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Stock Assessment of Broad Whitefish, Humpback Whitefish and Least Cisco in Whitefish Lake, Yukon Delta National Wildlife Refuge, Alaska, 2001-2003

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Abstract

Whitefish *Coregoninae* spp. are an important subsistence fish harvested year-round in the Kuskokwim River drainage. Conservation concerns regarding reduced size and abundance of broad whitefish *Coregonus nasus* resulted in the 1992 creation of subsistence regulations for whitefish in Whitefish Lake. To understand the dynamics of whitefish utilizing Whitefish Lake, we used a flexible picket weir and deployed Floy tags to assess the abundance, age at length composition and migratory patterns of broad whitefish, humpback whitefish, *C. pidschian*, and least cisco *C. sardinella* between 2001 and 2003. Emigrations were highest in 2003 for broad whitefish with 254 leaving the lake. Humpback whitefish and least cisco emigrations were highest in 2002 with 31,985 and 26,195, respectively. Inter year tag returns indicated fidelity to the lake. Maximum ages were 20, 29, and 14 for broad and humpback whitefish and least cisco, respectively. Extensive migrations were indicated through the return of tagged whitefish harvested by subsistence fishers between the village of Tuluksak (rkm 192) and Medfra (rkm 863). Otolith chemical analysis indicated fish using Whitefish Lake are anadromous.

Introduction

Broad whitefish *Coregonus nasus* and humpback whitefish *C. pidschian* have long been considered the most important non-salmon subsistence species in the lower Kuskokwim River delta area (Baxter 1975). Because of what appeared to be an abundance of fish throughout their distribution in the 1960’s and 1970’s, Baxter investigated the possible development of commercial fisheries in the Yukon-Kuskokwim Delta region. During that time, gill net surveys of lakes on the Kuskokwim Delta and in tributaries to the Kuskokwim River indicated that broad whitefish were more abundant than humpback whitefish. One survey in 1974 of Whitefish Lake (near Kalskag) resulted in the capture of 28 broad whitefish and 9 humpback whitefish in an overnight gill net set (Baxter unpublished notes). Baxter (1973 and 1975) noted that broad whitefish have always been considered the most desirable of the whitefish spp. partly because they had fewer parasites and a superior flesh. Between 1967 and 1970, commercial sales in the local Bethel market consisted of approximately 18,000 whitefish or 24,594 kilograms (kg), most of which were broad whitefish. Baxter noted that humpback whitefish rarely entered the local market and that the majority of broad whitefish harvest was taken incidentally during the August coho salmon fishery.

Whitefish harvested for subsistence purposes, contribute substantially to the overall subsistence harvests in the Kuskokwim River drainage. Harvest of whitefish occurs throughout the year by gill nets used under the ice during the winter or in open water during the spring, summer, and fall, or by jigging (rod and reel, or stick) during the summer and winter. Some spearing occurs through the ice in the early winter in places like Ophir Creek, a tributary of Whitefish Lake. Whitefish have received little management attention in the Kuskokwim River over the past 30 years despite the heavy subsistence use. Fisheries enumeration projects and annual subsistence

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harvest surveys have primarily focused on salmon (Ward et al. 2003). As an example, catch calendars are mailed out annually to gather harvest information on subsistence caught salmon; but surveys focusing on non-salmon species only occur occasionally.

Brelsford (1987) surveyed the villages of Aniak, Crooked Creek, and Red Devil gathering seasonal harvest information for fish by harvest area and dates harvested, but information was not recorded by species or amount harvested. Harvest surveys were conducted in Kwethluk in 1990 (Coffing et al. 1991) and in Akiachak in 1998 (Coffing et al. 2001). Coffing's Akiachak results showed that blackfish (*Dallia pectoralis*) constituted 27% of the total non-salmon fish harvest, burbot (*Lota lota*) 17.8%, northern pike (*Esox lucius*) 15.2%, broad whitefish 12.8%, smelt (*Osmerus mordax*) 11.3%, humpback whitefish 11.1% and inconnu (*Stenodus leucichthys*) 1.0% (Coffing et al. 2001). Broad and humpback whitefish comprised 24% of the non-salmon harvest. A majority of Kwethluk residents harvested a greater amount of non-salmon fish compared to salmon. Non-salmon harvest totaled over 62,595 kg, or approximately 121 kg per household. During times of reduced salmon abundance (e.g., 1999-2002), non-salmon species likely play an even more important role in the subsistence way of life common throughout the drainage.

In the early 1970's, the State of Alaska's commercial fishing regulations (5 AAC 39.780) for the Kuskokwim drainage required "a permit to fish for whitefish, inconnu, char and allied (similar) species in fresh and salt water". The regulations prohibited commercial fishing for whitefish or northern pike in the Johnson River and Whitefish Lake. Baxter, as far back as 1973, mentioned that decreased numbers of whitefish in the Johnson River and Whitefish Lake were probably the result of over exploitation. Local subsistence users in Aniak and Kalskag have used Whitefish Lake as a primary area to target whitefish especially large broad whitefish. These subsistence users expressed concern over a decline in size and numbers of broad whitefish in Whitefish Lake, pointing to previous times when large numbers of whitefish were removed and possibly taken to market in Bethel. Based upon these concerns, time and gear regulations for whitefish were established in 1992 for subsistence fishing in Whitefish Lake.

Baxter (1975) also concluded that whitefish use tundra ponds and lakes to feed during the summer, and then migrate in the fall into the main Kuskokwim River to spawn, and then return to the lower Kuskokwim to over-winter; mature males leave the lakes first followed by mature females. Baxter did not locate spawning grounds, but tagged 5,010 whitefish of four species between 1966 and 1972.and noted that the two major species, broad and humpback whitefish appeared to mingle throughout the Kuskokwim River. One fish tagged in the Kialik River below Bethel (species unknown) was recovered at Nikolai (941 river kilometers upstream) indicating that fish travel extensively.

Little research has been conducted on whitefish biology in the Kuskokwim River since Baxter's lower river work and Ken Alt's upper river studies (1976). Whitefish have been observed passing up and down through salmon enumeration weirs on tributaries of the lower Kuskokwim River (i.e., Tuluksak and Kwethluk rivers) in late summer (Harper 1997, 1998; Harper and Watry 2001), and these rivers have very few if any tundra ponds associated with them above the weirs. Many whitefish (assumed mostly humpback) can be seen in September at the mouths of old side channels of the Aniak River (D. Cannon, Aniak, personal communication).

Broad whitefish populations are complex because they can be composed of several different life history types. Anadromous broad whitefish have a brackish or salt water phase and a freshwater phase, migrating between the two during their lives, while lacustrine populations spend their entire life in particular lakes, and riverine populations can spend their entire life in a particular river (Reist 1997). Anadromous forms migrate upstream in the fall to spawn in river sections or tributaries with shallow fast flowing waters and clean gravel (Chang-Kue and Jessop, 1997). The eggs develop under the ice and in the spring fry wash downstream with spring floods. Broad whitefish young from the Mackenzie River, feed and overwinter in the brackish coastal waters until they are sexually mature around 8 years of age (Bond and Erickson, 1985). These fish then migrate upstream and spawn. In Whitefish Lake and the Kuskokwim River, the presence of life history types, anadromous, lacustrine, or riverine is unknown. Rearing areas for broad whitefish are unknown but are suspected to be somewhere in the lower Kuskokwim River; likewise, very few spawning areas have been documented in the upper river (Alt 1972). Brown (2004, 2000) chemically analyzed otoliths and determined that some Selawik River whitefish and Yukon River inconnu are anadromous. This same life history characteristic is suspected of Kuskokwim River whitefish.

Study objectives included monitoring movements of whitefish into and out of Whitefish Lake, collecting biological data that included length at age and maturity of whitefish using the lake, life history type, determining if there was a conservation concern for broad whitefish and collecting subsistence harvest information from within the lake.

Study Area

The Kuskokwim River is the second largest drainage in Alaska (Figure 1). The glacially turbid main stem originates in the Kuskokwim Mountains and the Alaska Range, on the northwest side of Mt McKinley and courses for approximately 1,498 river kilometers (rkm). The river flows in a southwest direction and drains into the Bering Sea. Population centers are located at Bethel, Aniak, and McGrath, while an additional 19 small villages are scattered along its length.

Whitefish Lake is a shallow 8,064-hectare lake averaging <1.5 meters in depth and is located within the Yukon Delta National Wildlife Refuge. It is approximately 20 km southeast of Lower Kalskag and 30 km southwest of Aniak, and its location (N61^{o} 24’ W 160^{o} 01’) could be considered to be in the upper end of the Lower Kuskokwim River Drainage. The lake drains into the Kuskokwim River via a 15 kilometer (km) river channel. The Whitefish Lake drainage encompasses 44,340 hectares and includes several small inlet streams that drain into the lake at an elevation of about 19.5 meters. Pondweed (*Potemegetan spp.)* is the primary rooted aquatic vegetation that occurs throughout the lake, and is very dense around the lake’s perimeter. Frequent winds blowing across the lake stir up the bottom and cause turbidity. Flow contribution from Ophir Creek, the largest inlet stream, was only 2.63 m^3/sec. when measured on 6 September 2000.

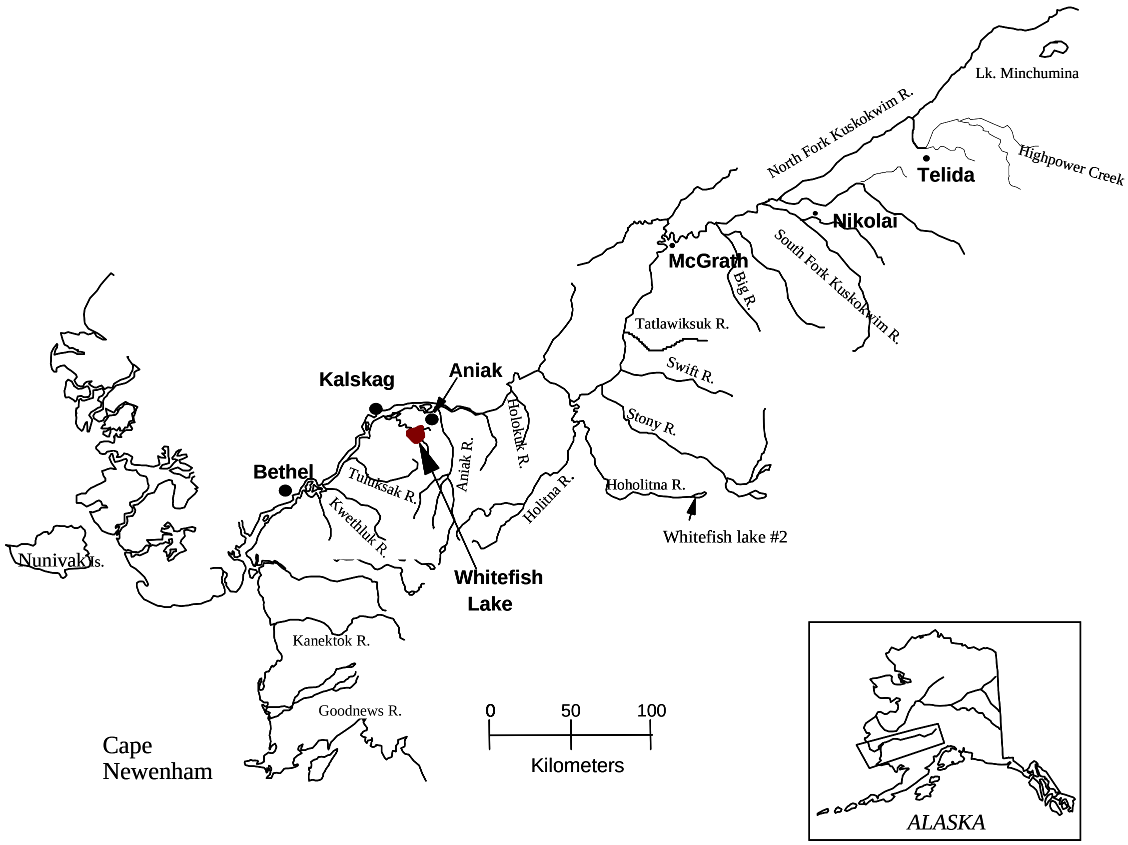

FIGURE 1.–Kuskokwim River drainage, Alaska

Methods

Weir Construction and Operations

A flexible picket weir was installed and operated at the outlet of Whitefish Lake (61° 24' 854", 160° 01' 354") during 2001, 2002, and 2003. The weir consisted of an upstream and downstream trap and a boat passage panel. Weir panels were similar to what Gates and Palmer (2004) used on McLees Lake, Unalaska Island with minor modifications to the picket spacing (2.5cm). Daily movements of fish were counted as they moved in either direction, or as they were netted out of the trap. Most fish were netted out of the upstream and downstream traps, examined for tags, tagged if untagged and released. In order to prevent crowding and minimize handling stress, the traps were closed during the day when water temperatures exceeded 15ºC.

Physio-Chemical

Water temperatures were recorded using both hand held thermometers and Optic® Hobo thermaloggers. Water temperatures were recorded 150 meters downstream from the outlet of the lake in a well-mixed area. Secchi disc transparency, a measure of light penetration, was collected each day between 8 and 10 am daily.

Abundance Estimation

It was assumed that the operational period would include the majority of the fish migrating in and out of the lake, so weir passage counts were used as estimates of the total whitefish populations in Whitefish Lake. For broad whitefish only, a Petersen estimator (Ricker 1975) was used to estimate total broad whitefish numbers in the lake for 2003. All broad whitefish immigrating into the lake in the spring of 2003 were marked using individually numbered T-bar Floy® tags. All whitefish emigrating the lake were examined for tags and if not tagged were tagged with numbered floy tags.

Biological Data

All fish captured were identified to species; a daily subsample ranging from 100% to every 10th fish during heavy passage was measured for fork length (length) to the nearest 10 mm and weighed wet to the nearest 25 g using a spring chatillion scale and a net basket. Weight-length relationships were described by the equation:

$$\text{Log}_{10}W = a + b\,(\text{Log}_{10}L) \qquad (1)$$

Where: W= weight in grams
L= fork length in millimeters
a = Y axis intercept
b = slope of the regression line

A KS test (Sokal and Rohlf 1981) was used to test the hypothesis that length distributions from fish sampled in 2002 and 2003 were similar in length.

Sagital otoliths were collected for aging and otolith chemical examination from a minimum of ten fish within each 10 mm size group. Otoliths were thin-sectioned (sectioned) in the transverse plane through the core (Secor et al. 1992), mounted on a glass slide, and polished so that growth increments could be clearly viewed with transmitted light. Each otolith section was approximately 200 µm thick. Those sectioned otoliths that were eventually selected for chemical analyses were further polished on a lapidary wheel with 1 µm diamond abrasive. They were coated with a thin layer of conductive carbon in final preparation for analysis. Otolith aging criteria followed the methods and illustrations of Chilton and Beamish (1982) and Howland et al. (2004).

Otolith Chemistry

Fish otoliths are composed primarily of calcium carbonate. They grow continually throughout a fish's life, as dissolved material in the body fluids precipitate on the outer surface (Campana 1999). Marine water has a relatively high concentration of strontium (Sr) ions in solution compared to freshwater (Martin and Meybeck 1979; de Villiers 1999). As a result, the material that precipitates on fish otoliths when they are in marine water is highly enriched with Sr compared to material precipitated when they are in freshwater (Campana 1999). Areas of enhanced Sr in fish otoliths can be identified with an electron microprobe (Campana et al. 1997), and these areas provide evidence of fish migrations to marine water.

A random subsample of 10 otoliths each from least cisco, humpback whitefish, and broad whitefish were selected for otolith chemical analyses to detect fish that had been to marine water. Otolith preparation and analysis was performed by Randy Brown (U.S. Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office). The objective was not to estimate the proportion of anadromous versus freshwater components of the population, rather, to detect anadromous fish. The sampling problem was therefore one of detection probability, which required fewer samples than proportion estimation. Specifically stated the problem was: what is the probability of selecting at least one anadromous fish in a random sample of 10 if the actual proportion of anadromous fish in the population is 0.5. This probability was calculated based on the binomial probability distribution, using a range of sample sizes and a range of actual proportion values (Figure 2). We found, for example, that with a sample size of 10, there was a 97% probability of selecting at least one anadromous fish when the actual proportion of anadromous fish in the population was 0.3. This was judged an adequate sample size for the investigation.

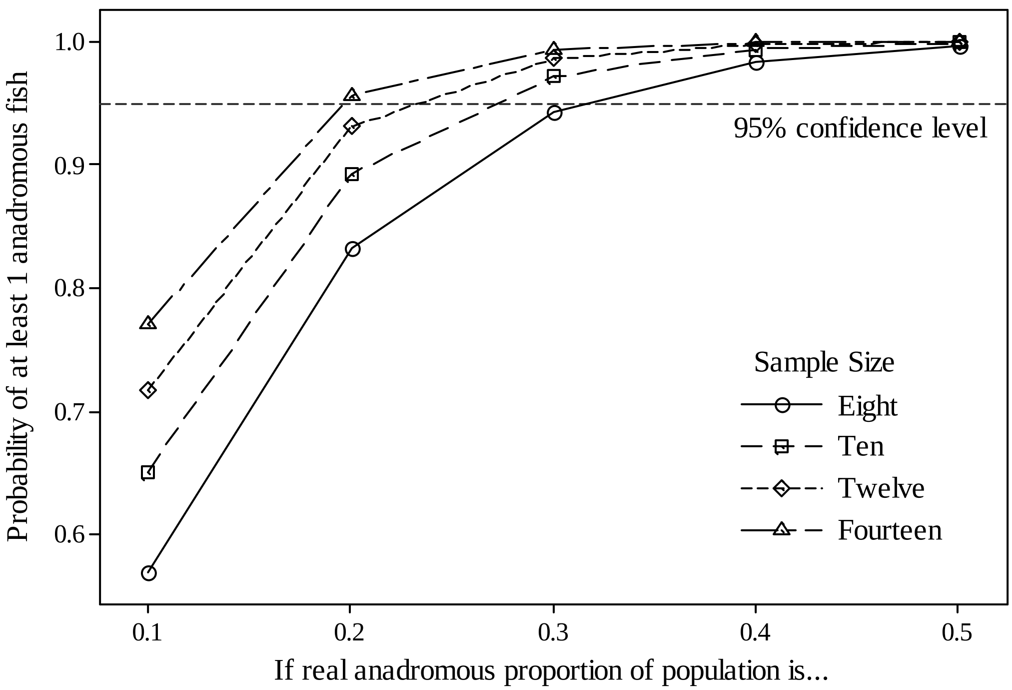

FIGURE 2.– Plot of the probability of detection of at least one anadromous fish in a given sized sample with a selection of hypothesized anadromous proportions in a population.

A wavelength-dispersive electron microprobe (WD-EM) was used for chemical analyses of otoliths in this study. The technology functions by bombarding points on a sample surface with a focused beam of electrons. Atoms within the material are ionized by the electron beam and emit x-rays unique to each element. Spectrometers are tuned to count the x-rays from elements of interest, in this case, Sr. The x-ray counts at each sample point are proportional to the elemental concentration in the material (Potts 1987; Reed 1997; Goldstein et al. 2003).

Strontium x-ray counts were collected from a series of points along a core (precipitated during the first year of life) to margin (precipitated just prior to the fish's death) transect for each otolith. The electron beam used for this procedure was 5 µm in diameter and was operated at an accelerating voltage of 15 kilo-electron-volts, and a nominal current of 20 nano-amperes (nA). Center-to-center distance between transect points was approximately 8 µm and the penetration depth of the beam was about 3 µm (Gunn et al. 1992). X-ray counts were collected for 25 s at each point. Strontium x-ray counts were converted to estimates of Sr ppm concentration based on a regression equation relating the two measures, similar to the process described by Howland et al. (2001).

Classification of Whitefish Lake whitefish as freshwater resident or anadromous life history forms was accomplished empirically by comparing their otolith Sr distribution graphs with those of known life history fish. This qualitative technique was used effectively by Babaluk et al. (1997) in an investigation of the anadromous behavior of Arctic char *Salvelinus alpinus* in a northern Canadian lake. Strontium graphs of twenty known life history salmonid fish (10 freshwater resident and 10 anadromous) were prepared for comparison. All known life history fish were of a size common for mature individuals, and each were collected in habitats and circumstances that guaranteed they actually belonged in the life history category in which they were placed. Known freshwater fish included Dolly Varden *S. malma*, Arctic grayling *Thymallus arcticus*, lake trout *S. namaycush*, steelhead *O. mykiss* (broodstock from a hatchery that wasn't ever released), inconnu, broad whitefish, lake whitefish, humpback whitefish, least cisco *C. sardinella*, and round whitefish *Prosopium cylindraceum*. Known anadromous fish included coho salmon *O. kisutch*, sockeye salmon *O. nerka*, steelhead, Dolly Varden, inconnu, broad whitefish, humpback whitefish, least cisco, Bering cisco *C. laurettae*, and Arctic cisco *C. autumnalis*. Strontium graphs of known freshwater fish had low point-to-point variability and low concentration levels of Sr compared to those of their anadromous conspecifics, which had low levels of Sr in their cores, reflecting their freshwater natal environments, and areas where Sr concentration levels rose precipitously, reflecting periods of time spent in marine water.

Maturity Investigations

Whitefish are fall spawners and portions of mature fish in northern populations do not spawn during consecutive years (Bond and Erikson 1992, 1985). Immature and mature fish are sometimes found in different lakes. Lakes on the Tuktoyaktuk Peninsula on the Beaufort Sea contained a large portion of immature rearing fish (Chang Kue and Jessop 1992). As spawning time approaches mature fish change physiologically. Spawning tubercles develop on scales along the sides and heads of fish (McPhail and Lindsay 1970). Milt is readily expressed from males. Females develop egg masses that physically extend the body cavity. Eggs of females can comprise 15% and greater of the body mass in late summer and fall prior to spawning (Bond and Erickson 1985). A quantitative assessment of sexual development, gonodosomatic index (GSI), was used to determine maturity of coregonid species selected at random and sacrificed throughout their emigration for biological analysis. The GSI was calculated as the weight of gonads divided by the total body weight (before gonad removal) X 100. Gonad tissue (eggs), was weighed using an electronic scale to the nearest g. Maturing fish can be readily identified by mid-July having a GSI index of > 3.8 in broad whitefish and >2.1 in least cisco (Bond and Erickson 1985). Sexual maturity of whitefish in Whitefish Lake was also determined by the presence of one or a combination of spawning turbercles, running milt, and the GSI index. Sex was determined by observing expulsion of sex products or identification of gonads during GSI sampling.

