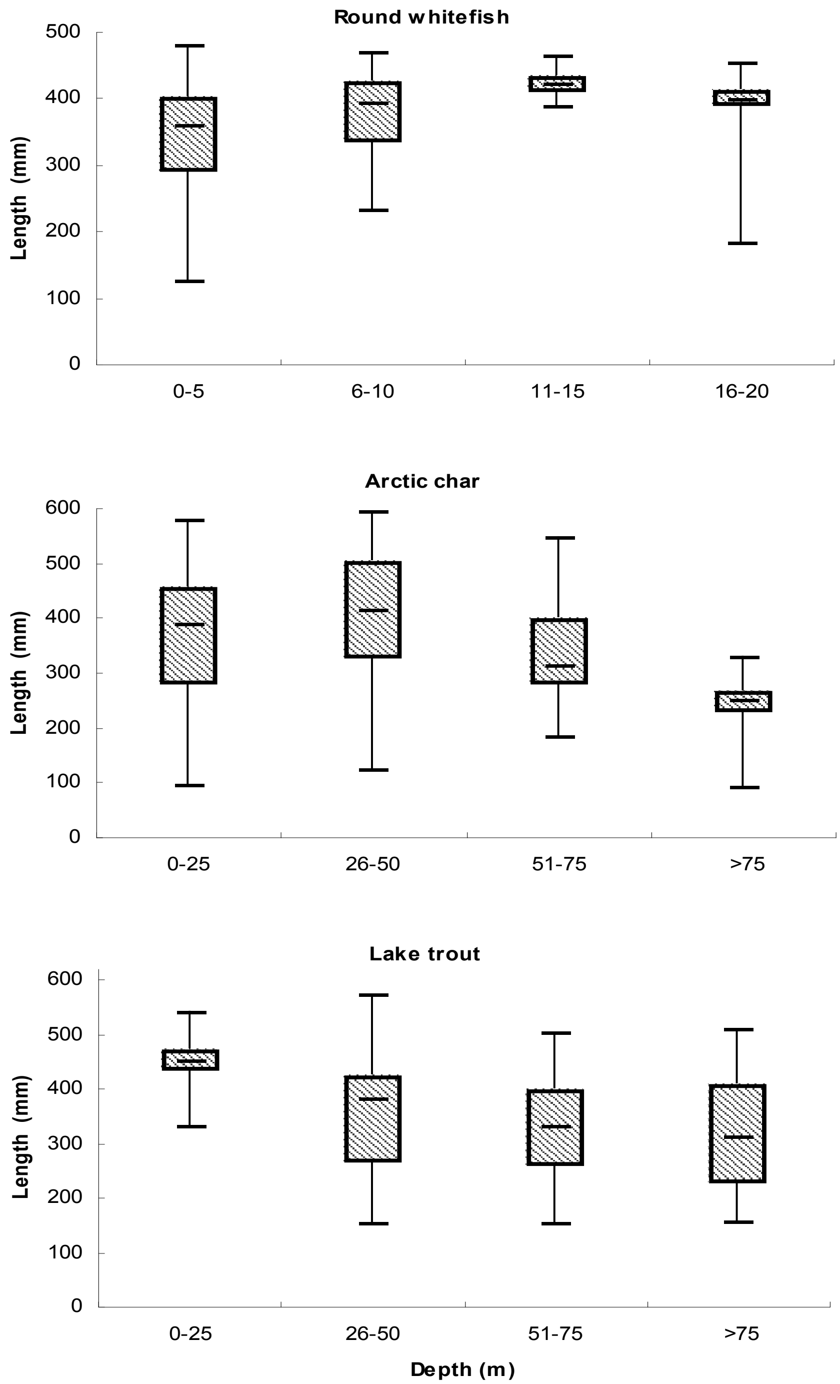


Figure 8. Relationship of length to depth for lake trout, Arctic char, and round whitefish in the Ugashik lakes in 2003-2004. In each box plot the central horizontal bar = median, the box = inter-quartile range, and the vertical lines = maximum and minimum values.

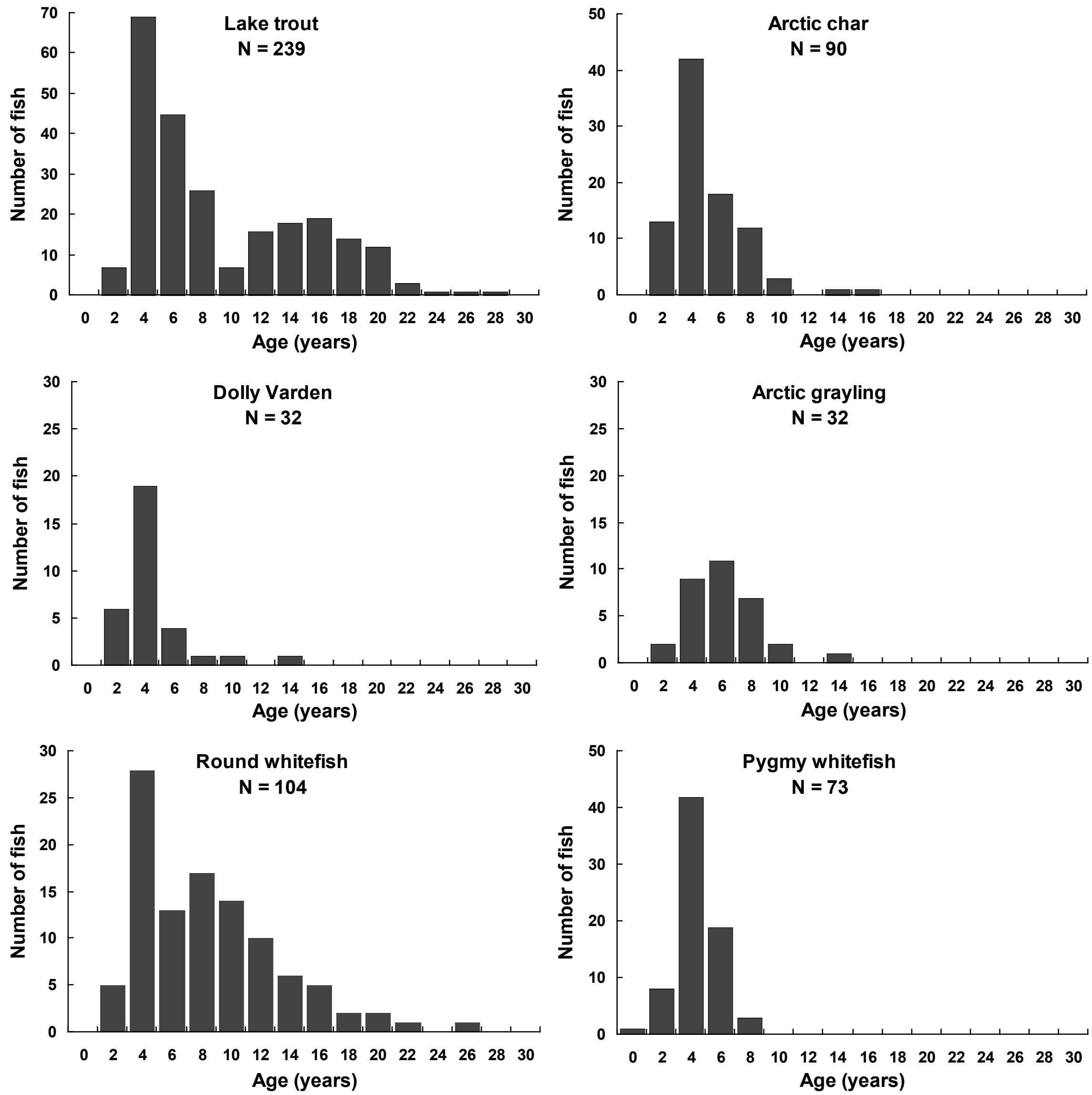


Figure 9. Age distribution of six fish species captured by gill nets in Upper and Lower Ugashik lakes, 2003-2004.

Substrate

Silt was the only substrate found in the 24 substrate measurements taken in water deeper than 20 m. Given that pygmy whitefish were only found below 20 m they were only found in the silt substrate (Figure 10). Silt was only measured at one sample site in the 0 – 20 m depth range; therefore, we excluded it from the electivity index analyses.

Overall, lake trout were neutral towards gravel and cobble. They were infrequently caught over boulder and sand in 0 -20 m water (Figure 11). Arctic char were neutral towards cobble, sand, and gravel. They were rarely caught over boulder. Dolly Varden were often caught over boulder and less often over cobble. They were neutrally towards gravel and sand. Arctic grayling were often caught over gravel and were neutral near cobble. They were rarely caught over boulder. Round whitefish were most frequently caught over cobble and they were rarely captured over sand. They were neutral towards boulder and gravel.

Large lake trout (Table 1) were neutral towards boulder, cobble, and sand and were frequently caught over gravel (Figure 12). Small lake trout were seldom found over boulder, cobble, and sand, and were frequently caught over gravel.

Large Arctic char (Table 1) were rarely caught over boulder, were neutral towards cobble and sand, and they were most frequently caught over gravel (Figure 12). Arctic char in the medium size group were caught over cobble less often than sand. They were randomly caught over boulder and gravel. Small Arctic char were not found over any particular substrate type more often than other substrate types.

