FEASIBILITY STUDY FOR ESTIMATING BROAD WHITEFISH PRODUCTION IN TAPPED LAKES OF THE COLVILLE DELTA

Final Report

April 2008

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EXECUTIVE SUMMARY

A considerable amount of effort has been expended in identifying important fish habitats within the Colville Delta. These efforts have identified tapped lakes as being important rearing areas for a variety of fish species, with broad whitefish being especially abundant in these habitats. Broad whitefish is the most important subsistence fish species that feeds within the delta; the other favorite fish, Arctic cisco, uses the delta primary for wintering, not feeding. Most studies in recent years use fyke nets for sampling fish. These nets provide an index of fish abundance, but there remains a question as to how many fish are represented by these catch rates. In addition, available information does not provide information on fish density or production rates. Such information is useful for estimating the production capacity of tapped lakes, which can be used when evaluating harvest guidelines. The objective of this study is to evaluate methods to estimate the number of broad whitefish using selected tapped lakes during the summer feeding period and begin to assess the production potential for broad whitefish from such lakes.

Methods

Two tapped lakes were selected for sampling in 2007. Each lake has a single inlet/outlet channel. One (M9521) is an 85.8 hectare (212 acre) lake connected to the Sakoonang Channel, while the other (M9625) is a 30.8 hectare (76 acre) lake connected to the Tamayagiaq Channel. Sampling was by fyke net during three time periods: June 19-27, July 22-29 and August 17-23. These three periods were selected to release tagged broad whitefish during the spring out-migration, the summer feeding period, and the late summer return to the river prior to wintering.

Growth as expressed by increasing fork length through the summer was estimated from broad whitefish length frequencies. Length and weight data obtained from field measurements were used to calculate length-weight relationships and estimate growth in terms of weight gain.

The number of fish inside the lakes (upstream of the fyke nets) was estimated based on the number of tagged fish in the lake on any given day and the number of tagged and untagged fish captured during downstream movement. The number of fish present in the lake at the beginning of day 1 of a given sampling period was estimated using a maximum likelihood approach. Major assumptions of this approach are that each fish upstream of the fyke net has equal capture probability, and that no tag loss occurs. All tagged fish were also fin clipped, thus the affect of tag loss on estimates can be assessed through simulations.

The number of fish in July and August was estimated using an open Cormack-Jolly-Seber (CJS) capture-recapture model. Each 7-9 day sampling period was considered a single sampling event. The model also provides an estimate of “survival” (1 – mortality or emigration) between sampling events.

Results

Tapped lakes sampled in 2007 are in the mid to outer portion of the Colville River delta and are within tidal influence of the Beaufort Sea. As a result, lake levels rise and fall twice daily. Water in the channels connecting the lakes to the river reverses flow during each tidal exchange, which promotes variable water chemistry through the open water period.

Sampling at the two tapped lakes resulted in a catch of 17 fish species. Broad whitefish were the most abundant species caught during the entire season, followed by humpback whitefish, least cisco and round whitefish. Catch rates tended to be lowest in July at both stations. Species composition reflected the estuarine nature of the study area, with Arctic cisco, rainbow smelt, fourhorn sculpin and Arctic flounder being frequently caught.

A single sockeye salmon smolt (62 mm) was captured on Aug 23 at M9625.

Size Structure and Growth. Length-frequencies of broad whitefish moving upstream and downstream in lake M9521 were similar within sampling periods. Overall, 45% of broad whitefish moving downstream in lake M9625 were greater 200 mm, compared to only 20% of those moving upstream. For lake M9521, 47% moving downstream were greater than 200 mm compared to 28% moving upstream.

The length-weight relationship for broad whitefish (160-375 mm) collected in June was significantly different from those collected in July and August. The relationships for fish from July and August were not statistically different, so data for these periods were pooled for subsequent analyses. The relationships from summer 2007 were all significantly different from similar data collected in both 1985 and 1995-1996, while those two earlier periods were not different from each other.

Weights calculated for three evaluation lengths (200, 250 and 300 mm) indicated that broad whitefish in June had significantly lower body weights than fish captured later in summer. Broad whitefish from 1985 and 1995-1996 were heavier for a given length than fish caught in 2007, especially at greater lengths.

Increases in length through summer averaged 0.72 mm/day over all ages, with age-1 fish showing the most rapid growth at 0.83 mm/day. Weights of ages 1 and 2 doubled through the summer, while weights of older fish (4-6) increased by approximately 60-70%.

Stomachs were examined from 160 broad whitefish between 215 and 475 mm fork length. Most (59.4%) of the stomachs were empty, with the remaining samples having some detectable contents. Chironomid larvae (midges) were the only identifiable food item observed.

Tagging Results. A total of 1,227 tags were released. Fifty-five fish were re-captured after the initial sampling event. Of these 55 fish, five fish were recaptured a second time. Three additional fish were recaptured (as evident by fin clips), but had lost their tags.

The total number of fish migrating through the channels below each lake and the ratio of fish migrating downstream and upstream differ considerably between the two lakes. Far fewer fish were caught below lake M9521 than below lake M9625 and while the number of fish migrating downstream at lake M9521 approximately balanced the number of fish migrating upstream, the number of fish migrating downstream from lake M9625 (698) far exceeded the number migration upstream (118). It appears that lake M9625 acts as a "source" lake, particularly early in the season. The ratio of fish emigrating (moving downstream) to those immigrating (upstream) is over 9:1 in late June, decreasing to 4:1 in late July and to 2.9:1 in late August. There was some hint on the last day of sampling (August 23) that the ratio may reverse later in the summer.

Broad Whitefish Abundance by Sampling Period. The number of fish (200 mm or greater) in lake M9625 declined from a mean estimate of 1,271 in June to 344 in July. Since lake M9625 covers an area of approximately 30.8 hectares (76 acres), these estimates equate to densities of 41.3 fish per hectare in June, declining to 11.2 fish per hectare in July. The decline is consistent with an estimated daily emigration rate of 4.35% during the June sampling period and 4.17% during the July period. The estimated number of fish in the lake in August was unrealistically high (185,900) due to the small number of recaptures and had a 95% confidence interval ranging from 774 to 1.2 million.

While the daily emigration rate is uncertain due to uncertainties in the abundance estimates, the absolute rate of downstream and upstream movement can be computed, assuming that fish do not bypass the net. An average of 50 fish /day moved downstream past the net and an average of 5.2 fish / day moved upstream past the net in June, for a net downstream movement of 45 broad whitefish / day. In July, the rates were 15 fish / day downstream and 4.7 fish / day upstream for a net of 10 fish / day moving downstream. In August, the rates were 15.5 fish / day downstream and 5.3 fish / day upstream for a net of 10 fish / day moving downstream. Thus the absolute rate of downstream movement decreased substantially between June and July, while the rate of upstream movement stayed nearly constant at approximately 5 fish / day throughout the season.

The small number of recaptures in lake M9521 did not result in reasonable estimates for that lake.