Harvest

A census of subsistence harvests was accomplished through exit surveys of boats leaving the lake during 2001-2003. Sub-samples were examined for length, and when allowed, otoliths and GSI data were collected.

Catch per Unit of Effort (CPUE) –The fishery was characterized by the number of fish caught per boat similar to deliveries in a commercial fishery. Catch for each boat (overnight set) was equal to catch/units of gear. Harvest locations within the lake were noted. The legal net length in Whitefish Lake is 15 fathoms; therefore, a 50 fathom net equates to 50/15 or 3.33 units of gear. During 2003, net lengths were either directly measured or calculated by dividing the number of total net floats by the number of floats per meter and converted to fathoms. Mesh size of sampled nets was measured for stretch length and classified as whitefish nets (50 to 100 mm), chum salmon nets (110 to 139 mm), and coho salmon nets (140 to 165 mm).

Movements and Harvest Areas

The geographic range and harvest of the Whitefish Lake stocks were investigated through tag recoveries. Least cisco, broad, and humpback whitefish captured at the weir were tagged with gray colored Floy® t-bar tags. Each tag was individually labeled with a unique number on one side and KNA USFWS on the other side, and a 1-800 telephone number so that subsistence fishermen could call in information. Heavy passage days required tagging of every fifth or tenth fish, while maintaining observations for fish previously tagged. Kuskokwim Native Association (KNA) developed a reward system and posted notices in villages along the Kuskokwim River to encourage people to turn in tag numbers and areas of harvest. Subsistence harvests in Whitefish Lake were sampled to record returns of tagged fish and estimate harvests. To compare inter and intra year movements, tagged fish were assigned a statistical week beginning with the first week of each year. Visual surveys to detect the presence of whitefish in the lower 100 meters of Ophir Creek were conducted periodically throughout the summer.

Results

Weir Operations

Installation of the weir was delayed in 2001 due to the late approval of a land lease, and it was only operated between 21 September and 11 October 2001. On the night of 11 October, the outlet froze over and the weir had to be chipped from the ice the following day.

In 2002, the installation of the weir occurred on 16 June and operations continued through 28 September; although the final day of full counts, was the 25th. A boat gate was installed to accommodate the heavy subsistence related boat traffic by residents hunting waterfowl and moose, fishing and berry picking. The large spring movement of fish into the lake was missed by the late installation of the weir (Figure 3). Personnel injuries during mid summer reduced crew size, and precluded 24 hr operations during portions of June and July. Highly turbid water required dip-netting fish out of the trap for positive identification. In order to minimize fish crowding and handling stress, traps were closed during the day when temperatures exceeded 15° C. During August and September, fish traps were closed when it was too dark to see or identify fish. Late in the season, weir scour occurred as storm surges caused masses of rooted aquatic plants to plug the weir, which caused scouring of the stream bottom. On 26 September, scouring reached depths of two meters that effectively sank portions of the weir and opened holes below panels. The weir was removed on 28 September.

During 2003, the weir operated from 2 May through 17 October. Lake ice broke up and flowed out of the lake between 11 and 15 May. The boat gate was lowered to relieve ice pressure on the weir and fish may have passed into or out of the lake. For the rest of the year, the trap was operated during peak passage times. In 2003, the weir operated 24hrs each day in anticipation of extreme peak daily passages as was observed in 2002. Whitefish emigrations were noted to peak after 2200 h when daylight faded.

Physico-Chemical

Water temperatures at the lake outlet were influenced by extensive shallow littoral areas that resulted in temperatures 1 to 2ºC above those in the middle of the lake. Emergent vegetation was present over approximately 25% of the lake surface by late summer. Boating was difficult in the southwest half of the lake and shallows due to emergent vegetation.

2002-Water temperatures exceeded 20°C for 13 days during 2002 with a maximum of 24°C on 17 June (Figure 3). Temperatures steadily decreased after 5 August to less than 5°C by 7 October. Oxygen levels measured at five locations across the lake on 2 April 2002 were less than 1.4 ppm, while the oxygen in Ophir Creek was above 10 ppm. Ice thickness on 2 April was approximately 1.2 meters over 0.25 m of water. Water levels were very high in the spring decreasing throughout the summer until the end of August (Figure 4).

2003-Water temperatures dipped between 9 and 14 May as lake ice broke up and began moving out of the lake. Early high temperatures prior to 9 May were the result of warm waters from the shallow ice-free area along the perimeter of the lake flowing out of the lake. Average daily temperatures exceeded 20°C for 21 days during the season between 28 May and 9 August 2003. The maximum average daily water temperature recorded was 24ºC on 9 August 2003 and steadily decreased to 3ºC by the end of September (Figure 3). Water almost quit flowing from the lake for a short time on 17 July when strong onshore winds moved water away from the outlet (Figure 4).

Water transparency–Secchi Disk readings in 2003 ranged from 0.1 m to 1.8 m and averaged 0.47 m for the season (Figure 4). The high transparency readings in May were the result of ice cover on the lake. Wind caused visibility to decrease. Maximum secchi disk readings of 1.8 m reflect the maximum channel depth where readings were taken in the outlet. Water turbidity did not allow for clear identification of fish as they passed out of the traps. Therefore, fish were dipped out of the traps for identification, counted and released either up stream if immigrants or down stream if emigrants.

Biological Data

Broad Whitefish

Timing of migrations–2001–Only 2 broad whitefish entered the lake and only 9 left the lake during the shortened operation period of 2001 (Table 1, Appendix 1).

2002–Broad whitefish counts consisted of 147 emigrants counted through the down stream trap and 3 immigrants through the upstream trap. Peak emigrations of 55 and 36 broad whitefish coincided with large numbers of least cisco and humpback whitefish leaving on 31 July and 1 August (Figure 3, Appendix 2). Broad whitefish were not observed leaving the lake again until the last week of August 2002. Seven broad whitefish left the lake on 25 September, the final day of complete counts.

2003–The majority of the 57 broad whitefish immigration occurred between 2 and 31 May (Figure 3). Emigrating broad whitefish (*N*=254) were counted leaving the lake between 4 June and 17 October. Daily counts were sporadic between 4 June and 20 September and did not exceed two individuals. Daily emigration picked up after 20 September and peaked on 27 September when 60 broad whitefish departed (Figure 3, Appendix 3). Broad whitefish comprised less than 3% of the fish counted entering the lake and less than 1% of the total number of fish leaving the lake during all three years.

TABLE 1.–Total immigration and emigration counts of broad and humpback whitefish and least cisco for 2001, 2002, and 2003 operations at Whitefish Lake weir.

	Upstream Migration			Downstream Migration		
Weir Operations	Broad Whitefish	Humpback Whitefish	Least Cisco	Broad Whitefish	Humpback Whitefish	Least Cisco
09/21 - 10/11/2001	2	4	2	9	155	92
06/16 - 9/25/2002	3	82	121	147	31,985	26,195
05/02 - 10/18/2003	57	1,516	187	254	27,822	15,134

Length-frequency distribution–Lengths were collected from 9, 29, and 254 broad whitefish passing the weir in 2001, 2002, and 2003. Lengths were pooled for all collections and ranged from 270 to 650 mm with a mean of 531 mm (Figure 5). A KS test of cumulative length frequencies indicated no significance difference between the 2002 and 2003 collections P=0.754 max difference D=0.132.

Length-weight relationships for male and female broad whitefish showed an allometric growth pattern with weight increasing at a faster rate than length (Figure 6). Length (L) and weight (W) relationships for broad whitefish collected at Whitefish Lake from both the weir passage (N=294) and subsistence harvested fish (N=113) are described by the equation:

$\text{Log}_{10} W = -4.5418 + 2.9186 (\text{Log}_{10} L),\ r^2 = 0.807$

Otolith chemistry–Otolith Sr distribution was evaluated along core to margin transects for ten broad whitefish collected in Whitefish Lake. Strontium concentration graphs from, 7 of 10 broad whitefish were consistent with those of known anadromous fish, containing greater overall variability than known freshwater resident fish and precipitous peaks of Sr concentration characteristic of known anadromous species (Figure 7 and 8). Strontium concentration graphs from 3 of 10 broad whitefish contained somewhat greater variability than is common for known freshwater resident fish, but did not have the precipitous peaks of Sr concentration seen in known anadromous fish, so they were tentatively classified as freshwater residents. These data indicate that a majority of the broad whitefish range downstream to marine environments during the course of their lives.

Maturity investigations–GSI indexes of broad whitefish leaving the lake between June and October 2003 increased with successive emigration pulses (Figure 9). Large broad whitefish with a GSI of less than 5%, however, were sampled leaving the lake in September coinciding with fish having GSI's exceeding 20%. GSI values were plotted against fork length to determine minimum size at maturity for female broad whitefish; all fish sampled appeared to be mature fish, but a minimum size of maturity using a GSI could not be determined with accuracy from the available samples (Figure 10). Sampled fish with tubercles and running milt present indicated males matured as small as 380 mm. The smallest sampled mature female was 470 mm.

Otolith age–Ages of broad whitefish ranged from four to 20 years (*N*=26), while the mean age was 10 years (Figure 11). Growth slowed between age 4 and 6, but the largest fish was not the oldest. Due to the limited numbers of broad whitefish passing the weir, otoliths were collected almost exclusively (98%) from 2001 and 2002 subsistence-harvested fish.

Abundance estimation–A Petersen estimator was used to estimate total population of broad whitefish during 2003. The marking event consisted of fifty-four broad whitefish captured in the upstream trap and released into the lake. One of the 54 was a recapture from 2002 returning to the lake. Histories of several fish complicated the estimate. For example, one broad whitefish was tagged entering the lake on 11 May and was harvested in the Kuskokwim River on 27 June, after passing down stream undetected, This tag was removed from the tagged pool of fish. A second fish was tagged entering the lake on 12 May and was recaptured reentering the lake on 25 May. A third fish was tagged entering the lake on 25 May and was recaptured reentering the lake on 12 June. These fish were counted only once in the 54 total marks. The weir was inoperable for periods during ice-breakup that is suspected to have contributed to movement without detection of the 11 and 12 May tagged fish. All broad whitefish exiting the lake were trapped in the downstream passage chute examined for marks, tagged, and released. A total of 254 fish were captured in the downstream passage trap and examined for tags. Recaptures included 21 broad whitefish passing the weir. The population estimate used only weir recaptures for broad whitefish in 2003 and was 637 fish, with a 95% CI $\pm$ 364. Subsistence users harvested 141 broad whitefish during 2003 of which three were recaptures. The exploitation rate of the estimated population of broad whitefish using Whitefish Lake is approximately 22% (14%-38%)

Both in the subsistence fishery and in the downstream weir passage, broad whitefish tagged in 2002 that were not observed entering the lake were recaptured. This and the low number of marks put out in May and June indicates that the majority of the broad whitefish entered the lake prior to weir installation in May and approximately 40% of the population left the lake in September and October. Complete mixing was assumed due to the long period between mark and recapture events.

Humpback whitefish

Timing of Migrations 2001–Immigration and emigration were minimal during the shortened operations period in 2001. Only 4 humpback whitefish entered and 155 left the lake between 21 September and 11 October.

2002–Immigration of humpback whitefish was minimal compared to the emigration indicating most entered prior to the installation of the weir (Table 1, Figure 3). Incomplete emigrant counts consisted of 31,985 humpback whitefish (Table 1, Appendix 2). Emigration started in the middle of June and daily counts peaked with 3,242 on 11 July, 3,165 on 17 July, and 3,111 on 18 July (Figure 3). Humpback whitefish exhibited a strong diel periodicity with most passing the weir after 2200 hours, and before 0600h. Minimal counts were made on 9, 10, 11, 29, 31 July and 1 August when high water temperatures and crowding resulted in stressed fish in the trap. The trap gate was opened on these dates after 2400h to pass fish. Due to the turbidity of the water and mixed species, estimates were not made. A second small push of humpback whitefish was counted past the weir leaving the lake between 24 and 28 August. Except for four days, the September emigrations consisted of less than 50 fish per day.

2003–Humpback whitefish comprised 64% of the whitefish emigration and 86%, of the immigrants in 2003 (Table 1). Seventy-five percent of the immigration total of 1,516 humpback whitefish entered the lake in May. The remainder entered in smaller pulses in September and October (Figure 3). Some of these fish were tagged leaving the lake and within hours to days returned to re-enter the lake. Emigration during 2003 totaled 27,822, and consisted of five major pulses, each separated by distinct lulls in passage. The first pulse peaked on 13 June and the last on 29 September. The maximum daily emigration of humpback whitefish occurred on 8 July, and consisted of 1,820 fish. Additional peaks of over 1,000 fish per day followed in August and in late September (Figure 3). Humpback whitefish comprised the majority of the fish counted through the upstream and downstream traps in all three years.

Length-frequency distributions–Humpback whitefish lengths from the 2001 sample (N=155) ranged from 200 to 490 mm with a mean of 355 mm (Figure 12). The 2002 sample (N=5,821) ranged from 210 to 550 mm, had a uni-modal distribution with the largest group being 420 mm and a mean length of 415 mm. The 2003 sample ranged from 220 to 510 mm (N=10,449), and had a uni-modal distribution with a mode of 420 mm and a mean of 413 mm, similar to 2002. A KS test of cumulative length frequencies indicated lengths of fish in 2002 differed from those in 2003 $P<0.001$, max difference $D=0.31$.

Length-weight relationships for male and female humpback whitefish showed an allometric growth pattern with weight increasing at a faster rate than length (Figure 6). Length (L) and weight (W) relationships for Whitefish Lake humpback whitefish are described by the equation:

$\text{Log}_{10}\, W = -3.3635 + 2.4287\, (\text{Log}_{10} L),\ r^2 = 0.712,$

Otolith chemistry–Otolith Sr distribution was evaluated along core to margin transects for ten humpback whitefish, collected in Whitefish Lake. Strontium concentration graphs from, 10 of 10 humpback whitefish, were consistent with those of known anadromous fish, containing greater overall variability than known freshwater resident fish and precipitous peaks of Sr concentration characteristic of known anadromous species (Figure 7 and 8). These data indicate that a majority of the humpback whitefish range downstream to marine environments during the course of their lives.
Otolith age– A sample of 99 humpback whitefish ranged from one to 29 years, and averaged 10 years *(N=99)*. Age at length analysis indicated growth slowed after age 6, or the onset of sexual maturity. Overlap of length at age indicated the largest fish were not the oldest (Figure 11).

Maturity investigations–Humpback whitefish GSI percentages increased with each emigration sample between June and October 2003 (Figure 9). Large humpback whitefish with a GSI of less than 5% were however sampled leaving the lake in September at the same time as fish with GSI exceeding 20%. GSI vs. length indicated minimum size at maturity for female humpback whitefish was approximately 350 mm (Figure 10).

Humpback whitefish (*N*=424) harvested between 1 and 16 October near Ophir Creek were classified as mature current year spawners or fish that would not spawn that year consisting of either mature non-consecutive spawners or immature individuals. Classification was based upon the presence or absence of spawning tubercles and/or the expression of milt or eggs (Figure 13). Both the presence of spawning tubercles and the expression of sex products corroborated with the GSI results that humpback whitefish were mature around 350 mm. One 310 mm female was classified as mature due to the presence of expressible eggs. Approximately 74% of the harvested fish were classified as mature, and 76% had developed tubercles. With the exception of one fish 310 mm, the sample consisted of fish equal to or larger than the minimum size at maturity as determined by GSI of 350 mm.

Abundance estimation–A population estimate was not conducted for humpback whitefish. Emigration counts, which peaked in mid summer and gradually tapered off into September and October were used as an index of the minimum number of humpback whitefish using the lake.

Least cisco

Timing of Migrations 2001– Immigration of least cisco in 2001 was minimal and consisted of only 2 fish. Only 92 least cisco were counted emigrating in September and October.

2002–Immigration counts of least cisco were minimal (*N*=121). Emigration counts were considered incomplete and consisted of 26,195 least cisco (Table 1, Figure 3). Peak emigration movements were recorded on 31 July and 1 August with partial counts consisting of 7,281 and 6,582 least cisco. Partial counts on these two days accounted for over 50% of the total emigration of least cisco (Appendix 2, Figure 3). On 30 July, between 2230h and 2400h, 750 least cisco and 306 humpback whitefish were passed before counts were suspended due to an excess number of fish and the trap was left open. Again, on 31 July between 2200h and 2400h a large push of fish resulted in 4,859 least cisco dip netted from the trap over those two hours. The crew struggled between midnight and 0200h on 1 August to dip net out of the trap and identify an additional 3,495 least cisco. Crowding around the boat gate, surges against the weir and hundreds of least cisco entering the down stream trap simultaneously necessitated opening the trap and lowering the boat gate to pass an estimated 2,500 least cisco in 10 minutes. Smaller emigration peaks began on 23 August, and 13 September, each peak was characterized by a large diel fish pulse after dark.

2003–Least cisco immigration movements (*N*=187) occurred primarily in May with only 29 entering in late September and 11 in October (Figure 3, Appendix 3). Least cisco (*N*=15,134) left the lake in five emigration pulses beginning in June and extending into September and early October (Figure 3). Other smaller emigration peaks began on 23 August, and 13 September, each peak was characterized by diel pulses of fish emigrating from the lake after dark.

Length-frequency distributions–Fork lengths from the 2001 sample (N=92) ranged from 120 to 390 mm and averaged 301 mm, (Figure 14). Lengths during 2002 ranged from 120 to 450 mm, with a mean of 334 mm (N=1,803). Lengths of 2003 sampled least cisco ranged from 130 to 440 mm, with a mean of 326 mm (N=1,098). The 2003 sample exhibited a uni-modal distribution with the largest group in the 310 mm size class. A KS test of cumulative length frequencies indicated a significant difference between the 2002 and 2003 collections, $P<0.001$, max difference D=0.122.

Length-weight relationships for male and female least cisco showed an allometric growth pattern with weight increasing at a faster rate than length (Figure 6). Length (L) and weight (W) relationships for least cisco collected at Whitefish Lake are described by the equation:

$\text{Log}_{10} W = -5.3085 + 3.1511 (\text{Log}_{10} L)$, $r^2 = 0.833$,

Maturity investigations–GSI indexes of least cisco leaving Whitefish Lake between June and October increased with successive emigration pulses (Figure 9). However, large least ciscoes with a GSI of less than 5% were sampled leaving the lake in September concurrently with fish with GSI's exceeding 20%. When GSI values were plotted against length, 300 mm was the minimum estimated size at maturity (Figure 11). These fish would be approximately age 3.

Otolith chemistry–Otolith Sr distribution was evaluated along core to margin transects for ten least cisco, collected in Whitefish Lake. Strontium concentration graphs from, 9 of 10 least cisco were consistent with those of known anadromous fish, containing greater overall variability than known freshwater resident fish and precipitous peaks of Sr concentration characteristic of known anadromous species (Figure 7 and 8). Strontium concentration graphs from one of 10 least cisco, contained somewhat greater variability than is common for known freshwater resident fish, but did not have the precipitous peaks of Sr concentration seen in known anadromous fish, so this fish was tentatively classified as a freshwater resident. These data indicate that a majority of the least cisco range downstream to marine environments during the course of their lives.

Otolith age –Least cisco ranged in age from one to 14 years (N=97), with the mean age being 6 years (Figure 11). Age at length analysis for least cisco indicated growth slowed after age three, and the largest fish was not the oldest.

Abundance estimation–A population estimate was not conducted for least cisco. Emigration counts, which peaked in mid summer and tapered off into September and October, were used as an index of the minimum number of humpback whitefish using the lake.

Whitefish Harvest

In late July, subsistence users began harvesting whitefish in the lake. Maximum monthly harvests were recorded in September for broad whitefish and October for humpback whitefish and least cisco (Table 2). In-lake harvests occur primarily within a ¼ - ½ kilometer of the inlet and outlet, which accounted for 21% and 79% of the harvest respectively. Traditional harvest methods consisted of attaching a gill net between two poles pounded into the lake bottom parallel to the lakeshore. Depths at the harvest sites were generally 1-1½ meters with net lead lines resting on the bottom. In 2003, lengths of nets were either estimated or verified. The legal limit for nets fished in Whitefish Lake is 15 fathoms or 27.4 meters yet 57% of the nets were longer than the legal limit and 75% of the fish were harvested with the use of these longer nets.

Catch per Unit of Effort– Daily CPUE ranged from 0.6 to 12.6 for broad whitefish, 0.9 to 126 for humpback whitefish, and 1.0 to 52 for least cisco. Most of the broad and humpback whitefish were harvested using nets from 110 to 146 mm (Figure 15). The highest harvests by species were in September for broad whitefish and least cisco and October for humpback whitefish.

TABLE 2.–Subsistence harvest by month and species from Whitefish Lake, 2003.