Large Dolly Varden (Table 1) were rarely captured over boulder and cobble (Figure 12). They were frequently captured over gravel and were neutral toward sand. Medium sized Dolly Varden were frequently caught over boulder, they seldom used cobble, and neutrally used gravel and sand. Small Dolly

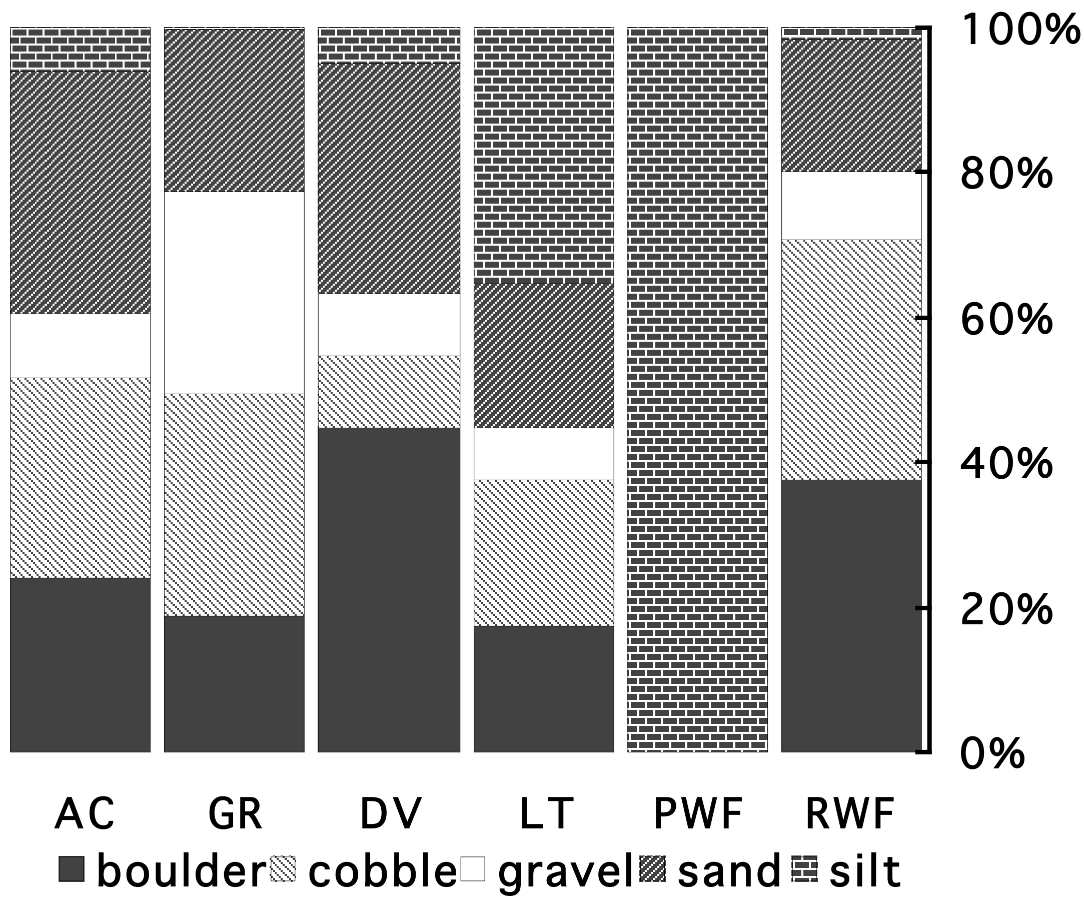


Figure 10. Frequency of each fish species (AC = Arctic char, GR = Arctic grayling, DV = Dolly Varden char, LT = lake trout, PWF = pygmy whitefish, RWF = round whitefish) found at each substrate type over all depths. Total collections (N = 102) yielded boulder, 24.51%; cobble, 19.61%; gravel, 5.88%; sand, 25.49%; and, silt, 24.51%.

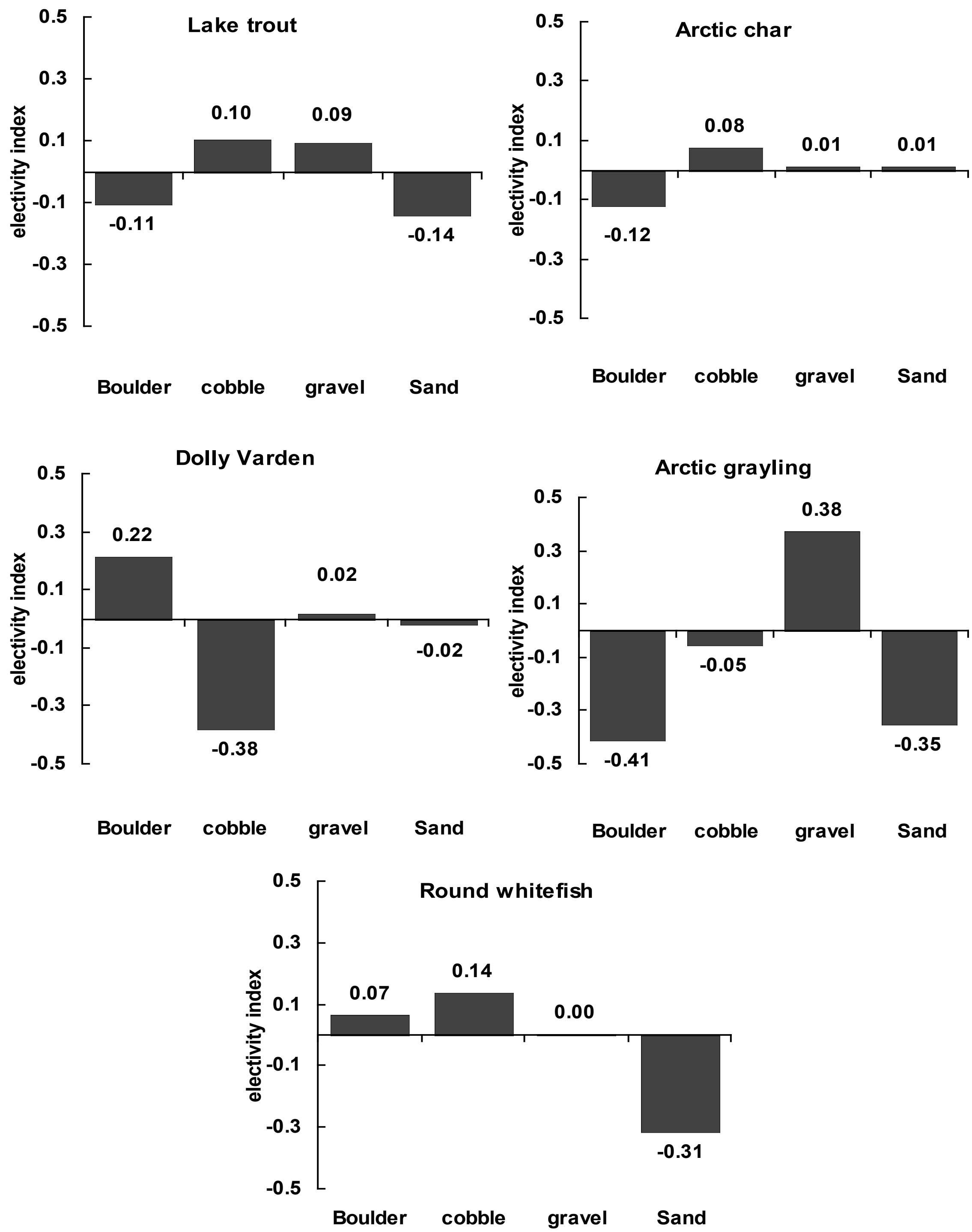


Figure 11. Electivty indices used to evaluate fish distribution over substrate type in 0 – 20 m depth, Upper and Lower Ugashik lakes, 2003-2004. Pygmy whitefish were not located at this depth and were not included in this analysis.

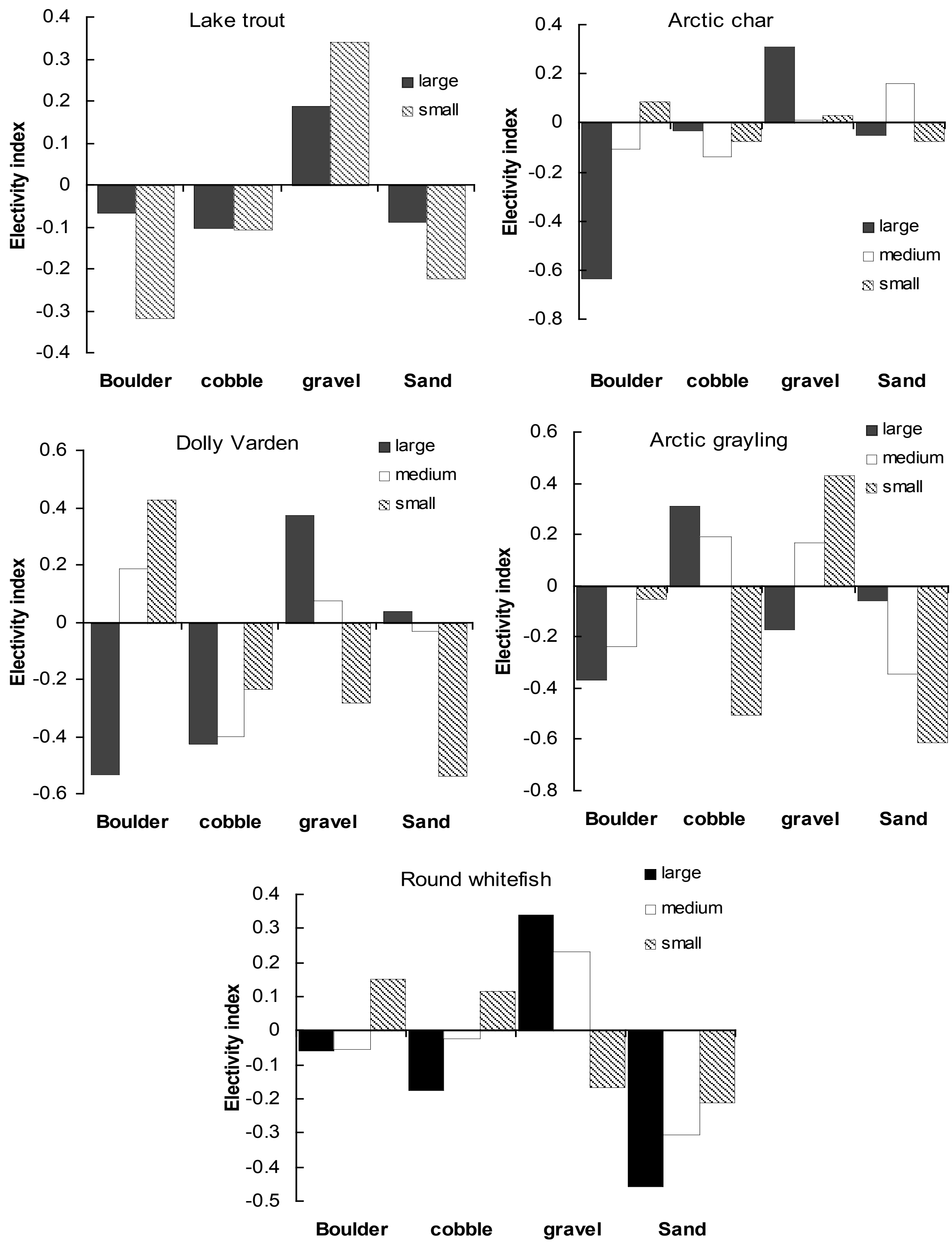


Figure 12. Electivity indices for five of the six species sampled, size dependency on substrate particle type in the Ugashik lakes for 2003-2004. Pygmy whitefish were not included in this analysis because they were not found in less than 20 m.