Broad Whitefish Abundance Across Sampling Periods. *Lake M9625*: If we assume that immigration is negligible, but allow for losses (emigration), the estimated population sizes from the open Cormack-Jolly-Seber (CJS) capture-recapture model are 1,791 (SE = 1,969) in late July and 1,479 (SE = 1,627) in late August, respectively. This is consistent with the estimates by period based on daily data in the sense that the estimate of total abundance in the lake / channel region for July is (considerably) larger than the number of fish in the lake alone (i.e. upstream of the fyke net). However, the standard error estimates are larger than the means, thus any reasonable confidence interval includes zero. The estimate can be interpreted as the population of broad whitefish that the tagged fish, which were released at a single location, have mixed with over the course of a month.

The estimate of “survival” (the proportion of fish remaining in the area in July) was 0.84 with a 95% confidence interval of 0.35 to 0.98.

Lake M9521: Estimated population sizes were 8,928 (SE = 10,795) in July and 6,731 (SE = 8,146) in August. The large standard errors indicate the enormous uncertainty about these estimates, although minimum estimates are obviously provided by the number of unique fish captured in the net (243, 124, and 91 in June, July, and August, respectively).

Estimates using Petersen-type Estimator. *Lake M9625*: Because emigration was obviously occurring, the estimated average net daily emigration rate of 4.26% was used to estimate the number of fish tagged in June that were still in the channel or lake in July. A total of 496 fish were tagged in June. This results in a population estimate of 2,419 broad whitefish in the area in July, which is about 7 times as many fish as were estimated to be present upstream of the sampling location based on the daily data for July (344 fish). If the two fish that lost tags and were recaptured in July were both tagged in June and are included in the number of recaptured fish, the estimated abundance is reduced to 1,935 fish. These estimates are broadly consistent with the CJS estimator, but are less variable.

Lake M9521: Because of the small number of fish recaptured between periods, the estimates are highly uncertain. Only one fish that was tagged in June was recaptured in July and 2 fish that were tagged in July were recaptured in August. Assuming that no net emigration is occurring from this lake (based on the balanced numbers of fish moving upstream and downstream), the number of fish “represented” by the tagged fish (i.e. the population with which the tagged fish have mixed) is 15,371 (SE = 8,768) in July and 3,916 (SE = 1,904) in August. The standard error estimates are too high for the estimates to be useful.

All of these estimates of abundance in the broader lake/channel region should be interpreted with caution, because the extent to which broad whitefish migrate into and out of the lake/channel area is unclear, and it is not obvious what population is actually estimated. However, these estimates do suggest that this single small lake may be utilized by up to several thousand fish over the course of the summer and that well over a thousand fish are likely to be present within the lake (upstream of the fyke net) early in the season.

The delta region forms an open system where broad whitefish migrate up and down the Colville River and use different lake systems, as evident in the recapture of individuals that were tagged near one lake and recaptured near the other lake. Of the 10 tagged fish that were recaptured in lake M9521, 2 fish (20%) originated in lake M9625 and of the 45 tagged fish that were recaptured in lake M9625, 5 fish (11%) originated in lake M9521. This suggests considerable exchange between lake systems during the summer.

Other Species. While broad whitefish was the primary focus of this study, other species were also encountered, often in high abundance.

Humpback whitefish were second in abundance to broad whitefish, with most of the catch recorded at lake M9521 in June and lake M9625 in August. The fish at lake M9521 in June were mostly caught moving downstream, while those caught in August were moving in both directions. Humpback whitefish caught in June were primarily age-1 and a group of large older fish likely covering a wide range of ages. By August, catches were primarily age-0 fish, with some age-1 and a scattering of larger fish. Few were caught in size ranges expected for ages 2 through 4.

Least cisco were third in abundance, with most of the catch recorded in June at both lakes. The fish at lake M9521 in June were moving in both directions, while those caught at lake M9625 were primarily going downstream. Similar to the pattern in humpback whitefish, least cisco caught in June were primarily age-1 and a group of large older fish likely covering a wide range of ages. By August, the catches were primarily age-0 and 1 fish, with a scattering of larger fish. Few were caught in the size ranges expected for ages 2 through 4.

Round whitefish were fourth in abundance, with most of the catch recorded in June at lake M9521. The fish at lake M9521 in June were moving in both directions, however, the larger catches were in the downstream direction. Round whitefish caught in June were from at least three or more age groups, with most fish less than 250 mm. Few large round whitefish were caught. By August, the catches were primarily age-1 fish, along with a few age-0 fish.

Arctic cisco were eighth in abundance with 240 caught during summer sampling. Most of the catch (86%) was recorded in June at both lakes. Ages 1 and 2 were both abundant in June, while age-1 fish persisted through summer. Age-0 (young-of-the-year) appeared in August sampling, indicating that there was recruitment during summer 2007. A strong recruitment into the Colville Delta region during mid-August 2007 was previously reported by Williams et al. (2007) from results of sampling in the eastern Colville Delta.

Other species caught in moderate abundance include rainbow smelt, Arctic grayling, longnose sucker and Dolly Varden char. Rainbow smelt are common in tapped lakes and likely spawn in channels connecting lakes to the river shortly after channel ice clears in the spring. Only one smelt longer than 125 mm was caught after June, indicating that most of the larger fish left the lakes after spawning. Catches increased through summer as young-of-the-year became large enough to catch.

Arctic grayling were mostly immature fish (less than 200 mm), with most caught during June. The July catch was 19% of the catch, with 5% caught in August.

The catch of longnose sucker was relatively evenly distributed through the summer, with 30% of effort-corrected catch from June, 43% from July and 27% from August. Captured longnose suckers covered a broad range of sizes.

The catch of Dolly Varden char was greatest in June, when 45 of the 46 fish were caught. Fish caught in June were all first-year downstream migrants (183-253 mm). The one fish caught in August (at 447 mm) was likely returning from its first summer at sea. All Dolly Varden char were caught at lake M9625.

Discussion

The study confirmed that broad whitefish heavily use tapped lakes within the outer portion of the Colville Delta as summer feeding areas, with chironomid larvae providing the principal prey. Broad whitefish (200 mm and larger) were most abundant in the lakes in mid to late June as the lakes cleared of ice and became one of the first areas available for feeding. For lake M9625, density of broad whitefish (200 mm and larger) was estimated at 41.3 fish per hectare in June, decreasing to 11.2 fish per hectare by late July. The shallowness of the basins promote melting both from solar radiation and breakup overflow from the river, thus these basin are clear of ice prior to the adjacent coastal region, and earlier than nearby freshwater lakes. By the onset of sampling on June 18, water temperatures in lakes M9521 and M9625 already exceeded 10^{o}C, while coastal regions were still ice-bound. Use of tapped lakes by larger fish decreases in July, as fish likely disperse into other habitats that become available.

Growth, as evidenced by increasing size of age modes through the summer, averaged 0.72 mm/day, which resulted in weight gains of around 100% in younger fish (ages 1 to 3) to 60-70% in older fish (ages 4-6).

