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Stock Assessment and Relative Age Validation of Humpback Whitefish and Least Cisco in the Chatanika River During 1993

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ABSTRACT

Stock assessment of humpback whitefish *Coregonus pidschian* and least cisco *Coregonus sardinella* occurred in a 78.2 km (48.9 miles) section of the Chatanika River, near Fairbanks, Alaska during August 1993. Mark-recapture experiments were utilized to estimate abundance of both species. The investigation was timed to correspond to the upstream spawning migration of both species, and to provide in-season estimates of abundance prior to the onset of a recreational spear fishery. An estimated 13,112 (SE = 1,096) humpback whitefish (≥360 mm FL) were present in the study area. The assessed stock was characterized by a high proportion of large humpback whitefish (≥430 mm FL) with ages 7, 8, and 9 predominating. An estimated 46,562 (SE = 5,971) least cisco (≥290 mm FL) were present in the study area. The majority of the assessed stock was between 310 and 350 mm FL, with ages 3, 4, and 5 most abundant. Survival of fully represented age classes between August 1992 and August 1993 ranged from approximately 47 to 53 percent for least cisco and humpback whitefish, respectively. Patterns of annual catches, migratory movements, and abundances were examined in the context of a non-consecutive spawning life history pattern found in other *corregonids* in Alaska and Canada. The ability to detect annular growth on scales of both species was evaluated using data from release-recapture studies. Annular growth, formed during a hiatus of one or more years, was correctly detected approximately 31% of the time with humpback whitefish, and 35% with least cisco.

KEY WORDS: humpback whitefish, *Coregonus pidschian*, least cisco, *Coregonus sardinella*, abundance estimation, age composition, length composition, spawning stock, survival, migratory movements, relative age validation, aging error, scales.

INTRODUCTION

Each year during summer and early fall, humpback whitefish *Coregonus pidschian* and least cisco *Coregonus sardinella* make large-scale movements into the Chatanika River to spawn (Figure 1). The Chatanika River is fed by runoff in the White Mountains northeast of Fairbanks, Alaska. It flows to the southwest, draining through the Minto Flats area, and into the Tolovana River which flows into the Tanana River. A significant recreational fall spear fishery for whitefish developed during the 1980's, primarily between the Elliott Highway Bridge and the Olnes Pond Campground, with a limited harvest taken along the Steese Highway. Estimates of whitefish harvests on the Chatanika River increased from 1,635 in 1977 to a high of 25,074 whitefish in 1987 (Mills 1979-1992).

In response to the rapid growth of the whitefish spear fishery and increasing harvests, stock assessments were initiated in 1986. Several methods of estimating abundance of whitefish, including sidescan sonar, counting towers, and mark-recapture experiments, were evaluated in 1986 and 1987 (Hallberg and Holmes 1987, Hallberg 1988). Based on those evaluations, mark-recapture experiments were chosen to estimate abundance. Electrofishing boats were used to capture whitefish for marking; creel surveys conducted during the spear fishery were used as the recapture event in 1988 and 1989 (Hallberg 1989, Timmons 1990). These early experiments were conducted in close proximity to the fishery, within a few kilometers of the Elliott Highway Bridge, which later proved problematic. In 1988, least cisco tagged in the vicinity of the Alyeska Pipeline crossing never entered the fishery, precluding an estimate of abundance for least cisco. In 1989, large numbers of least cisco and humpback whitefish were found well downstream of the previously studied areas. In the 1990 and 1991 assessments, investigations focused on assessing the geographic extent of the exploited population. Humpback whitefish and least cisco were found to be migrating upstream as early as July. Additionally, the previous assumption that the Alyeska Pipeline delimited the downstream extent of the exploitable portion of whitefish stocks was violated when fish tagged in the Goldstream Creek area of Minto Flats were later recovered far upstream in the Chatanika River (Timmons 1991).

Prompted by concern over increasing sport harvests of whitefish, in 1987 the Board of Fisheries restricted harvest of whitefish in the Tanana River drainage to a bag limit of 15 fish per day. Although estimated harvest of whitefish initially dropped during the 1988 season (Mills 1989), estimated harvest nearly doubled in 1989 while estimated fishing effort (days fished) for the Chatanika River changed little (Mills 1990). Further management actions have led to emergency closures during the 1990 season, and a complete closure in 1991 when a preliminary assessment indicated the need for conservation of the spawning stocks. Research efforts in 1991 confirmed preliminary estimates: abundance of humpback whitefish over a 110 km section of the river was estimated at only 15,313 fish, and these were mostly older fish (Timmons 1991). Board of Fisheries action in 1992 included additional regulations which shortened the season to one month and reduced the geographic

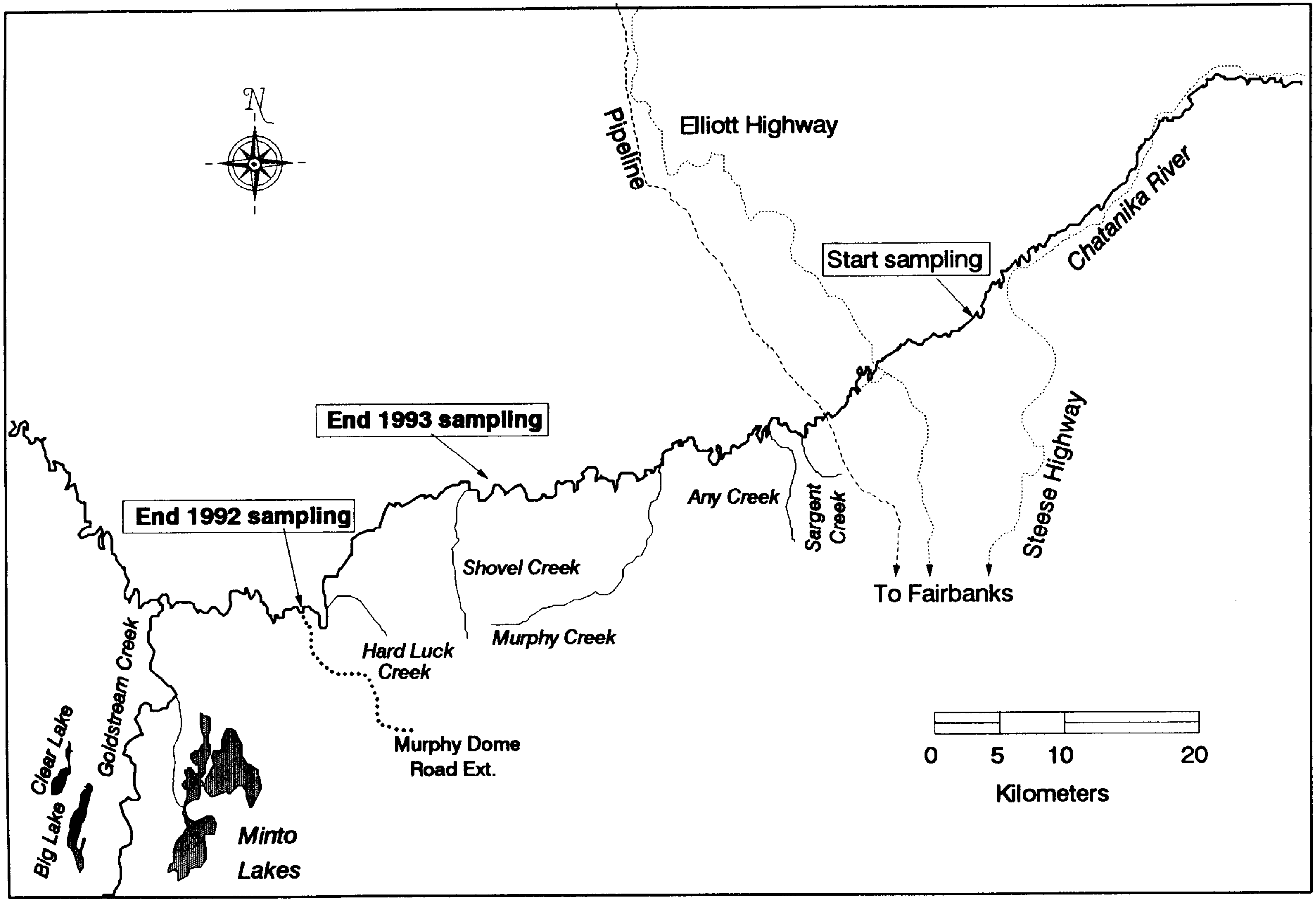

Figure 1. Map of the 1992 and 1993 study areas in the Chatanika River, encompassing 102 km sampled during 1992 and 78.2 km sampled in 1993.

area of the fishery. With the new regulations, a low level fishery has been allowed to continue. Sport harvests of both species has decreased in recent years due closure of the fishery in 1991, an early freeze in 1992, and high water conditions in 1993. It is anticipated that the regulation change and reduced harvests will better facilitate rebuilding of the stocks.

Information gathered in the past several years has increased the breadth of knowledge needed for sampling these migratory populations over a large sampling area, and has indicated constraints for stock assessment and management. There is a conservation concern for humpback whitefish because of low recruitment, and a shift towards older and larger fish. Because of this concern, managers need assessment information prior to the spearing season in September. As a result, the timing of stock assessment has been constrained to late August.

OBJECTIVES

Specific objectives for the 1993 studies on humpback whitefish and least cisco in the Chatanika River were to estimate:

1. abundance of humpback whitefish greater than 359 mm FL and least cisco greater than 289 mm in a 105 km (65.0 mi) area of the Chatanika River, beginning 15 km (9.4 mi) above the Elliott Highway Bridge downstream to the Murphy Dome Road Extension; and,

2. age and length compositions of humpback whitefish and least cisco inhabiting the 105 km (65.0 mile) section of the Chatanika River.

In addition to these objectives, additional analyses were conducted and past age-size assessment data were archived. Additional topics of analysis included the estimation of survival, mortality and exploitation of the assessed stocks of whitefish, and the characterization of migratory movements with regards to timing and sampling location. A repository of existing age and length data from 1986 and subsequent investigations was initiated, and is found in Appendices A1-A4. Additionally, a separate examination of relative age validation using scale ages from recaptured whitefish was conducted and is reported in Appendix B1.

METHODS

Study Area and Sampling Design

Past stock assessments for both species of whitefish occurred over limited areas of the Chatanika River accessed by the Elliott Highway, but recent assessments have extended sampling significantly downstream. The assessments prior to 1990 were within an area 15.0 km above and below the Elliott Highway crossing. This section of the Chatanika River is characterized by moderate gradient, with short meandering stretches interspersed with gravel riffles. This area has been thought to provide spawning habitat for the whitefish as well as being affected by the recreational spear fishery. In 1991, the study area was extended downstream an additional 83.7 km after detecting exploitation of whitefish tagged well below the spearfishing area (Timmons 1991). The addition to the study area included several different types of river habitat. Immediately downstream, moderate gradient habitat (described above) continues for 5 km before changing to a low gradient section of slow flows, with silt and sand bottom and high cutbanks. This middle portion extends downstream 51.4 km, beginning with continuous meanders and oxbows which changes to long straight reaches. Then the river changes to a higher gradient, and continues 28.2 km to the end of the study area as a series of wide shallow runs and riffles, with coarse cobble and bedrock substrate.

Field Sampling

To minimize potential bias in the abundance estimation experiment, the hiatus between events was shortened and the study area was enlarged in 1992 (Fleming 1993). The 1993 investigation used near identical timing and the same seven-day hiatus, based on the relative success in 1992.

The mark-recapture experiment on the Chatanika River in 1993 began on 16 August, and was completed on 26 August. There were two distinct sampling events. Sampling was performed by three crews, each with three persons. Two of the crews used pulsed DC electrofishing boats to capture fish, while the third crew sampled fish in a separate boat. Each sampling event lasted five days and consisted of a single downstream pass by the three crews working together. The upstream limit of the 1992 and 1993 study section was approximately 4 km upstream of the Elliot Highway bridge. The 1993 lower sampling boundary was downstream 74.0 km, 24.1 km above the terminus of the Murphy Dome Road Extension (Figure 1). The study section in 1993 was reduced in area from that sampled in 1991 and 1992 for the following reasons: 1) boat passage in the vicinity of the upper and lower boundaries was made difficult by low water conditions; 2) relatively lower catches had been observed in the downstream portion of the study section in the two previous years so that only a small portion of the humpback whitefish and least cisco population would be omitted from the mark/recapture experiment; and, 3) to minimize costs associated with the project.

To limit holding time and stress of captured fish and to ensure an even distribution of marked fish in the study area, sampling was conducted as a series of 39 discrete "runs". A run consisted of 20 min of electrofishing in the downstream direction. In the upper and lowermost portions of the river, where the stream channel was confined, electrofishing boats were often fished in a staggered formation. In the middle portion, where the river was more typically wide and slow, boats were fished side-by-side along each bank. Variable voltage pulsator (VVP) settings were 60 Hz pulse DC ranging from 190 to 250 volts and 2 to 7 A. Water conditions were low and clear with the exception of the first two days of the second sampling event, in which lowered water clarity coincided with a falling hydrograph. Water temperatures ranged between 8.0 ^{o}C and 11.0 ^{o}C. Stunned fish were dipped and placed into large aerated live wells to await sampling. At the completion of each run, labeled flagging was staked and left at the downstream sampling end-point for later reference. At each flagged location, a global positioning system (GPS) unit determined near-exact location for later referencing of release-recapture information. All captured fish in the first sampling event were measured to the nearest millimeter FL, fin clipped (upper caudal clip), and tagged with an individually numbered gray Floy FD-67 internal anchor tag at the base of the dorsal fin. During the second (recapture) sampling event, all fish were examined for marks, measured, and fin clipped (lower caudal clip). Additionally, scales were collected systematically from approximately one out of every three least cisco and one out of every two humpback whitefish, gently cleaned, and mounted directly onto gum cards for later pressing and aging. Fish with tag losses were given new tags, and previous fin clips were noted. Data collection procedures from previously marked humpback whitefish and least cisco were similar, but previous fin clips, tag losses, tag numbers, and colors were also recorded. Scales were also collected from all humpback whitefish and least cisco tagged in previous years for relative age validation. All data was recorded on Alaska Department of Fish and Game Tagging Length Form, Version 1.0.

Abundance Estimation

The use of a closed model abundance estimator using mark-recapture experiments assumes the following (Seber 1982):

1) the population in the study area must be closed, i.e. the effects of migration, mortality, and recruitment are negligible;

2) all fish have the same probability of capture during the first event or in the second event or marked and unmarked fish mix randomly between the first and second events;

3) marking of fish does not affect their probability of capture in the second event, and;

4) fish do not lose their mark between events.

Sampling was designed to lessen risks associated with closure (assumption 1) by shortening the duration of the mark-recapture experiment considerably and sampling as much of the river as practically feasible. It was improbable that substantial migration, mortality, or recruitment occurred during the seven day hiatus given the large size of the sampling area. This assumption could be partially examined through comparison of the marked-to-unmarked ratios in the lowermost section (subject to immigration from fish downstream). Assumptions 2 and 3 were examined for size and geographic differences in capture probability. Size selectivity was tested with two Kolmogorov-Smirnov two-sample tests. The first test examined the cumulative length frequency distributions of marked fish with those recaptured. The second test compared cumulative length frequency distributions of fish from the first (mark event) and second (recapture event) samples. The results of these tests suggested methods to alleviate size bias (Appendix A1). Spatial differences in capture probability were evaluated through comparisons of area specific recapture-to-catch ratios. An iterative series of chi-square tests was performed on the recapture and catch locations to find the location in the sampling area where the maximal differences in capture probability occurred. If the chi-square statistic (1 df) was statistically significant at this location, the mark-recapture experiment could be stratified at this location. The last testable assumption was met by double marking each fish, with a tag and a fin-clip specific to the 1993 mark-recapture experiment.

Examination of the assumptions demonstrated that size-selective sampling was detected for least cisco, requiring the data to be stratified into size classes. To delimit the stratified size classes, an iterative series of chi-square tests was performed to find maximal differences in capture probability. The length at which the chi-square statistic was maximal demarcated the size strata. Because the assumption of equal capture probability by geographic area was not violated for least cisco, the modified Petersen estimator of Bailey (1951, 1952) was selected. Use of Bailey's modification was sought because of the systematic sampling approach, and the level of mixing (localized, not complete; Seber 1982) of marked and unmarked fish over the length of the sampling area (Seber 1982). Stratified and unstratified point estimates of abundance were estimated as:

$$\hat{N} = \frac{M(C+1)}{(R+1)} \qquad (1)$$

where:

- M = the number of fish marked and released during the marking event sample;
- C = the number of fish examined for marks during the recapture event;
- R = the number of fish recaptured during the second sampling event (recapture); and,
- $\hat{N}$ = estimated abundance of humpback whitefish or least cisco.

Variance of the abundance estimate was estimated by (Bailey 1951, 1952):

$$V[\hat{N}] = \frac{\hat{N} M (C - R)}{[(R+1)(R+2)]} \qquad (2)$$

Examination of the assumptions demonstrated that size selectivity was not detected for humpback whitefish, but differential capture probabilities by areas sampled, and incomplete mixing were evident. Incomplete mixing precluded use of the Petersen model (Bailey 1951, 1952) to estimate abundance. Subsequently, the methods of Darroch (1961) were selected. The Darroch estimator is a multidimensionally-expanded version of a Petersen model which: simultaneously estimates abundance by the selected strata (areas); accounts for movements between strata; and estimates stratified probabilities of movement and capture. Areas were stratified on the basis of differential capture probabilities; adjacent river areas that shared statistically similar capture probabilities were grouped. The partially stratified (by area) estimate of abundance was then calculated from the model (using the notation of Seber 1982):

$$\hat{N} = \underline{u}'\underline{M}^{-1}\underline{a} + A \qquad (3)$$

where:

- $\underline{u}$ = a vector of the number of unmarked humpback whitefish examined by area during the recapture event;
- $\underline{M}$ = a matrix of the number of recaptures partitioned by area marked and area recaptured;
- $\underline{a}$ = a vector of the number of humpback whitefish marked and released by area; and,
- A = the total number of humpback whitefish marked and released (a scalar).

Variance of this estimator is calculated by (Darroch 1961):

$$V = \sum_{y} \hat{\eta}_y^2 \hat{\mu}_y / a_y + \sum_{x} \hat{U}_x(\hat{p}_x^{-1} - 1 \qquad (4)$$

where:

- $\hat{p}_x^{-1}$ = the xth element of the vector formed by $\underline{M}^{-1}\underline{a} = \underline{\rho}$, or the inverse of the probability of capture in area x;
- $\hat{U}_x$ = the number of unmarked fish in area x at the time of sampling $(u_x p_x^{-1})$;
- a_y = the number of fished marked in area y (from vector a);
- $\hat{\eta}_y$ = the number of unmarked fish in area y at the time of marking; and,
- $\hat{\mu}_y$ = $(\Sigma\ \theta_{yx} / p_x)$-1, where θ_{yx} is the probability of movement from area *y* to area *x* and p_x is the probability of capture in area x.