Species	Month				
	June	July	August	September	October
Broad Whitefish	0	2	60	48	33
Humpback Whitefish	0	3	315	124	639
Least Cisco	0	0	15	78	32
Northern Pike	0	1	9	4	54

Subsistence harvests checked during 2001-2003 included 272 broad whitefish, 1,637 humpback whitefish, and 148 least cisco. Effort in 2001 was not estimated. Approximately 48 nets were set in 2002 between 1 August and 7 October. In 2003, we obtained harvest information, net lengths, and mesh size from 44 nets fished between 16 August and 16 October. Harvest within Whitefish Lake during 2003 totaled 141 broad whitefish with an additional 22 collected for samples. The total emigration was only 254 during this same time. In addition to these fish, a subsistence fisher during 2003 set a net at the confluence of the Kuskokwim River and the outlet creek from Whitefish Lake. That net accounted for an additional 15 tagged broad whitefish leaving the lake plus an undetermined number of untagged fish. A total of 1,085 humpback whitefish were harvested and a total of 27,822 passed out of the lake for a harvest rate of 4% and 125 least cisco were harvested while 15,134 were enumerated passing out of the lake for a harvest rate of only 0.8%. Overall, broad whitefish comprised less than 1% of the total enumerated whitefish leaving the lake in 2003, but made up 12% of the total fish harvest. Humpback whitefish comprised 65% of the enumerated fish and 79% of the harvest; least cisco comprised 34% of the enumeration and only 9% of the harvest.

A KS test of the equality of lengths of broad and humpback whitefish and least cisco emigrating from Whitefish Lake in 2001-2003 versus subsistence harvests, suggests a harvest bias towards the largest of all three species (Figure 16). The test used lengths of 292 out-migrant weir samples and 241 subsistence caught broad whitefish, maximum distance D = 0.147, $p<0.01$. Humpback whitefish weir samples (2001-2003 N=16,495) and subsistence harvests (N=1,637) were compared with a maximum distance D=0.333, $p<0.01$. Least cisco, weir samples (N=2,993) between 2001 and 2003 were compared to 150 subsistence samples, with a maximum distance D=0.204, $p < 0.01$.

Movements and Harvest Areas–Fish were tagged in each of the three years of weir operations (Table 3). During heavy passage, approximately every fifth or 10th fish was tagged. Due to water clarity, most fish were netted out of the trap for species identification, and tag information.

TABLE 3.–Whitefish tagged by species and year, Whitefish Lake 2001-2003.

Year	Broad Whitefish	Humpback Whitefish	Least Cisco
2001	9	147	67
2002	31	2,431	1,860
2003	283	10,147	1,042
	323	12,725	2,969
Known subsistence harvest of tagged whitefish 2001-2003	24	58	3

Only five broad whitefish tagged emigrating in 2002 were recaptured emigrating in 2003. One broad whitefish leaving in July left a month earlier in June of 2003. Three of the four broad whitefish tagged in September left within 2 days of the 2002 emigration date, while one left more then two months earlier in July (Figure 17).

Humpback whitefish tagged in 2001 and 2002 leaving the lake were recaptured leaving the lake in 2002 and 2003. Tag recaptures indicate a fidelity to the lake as a feeding area. Some humpback whitefish switched emigration timing between years. For example, 14 of the 147 humpback whitefish tagged emigrating in the fall of 2001 were recaptured emigrating in 2002. Twelve of the 14 switched to a spring emigration in 2002, effectively leaving 14 weeks early. In 2003 we recaptured 18 of the 147 humpback whitefish tagged in 2001 as they left the lake. Nine or 50% remained fall emigrants, one switched to a spring emigration and eight were summer out-migrants. Inter-year recapture data was available for 650 humpback whitefish tagged leaving the lake in 2002 and recaptured leaving the lake in 2003. Approximately 54% moved out of the lake at approximately the same time both years. These fish moved within plus or minus two statistical weeks of the week tagged emigrating in 2002 (Figure 17). Humpback whitefish moving more than two statistical weeks early comprised 14% while 19% delayed their emigration date by eight or more statistical weeks.

Seventy-four least cisco tagged emigrating in 2002 were recaptured emigrating in 2003. The majority left the lake in 2003 within two weeks of the same statistical week they were tagged in 2002. Five of the fish left eight weeks later and two out-migrated four weeks earlier than in 2002 (Figure 17).

Whitefish tagged in Whitefish Lake were harvested by subsistence fishermen outside of the lake in several locations. Harvest locations for broad whitefish in the Kuskokwim River included one at the confluence of the Stony River (rkm 536), one at Birch Tree crossing (rkm 294) and 15 at the confluence of Whitefish Lake Creek (rkm 259) and the Kuskokwim River (Table 3; Figure 18). Tags were returned from seven humpback whitefish harvested outside of Whitefish Lake. These included one humpback whitefish harvested downriver near Tuluksak village, rkm 192 and one as far up river as Medfra, rkm 863. Others were harvested near Birch Tree Crossing, rkm 294. Three least cisco tag returns indicated movements up the Kuskokwim River to Red Devil rkm 473 (one), and two fish down stream to Tuluksak, rkm 192.

Other species

2002–Five additional species other than whitefish entered the lake including 198 northern pike, 65 longnose suckers, six coho salmon *Oncorhynchus kitsutch*, one sockeye salmon *O. nerka*, and one chum salmon, *O. keta.* Weir counts of other fish leaving the lake included 156 northern pike, 120 longnose suckers, and one chum salmon (Appendix 2).

2003–Other species entering the lake included 248 northern pike, 48 longnose suckers, 264 coho salmon, and one chum salmon. Other fish leaving the lake included two inconnu, *Stenodus leucichthys*, one round whitefish *Prosopium cylindraceum*, 99 northern pike 162 longnose suckers and 150 adult coho salmon. Some coregonids may have been hybrids and were listed with other unidentified coregonids (Appendix 2).

Discussion

Population assessment using a weir on Whitefish Lake was difficult, yet effective at understanding broad and humpback whitefish and least cisco abundance and immigration and emigration timing. Unexpected large numbers of emigrant fish in July 2002 exceeded the capacity of the crew to monitor all fish passage. During September 2002, high wind events uprooted aquatic weeds that clogged the weir and caused scouring of the mud bottom, eventually breaching the weir. In the spring of 2003 after the weir was installed, ice coming out of the lake curtailing complete counts during a one week period.

We confirmed previous work (Baxter 1973, 1974) that broad and humpback whitefish and least cisco do not use these shallow tundra lakes during the winter. Their seasonal usage begins early in the spring, entering these shallow tundra lakes as increasing flows lift the ice and provide sufficient quantities of oxygen. Both the Kuskokwim River and Whitefish Lake are still frozen at this time. Early arrival confirms the important role these feeding lakes play in the ecology of whitefish. Access to shallow feeding lakes such as Whitefish Lake during the spring and summer appears to be critical in the life history of these species.

Broad Whitefish

Weir operations beginning 2 May 2003 were the earliest a weir could be installed yet we were only able to monitor the tail end of the broad whitefish immigration. Throughout the summer, very few fish entered or left the lake. The majority of the broad whitefish began leaving Whitefish Lake the last week of September as water temperatures decreased to around 2ºC. Emigrant numbers dropped off as water temperatures rose from the low of 2ºC back up to 10ºC on 3 October. Emigrant numbers again increased as water temperatures fell from 3-17 October and approached 3ºC. Other authors have stated that spawning occurs close to freeze up or shortly after (Alt 1976; Chang-Kue and Jessop 1997) so these emigrations are probably spawning related. Emigration of broad whitefish (>200 mm) from Kukjuktuk Creek near the Mackenzie River delta began in mid July and peaked between 20 July and 16 August. Numbers dropped off but continued with small numbers through the end of September. Water temperatures on Kukjuktuk Creek decreased to near freezing on approximately 13 September (Chang-Kue and Jessop 1992) almost a month earlier than when Whitefish Lake freezes. Those fish were composed primarily of smaller sized younger fish that would spawn for their first time or were immature and were migrating back to coastal overwintering areas. Movement of those first time spawners and immature broad whitefish in Kukjuktuk Creek may be different from older mature prespawners that feed in other lakes associated with the Mackenzie River. This may be due to a longer distance to spawning grounds, and travel that requires migrating through brackish waters along the coast to reach the Mackenzie River. Broad whitefish rearing in the lower Kuskokwim River may follow this same pattern of a mid to late summer migration to spawning grounds in the Kuskokwim River before recruiting to Whitefish Lake the following year.

The majority of the broad whitefish using Whitefish Lake are large adult fish foraging during the summer months. Eighty-four percent of the sampled broad whitefish were larger than 500 mm and only 2% were less than 400 mm. Minimum lengths at maturity for sampled fish were 380 mm for one sampled male and 470 mm for a single female. Size and maturity for broad whitefish in other populations is approximately 8 years and 445 mm in the Selawik River (Brown 2004) and ages 5-7, and 400-460 mm in the upper Kuskokwim River (Alt 1976).

Broad whitefish in Whitefish Lake are also large compared to other populations. Broad whitefish sampled near Horseshoe Bend on the Mackenzie River in 1993 ranged in size from 405 to 643 mm, with a mode of 500 mm (Babaluk et al. 2001). In Kukjuktuk Creek, emigration in 1979 consisted of 73,813 broad whitefish greater than 200 mm (Chang-Kue and Jessop 1992). Approximately 3% were longer than 475 mm and none larger than 600 mm. Mean lengths of broad whitefish sampled from Travaillant Lake, a tributary lake to the lower Mackenzie River, was 453 mm and less than 10% were larger than 500 mm (Harris et al. 2004). Lengths found in the Selawik River population ranged from 275 to 560 mm with a median length of 456 mm (Brown 2004). Baxter (1973) sampled 777 broad whitefish from the Kuskokwim River and tundra lakes below Bethel using experimental gill nets. Lengths ranged from 90 to 650 mm, with a mode of 420 mm. Approximately 76% of his sample was between 400 and 500 mm, but only 3% were greater than 500 mm. Samples (N=73) from the Holitna River ranged from 360 to 560 mm (Alt 1976). Differences in length composition between lower Kuskokwim River locations and Whitefish Lake suggest broad whitefish recruit to the lake after rearing in the lower river. This is consistent with our otolith analysis, which indicated the majority of the broad whitefish are anadromous, spending a portion of their early life in marine or brackish water.

Our data suggest some broad whitefish that use Whitefish Lake are mature non-consecutive year spawners. The proportion of fish utilizing Whitefish Lake that are non-consecutive spawners may be lower than northern stocks due to the longer growing season present in the southern most range of the species in Alaska. A larger sample would confirm the percentage of the population that are non-consecutive year spawners.

The population estimation for broad whitefish in Whitefish Lake was only 417 ± 137. Tag returns indicate some broad whitefish had not emigrated by 17 October when the weir was removed. Alt (1972) found broad whitefish spawn in the Kuskokwim River between late October and early November, which would suggest that the majority of the broad whitefish in Whitefish Lake should have emigrated by 17 October when the weir was removed and water temperatures were low.

Consistent with work on the Mackenzie River in Canada and in the Selawik and Chatanika rivers in Alaska (Fleming 1996; Babaluk et al. 2001; Brown 2004), broad whitefish in the Kuskokwim River are a long-lived species. Maximum ages found in the Mackenzie River for broad whitefish was 27 years (Babaluk et al. 2001) and 31 years for broad whitefish in Travaillant Lake, a tributary lake in the lower river delta (Harris et al. 2004). Brown (2004) found that broad whitefish in the Selawik River ranged up to 27 years. The maximum otolith age for Whitefish Lake broad whitefish was 20 years. Our sampling method to collect fish from each size category for age analysis represents the range of ages present, but not the composition of the population by age class as the oldest fish were not the largest broad whitefish specimens. A large sample was not taken because of the small population found in Whitefish Lake.

Traditional knowledge indicates that the number of broad whitefish in Whitefish Lake and in the Kuskokwim River in general has decreased, which may be the result of several factors. First, there is a harvest bias at Whitefish Lake and probably other places in the Kuskokwim River. Less than 1% of the fish emigrating from Whitefish Lake were broad whitefish however, they comprised almost 12% of the harvest. Broad whitefish are a preferred food fish, and larger mesh gear is generally used to harvest the larger whitefish. Emigration timing, which occurs over a relatively short period, subjects the fish to intense fishing pressure. Evidence for this includes the high catch rate, which equaled 22% of the estimated 2003 Whitefish Lake population. In addition, tag returns from 2001 to 2003 indicated broad whitefish were harvested in several locations in the Kuskokwim River, which would increase the harvest rate of this population if tags were not recognized or reported. This extensive movement and harvest pressure may play an important role in population numbers in Whitefish Lake. Second, anecdotal information suggests that during commercial fishing periods for salmon in the Kuskokwim River, broad whitefish were caught regularly as a by-catch. Baxter (1975) noted that whitefish sales in Bethel stores in the late 1960’s and early 1970’s came primarily from the by-catch in the salmon fishery. Numbers in the by-catch however have gradually decreased (James Charles 2005, personal communication, Tuntatuliak, Alaska). The directed harvest for large whitefish and broad whitefish in particular and by-catch in the Kuskokwim River salmon fishery over the past four or five decades may have reduced the populations. Baxter (1975) also noted that the Johnson River, Eek River, Kinia River, and Whitefish Lake were some of the river systems that he felt were experiencing problems from over fishing of whitefish stocks. Third, periods of low recruitment coupled with high levels of harvest pressure over the past four or five decades in the Kuskokwim drainage may not allow the population to recover. Gallaway et al. (1997) monitored fluctuating year class strengths of broad whitefish along the Arctic coast. Numbers of this lightly exploited population fell five fold between 1982 and 1987. This was followed by a rebuilding period to 1991 followed by a subsequent reduction again in 1992. Gaps in year class strength have also been noted on the Selawik River (Brown 2004), and in humpback whitefish and least cisco in the Chatanika River (Fleming 1996). Fourth, environmental factors in Whitefish Lake may have changed reducing the quality of lake habitat, and the number of broad whitefish that use the lake. Climate records indicate that the period 1949 to 1975 was substantially colder than the period from 1977 to 2003 (Alaska Climate Research Center). Between these two periods, Bethel has experienced a 3.2°C average rise in spring temperatures and a 2°C average annual rise in temperature. Baxter's work and comments about the abundance of broad whitefish occurred prior to this environmental shift and the by-catch in the commercial fisheries that occurred during the 1970's and early 1980's.

Humpback Whitefish

Differences in numbers of humpback whitefish immigrating and emigrating in 2003 indicate that the majority entered the lake prior to 1 May. The lake normally has very low winter oxygen levels requiring fish to leave sometime after the end of October when the aquatic vegetation decomposes under the ice. The number of fish counted entering the lake verses those leaving indicated that the majority would have had to immigrate into the lake prior to the ice leaving the lake. Small numbers of humpback whitefish however continued to immigrate throughout the summer. Noteworthy was the fact that more than 50% of the humpback whitefish emigration occurred in one large pulse in 2002, but was distributed over approximately five pulses in 2003. Also in both years, more than 50% of the humpback whitefish and least cisco emigration occurred before August when the subsistence fishery was just beginning. Fleming (1996) found fish arrived on the Chatanika River spawning grounds in pulses. Our data would support that type of movement as smaller emigration pulses of humpback whitefish occurred from the end of August to the end of September in both 2002 and 2003. Emigration pulses of humpback whitefish from Whitefish Lake coincided with increases of whitefish caught at the salmon fish wheels operated near Kalskag (Jason Pawluk ADF&G, Anchorage, personal communication). This may indicate that they are joining humpback whitefish from other areas in the drainage as they migrate upriver to spawning areas.

The majority of the humpback whitefish using Whitefish Lake are large mature fish, foraging during the summer months. Ninety-seven percent of the sampled humpback whitefish were larger than 350 mm, the minimum size of maturity in Whitefish Lake. Fleming (1996) found humpback whitefish matured at 323 mm but considered 450 mm the size when all humpback whitefish were mature in the Chatanika River. Alt (1979) sampled humpback whitefish in 12 coastal and interior rivers and three lakes noting that maturity was first reached between 310 and 360 mm. Humpback whitefish sampled in Highpower Creek at the headwaters of the Kuskokwim were mature at 396 mm or age 5 (Alt 1979). In the Chatanika River, Clark and Bernard (1988) determined humpback whitefish were mostly mature at age 7. Northern populations of humpback whitefish along the Arctic coast, where the growing season is shorter, begin to mature later at age 10 and reach 100% maturity at age 14 (Moulton et al. 1997). Based upon otolith ages and GSI indexes, humpback whitefish may mature as early as age 4 in Whitefish Lake.

Humpback whitefish foraging in Whitefish Lake are large compared to other populations. The average length of humpback whitefish sampled in Whitefish Lake was approximately 416 mm. Fish larger than 400 mm comprised 70% of the population and only 3% were less than 350 mm. The median length of 420 mm was, however, longer than the median length (395mm) found in the Selawik River study (Brown 2004). By comparison, lengths from 665 humpback whitefish sampled from the Kutukhun River, a Kuskokwim tributary below Bethel, averaged 365 mm, and fish larger than 400 mm, and smaller than 350 mm comprised 25% and 40% respectively (Baxter unpublished notes, 1972, 1973). Using size as a proxy, humpback whitefish probably recruit to Whitefish Lake when they are approximately 4-6 years of age. This recruitment is consistent with otolith analysis indicating that humpback whitefish are anadromous and spend part of their younger years in a brackish or marine water environment.

Our data suggest some humpback whitefish that use Whitefish Lake are mature non-consecutive year spawners. This phenomenon of mature-sized non-consecutive spawning or resting least cisco and broad and lake whitefish has been observed in Canada and Alaska (Morin et al. 1982; Bond and Erickson 1985; Moulton et al. 1997). Alt (1979) observed humpback whitefish spawning between 18 September and 15 October in the Chatanika River when water temperatures ranged from 0 to 3ºC. We first noted spawning tubercles on fish leaving the lake the first week of September, so fish examined during October when fish are nearing the spawning period should be easily identified as non-consecutive spawners or spawners. Fleming (1996) considered 450 mm the size when all humpback whitefish were mature on the Chatanika River. He also checked humpback whitefish for sexual maturity between 26 and 30 September and found he could not determine the sex of up to 36% of the humpback greater than 450 mm by gently stripping fish to express sex products. We examined 424 humpback whitefish harvested in Whitefish Lake near the inlet creek between 1 and 16 October for spawning tubercles and maturity. Spawning tubercles were developed in 87% and 78% of the males and females respectively. All fish were examined for sex by using a gentle stripping action on the abdomen, and 87% and 79% of the males and females were ripe or mature. Fish that were not classified as mature and those without spawning tubercles were distributed throughout all the size groups. These fish were classified as either immature or skip spawners.

Emigration counts of 31,858 and 27,822 in 2002 and 2003 respectively were considered to represent the majority of the humpback whitefish using Whitefish Lake. There are several factors, which were considered in this conclusion. First, spawning occurs the end of September or the first of October when temperatures are around 0-3ºC. Second, spawning tubercles were first noted on fish leaving the lake the first week of September indicating a physical change beginning in mature fish migrating to spawning grounds. Therefore, most fish should have left the lake if they were going to spawn in other tributaries to the Kuskokwim River. These estimates however do not include fish that may have been spawning in Ophir Creek and left late.

Ophir Creek the only clear water tributary to Whitefish Lake is considered a possible spawning area based upon the interpretation of the following: First, Ophir Creek is known as a traditional location to harvest whitefish during the fall and early winter (George Morgan, Kalskag, Alaska personal communication). Whitefish are harvested using nets near the mouth of the river during the open water period. They are also harvested in the first 100 meters of the creek with spears during the open water period, and when ice is thick enough for winter travel. Visual surveys of Ophir Creek indicated whitefish were not present until late September. Second, large humpback whitefish were harvested between 1 and 17 October near Ophir Creek in spawning condition. These factors would appear to indicate some humpback whitefish might spawn in the inlet creek. A lacustrine or riverine life history type may explain why small young of the year fish were not noted in emigrations. Young of the year fish from this spawning population may spend their summers in the lake and winters in the inlet creek. Micro chemical analysis of otoliths from these would confirm this life history type.

Consistent with work in other areas, the humpback whitefish in Whitefish Lake are long lived reaching a maximum sampled age of 29 years. Brown (2004) found ages of humpback whitefish in the Selawik River ranged up to 27 years. The largest specimens however were not the oldest ages in the samples.

We also found humpback whitefish switching emigration timing between years. Some switching may result from additional forage time needed to restore fat reserves depleted during the previous fall migration and spawning. Both robust and skinny fish were noted in the samples. Analysis of GSI by age was not performed.

Harvest pressure on humpback whitefish using Whitefish Lake appears to be minimal. Humpback whitefish harvests accounted for less than 5% of the 27,822 fish observed leaving the lake in 2003. Humpback whitefish leave the lake throughout the summer and fall, with up to 50% prior to the onset of the in lake subsistence fishery. Their fidelity to the lake and the fact that some switch emigration timing during the summer one year to fall the next removes a portion of them from successive years of harvest pressure in the lake.

We were unable to detect any trends in the recruitment of humpback whitefish to the Whitefish Lake feeding area due to the short duration of the study. Additional otolith work would be necessary to detect past recruitment gaps. Other Alaska populations however appear to be highly variable. Fleming (1996, 1997, 1999) working with spawning populations of humpback whitefish in the Chatanika River, a tributary of the Yukon River, found that species was experiencing several years of low recruitment. Pre-recruit year classes of humpback whitefish (ages 1-6), which were not fully vulnerable to his sampling gear on the spawning grounds represented between 21% and 27% of the sampled population for several years but in 1997 represented 47% of the population indicating better recruitment. Brown (2004) also noted periodic patterns of what appeared to be age class failure in both broad and humpback whitefish.

Least Cisco

The difference between the immigration and emigration indicated that the majority of the least cisco immigrated into the lake prior to the weir being operated. Counts of fish entering the lake comprised less than 1% of the fish leaving the lake in 2003. Least cisco primarily entered the lake under the ice but a small number continued to enter throughout the summer. More than 50% of the least cisco emigration occurred in one large pulse in 2002. Even with the emigration occurring in five pulses in 2003, more than 50% of the least cisco emigration occurred before August. Large emigrations of least cisco have also been recorded prior to the middle of August in Kukjuktuk Creek, an Arctic coastal watershed east of the McKenzie River (Chang-Kue and Jessop 1992). Emigration pulses of least cisco from Whitefish Lake coincided with increases of whitefish caught at the salmon fish wheels operated near Kalskag (Jason Pawluk, ADF&G, Anchorage, personal communication).