Broad Whitefish Abundance. The above abundance estimators may provide reasonable estimates of the approximate number of broad whitefish utilizing the area, but the extent of the area that is represented by the single fyke net station is unclear because of the open connection between the lakes and the Colville River/delta. Clearly, there was considerable exchange between the two lakes and presumably there would be similar exchanges with other lakes and side channels in the delta, probably over considerable distances given the observed movement of broad whitefish between the two lakes in this study. Therefore an absolute abundance estimate of broad whitefish in the larger region could only be obtained with considerable sampling effort. An approach based on intensively sampling a few lakes to estimate the number of fish using that particular lake (+ the channel connecting it to the river) at any given time and on the number and size of lakes and side channels in the area of interest would be the best approach.

Sockeye Salmon Presence in the Colville River. As far as can be determined, the capture of a sockeye salmon smolt is the first such record from a drainage east of Barrow, and demonstrates that sockeye are likely reproducing in the Colville River drainage. Adult sockeye salmon have been reported in the Canadian Arctic, however there is no documentation of juvenile salmon. Sockeye salmon adults were caught in the

Tingmiaqsiugvik (Ublutuoch) River in 2005 and catches of adult sockeye seem to be increasing in coastal gill nets set near Barrow.

Recommendations for Similar Studies. The analysis here provides what could be considered a minimum estimate of fish using lake M9625 at the beginning of each sampling period, as well as an estimate of the number of fish utilizing an unknown “mixing region” (which will overlap with the “mixing region” of multiple other lakes). Tag returns from lake M9521 were too few to generate reliable abundance estimates. To improve estimates of large broad whitefish utilizing this or other lakes during a given sampling period, some possible approaches include:

• If an estimate of the number of broad whitefish in a lake at a given point in time is desired, the best approach may be to put more effort into sampling and tagging a large number of fish randomly (to the extent possible) within the lake, using a fyke net or other non-selective gear, and then to resample fish in the channel downstream from the lake, starting immediately after tagging and until a good sample size of tagged fish is obtained. In fact sampling could be continued until a desired level of precision is achieved.

•If sampling in the lake is not possible, two fyke net assemblies could be set up in a single channel, one very close to the lake and one close to the river. With two nets, the rates of upstream and downstream migration between the lake and the river can be directly estimated and estimates of the number of fish within the channel as well as within the lake could be obtained. The assumption of equal capture probability may still be an issue if mixing within the lake is limited.

•Because one of the main concerns is that fish do not mix adequately before being recaptured, there may be ways to improve “mixing” by releasing fish in the lake rather than directly upstream of the net.

•An analytical approach could be developed that takes into account differences in capture probability (to get around the assumption of equal capture probability), for example by modeling the capture probability as a function of “days at large”. This would require some simulations to see if the number of recaptures is sufficient to obtain reasonable estimates, but should be relatively straightforward otherwise.

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INTRODUCTION

A considerable amount of effort has been expended in identifying important fish habitats within the Colville Delta (Bendock and Burr 1986, Fawcett et al. 1986, Moulton 1997). These efforts have identified tapped lakes as being important rearing areas for a variety of fish species, with broad whitefish being especially abundant in these habitats. Broad whitefish is the most important subsistence fish species that feeds within the delta; the other favorite fish, Arctic cisco, uses the delta primary for wintering, not feeding.

Most of the studies in recent years use fyke nets for sampling fish. These nets provide an index of fish abundance, but there remains a question as to how many fish are represented by these catch rates. In addition, available information does not provide information on fish density or production rates. Such information is useful for estimating the production capacity of tapped lakes, which can be used when evaluating harvest guidelines.

The number of fish using an area can be estimated through mark-recapture techniques. A way to address the production capacity of tapped lakes is to obtain data on the number of fish using these lake basins during the summer, along with growth, feeding and prey information. The objective of this study is to evaluate methods to estimate the number of broad whitefish using selected tapped lakes during the summer feeding period and begin to assess the production potential for broad whitefish from such lakes. Examination of broad whitefish lengths from sampling in 1995-1996 (Moulton 1997) indicates that the target sizes, 200-400 mm, move downstream towards the coast for feeding during most of the summer, returning to the delta in mid-August. Tapped lakes near the coast are likely to support more broad whitefish than lakes farther inland.

METHODS

Field Sampling

Two tapped lakes selected for sampling were M9521 and M9625 (Figure 1). These lakes each have a single inlet/outlet channel, which prevented fish from using channels that were not sampled. Lake M9521 is an 85.8 hectare (212 acre) lake connected to the Sakoonang Channel (Figure 2), while lake M9625 is a 30.8 hectare (76 acre) lake connected to the Tamayagiaq Channel (Figure 3). The sampling stations were separated by approximately 13.7 river kilometers (8.5 river miles).

Sampling was conducted in three time periods: June 19-27, July 22-29 and August 17-23. These three periods were selected to release tagged broad whitefish during the spring out-migration, the summer feeding period, and the late summer return to the river prior to wintering.

Sampling was by fyke net so that fish could be released unharmed. Fyke nets used had an opening 1.1 m deep by 1.1 m wide, the trap end was 4.9 m long, made of 9.5 mm mesh. The wings (5 m long) and lead (60 m long) were made of 12.7 mm mesh. Nets were emptied daily and duration of each set was recorded to allow calculating catch rates. Fyke nets were arranged to sample fish moving both upstream and downstream (Figure 4). Fish were anaesthetized with MS-222 prior to handling, measured to the nearest 1 mm and released, with no fish retained for laboratory analysis. Broad whitefish with a fork length of 200 mm or greater received a Floy anchor tag, and were weighed to the nearest gm with a hand-held Pescola spring scale. The adipose fin was removed from tagged fish to allow estimating tag loss.

Water chemistry measurements obtained daily at each fyke net were water temperature, specific conductance, and turbidity. Temperature and specific conductance were daily *in situ* measurements taken within 15 cm (6 inches) of the surface at the fyke net station in each lake with a YSI Model 85 meter. Turbidity was measured with an H.F. Scientific DRT15CE turbidity meter.

Stomach contents of broad whitefish were obtained by gastric lavage of larger individuals using a stomach pump and water. After initial trials of the method in June, a minimum size of 250 mm was selected for this procedure in order to minimize handling stress on small fish. Stomachs contents were examined for dominant types present. There was no attempt to quantify the contents because fish were caught by fyke net and there was no way to tell how long the fish had been in the net prior to sampling. Few of the sampled stomachs were full, indicating that fish had been in the net for some time.

Data Analysis

Growth

Growth as expressed by increasing fork length through the summer was estimated from broad whitefish length frequencies. Modes representing ages 0 through 6 were identified by inspection of length frequencies generated from field-collected measurements. Age data based on otoliths collected from the study area in 1995-1996 (Moulton 1997) were used to verify the selection of length modes.

Length and weight data obtained from field measurements were used to calculate length-weight relationships and estimate growth in terms of weight gain. Length and weight measurements were log transformed prior to calculating relationships. The length-weight analysis was restricted to fish between 160 and 375 mm fork length because the weights obtained by the spring scale appeared unreliable for smaller fish. Statistical comparisons of length-weight relationships were tested with analysis of covariance (ANCOVA).