Varden were frequently caught near boulder, and were less often caught over cobble, gravel, and sand.

Large Arctic grayling (Table 1) were often captured over cobble and were less frequently caught over boulder and gravel. They were neutral towards sand (Figure 12). Arctic grayling in the medium size group rarely were found near boulder and sand. They were frequently caught over cobble and gravel. The small fish were hardly ever captured over cobble and sand. They were more frequently captured over gravel, and were neutral towards boulder.

Round whitefish in the large size group (Table 1) were frequently captured over gravel and were less frequently caught over cobble and sand. They were neutral towards boulder (Figure 12). Medium round whitefish were rarely caught near sand and were more often caught over gravel. They were neutral towards boulder and cobble. Small round whitefish were frequently captured over boulder and cobble, and seldom caught over gravel and sand.

Food habits

Stomachs contents were quantified from 256 lake trout, 92 Arctic char, 33 Dolly Varden, 29 Arctic grayling, 101 round whitefish, and 60 pygmy whitefish (Table 3). Molluscs were frequently found in the stomachs of the two whitefish species (two types of Gastropoda, and Sphaeriidae, a fingernail clam species). The two most frequently captured predatory fish species, lake trout and Arctic char, ate a variety of food, with less emphasis on molluscs. Lake trout had the most fish in their stomachs.

The major types of insects found in all species stomachs included chironomids, other Diptera, Coleoptera, Tricoptera, and Hymenoptera. Tricopeterans were in aquatic stages, chironomids were mostly adult midges; Hymenoptera, Coleoptera, and Hemiptera were terrestrial stages. All fish species, except pygmy whitefish, had isopods (*Saduria entomon*) in their stomachs.

Table 3. Food of Ugashik Lakes salmonids collected during summer, 2003-04, expressed as percentage frequency of occurrence of food items. Percentage of empty stomachs is included.

Food Types	lake trout (*N* = 256)	Arctic char (*N* = 92)	Dolly Varden (*N* = 33)	Arctic grayling (*N* = 29)	round whitefish (*N* = 101)	pygmy whitefish (*N* = 60)
Gastropoda (snails)	1.56	7.61	3.03	6.90	70.30	0.00
Sphaeriidae (fingernail clam)	4.30	4.35	3.03	0.00	5.94	46.67
Isopoda	19.53	7.61	3.03	48.28	11.88	0.00
Amphipoda	31.25	51.09	15.15	10.34	1.98	13.33
Arachnida	0.00	0.00	0.00	3.45	0.00	0.00
Insects						
Tricoptera	0.39	2.17	6.06	6.90	11.88	0.00
Diptera*	1.56	5.43	6.06	34.48	0.00	1.67
adult mosquito	0.00	0.00	0.00	6.90	0.99	0.00
larvae	3.52	5.43	6.06	3.45	4.95	1.67
pupae	8.20	4.35	0.00	3.45	3.96	0.00
Chironomidae	2.34	7.61	6.06	17.24	12.87	0.00
Hymenoptera	0.00	4.35	6.06	20.69	0.00	0.00
Coleoptera	0.39	2.17	12.12	10.34	0.99	0.00
Ephemeroptera	0.00	1.09	0.00	0.00	0.00	0.00
Unidentifiable insect sp.	1.95	1.09	24.24	24.14	2.97	1.67
Plecoptera	0.00	0.00	0.00	3.45	0.00	0.00
larvae	0.00	0.00	0.00	3.45	0.00	0.00
Hemiptera	0.00	2.17	3.03	10.34	0.99	0.00
Fish						
Sculpin sp.	14.06	0.00	0.00	0.00	0.00	0.00
9-spine stickleback	1.56	0.00	0.00	0.00	0.00	0.00
Stickleback sp.	0.78	0.00	0.00	0.00	0.00	0.00
Unidentifiable fish sp.	22.66	5.43	0.00	0.00	0.00	0.00
salmon smolt	1.17	0.00	0.00	0.00	0.00	0.00
salmon eggs	0.00	0.00	6.06	0.00	0.00	0.00
unidentifiable content	3.52	2.17	6.06	6.90	0.99	30.00
empty stomachs	16.80	14.13	30.30	0.00	6.93	10.00

* unidentifiable life stage

Lake trout diet. – Major food items in the diet of lake trout were amphipods (31%), isopods (20%), and fish (sculpin species, 14%; unidentifiable fish 23%) (Table 3). Seventeen percent of lake trout stomachs were empty. Diet varied little from month to month (June, July, and August) (Table 4). Lake trout diet also varied little by depth, with the exception of the deepest depths (> 75 m) (Table 5). They did not eat as many insects at the greatest depths. The few sticklebacks were found in stomachs of lake trout captured in the near shore strata (0-25 m). Most stomach samples were from lake trout captured over silt; this is explained by the fact that most lake trout were caught in the deeper water and silt was the only substrate type found deeper than 20 m. When compared by substrate particle size, no difference was found in the type of food lake trout were eating (Table 6). When compared by lake trout size groups, stomach contents showed that large lake trout ate more isopods than the medium or small size groups (Table 7).

Arctic char diet. –The major food in Arctic char stomachs were amphipods (52%) (Table 3). Fourteen percent of the stomachs were empty. Fish were found in some of the stomachs, but they were unidentifiable as to species. Arctic char diet varied by month. They only ate amphipods in July and August, and fish were more frequent in the stomachs sampled in June, although the June sample size was small compared to the other months (Table 8). Arctic char had a higher frequency of molluscs and terrestrial insects (Hymenoptera, Coleoptera, and Hemiptera) in their stomachs sampled in July. The majority of Arctic char were captured in depths less than 25 m deep (Table 9). Arctic char in water deeper than 25 m ate isopods and chironomids, but amphipods were consumed most frequently in deep water. Arctic char diet varied when analyzed by each substrate type (Table 10); fish caught over boulder and sand had the most diverse diets. Large Arctic char ate more molluscs than the medium or small size groups (Table 11). Large and small fish consumed isopods. Terrestrial insects (Hymenoptera, Coleoptera, Hemiptera) were only found in small Arctic char.

Table 4. Frequency of occurrence (percentage) of food items in lake trout diet by month of capture from the Ugashik lakes in 2003-2004.

Food items	June (n = 36)	July (n = 76)	August (n = 143)
Gastropoda	0	3.95	0.7
Sphaeriidae (fingernail clam)	5.56	3.95	4.2
Isopoda	19.44	34.21	11.89
Amphipoda	13.89	48.68	26.57
Arachnida	0	0	0
Tricoptera	0	2.63	1.4
Diptera unidentifiable	0	2.63	1.4
adult mosquito	0	0	0
D. larvae	5.56	1.32	4.2
D. pupae	2.78	0	13.29
Chironomidae	2.78	1.32	2.8
Hymenoptera	0	0	0
Coleoptera	0	1.32	0
unidentifiable insects	0	0	0
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	0	0
Sculpin sp.	16.67	21.05	9.79
Ninespine stickleback	0	1.32	2.1
Stickleback *sp.*	0	0	1.4
unidentifiable fish *sp.*	22.22	19.74	24.48
salmon smolt	0	1.32	1.4
unidentifiable content	0	0	0

Table 5. Frequency of occurrence (percentage) of food items in lake trout stomachs by capture depth (m) from the Ugashik lakes in 2003-2004.

	0 - 25 (n = 36)	26 - 50 (n = 74)	51 - 75 (n = 99)	> 75 (n = 46)
Gastropoda	11.11	0	0	0
Sphaeriidae (fingernail clam)	11.11	5.41	2.02	2.17
Isopoda	25	17.57	18.18	21.74
Amphipoda	19.44	25.68	29.29	54.35
Arachnida	0	0	0	0
Tricoptera	2.78	0	0	0
Diptera unidentifiable	2.78	1.35	2.02	0
adult mosquito	0	0	0	0
D. larvae	5.56	0	7.07	0
D. pupae	5.56	5.41	14.14	0
Chironomidae	5.56	5.41	0	0
Hymenoptera	0	0	0	0
Coleoptera	2.78	0	0	0
unidentifiable insects	11.11	0	1.01	0
Plecoptera	0	0	0	0
P. larvae	0	0	0	0
Hemiptera	0	0	0	0
Sculpin sp.	27.78	13.51	13.13	6.52
Ninespine stickleback	8.33	0	1.01	0
Stickleback sp.	2.78	0	1.01	0
unidentifiable fish sp.	36.11	25.68	17.17	19.57
salmon smolt	5.56	0	1.01	0
unidentifiable content	5.56	4.05	1.01	6.52

Table 6. Frequency of occurrence (percentage) of diet items, analyzed by substrate type, in lake trout stomachs sampled, in the Ugashik lakes in 2003-2004.

	boulder (n = 8)	cobble (n =5)	gravel (n = 5)	sand (n = 6)	silt (n = 108)
Gastropoda	25	0	0	33.33	0
Sphaeriidae (fingernail clam)	0	20	40	16.67	4.63
Isopoda	37.5	20	0	50	23.15
Amphipoda	12.5	0	40	16.67	28.7
Arachnida	0	0	0	0	0
Tricoptera	12.5	0	0	0	0
Diptera unidentifiable	0	0	0	0	0.93
adult mosquito	0	0	0	0	0
D. larvae	25	0	0	0	0.93
D. pupae	0	0	20	16.67	1.85
Chironomidae	12.5	0	0	0	4.63
Hymenoptera	0	0	0	0	0
Coleoptera	12.5	0	0	0	0
unidentifiable insects	12.5	20	0	0	0
Plecoptera	0	0	0	0	0
P. larvae	0	0	0	0	0
Hemiptera	0	0	0	0	0
Sculpin sp.	37.5	40	20	33.33	13.89
Ninespine stickleback	0	0	20	16.67	0
Stickleback sp.	0	0	20	0	0
unidentifiable fish sp.	37.5	60	40	33.33	28.7
salmon smolt	12.5	0	0	0	0.93
unidentifiable content	0	0	40	0	3.7

Table 7. Frequency of occurrence (percentage) of food items in lake trout stomach samples, analyzed by fish length group (Table 2) in the Ugashik lakes in 2003-2004.