Point estimates of abundance were calculated using the sampled mark-recapture matrix and methods of Darroch (1961). Additionally, stratified and unstratified point estimates of abundance were calculated with the Bailey modification to the Petersen model (Bailey 1951, 1952).

Age and Length Compositions

Apportionment of the estimated abundance among age or length classes depends upon the extent of sampling biases. The outcome of tests for size selectivity and geographic differences in capture probabilities, determined the necessary adjustments. Because length selectivity was detected for least cisco, the sampled age and length compositions could be adjusted by length-specific capture probabilities. The appropriate sample or samples (Appendix C1: from the first event, second, or both events) was used to estimate the age and length compositions. To accurately assess the stock composition[1] in the Chatanika River at the overall population level, additional steps were needed. First the conditional fractions based on the size-stratified samples were calculated:

$$\hat{p}_{ij} = n_{ij} / n_i \tag{5}$$

where:

n_i = the number sampled from stratum i in the mark-recapture experiment;
n_{ij} = the number sampled from stratum i that belong to group j; and,
p_{ij} = the estimated fraction of the fish in group j in stratum i.

Note that $\sum_j p_i = 1$. The variance for p_{ij} was estimated as:

$$V[\hat{p}_{ij}] = \frac{\hat{p}_{ij}(1 - \hat{p}_{ij}}{n_i - 1} \tag{6}$$

The estimated abundance of group j in the population ($\hat{N}_j$) was calculated as:

$$\hat{N}_j = \sum_i \hat{p}_{ij}\hat{N}_i \tag{7}$$

where: $\hat{N}_i$ = the estimated abundance in stratum i of the mark-recapture experiment.

The variance for $\hat{N}_j$ was estimated as a sum of the exact variance of a product from Goodman (1960):

$$\hat{V}[\hat{N}_j] = \sum_i(V[\hat{p}_{ij}]\hat{N}_i^2 + V[\hat{N}_i]\hat{p}_{ij}^2 - V[\hat{p}_{ij}]V[\hat{N}_i] \tag{8}$$

The estimated fraction of the population that belongs to group j (pj) was:

$$\hat{p}_j = \hat{N}_j / \hat{N} \tag{9}$$

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[1] Composition here refers to age and 10 mm FL incremental size composition.

where: $\hat{N} = \Sigma \hat{N}_i$.

The variance of the estimated fraction was approximated with the delta method (see Seber 1982; ignoring the hat symbols, all quantities were estimated):

$$V[p_j] \approx \sum_i V[p_{ij}]\left\{\frac{N_i}{N}\right\}^2 + \frac{\sum_i \{V[N_i](p_{ij} - p_j)^2\}}{N^2} \tag{10}$$

Each stock assessment category utilized the above approach, where substitutions for class were: age classes; and 10 mm FL incremental size groupings.

When no adjustments were required for length selectivity or geographic differences in capture probability, the proportion of fish at age k (or length class k) was estimated using the appropriate sample (Appendix A1: from the first event, second, or both events) by:

$$\hat{p}_k = \frac{y_k}{n} \tag{11}$$

where: $\hat{p}_k$ = the proportion of fish that are age or length class k;
y_k = the number of fish sampled that are age or length class k; and,
n = the total number of fish sampled.

The unbiased variance of this proportion was estimated as:

$$V[\hat{p}_k] = \frac{\hat{p}_k(1 - \hat{p}_k}{n - 1} \tag{12}$$

Survival, Mortality, and Exploitation

An initial examination of survival, mortality, and exploitation was facilitated by consecutive annual stock assessments conducted in 1992 and 1993. Harvest estimates (Hallberg 1993) provided point estimates of humpback whitefish and least cisco harvests for the 1992 spear fishery. Because sampling in 1993 did not cover the entire portion sampled in 1992, abundance estimates from 1992 (102.1 km; Fleming 1993) were re-estimated to the shorter (78.2 km) 1993 study area. Care was taken to remove all records of fish downstream of the 1993 study area boundary that were handled (marked, examined, or recovered from) prior to the re-estimation. The re-estimated abundances were then apportioned by age class using 1992 composition estimates (Fleming 1993).

Survival was estimated as the proportion of the summed abundance from a portion of an age series at one time (year t), that are estimated to be present at a later time (Ricker 1975). Only ages that appear to be fully recruited were used as the portion of an age series. Humpback whitefish age 7 years and older, and least cisco age 3 and older were thought to be fully recruited to the study's objective sizes at the time and location of the stock assessment. The annual rate S, was estimated for humpback whitefish, as:

$$\hat{S} = \frac{\hat{N}_{t+1}}{\hat{N}_t} \tag{13}$$

where:

$\hat{S}$ = the estimated proportion of humpback whitefish age 7 and up (k= ages: 7,8,9,10,...15), in year t that survive to year t+1 as age 8 and up (k = ages: 8,9, 10, 11,...16); and,

$\hat{N}_t$ = the summed estimated abundance of humpback whitefish age 7 years and up in year t; and,

$\hat{N}_{t+1}$= the summed estimated abundance of humpback whitefish age 8 years and up in year t+1

The variance of $\hat{S}$ was approximated with the delta method (Seber 1982; ignoring hat symbols) as:

$$V[S] \approx \left[\frac{N_{t+1}}{N_t}\right]^2 \left[\frac{V[N_{t+1}]}{[N_{t+1}]^2} + \frac{V[N_t]}{N_t^{\,2}}\right] \tag{14}$$

where the variance for N_t and N_{t+1} were each estimated as a sum of the exact variance of a product from Goodman (1960):

$$V[\hat{N}_t] = \sum_{k=7}^{15}(V[\hat{p}_k]\hat{N}_{92}^{\,2} + V[\hat{N}_{92}]p_k^{\,2} - V[p_k]V[\hat{N}_{92}] \tag{15}$$

and;

$$V[\hat{N}_{t+1}] = \sum_{k=8}^{16}(V[\hat{p}_k]\hat{N}_{93}^{\,2} + V[\hat{N}_{93}]p_k^{\,2} - V[p_k]V[\hat{N}_{93}] \tag{16}$$

where:

$\hat{N}_{92}$ = the area readjusted abundance estimate for humpback whitefish $\hat{N}_{92}$ 360 mm FL in 1992; the variance of N_{92} was from the Petersen model estimator;

$\hat{N}_{93}$ = the abundance estimate for humpback whitefish $\geq$ 360 mm FL in 1993; the variance of N_{93} was from the unstratified Petersen model used to estimate abundance; and,

$\hat{p}_k$ = the estimated fraction of the fish in age class k from 1992 and 1993 stock assessments.

The same approach was used to estimate survival of least cisco. Estimates of abundance at age were from the same sources, but for fish age 3 years and up (in 1992), and fish 4 years and up (1993). The estimated fraction, p_k, incorporates the adjustments made for size selective sampling. The annual survival rates were converted into annual and instantaneous rates of mortality with respect to the following relationships (from Ricker 1975):

Z = the instantaneous total mortality rate;
Z = -Ln (S);
F = the instantaneous rate of fishing mortality;
M = the instantaneous rate of natural mortality;
Z = F + M;
A = the annual mortality rate; and,
A = 1 - e-z, where e = 2.71828.

The survival rates estimated for humpback whitefish age 7 and older, and least cisco age 3 and older were assumed to be representative and applied only to the assessed stock. In order to apportion total instantaneous mortality (Z) among fishing (F) and natural (M) mortality components, Baranov's catch equation (Ricker 1975) was rearranged and solved for F:

$$F = \frac{Z}{A} * \frac{C}{N} \qquad (17)$$

where:

C = the 1992 estimated harvest of humpback whitefish (or least cisco) from the Chatanika River spearfishery (Hallberg 1993);

N = the 1992 abundance estimate (Fleming 1993) of humpback whitefish (or least cisco); and,

Z = the estimated total instantaneous mortality rate calculated for fully-recruited year classes (humpback whitefish age 7 and older: least cisco age 3 and older).

Before estimating natural mortality and exploitation parameters, a classification of the whitefish spear fishery was needed to select the most biologically appropriate estimator. The two types proposed by Ricker (1975) are:

Type 1 = where natural mortality occurs during a time of year other than the fishing season; the population decreases during the fishing season because of catch (harvest) removals only; or,

Type 2 = where natural mortality occurs along with fishing; each occurs at a constant instantaneous rate, or the two rates vary in parallel fashion.

Because the fishery is discrete, the Type 1 classification was selected. The rate of exploitation (u) estimated for a Type 1 fishery was (Ricker 1975):

$$u = 1 - e^{-F} \qquad (18)$$

The expectation of natural death was estimated (Ricker 1975):

$$v = n(1-u) \qquad (19)$$

where:

v = expectation or probability of natural death; and,
n = conditional rate of natural mortality, which is calculated as (from Ricker 1975): $n = 1-e^{-M}$

Migratory Movements

During both the 1992 and 1993 field investigations, latitude and longitude measurements were made with a hand-held Global Positioning System (GPS) at the conclusion of each 20 min electrofishing sample. These locations were used to demarcate the boundaries of each electrofishing sample, and log the release location of all sampled fish. During 1992, there was a total of 48 consecutive 20-min electrofishing samples (Fleming 1993), and in 1993 there were 39. Subsequent to the field investigation, the 1992 and 1993 sample locations were plotted on USGS 1:63,360 topographic maps. A digitizing tablet was used to estimate river mileage between sampling unit boundary locations, and cumulative distance downstream from the upstream sampling boundary (Figure 1). As a quality control measure, the cumulative river mileage to a known landmark and sampling location from both 1992 and 1993 were compared and relative error estimated.

Each fish that was marked and released during the first sampling event and subsequently recovered, yielded information on the extent of movement over a seven day period. Distance traveled was estimated as the in-stream distance from release to recovery locations. Because exact recovery locations could not be ascertained upon dipnetting for each individual fish, the mid-sampling unit distance was arbitrarily assigned as the recovery location, rather than the sampling unit downstream boundary. Estimates of migratory movements for both species were estimated for a seven day period (between sampling events) in 1992 and 1993, and fish that were later recovered in harvest creel sampling. Additionally, fish captured in both years yielded locational and distributional differences with respect to yearly samples.

RESULTS

Field Sampling

A total of 2,519 humpback whitefish ($\geq$ 360 mm FL) and 3,580 least cisco ($\geq$ 290 mm FL) were captured over a 10-day period in the latter half of August. During the first sampling event, the water conditions were low and clear, with stream temperatures between 8.5 °C and 11.0 °C. Low water conditions and stream channel alterations in the uppermost section precluded sampling in 1992 and 1993, as far upstream as was done in the 1991 assessment. Rainfall on 21 August led to higher water conditions at the onset of the second sampling event. The river level dropped during the first two days to conditions similar to the first sampling event. During the field investigation, 1,109 humpback whitefish ($\geq$ 360 mm FL) were marked and released alive over the 49 miles of river in the first sampling event. In the second sampling event, 1,536 were examined for marks, yielding 129 recaptures. From both sampling events, 69 fish and 56 fish retained tags from 1991 or earlier, and 1992, respectively. Concurrently, 1,681 least cisco ($\geq$ 290 mm FL) were marked and released alive in the first sampling event, and in the second sampling event 1,976 were examined for marks, yielding 77 recaptures. From both sampling events, 39 fish and 28 fish retained tags from 1991 or earlier, and 1992, respectively.

The observed tag shedding rate from the marking to the recapture event was 6.2%, based on eight of 129 humpback whitefish that were recaptured without tags, and 1.2% for least cisco based on one of 77 recaptures. The overall acute mortality rate from the experiment was three out of 2,519 individual humpback whitefish handled, or 0.1%. The overall acute mortality rate was 0.2% for least cisco, based on seven mortalities from 3,580 fish handled.

<u>Abundance Estimation</u>

A Kolmogorov-Smirnov comparison of cumulative distribution functions (CDF's) from the humpback whitefish mark-recapture experiment resulted in the detection of length selectivity in the first sampling event (mark vs recaptures: D = 0.07, P = 0.52; and, mark vs catch: D = 0.07, P = 0.0012). As a result, abundance was estimated using an unstratified approach with regards to size selectivity (Case II; Appendix C1). The examination for differential capture probability (recapture-to-catch ratios) by geographic area indicated that recapturing humpback whitefish in upstream areas was more likely than downstream sampling areas. The difference in stratified capture probabilities was maximized at a location 27.4 km downstream from the Elliot Highway Bridge (χ^2 = 28.05, df = 1, P < 0.001). Capture probabilities for the upstream (sampling runs 1-18) and downstream (sampling runs 19-39) strata were 0.096 and 0.045, respectively (Table 1). Because of differential capture probabilities, observed upstream movement, and partial mixing between the areas, methods of Darroch (1961) were employed to estimate abundance. The estimated abundance of humpback whitefish was 14,055 fish (SE = 1,332, CV = 9.4%) greater than 359 mm FL. This estimate was based upon use of 121 recaptures with complete capture histories, not including the eight fish that had shed their tags. In comparison, the unstratified Petersen estimate (using 121 recaptures) was 13,972 fish (SE = 1,208 fish). Because of the similarities of the estimates, the unstratified Petersen model estimator was selected because of its lower standard error. The addition of the eight recaptured fish with tag losses adjusted the estimate to 13,112 humpback whitefish greater than 359 mm FL (SE = 1,096, CV = 8.3%).

Table 1. Numbers of marked and recaptured humpback whitefish (≥ 360 mm FL) by stratified sampling section, Chatanika River, 16 - 26 August 1993 [a].

	Marking Event		Section Recaptured[b]		Recovered	
	Number marked	Section	(runs 1-18) Upper	(runs 19-39) Lower	Yes	No
	744	Upper	80	1	81	663
	365	Lower	24	16	40	325
Total	1,109	Recaptured (R)	104	17	S = 121	988
		Unmarked (U)	1,062	353	S = 1,415	
		Catch (C)	1,166	370	S = 1,536	
		R/C Ratio[c]	0.096	0.045		

[a] This table only includes recaptured fish with complete capture histories, so that movement and mixing can be ascertained. The eight humpback whitefish that had shed their tags during the experiment were later included in the final estimate.

[b] The Chatanika River was delineated into two sections on a basis of maximizing differences in R/C ratio. The upper section was 32.0 km in length, while the lower was 46.2 km.

[c] Capture probabilities were tested for statistical similarity using chi-square tests on numbers of recaptured (R) and examined (C) humpback whitefish. Rejection of the null hypothesis of similarity between adjacent sections (χ^2 = 4.44, 1 df, P = 0.035) suggests that section-specific differences in capture probability existed within the experiment.

A Kolmogorov-Smirnov comparison of cumulative distribution functions (CDF's) from the least cisco mark-recapture experiment showed that length selectivity occurred in both sampling events (Figure 2A - mark vs recaptures: D = 0.19, P = 0.01; and, Figure 2B - mark vs catch: D = 0.02, P = 0.76). As a result, abundance was estimated using a stratified approach with regards to size selectivity (Case III; Appendix C1). The difference in stratified capture probabilities was maximized at a fork length of 344 mm (χ^2 = 8.87, df = 1, P = 0.003). Length strata selected for abundance estimation were: 290 to 344 mm FL (small), and, 345 mm FL and larger (large). The examination of differential capture probability (recapture-to-catch ratios) by geographic area indicated that recapture of least cisco in upstream areas was more likely than downstream sampling areas. The difference in stratified capture probabilities was maximized at a location 24.7 km downstream (sampling run 17) from the Elliot Highway Bridge (χ^2 = 4.44, df = 1, P = 0.035). The distribution of recaptured fish relative to this location, 76 above, and only 1 below, precluded use of an area stratified estimate.

The estimated abundance of small least cisco was 34,259 fish (SE = 5,705; Table 2). The estimate for large least cisco was 12,303 fish (SE = 1,763). The sum of stratified estimates for abundance was 46,562 fish (SE = 5,971, CV = 12.8%) greater than 289 mm FL in the Chatanika River at the time of the first sampling event.

Age and Length Compositions

Scale samples were collected from 1,323 humpback whitefish, of which 881 were aged, with an incidence of 33% regenerated or illegible scales. Ages observed for humpback whitefish in the Chatanika River ranged from 1 to 16 years for fish between 360 and 540 mm FL, with 8 years as the median age. The predominant age class present among humpback whitefish sampled in the Chatanika River was age 8 (20.0% of the stock; Figure 3) followed by age 9 (18.8% of the stock). The median sized humpback whitefish was 444 mm FL, with a peak in relative abundance between 440 and 449 mm FL (Figure 4).

Scale samples were collected from 1,142 least cisco, of which 868 were aged, with an incidence of 24% regenerated or illegible scales. Ages observed for least cisco in the Chatanika River ranged from 2 to 10 years for fish between 290 and 421 mm FL, with 4 years as the median age. The predominant age class present among least cisco sampled in the Chatanika River was age 4 (40.0% of the stock; Figure 5) followed by age 3 (26.0% of the stock). The median size least cisco was 340 mm FL, with maximum relative abundance occurring between 330 to 339 mm FL (Figure 6).

Age composition estimates for humpback whitefish and least cisco for the years 1986 through 1993 are summarized in Appendices A1 and A2. Mean length-at-age estimates for both species are summarized in Appendices A3 and A4.