Differences in the length-weight relationships were evaluated by calculating weights associated with three evaluation lengths: 200, 250 and 300 mm. This calculation provides a way to illustrate the differences among the various relationships.

Daily growth in terms of length and weight was estimated by calculating the mean size of each assigned age group from June and August and dividing the difference in these two time periods by 57.2 (the number of days between the mean date of capture in June and the mean date of capture in August).

Abundance Estimates

Estimating within-lake broad whitefish abundance by sampling period. The fact that the fyke nets intercepted all or nearly all of the fish migrating up or down the channel provides an opportunity to estimate the number of fish inside the lakes (upstream of the fyke nets) based on the known number of tagged fish in the lake on any given day and the number of tagged and untagged fish captured during downstream movement.

The number of fish present in the lake (upstream of the fyke nets) at the beginning of day 1 of a given sampling period was estimated using a maximum likelihood approach. The number of fish changes from day to day (and decreases in lake M9625 over time because of the much larger number of fish moving downstream). The approach only works WITHIN a given sampling period, i.e. while sampling is occurring continuously, and assumes that fish do not bypass the fyke net during the sampling period without being captured. Providing daily estimates of N_t, allows estimating daily emigration rates as well. The approach proceeds as follows:

The number of marked fish that are in the lake (upstream of the fyke nets) on any given day, M_t, is computed as follows:

$$M_t = M_{t-1} + n_{t-1}^u + m_{t-1}^u - m_{t-1}^d$$

where n^u_{t-1} is the number of previously untagged fish captured on day *t-1* that were tagged and released upstream, m^u_{t-1} is the number of previously tagged fish that were recaptured and released upstream on day *t-1*, and m^d_{t-1} is the number of previously tagged fish that were recaptured and released downstream on day *t-1*. Given the number of fish present in the lake at the beginning of day 1 (N_1, which is unknown but estimated in the model), we can compute the total number of fish on day *t* as:

$$N_t = N_{t-1} + n^u_{t-1} - n^d_{t-1}$$

where n^d_{t-1} is the number of untagged fish captured on day *t-1* that were tagged and released downstream.

The expected number of tagged fish caught in the (downstream) fyke net on a given day depends on the total number of fish caught going downstream ($m^d_{t-1} + n^d_{t-1}$) and on the probability that a given fish is tagged, which is equal to the fraction of fish that have tags or $p_t = M_t \ / \ N_t$. The expected number of marked fish being captured on a given day follows a binomial distribution with probability p_t and sample size $n^d_t + m^d_t$. Thus the likelihood of capturing m^d_t tagged fish going downstream can be computed from the binomial probability distribution:

$$L_t(m^d_t \mid p_t, n^d_t + m^d_t) = \binom{n^d_t + m^d_t}{m^d_t} p_t^{n^d_t + m^d_t} (1 - p_t)^{n^d_t}$$

Because M_t, m^d_t, m^u_t, n^d_t, and n^u_t are all known, the likelihood only depends on N_1, which can be estimated by finding the value of N_1 that maximizes the sum of the likelihoods over all days (= maximum likelihood estimate). A Bayesian version of the model was used to describe the full uncertainty in the estimate of N_1 (posterior distribution, estimated in WinBUGS). Daily net "emigration" rates were estimated by taking the net number of fish migrating downstream on day *t* (i.e. the difference between those going downstream and those going upstream: $n^d_t + m^d_t - n^u_t - m^u_t$) and dividing them by the estimated number of fish in the lake at the beginning of the day (N_t).

Major assumptions of this approach are that each fish upstream of the fyke net has equal capture probability (complete "mixing" between daily sampling events), and that no tag loss occurs. All tagged fish were also fin clipped, thus the affect of tag loss on estimates can be assessed through simulations.

Estimating overall broad whitefish abundance across sampling periods. The number of fish in July and August was estimated using individual capture histories of each fish that was tagged based on an open Cormack-Jolly-Seber (CJS) capture-recapture model (Amstrup et al. 2005; Seber, 1982). An estimate of abundance for the first sampling event cannot be obtained from this model. Each 7-9 day sampling period was considered a single sampling event, thus all fish caught during one of these periods are treated the same. The model also provides an estimate of "survival" (1 – mortality or emigration) between sampling events. The model was fit using the 'mra' package for R, written by Trent McDonald from WEST, Inc.

The estimated population consists of all fish that are available to the sampling gear and again assumes that all fish have the same capture probability, implying complete mixing. The model does allow for losses due to mortality or emigration, the effects of which are equivalent, but cannot be separated. It may be reasonable to assume that natural mortality is negligible on the time scales involved and that losses are due to emigration only. Including losses is obviously important in the case of this lake because many broad whitefish are leaving the area, as evident by the large number of fish moving downstream past the net. The fact that the sampling location is completely open to the Colville River and the apparent high movement rates suggest that fish may be regularly moving in and out of the channel. Therefore, there may be considerable immigration into the area between sampling events. Clearly, there is at least some immigration occurring because two fish (out of 458) that were tagged in lake M9521 were recaptured in lake M9625, but the extent of immigration is unknown, and cannot be estimated from the sampling.

The CJS model will be unbiased as long as both tagged and untagged fish are leaving the area at the same rate (emigration), but it cannot account for both emigration and immigration from the Colville River into the channel/lake. The effect of immigration is that it dilutes the number of tagged fish, thereby resulting in higher abundance estimates. If only immigration were occurring the abundance estimate would reflect abundances after immigration, but if both emigration and immigration occur, the estimates may be biased either way relative to the abundance during a given period.

The CJS model was fit to the tagging data from both lakes separately.

As an alternative estimator and because of the low number of previously tagged fish that were recaptured in August (7 total, 3 of which were tagged in June, 4 in July), the total number of fish marked in June and the number of these fish that were recaptured in July were used to estimate population sizes in July based on a modified Petersen estimator (Chapman modification, see e.g. Williams, Nichols & Conroy, 2002):

$$N_{July} = \frac{(M_2 + 1) * (n_2 + 1)}{m_2 + 1} \qquad \text{(Eq. 1)}$$

where M_2 is the number of tagged fish in the area during the July sampling period (counting only fish tagged in June), n_2 is the total number of fish captured in July, and m_2 is the number of tagged fish from June recaptured in July.

RESULTS

Physical Conditions

The tapped lakes sampled in 2007 are in the mid to outer portion of the Colville River delta and are within tidal influence of the Beaufort Sea. As a result, lake levels rise and fall twice daily. Water in the channels connecting the lakes to the river reverses flow during each tidal exchange, which promotes variable water chemistry through the open water period.

The temporal pattern of water temperature was similar at both stations, although temperatures at lake M9521 were more variable (coefficient of variation = 0.23 in M9521, 0.13 in M9625) and responded faster to changing air temperature than at lake M9625 (Figure 5). Specific conductance was initially higher at lake M9521, and remained higher through July (Figure 5). By August, both lakes had similar values. Turbidity decreased at both lakes from June through July. High winds in August re-suspended silt from the lake bed and turbidity increased rapidly at both lakes. Lake M9521 consistently showed higher turbidity than M9625.