	Small (n = 81)	Medium (n = 82)	Large (n = 87)
Gastropoda	4.94	0	0
Sphaeriidae (fingernail clam)	7.41	4.88	1.15
Isopoda	43.21	15.85	1.15
Amphipoda	34.57	26.83	32.18
Arachnida	0	0	0
Tricoptera	1.23	0	0
Diptera unid.	1.23	3.66	0
adult mosquito	0	0	0
larvae	2.47	4.88	3.45
pupae	4.94	10.98	8.05
Chironomidae	2.47	2.44	2.3
Hymenoptera	0	0	0
Coleoptera	1.23	0	0
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	0	0
unidentifiable insect sp.	3.7	1.22	0
Sculpin sp.	22.22	9.76	11.49
Ninespine stickleback	1.23	1.22	1.15
Stickleback sp.	0	1.22	1.15
unidentifiable fish sp.	25.93	20.73	22.99
salmon smolt	2.47	1.22	0
salmon eggs	0	0	0
unidentifiable content	3.7	1.22	5.75

Table 8. Frequency of occurrence (percentage) of food items in Arctic char diet by month of capture from the Ugashik lakes in 2003-2004.

	June (n = 11)	July (n = 41)	August (n = 40)
Gastropoda	0	14.63	2.5
Sphaeriidae (fingernail clam)	0	7.32	2.5
Isopoda	18.18	4.88	7.5
Amphipoda	0	48.78	67.5
Arachnida	0	0	0
Tricoptera	18.18	0	0
Diptera unid	0	0	0
adult mosquito	0	0	0
larvae	0	9.76	2.5
pupae	9.09	2.44	5
Chironomidae	18.18	2.44	10
Hymenoptera	0	9.76	0
Coleoptera	0	4.88	0
Ephemeroptera	9.09	0	0
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	4.88	0
unidentifiable insect sp.	0	2.44	0
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	18.18	4.88	2.5
salmon smolt	0	0	0
unidentifiable content	9.09	2.44	0

Table 9. Frequency of occurrence (percentage) of food items in Arctic char diet by capture depth(m) from the Ugashik Lakes in 2003-2004

	0 - 25 (n = 61)	26 - 50 (n = 16)	51 - 75 (n = 10)	> 75 (n = 5)
Gastropoda	11.68	0	0	0
Sphaeriidae (fingernail clam)	6.56	0	0	0
Isopoda	4.92	12.5	20	0
Amphipoda	47.54	56.25	40	100
Arachnida	0	0	0	0
Tricoptera	3.28	0	0	0
Diptera unid	0	0	0	0
adult mosquito	0	0	0	0
larvae	6.56	0	10	0
pupae	4.92	0	10	0
Chironomidae	4.92	25	0	0
Hymenoptera	6.56	0	0	0
Coleoptera	1.64	0	10	0
Ephemeroptera	1.64	0	0	0
Plecoptera	0	0	10	0
P. larvae	0	0	10	0
Hemiptera	3.28	0	0	0
unidentifiable insect sp.	0	0	10	0
Sculpin sp.	0	0	0	0
Ninespine stickleback	0	0	0	0
Stickleback sp.	0	0	0	0
unidentifiable fish sp.	8.2	0	0	0
salmon smolt	0	0	0	0
unidentifiable content	3.28	0	0	0

Table 10. Frequency of occurrence (percentage) of diet items, analyzed by substrate type, in Arctic char stomachs sampled, in the Ugashik lakes in 2003-2004

	boulder (n = 17)	cobble (n =7)	gravel (n = 6)	sand (n = 14)	silt (n = 21)
Gastropoda	11.76	0	33.33	14.29	0
Sphaeriidae (fingernail clam)	0	0	16.67	14.29	0
Isopoda	5.88	14.29	0	7.14	4.76
Amphipoda	29.41	71.43	66.67	42.86	61.9
Arachnida	0	0	0	0	0
Tricoptera	11.76	0	0	0	0
Diptera unid	0	0	0	0	0
adult mosquito	0	0	0	0	0
larvae	5.88	0	33.33	7.14	0
pupae	5.88	14.29	0	0	0
Chironomidae	17.65	0	0	0	19.05
Hymenoptera	11.76	0	0	14.29	0
Coleoptera	0	0	0	7.14	0
Ephemeroptera	5.88	0	0	0	0
Plecoptera	0	0	0	0	0
P. larvae	0	0	0	0	0
Hemiptera	5.88	0	0	7.14	0
unidentifiable insect sp.	0	0	0	0	0
Sculpin sp.	0	0	0	0	0
Ninespine stickleback	0	0	0	0	0
Stickleback sp.	0	0	0	0	0
unidentifiable fish sp.	11.76	14.29	0	7.14	0
salmon smolt	0	0	0	0	0
unidentifiable content	5.88	0	0	0	0

Table 11. Frequency of occurrence (percentage) of food items in Arctic char stomach samples, analyzed by fish length group (Table 2) in the Ugashik lakes in 2003-2004.

	Small (n = 28)	Medium (n = 29)	Large (n = 29)
Gastropoda	17.86	3.45	3.45
Sphaeriidae (fingernail clam)	10.71	0	3.45
Isopoda	10.71	0	13.79
Amphipoda	39.29	62.07	55.17
Arachnida	0	0	0
Tricoptera	3.57	3.45	0
Diptera unid.	0	0	0
adult mosquito	0	0	0
larvae	7.14	6.9	3.45
pupae	7.14	6.9	0
Chironomidae	7.14	10.34	6.9
Hymenoptera	0	3.45	10.34
Coleoptera	0	0	6.9
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	0	6.9
unidentifiable insect sp.	0	0	3.45
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	3.57	0	10.34
salmon smolt	0	0	0
salmon eggs	0	0	0
unidentifiable content	0	0	3.45

Dolly Varden diet. – Dolly Varden stomachs mostly contained amphipods (15.15%), Coleoptera (12.12%), and unidentifiable insects (24.24%). Thirty percent of the 33 stomachs sampled were empty (Table 3). Dolly Varden caught in July had the most diverse diets (Table 12). Amphipods and Coleoptera occured most frequently in Dolly Varden stomach samples. Sample sizes in June and August were small. Dolly Varden ate insects in June. Salmon eggs and Hemiptera were present in stomachs analyzed from August. The majority of Dolly Varden were captured at depths of 0 – 5 m, and the most frequent diet items in those 27 stomachs analyzed were amphipods, Coleoptera, and various other insects (Table 13). Dolly Varden caught over boulder had the most diverse diet (Table 14). These fish ate amphipods, Coleoptera, chironomids, and salmon eggs. Molluscs were only found in the stomachs of larger Dolly Varden (Table 15). Small fish ate insects and isopods.

Arctic grayling diet. – Stomachs from all Arctic grayling contained food. Isopods (48%), various life stages of Diptera, including 17% Chironomids, and Hymenoptera (21%) were the most frequently eaten food items (Table 3). Arctic grayling ate a diversity of food items for both July and August (Table16). Snails were only observed in Arctic grayling captured in August. They ate a high frequency of Dipteran life stages in July. Isopods were frequently eaten during both months. The majority of Arctic grayling were captured at depth of 0 – 5 m (Table 17). Isopods and Diptera were most frequent in their diet. Amphipods seemed to be of minimal importance to Arctic grayling diets, compared to the other fish species. The only terrestrial insects in Arctic grayling diet were in the stomachs of the fish caught over boulder and cobble (Table 18). Diptera and isopods were found in fish caught at all substrate particle sizes. There were no major differences in the food habits for each Arctic grayling size group (Table 19).

Table 12. Frequency of occurrence (percentage) of food items in Dolly Varden diet by month of capture from the Ugashik lakes in 2003-2004.

	June (n = 5)	July (n = 22)	August (n = 6)
Gastropoda	0	4.55	0
Sphaeriidae (fingernail clam)	0	4.55	0
Isopoda	0	4.55	0
Amphipoda	0	23.81	0
Arachnida	0	0	0
Tricoptera	20	4.55	0
Diptera unid	20	4.55	0
adult mosquito	0	0	0
larvae	0	9.09	0
pupae	0	0	0
Chironomidae	20	4.55	0
Hymenoptera	0	9.09	0
Coleoptera	0	18.18	0
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	0	16.67
unidentifiable insect sp.	40	27.27	0
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	0	0	0
salmon smolt	0	0	0
salmon eggs	0	0	50
unidentifiable content	0	14.29	0

Table 13. Frequency of occurrence (percentage) of food items in Dolly Varden stomachs by capture depth (m) from the Ugashik lakes in 2003-2004

	0 - 5 (n = 27)	6 - 10 (n = 3)	11 - 15 (n = 0)	16 - 20 (n = 1)	21 - 25 (n = 2)
Gastropoda	0	0	0	100	0
Sphaeriidae (fingernail clam)	0	0	0	100	0
Isopoda	3.7	0	0	0	0
Amphipoda	15.38	0	0	0	50
Arachnida	0	0	0	0	0
Tricoptera	7.41	0	0	0	0
Diptera unid	0	0	0	0	0
adult mosquito	0	0	0	0	0
larvae	7.41	0	0	0	0
pupae	0	0	0	0	0
Chironomidae	7.41	0	0	0	0
Hymenoptera	7.41	0	0	0	0
Coleoptera	11.11	33.33	0	0	0
Plecoptera	0	0	0	0	0
P. larvae	0	0	0	0	0
Hemiptera	3.7	0	0	0	0
unidentifiable insect sp.	29.63	0	0	0	0
Sculpin sp.	0	0	0	0	0
Ninespine stickleback	0	0	0	0	0
Stickleback sp.	0	0	0	0	0
unidentifiable fish sp.	0	0	0	0	0
salmon smolt	0	0	0	0	0
salmon eggs	5	33.33	0	0	0
unidentifiable content	14.29	0	0	0	0