Whitefish Lake is used by large mature least cisco foraging during the summer months. More than half of the sample was larger than 300 mm, the minimum size of maturity in Whitefish Lake, which corresponded to ages 3 or 4. Samples taken from the Lower Kuskokwim River were also mature at 300 mm (Baxter 1974). In the Chatanika River, Clark and Bernard (1988) determined least cisco were mature at age 4. Moulton et al. (1997) found 50% of the female least cisco in Dease Inlet reached maturity by age 8 as opposed to ages 3 or 4 in Whitefish Lake.

Least cisco were similar in size to other populations. Lengths ranged from 120 to 450 mm similar to lengths found in Canada (Chang-Kue and Jessop 1992). Least cisco collected from the Yukon-Kuskokwim Delta by Baxter (1974) ranged between 250 and 470 mm.

Our data suggest some mature sized least cisco are non-consecutive spawners. Mature-sized resting or non-consecutive spawning least cisco have been observed in Canada (Morin et al. 1982; Bond and Erickson 1985; and Moulton et al. 1997). GSI data indicted that a portion of the least cisco using Whitefish Lake exhibit this same pattern. On the Arctic coast, only about 50% of the least cisco judged mature, spawned that year in Dease Inlet (Moulton et al., 1997).

Emigration counts of 26,043 and 15,134 in 2002 and 2003 respectively were considered to represent the majority of the fish using Whitefish Lake. There are several factors, which were considered in this conclusion. First, spawning takes place around the end of September or beginning of October when temperatures drop near freezing. Second, emigration counts decreased as the season progressed and were in the low double digits for a week just before the weir was removed.

Least ciscoe were also found to switch emigration timing between years. Some switching may result from additional time needed to forage and restore fat reserves used during spawning and migration the previous fall.

Least cisco attained a maximum age of 14 years in Whitefish Lake similar to other populations. Brown (2004) found ages of least cisco reached 16 years. Moulton (1997) working in Dease Inlet on the Beaufort Sea found least cisco up to 25 years, almost twice as old as the least cisco found in Whitefish Lake. The oldest least cisco was not the largest.

Harvest pressure on least cisco using Whitefish Lake appears to be minimal with a known harvest of only 0.8% of the 15,134 out-migrants. In addition, subsistence users did not appear to be targeting this species in Whitefish Lake. Tag returns from 2001 to 2003 indicated that least cisco were harvested in several locations outside of the lake. Least cisco leave the lake throughout the summer and fall, with up to 50% emigrating prior to the onset of the in lake subsistence fishery. Harvest pressure on least cisco in Whitefish Lake is currently minimal.

We were unable to detect any trends in the recruitment of least cisco to the Whitefish Lake feeding area due to the short duration of the study. Additional otolith aging would be necessary to detect past gaps in recruitment. Other Alaska populations however appear to be highly variable. Fleming (1996, 1997, 1999) working with spawning populations of least cisco in the Chatanika River, a tributary of the Yukon River, found that species was experiencing several years of low recruitment. Age 3 least cisco comprised only 5% of the Chatanika River population in 1997, compared to an average 22% over nine previous years (1986-1994).

Conclusions/Recommendations

The distribution of important foraging lakes like Whitefish Lake within the Kuskokwim River drainage is unknown. If large populations reside in other lakes that are lightly exploited they may contribute to the drainage wide populations of Kuskokwim River broad and humpback whitefish and least cisco. Intensified management however may be needed if Whitefish Lake represents a significant portion of the middle river population. We also do not know what role large lakes play in the ecology of whitefish in the Kuskokwim River drainage.

We were not able to satisfy all the assumptions needed for a mark-recapture estimate of humpback whitefish and least cisco. Although the majority of fish entered the lake prior to the end of May of 2003, some fish continued to enter the lake throughout the summer of 2003 (Figure 3). Fish however, also exited the lake throughout the summer in both 2002 and 2003 (Figure 3). The lack of separation in lake entry and exit precludes the use of a two-event Petersen estimator of abundance. Tag loss was also very high. The use of alternative abundance estimators may be explored in the future. A temporally stratified Darroch (1961) estimator might be employed, though the comparatively low rate of fish entry after May might cause the estimator to be unstable. Open population models might also be employed and the lake entry and exit timing for the three species in this study will be useful in study design. However, high tag loss in some years and the possibility that fish might not utilize the lake in every year are potential problems that would need to be addressed. Weir passage data however probably represents the majority of the fish in Whitefish Lake. Missing tags indicate that some fish remained in the lake after the weir was removed. The decreasing number of out-migrants indicates that few fish remained after the middle of October.

Given what we have learned from this study and the shifting focus of our research to locating spawning aggregates, estimating humpback whitefish and least cisco abundance in Whitefish Lake may be less important than previously thought. Because the lake probably contains multiple stocks, the risk of over fishing under the current subsistence harvest pressure and timing is considered minimal for humpback whitefish and least cisco that leave the lake to spawn. If however there is confirmation that a stock is spawning in Ophir Creek, that stock may be vulnerable to over fishing because the timing of the fishery occurs when fish are congregating near the creek mouth.

Humpback whitefish and least cisco importance and status in other lakes where subsistence harvest occurs is currently unknown. Historical trends in other lakes are unknown. Whitefish Lake probably contains broad and humpback whitefish and least cisco from multiple spawning populations. Because Whitefish Lake is a major subsistence harvest location drawing people from as far away as Bethel, harvest monitoring should be continued, and population assessments should be conducted on a periodic basis. Since whitefish are subject to climatic variables that affect recruitment a monitoring program that would cover up to six years would be necessary to determine gaps in recruitment.

Management of broad whitefish in the Kuskokwim River and Whitefish Lake is in need of distinguishing between two alternatives: is the subsistence harvest only a fraction of a large stock or does the harvest represent a large fraction of a relatively small stock? Within Whitefish Lake, the harvest is a large fraction of a relatively small group of foraging broad whitefish migrating to their spawning areas. The risk of continuing the current heavy harvest pressure on the small number of broad whitefish in Whitefish Lake is unknown. Because all of the fish must pass through a small area over a short period, and the harvest is concentrated during this time, the risk of over harvesting may be great. If the lake population was larger and the emigration occurred over a longer period, the risk would be lower such as with the humpback whitefish. Because it is a mixed fishery, harvest pressure has probably not followed fishing success for broad whitefish and gradually decreased. Instead, because it is a mixed fishery and catch rates for humpback whitefish remain high, fishing pressure has remained high. Following this to its logical conclusion would be: do numbers of broad whitefish in Whitefish Lake reflect the overall Kuskokwim River population. Traditional knowledge would indicate that over all the broad whitefish population has been reduced and now is only a fraction of historical numbers. For example, 30-40 years ago broad whitefish comprised 90% of the subsistence harvests in the lakes near Tuntutuliak in the lower Kuskokwim River drainage whereas now they only comprise 10% (Robert Enoch, Tuntutuliak, personal communications). Humpback whitefish and least cisco need the same question answered.

Kuskokwim River whitefish, which were once thought of as an inexhaustible resource, need additional research. Thera (1998) modeled the Mackenzie River broad whitefish population and found the model was most sensitive to density dependent mortality of juveniles in freshwater lakes, fishing mortality associated with upstream and downstream migrants, and fecundity. Density dependent mortality studies are often expensive and difficult. Locating major rearing areas would help determine habitat use and environmental impacts that may influence recruitment. Estimating fecundity requires locating spawning grounds, from which reproductive lifetime, spawning frequency, and age-specific fecundity data can be gathered.

Because of the increased interest in resource extraction in the Kuskokwim River drainage, delineating and protecting critical spawning is important. Second, and concurrently an estimate of annual subsistence harvests by species, especially broad and humpback whitefish should be completed for the Kuskokwim River. Including non-salmon fish by species on the State’s catch calendar used for recording subsistence salmon harvests is a relatively inexpensive method to gather the information. Third, areas sampled by Baxter in the late 1960’s and early 1970’s should be re-sampled to detect if a shift in species composition has occurred. Fourth, the current regulations for Whitefish Lake have been in place since 1992, yet enforcement of the legal net length has not occurred. Population work on spawning grounds may indicate additional regulations are required such as time and area regulations to protect broad whitefish leaving Whitefish Lake. Changes in future management and regulations will require stakeholder participation and acceptance.

Musick (1999) suggests that iteroparity (multiple year spawning) may be an evolutionary adaptation for fish with long life spans and high juvenile mortality. This adaptation may be necessary to maintain stable populations for groups like whitefish and has been found in other species such as the Cui-ui, (*Chasmistes cujus*) which is long lived and copes with periods of environmental conditions that has precluded spawning for numerous years (Scoppettone et al, 2000). It is also found in fish in the Clupeidae and Serranidae families that are long lived and cope with fluctuating environmental conditions that exert a high juvenile mortality (Longhurst 2002). Management however needs to recognize that static harvest pressure over multiple years of low recruitment may have detrimental long-term effects by removing the populations buffering capacity for environmental factors.

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References

Alt, K.T. 1972. A life history study of sheefish and whitefish in Alaska. Federal Aid in Fisheries Restoration, Annual Report of Progress, 1971-1972. Project F-9-4, R II. Alaska Department of Fish and Game, Sportfish Division, Juneau, Alaska.

Alt, K.T. and D.R. Kogl, 1973. Notes on the whitefish of the Colville River, Alaska. J. Fish. Res. Board Can. 30(4):554-556.

Alt, K. T. 1976. Age and growth of Alaskan broad whitefish *Coregonus nasus*. Transactions of the American Fisheries Society 105:526-528.

Alt, K. T. 1979. Contributions to the life history of the humpback whitefish in Alaska. Transactions of the American Fisheries Society 108:156-160.

Alaska Climate Research Center, University of Alaska Fairbanks, Fairbanks, AK Temperature Change in Alaska: 1949 - 2003 http://climate.gi.alaska.edu/ClimTrends/Change/7704Change.html (2/2006).

Babaluk, J. A., N. M. Halden, J. D. Reist, A. H. Kristofferson, J. L. Campbell, and W. J. Teesdale. 1997. Evidence for non-anadromous behavior of Arctic charr (*Salvelinus alpinus*) from Lake Hazen, Ellesmere Island, Northwest Territories, Canada, based on scanning proton microprobe analysis of otolith strontium distribution. Arctic 50: 224-233.

Babaluk, J. A., R. J. Wastle, and M.A. Treble. 2001. Results of tagging and biological studies in the lower Mackenzie River, Northwest Territories, conducted during 1992 and 1993 Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 2387, Winnipeg.

Baxter, R. 1973. Whitefish of the Yukon - Kuskokwim Rivers. *Coregonus pidschian*, Pallas 1777, Humpback whitefish Unpublished data/notes.

Baxter, R. 1973. Whitefish of the Yukon - Kuskokwim Rivers. *Coregonus nasus*, Pallas 1777, Broad whitefish Unpublished data/notes.

Baxter, R. 1974. Fish of the Yukon – Kuskokwim Delta, Alaska. *Coregonus sardinella* Valenciemnnes, 1848, Least Cisco. Unpublished mimeo/notes.

Baxter R. 1975 Whitefish Investigations of the Yukon – Kuskokwim Delta. Unpublished mimeo 41 pgs.

Bond, W. A., and R. N. Erickson. 1985. Life history studies of anadromous coregonid fishes in two freshwater lake systems on the Tuktoyaktuk Peninsula, Northwest Territories. Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1336, Winnipeg.

Bond, W. A., and R. N. Erickson. 1993. Fisheries investigations in coastal waters of Liverpool Bay, Northwest Territories. Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 2204, Winnipeg.

Brelsford, T., R. Petersen, and T.L. Haynes. 1987. An overview of resource use in three central Kuskokwim River communities, Aniak, Crooked Creek, and Red Devil. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper 141, Fairbanks

Brown, R.J. 2000. Migratory patterns of Yukon River inconnu as determined with otoliths microchemistry and radio telemetry. Master's Thesis, University of Alaska, Fairbanks, Alaska.

Brown, R.J. 2004. A biological assessment of whitefish species harvested during the spring and fall in the Selawik River Delta, Selawik National Wildlife Refuge, Alaska. U.S. Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 77.

Campana, S. E. 1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Mar. Ecol. Prog. Ser. 188: 263-297.

Campana, S. E., and 18 coauthors. 1997. Comparison of accuracy, precision, and sensitivity in elemental assays of fish otoliths using the electron microprobe, proton-induced X-ray emission, and laser ablation inductively coupled plasma mass spectrometry. Can. J. Fish. Aquat. Sci. 54: 2068-2079.

Chilton, D.E., and R.J. Beamish. 1982. Aging determination methods for fishes studies by the ground fish program at the pacific Biological Station. Canadian Special Publication of Fisheries and Aquatic Sciences 60.

Chang-Kue, K. T. J., and E. F. Jessop. 1992. Coregonid migration studies at Kukjuktuk Creek, A coastal drainage on the Tuktoyaktuk Peninsula, Northwest Territories. Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 1811, Winnipeg.

Chang-Kue, K. T. J., and E. F. Jessop. 1997. Broad whitefish radiotagging studies in the lower Mackenzie River and Adjacent coastal region, 1982-1993. p. 117-148. In R.F. Tallman and J.D. Reist. (eds) The proceeding of the broad whitefish workshop: the biology, traditional knowledge and scientific management of broad whitefish (Coregonus nasus (Pallus)) in the lower Mackenzie River. Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 2193, Winnipeg.

Clark, J. H., and D.R. Bernard. 1988. Fecundity of humpback whitefish and least cisco, Chatanika River, Alaska. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 77, Juneau.

Coffing, M. 1991. Kwethluk Subsistence: Contemporary Land Use Patterns, Wild Resource Harvest and Use, and the Subsistence Economy of a Lower Kuskokwim River Area Community. Alaska Department of Fish and Game, Division of Subsistence Technical Paper No. 157, Juneau.

Coffing M.W., L. Brown, G. Jennings, and C.J. Utermohle. 2001. The subsistence harvest and use of wild resources in Akiachak, Alaska, 1998. Alaska Department of Fish and Game Subsistence Division, Technical Paper No. 258 Juneau, Alaska

Darroch, J. N. 1961. The two-stage sample capture-recapture census when tagging and sampling are stratified. Biometrika 48: 241-260.

de Villiers, S. 1999. Seawater strontium and Sr/Ca variability in the Atlantic and Pacific oceans. Earth and Planetary Science Letters 171: 623-634.

Fleming, D. F. 1996. Stock assessment and life history studies of whitefish in the Chatanika River during 1994 and 1995. Alaska Department of Fish and Game, Fishery Data Series No. 97-36, Anchorage, Alaska.

Fleming, D. F. 1997. Stock assessment and life history studies of whitefish in the Chatanika River during 1996 and 1997. Alaska Department of Fish and Game, Fishery Data Series No. 97-36, Anchorage, Alaska.

Gates, K. S. and D.E. Palmer. 2004. Estimation of sockeye salmon escapement into McLees Lake, Unalaska Island, Alaska, 2003. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Report Number 2004-1, Kenai, Alaska.

Gallaway, B.J., R.G. Fechhelm, W.B. Griffiths, and J.G. Cole. 1997. Population dynamics of broad whitefish in the Prudhoe Bay region, Alaska. In James Reynolds ed. Proceedings of Fish Ecology in Arctic North America, American Fisheries Society Symposium #19, Fairbanks, Alaska pp 119-126.

Goldstein, J. I., D. E. Newbury, P. Echlin, D. C. Joy, C. E. Lyman, E. Lifshin, L. Sawyer, and J. R. Michael. 2003. Scanning electron microscopy and x-ray microanalysis, 3rd ed. Kluwer Academic/Plenum Publishers, New York.

Gunn, J.S., I.R. Harrowfield, C.H. Proctor, and R.E. Thresher. 1992. Electron probe microanalysis of fish otoliths-evaluation of techniques for studying age and stock discrimination. J. Exp. Mar. Biol. Ecol. 158: 1-36.

Haas, R.E. and C.W. Recksiek. 1995. Age verification of winter flounder in Narragansett Bay, Trans. Am. Fish. Soc. 124(1) 103-111.

Hallberg, J.E., K.T. Alt, and M.R. Doxey 1986. Annual Performance Report for Interior Whitefish Program. Federal Aid in Fish Restoration and Anadromous Fish Studies, Vol 27, Study W-8-1. Alaska Department of Fish and Game, Juneau, Alaska.

Harper, K. 1997. Run timing and abundance of adult salmon in the Tuluksak River, Yukon Delta National Wildlife Refuge, Alaska, 1994. U.S, Fish and Wildlife Service, Alaska Fisheries Technical Report number 41, Kenai, Alaska.

Harper, K. 1998. Run timing and abundance of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 1992. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number 44.

Harper, K. C., and C. B. Watry. 2001. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska 2000. U.S. Fish and Wildlife Service Alaska Fisheries Data Series Number 2001-4, Kenai, Alaska.

Harris, L., and K. Howland. 2004. Travaillant Lake fish movement study and population assessment 2003. Gwich'in Renewable Resource Board, Inuvik, NT.

Howland, K. L., W. M. Tonn, J. A. Babaluk, and R. F. Tallman. 2001. Identification of freshwater and anadromous inconnu in the Mackenzie River system by analysis of otolith strontium. Trans. Am. Fish. Soc. 130: 725-741.

Howland, K. L., M. Gendron, W. M. Tonn, and R. F. Tallman. 2004. Age determination of a long-lived coregonid from the Canadian North: comparison of otoliths, fin rays and scales in inconnu (Stenodus leucichthys). Ann. Zool. Fennici 41: 205-214.

Longhurst, A. 2002. Murphy's law revisited longevity as a factor in recruitment to fish populations. Fisheries Research 56: 125-131.

Martin, J-M, and M. Meybeck. 1979. Elemental mass-balance of material carried by major world rivers. Marine Chemistry 7: 173-206.

Mecklenburg C.W., T.A. Mecklenburg and L.K. Thorsteinson. 2000. Fishes of Alaska. American Fisheries Society, Bethesda, Maryland.

Morin, R., J.J. Dodson, and G. Power. 1982. Life history variations of anadromous cisco *Coregonus artedii*, lake whitefish *Coregonus clupeaformis,* and round whitefish *prosopium cylindraceum* populations of Eastern James-Hudson Bay. Canadian Journal of Fisheries and Aquatic Sciences. 39: 958-967

Moulton, L.L, L.M. Philo, and J.C. George. 1997. Some reproductive characteristics of least ciscoes and humpback whitefish in Dease Inlet, Alaska. In James Reynolds ed. Proceedings of Fish Ecology in Arctic North America, American Fisheries Society Symposium #19, Fairbanks, Alaska pp 119-126.

Musick, J.A. 1999. Ecology and conservation of long-lived marine animals. In J.A. Musick ed. Life in the Slow Lane: Ecology and Conservation of Long-Lived Marine Animals, American Fisheries Society Symposium # 23.

Potts, P. J. 1987. A handbook of silicate rock analysis. Chapman & Hall, London.

Reed, S. J. B. 1997. Electron microprobe analysis, 2nd ed. Cambridge University Press, Cambridge, Massachusetts.

Reist, J.D. 1997. Stock structure and life history types of broad whitefish in the lower Mackenzie River basin- a summary of research, p. 85-96. In R.F. Tallman and J.D. Reist. (eds) The proceeding of the broad whitefish workshop: the biology, traditional knowledge and scientific management of broad whitefish (Coregonus nasus (Pallus)) in the lower Mackenzie River. Department of Fisheries and Oceans, Canadian Technical Report of Fisheries and Aquatic Sciences, No. 2193, Winnipeg.

Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of Fish Populations. Bulletin of the Fishery Research Board of Canada 191.

Scoppettone, G.G., P. H. Rissler and M. E. Buettner. 2000. Reproductive Longevity and Fecundity Associated with Nonannual Spawning in Cui-ui. Transactions of the American Fisheries Society 129: 658-669

Secor, D. H., J. M. Dean, and E. H. Laban. 1992. Otolith removal and preparation for microstructural examination. Pages 19-57 *in* D. K. Stevenson, and S. E. Campana, editors, Otolith microstructure examination, and analysis. Canadian Special Publication of Fisheries and Aquatic Science, no. 117.

Sokal, R. R., and F.J. Rohlf. 1981. Biometry, 2nd edition. W.H. Freeman and Company, New York.

Thera, T.M. 1996. A quantitative life-cycle model to identify research priorities and test management strategies for the Mackenzie River broad whitefish (Coregonus nasus). Masters thesis University of Manitoba.

Ward, T. C., M. Coffing, J. L. Estensen, R. L. Fisher and D. B. Molyneaux. 2003. Annual Management Report for the Commercial Fisheries of the Kuskokwim Area, 2002. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 3A03-27, Anchorage Alaska.