Species Composition

Sampling at the two tapped lakes during 2007 resulted in a catch of 17 fish species (Table 2). Broad whitefish were the most abundant species caught during the entire season (28.5% of the total catch), followed by humpback whitefish (26.6%), least cisco (16.2%) and round whitefish (15.0%). No other single species exceeded 5% of the overall catch. Broad whitefish were a dominant component at each lake during each sampling period (Figure 6). The three dominant species (broad whitefish, humpback whitefish and least cisco) were the most abundant species at both lakes, while rainbow smelt outnumbered round whitefish at lake M9625. The high abundance of round whitefish at lake M9521 was the result of high catches during June. Catch rates tended to be lowest in July at both stations (Table 3). The species composition reflected the estuarine nature of the study area, with Arctic cisco, rainbow smelt, fourhorn sculpin and Arctic flounder being frequently caught.

A single sockeye salmon smolt (62 mm) was captured on Aug 23 at lake M9625. The identification was initially based on appearance and was verified through genetic analysis.

Broad Whitefish

Catch Rates

Catches of broad whitefish at lake M9521 tended to be highest in the upstream direction, although a chi-square test indicated the differences were not significant (chi-square = 3.522, p= 0.061). On 16 of the 23 sample dates, upstream catches exceeded the downstream catches (Figure 7). For broad whitefish 200 mm or greater, the difference was less, with 14 of the 23 sample dates showing higher catches in the upstream direction, the differences were again not significant.

At lake M9625, the apparent movement pattern was opposite, with catches in the downstream direction higher than those in the upstream direction; these differences were significant (chi-square = 4.167, p= 0.041). On 17 of the 24 sample dates, upstream catches exceeded the downstream catches (Figure 7). For broad whitefish 200 mm or greater, the difference was greater (chi-square = 8.167, p= 0.004), with 19 of the 24 sample dates showing higher catches in the downstream direction.

Mean catch rates for each sampling period showed the same patterns at each lake (Figures 8 and 9).

Size Structure and Growth

Length-frequencies of broad whitefish moving upstream and downstream in lake M9521 were similar within sampling periods (Figure 10). The greatest difference was in number of 120-150 mm fish moving upstream in August, a downstream movement of similar-sized fish was not observed. In lake M9625, a relatively greater proportion of larger fish (i.e. greater than 200 mm) was caught moving downstream during all months as compared to those moving upstream (Figure 10). Overall, 45% of broad whitefish moving downstream in lake M9625 were greater 200 mm, compared to only 20% of those moving upstream. For lake M9521, 47% moving downstream were greater than 200 mm compared to 28% moving upstream.

Length frequencies were used to construct length-at-age tables in order to estimate growth. Length frequencies from each sampling month were examined and ages were assigned to dominant modes (Figure 11). Otolith-derived age data from 1995-1996 (Moulton 1997) were used to assist with determining breaks between age groups (Table 4).

The length-weight relationship for broad whitefish (160-375 mm) collected in June was significantly different from those collected in July and August. The relationships for fish from July and August were not statistically different, so data for these periods were pooled for subsequent analyses (Table 5). The relationships from summer 2007 were all significantly different from similar data collected in both 1985 and 1995-1996, while those two earlier periods were not different from each other. In those studies, the lengths and weights were measured in the laboratory on triple beam (1985) or electronic (1995-1996) balances and differences may have been caused by the different handling techniques.

Weights calculated for three evaluation lengths (200, 250 and 300 mm) indicated that broad whitefish in June had significantly lower body weights than fish captured later in summer (Table 6). Broad whitefish from 1985 and 1995-1996 were heavier for a given length than fish caught in 2007, especially at greater lengths.

Lengths and weights were estimated for age groups 1 to 6 based on ages assigned by length frequency analysis (Table 7). While these data are likely to be less accurate than data based on otolith-derived ages, the mean lengths fall within the range of values obtained during earlier studies (Fawcett et al. 1987, Moulton 1997). Errors are likely to be greater in older ages (i.e. ages 5 and 6) because fewer fish in these sizes were caught and length modes are less distinct. Increases in length through summer averaged 0.72 mm/day over all ages, with age-1 fish showing the most rapid growth at 0.83 mm/day (Table 8). Weights of ages 1 and 2 doubled through the summer, while weights of older fish (4-6) increased by approximately 60-70%.

Feeding Patterns

Stomachs were examined from 160 broad whitefish between 215 and 475 mm fork length. Four fish less than 250 mm were tested in June, after which only larger fish were sampled. Most (59.4%) of the stomachs were empty, with the remaining samples having some detectable contents. Most of the stomachs had small amounts of food, few were judged to be full. Chironomid larvae (midges) were the only identifiable food item observed.

Tagging Results

A total of 1,227 unique tags were released. Fifty-five fish were re-captured after the initial sampling event. Of these 55 fish, five fish were recaptured a second time. Three additional fish were recaptured (as evident by fin clips), but had lost their tags. They were released with new tags. Two of these recaptures occurred in July and one in August; therefore it is not known when they were first tagged and these individuals were either ignored in the analysis or their impact on estimates was explored through simulations. The effect of ignoring these tagged fish is that total abundances may be slightly under- or over-overestimated, depending on assumptions about when the fish were first tagged. Sensitivity analyses (i.e. including these fish in the analysis under various assumptions) suggested that abundances in lake M9625 (upstream of the fyke nets) in July may be underestimated by as much as 3% or overestimated by as much as 12%.

The total number of fish migrating through the channels below each lake and the ratio of fish migrating downstream and upstream differ considerably between the two lakes. Far fewer fish were caught below lake M9521 than below lake M9625 and while the number of fish migrating downstream at lake M9521 approximately balanced the number of fish migrating upstream, the number of fish migrating downstream from lake M9625 (698) far exceeded the number migration upstream (118, Table 9). It appears that lake M9625 acts as a “source” lake, particularly early in the season. The ratio of fish emigrating (moving downstream) to those immigrating (upstream) is over 9:1 in late June, decreasing to 4:1 in late July and to 2.9:1 in late August. There was some hint on the last day of sampling (August 23) that the ratio may reverse later in the summer (Table 9).

There was no significant difference between the length of recaptured fish and the length of all other tagged fish (t-test: $p = 0.529$, mean length of 248.4 and 254.5 mm, respectively). Similarly, there was no difference between their respective weights. However, there was a highly significant difference in average size (length and weight) between fish captured below the two lakes, with fish at lake M9625 considerably larger on average than at lake M9521 (Figure 12; t-tests: Mean lengths 259.5 and 245.7g, $p < 0.0001$, mean weights 163.7 and 202.7g, $p < 0.0001$). However, a simple condition index (residuals from regression of log(weight) on log(length), suggests that fish at lake M9521 are actually in somewhat better condition (i.e. higher weight at a given length, Figure 13), although the difference is small (t-test: mean residuals of 0.013 and -0.007, $p = 0.0002$).