Table 14. Frequency of occurrence (percentage) of diet items, analyzed by substrate type, in Dolly Varden stomachs sampled, in the Ugashik lakes in 2003-2004.

	boulder (n = 15)	cobble (n =3)	sand (n = 8)	silt (n = 5)
Gastropoda	0	0	12.5	0
Sphaeriidae (fingernail clam)	0	0	12.5	0
Isopoda	6.67	0	0	0
Amphipoda	14.29	0	25	20
Arachnida	0	0	0	0
Tricoptera	6.67	0	12.5	0
Diptera unid	6.67	0	12.5	0
adult mosquito	0	0	0	0
larvae	6.67	0	12.5	0
pupae	0	0	0	0
Chironomidae	13.33	0	0	0
Hymenoptera	6.67	0	12.5	0
Coleoptera	13.33	0	0	0
Plecoptera	0	0	0	0
P. larvae	0	0	0	0
Hemiptera	0	33.33	0	0
unidentifiable insect sp.	20	0	25	60
Sculpin sp.	0	0	0	0
Ninespine stickleback	0	0	0	0
Stickleback sp.	0	0	0	0
unidentifiable fish sp.	0	0	0	0
salmon smolt	0	0	0	0
salmon eggs	7.69	0	0	0
unidentifiable content	25	0	0	0

Table 15. Frequency of occurrence (percentage) of food items in Dolly Varden stomach samples, analyzed by fish length group (Table 2) in the Ugashik lakes in 2003-2004.

	Small (n = 9)	Medium (n = 12)	Large (n = 10)
Gastropoda	11.11	0	0
Sphaeriidae (fingernail clam)	11.11	0	0
Isopoda	0	0	10
Amphipoda	22.22	25	0
Arachnida	0	0	0
Tricoptera	0	8.33	10
Diptera unid.	11.11	8.33	0
adult mosquito	0	0	0
larvae	0	8.33	10
pupae	0	0	0
Chironomidae	0	16.67	0
Hymenoptera	0	8.33	10
Coleoptera	0	8.33	30
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	0	10
unidentifiable insect sp.	11.11	16.67	50
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	0	0	0
salmon eggs	0	10	0
unidentifiable content	0	33.33	0

Table 16. Frequency of occurrence (percentage) of food items in Arctic grayling diet by month of capture from the Ugashik lakes in 2003-2004.

	June (n = 1)	July (n = 23)	August (n = 5)
Gastropoda	0	0	40
Sphaeriidae (fingernail clam)	0	0	0
Isopoda	0	47.83	60
Amphipoda	0	8.7	20
Arachnida	0	0	20
Tricoptera	0	8.7	0
Diptera unid.	0	39.13	20
adult mosquito	0	4.35	20
larvae	0	4.35	0
pupae	0	4.35	0
Chironomidae	0	17.39	20
Hymenoptera	0	13.04	60
Coleoptera	0	4.35	40
Plecoptera	0	0	20
P. larvae	0	0	20
Hemiptera	0	0	60
unidentifiable insect sp.	0	21.74	40
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	0	0	0
salmon eggs	0	0	0
unidentifiable content	100	4.35	0

Table 17. Frequency of occurrence (percentage) of food items in Arctic grayling stomachs by capture depth (m) from the Ugashik lakes in 2003-2004. .

	0 - 5 (n = 27)	6 - 10 (n = 2)
Gastropoda	3.7	50
Sphaeriidae (fingernail clam)	0	0
Isopoda	44.44	100
Amphipoda	11.11	0
Arachnida	3.7	0
Tricoptera	7.41	0
Diptera unid.	37.04	0
adult mosquito	7.41	0
larvae	3.7	0
pupae	3.7	0
Chironomidae	14.81	50
Hymenoptera	22.22	0
Coleoptera	7.41	50
Plecoptera	3.7	0
P. larvae	3.7	0
Hemiptera	11.11	0
unidentifiable insect sp.	18.52	100
Sculpin sp.	0	0
Ninespine stickleback	0	0
Stickleback sp.	0	0
unidentifiable fish sp.	0	0
salmon eggs	0	0
unidentifiable content	7.41	0

Table 18. Frequency of occurrence (percentage) of diet items, analyzed by substrate type, in Arctic grayling stomachs sampled, in the Ugashik lakes in 2003-2004.

	boulder (n = 11)	cobble (n =9)	gravel (n = 5)	sand (n = 3)
Gastropoda	9.09	0	0	33.33
Sphaeriidae (fingernail clam)	0	0	0	0
Isopoda	72.73	44.44	20	33.33
Amphipoda	27.27	0	0	0
Arachnida	9.09	0	0	0
Tricoptera	0	0	40	0
Diptera unid.	45.45	22.22	20	66.67
adult mosquito	18.18	0	0	0
larvae	9.09	0	0	0
pupae	9.09	0	0	0
Chironomidae	0	0	60	33.33
Hymenoptera	36.36	22.22	0	0
Coleoptera	18.18	0	0	33.33
Plecoptera	9.09	0	0	0
P. larvae	9.09	0	0	0
Hemiptera	9.09	22.22	0	0
unidentifiable insect sp.	36.36	11.11	20	33.33
Sculpin sp.	0	0	0	0
Ninespine stickleback	0	0	0	0
Stickleback sp.	0	0	0	0
unidentifiable fish sp.	0	0	0	0
salmon eggs	0	0	0	0
unidentifiable content	9.09	11.11	0	0

Table 19. Frequency of occurrence (percentage) of food items in Arctic grayling stomach samples, analyzed by fish length group (Table 2) in the Ugashik lakes in 2003-2004.

	Small (n = 9)	Medium (n = 10)	Large (n = 9)
Gastropoda	11.11	0	11.11
Sphaeriidae (fingernail clam)	0	0	0
Isopoda	66.67	60	22.22
Amphipoda	0	10	22.22
Arachnida	0	0	11.11
Tricoptera	0	0	22.22
Diptera unid.	22.22	50	33.33
adult mosquito	0	10	11.11
larvae	0	10	0
pupae	0	10	0
Chironomidae	11.11	0	33.33
Hymenoptera	33.33	10	22.22
Coleoptera	11.11	10	11.11
Plecoptera	0	0	11.11
P. larvae	0	0	11.11
Hemiptera	22.22	0	11.11
unidentifiable insect sp.	44.44	20	11.11
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	0	0	0
salmon eggs	0	0	0
unidentifiable content	0	10	11.11

Round whitefish diet. – Gastropods (70.30%) were the most frequently found food in round whitefish stomachs (Table 3). Isopods, Tricoptera, and chironomids were also frequently found in the stomachs sampled. Slightly less than 7% of the stomachs were empty. Gastropods were found in round whitefish stomachs during all months (Table 20). Isopods were only present in their diet during July and August. Amphipods were only found in their diet in August. Round whitefish in the 6 – 10 m depth strata had isopods in their stomachs more often than the fish found in more shallow water (Table 21). Dipterans, including chironomids, were only found in the diets of the fish closest to shore. Round whitefish diet varied with substrate particle size. Clams were only in the stomachs sampled from boulder and gravel (Table 22). Isopods were found in the fish stomachs sampled from gravel. Amphipods were found in fish caught near cobble. There was little variation in diet when size groups of round whitefish were analyzed (Table 23). Gastropods were eaten by all sizes of round whitefish. Stomachs sampled from medium and small fish had a higher frequency of Tricoptera in their stomachs than large fish. The frequency of isopods in round whitefish stomachs diminished with decreasing size of fish.

Pygmy whitefish diet. – Fingernail clams (Sphaeriidae) were the most frequent food in stomachs of pygmy whitefish (47%) (Table 3) in both July and August (Table 24). Amphipods were only present in stomachs analyzed from August. Clams were most frequently found in the pygmy whitefish stomachs in 50 – 75 m depth (Table 25). Amphipods were exclusively in the diet of fish caught in water deeper than 50 m. All pygmy whitefish were close in length; therefore it was not feasible to compare food habits by size groups.

Table 20. Frequency of occurrence (percentage) of food items in round whitefish diet by month of capture from the Ugashik lakes in 2003-2004.

	June (n = 5)	July (n = 61)	August (n = 35)
Gastropoda	60	68.85	74.29
Sphaeriidae (fingernail clam)	0	9.84	0
Isopoda	0	16.39	5.71
Amphipoda	0	0	5.71
Arachnida	0	0	0
Tricoptera	20	8.2	17.14
Diptera unid.	0	0	0
adult mosquito	0	1.64	0
larvae	0	4.92	5.71
pupae	20	4.92	0
Chironomidae	20	18.03	2.86
Hymenoptera	0	0	0
Coleoptera	20	0	0
Plecoptera	0	0	0
P. larvae	0	1.64	0
Hemiptera	0	0	0
unidentifiable insect sp.	0	2.56	0
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
Unidentifiable fish sp.	0	0	0
salmon eggs	0	0	0
unidentifiable content	0	0	0

Table 21. Frequency of occurrence (percentage) of food items in round whitefish stomachs by capture depth (m) from the Ugashik lakes in 2003-2004.