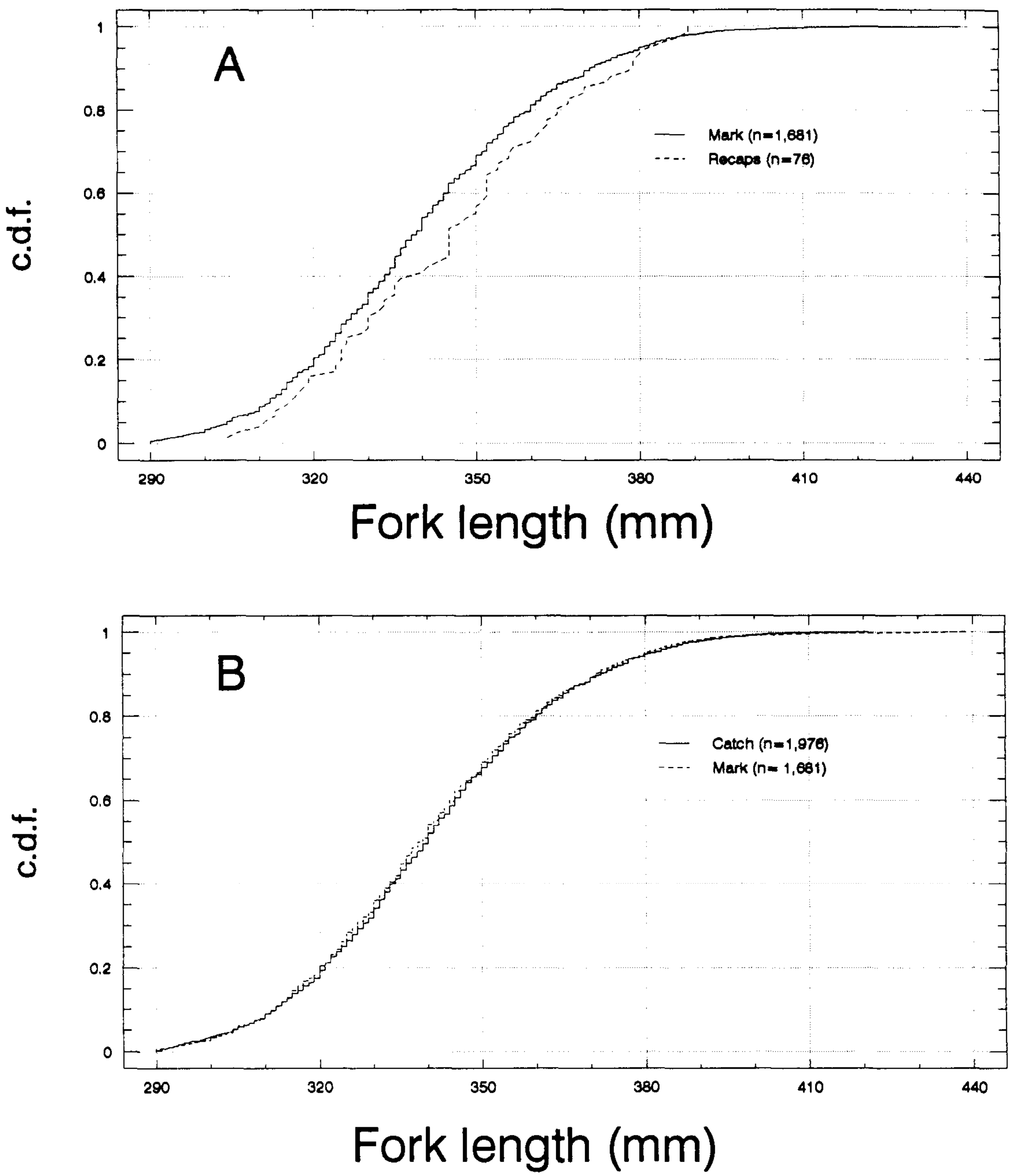

Figure 2. Cumulative distribution functions of lengths of least cisco marked versus lengths of least cisco recaptured (A) and versus lengths of least cisco examined for marks (B) in the Chatanika River, 16 - 26 August 1993.

Table 2. Size-stratified and unstratified abundance estimates of least cisco (≥ 290 mm FL) in the Chatanika River, at the time of the first sampling event, 16 - 19 August 1993.

Length category	Mark M	Catch C	Recap R	ρ [a]	N [b]	SE[N] [c]
290 to 344 mm	1,005	1,158	33	0.03	34,259	5,705
≥ 344 mm	676	818	44	0.05	12,303	1,763
Total	1,681	1,976	77	---	46,562	5,971
Unstratified	1,681	1,976	77	0.04	42,607	4,698

[a] ρ is the point estimated probability of capture.
[b] N is the point estimated abundance in a stratified length category or unstratified population.
[c] SE[N] is the standard error of N.

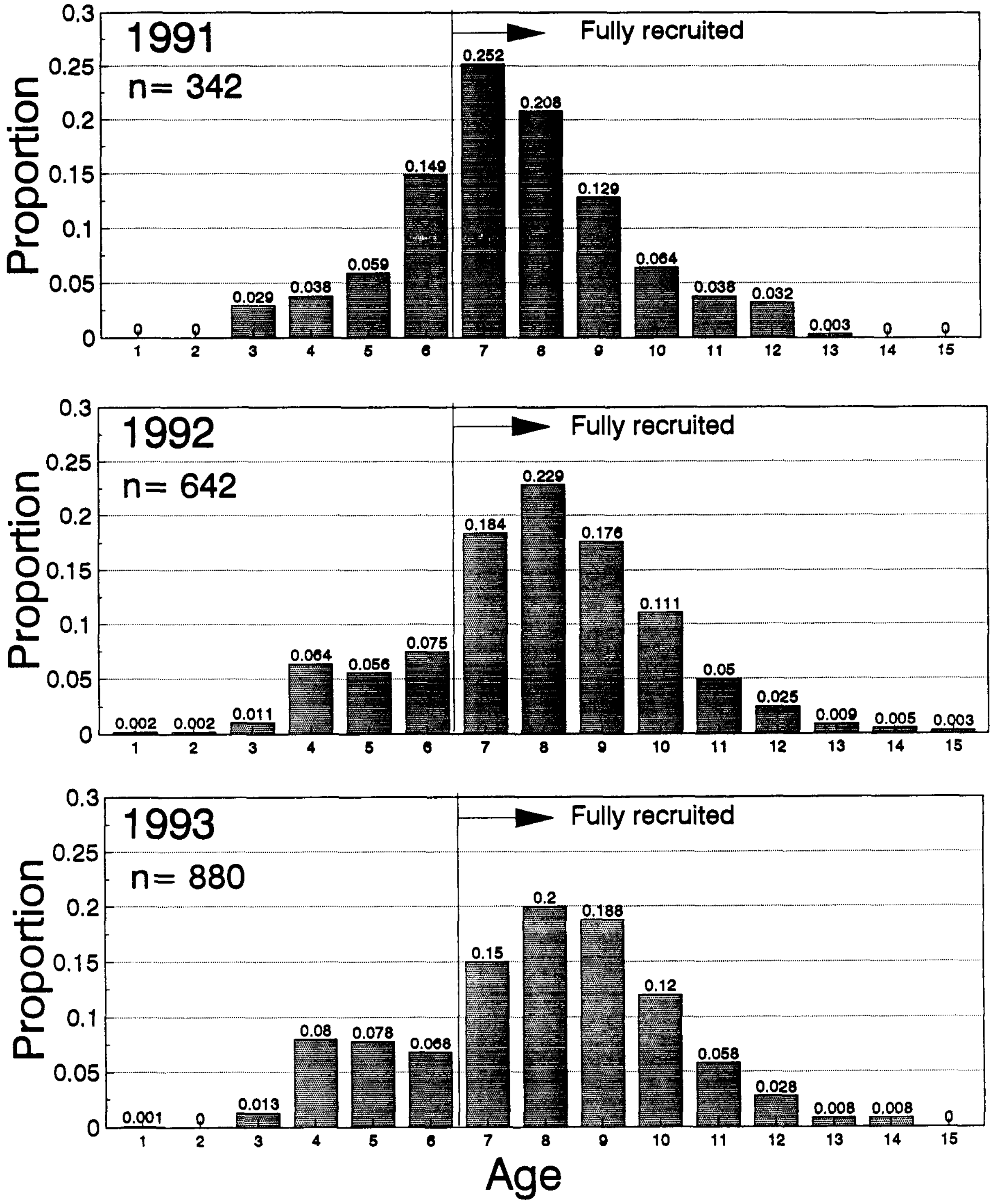

Figure 3. Estimated proportion of humpback whitefish (≥360 mm FL) by age in the Chatanika River during 1991- 1993.

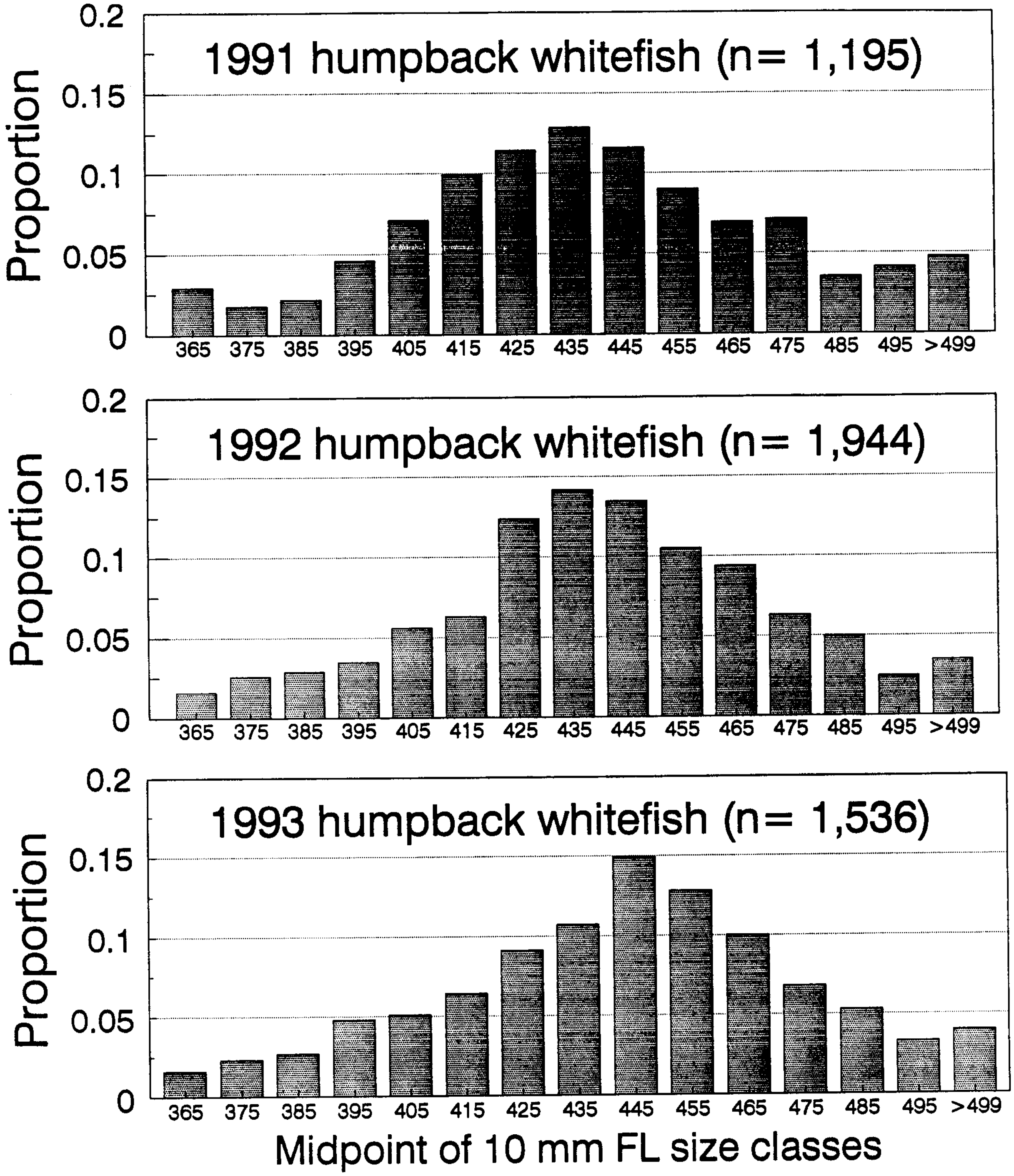

Figure 4. Estimated proportion of humpback whitefish by length (≥360 mm FL) in the Chatanika River during 1991- 1993.

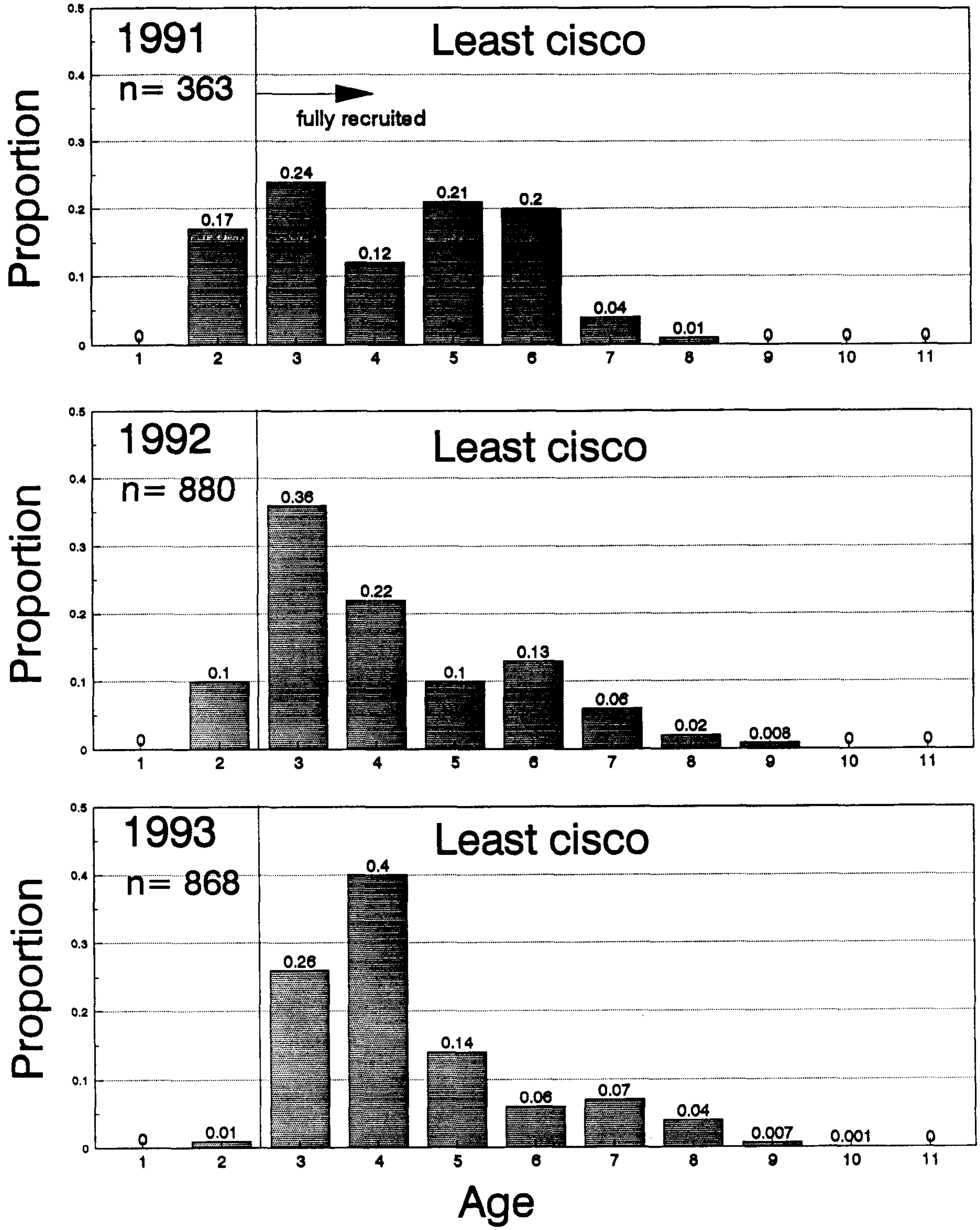

Figure 5. Estimated proportion of least cisco (≥290 mm FL) by age in the Chatanika River during 1991 - 1993.

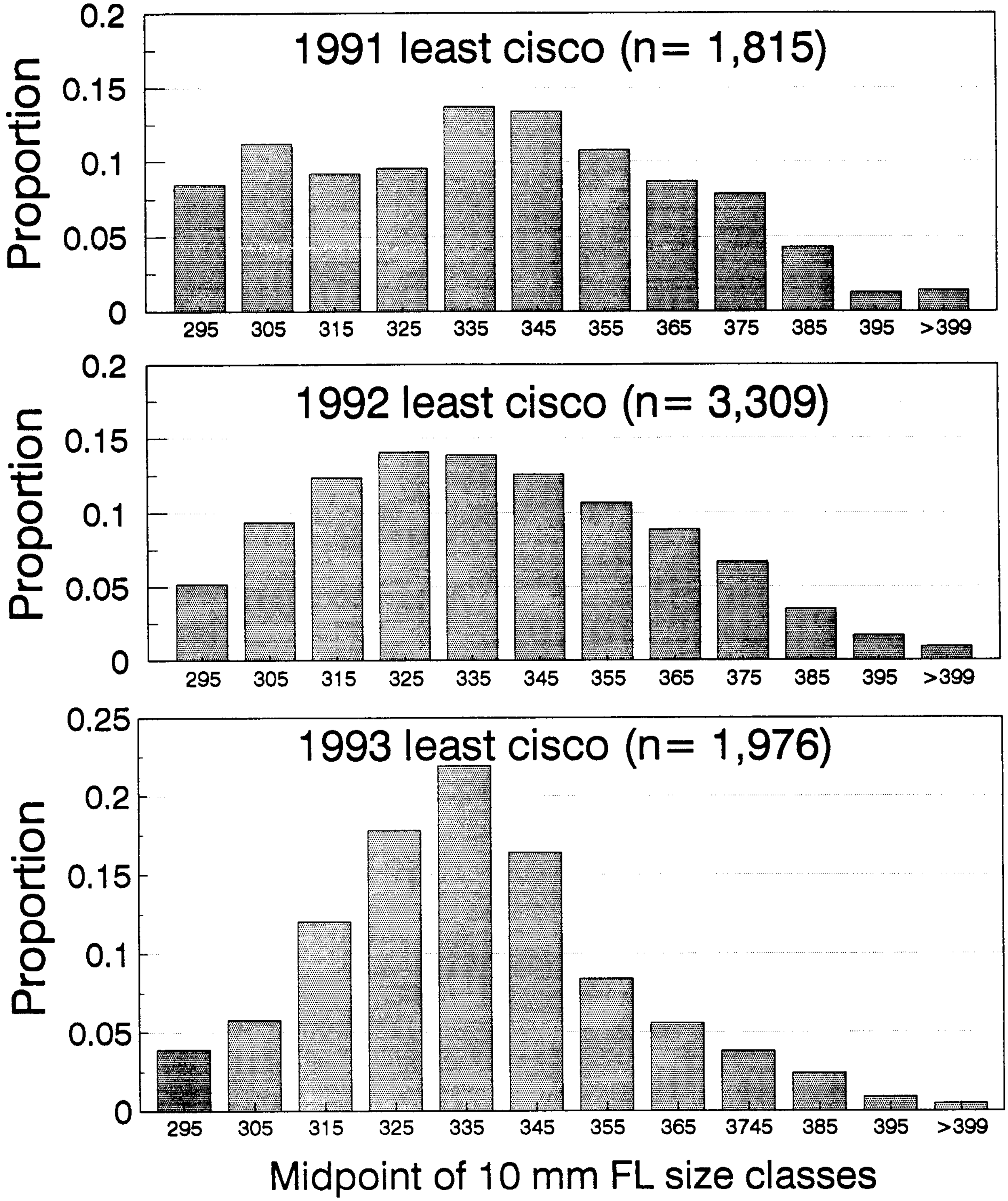

Figure 6. Estimated proportion of least cisco ($\geq$290 mm FL) by length in the Chatanika River during 1991 - 1993.