There was also a large and significant difference in length and weight of fish in both lakes among sampling periods (Figure 14, ANOVA of log(weight) on period: $F = 10.24$, $p < 0.0001$ for lake M9625, $F = 50.98$, $p < 0.0001$ for lake M9521). In general, fish were considerably smaller during the July sampling period compared to the other sampling periods in lake M9625. In this lake, the mean weight of fish in July was significantly smaller than mean weight in either June ($p = 0.015$) or August ($p < 0.001$), and mean weight was significantly larger in August than in June ($p = 0.011$). In lake M9521, fish were significantly larger in June than in the other months ($p < 0.0001$), but were not significantly difference between July and August at the 95% level ($p = 0.069$).

Broad Whitefish Abundance by Sampling Period

The number of fish (200 mm or greater) in lake M9625 declined from a mean estimate of 1,271 in June to 344 in July (Table 10). Since lake M9625 covers an area of approximately 30.8 hectares (76 acres), these estimates equate to densities of 41.3 fish per hectare in June, declining to 11.2 fish per hectare in July. The decline is consistent with an estimated daily emigration rate of 4.35% during the June sampling period and 4.17% during the July period. If an average daily emigration rate of 4.26% is applied to the estimate for the first period over 32 days (time between beginning of June and July sampling periods), the expected number of fish remaining in the lake on July 22 is 315 ($N_{July} = N_{June} * [1 – 0.0426]^{32}$), which is close to the estimated number of fish in the lake at the beginning of the July sampling period (344). The estimated number of fish in the lake in August was unrealistically high (185,900) due to the small number of recaptures and had a 95% confidence interval ranging from 774 to 1.2 million. These unrealistic results for August were not included in Table 2.

There is considerable uncertainty in the abundance estimates with 90% confidence intervals of 807 to 2,083 fish for June 19 and 193 to 653 fish on July 22. The estimated average emigration rates are similarly uncertain as they depend directly on the estimates of N_t. Figure 15 shows the full probability distribution of the abundance estimates and of the estimated average net daily emigration rates.

While the daily emigration rate is uncertain due to uncertainties in the abundance estimates, the absolute rate of downstream and upstream movement can be easily computed, assuming that fish do not bypass the net. An average of 50 fish /day moved downstream past the net and an average of 5.2 fish / day moved upstream past the net in June, for a net downstream movement of 45 broad whitefish / day. In July, the rates were

15 fish / day downstream and 4.7 fish / day upstream for a net of 10 fish / day moving downstream. In August, the rates were 15.5 fish / day downstream and 5.3 fish / day upstream for a net of 10 fish / day moving downstream. Thus the absolute rate of downstream movement decreased substantially between June and July, while the rate of upstream movement stayed nearly constant at approximately 5 fish / day throughout the season.

The small number of recaptures in lake M9521 did not result in reasonable estimates for that lake.

Broad Whitefish Abundance Across Sampling Periods

Lake M9625: If we assume that immigration is negligible, but allow for losses (emigration), the estimated population sizes from the open Cormack-Jolly-Seber (CJS) capture-recapture model are 1,791 (SE = 1,969) in late July and 1,479 (SE = 1,627) in late August, respectively. This is consistent with the estimates by period based on daily data in the sense that the estimate of total abundance in the lake / channel region for July is (considerably) larger than the number of fish in the lake alone (i.e. upstream of the fyke net). However, the standard error estimates are larger than the means, thus any reasonable confidence interval includes zero. The estimate can be interpreted as the population of broad whitefish that the tagged fish, which were released at a single location, have mixed with over the course of a month.

The estimate of "survival" (the proportion of fish remaining in the area in July) was 0.84 with a 95% confidence interval of 0.35 to 0.98.

Lake M9521: Estimated population sizes were 8,928 (SE = 10,795) in July and 6,731 (SE = 8,146) in August. The large standard errors indicate the enormous uncertainty about these estimates, although minimum estimates are obviously provided by the number of unique fish captured in the net (243, 124, and 91 in June, July, and August, respectively).

Estimates using Petersen-type Estimator

Lake M9625: Because emigration was obviously occurring, the estimated average net daily emigration rate of 4.26% was used to estimate the number of fish tagged in June that were still in the channel or lake in July. A total of 496 fish were tagged in June. Applying a 4.26% daily net emigration rate over the 32-day time period between the mid-points of sampling in June and July implies that only M_2 = 123 tagged fish remain in the area in July. This results in a population estimate of 2,419 broad whitefish in the area in July, which is about 7 times as many fish as were estimated to be present upstream of the sampling location based on the daily data for July (344 fish, Table 10). If the two fish that lost tags and were recaptured in July were both tagged in June and are included in the number of recaptured fish, the estimated abundance is reduced to 1,935 fish. These estimates are broadly consistent with the CJS estimator, but are less variable (see below).

The estimates may be much higher than estimates of fish upstream of the fyke nets for several reasons:

- The estimate reflects a much larger population of fish that move into and out of the general sampling region, whereas the approach based on daily data in the previous section only estimates the population upstream of the sampling location at the beginning of the July sampling event.

- As noted above, the number of broad whitefish above the sampling location is likely to be underestimated due to incomplete mixing in the lake between the daily sampling events (i.e. fish that are captured and tagged on a given day have a higher probability of being re-captured on the following day(s) than fish further upstream or in the lake).

- The actual emigration rate may be much larger than the estimated net emigration (which was estimated as the difference between upstream and downstream movement). The net emigration is a combination of tagged and untagged fish leaving the area and untagged fish entering from outside. Thus, if there is considerably immigration and the emigration rate is higher than estimated, the actual number of tagged fish that are still in the area in July (M_2) may be even lower than estimated. This would reduce the population estimate (N_{July}) in Eq. 1.

A simple simulation approach was used to incorporate uncertainty in the net emigration rate and in the number of recaptured fish (because of tag loss) into this estimate. The true number of recaptured fish is uncertain because none, one, or both of the fish that had lost their tags and were recaptured in July may have been tagged in June. Uncertainty in the number of recaptures (m_2) was included by randomly drawing 7, 8, or 9 fish (with equal probability) for use in the Eq. 1. Similarly, to account for uncertainty in the number of tags still in the area in July (M_2), emigration rates were randomly sampled from the full probability distribution of average daily emigration rates (e) that was estimated above (posterior distribution from Bayesian approach). Using random draws of e, the number of tagged fish that did not emigrate between the mid-point of the June and July surveys (32 days) was calculated as:

$$M_2 = M_1 * (1-e)^{32}$$

where M_1 = 496 is the total number of tagged fish released in June. The corresponding population size can then be estimated using the modified Petersen estimator in Eq. 1. The results suggest a population size between 1,190 and 4,189 broad whitefish in July (95% credibility interval, Figure 16) with a mean of 2,166 fish. The mode of the distribution (1,789) is close to the maximum likelihood estimate from the CJS model, but the estimated uncertainty is much lower (and more realistic).

Lake M9521: Because of the small number of fish recaptured between periods, the estimates are highly uncertain. Only one fish that was tagged in June was recaptured in July and 2 fish that were tagged in July were recaptured in August. Assuming that no net emigration is occurring from this lake (based on the balanced numbers of fish moving upstream and downstream), the number of fish "represented" by the tagged fish (i.e. the population with which the tagged fish have mixed) is 15,371 (SE = 8,768) in July and

3,916 (SE = 1,904) in August. The standard error estimates are too high for the estimates to be useful.