	0 - 5 (n = 64)	6 - 10 (n = 27)	11 - 15 (n = 4)	16 - 20 (n = 6)
Gastropoda	65.63	81.48	100	50
Sphaeriidae (fingernail clam)	7.81	3.7	0	0
Isopoda	4.69	18.52	50	33.33
Amphipoda	3.13	0	0	0
Arachnida	0	0	0	0
Tricoptera	12.5	7.41	0	33.33
Diptera unid.	0	0	0	0
adult mosquito	1.56	0	0	0
larvae	7.81	0	0	0
pupae	6.25	0	0	0
Chironomidae	15.63	3.7	0	33.33
Hymenoptera	0	0	0	0
Coleoptera	1.56	0	0	0
Plecoptera	0	0	0	0
P. larvae	1.56	0	0	0
Hemiptera	0	0	0	0
unidentifiable insect sp.	2.78	0	0	0
Sculpin sp.	0	0	0	0
Ninespine stickleback	0	0	0	0
Stickleback sp.	0	0	0	0
unidentifiable fish sp.	0	0	0	0
salmon eggs	0	0	0	0
unidentifiable content	0	0	0	0

* no round whitefish were found deeper than 20 m.

Table 22. Frequency of occurrence (percentage) of diet items, analyzed by substrate type, in round whitefish stomachs sampled, in the Ugashik lakes in 2003-2004.

	boulder (n = 28)	cobble (n =23)	gravel (n = 18)	sand (n = 11)	silt (n = 2)
Gastropoda	75	60.87	88.89	63.64	100
Sphaeriidae (fingernail clam)	17.86	0	5.56	0	0
Isopoda	0	0	38.89	0	0
Amphipoda	0	8.7	0	0	0
Arachnida	0	0	0	0	0
Tricoptera	7.14	17.39	16.67	9.09	0
Diptera unid.	0	0	0	0	0
adult mosquito	0	0	0	9.09	0
larvae	3.57	0	5.56	18.18	0
pupae	0	13.04	0	0	0
Chironomidae	17.86	13.04	5.56	18.18	0
Hymenoptera	0	0	0	0	0
Coleoptera	3.57	0	0	0	0
Plecoptera	0	0	0	0	0
P. larvae	0	0	0	0	0
Hemiptera	0	0	0	0	0
unidentifiable insect sp.	0	4.35	0	0	50
Sculpin sp.	0	0	0	0	0
Ninespine stickleback	0	0	0	0	0
Stickleback sp.	0	0	0	0	0
unidentifiable fish sp.	0	0	0	0	0
salmon eggs	0	0	0	0	0
unidentifiable content	4	0	0	0	0

Table 23. Frequency of occurrence (percentage) of food items in round whitefish stomach samples, analyzed by fish length group (Table 2) in the Ugashik lakes in 2003-2004.

	Small (n = 32)	Medium (n = 31)	Large (n = 32)
Gastropoda	81.25	70.97	62.5
Sphaeriidae (fingernail clam)	3.13	12.9	3.13
Isopoda	25	9.68	3.13
Amphipoda	0	3.23	3.13
Arachnida	0	0	0
Tricoptera	3.13	19.35	15.63
Diptera unid.	0	0	0
adult mosquito	0	0	3.13
larvae	3.13	6.45	3.13
pupae	0	9.68	3.13
Chironomidae	12.5	12.9	15.63
Hymenoptera	0	0	0
Coleoptera	0	0	3.13
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	.	3.23	0
unidentifiable insect sp.	3.13	0	3.13
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	0	0	0
salmon eggs	0	0	0
unidentifiable content	0	0	4.17

Table 24. Frequency of occurrence (percentage) of food items in pygmy whitefish diet by month of capture from the Ugashik lakes in 2003-2004.

	June (n = 10)	July (n = 14)	August (n = 36)
Gastropoda	0	0	0
Sphaeriidae (fingernail clam)	0	85.71	44.44
Isopoda	0	0	0
Amphipoda	0	0	22.22
Arachnida	0	0	0
Tricoptera	0	0	0
Diptera unid.	0	0	2.78
adult mosquito	0	0	0
larvae	0	7.14	0
pupae	0	0	0
Chironomidae	0	0	0
Hymenoptera	0	0	0
Coleoptera	0	0	0
Plecoptera	0	0	0
P. larvae	0	0	0
Hemiptera	0	0	0
unidentifiable insect sp.	80	14.29	22.22
Sculpin sp.	0	0	0
Ninespine stickleback	0	0	0
Stickleback sp.	0	0	0
unidentifiable fish sp.	0	0	0
unidentifialbe content	0	0	2.78

Table 25. Frequency of occurrence (percentage) of food items in pygmy whitefish stomachs by capture depth (m) from the Ugashik lakes in 2003-2004.

	0 - 25 (n = 0)	26 - 50 (n = 15)	51 - 75 (n = 42)	> 75 (n = 3)
Gastropoda	0	0	0	0
Sphaeriidae (fingernail clam)	0	33.33	52.38	33.33
Isopoda	0	0	0	0
Amphipoda	0	0	14.29	66.67
Arachnida	0	0	0	0
Tricoptera	0	0	0	0
Diptera unid.	0	6.67	0	0
adult mosquito	0	0	0	0
larvae	0	0	2.38	0
pupae	0	0	0	0
Chironomidae	0	0	0	0
Hymenoptera	0	0	0	0
Coleoptera	0	0	0	0
Plecoptera	0	0	0	0
P. larvae	0	0	0	0
Hemiptera	0	0	0	0
unidentifiable insect sp.	0	46.67	26.19	0
Sculpin sp.	0	0	0	0
Ninespine stickleback	0	0	0	0
Stickleback sp.	0	0	0	0
unidentifiable fish sp.	0	0	0	0
unidentifialbe content	0	0	2.38	0

Discussion

The Ugashik lakes are not thermally stratified in summer and some species did not behave how they are expected in lakes that do have summer stratification (e.g. the char species stayed in shallow waters all summer). In a thermally stratified lake in summer months, fish assemblages would become spatially segregated. The species requiring colder, more oxygen rich water would move to deeper, colder areas of the lake due to warming water temperatures, while the smaller species could continue to occupy shallow, littoral areas (Jackson et al. 2001). For cold water species like salmonids, higher water temperatures produce more physiological stress. An increase in temperature increases metabolic demand of fish, decreases the oxygen saturation levels in water, and thus decreases the oxygen available to the fish which could become lethal (Jackson et al. 2001, USEPA 2001). Most cold water fish would be restricted to deeper water, and make forays above the hypolimnion (assuming there was adequate oxygen saturation) to feed (Sellers et al. 1998).

Time

The only statistically significant differences in CPUE from temporal effects were for the three char species. Each species was examined for intraspecific temporal differences. Gill net CPUE for Dolly Varden was higher in July than in June or August. We suspect they either follow the salmon as they enter the Ugashik lakes in late June in preparation for spawning, or they may be residents of the streams draining into the Ugashik lakes until the salmon run begins.

The Dolly Varden in the Ugashik lakes are assumed to be the northern form of the species. Dolly Varden studied in Becharof Lake, also on the Alaska Peninsula, appeared to be the classic northern form (Scanlon 2000). This form of Dolly Varden occurs from the northern drainages on the Alaska Peninsula northward to the Yukon border with Canada (Behnke 1980). It is noted as being amphidromous or a resident of lakes or rivers (Behnke 1980, Stuby 1995).

Lake trout and Arctic char were both more abundant in the catch from July than in August. Adams (1990) found a temporal difference in CPUE of lake trout in Walker Lake. More lake trout were caught in early season than late-season sampling. He interpreted the lake trout as being more active soon after ice-out. This could be due to a higher number of lake trout feeding soon after ice-out and during early summer (Martin 1952). In stratified lake systems lake trout begin a migration to deeper water in June, as surface waters warm, (Martin 1970), and in isothermal lakes, lake trout are known to be distributed throughout the water column (Martin and Olver 1980). In the Ugashik lakes, lake trout were frequently caught in the more shallow waters (0-25 m) of the lake during June, July, and August (Figure 4). More lake trout were caught in deeper water in August than in June or July.

The Arctic char is a flexible species that adapts well to a variety of lacustrine, marine, and riverine habitats (Johnson 1980). In two Norwegian subarctic lakes, which are stratified during the summer, no Arctic char were caught in the littoral or pelagic areas in June, while the CPUE in the profundal zone increased (Klemetsen 2003b). The authors witnessed a habitat shift to deeper water in the summer months. Arctic char in the Ugashik lakes were most frequently captured in the 0 – 25 m area during June, July, and August.

Depth

There was overlap in salmonid depth distribution in the Ugashik lakes, which was most likely linked to the uniform temperatures found in the lakes. The fish that traditionally seek cooler temperatures in the summer months in stratified lakes were captured in the Ugashik lakes shoreline habitat all summer (Figure 4). Arctic char in subarctic lakes use pelagic, profundal, and littoral zones in the open water season (Klemetsen et al. 2003b), but most of the Arctic char in the Ugashik lakes were found in the littoral areas of the lakes. Lake trout were ubiquitous at all depths sampled. They are able to live at great depths, low light and low temperatures (Johnson 1976). Depth was not as important to them as it was for other species. Arctic grayling, Dolly Varden, and round whitefish were consistently caught in shallow water; they were never found in deeper portions of the lakes.

Pygmy whitefish are found in a wide variety of habitats, and are generally found in areas of northern North America that have experienced little human contact. They are typically a demersal species found >6 m deep in cold lakes (Mackay 2000). They were also found in the deeper waters of the Ugashik lakes. In the summer adults may avoid the littoral zone (McPhail and Zemlak 2001). Pygmy whitefish may not have been found in the near shore area of the Ugashik lakes because they were not spawning. Pygmy whitefish generally spawn between November and January in shallow areas of lakes and in streams (Morrow 1980). In the Naknek Lake system, which does not have consistent thermal stratification in the summer (Hartman and Burgner 1972), on the Alaska Peninsula, they were found in benthic habitats at all depths from shallow littoral areas of less than 1 m to 168 m deep (Heard and Hartman 1965). McCart (1965) found that when other whitefish species are present in lakes the pygmy whitefish tend to live in deeper water. Interspecific interactions may influence the depth distribution of pygmy whitefish (McPhail and Zemlak 2001).

McCart (1963) and Lindsey (1981) found two different sympatric forms of pygmy whitefish in Naknek and Aleknagik lakes in the Bristol Bay region of southwest Alaska. They found a high and low gill raker form. The high-count form was found in deep water and grew slower. The low-count form occurred in both deep and shallow water. Chignik Lake, south of the Ugashik lakes on the Alaska Peninsula, contains three sympatric forms of pygmy whitefish. One is a plankton feeder, and the other two are benthic feeders: one is found in shallow water and the other in deep water (Lindsey 1981).