Survival, Mortality, and Exploitation

Survival was estimated for the portion of the Chatanika River whitefish that were defined as fully recruited to the assessed stock. Full recruitment was judged to be the condition when a group of fish (year class or size class) have become fully represented in catches. In the Chatanika River, humpback whitefish appear to reach their maximum representation or presence at age 7, while least cisco recruit by age 3.

The reduced sampling area abundances of humpback whitefish and least cisco for 1992 were estimated with Bailey's modification to the Petersen estimator. The estimated abundance of humpback whitefish in the 78.2 km section was 19,187 fish (SE = 1,617) greater than 359 mm FL. The estimate for least cisco was 75,035 fish (SE = 8,555) greater than 289 mm FL.

The fully recruited portion of the assessed humpback whitefish stock in 1992 was 15,188 fish age 7 years and older, and 9,972 fish in 1993 (Figure 7). Following the 1992 fishery and overwintering, through 1993, it was estimated that 8,007 fish age 8 years and older, or 52.7% (SE = 4%), survived and were present. The 95% confidence range of the survival rate fell between 44% and 61%. The total instantaneous rate of mortality (Z) was 0.64.

The fully recruited portion of the assessed least cisco stock in 1992 was 67,617 fish age 3 years and older, and 45,680 fish in 1993 (Figure 8). Following the 1992 fishery, and overwintering, through 1993, it was estimated that 31,545 fish age 4 years and older, or 46.6% (SE = 4%), survived and were present. The 95% confidence range of the survival rate was 36% to 57%. The total instantaneous rate of mortality (Z) was 0.76.

Following the 1992 recreational spear fishing season, Hallberg (1993) estimated harvests of 392 humpback whitefish and 1,898 least cisco. The instantaneous rate of fishing mortality (F) was calculated by Baranov's catch equation. Instantaneous fishing mortality (F) was estimated at 0.04 for humpback whitefish and 0.06 for least cisco. Exploitation rates, or expectation of death attributable to the fishery (u), and the expectations of natural death (v) were estimated for both species. The rates expressed as percentages were as follows:

Source of Mortality:	Humpback Whitefish (1992 to 1993)	Least Cisco (1992 to 1993)
Fishery:	u = 3.9 %	u = 5.6 %
Natural:	v = 43.4 %	v = 47.8 %
Total:	A = 47.3 %	A = 53.4 %

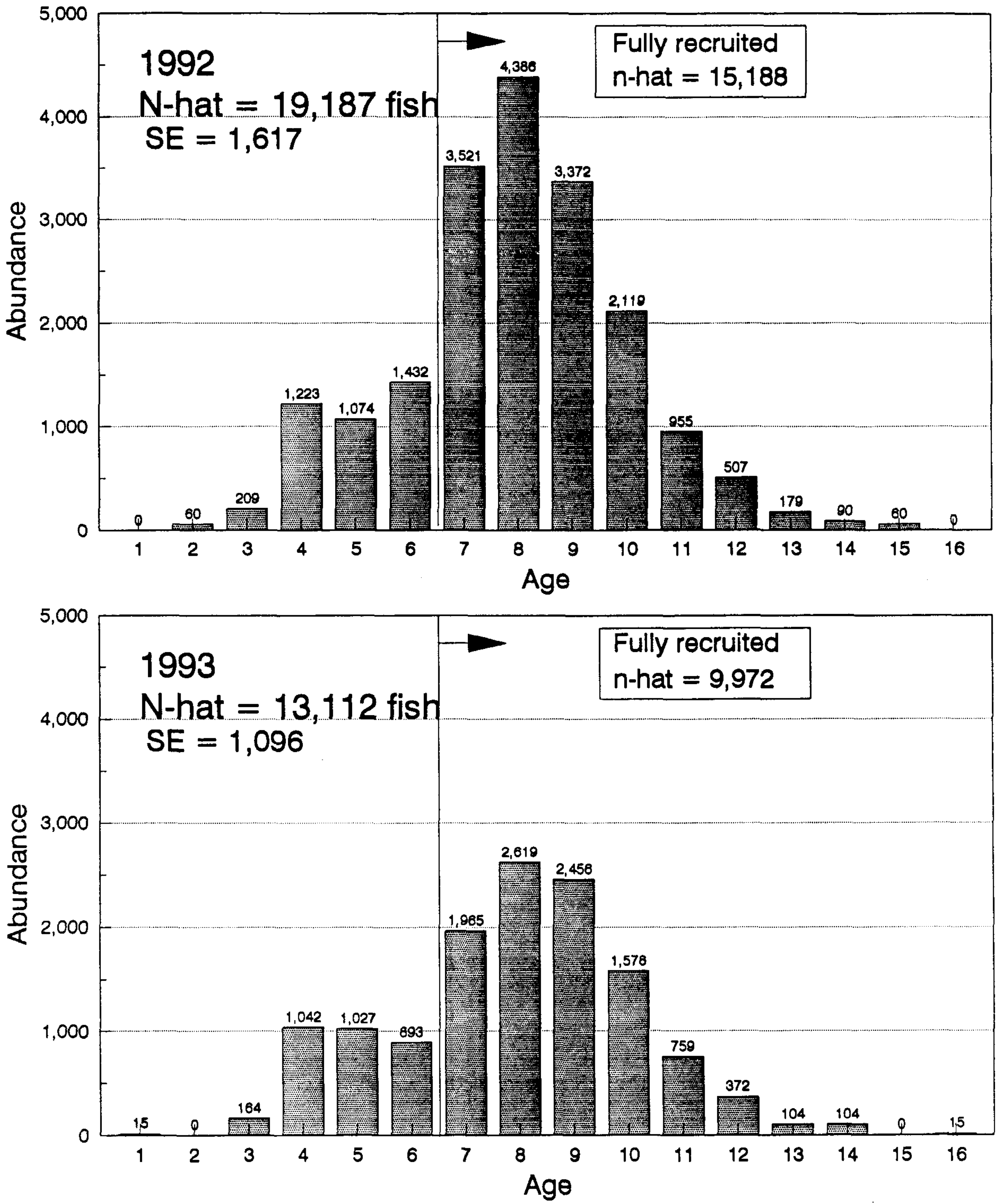

Figure 7. Apportionment of estimated abundance by age class for humpback whitefish (≥360 mm FL) present in the Chatanika River during August 1992 and 1993.

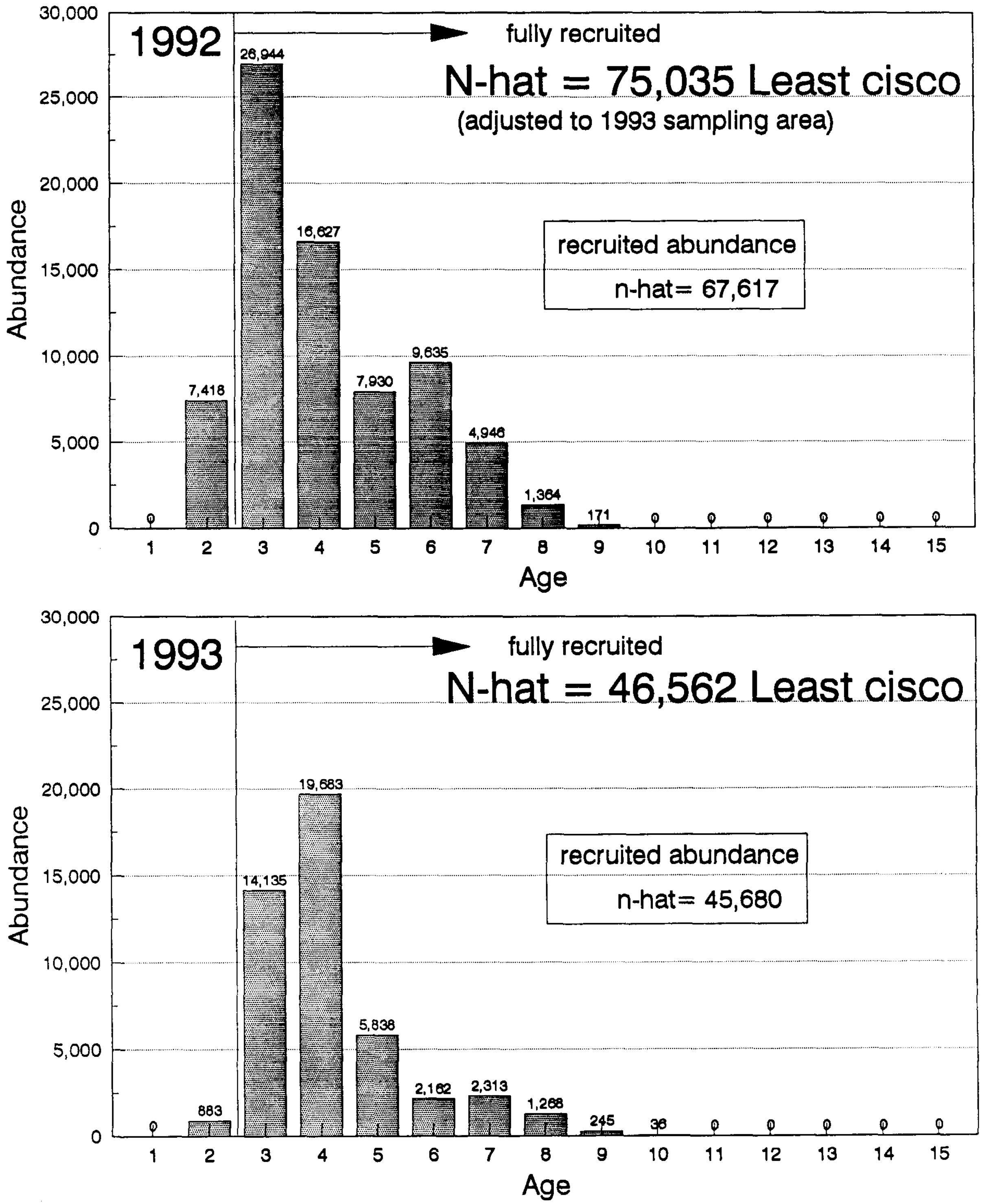

Figure 8. Apportionment of estimated abundance by age class for least cisco ($\geq$290 mm FL) present in the Chatanika River during August 1992 and 1993.

Migratory Movements

After plotting all sampling unit boundaries that corresponded to 20 min electrofishing samples for 1992 and 1993, the individual sampling unit segment lengths (river miles) were summed at a known landmark to assess measurement error. The 1992 and 1993 cumulative measurements differed by 1.2 km (0.73 mi), which represented a 1.9% relative error. The average individual sampling unit segment lengths were 2.0 km (1.27 mi) in 1992 and 2.0 km (1.26 mi) in 1993.

Frequency distributions of movements by individual fish in the 1992 and 1993 samples (Figures 9 and 10) appeared to be skewed such that median statistics were chosen to supplement sample means, particularly for comparisons. Both means and medians are presented to summarize movements and release location:

	Humpback Whitefish		Least Cisco	
Statistic:	1992	1993	1992	1993
Sample Size:	135	121	87	76
Minimum	-4.1	-12.0	-3.3	-2.3
Maximum:	19.4	15.8	19.4	9.9
Mean:	5.9	3.9	6.0	1.3
Median:	5.8	3.2	5.0	0.0
CI lower:	4.5	2.5	3.4	0.0
CI upper:	7.1	3.9	7.2	1.5
Median Release River Miles[2]:	19.8	10.3	23.1	8.5

The median distances traveled by humpback whitefish and least cisco over the seven day sampling hiatus were found to be statistically different between years using 95% confidence intervals of the medians (Zar 1984) and Kolmogorov-Smirnov two-sample tests (humpback whitefish: $D = 0.23$, $P = 0.0027$; and, least cisco: $D = 0.52$, $P < 0.01$). Additionally, the locations at which these fish were released during mark recapture sampling were compared between years. In 1992, the median release locations for recaptured fish of both species were significantly different using 95% confidence intervals of the medians (Zar 1984) and Kolmogorov-Smirnov two-sample tests (humpback whitefish: $D = 0.48$, $P < 0.01$; and, least cisco: $D = 0.72$, $P < 0.01$).

[2] Median release river miles were estimated from the release river miles relative to the upstream sampling boundary, i.e. 19.8 refers to 198.8 miles downstream of the upper boundary.

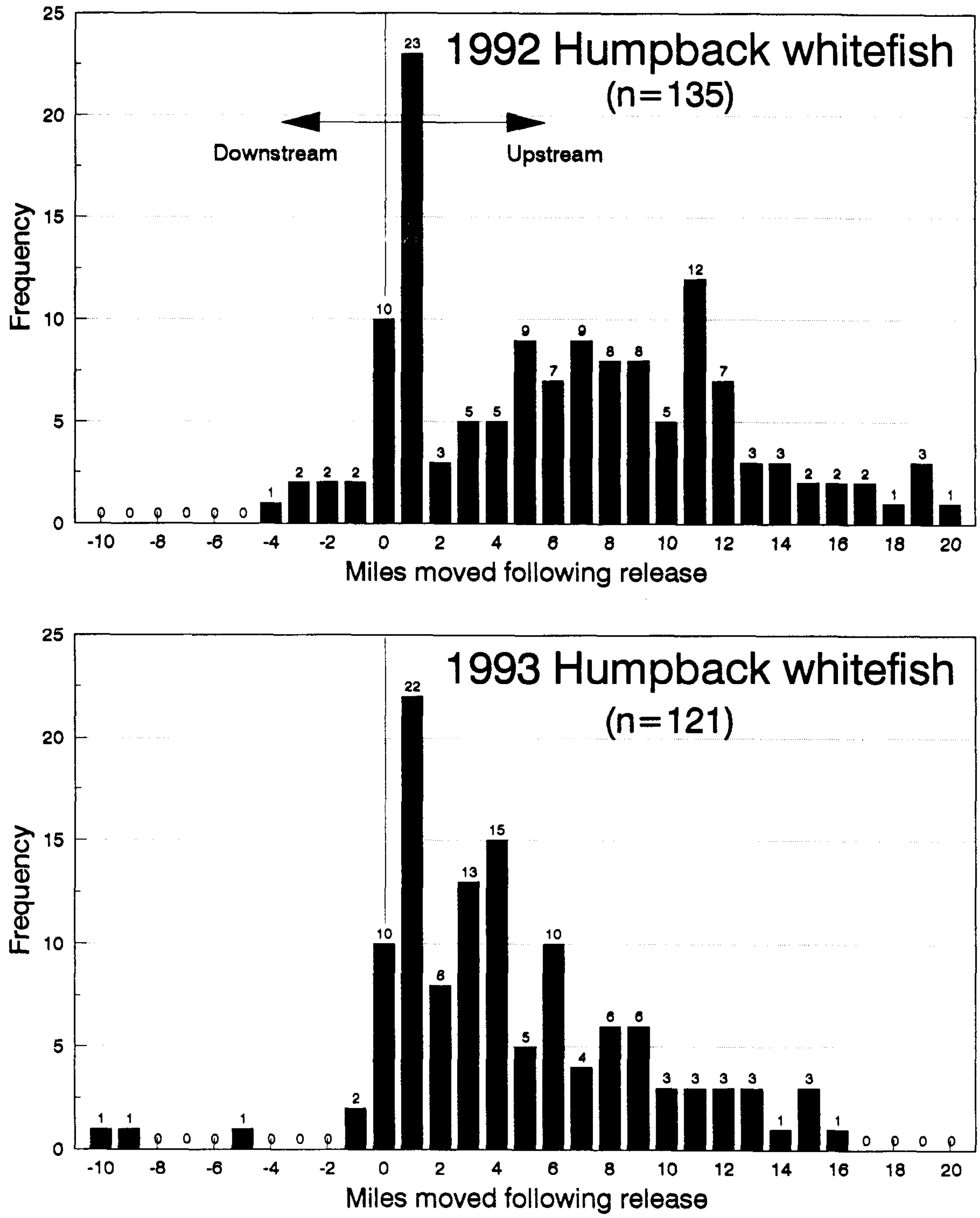

Figure 9. Observed frequencies of movements by recaptured individual humpback whitefish (≥360 mm FL) over a seven-day sampling hiatus on the Chatanika River during August 1992 and 1993.