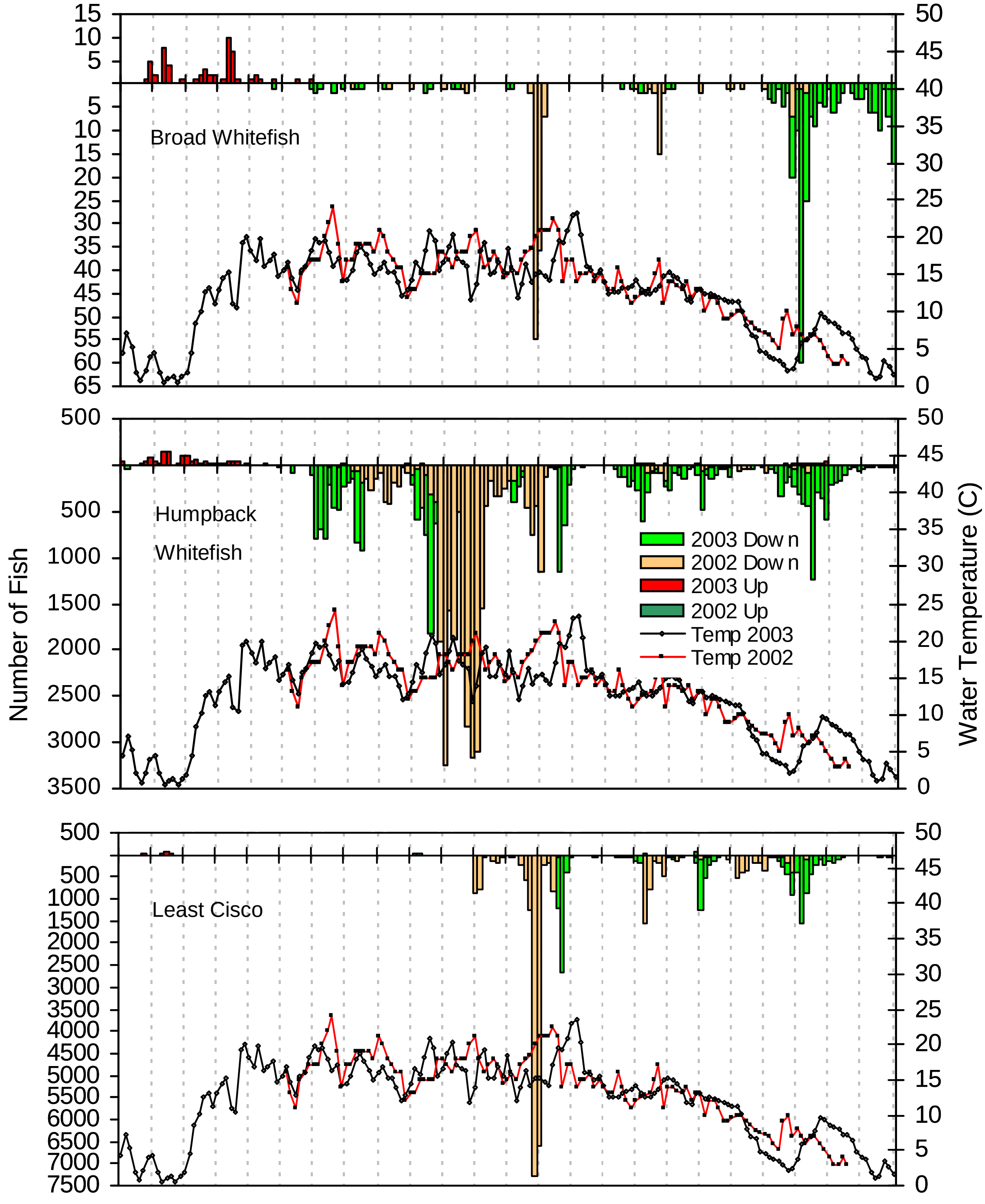

FIGURE 3.–Broad and humpback whitefish and least cisco immigration (upper bars) and emigration (lower bars) counts at the Whitefish Lake weir in 2002 and 2003. Counts in 2002 did not start until 16 June. Temperature recorded at the outlet of the lake.

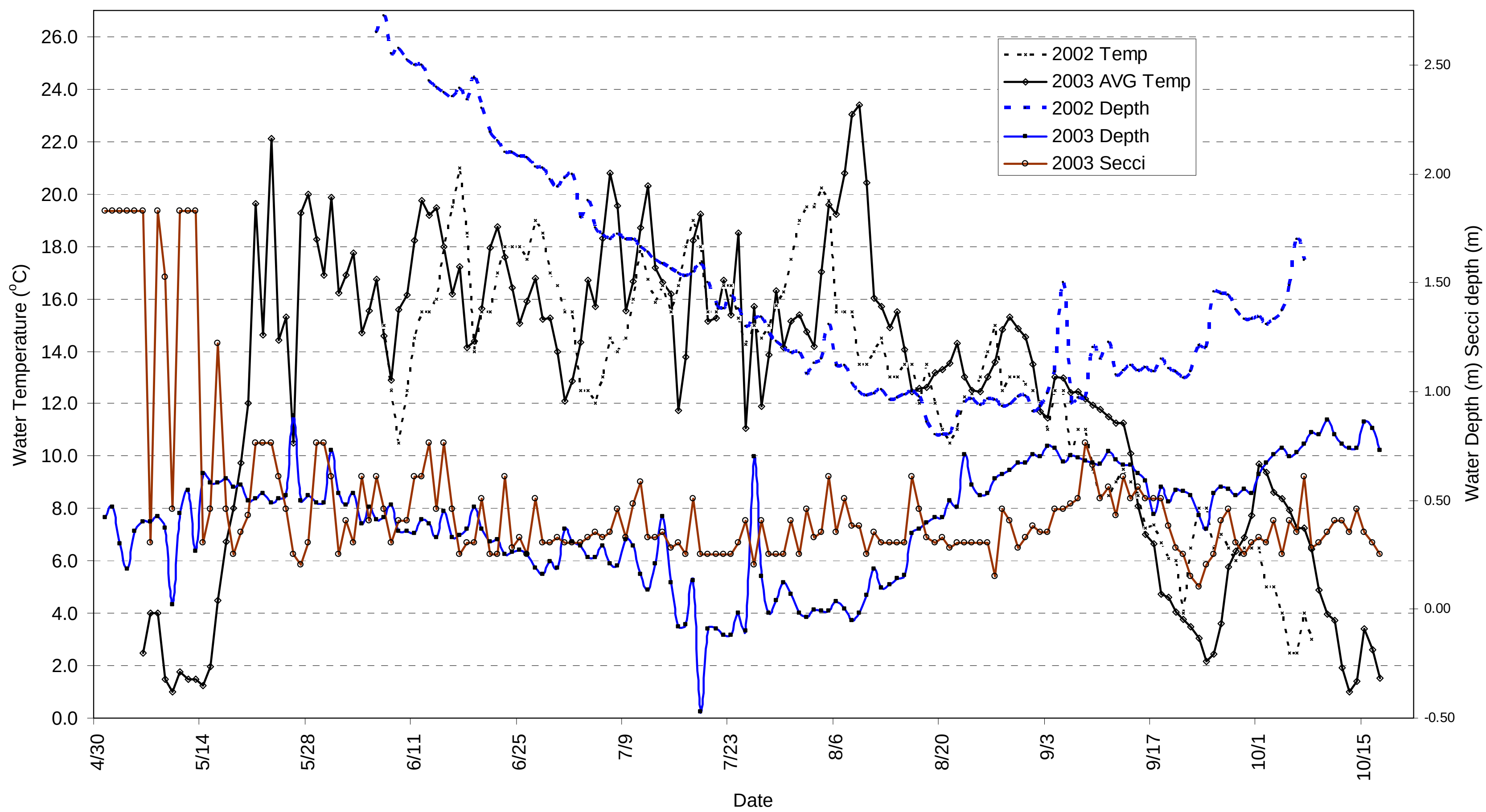

FIGURE 4.–Temperature, relative stage height and water clarity (secchi disk) data, from Whitefish Lake, 2002 and 2003

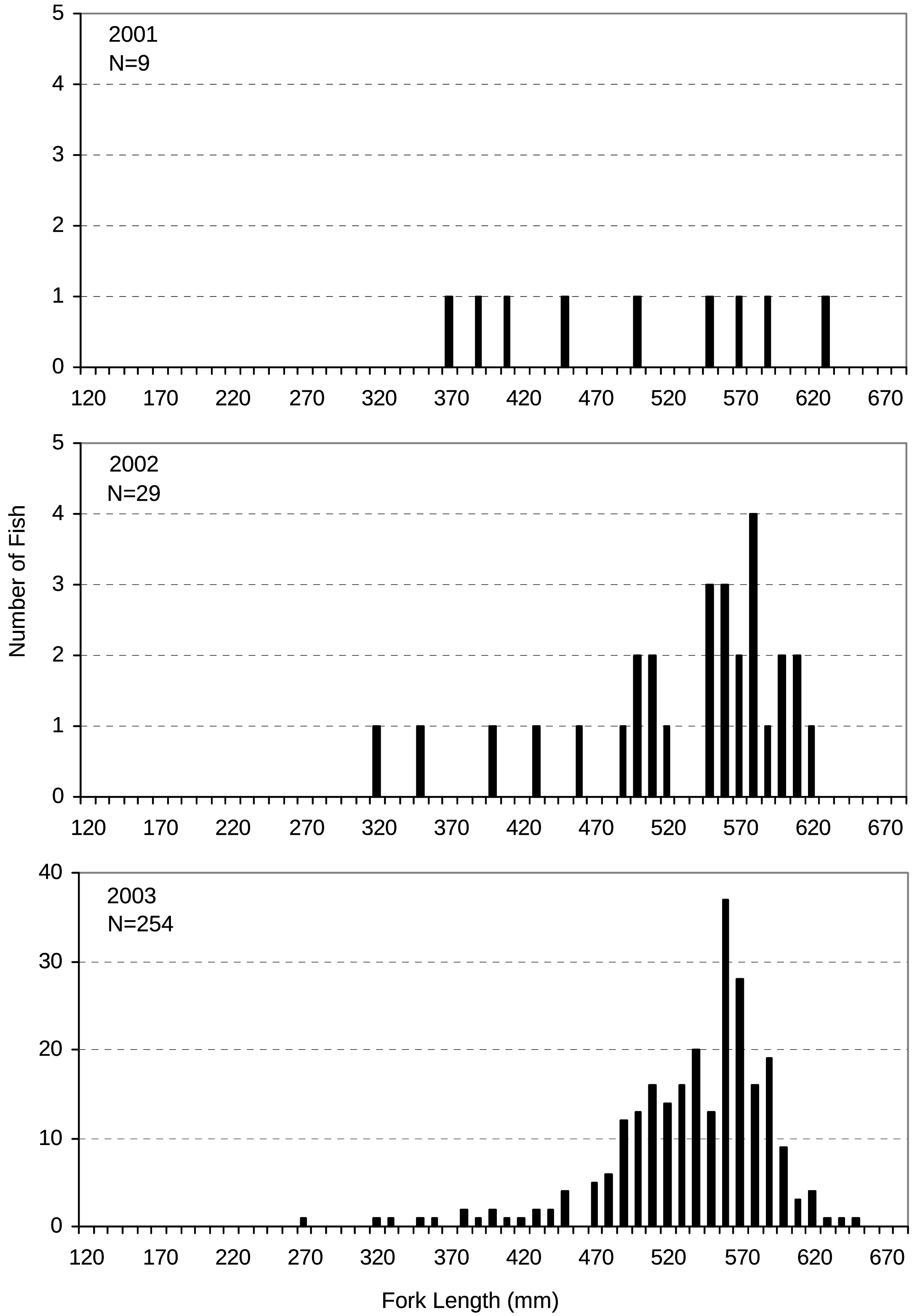

FIGURE 5.–Length composition of broad whitefish sampled at Whitefish Lake weir, 2001, 2002, and 2003.

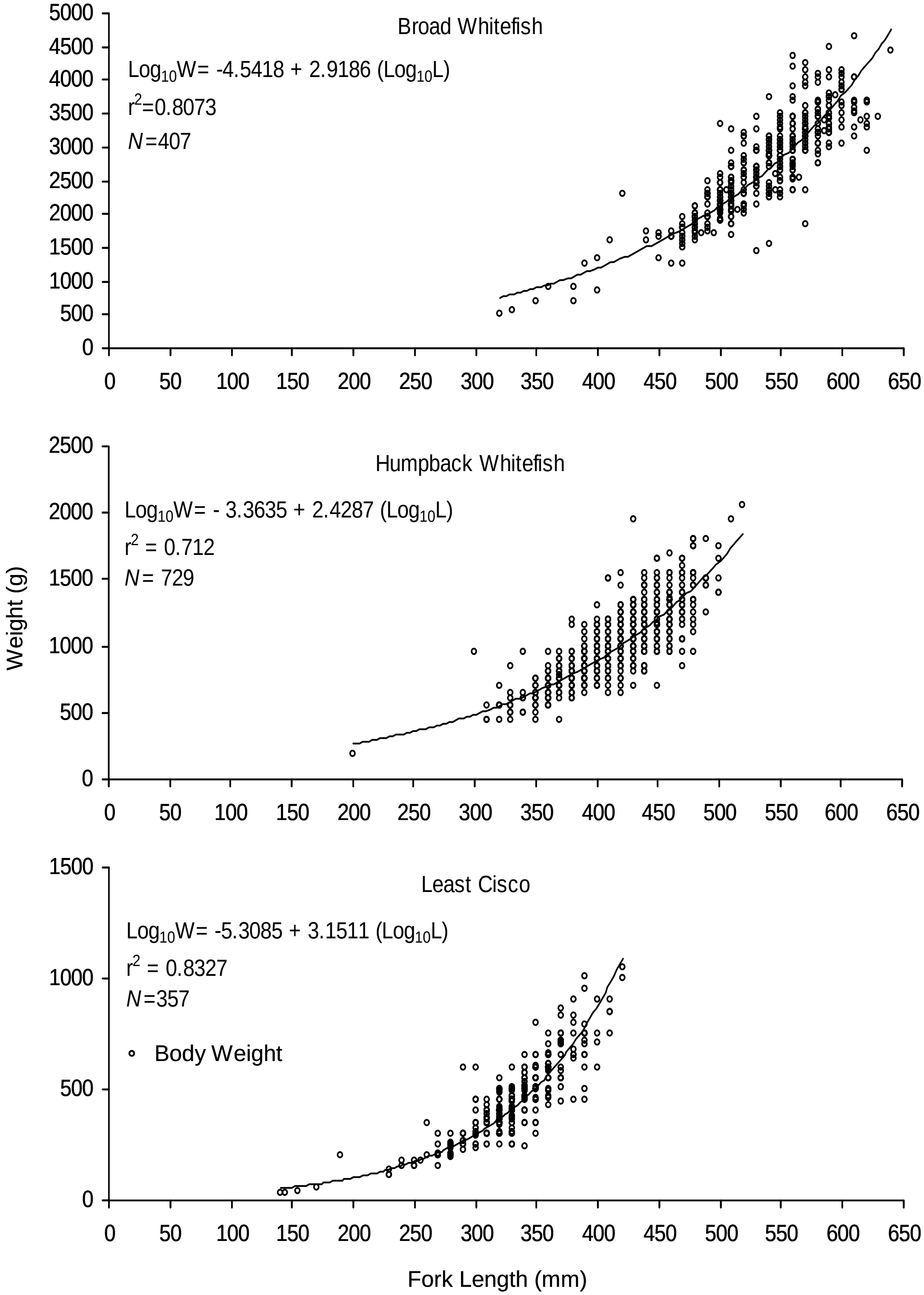

FIGURE 6.–Relationship of length to weight of broad and humpback whitefish and least cisco sampled at Whitefish Lake 2001-2003.

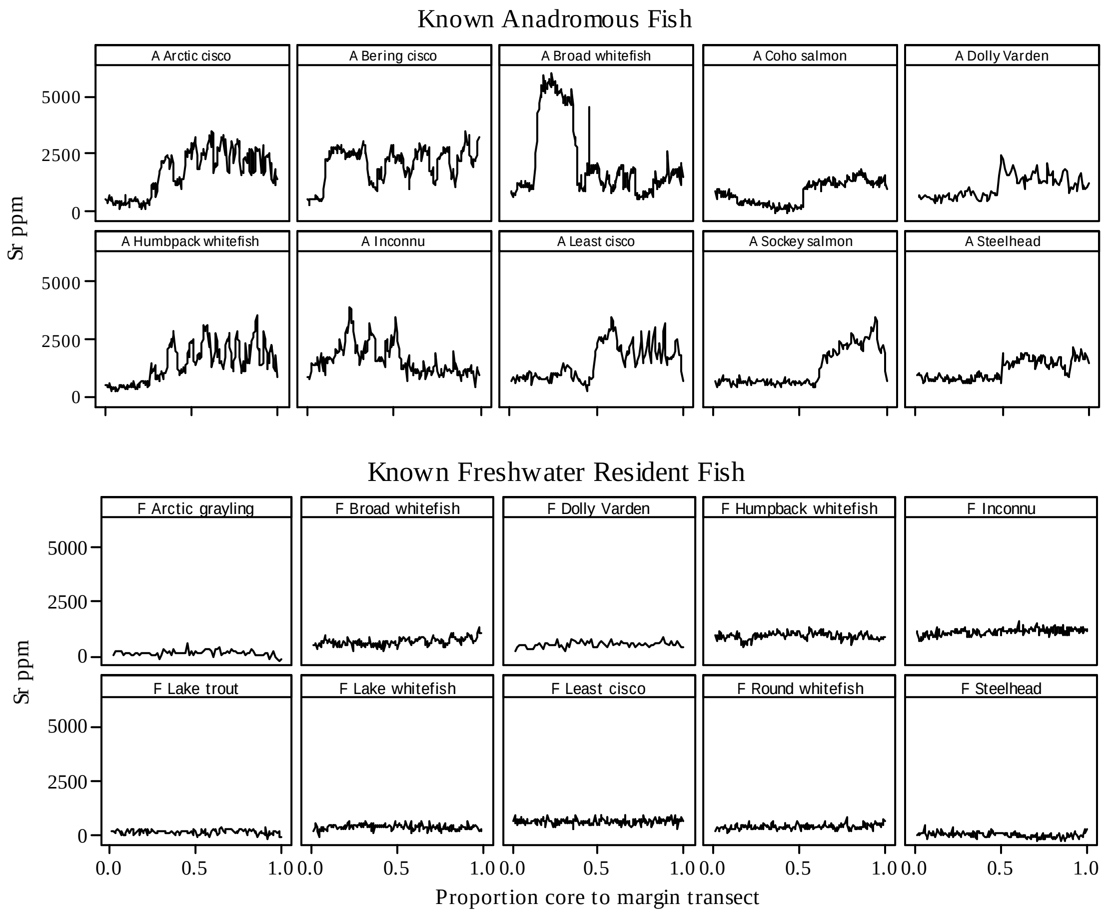

FIGURE 7.–Graphs of otolith Sr distribution along core to margin transects of 10 known anadromous fish (top two rows) and 10 known freshwater resident fish (bottom two rows) presented to aid in classifying samples of unknown life history least cisco, humpback whitefish, and broad whitefish captured in Whitefish Lake.

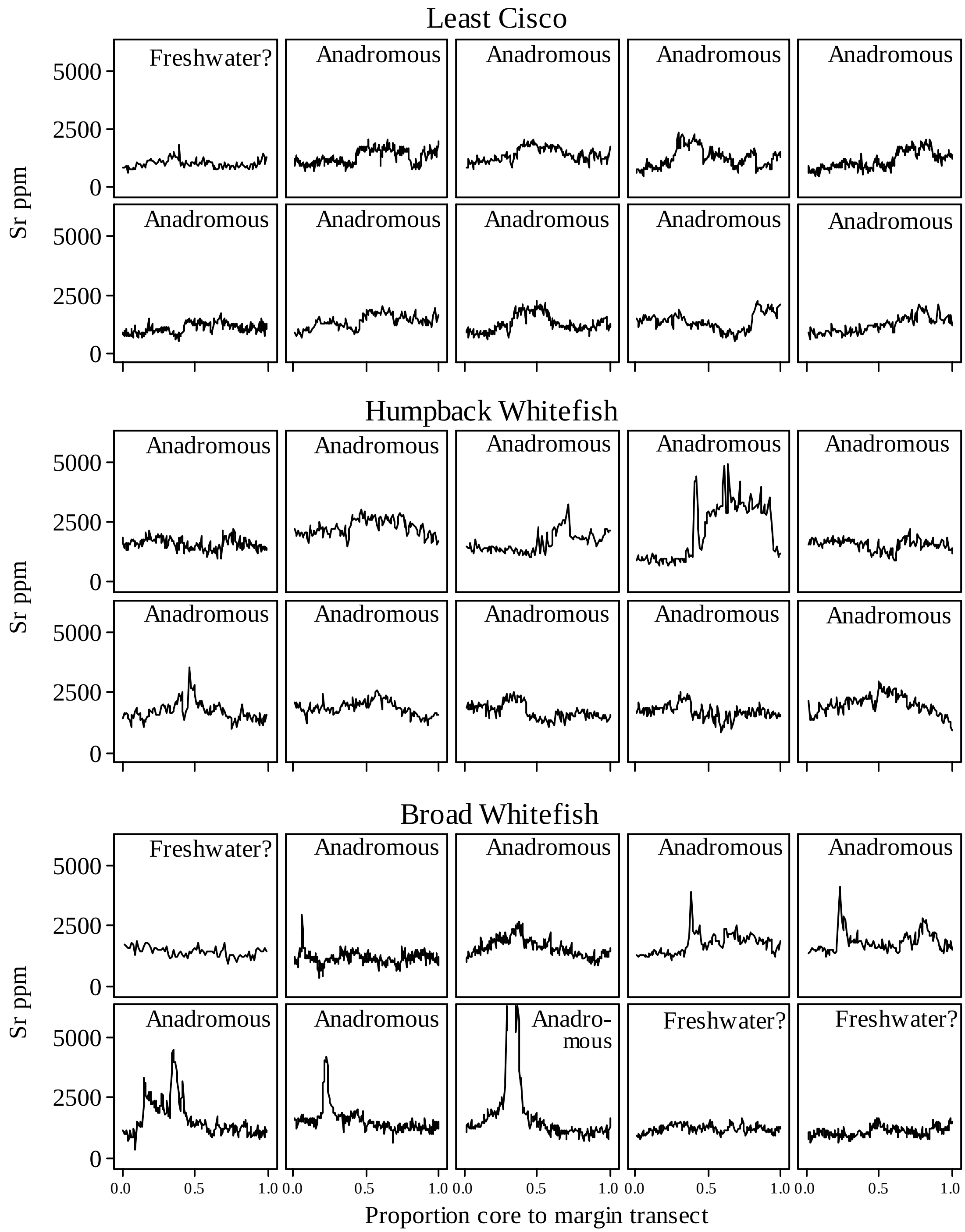

FIGURE 8.–Graphs of otolith Sr distribution along core to margin transects from 10 samples each of least cisco (top two rows), humpback whitefish (middle two rows), and broad whitefish (bottom two rows) from Whitefish Lake.