It is quite possible that the Ugashik lakes have at least two forms of pygmy whitefish. During a collection for this study, two morphologically distinct forms of pygmy whitefish were hauled from 55-m deep in the same net (unpublished data).

Length and age

In northern fish populations there is an overlapping range of ages for fish in a given length group (Johnson 1972, 1976). This was also true in the Ugashik lakes. The oldest fish was not always the longest fish. The oldest lake trout (28 years) was 32 mm smaller than the longest fish that was aged, 526 mm, which was estimated to be 19 years of age. Round whitefish had similar variation in age and length.

The Ugashik lakes hold the record for the largest Arctic grayling caught by angling in Alaska (USFWS 1985). Sizes of Arctic grayling in the Ugashik lakes were more consistent with western Arctic grayling sizes than with interior Arctic grayling. Neyme (2005) found the most mature Arctic grayling in western Alaska to be greater than 300 mm. The mean length of captured Ugashik lake Arctic grayling was 390 mm.

Age-6 Arctic grayling dominated the sample aged in this study, and based on historical data (Meyer 1990) this coincides with ages from the past four decades. The oldest fish recorded from the current aged sample was 13, and due to a small sample size further sampling is likely to produce older fish. The oldest western Alaskan Arctic grayling found was 29 years old (Neyme 2005).

Pygmy whitefish in northern populations mature at a younger age and smaller size than southern populations (Mackay 2000). Maximum length reported for pygmy whitefish is 260-mm fork length in British Columbia (McCart 1963). In most waters they only reach 100 to 140 mm in total length (Mackay 2000), which is more consistent with the Ugashik lakes fish. Pygmy whitefish had a small range of lengths, 80-130 mm, yet this narrow range had fish aged 0 to 7. They appear to grow rapidly in their first years of life (McPhail and Zemlak 2001).

Round whitefish in the Ugashik lakes were similar in length to round whitefish studied in Lake Michigan (Armstrong et al. 1977). According to Hale (1981) round whitefish in Alaskan waters are usually less than 400-mm fork length, although larger specimens have been caught. Hale (1981) reported that one and two year old round whitefish live in similar areas as adults but in shallower water. Most small (≤ 250 mm) round whitefish in the Ugashik Lakes were located close to the shoreline. Age comparisons cannot be made between the Lake Michigan fish study and the Ugashik lakes fish because different methods were used to estimate ages. Scales were used in the Lake Michigan study and otoliths were used to age the Ugashik fish.

The location within lakes where lake trout are generally found is often related to the size of the fish (Adams 1990, Johnson 1972). Johnson (1972) found that in lakes in northern Canada large lake trout (> 400 mm) were near the shorelines and smaller lake trout (< 400 mm) were captured in deeper waters offshore. Adams (1990) had similar findings in Walker Lake in the Brooks Range, Alaska. Lake trout in Alaska have slow growth rates and are easily overharvested. Their growth is related to latitude; the farther north they live, the later lake trout mature (Burr 1987). The oldest recorded lake trout was more than 50 years old (Burr 1987).

Arctic char were not homogenously distributed within lakes in Greenland (Sparholt 1985). Small and large fish were found in the littoral zone, and intermediate sized fish were in the pelagic zone. This was not the case in the Ugashik lakes, 90% of the Arctic char were found in less than 10 m of water.

Substrate

It appears that the substrate type usage of the salmonids in the Ugashik lakes depended upon the size of the fish. Food items found on or near the different substrate particle sizes is a more coherent reason that the fish were captured over a particular substrate type. Smaller Arctic char, Dolly Varden, and round whitefish were caught over boulder and cobble more often than larger fish; this is most likely related to predator avoidance. Young fish use substrate for shelter, Hale (1981) reported that round whitefish fry used boulder for shelter. Small and large lake trout in the Ugashik lakes, from 0 – 20 m deep, used gravel more than any of the other substrates particle sizes.

Interspecific interactions may influence the depth distribution of pygmy whitefish (McPhail and Zemlak 2001). One of the forms of Ugashik lakes pygmy whitefish is probably the benthic deep-water form, feeding on zoobenthos (clams, in these lakes), they may stay in deeper water because it is not preferred or used by the round whitefish. McCart (1965) found that when other whitefish species are present in lakes the pygmy whitefish tend to live in deeper water. Since fingernail clams are found in soft sediment (Merrick et al. 1992), the pygmy whitefish may have keyed in on that seemingly abundant food source which is not utilized by many of the other species in the Ugashik lakes. Pygmy whitefish may be found over silt and at great depths because of food availability and the round whitefish in the Ugashik system.

Gastropods were the predominant food of round whitefish in the Ugashik lakes. Depending on the snail species, some occupy rocky substrate and some are found in soft sediment (Merrick et al. 1992). Hale (1981) found reports of North Slope round whitefish over mud, cobble, and boulders. They are also found over gravel in streams. Round whitefish in the Ugashik lakes were caught over boulder, cobble, and gravel.

In August, lake trout were mostly caught over silt. Silt was the only substrate observed in collections deeper than 20 m; this indicated that most of the lake trout caught in August were in the deeper water. In Great Bear Lake of northern Canada, small lake trout (<100mm) used a variety of habitats: rocky shoreline, inflowing streams, and deeper waters. They stayed in the periphery of the areas used by adult fish (Johnson 1975). According to Johnson (1972) smaller lake trout will typically be pushed into less desirable habitats (near shore

– more vulnerable to predation, or deeper water where there usually is more limited food supply). Most of the smaller lake trout in the Ugashik lakes were in the deeper water. The small lake trout in 0 – 20 m were mostly found over gravel.

Food habits

An unusual feature of the Ugashik lakes is the absence of cladoceran zooplankton (water fleas) (Mathisen et al 1998). Cladocerans are an important zooplankton usually well represented in most other clear water lakes (Edmundson and Todd 2000). Cladocerans are typically eaten by the traditionally pelagic form of pygmy whitefish (Heard and Hartman 1965), sometimes Arctic char (Johnson 1980), and possibly Arctic grayling, which are often planktivorous (Merrick et al. 1992).

Lake trout appeared to exploit almost any food that was in abundance and their diet may change with age, size, and season. Lake trout are omnivorous but are commonly classified as piscivores in large lakes (Martin and Olver 1980, Merrick et al. 1992). They have a diverse diet, which may include fish, crustaceans, insects, molluscs, plant material, mammals, annelids, and plankton such as cladocerans (Martin and Olver 1980). They are known to eat whitefish, sculpin, and ninespine stickleback. When amphipods were found in stomachs they tended to be from smaller lake trout or eaten seasonally (Martin and Olver 1980). In the Ugashik lakes, both small and large lake trout ate amphipods, with no apparent temporal difference. Lake trout ate more of almost every type of food in July. In other lake systems, lake trout began a migration to deeper water because of lake stratification and the warming of shallow water in June, and the presence of insects in their diets decreased (Martin 1970, Martin and Olver 1980). Their consumption of insects was largely confined to May and June for fish in Lake Opeongo, Ontario (Martin 1970). Lake trout in the Ugashik lakes ate some types of insects less frequently in July (Table 4), but in August, when most were found over silt, many had dipteran larvae and pupae in their stomachs which coincides with the Toolik Lake study (Merrick et al. 1992). In Toolik Lake, Alaska, large lake trout captured over soft sediment had more fish, clams, and chironomids in their stomachs than when captured over rocky shoals.

Overall, only 4.3% of lake trout stomachs sampled in the Ugashik lakes had clams in their diet. Lake trout ate a few clams in cobble, gravel, sand, but most were in silt which may be due to lake trout eating pygmy whitefish (we could not document this because many fish in stomachs were unidentifiable) which had high affinity for eating clams in the silt area; thus the clams in the lake trout stomachs could be residual food from the stomachs of the prey fish.

In general, smaller younger lake trout tend to feed on invertebrates and larger lake trout are more piscivorous (Martin and Olver 1980). Sculpins were the most frequent fish in the Ugashik lakes lake trout diet. Sculpin often form a substantial forage base for lake trout. They are typical occupants of benthic habitats in oligotrophic lakes (Ryder 1972). Despite a perceived abundance of sockeye salmon juveniles in the Ugashik lakes, there was little evidence of lake trout (or the other two char species) feeding on them. The Ugashik lakes are salmon nursery lakes. However, very few sockeye juveniles were caught in the gill nets during this study. This could be due to the timing of the study, or by chance, gill net collections may not have been in prime rearing habitat for the salmon juveniles. It is possible that the char species were feeding on the salmon juveniles during the out migration in early spring, and switching to other food sources during the summer months. The char stomachs sampled did contain some unidentifiable fish that could have been salmon juveniles, but they could also have been juveniles of other salmonids. Exact species could not be confirmed without specific laboratory diagnostic testing of prey fish bones (Hansel et al. 1988).

Few small lake trout had isopods in their stomachs (Table 7). One could assume this was because of the size of their mouths versus the size of the isopods, but a wide range in size of isopods was observed in the Ugashik lakes. Also, round whitefish and Arctic grayling with their small mouths, consumed many isopods. It is possible that larger isopods did not live in deeper water where more small lake trout were found.

Abundance of isopods increases with depth (Narver 1968). Isopods are the dominant zoobenthos in Becharof Lake (Mathisen and Sands 1999). Isopods were found in shallow depths in Chignik Lake, this might also be true for the Ugashik lakes because they were found in Arctic grayling and round whitefish stomachs. Of course, those fish species could move at night and feed on isopods at greater depths, but Arctic grayling were never caught in water greater than 10 m deep during daylight. The isopods were very large and prevalent, and most likely a good food source for the species found in the lakes.

Besides lake trout, a small percentage of fish was found in the stomachs of the other predatory fish species – Arctic char and Dolly Varden. It is possible that Arctic char and Dolly Varden did not eat as many fish as lake trout because of habitat segregation or food source segregation. Arctic char were mainly found in near shore waters, while lake trout were caught at all depths. There is evidence that, in large lakes, Arctic char and lake trout compete for dominance, with lake trout usually excluding the Arctic char or relegating them to a subordinate position (Johnson 1980).