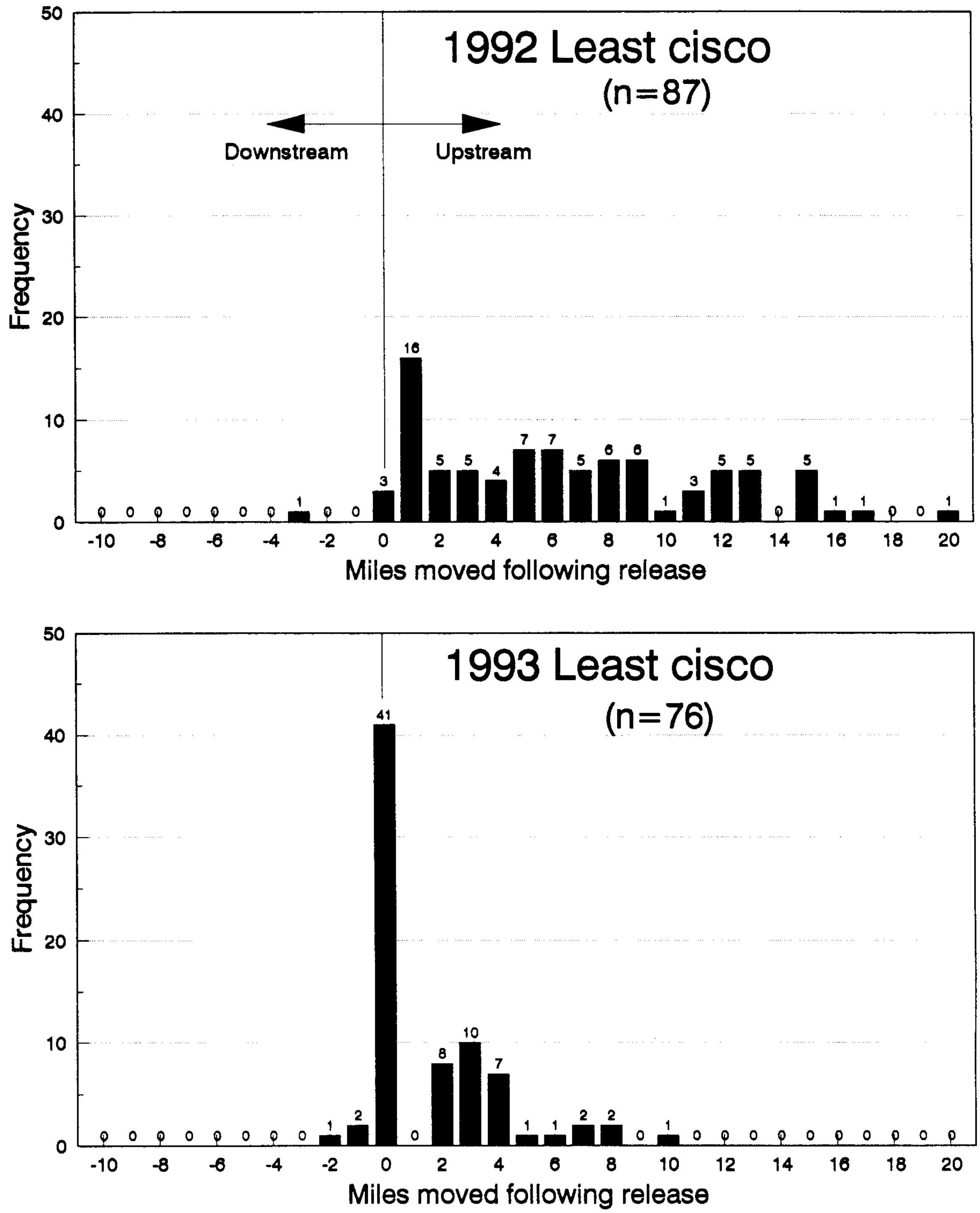

Figure 10. Observed frequencies of movements by recaptured individual least cisco ($\geq$290 mm FL) over a seven-day sampling hiatus on the Chatanika River during August 1992 and 1993.

Variables such as release rivermile (r-mile), fish size (mm FL) and the observed distance traveled were examined for correlation; significance at or above the 95% level are denoted as (**), the 90% level as (*), and no significance (NS):

Statistic Correlation:	Humpback Whitefish 1992	Humpback Whitefish 1993	Least Cisco 1992	Least Cisco 1993
Distance with:				
Release Mile	0.253	0.577	0.510	0.507
(P-value)	**	**	**	**
Size (mm FL)	0.171	0.079	0.060	0.007
(P-value)	*	NS	NS	NS
Size (mm FL) with:				
Release Mile	0.257	0.233	0.097	0.227
(P-value)	**	*	NS	**
Degrees of Freedom	133	119	85	74

Fifty-nine humpback whitefish and 26 least cisco that were marked and released in 1992 were recaptured after a year at large during the 1993 stock assessment. The median differences in river mileage between release and recovery locations for humpback whitefish was 12.4 km (7.7 mi) upstream of their 1992 release locations during the same calendar week. The 95% confidence interval of the median was 4.5 to 21.4 km (2.8 to 13.3 mi) upstream. For least cisco the median value was 12.7 km (7.9 mi) upstream and the 95% confidence interval of the median was 6.9 to 38.9 km (4.3 to 24.2 mi) upstream.

Following stock assessment efforts in both years, some marked fish of both species were harvested during the September spear fishery. Distances from the release location to the location of harvest were estimated in a similar fashion (Figure 11). The 1992 and 1993 harvests included humpback whitefish released during late August as far downstream as 62.1 km (38.6 mi) and least cisco from as far downstream as 102.0 km (63.4 mi).

DISCUSSION

Considerable changes from 1992, in catch numbers and relative locations of catches along the river in 1993 (Figures 12 and 13), and a decline in abundance, provoke discussion and questions. In 1993, most fish captured were in upstream areas, while in 1992, additional fish were captured in downriver areas. The abundance of humpback whitefish and least cisco estimated for a 49 mile portion of the Chatanika River during late August was 13,112 humpback whitefish and 46,562 least cisco. In 1992, an estimated 19,187 humpback

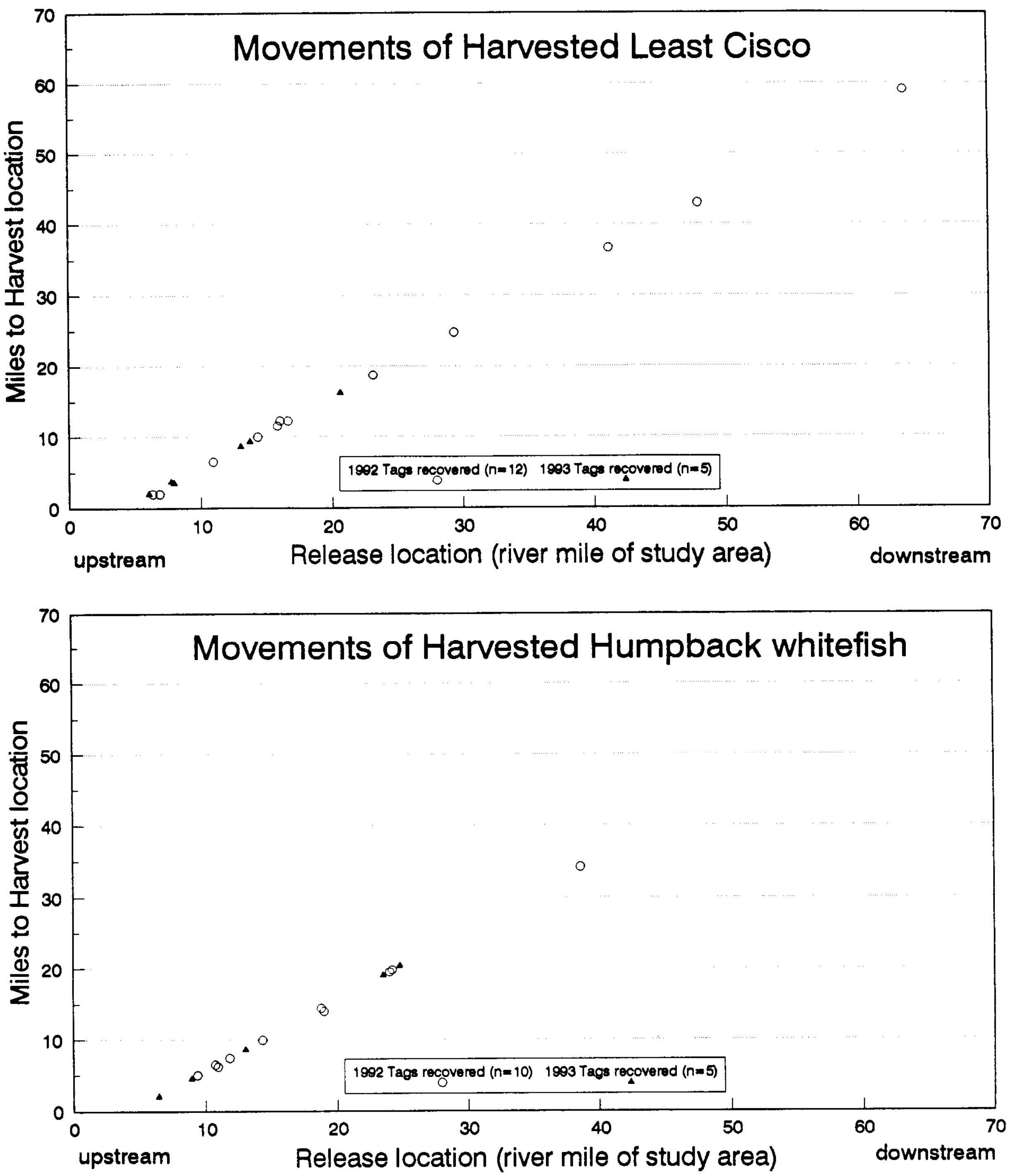

Figure 11. Observed movements by tagged individual least cisco (≥290 mm FL) and humpback whitefish (≥360 mm FL) between release in August 1992 and 1993, and harvest on the Chatanika River during September 1992 and 1993.

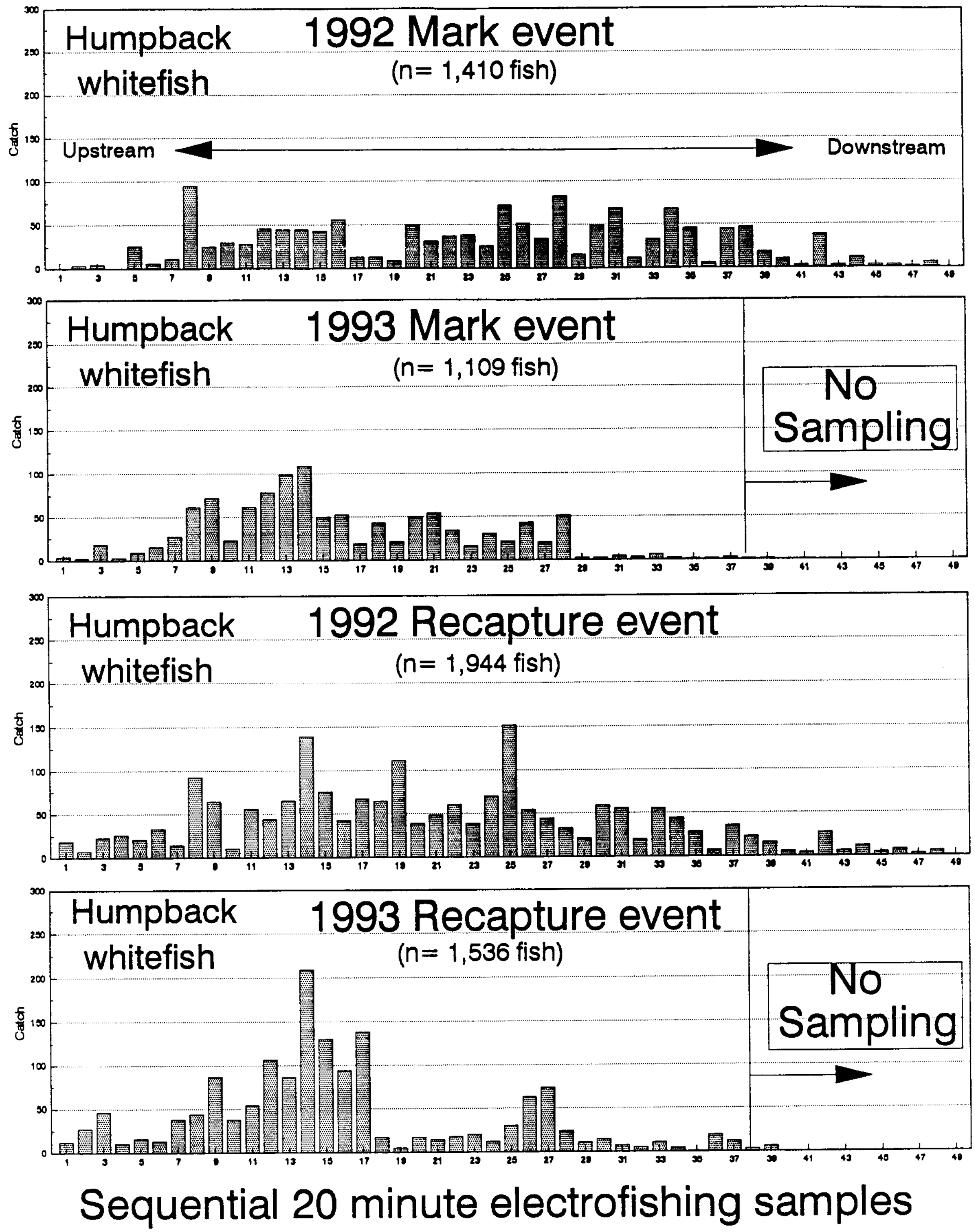

Figure 12. Systematic marking and recapture event sample catches of humpback whitefish (≥360 mm FL) during August 1992 and 1993 stock assessments in the Chatanika River.

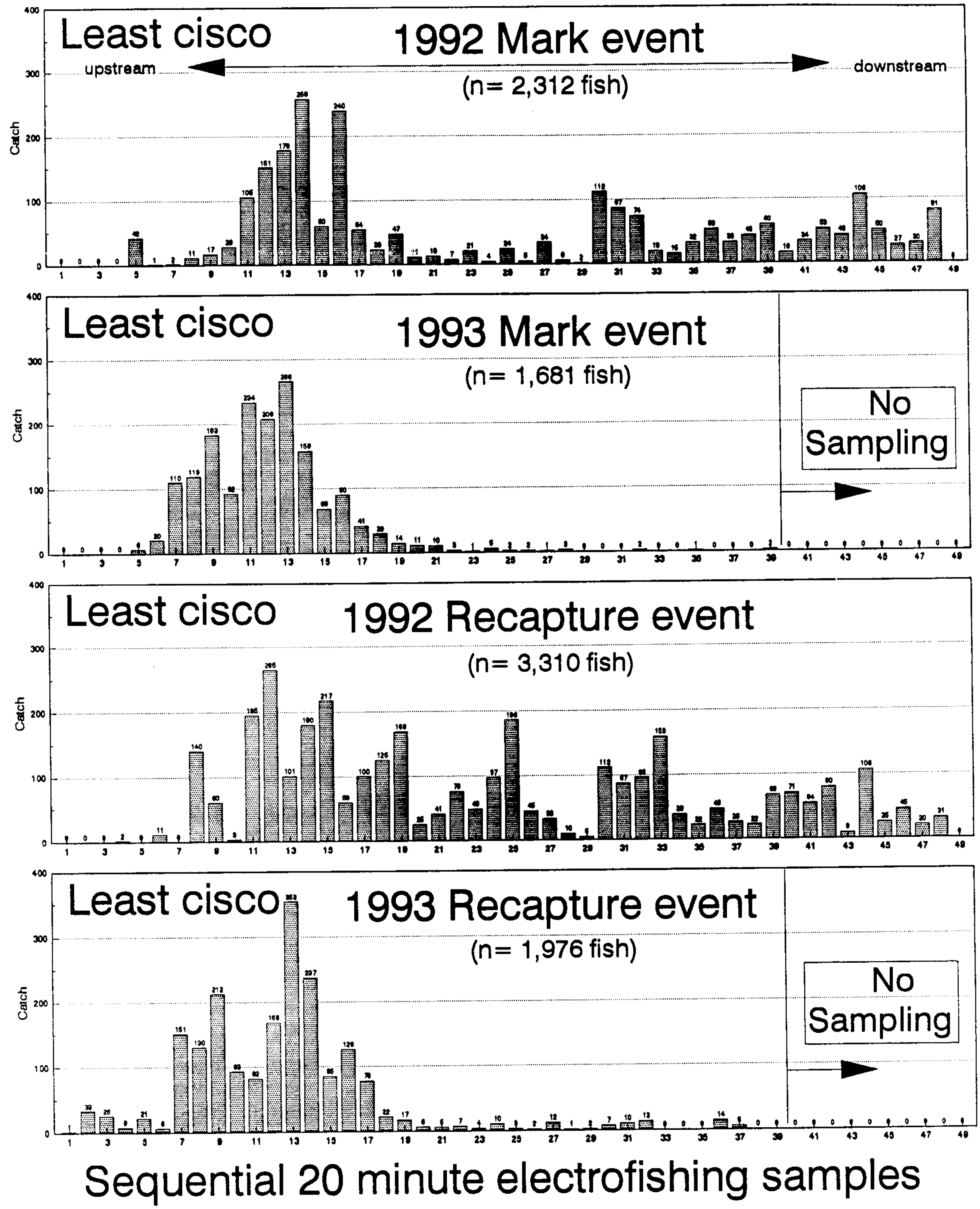

Figure 13. Systematic marking and recapture event sample catches of least cisco (≥290 mm FL) during August 1992 and 1993 stock assessments in the Chatanika River.

whitefish and 75,035 least cisco inhabited the same 78.8 km (49 mi), at a similar time. Assumptions that members of both species of whitefish return to the Chatanika River each year to spawn may not adequately explain observed differences in abundance and catches. The large differences in abundance across one year stimulates questions, possibilities, and concerns with the present and past investigation.

It appears that the assumption of geographic closure was met in 1992 and 1993. The observed relationship between distance traveled upstream and the area of release directly affects our interpretation of closure. Fish released in upstream areas moved less than those released in lower river areas. Fish released in the upper portion of the study area moved only slightly relative to the distance remaining to leave upstream, out of the study area (Figures 14 and 15). The small movements of these fish along with consistently low catches in the upper 12.9 km (8 mi) of sampled river (Figures 12 and 13) indicate geographic closure. In the lower river, findings from fish released in 1992 indicated that 10 of 20 recaptured fish released downstream of the 1993 lower sampling boundary, moved upstream across that boundary during the 7-day sampling hiatus. From this finding and the observed correlation between distance traveled and release location, we might assume that if many fish were present immediately downstream of the sampling boundary in 1993 during the first event, they would likely be detected during second event sampling. Second event catches in 1993 remained low, and did not increase.

A potential source of bias in abundance estimation is tag shedding. If shed tags were not detected using a double marking method, abundance would likely be biased high. If detection error was gross in one assessment relative to another, accuracy of the estimates could vary, and lead to errors in subsequent estimates of recruitment and survival. Anchor tag shedding during the 1993 release-recapture experiment occurred more often with humpback whitefish (6.2% tag loss detected) than least cisco (1.2% tag loss detected). If the 1992 detected tag shedding rate (1.5% and 0%, respectively) were increased to 1993 levels, the 1992 estimated abundances would decrease by only 868 humpback whitefish and 977 least cisco. This source of bias could not account for the differences in abundance.

If a Jolly-Seber approach was desired to estimate abundance, survival, and temporary emigration, present levels of long-term tag shedding would present problems. Tag shedding across years has been estimated at 42% for humpback whitefish, and 14.8% for least cisco (Fleming 1993). Waldman et. al (1990) found that among striped bass *Morone saxatilis* anchor tag loss occurred more often and quickly with fish above a particular size. The authors concluded that the increase in distance between neural spines or *pterygiophores*, associated with increasing fish size was the underlying mechanism for this selective tag loss. At present, no experiments or measurements with the two species have been undertaken to test a similar hypothesis. It is possible that anchor tags with a longer T-anchor may reduce tag shedding.