All of these estimates of abundance in the broader lake/channel region should be interpreted with caution, because the extent to which broad whitefish migrate into and out of the lake/channel area is unclear, and it is not obvious what population is actually estimated. However, these estimates do suggest that this single small lake may be utilized by up to several thousand fish over the course of the summer and that well over a thousand fish are likely to be present within the lake (upstream of the fyke net) early in the season.

The delta region forms an open system where broad whitefish migrate up and down the Colville River and use different lake systems, as evident in the recapture of individuals that were tagged near one lake and recaptured near the other lake. Of the 10 tagged fish that were recaptured in lake M9521, 2 fish (20%) originated in lake M9625 and of the 45 tagged fish that were recaptured in lake M9625, 5 fish (11%) originated in lake M9521. This suggests considerable exchange between lake systems during the summer.

The data are insufficient to estimate movement rates, but movement between lakes can occur rapidly. This was evident in two fish (60058, 60089) that were tagged in lake M9625 on 6/20 and were recaptured in lake M9521 on 6/25 and 6/27 and a third fish (61133) that was tagged in lake M9625 on July 27 and recaptured in lake M9521 the following day. Four other fish were captured in the other lake one or two months after being tagged.

Other Species

While broad whitefish was the primary focus of this study, other species were also encountered, often in high abundance (Table 2).

Humpback Whitefish

Humpback whitefish were second in abundance to broad whitefish, with most of the catch recorded at lake M9521 in June and lake M9625 in August (Figure 6). The fish at lake M9521 in June were mostly caught moving downstream, while those caught in August were moving in both directions (Figure 17). Humpback whitefish caught in June were primarily age-1 and a group of large older fish likely covering a wide range of ages (Figure 18). By August, catches were primarily age-0 fish, with some age-1 and a scattering of larger fish. Few were caught in size ranges expected for ages 2 through 4.

Least Cisco

Least cisco were third in abundance, with most of the catch recorded in June at both lakes (Figure 6). The fish at lake M9521 in June were moving in both directions, while those caught at lake M9625 were primarily going downstream (Figure 19). Similar to the pattern in humpback whitefish, least cisco caught in June were primarily age-1 and a group of large older fish likely covering a wide range of ages (Figure 20). By August, the catches were primarily age-0 and 1 fish, with a scattering of larger fish. Few were caught in the size ranges expected for ages 2 through 4.

Round Whitefish

Round whitefish were fourth in abundance, with most of the catch recorded in June at lake M9521 (Figure 6). The fish at lake M9521 in June were moving in both directions, however, the larger catches were in the downstream direction (Figure 21). Round whitefish caught in June were from at least three or more age groups, with most fish less than 250 mm (Figure 22). Few large round whitefish were caught. By August, the catches were primarily age-1 fish, along with a few age-0 fish.

Arctic Cisco

Arctic cisco were eighth in abundance with 240 caught during summer sampling. Most of the catch (86%) was recorded in June at both lakes (Figure 6). Ages 1 and 2 were both abundant in June, while age-1 fish persisted through summer (Figure 23). Age-0 (young-of-the-year) appeared in August sampling, indicating that there was recruitment during summer 2007. A strong recruitment into the Colville Delta region during mid-August 2007 was previously reported by Williams et al. (2007) from results of sampling in the eastern Colville Delta.

Others

Other species caught in moderate abundance include rainbow smelt, Arctic grayling, longnose sucker and Dolly Varden char. Rainbow smelt are common in tapped lakes and likely spawn in channels connecting lakes to the river shortly after channel ice clears in the spring. Only one smelt longer than 125 mm was caught after June, indicating that most of the larger fish left the lakes after spawning. Catches increased through summer as young-of-the-year became large enough to catch.

Arctic grayling were mostly immature fish (less than 200 mm), with most (77% of effort-corrected catch) caught during June (Figures 6 and 24). The July catch was 19% of the catch, with 5% caught in August.

The catch of longnose sucker was relatively evenly distributed through the summer, with 30% of effort-corrected catch from June, 43% from July and 27% from August. Captured longnose suckers covered a broad range of sizes (Figure 24).

The catch of Dolly Varden char was greatest in June, when 45 of the 46 fish were caught. Fish caught in June were all first-year downstream migrants (183-253 mm, Figure 24). The one fish caught in August (at 447 mm) was likely returning from its first summer at sea. All Dolly Varden char were caught at lake M9625.

DISCUSSION

The study confirmed that broad whitefish heavily use tapped lakes within the outer portion of the Colville Delta as summer feeding areas, with chironomid larvae providing the principal prey. Broad whitefish (200 mm and larger) were most abundant in the lakes in mid to late June as the lakes cleared of ice and became one of the first areas available for feeding. For lake M9625, density of broad whitefish (200 mm and larger) was estimated at 41.3 fish per hectare in June, decreasing to 11.2 fish per hectare by late July. The shallowness of the basins promote melting both from solar radiation and breakup overflow from the river, thus these basin are clear of ice prior to the adjacent coastal region, and earlier than nearby freshwater lakes. By the onset of sampling on June 18, water temperatures in lakes M9521 and M9625 already exceeded 10^{o}C, while coastal regions were still ice-bound. Use of tapped lakes by larger fish decreases in July, as fish likely disperse into other habitats that become available.

Growth, as evidenced by increasing size of age modes through the summer, averaged 0.72 mm/day, which resulted in weight gains of around 100% in younger fish (ages 1 to 3) to 60-70% in older fish (ages 4-6). Growth rates were similar to those reported in earlier studies, as evidenced in the following table:

Age (Years)	Year	Location	Growth (mm/day)
1	1982	Sag. Delta	0.83
1	1984	Prudhoe Bay	0.83
1	1985	Colville Delta	0.68
1	2007	Colville Delta	0.83
2	1982	Sag. Delta	0.73
2	1984	Prudhoe Bay	0.83
2	1985	Colville Delta	0.55
2	2007	Colville Delta	0.58

(1982 data from Griffiths et al. 1983, 1984 data from Moulton et al. 1985, 1985 data from Fawcett et al. 1986)

Broad Whitefish Abundance

The above abundance estimators may provide reasonable estimates of the approximate number of broad whitefish utilizing the area, but the extent of the area that is represented by the single fyke net station is unclear because of the open connection between the lakes and the Colville River/delta. Clearly, there was considerable exchange between the two lakes and presumably there would be similar exchanges with other lakes and side channels in the delta, probably over considerable distances given the observed movement of broad whitefish between the two lakes in this study. An absolute abundance estimate of broad whitefish in the larger region could only be obtained with considerable sampling effort. An approach based on intensively sampling a few lakes to estimate the number of fish using that particular lake (+ the channel connecting it to the river) at any given time and on the number and size of lakes and side channels in the area of interest would be the best approach.