Char in the presence of brown trout change their diet to utilize prey items (e.g. cladocerans and copepods) that are underused by the trout (Johnson 1980). Isopods did not seem to be a major part of Arctic char diet in the Ugashik lakes, although it was assumed they would be due to thier frequency in stomachs other species (i.e. lake trout, Arctic grayling, round whitefish). Arctic char selected more amphipods than other fish species.

Arctic char found in the littoral zones of two subarctic Norwegian lakes ate amphipods, molluscs, and insects (Klemetsen et al. 2003b). There, large fish ate more amphipods and fewer insects, and small Arctic char did not eat fish. In

Greenland lakes (Sparholt 1985) larger Arctic char ate zooplankton, chironomid pupae and terrestrial insects while the small Arctic char fed on chironomid larvae and crustaceans. All Arctic char ate similar foods in the early summer, but there was increased segregation of food niches as the summer progressed (Sparholt 1985). In the Ugashik lakes, large Arctic char had a higher frequency of molluscs and a lower frequency of amphipods in their stomachs than medium and small fish. Terrestrial insects and fish occurred more frequently in the stomachs sampled from small fish. Arctic char had a higher frequency of occurrence of terrestrial insects in their stomachs in July, and more amphipods in August (Table 8).

Arctic grayling are opportunistic feeders. Their diet contains both aquatic and terrestrial invertebrates (Meyer 1990). According to Villegas (1993), Arctic grayling at the Ugashik Narrows potentially feed on stoneflies (Plecoptera), caddisflies (Trichoptera), aquatic and terrestrial beetles (Coleoptera), and larval and adult forms of aquatic Diptera, Isopoda, salmonid eggs, and sockeye salmon smolt. In this study, isopods were a major food in Arctic grayling diets. Grayling did not eat as many snails and bottom dwelling food items as the other fish species. Arctic grayling took advantage of inhabiting the shallow waters by eating many types of terrestrial insects.

Round whitefish are opportunistic bottom feeders; they eat small benthic invertebrates in shallow, near shore areas of lakes (Hale 1981). Snails and midge larvae (mainly chironomids) were eaten most frequently by Lake Michigan round whitefish (Armstrong et al 1977). Isopods and amphipods comprised only a small percentage of the overall diet of round whitefish sampled by Armsrong et al. In the Ugashik lakes, round whitefish frequently had isopods in their stomachs. According to Narver (1968) isopods are located on bottom of lakes at night. This infers that round whitefish feed on them at night, if the isopods have the same behavior in Ugashik lakes. Round whitefish may feed on isopods some of the time because their exoskeletons are more easily digested than the hard, indigestible shells of the gastropods. The hard snail shells would have a slower evacuation rate than softer food sources. In the Ugashik lakes, round whitefish frequently consumed gastropods during all summer months. Isopods and amphipods had higher frequency of occurrence in July and August, respectively.

Pygmy whitefish have a flexible diet. In British Columbian lakes they ate plankton and benthic invertebrates. The most important food items were cladocerans, and midge larvae and pupae (McCart 1965). In the Naknek lake system, pygmy whitefish ate crustacean zooplankton (cladocerans and copepods) and insects (mainly chironomids and plecopteran nymphs) (Heard and Hartman 1965). Lake Superior pygmy whitefish mainly consumed amphipods (Eschmeyer and Bailey 1955). The key food of the Ugashik lakes pygmy whitefish was clams.

Pygmy whitefish in British Columbia ate organisms taken from benthic foraging (include littoral region) and limnetic (water column) habitats of the lake (McPhail and Zemlak 2001). Limnetic taxa were most abundant and benthic invertebrate groups were rare in the pygmy whitefish stomachs from British Columbia, suggesting they forage periodically in littoral areas but mostly target organisms swimming in the water column. The absence of organisms associated with the lake surface in the stomach samples suggests pygmy whitefish live primarily at depth (McPhail and Zemlak 2001). Pygmy whitefish must have remarkable ability to forage successfully under low light conditions; they are commonly found in water deeper than seven meters (McPhail and Lindsey 1970). Two or more forms of pygmy whitefish have been identified in western North America and are sympatric in some lakes in Alaska (McCart 1970). The diets of the two forms differ: the low gill raker form feeds on benthic invertebrates and the high gill raker form feeds on zooplankton.

Ultimately, the salmonids of the Ugashik lakes are influenced by the atypical thermal composition of the lakes. The species did not move into different areas due to changing water temperatures in the summer months. Most of these species are opportunistic feeders, and consume food such as isopods and amphipods. Some traditionally eat cladocerans but because they are mysteriously absent from this lake system the fish eat other food items. Pygmy whitefish are traditionally found in deeper waters, but eat different foods – none in literature were found to eat clams but that was the main food for them in the Ugashik lakes. Arctic char and Dolly Varden did not eat as many fish as expected. This could be because they were only sampled in the summer months, or small fish, like juvenile salmon, could have been located in different areas of the lakes.

Conclusion

This study provided the first examination of the ecological factors that influence the summer distribution of salmonids in the Ugashik lakes, and it also documented some of the species composition of the lakes for the first time. The absence of consistent summer thermal stratification provided the opportunity to divulge any anomalies in fish distribution that were unique to fish that live in this environment. Ugashik lakes fish behaved differently in summer months than fish in stratified lake systems. Lake trout and Arctic char usually move to deeper, colder waters in the summer months (Klemetsen et al. 2003b and Martin 1970), this in not necessarily the case in the Ugashik lakes. Both species were frequently captured in shallow water all summer. Fewer Dolly Varden were captured in June, and most were found in July in shallow water. Presumably, they were following the salmon as they spawn in the lakes. Arctic grayling, Dolly Varden, and round whitefish were never caught in deep water. Pygmy whitefish utilized depth and food that was unexploited by other fish species. Lake trout and round whitefish were most abundant in the collections and had the oldest individuals.

Isopods were a major food source for these fish (except pygmy whitefish) in the Ugashik lakes. Managers should study isopods to find out more about their life history, which might help determine fish behavior. A study of isopod behavior may help determine why small lake trout did not eat many, and why fish with small mouths (Arctic grayling and round whitefish) had high frequency of them in their stomachs. The answer could simply be that small isopods are found in shallow water while the larger isopods are in deeper water.

The Ugashik lakes fish behavior was not always the same as what was found in the literature. This illustrates the uniqueness of different lake systems, and emphasizes the need to study individual systems. Arctic char in other subarctic lakes use pelagic, profundal, and littoral zones in summer (Klemetsen et al. 2003b), but in the Ugashik lakes were mostly caught in the littoral areas. Lake trout were present in shallow waters all summer in the Ugashik lakes, but Martin (1970) stated that in other lake systems lake trout migrated to deeper water in June. Clams were the most prevalent food item observed in stomachs of pygmy whitefish in the Ugashik lakes but were never documented as their food in the literature. Similarly, isopods were abundant in the diet of Ugashik lakes round whitefish and Arctic grayling but not documented in the available literature.

According to Johnson (1976), in Arctic lakes with an outlet to the sea, species such as Arctic char, lake trout, lake whitefish, and two species of cisco all exist together. The macroinvertebrate marine-glacial relict species of isopods *Saduria entomon* and amphipods *Gammaracanthus loricatus* var. *aestuariourum* or the freshwater amphipod *Gammaraus lacustris* are also present. The Ugashik lakes, although technically not arctic lakes, closely follow Johnson’s prescription for lakes with access to the sea.

There is discontinuous distribution of some fish species on the Alaska Peninsula. Prior to this study, it was uncertain what whitefish species would be found in these lakes. It was expected that the Ugashik lakes salmonid community would be similar to that of Becharof Lake, six miles to the north, but least cisco and lake whitefish were not captured in the Ugashik lakes. Lake trout were frequently caught in the Ugashik lakes, but there is no confirmed record of them, only anecdotal evidence from anglers, in Becharof Lake. There have not been studies on this phenomenon on the Alaska Peninsula, but it may prove important to future management. A more complete understanding of ecological processes and fish behavior in the Ugashik lakes would be valuable. Gathering baseline information of ecological factors is important for the future monitoring and management of fish population trends and for tracking any change that may occur.

Recommendations

The Ugashik lakes represent a great laboratory for future study of these non-salmon species. Future projects could involve morphological studies of pygmy whitefish and Arctic char; are there more than one form of these species in the lakes? Interactions between pygmy whitefish and round whitefish: do round whitefish really induce pygmy whitefish to live in the deep water and consume food they otherwise would not eat? Do lake trout push Dolly Varden and Arctic char to use other food sources they would not ordinarily consume? Gill netting at night could help determine if round whitefish and Arctic grayling travel to deeper water at night to eat isopods or if isopods move to shallow water.

Some literature suggests a steady increase in fishing pressure in southwest Alaska (Jaenicke et al 1996). Managers should consider the effect that the constant water mixing has on the distribution of lake trout; namely, they do not make a mass migration to colder, deeper water in the warmer months. Larger lake trout are in shallow water. They may be closer to the surface and more vulnerable to anglers.

The close proximity of Ugashik lakes to a volcano (Upper Ugashik Lake is at the foot of Mt. Peulik) is another unstudied avenue that could prove to be very important to the future management of these lakes. Recently, in August 2005, Mount Chiginagak, a volcano just to the south of Lower Ugashik Lake, expunged an acidic slurry that changed the entire pH of Mother Goose Lake and seemingly pushed out the fish that previously resided there (J. Larson, USFWS, personal communication). By monitoring water quality, fish behavior, and distribution in the Ugashik lakes now, if an event like this ever occurred there, researchers could begin to document lake succession after a change in acidification.

If climate change drastically affects the water temperature in the Ugashik lakes it will be interesting to follow the behavior of the species that are typically found in the deeper water in other lake systems (*i.e*. If the lakes stratify, will lake trout and Arctic char start a summer migration to deeper water? How will a temperature change affect the food base? If water temperature increased, what would potential stratification do to the Ugashik lakes fish distribution?).

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