During our stock assessments of whitefish, we capture some fish belonging to nearly every age class, but the predominance of larger and older whitefish

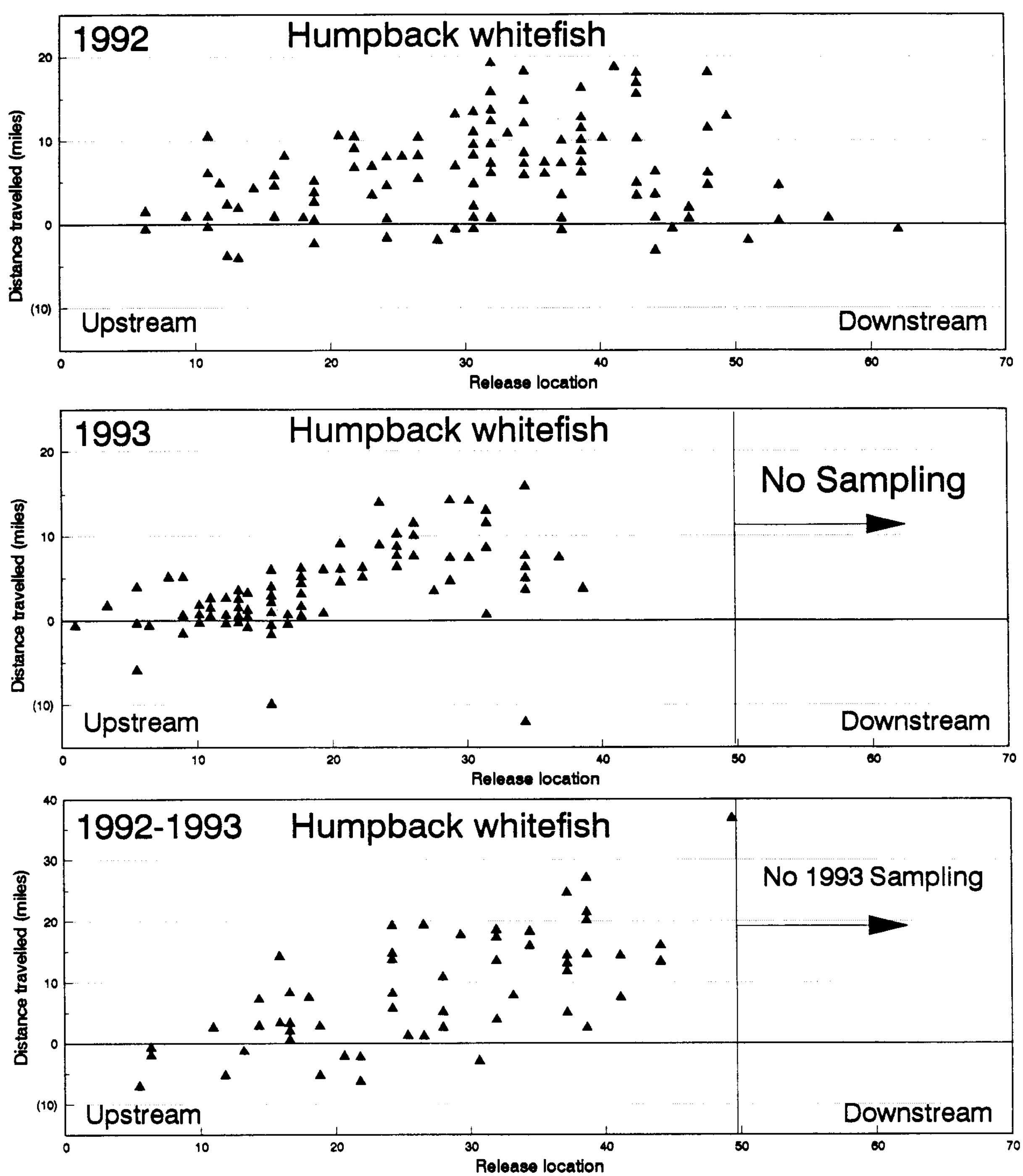

Figure 14. Observed movements by recaptured individual humpback whitefish (≥360 mm FL) relative to release location (miles downstream of upper sampling boundary) on the Chatanika River over seven-day periods in August 1992 and 1993, and of fish released in 1992 recaptured in August 1993.

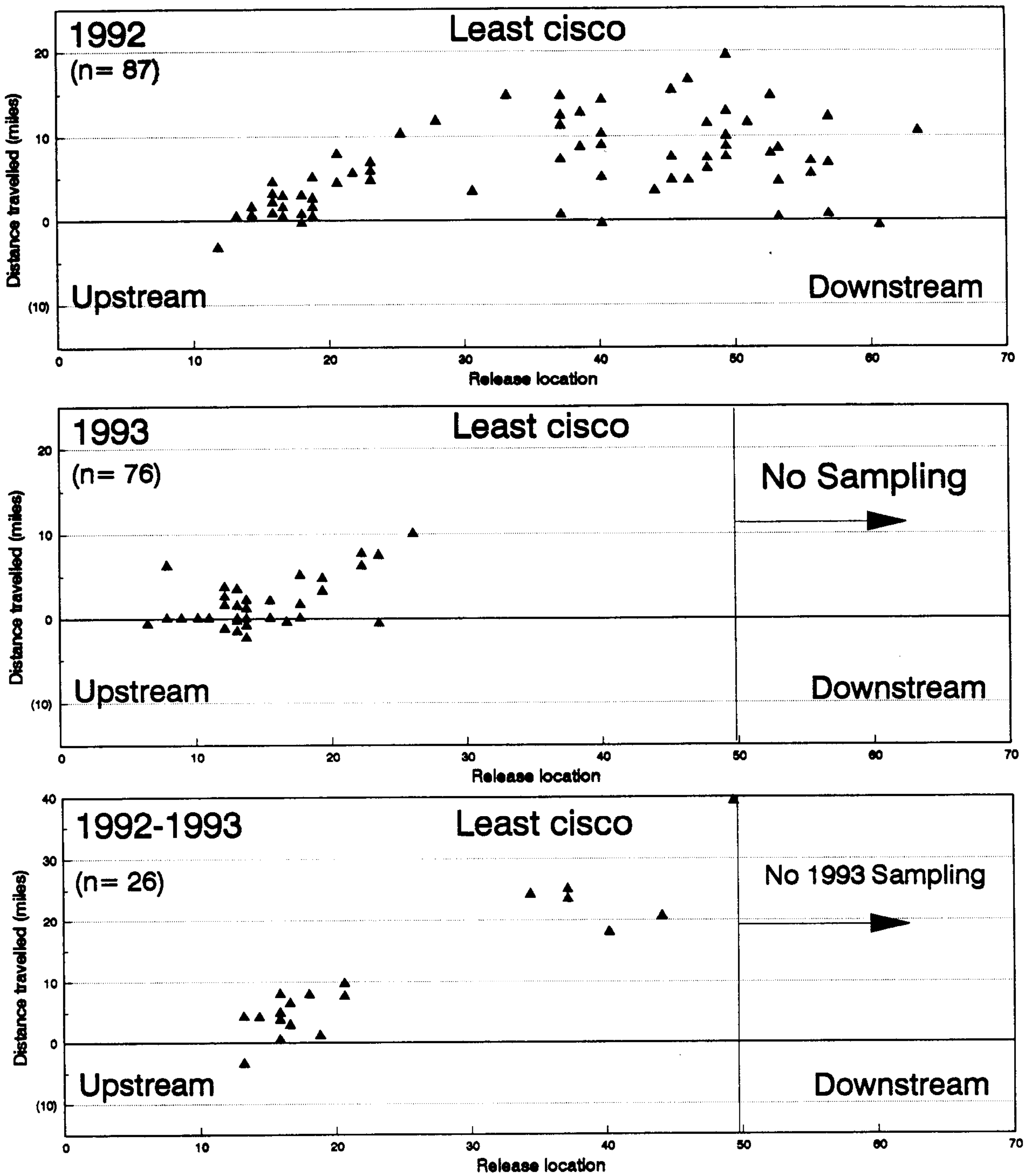

Figure 15. Observed movements by recaptured individual least cisco (≥290 mm FL) relative to release location (miles downstream of upper sampling boundary) on the Chatanika River over seven-day periods in August 1992 and 1993, and of fish released in 1992 and recaptured in August 1993.

limits the assessment program to largely the adult portion of the population. Because of this constraint, the overall population abundance, composition, and dynamics cannot be estimated or described. Although maturity has not yet been intensively examined, the current objective sizes (humpback whitefish $\geq$ 360 mm FL and least cisco $\geq$ 290 mm FL) are thought to include sexually mature whitefish. Secondarily, past and present assessment data indicate the age at which these species are fully recruited or represented is by age 7 for humpback whitefish and age 3 for least cisco. Estimates of survival in the present assessment use only fish at and above these ages, and exclude information on pre-recruited fish. Unless information can be collected on smaller and presently pre-recruited fish in their respective habitats, estimation of population dynamic parameters will be constrained to primarily adults of both species.

Adjusted age and length compositions from 1993 continue to indicate a lack of younger and smaller humpback whitefish. Again, as in 1992, the assessed stock appears to have continued the shift towards larger humpback whitefish and older and larger least cisco. The outcome of high harvests on parent stock humpback whitefish in 1986, may now be present as the estimated 7 year old recruits this year. The apportioned estimates of abundance-at-age indicate that 1993 recruitment levels fell short of 1992 levels by 44% for humpback whitefish, and 47% for least cisco (Figures 7 and 8).

Survival, mortality, and exploitation of the fully recruited portion of the stocks were estimated from 1992 to 1993. The fully recruited abundances of both humpback whitefish and least cisco decreased markedly between August sampling in 1992 and 1993. Estimated survival for humpback whitefish was 52.7% for fish age 7 and older, between August 1992 and August 1993. Similarly, survival estimated with least cisco age 3 and up, from 1992 to 1993, was 46.6%. Arctic grayling, *Thymallus arcticus*, have similar annual survival rates for fully recruited fish, ranging from 44 to 79% (Clark 1993).

However, estimates of whitefish mortality should be scrutinized. The estimated levels of exploitation from the 1992 sport harvest were not the major cause of the observed decline between these two years of sampling. Estimates of survival (or mortality) also depend on the quality of aging data and limitations of the assessment information collected. The use of a portion of an age series to estimate survival is preferred over a cohort-specific method if aging error is of concern. The effect of aging error on survival estimates depends on the presence or absence of bias.

Relative aging error was examined for humpback whitefish and least cisco aged a year or more apart through examination of release-recapture data (Appendix B). The errors found were approximately balanced (Appendix B, Figure B1), with the extent of aging errors not significantly associated with increasing size. Although an increasing size relationship with aging error has been found with other interior Alaskan species such as Arctic grayling (Merritt and Fleming 1991), the size and age range of the assessed whitefish stocks are primarily restricted to slow-growing adults. Although the assessed aging errors can markedly redistribute age compositions, no substantial bias in estimates of survival should occur, as long as patterns of aging error remain stable over time, and subsequent assessments.

An important constraint on annual stock assessments is whether all fish targeted by the assessment program are present to be sampled. Although a study area, such as the sampled segment of the Chatanika River, may be geographically closed to immigration or emigration during assessment, uncertainty can exist as to whether all animals have entered the study area. Fidelity to a spawning area incorporates geographic and timing elements. Based on the recapture of tagged individuals in years subsequent to marking, we know that some of the same fish return to the Chatanika River each year. If animals are absent, yet alive somewhere else, survival will be underestimated. It is likely that some level of temporary or permanent emigration may already exist with this stock. Several notable emigrations by humpback whitefish tagged in the Chatanika River have been documented by recoveries elsewhere in the Tanana River drainage. One fish, released during the 1991 assessment, was recovered approximately 402.2 km (250 river mi) away, another nearly 321.8 km (200 mi). Both fish were recovered the year following their release during a probable spawning migration. It is unknown if these fish would have returned to the Chatanika River at a later date, or if similar movements are numerous, yet are not detected.

If more than one stock of whitefish exist within a geographic range, such as the Minto Flats region, some level of inter-stock mixing may occur and affect interpretation of assessment data. Allocative disputes over commercially exploited lake whitefish populations in Lake Michigan have prompted studies to identify discrete stocks. Walker et al. (1993) found that home ranges of lake whitefish in Grand Traverse Bay, Lake Michigan never completely overlapped in three regions of the bay. Among home ranges, it was found that spawning home ranges were generally smaller than the non-breeding ranges, i.e. less overlap during spawning, more overlap when feeding. In August 1984, adult pre-spawning humpback whitefish and least cisco were netted in the upper Tolovana River, which also runs through the Minto Flats area (Al Townsend-ADF&G unpublished data). Although no tagging was conducted, it is likely that at some time, this spawning stock mixes or mixed with fish belonging to the Chatanika River spawning stock. Although subsequent year tag recoveries indicate that some level of annual fidelity exists with humpback whitefish and least cisco, our assessment has been constrained in terms of other areas of spawning habitat available. The geographic range of Chatanika River spawning stocks and mixing with other potential spawning stocks could be addressed with additional tagging studies. One approach to better describe behaviors of stocks and their home ranges would utilize radio telemetry on a number of individual whitefish. Investigations could track individuals from one or more spawning stock through several years of feeding, migratory, spawning, and overwintering activity. It is likely that this technology would give more detailed information than could be achieved with netting expansive areas to recapture anchor tagged fish.

Based upon the successive recaptures of tagged whitefish in the Chatanika River between years, it is known that both species are *iteoparous*, and return to spawn in the Chatanika River on two or more occasions. Depending on metabolic and energetic constraints, these stocks may have a non-successive spawning pattern (Craig 1989). Lambert and Dodson (1990) empirically demonstrated that cisco, *Coregonus artedii*, and lake whitefish, *Corregonus clupeaformis*, studied on the Eastmain River (tributary to James Bay, Canada) could not spawn in two successive years. Visible differences in somatic growth were not evident between pre-spawning and skip-spawning fish; differences were associated with tissue energy content. Because the pre-spawning anadromous whitefish migrate earlier than their non-reproductive or skip-spawning counterparts, feeding duration is shortened in spawning years. A non-consecutive pattern of spawning allows the skip-spawning component of the stock to build up energy reserves that otherwise could not be accrued with annual spawning. Skip spawning is thought to frequently occur with several Arctic anadromous fishes in Alaska, and is thought to be triggered by limitations in annual food supply (Craig 1989). Kepler (1973) reported a presence of retained eggs within a portion of ovary samples of both whitefish species sampled in the Minto Flats area during July and August 1972. The incidence of spawner-sized fish that both retained eggs from the past year's spawning, and had eggs conditioning for spawning that year (consecutively spawn) was 38% of examined humpback whitefish and 15% of the least cisco. Following the spawning period in October 1973, 11 post-spawning (spent) least cisco were examined and retained eggs were enumerated (P. Kepler-unpublished data). The total number of eggs retained in these fish ranged from zero to fifty. If so few eggs are retained following spawning, the likelihood of detection nine months later would be small. Resorption of retained eggs or difficulty of finding a few retained eggs amongst many conditioning ova in ovary samples could underestimate the proportion of fish that consecutively spawn. Future detection of non-consecutive spawning may be inferred from locating individuals outside spawning areas of the river in Fall, using radio telemetry.

If constraints exist to induce a non-consecutive spawning pattern in the Chatanika whitefish stocks, the non-consecutive spawners may share behaviors found elsewhere in studies on anadromous whitefish stocks. Bernatchez and Dodson (1987) found migratory timing differences between pre-spawning and skip-spawning components of anadromous lake whitefish and cisco stocks. Pre-spawning fish migrated upstream from James Bay to spawning areas on the Eastmain River when temperatures were at 10°C, and resided at spawning areas for 6-10 weeks prior to spawning when temperatures fell below 5°C. The timing mechanism for migration was explained by optimal swimming capacities at the higher temperatures and lowest at 5°C. In the Chatanika River, Townsend and Kepler (1973) documented upstream movements of pre-spawning humpback whitefish as early as 24 June, and least cisco by 2 July in the lower Chatanika River. The pattern was repeated in 1990 when a weir on the lower portion of the Chatanika River passed upstream migrating adult whitefish as soon as it was in operation, during the second week in July (Timmons 1991). During the last eight days of weir operation, which terminated on 31 July, only 18 whitefish were passed upstream. Water temperatures in the Chatanika River during this period ranged from 12 to 18°C.

Extended summer residence by whitefish in the Chatanika River appears to be supported by catch, movement, and abundance patterns seen in the three years of large-area sampling on the Chatanika River. The pattern of catches in 1993 indicated a more localized concentration of fish than catches in 1992, which were dispersed. In 1993, the median movements by recaptured fish of both species was less than those observed in 1992. The correlation between release location and distance traveled may also support the idea of extended residence by pre-spawning whitefish in the Chatanika River. Fish that moved little were generally in upstream areas, while the larger movements tended to be associated with fish located further downstream (Figures 14 and 15). Hypothetically, the lower estimated abundance and level of movement in 1993 may have corresponded to extended resident fish present in the mid-upper portion of the study area. In comparison, the 1992 estimate may have included extended resident fish upstream, and immigrating fish moving more rapidly through the lower portions.

Studies conducted by Lambert and Dodson (1990) on the same Eastmain River populations of whitefish found that non-reproducing fish (skip spawners and immature fish) entered the river several months later than pre-spawners, prior to overwintering in the river. In 1991, catches made on 13-14 September using one electrofishing boat in the lower 44 km included 134 humpback whitefish, and 700 least cisco (Fleming- unpublished data). Observed marked-to-unmarked ratios of least cisco in the lower river at this time were approximately one-third of upstream areas (Timmons 1991) indicating a substantial influx by unmarked fish may have occurred. Lower river catches of whitefish during late August 1992 may have corresponded to the onset of an overwintering migration, consisting of non-spawning fish. Higher numbers of these fish may have positively influenced the 1992 median distance traveled during the 7-day sampling hiatus, and the 1992 estimate of abundance. The decline in catches in the same area in 1993 may have corresponded to the timing of an interim period, between modes of immigration. The greater upstream catches, relative to downstream catches, may have reduced the median level of movement seen in 1993 relative to 1992.

If energetic constraints periodically exist for whitefish in the Chatanika River and induce non-consecutive patterns of spawning, then patterns of abundance may be explained more easily. Although it is possible that the survival of humpback whitefish and least cisco could have been ~ 53 and 47%, respectively, belief in this level of mortality ignores the earlier 1991 finding of mid-September catches of both species. Using an assumption that the non-consecutive spawning life history is most appropriate, the last three estimates can be better explained. The lowest abundances, 13,112 humpback whitefish and 46,562 least cisco in 1993, primarily consisted of extended-residence pre-spawning fish. The higher 1992 estimate (20,180 humpback whitefish and 86,989 least cisco) may have also included the addition of early arriving non-spawners moving upstream prior to overwintering. Lastly, the 1991 estimate, in which Timmons (1991) estimated 15,313 humpback whitefish, and 135,065 least cisco (Timmons 1991) during September, may have included spawners and non-spawners. The longer duration of the 1991 release-recapture experiment may have resulted in upstream emigration by humpback whitefish, based on past observations of their use of upstream areas.