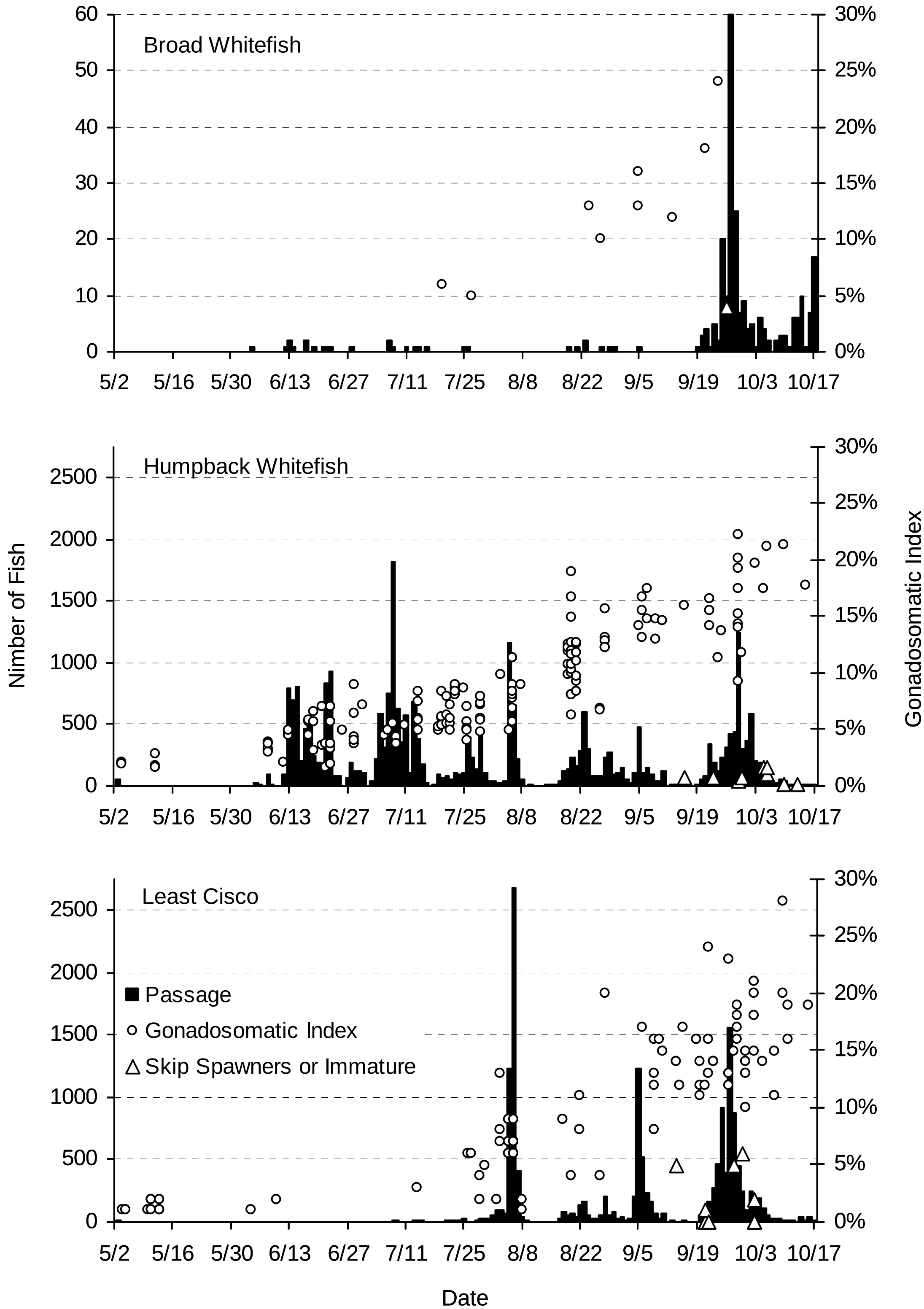

FIGURE 9.–Relationship of gonadosomatic index with broad and humpback whitefish and least cisco fish passage, Whitefish Lake.

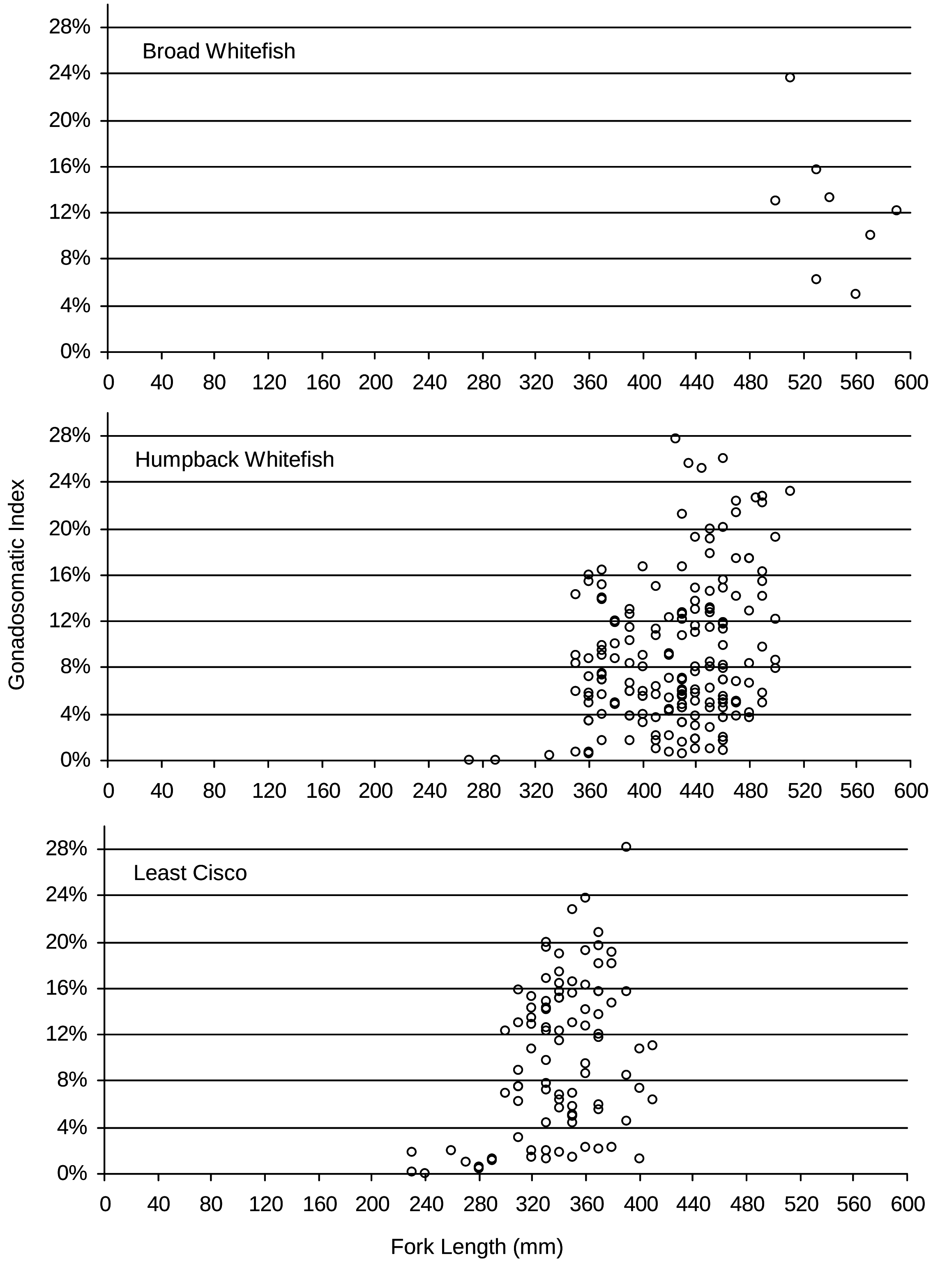

FIGURE 10.–Relationship of gonadosomatic index to length of broad and humpback whitefish and least cisco, Whitefish Lake.

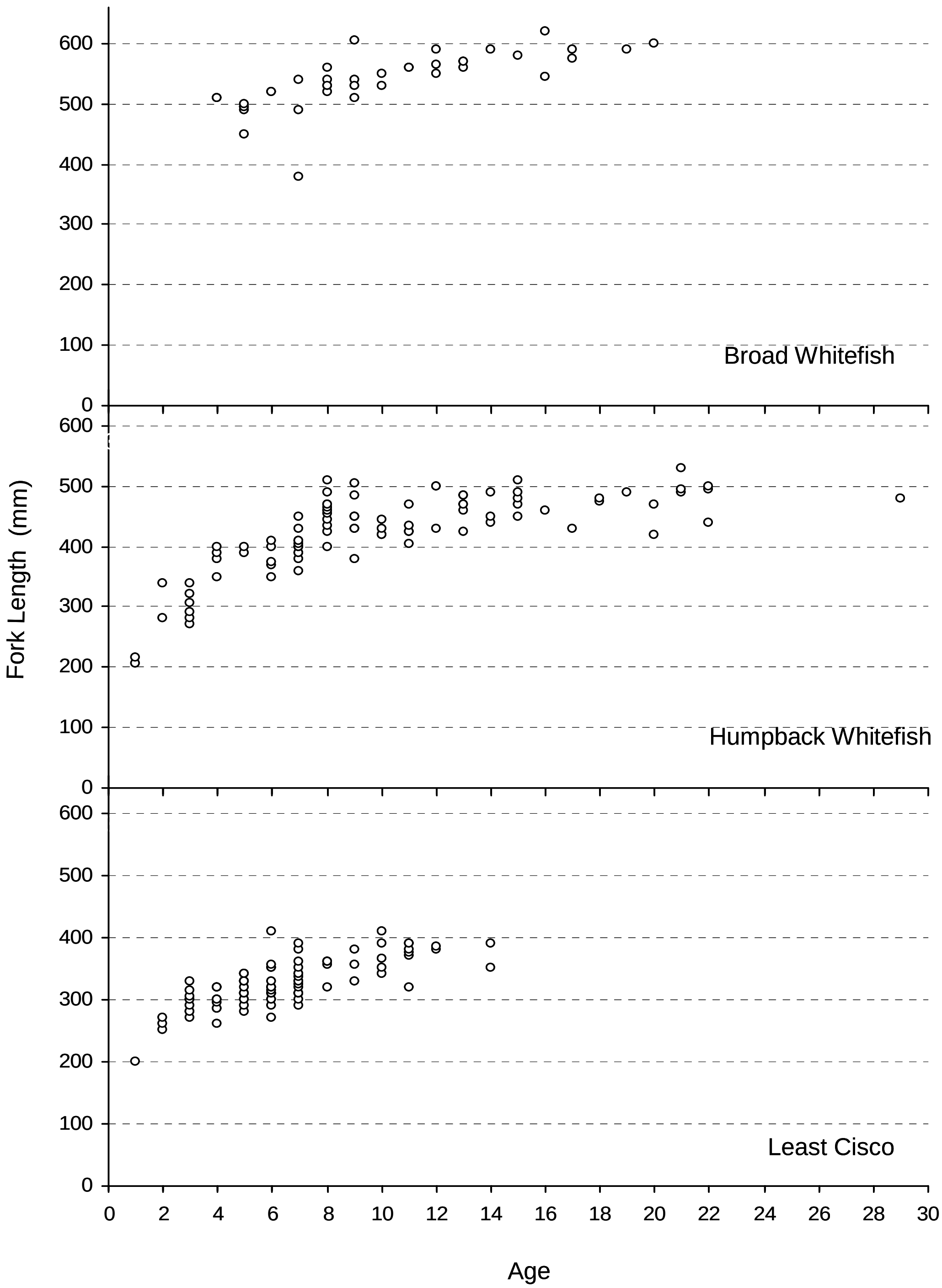

FIGURE 11.–Length at age for broad and humpback whitefish and least cisco from Whitefish Lake, 2001-2002.

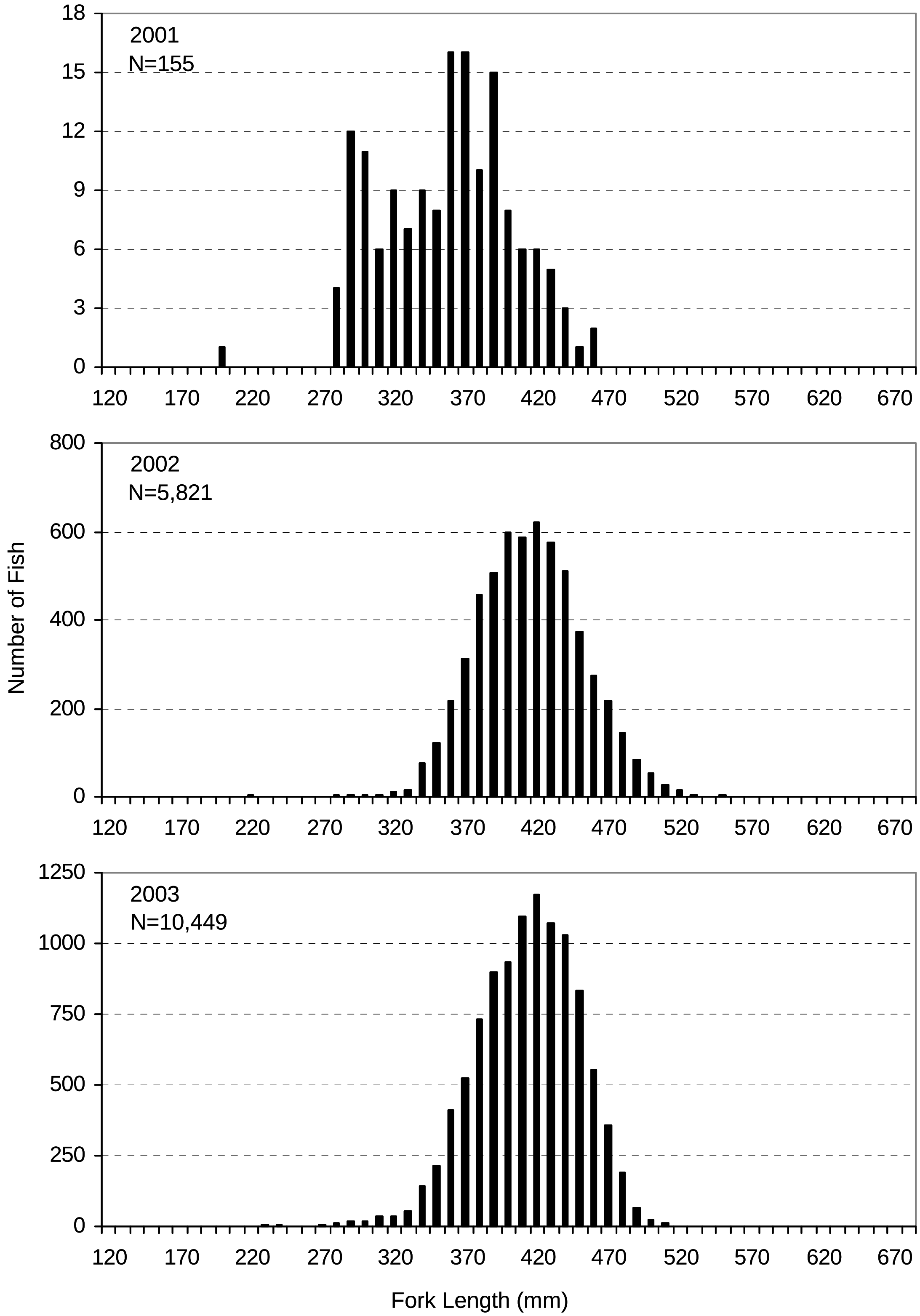

FIGURE 12.–Length composition of humpback whitefish sampled at Whitefish Lake weir, 2001, 2002, and 2003.

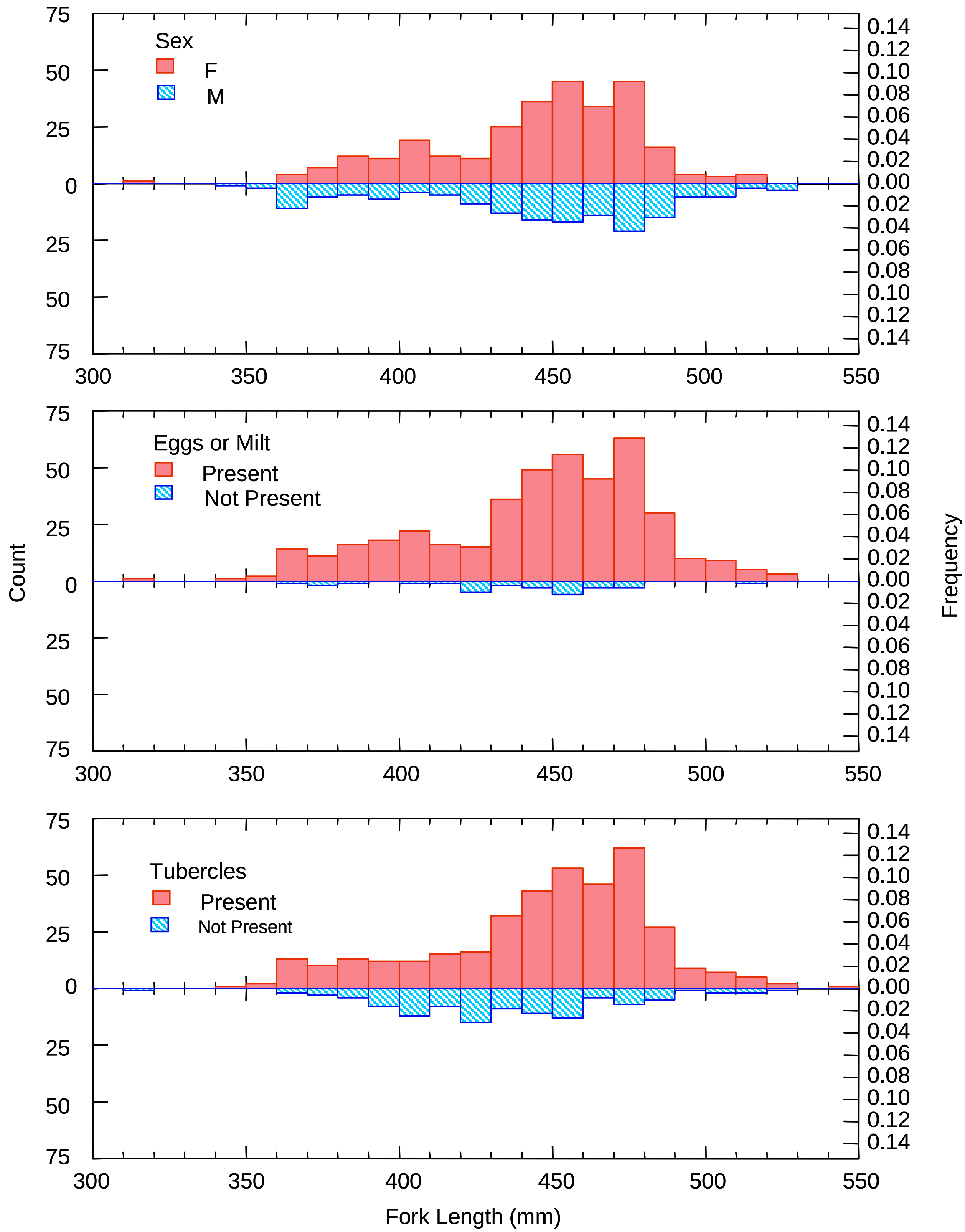

FIGURE 13.–Sex, maturity index, and presence of spawning tubercles of humpback whitefish harvested near Ophir Creek, the primary inlet of Whitefish Lake between October 1 and 16, 2003.

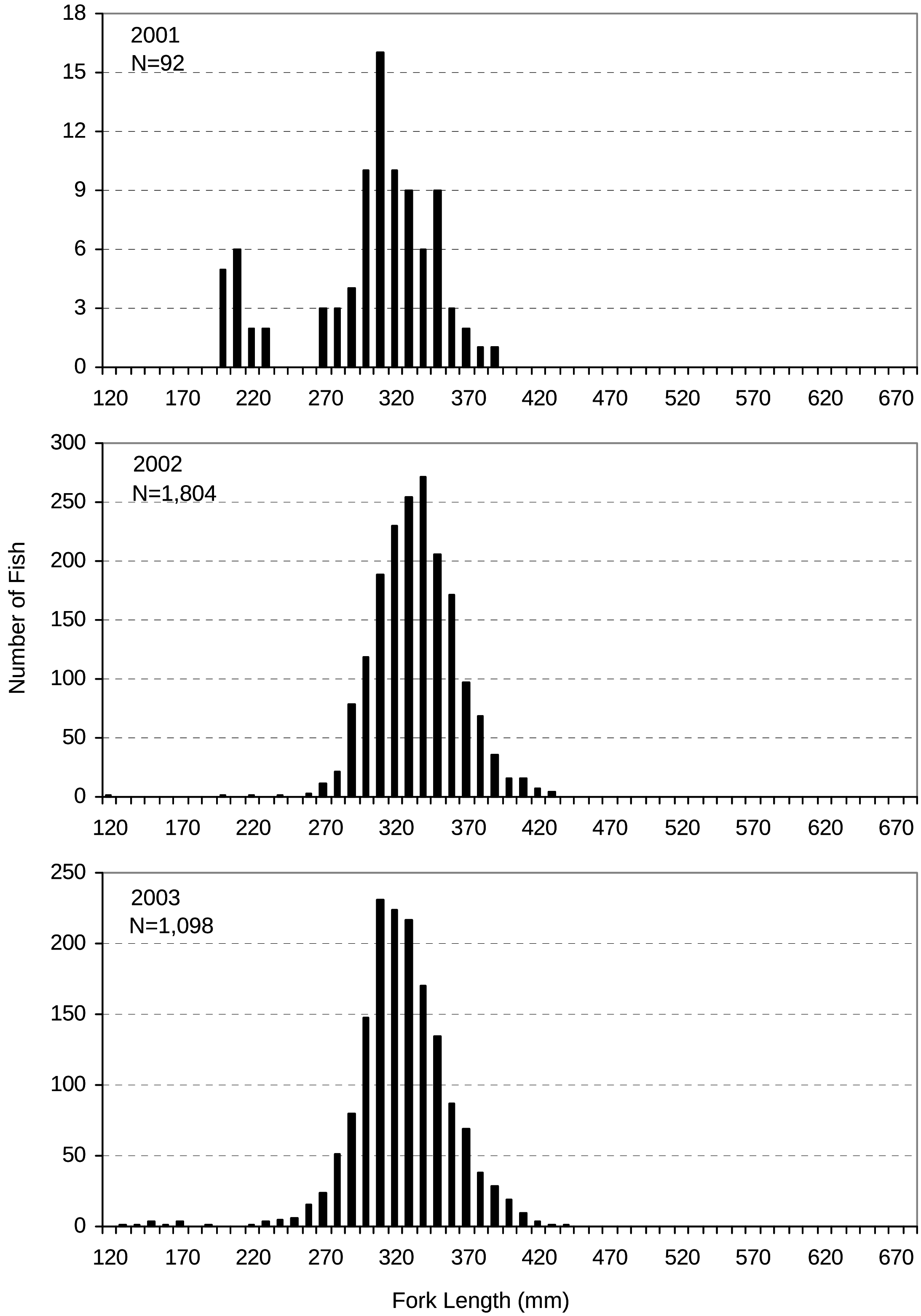

FIGURE 14.–Length composition of least cisco samples passing the Whitefish Lake weir, 2001, 2002, and 2003.