If a non-consecutive pattern of spawning exists for whitefish which use the Chatanika River, then stock assessment data could be biased. In any year, the proportion of fish that may skip spawning could change with changes in the population's composition, as well as by energetic constraints. It will be important to gather information that either documents this pattern, or refutes it. Additionally, the contribution of late immigrating fish needs to be estimated to spawning and to harvest areas.

CONCLUSION AND RECOMMENDATIONS

Recently detected declines in the estimated abundances of humpback whitefish and least cisco may have been caused by the single or combined influences of area and timing of assessments, migratory timing of an alternative life history pattern, or natural mortality. No definitive answer to this decline is available at this time, because the life history of Chatanika River whitefish is not yet completely described, and similar survival rates have been observed in other interior Alaska species. The early upstream movement and presence of humpback whitefish and least cisco in the Chatanika River may be an adaptation to conserve energy during spawning migrations. Past investigations have also captured substantial numbers of both species in the lower portion of the study area in mid-September. Results from the past three years of stock assessment appear to fit a non-consecutive spawning life history pattern, which has been documented in northern Alaska and areas in Canada for similar species of whitefish. Future investigations need to determine whether non-consecutive life history patterns exist for whitefish in the Chatanika River. The non-consecutive spawning life history may be detected through investigations of maturity and by annual fidelity to the Chatanika River using radio telemetry. Simultaneously, tagged fish should be released during September in the lower river to examine the contributions of whitefish arriving later than the current assessment. Information gained by a better understanding of Chatanika River whitefish life history and time-area contributions will better facilitate the refinement of this assessment program. If a non-consecutive pattern exists, or, late immigrating whitefish do not enter the area of the fishery, assessment and management staff might target assessment work on a particular portion of the whitefish stocks as an index, i.e. extended residence pre-spawners earlier in August.

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APPENDIX A

Appendix A1. Summary of age composition estimates and standard errors for humpback whitefish sampled in the Chatanika River, 1986 - 1993[a].

	1986 15 September- 14 October			1987 11 September- 17 October			1988 17 August - 21 September			1989 16 August - 27 September		
Age Class	n[b]	p[c]	SE[d]	n	p	SE	n	p	SE	n	p	SE
1	0	---	---	0	---	---	0	---	---	0	---	---
2	0	---	---	0	---	---	0	---	---	0	---	---
3	1	<0.01	<0.01	10	0.03	0.01	3	0.01	<0.01	0	---	---
4	50	0.22	0.02	95	0.31	0.03	85	0.16	0.02	13	0.01	<0.01
5	102	0.44	0.03	118	0.38	0.03	230	0.42	0.02	211	0.21	0.01
6	33	0.14	0.02	56	0.18	0.02	155	0.28	0.02	433	0.44	0.01
7	19	0.08	0.02	20	0.07	0.01	54	0.10	0.01	198	0.20	0.01
8	19	0.08	0.02	2	<0.01	<0.01	14	0.03	0.01	84	0.09	0.01
9	6	0.03	0.01	3	<0.01	<0.01	5	0.01	<0.01	23	0.02	<0.01
10	2	0.01	<0.01	1	<0.01	<0.01	0	---	---	9	0.01	<0.01
11	0	---	---	0	---	---	0	---	---	8	0.01	<0.01
12	0	---	---	0	---	---	0	---	---	1	<0.01	<0.01
13	0	---	---	0	---	---	0	---	---	2	<0.01	<0.01
14	0	---	---	0	---	---	0	---	---	0	---	---
15	0	---	---	0	---	---	0	---	---	0	---	---
16	0	---	---	0	---	---	0	---	---	0	---	---
Total	232	1.00		305	1.00		546	1.00		1,368	1.00	

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Appendix A1. (Page 2 of 2).

Age Class	1990 20 August - 12 September			1991 9 - 14 September			1992 24 - 28 August			1993 23 - 26 August		
	n[b]	p[c]	SE[d]	n	p	SE	n	p	SE	n	p	SE
1	0	---	---	0	---	---	0	---	---	1	<0.01	<0.01
2	0	---	---	0	---	---	2	<0.01	<0.01	0	---	---
3	4	<0.01	<0.01	10	0.03	0.01	7	<0.01	<0.01	11	0.01	<0.01
4	25	0.05	0.01	13	0.04	0.01	41	0.06	0.01	70	0.08	0.01
5	136	0.27	0.02	20	0.06	0.01	36	0.06	0.01	69	0.08	0.01
6	179	0.36	0.02	51	0.15	0.02	48	0.07	0.01	60	0.07	0.01
7	103	0.21	0.02	86	0.25	0.02	118	0.18	0.01	132	0.15	0.01
8	37	0.07	0.01	71	0.21	0.02	147	0.23	0.02	176	0.20	0.01
9	8	0.02	<0.01	44	0.13	0.02	113	0.18	0.01	165	0.19	0.01
10	3	<0.01	<0.01	22	0.06	0.01	71	0.11	0.01	106	0.12	0.01
11	2	<0.01	<0.01	13	0.04	0.01	32	0.05	0.01	51	0.06	0.01
12	0	---	---	11	0.03	0.01	17	0.02	<0.01	25	0.03	0.01
13	0	---	---	1	<0.01	<0.01	6	<0.01	<0.01	7	<0.01	<0.01
14	0	---	---	0	---	---	3	<0.01	<0.01	7	<0.01	<0.01
15	0	---	---	0	---	---	2	<0.01	<0.01	0	---	---
16	0	---	---	0	---	---	0	---	---	1	<0.01	<0.01
Total	497	1.00		342	1.00		642	1.00		881	1.00	

[a] All fish captured with an electrofishing boat with exception of 1986 and 1987, which were harvest samples from the spear fishery. Data sources were: 1986-Hallberg and Holmes (1987); 1987-Hallberg (1988); 1988- Hallberg (1989); 1989- Timmons (1990); 1990-1991- Timmons (1991), 1992- Fleming (1993); and, 1993 - this report.

[b] n = sample size.

[c] p = proportion.

[d] SE = standard error of the proportion.

Appendix A2. Summary of age composition estimates and standard errors for least cisco sampled in the Chatanika River, 1986 - 1993[a].

Age Class	1986 15 September- 14 October			1987 11 September- 17 October			1988 17 August - 21 September			1989 16 August - 27 September		
	n[b]	p[c]	SE[d]	n	p	SE	n	p	SE	n	p	SE
1	0	---	---	0	---	---	0	---	---	0	---	---
2	2	<0.01	<0.01	2	<0.01	<0.01	0	---	---	1	<0.01	<0.01
3	195	0.31	0.02	110	0.18	0.01	76	0.13	0.01	95	0.07	0.01
4	314	0.50	0.02	238	0.39	0.02	199	0.35	0.02	543	0.43	0.01
5	93	0.15	0.01	162	0.27	0.02	208	0.36	0.02	478	0.38	0.01
6	17	0.03	<0.01	73	0.12	0.01	68	0.12	0.01	125	0.10	0.01
7	8	0.01	<0.02	14	0.02	<0.01	19	0.03	0.01	26	0.02	<0.01
8	0	---	---	5	<0.01	<0.01	42	0.01	<0.01	1	<0.01	<0.01
9	0	---	---	0	---	---	0	---	---	0	---	---
10	0	---	---	0	---	---	0	---	---	0	---	---
Total	629	1.00		341	1.00		574	1.00		1,269	1.00	

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Appendix A2. (Page 2 of 2).

Age Class	1990 20 August - 12 September n[b]	p[c]	SE[d]	1991 9 - 14 September n	p	SE	1992 24 - 28 August n	p	SE	1993 23 - 26 August n	p(adj)[e]	SE
1	0	---	---	0	---	---	0	---	---	0	---	---
2	2	<0.01	0.04	63	0.17	0.02	87	0.10	0.01	14	0.02	<0.01
3	265	0.21	0.02	86	0.24	0.02	316	0.36	0.02	230	0.26	0.02
4	148	0.11	0.02	45	0.12	0.02	195	0.22	0.01	351	0.40	0.02
5	383	0.30	0.02	75	0.21	0.02	93	0.10	0.01	125	0.14	0.01
6	379	0.30	0.02	73	0.20	0.02	113	0.13	0.01	52	0.06	0.01
7	87	0.07	0.03	17	0.05	0.01	58	0.06	<0.01	57	0.07	0.01
8	18	0.01	0.03	4	0.01	<0.01	16	0.02	<0.01	32	0.04	0.01
9	0	---	---	0	---	---	2	<0.01	<0.01	6	0.01	0.01
10	0	---	---	0	---	---	0	---	---	1	<0.01	<0.01
Total	1,282	1.00		363	1.00		880	1.00		868	1.00	

[a] All fish captured with an electrofishing boat with exception of 1986 and 1987, which were harvest samples from the spear fishery. Data sources were: 1986-Hallberg and Holmes (1987); 1987-Hallberg (1988); 1988- Hallberg (1989); 1989- Timmons (1990); 1990-1991- Timmons (1991), 1992- Fleming (1993); and, 1993 - this report.

[b] n = sample size.

[c] p = proportion.

[d] SE = standard error of the proportion.

[e] p(adj) = proportion adjusted for size selectivity.

Appendix A3. Summary of mean length at age data for humpback whitefish sampled in the Chatanika River, 1986 through 1993[a].

	1986 15 September - 14 October			1987 11 September - 17 October			1988 17 August - 21 September			1989 16 August - 27 September			1990 20 August - 12 September			1991 9 - 14 September		
Age Class	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD
1	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
2	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
3	1	354	---	19	345	20	3	349	5	0	---	---	4	378	24	49	358	35
4	50	370	7	199	368	13	85	368	16	13	400	18	25	403	20	36	355	24
5	102	391	10	245	386	14	230	383	14	211	403	29	136	406	23	38	398	25
6	33	402	17	138	409	15	155	397	15	433	407	21	179	409	13	96	414	29
7	19	414	17	54	427	18	54	420	16	198	415	28	103	423	20	154	425	23
8	19	432	30	18	452	17	14	438	20	84	419	27	37	421	24	134	432	25
9	6	428	42	10	469	18	5	464	19	23	441	34	8	438	17	70	443	25
10	2	438	3	3	497	5	0	---	---	9	450	27	3	430	5	32	464	28
11	0	---	---	0	---	---	0	---	---	8	474	54	2	459	10	23	463	48
12	0	---	---	0	---	---	0	---	---	1	468	---	0	---	---	15	481	15
13	0	---	---	0	---	---	0	---	---	2	489	7	0	---	---	2	481	13
14	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
15	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
16	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
Total	232	395	60	686	---	---	546	---	---	982	---	---	497	---	---	649	---	---

-continued-

Appendix A3. (Page 2 of 2).

	1992[e] 24-28 August			1993 23-26 August		
Age Class	n	FL	SD	n	FL	SD
1	0	---	---	0	---	---
2	0	---	---	0	---	---
3	7	372	11	27	342	31
4	41	386	18	80	385	23
5	36	394	21	69	403	21
6	148	420	28	60	424	19
7	118	429	24	132	435	23
8	147	436	22	176	444	23
9	113	447	24	165	449	23
10	71	460	24	106	461	23
11	32	458	20	51	469	25
12	16	480	21	25	484	25
13	6	498	34	7	477	30
14	3	505	52	7	504	32
15	2	562	24	0	---	---
16	0	---	---	1	494	---
Total	631	---	---	909	---	---

[a] All fish captured with an electrofishing boat with exception of 1986 and 1987, which were harvest samples from the spear fishery. Data sources were: 1986-Hallberg and Holmes (1987); 1987-Hallberg (1988); 1988- Hallberg (1989); 1989- Timmons (1990); 1990-1991- Timmons (1991), 1992- Fleming (unpublished data); and, 1993 - this report.

[b] n = sample size.

[c] FL = mean fork length (mm) at age.

[d] SD = sample standard deviation of FL.

[e] For humpback whitefish greater than 359 mm FL only.

Appendix A4. Summary of mean length at age data for least cisco sampled in the Chatanika River, 1986 - 1993[a].

	1986 15 September - 14 October			1987 11 September - 17 October			1988 17 August - 21 September			1989 16 August - 27 September			1990 20 August - 12 September			1991 9 - 14 September		
Age Class	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD	n	FL	SD
1	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
2	2	288	18	2	254	17	0	---	---	1	310	---	2	298	---	151	293	23
3	195	305	14	110	303	11	76	304	11	95	325	19	265	306	16	210	317	26
4	314	312	18	238	314	11	199	315	11	543	331	23	146	330	24	84	336	16
5	93	329	29	162	328	9	208	325	13	478	335	22	381	338	16	165	348	35
6	17	348	16	73	345	12	68	339	15	125	340	22	376	343	19	154	355	21
7	8	361	20	14	375	12	19	358	19	26	353	20	86	345	28	41	365	12
8	0	---	---	5	400	16	4	397	33	1	344	---	18	357	21	5	389	9
9	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
10	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
11	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
12	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---	0	---	---
Total	629	313	25	604	---	---	574	---	---	1,269	---	---	1,274	---	---	810	---	---

-continued-

Appendix A4. (Page 2 of 2).

	1992[e] 24-28 August			1993 23-26 August		
Age Class	n	FL	SD	n	FL	SD
1	0	---	---	0	---	---
2	97	306	17	134	270	20
3	329	321	21	236	325	17
4	197	340	20	352	335	19
5	94	348	19	125	352	19
6	113	357	20	52	359	18
7	58	365	20	57	363	17
8	16	370	14	32	370	21
9	2	389	30	6	376	26
10	0	---	---	1	373	---
11	0	---	---	0	---	---
12	0	---	---	0	---	---
Total	906	---	---	995	---	---

[a] All fish captured with an electrofishing boat with exception of 1986 and 1987, which were harvest samples from the spear fishery. Data sources were: 1986-Hallberg and Holmes (1987); 1987-Hallberg (1988); 1988- Hallberg (1989); 1989- Timmons (1990); 1990-1991- Timmons (1991), 1992- Fleming (unpublished data); and, 1993 - this report.

[b] n = sample size.

[c] FL = mean fork length (mm) at age.

[d] SD = sample standard deviation of FL.

[e] For Least cisco greater than 289 mm FL only.

APPENDIX B

INTRODUCTION

Knowledge about the age structure of a population is vital to estimating survival, recruitment, age-related growth, and cohort abundance. Several studies indicate that older ages are often underestimated for many different species of fish (Beamish and McFarlane 1987). Underestimates of maximum ages can in turn cause overestimates of survival and maximum sustainable yield. Critical evaluation of the aging method(s), i.e. age validation, is therefore necessary to determine the precision and accuracy of the preferred aging method(s).

Power (1978), Mills and Beamish (1980), and Barnes and Power (1984) reported that using scales to age fish frequently underestimated ages compared with using other structures (otolith cross-sections, fin rays, and otoliths, respectively). While not dealing with whitefish directly, several authors (Beamish and Fournier 1981; Beamish and McFarlane 1983, 1987; Chang 1982) have called for validation of assigned ages to prove accuracy. Timmons (1991a) investigated the relative precision of six structures in aging humpback whitefish and least cisco and found scales and fin rays were the most precise although for humpback whitefish, the precision was negatively correlated to length. Power (1978) stated that long term tagging studies (20+ years) are necessary for proper age validation of fish living in Arctic environments.

The overall goal of this report is to summarize information on the relative accuracy of age determination for humpback whitefish and least cisco. True age validation was not possible because there was no way to be certain of the true age of the sampled fish. However, a relative age validation could be conducted by marking a group of fish and recapturing them over a number of years. The specific objectives of this study are to:

1. estimate the proportion of recaptured humpback whitefish and least cisco in the database whose assigned ages reflect time elapsed between captures; and,

2. estimate the magnitude of any bias in age determination of humpback whitefish and least cisco.

METHODS

Gum cards, to which scales were affixed, were used to make triacetate impressions using a scale press (30 s at 137,895 kpa, at a temperature of 97° C). Ages were obtained by counting annuli on scales viewed with a microfiche viewer at a magnification of 35x. The criteria used for identifying annuli included relative spacing of the circuli, "cutting over" and "crossing over" of the annulus, and bending or waviness of circuli (Jearld 1983).

Statistical Tests

Mark-recapture data including lengths and ages determined from scales has been collected for both species over several years. The humpback whitefish database contained 18,935 records, of which 3,561 records (18.8%) had an associated age. Of these 3,561 records, 127 fish were recaptured in the same year as initial capture, 75 fish were caught during 2 separate years and 3 fish were caught in 3 different years. The least cisco database contained 29,966 records, of which 5,522 (20.5%) had an associated age. Seventy-seven (77) fish recaptured the same year as initial capture, 30 fish were caught during 2 separate years and 3 fish were caught during 3 different years.

For the possible pairs of age estimates, error in age determination was calculated as:

$$ERROR = AGE_{t+\Delta t} - AGE_t - \Delta t \tag{B1}$$

where:

$AGE_{t+\Delta t}$ = age assigned at later capture;
AGE_t = age assigned at earlier capture; and,
Δt = the time elapsed between captures in years.

For fish caught three times, the comparisons were made between the first and the second captures, the first and the third capture and the second and third captures. No fish were caught more than three times.

The proportion of each species whose difference in estimated ages reflected the time elapsed between captures was calculated as:

$$q = \frac{a}{m} \tag{B2}$$

where:

a = the number of fish whose assigned ages agree with the time elapsed; and,
m = the total number of recaptured fish in the database.

For each species the distribution of the *ERROR* was examined and tested for symmetry. The effect of length on accuracy in determining age was examined through simple linear regression. The error in age determination was regressed on the length at time of recapture for both species. The distribution of the absolute difference between the two assigned ages was examined for fish caught twice in the same year.

RESULTS

Eighty-four (84) records were examined for humpback whitefish (same year recaptures not included). The increase in the number of scale-annulus increments agreed with the time elapsed between captures 29.8% of the time

(Figure B1). The error between the assigned ages and time elapsed was within one year (-1, 0, 1) 73.8% of the time. The distribution of the error was symmetrical (P > 0.05) and centered around zero. The mean error, or bias, was 0.07.

Thirty-six (36) records were examined for least cisco (same year recaptures not included). The increase in the number of scale-annulus increments agreed with the time elapsed between captures 36.1% of the time (Figure B1). The error was within one year (-1, 0, 1) 74.9% of the time . The distribution of the *ERROR* was not symmetrical but positively skewed (P > 0.05). The mean error, or bias, was 0.5.

As the length of the humpback whitefish increased the scale-annulus increments under represented the time elapsed (slope = -0.01, P = 0.06, Figure B2). For humpback whitefish with two age determinations done in the same year, the absolute difference between the two assigned ages increased with age (slope = 0.35, P < 0.01, Figure B3). Length of fish had no affect on the *ERROR* for least cisco (slope = 0.003, P = 0.78 Figure B2) and the absolute error remained almost constant across ages (slope = -0.02, P = 0.78, Figure B3) for least cisco caught in the same year.

DISCUSSION

The agreement between the time elapsed and the difference between age determinations was lower than expected. A high proportion of the scales (47 of 84 for humpback whitefish, 29 out of 36 for least cisco) had different readers for the initial and recapture age determination. Timmons (1991a) found significant differences between readers. Thus, the lack of agreement between the two estimated ages and time elapsed could be due, at least in part, to the difference between readers. For least cisco caught and recaptured in the same year, the scales were read by the same person and the average *ERROR* in age determination was -0.10. This is considerably smaller than the mean *ERROR* of 0.05 when different people may have read the scales.

The precision in age determination of least cisco was not affected by length or age. Humpback whitefish however, were more difficult to age as they got older. These findings agree with those of Timmons.

The error in the estimation of age is assumed to not have compromised the estimates of survival and recruitment based on cohort analysis for humpback whitefish because the error in age determination was normally distributed. Least cisco are being overaged, thus estimates of survival based on cohort analysis would be under estimated. However, the variation in the estimates of recruitment and survival for both least cisco and humpback whitefish has probably been underestimated because they did not account for the error found in age determination of the scales.

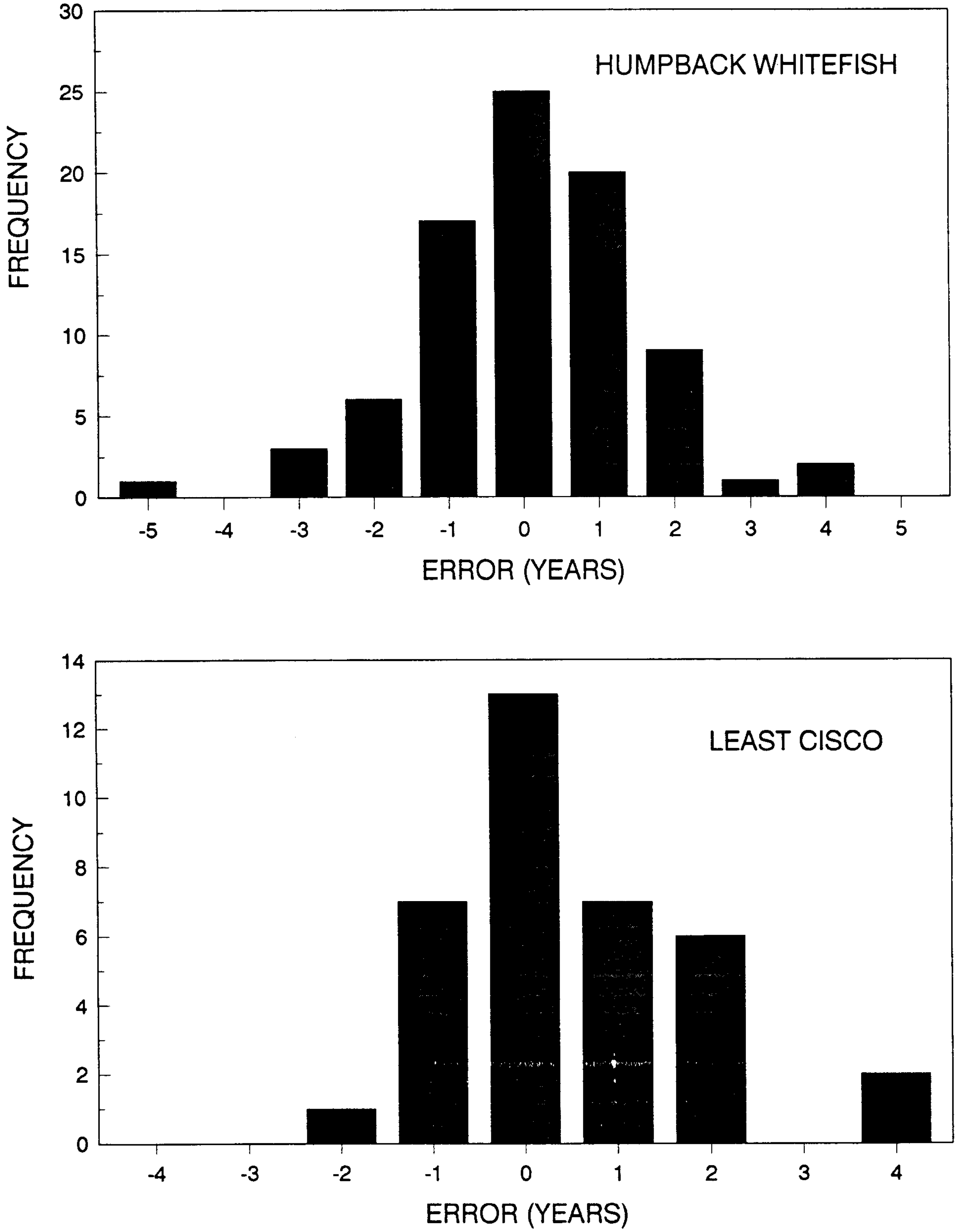
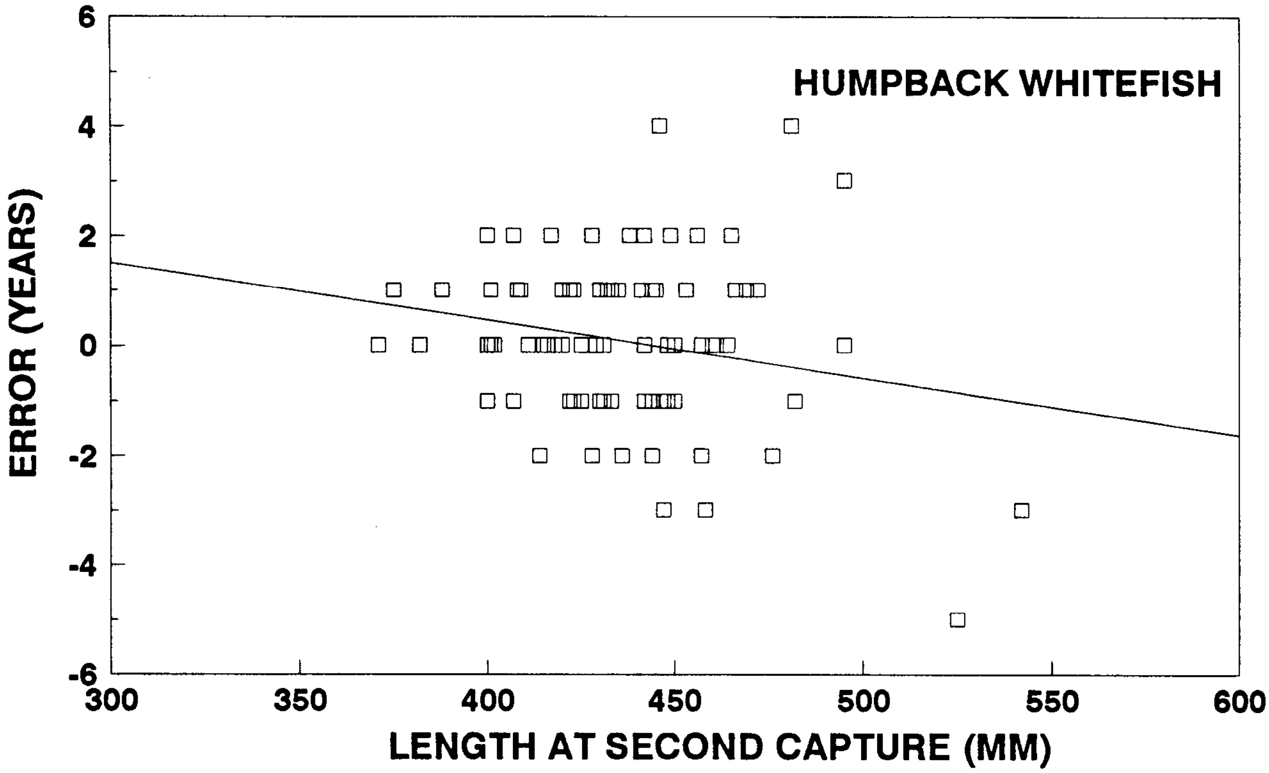


Figure B1. Frequency of error in aging humpback whitefish and least cisco scales.



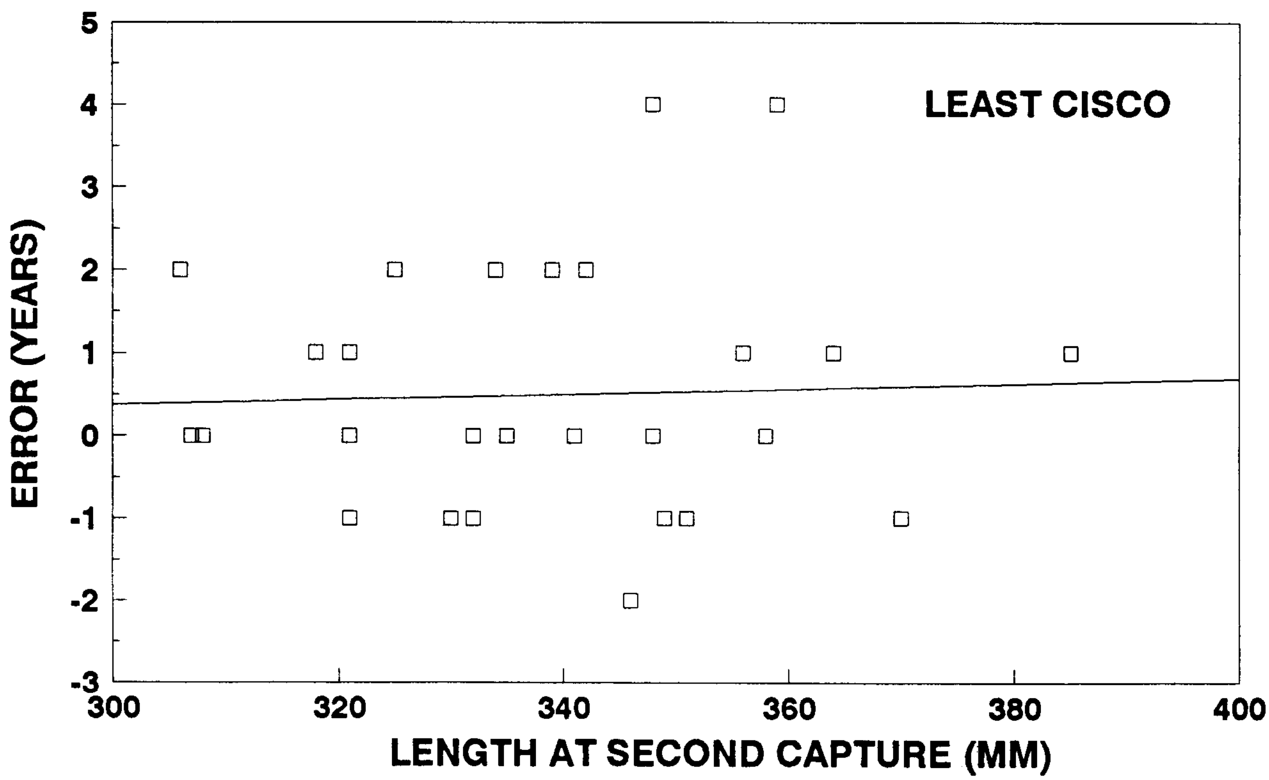
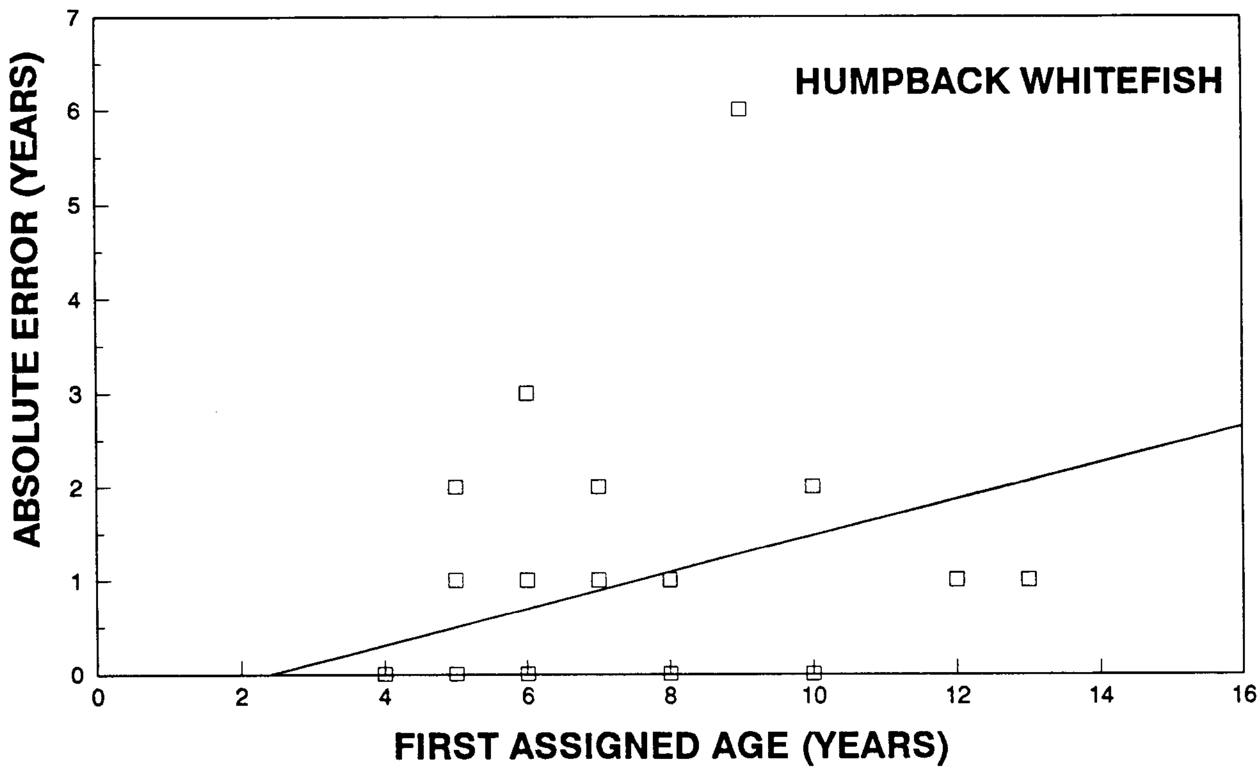


Figure B2. Aging error of humpback whitefish and least cisco compared related to fish length.



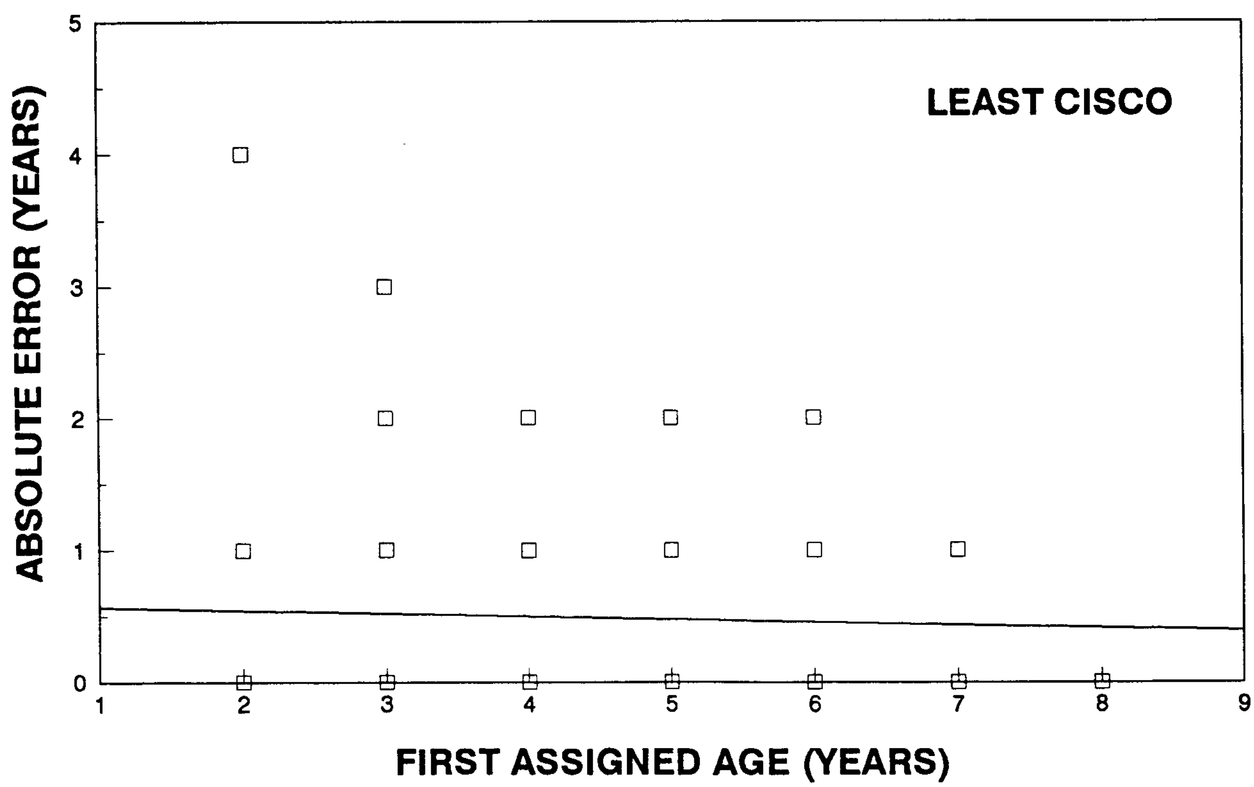


Figure B3. The absolute difference between two assigned ages related to fish age.

APPENDIX C

Appendix C1. Methodologies for alleviating bias due to gear selectivity by means of statistical inference.

Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]	
Fail to reject H_0	Fail to reject H_0
Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]	
Fail to reject H_0	Reject H_0
Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event	
Case III[e]	
Reject H_0	Fail to reject H_0
Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]	
Reject H_0	Reject H_0
Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification. If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities. If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.