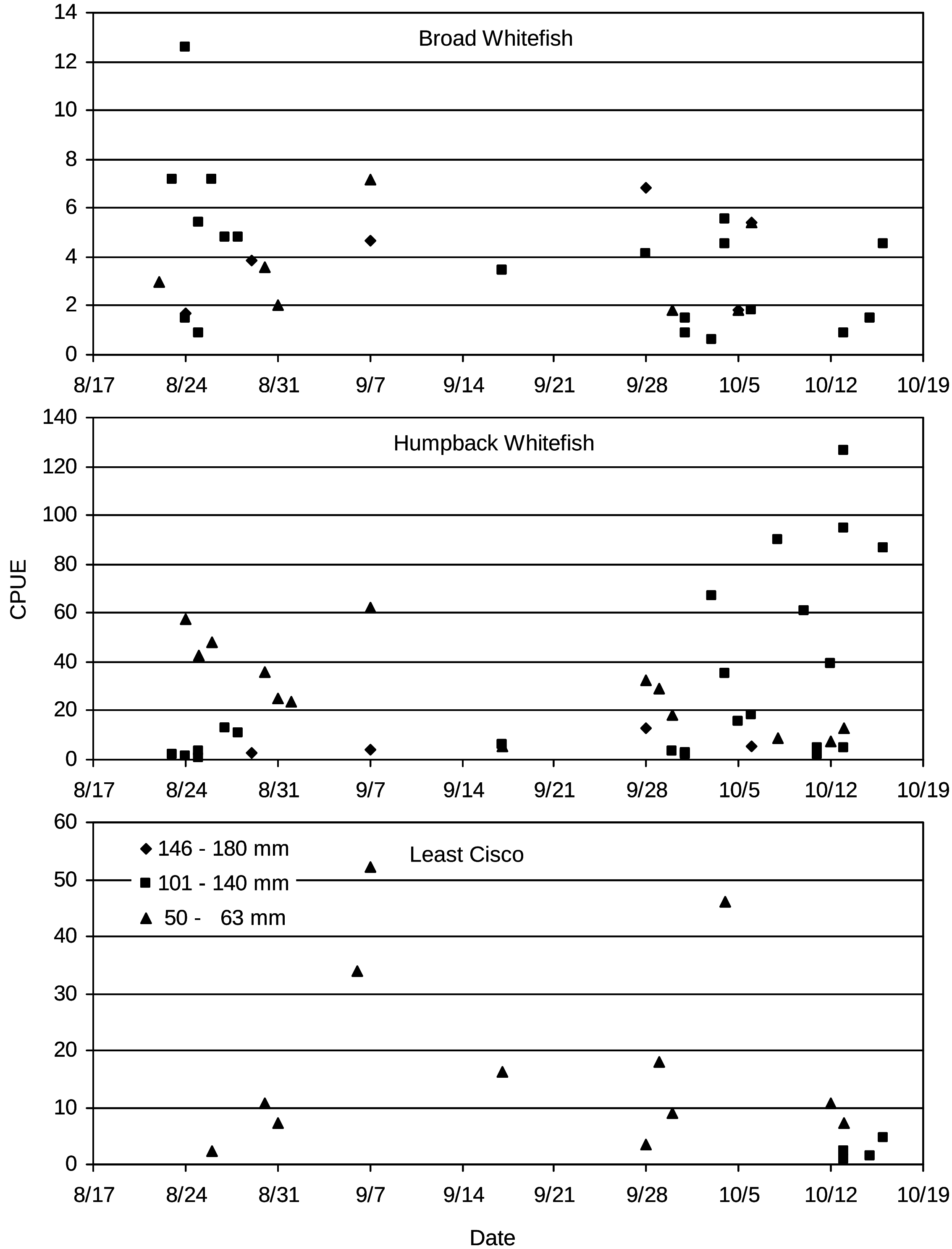

FIGURE 15.–Catch per Unit of Effort for broad and humpback whitefish and least cisco harvested in Whitefish Lake 2003. One unit of effort is equal to one net night, and 15 fathoms of net.

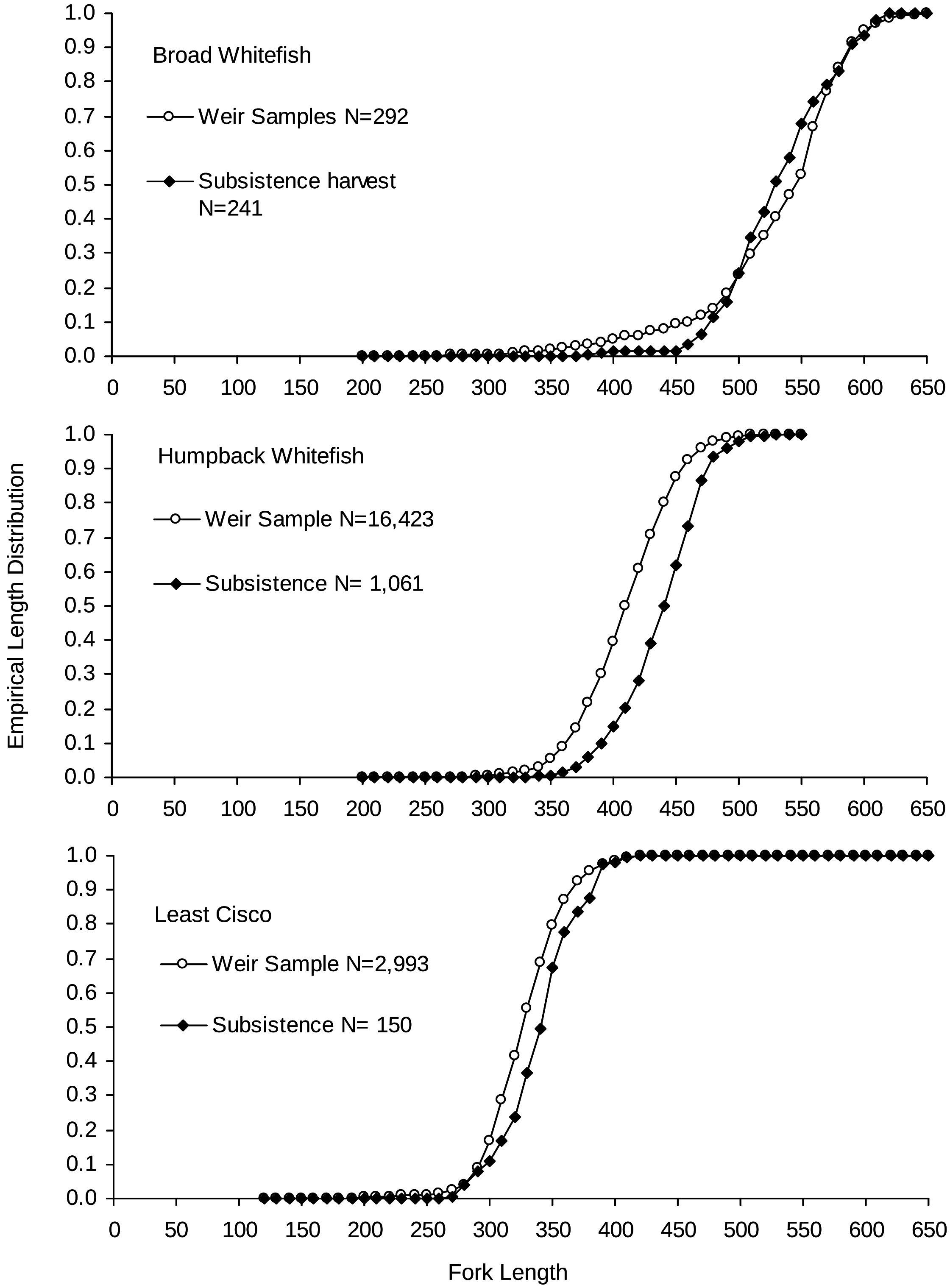

FIGURE 16.–Empirical distributions of the lengths of broad whitefish sampled at the weir and sampled for gonadosomatic index, subsistence harvests, and otolith samples.

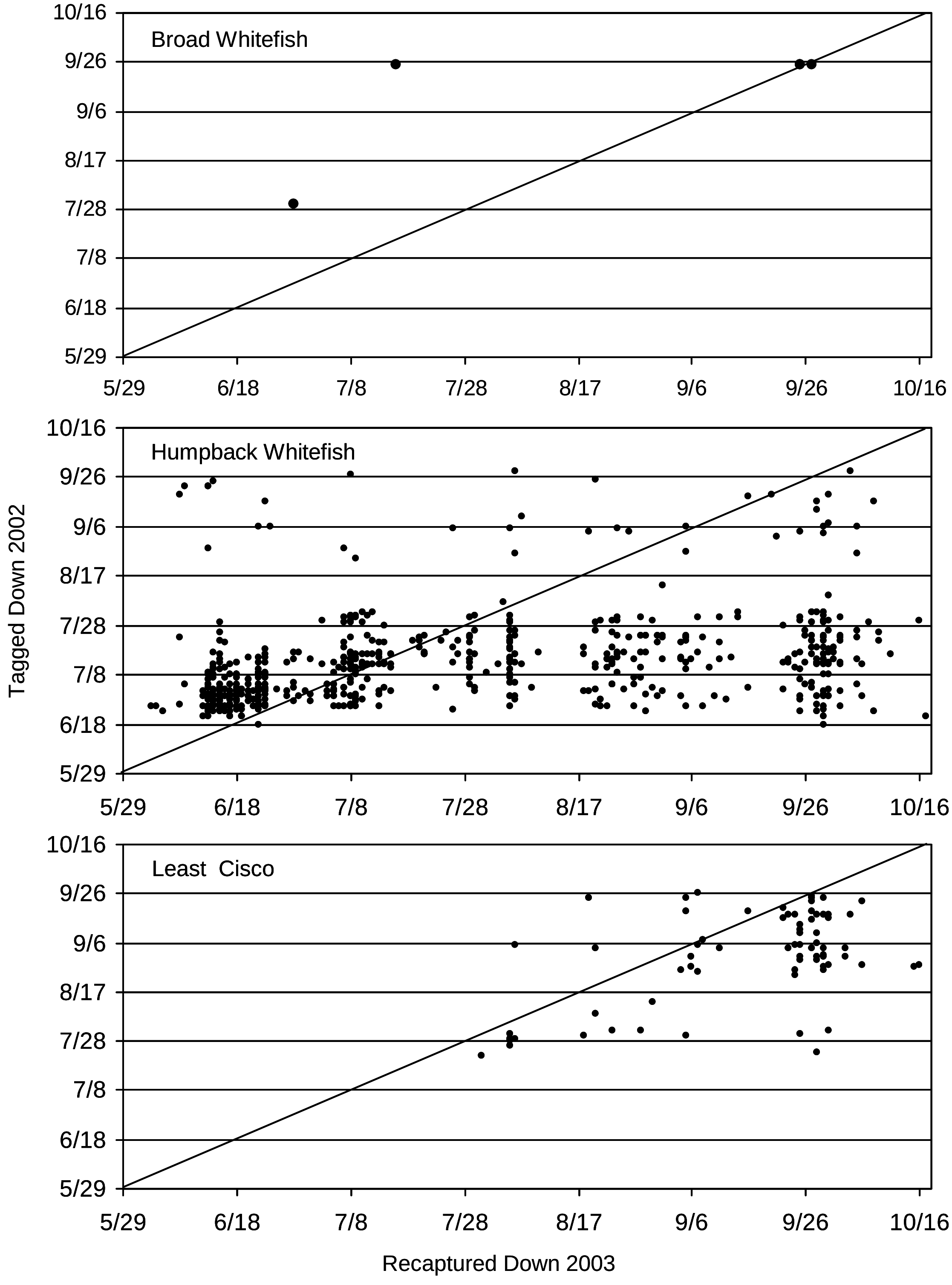

FIGURE 17.–Summary of 650 tagged and recaptured humpback whitefish out-migrating from Whitefish Lake, 2002 and 2003. Fish tagged while out-migrating during 2002 were recaptured while out-migrating in 2003. Fish out-migrating during the same week between years would fall on the diagonal.

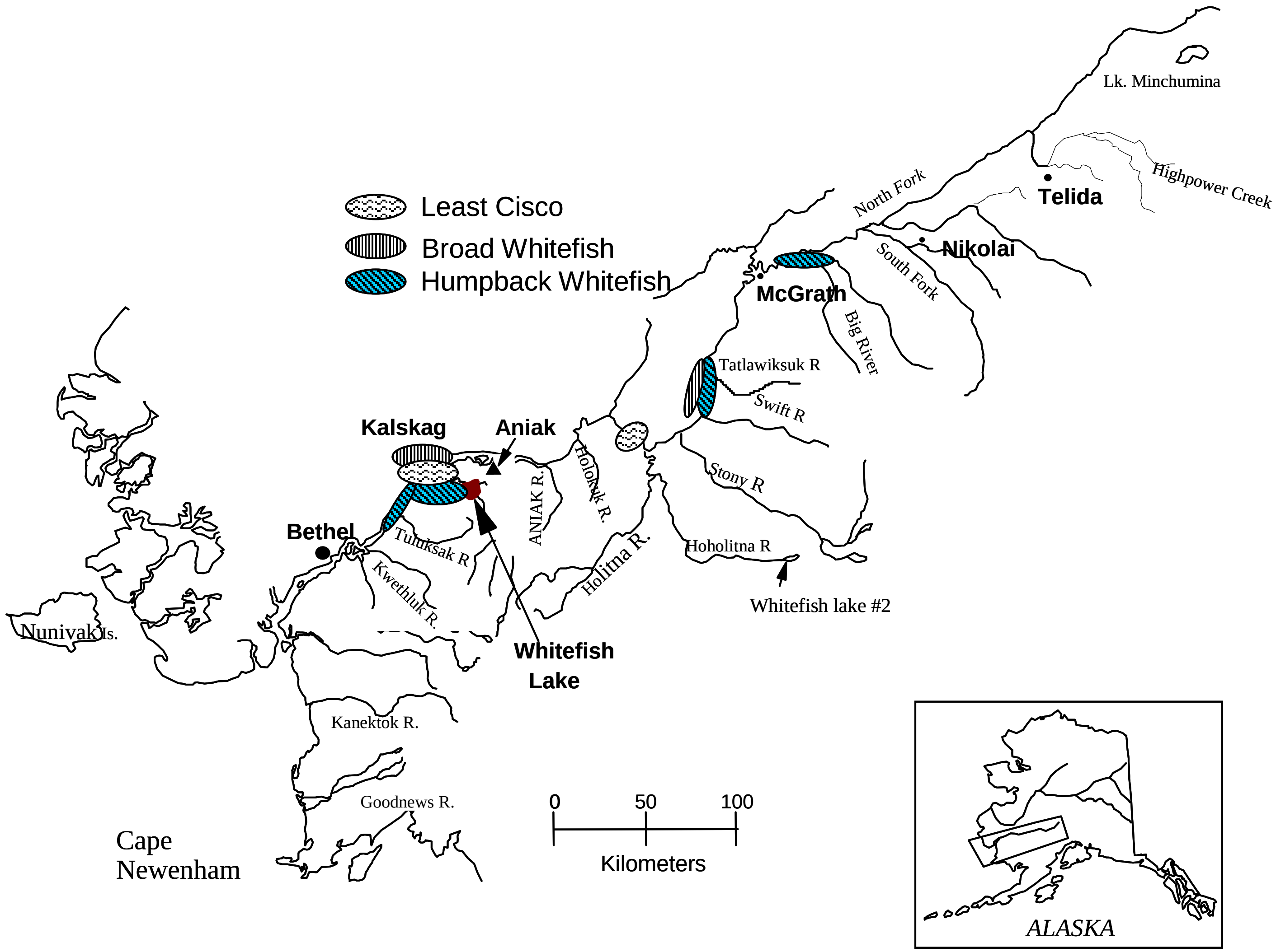

FIGURE 18.–Locations where broad and humpback whitefish and least cisco tagged in Whitefish Lake (2001-2003) have been harvested outside of the lake.

APPENDIX 1.–Daily passage of whitefish and other species into and out of Whitefish Lake 2001.

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
09/21	0	0	0	2	0	0	0	0	0	0	0	0	0	0
09/22	0	0	0	0	0	0	0	0	2	0	0	0	0	0
09/23	0	1	0	0	0	0	0	1	11	1	0	0	0	0
09/24	0	0	0	1	0	0	0	0	0	2	0	0	0	0
09/25	0	0	0	0	0	0	0	0	4	7	0	0	0	0
09/26	0	0	0	0	0	0	0	1	19	2	1	0	0	0
09/27	0	0	0	0	0	0	0	0	6	4	0	0	0	0
09/28	0	0	0	0	0	0	0	0	2	1	0	0	0	0
09/29	0	0	0	1	0	0	0	0	3	5	0	0	0	0
09/30	1	0	0	0	0	0	0	1	7	3	0	1	0	1
10/01	0	0	1	0	0	0	0	0	6	3	0	0	0	0
10/02	0	1	0	0	0	0	0	0	1	0	0	0	0	0
10/03	0	0	0	0	0	0	0	0	1	1	1	0	0	0
10/04	0	0	1	0	0	0	0	0	7	2	0	0	0	0
10/05	0	0	0	2	0	0	0	0	21	10	0	0	0	0
10/06	0	0	0	2	0	0	0	0	22	15	0	0	0	0
10/07	0	0	0	0	0	0	0	0	23	14	0	0	0	0
10/08	0	0	0	0	0	0	0	1	8	7	0	0	0	0
10/09	1	1	0	0	0	0	0	1	6	5	0	0	0	0
10/10	0	0	0	0	0	0	0	3	6	9	3	0	0	0
10/11	0	1	0	0	0	0	0	1	0	1	2	2	0	0
Totals:	2	4	2	8	0	0	0	9	155	92	7	3	0	1

APPENDIX 2.–Daily passage of whitefish and other species into and out of Whitefish Lake, 2002.

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
06/16	0	1	0	6	0	0	0	0	16	0	1	1	0	0
06/17	0	2	0	2	1	0	0	0	4	0	3	0	0	0
06/18	0	0	1	0	0	0	0	0	26	0	0	1	0	0
06/19	1	0	1	1	1	0	0	0	5	0	0	1	0	0
06/20	0	1	1	3	6	0	0	0	1	0	0	0	0	0
06/21	0	2	0	3	1	0	0	1	63	0	0	3	0	0
06/22	0	0	0	4	0	0	0	0	63	1	1	0	0	0
06/23	0	0	0	11	0	0	0	0	189	0	1	1	0	0
06/24	1	0	0	13	1	0	0	0	152	0	8	4	0	0
06/25	0	2	0	18	2	0	0	0	270	0	10	1	0	0
06/26	0	2	0	6	0	0	0	0	156	0	5	0	0	0
06/27	0	1	0	11	0	0	0	0	88	0	10	0	0	0
06/28	0	1	0	8	0	0	0	0	404	1	8	0	0	0
06/29	0	4	0	6	2	0	0	1	411	0	6	0	0	0
06/30	0	1	0	5	1	0	0	0	200	1	3	1	0	0
07/01	0	0	0	5	1	0	0	0	230	0	3	0	0	0
07/02	0	0	0	0	0	0	0	0	28	0	3	2	0	0
07/03	1	10	5	9	1	0	0	0	89	0	0	0	0	0
07/04	0	0	0	6	0	0	0	1	104	0	1	0	0	0
07/05	0	4	15	11	1	0	0	0	50	1	0	0	0	0
07/06	0	11	10	4	0	0	0	0	468	1	1	0	0	0
07/07[a]	0	0	0	4	0	0	0	0	114	0	0	0	0	0
07/08	0	2	1	8	0	0	0	0	319	0	3	0	0	0
7/9[b]	0	1	2	3	0	0	0	0	405	0	5	0	0	0
7/10[c]	0	0	0	5	0	0	0	0	1,900	0	2	1	0	0
7/11[d]	0	7	0	6	0	0	0	1	3,242	2	5	0	0	0
07/12	0	0	0	3	0	0	0	0	1,564	8	10	0	0	0
07/13	0	0	0	1	0	0	0	0	1,894	7	4	0	0	0
07/14	0	0	0	2	0	0	0	0	510	0	0	0	0	0
07/15	0	4	0	1	1	0	0	1	2,134	6	1	0	0	0

APPENDIX 2.–Daily passage 2002 (page 2 of 4)

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
07/16	0	0	0	0	0	0	0	2	2,833	25	18	0	0	0
07/17	0	0	0	2	0	0	0	0	3,165	33	1	0	0	0
07/18	0	0	0	0	0	0	0	0	3,111	866	10	0	0	0
07/19	0	0	0	0	0	0	0	0	1,550	778	1	0	0	0
07/20	0	0	0	0	0	0	0	0	451	55	2	8	0	0
07/21	0	0	0	0	0	0	0	0	168	3	0	1	0	0
07/22	0	0	2	0	0	0	0	0	341	121	1	4	0	0
07/23	0	0	1	1	0	0	0	0	346	196	3	6	0	0
07/24	0	3	1	0	0	0	0	0	252	40	0	0	0	0
07/25	0	0	0	0	0	0	0	0	176	22	1	3	0	0
07/26	0	0	0	0	0	0	0	0	177	62	1	4	0	0
07/27	0	0	0	1	0	0	0	0	4	21	0	0	0	0
07/28	0	0	2	1	1	0	0	0	72	244	0	1	0	0
7/29[e]	0	0	0	1	0	0	0	0	471	580	0	0	0	0
07/30	0	0	0	0	0	0	0	2	751	1,249	3	2	0	0
07/31[f]	0	0	0	0	0	0	0	55	436	7,281	2	0	0	0
08/01[g]	0	0	0	0	0	0	0	36	1,155	6,582	3	0	0	0
08/02	0	0	0	0	0	0	0	7	131	228	2	19	0	0
08/03	0	0	0	2	0	0	0	0	30	198	1	27	0	0
08/04	0	0	0	0	0	0	0	0	31	843	4	10	0	0
08/05	0	0	0	2	0	0	0	0	15	35	2	5	0	0
08/06	0	0	0	0	0	0	0	0	2	1	1	2	0	0
08/07	0	0	0	0	0	0	0	0	0	1	0	0	0	0
08/08	0	0	1	0	0	0	0	0	1	7	0	0	0	0
08/09	0	0	0	3	0	0	0	0	2	2	0	0	0	0
08/10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/11	0	1	0	1	0	0	0	0	1	1	0	0	0	0
08/12	0	0	1	0	0	0	0	0	1	2	0	0	0	0
08/13	0	0	0	0	1	0	0	0	5	35	0	0	0	0
08/14	0	0	0	0	0	0	0	0	1	1	0	0	0	0
08/15	0	0	0	0	0	0	0	0	0	19	0	2	0	0

APPENDIX 2.–Daily passage 2002 (page 3 of 4)

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
08/16	0	0	0	0	0	0	0	0	0	3	0	0	0	0
08/17	0	0	0	0	0	0	0	0	3	10	0	0	0	0
08/18	0	1	0	0	1	0	1	0	4	4	0	2	0	0
08/19	0	0	0	0	0	0	0	0	1	0	0	1	0	1
08/20	0	0	0	0	0	0	0	0	4	10	1	1	0	0
08/21	0	0	0	1	0	0	0	0	2	4	0	0	0	0
08/22	0	0	0	1	0	0	0	1	0	2	0	0	0	0
08/23	0	0	0	7	0	0	0	0	2	1	1	0	0	0
08/24	0	0	16	0	0	0	0	2	93	1,537	0	1	0	0
08/25	0	1	4	0	0	0	0	1	56	793	0	0	0	0
08/26	0	0	2	0	0	0	0	2	51	136	0	0	1	0
08/27	0	0	0	0	0	0	0	15	82	195	0	1	0	0
08/28	0	0	0	1	1	0	1	2	164	470	0	0	0	0
08/29	0	0	1	1	0	0	0	0	0	7	0	0	0	0
08/30	0	0	0	0	0	0	0	0	5	56	1	1	0	0
08/31	0	0	0	0	0	0	0	0	21	150	1	0	0	0
09/01	0	1	0	1	1	0	0	0	5	23	0	0	0	0
09/02	0	0	0	0	0	0	0	0	2	1	0	0	0	0
09/03	0	0	0	2	1	0	1	0	2	0	0	0	0	0
09/04	0	19	52	0	0	0	0	0	0	52	0	0	0	0
09/05	0	0	0	0	14	0	1	2	70	94	0	0	0	0
09/06	0	0	0	0	1	0	0	0	53	37	0	0	0	0
09/07	0	0	0	1	0	0	0	0	34	52	0	0	0	0
09/08	0	0	0	2	24	0	1	0	2	1	0	0	0	0
09/09	0	0	0	1	1	0	1	0	15	23	0	0	0	0
09/10	0	0	0	0	0	0	0	0	18	20	1	0	0	0
09/11	0	0	0	1	0	0	0	1	34	98	0	0	0	0
09/12	0	0	0	0	0	0	0	1	0	3	0	0	0	0
09/13	0	0	0	0	0	0	0	0	70	547	0	0	0	0
09/14	0	0	0	0	0	0	0	1	41	406	0	0	0	0
09/15	0	0	0	0	0	0	0	0	35	370	0	0	0	0

APPENDIX 2.–Daily passage 2002 (page 4 of 4)

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
09/16	0	0	0	0	0	0	0	0	12	25	0	0	0	0
09/17	0	0	0	0	0	0	0	0	13	181	0	0	0	0
09/18	0	0	1	0	0	0	0	0	16	171	0	1	0	0
09/19	0	0	0	0	0	0	0	1	86	336	0	0	0	0
09/20	0	0	0	0	0	0	0	0	5	14	0	0	0	0
09/21	0	0	1	0	0	0	0	0	6	16	0	0	0	1
09/22	0	0	0	0	0	0	0	0	8	43	1	1	0	0
09/23	0	0	0	0	0	0	0	0	8	51	0	0	0	0
09/24	0	0	0	0	0	0	0	0	14	164	0	0	0	0
09/25	0	0	0	0	0	0	0	7	43	401	0	1	0	0
09/26[h]	0	0	0	0	0	0	0	1	6	15	0	0	0	0
09/27[h]	0	0	0	0	0	0	0	1	31	26	2	0	0	0
09/28[h]	0	0	0	0	0	0	0	2	90	88	2	0	0	0
Totals:	3	82	121	198	65	0	6	147	31,985	26,195	156	120	1	2

[a] Trap left open, no counts from 00:00 to 08:00 . The number of fish that passed is unknown, but large numbers of humpback whitefish were present upstream of the weir
[b] Trap open, no counts from 00:00-08:00h. Estimated 100-200 humpback in trap when opened.
[c] Trap open, no counts from 00:00-10:00h. Estimated 1,000- 2,000 humpback may have passed.
[c] Trap open, no counts from 00:00-10:00h.
[d] 1,255 humpback passed 00:00-01:00h. Trap open, no counts 02:20-09:00h
[e] 00:00-02:00h 302 least cisco, 156 humpbck whitefish. Trap open, no counts 02:00-08:00h, unknown passage.
[f] Trap open, no counts from 00:00-0830h. Counts at end of day, 19:30-22:00h 2,073 least cisco, 182 humpback whitefish passed. 22:00-24:00h, 4,859 least cisco, 159 humpback, 55 broad whitefish passed.
[g] 00:00-02:00h 3,445 least cisco, 522 humpback and 35 broad whitefish passed downstream. 22:30-24:00h, 2,834 least cisco and 449 humpback whitefish and one broad whitefish passed. 00:00-00:30 on 8-2-02, no fish movement, no fish seen behind weir.
[h] Weir not fish tight. Storm surge caused scouring beneth panels.

APPENDIX 3.–Daily passage of whitefish and other species into and out of Whitefish Lake, 2003

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
05/02	0	31	3	17	0	0	0	0	3	0	1	0	0	0
05/03	0	6	1	9	0	0	0	0	52	8	4	0	0	0
05/04	0	2	2	4	0	0	0	0	4	2	4	0	0	0
05/05	0	0	0	0	0	0	0	0	0	0	0	0	0	0
05/06	0	17	0	4	0	0	0	0	0	0	0	0	0	0
05/07	1	39	10	5	0	0	0	0	6	0	0	0	0	0
05/08	5	91	1	13	0	1	0	0	0	0	0	0	0	0
05/09	2	48	5	1	0	2	0	0	0	0	0	0	0	0
05/10	0	16	0	7	0	0	0	0	0	0	0	0	0	0
05/11	8	141	23	12	0	1	0	0	0	0	0	0	0	0
05/12	4	139	51	2	0	2	0	0	0	0	0	0	0	0
05/13	0	6	16	0	0	2	0	0	0	0	0	0	0	0
05/14	0	24	1	1	0	0	0	0	0	0	0	0	0	0
05/15	1	93	3	1	0	0	0	0	2	0	0	0	0	0
05/16	0	106	1	1	0	0	0	0	0	0	0	0	0	0
05/17	0	32	2	10	0	0	0	0	0	0	0	0	0	0
05/18	1	64	4	10	0	0	0	0	0	0	0	0	0	0
05/19	2	26	0	3	0	0	0	0	0	0	0	0	0	0
05/20	3	46	1	3	0	0	0	0	1	0	0	0	0	0
05/21	2	25	0	4	0	0	0	0	0	0	1	0	0	0
05/22	2	9	0	2	0	0	0	0	4	1	4	0	0	0
05/23	0	19	0	3	0	0	0	0	3	0	3	0	0	0
05/24	1	14	0	2	0	0	0	0	0	0	1	0	0	0
05/25	10	40	0	6	0	0	0	0	0	0	1	0	0	0
05/26	7	41	6	8	0	0	0	0	0	0	1	0	0	0
05/27	1	32	0	5	0	0	0	0	0	0	1	0	0	0
05/28	0	7	0	10	1	0	0	0	0	0	0	0	0	0
05/29	0	18	0	1	0	0	0	0	0	0	0	0	0	0
05/30	1	5	0	3	0	0	0	0	0	0	2	0	0	0
05/31	2	4	0	0	1	0	0	0	1	0	4	0	0	0

APPENDIX 3.–Daily passage 2003 (page2 of 6)

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
06/01	1	6	0	2	2	0	0	0	0	0	0	0	0	0
06/02	0	14	0	4	9	0	0	0	2	0	1	0	0	0
06/03	0	1	0	2	0	0	0	0	4	0	3	0	0	0
06/04	1	0	0	1	0	0	0	1	6	0	1	0	0	0
06/05	0	0	0	5	9	0	0	0	21	0	0	0	0	0
06/06	0	1	0	2	1	0	0	0	7	0	0	0	0	0
06/07	0	1	0	0	0	0	0	0	5	0	0	0	0	0
06/08	0	3	0	0	9	0	0	0	92	0	0	0	0	0
06/09	1	0	0	6	2	0	0	0	10	0	4	0	0	0
06/10	0	0	0	1	0	0	0	0	0	0	1	0	0	0
06/11	0	2	0	0	2	0	0	0	1	0	0	0	0	0
06/12	1	0	0	1	0	0	0	1	98	0	3	0	0	0
06/13	0	1	0	1	0	0	0	2	793	2	3	0	0	0
06/14	0	0	0	1	0	0	0	1	701	1	0	0	0	0
06/15	0	1	0	4	0	0	0	0	807	1	2	4	0	0
06/16	0	1	0	2	0	0	0	0	206	0	3	0	0	0
06/17	0	5	0	0	2	0	0	2	468	0	1	2	0	0
06/18	0	0	0	0	0	0	0	0	489	0	1	0	0	0
06/19	0	9	0	6	0	0	0	1	242	0	2	0	0	0
06/20	0	1	0	3	3	0	0	0	192	0	0	1	0	0
06/21	0	0	0	5	1	0	0	1	153	0	0	0	1	0
06/22	0	5	0	2	4	0	0	1	840	1	0	7	1	0
06/23	0	0	0	3	0	0	0	1	929	1	4	0	0	0
06/24	0	1	0	2	0	0	0	0	83	0	0	0	0	0
06/25	0	0	0	1	0	0	0	0	83	0	0	0	0	0
06/26	0	0	0	0	0	0	0	0	2	0	0	0	0	0
06/27	0	0	0	1	0	0	0	0	74	0	1	0	0	0
06/28	0	4	0	1	0	0	0	1	195	0	3	0	0	0
06/29	0	5	0	3	0	0	0	0	123	0	0	0	0	0
06/30	0	0	0	0	0	0	0	0	122	0	2	0	0	0

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	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
07/01	0	0	0	0	0	0	0	0	115	0	0	1	0	0
07/02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/03	0	0	0	0	0	0	0	0	35	1	0	0	0	0
07/04	0	0	1	2	0	0	0	0	217	0	1	0	0	0
07/05	0	7	0	0	0	0	0	0	586	3	1	0	1	0
07/06	0	1	0	2	0	0	0	0	318	0	0	1	0	0
07/07	0	3	0	1	0	0	0	2	748	1	0	3	3	0
07/08	0	2	0	0	0	0	0	1	1,820	9	0	0	4	0
07/09	0	4	0	1	0	0	0	0	629	11	0	9	4	0
07/10	0	2	0	0	0	0	0	0	352	1	1	3	0	0
07/11	0	1	0	0	0	0	0	1	570	2	1	0	1	0
07/12	0	1	0	1	0	0	0	0	104	1	0	0	0	0
07/13	0	0	0	0	0	0	0	1	684	10	1	10	4	0
07/14	0	0	0	0	0	0	0	1	379	9	1	7	0	0
07/15	0	6	0	0	1	0	0	0	174	9	0	3	0	0
07/16	0	0	0	1	1	0	0	1	33	0	0	0	0	0
07/17	0	0	0	1	0	0	0	0	4	0	0	0	0	0
07/18	0	0	0	0	0	0	0	0	11	0	0	0	1	0
07/19	0	0	0	0	0	0	0	0	90	0	0	5	0	0
07/20	0	0	0	0	0	0	0	0	62	5	1	4	0	0
07/21	0	0	0	0	0	0	0	0	88	12	1	3	4	0
07/22	0	0	0	0	0	0	0	0	59	9	0	8	1	0
07/23	0	0	0	0	0	0	0	0	109	8	0	4	2	0
07/24	0	0	0	0	0	0	0	0	95	17	1	30	6	0
07/25	0	0	0	0	0	0	0	1	116	29	0	1	1	0
07/26	0	0	0	0	0	0	0	1	402	4	0	2	3	0
07/27	0	0	0	0	0	0	0	0	228	2	0	17	2	0
07/28	0	0	0	0	0	0	0	0	131	12	0	0	2	0
07/29	0	0	0	0	0	0	0	0	466	26	4	2	4	0
07/30	0	0	0	0	0	0	0	0	115	25	1	0	1	0
07/31	0	0	0	0	0	0	0	0	37	27	0	0	0	0

APPENDIX 3.–Daily passage 2003 (page 4 of 6)

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
08/01	0	0	0	0	0	0	0	0	41	52	0	0	1	0
08/02	0	0	0	0	0	0	0	0	34	91	2	0	0	0
08/03	0	0	0	0	0	0	0	0	31	93	0	0	0	0
08/04	0	0	0	0	0	0	0	0	40	62	0	0	1	0
08/05	0	0	0	0	0	0	0	0	1,157	1,226	1	0	2	0
08/06	0	0	0	0	0	0	0	0	661	2,679	0	0	0	0
08/07	0	0	0	0	0	0	0	0	213	405	1	0	1	1
08/08	0	0	0	0	0	0	0	0	50	38	0	0	0	1
08/09	0	0	0	0	0	0	0	0	6	16	0	0	0	0
08/10	0	0	0	0	0	0	0	0	17	3	0	1	1	0
08/11	0	0	0	0	0	0	0	0	1	1	0	3	0	0
08/12	0	1	0	2	0	0	0	0	0	0	1	0	0	0
08/13	0	0	1	1	0	0	0	0	4	1	0	0	0	0
08/14	0	0	0	1	0	0	0	0	7	2	0	0	0	0
08/15	0	0	0	0	0	0	5	0	7	0	0	0	1	1
08/16	0	0	0	1	0	0	1	0	13	0	0	0	1	1
08/17	0	1	1	2	0	1	31	0	35	26	0	1	0	2
08/18	0	0	0	0	0	0	10	0	121	76	1	1	1	3
08/19	0	2	0	0	0	2	14	1	134	54	0	1	1	1
08/20	0	5	0	0	0	0	6	0	237	66	0	1	1	0
08/21	0	6	0	0	0	0	6	1	169	46	0	0	0	1
08/22	0	21	1	1	0	0	8	0	281	141	0	0	0	61
08/23	0	21	2	0	0	0	43	2	605	165	2	2	0	7
08/24	0	8	1	1	0	0	0	0	297	61	1	0	1	0
08/25	0	13	0	0	0	0	5	0	88	28	0	0	0	1
08/26	0	7	1	0	0	0	2	0	81	33	0	0	0	0
08/27	0	7	0	1	0	0	5	1	77	54	0	0	1	0
08/28	0	9	0	2	0	0	2	0	228	203	0	3	1	2
08/29	0	0	0	0	0	0	0	1	273	56	0	2	0	4
08/30	0	0	0	2	0	0	0	1	96	80	0	3	0	2
08/31	0	2	1	4	0	0	1	0	103	26	0	0	0	0

APPENDIX 3.–Daily passage 2003 (page 5 of 6)

	Daily Upstream Passage							Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
09/01	0	5	0	0	0	0	2	0	152	37	0	1	0	3
09/02	0	2	0	0	0	0	0	0	49	12	0	2	0	0
09/03	0	0	0	0	0	0	0	0	25	25	0	0	0	0
09/04	0	3	1	1	0	0	0	0	105	204	0	1	0	0
09/05	0	1	1	1	0	0	0	1	475	1,237	0	1	0	0
09/06	0	0	2	1	0	0	0	0	106	523	1	0	0	0
09/07	0	0	2	2	0	0	0	0	145	238	0	1	0	0
09/08	0	0	0	0	0	0	0	0	100	159	1	2	0	0
09/09	0	1	0	1	0	0	0	0	40	64	1	0	0	0
09/10	0	0	1	0	0	0	16	0	40	28	0	1	0	2
09/11	0	1	0	0	0	0	13	0	128	70	0	0	0	0
09/12	0	1	0	0	0	0	0	0	4	0	0	0	0	0
09/13	0	0	0	1	0	0	0	0	15	8	0	0	0	0
09/14	0	1	0	0	0	0	0	0	13	5	0	0	0	0
09/15	0	1	0	0	0	0	0	0	6	0	0	0	0	0
09/16	0	0	0	0	0	0	0	0	52	8	0	0	0	0
09/17	0	1	0	0	0	0	0	0	0	2	0	0	0	0
09/18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09/19	0	0	0	1	0	0	0	1	17	4	0	0	0	0
09/20	0	2	0	0	0	0	0	3	50	52	0	0	0	0
09/21	0	3	0	0	0	0	0	4	79	39	0	0	1	0
09/22	0	4	0	0	0	0	0	1	337	163	0	0	0	0
09/23	0	12	5	0	0	0	0	5	192	279	0	0	0	0
09/24	0	2	1	2	0	0	0	2	118	460	1	0	0	0
09/25	0	15	4	0	0	0	0	20	231	923	0	2	2	0
09/26	0	17	4	0	0	0	0	10	312	403	0	0	2	0
09/27	0	9	5	1	0	0	0	60	425	1,561	0	0	12	0
09/28	0	14	8	1	0	0	37	25	436	870	2	2	3	5
09/29	0	12	0	0	0	0	21	7	1,241	447	0	1	3	9
09/30	0	16	2	0	0	0	17	9	306	248	1	1	0	0

APPENDIX 3.–Daily passage 2003 (page 6 of 6)

	Daily Upstream Passage								Daily Downstream Passage						
Date	Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon		Broad Whitefish	Humpback Whitefish	Least Cisco	Northern Pike	Longnose Sucker	Unidentified Coregonids	Coho Salmon
10/1	0	8	1	0	0	0	1		4	364	94	2	1	2	5
10/2	0	33	2	1	0	1	2		5	584	246	1	0	3	4
10/3	0	4	0	0	0	0	1		1	210	126	1	0	0	1
10/4[a]	0	5	0	1	0	0	4		6	187	187	1	0	1	12
10/5	0	0	3	0	0	0	4		4	166	103	0	0	1	3
10/6	0	1	1	0	0	0	0		2	117	57	0	0	0	2
10/7[b]	0	0	1	0	0	0	3		0	46	21	0	0	1	2
10/8	0	1	0	0	0	0	1		2	30	17	0	0	0	4
10/9	0	1	1	0	0	0	0		3	59	29	0	1	0	2
10/10	0	0	0	0	0	0	1		3	39	17	0	0	0	3
10/11	0	3	1	0	0	0	0		1	17	9	0	0	0	0
10/12	0	1	2	0	0	0	2		6	18	20	0	0	0	0
10/13	0	0	0	0	0	0	0		6	11	5	1	0	0	2
10/14	0	0	0	1	0	0	0		10	14	35	0	0	0	0
10/15	0	2	0	0	0	0	0		1	15	16	1	0	0	3
10/16	0	0	0	0	0	0	0		7	20	35	0	0	0	0
10/17	0	2	0	0	0	0	0		17	18	14	0	0	0	0
Totals:	57	1,516	187	248	48	15	264	0	254	27,822	15,134	99	162	91	150

[a] One sheefish passed downstream.
[b] One chum passed upstream.

The Alaska Region Fisheries Program of the U.S. Fish and Wildlife Service conducts fisheries monitoring and population assessment studies throughout many areas of Alaska. Dedicated professional staff located in Anchorage, Juneau, Fairbanks, Kenai, and King Salmon Fish and Wildlife Offices and the Anchorage Conservation Genetics Laboratory serve as the core of the Program's fisheries management study efforts. Administrative and technical support is provided by staff in the Anchorage Regional Office. Our program works closely with the Alaska Department of Fish and Game and other partners to conserve and restore Alaska's fish populations and aquatic habitats. Additional information about the Fisheries Program and work conducted by our field offices can be obtained at:

http://alaska.fws.gov/fisheries/index.htm

The Alaska Region Fisheries Program reports its study findings through two regional publication series. The **Alaska Fisheries Data Series** was established to provide timely dissemination of data to local managers and for inclusion in agency databases. The **Alaska Fisheries Technical Reports** publishes scientific findings from single and multi-year studies that have undergone more extensive peer review and statistical testing. Additionally, some study results are published in a variety of professional fisheries journals.