Sockeye Salmon Presence in the Colville River

As far as can be determined, the capture of a sockeye salmon smolt is the first such record from a drainage east of Barrow, and demonstrates that sockeye are likely reproducing in the Colville River drainage. Stephenson (2005a,b) documents the occurrence of adult sockeye salmon in the Canadian Arctic, however he finds no documentation of juvenile salmon. Sockeye salmon adults were caught in the Tingmiaqsiugvik (Ublutuoch) River in 2005 (Moulton 2006) and catches of adult sockeye seem to be increasing in coastal gill nets set near Barrow (J.C. George, North Slope Borough Dept of Wildlife Management, personal communication 2007).

Recommendations for Similar Studies

The analysis here provides what could be considered a minimum estimate of fish using lake M9625 at the beginning of each sampling period, as well as an estimate of the number of fish utilizing an unknown “mixing region” (which will overlap with the “mixing region” of multiple other lakes). Tag returns from lake M9521 were too few to generate reliable abundance estimates. To improve estimates of large broad whitefish utilizing this or other lakes during a given sampling period, some possible approaches include:

• If an estimate of the number of broad whitefish in a lake at a given point in time is desired, the best approach may be to put more effort into sampling and tagging a large number of fish randomly (to the extent possible) within the lake, using a fyke net or other non-selective gear, and then to resample fish in the channel downstream from the lake, starting immediately after tagging and until a good sample size of tagged fish is obtained. In fact sampling could be continued until a desired level of precision is achieved.

•If sampling in the lake is not possible, two fyke net assemblies could be set up in a single channel, one very close to the lake and one close to the river. With two nets, the rates of upstream and downstream migration between the lake and the river can be directly estimated and estimates of the number of fish within the channel as well as within the lake could be obtained. The assumption of equal capture probability may still be an issue if mixing within the lake is limited.

•Because one of the main concerns is that fish do not mix adequately before being recaptured, there may be ways to improve “mixing” by releasing fish in the lake rather than directly upstream of the net.

•An analytical approach could be developed that takes into account differences in capture probability (to get around the assumption of equal capture probability), for example by modeling the capture probability as a function of “days at large”. This would require some simulations to see if the number of recaptures is sufficient to obtain reasonable estimates, but should be relatively straightforward otherwise.

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Table 1. Fyke net effort (in net-days) during 2007 at lakes M9521 and M9625.

Lake	Direction	June 19-27	July 22-29	August 17-23	2007 Total
M9521	Downstream	8.6	7.8	6.0	22.5
	Upstream	8.3	7.7	6.0	22.0
M9625	Downstream	8.6	7.6	7.1	23.3
	Upstream	8.7	7.7	7.0	23.3
Total:		34.3	30.8	26.1	91.2

Table 2. Fish species caught in fyke nets at tapped lakes M9521 and M9625 during 2007, by month.

	M9521			M9625			
Species	June	July	August	June	July	August	Total
Broad whitefish	668	285	461	1,449	584	554	4,001
Humpback whitefish	1,202	59	19	391	26	2,032	3,729
Least cisco	631	227	98	1,132	53	135	2,276
Arctic cisco	90	15	3	116	1	15	240
Round whitefish	1,696	26	98	106	83	92	2,101
Arctic grayling	158	18	9	128	45	4	362
Dolly Varden char	0	0	0	45	0	1	46
Sockeye salmon (smolt)	0	0	0	0	0	1	1
Rainbow smelt	33	27	24	37	112	403	636
Burbot	5	3	3	3	1	3	18
Arctic cod	0	1	0	0	0	0	1
Longnose sucker	12	11	0	12	19	16	70
Arctic lamprey	3	0	0	0	0	0	3
Arctic flounder	6	4	0	11	10	21	52
Fourhorn sculpin	19	74	71	23	31	16	234
Threespine stickleback	0	0	1	0	0	2	3
Ninespine stickleback	45	5	79	7	36	95	267
No. of Fish	4,568	755	866	3,460	1,001	3,390	14,040
No. of Species	13	13	11	13	12	15	17
Effort (net-days)	16.97	15.52	12.02	17.33	15.29	14.04	91.16

Table 3. Mean catch rates (in fish per day) of fish species caught in fyke nets at tapped lakes M9521 and M9625 during 2007, by month.

	M9521			M9625		
Species	June	July	August	June	July	August
Broad whitefish	39.4	18.4	38.4	83.6	38.2	39.5
Humpback whitefish	70.9	3.8	1.6	22.6	1.7	144.8
Least cisco	37.2	14.6	8.2	65.3	3.5	9.6
Arctic cisco	5.3	1.0	0.2	6.7	0.1	1.1
Round whitefish	100.0	1.7	8.2	6.1	5.4	6.6
Arctic grayling	9.3	1.2	0.7	7.4	2.9	0.3
Dolly Varden char	0.0	0.0	0.0	2.6	0.0	0.1
Sockeye salmon (smolt)	0.0	0.0	0.0	0.0	0.0	0.1
Rainbow smelt	1.9	1.7	2.0	2.1	7.3	28.7
Burbot	0.3	0.2	0.2	0.2	0.1	0.2
Arctic cod	0.0	0.1	0.0	0.0	0.0	0.0
Longnose sucker	0.7	0.7	0.0	0.7	1.2	1.1
Arctic lamprey	0.2	0.0	0.0	0.0	0.0	0.0
Arctic flounder	0.4	0.3	0.0	0.6	0.7	1.5
Fourhorn sculpin	1.1	4.8	5.9	1.3	2.0	1.1
Threespine stickleback	0.0	0.0	0.1	0.0	0.0	0.1
Ninespine stickleback	2.7	0.3	6.6	0.4	2.4	6.8
Total CPUE (fish/day):	269.3	48.6	72.0	199.7	65.5	241.5

Table 4. Length intervals associated with ages assigned to length modes for broad whitefish caught by fyke net during 2007.

Age	Fork Length Interval In: Jun	Jul	Aug
0	25	28-69	33-99
1	60-119	70-139	100-154
2	120-159	140-184	155-194
3	160-199	185-224	195-244
4	200-239	225-264	245-284
5	240-279	265-309	285-330
6	280-324	310-356	330-380

Age-Length Data reported for 1995-1996[1]

Age	Fork Length (mm)	Standard Deviation	Sample Size
0	--	--	0
1	118.8	10.7	19
2	160.5	12.8	8
3	199.1	13.2	34
4	224.5	19.1	2
5	258.0	13.8	10
6	284.4	17.4	17

[1] data from Moulton (1997) based on otolith ages

Table 5. Similarities and differences in length-weight relationships for broad whitefish sampled in the Colville Delta during different time periods, based on analysis of covariance.

(single value indicates there was a significant difference in slopes, double value indicates slopes
were not different and the intercept was tested; NS = not significant, ** = highly significant, p<0.001)

Sample	Comparison Period				
Period	June	July	August	1985	1995/1996
June	--	**	**	NS/**	NS/**
July	--	--	NS/NS	--	--
Jul/Aug	--	--	--	**	**
1985	--	--	--	--	NS/NS

Table 6. Comparison of calculated weights from broad whitefish at 3 evaluation lengths, based on length-weight obtained within the Colville Delta during summers of 2007, 1985 and 1995-1996.

Sample Period	Length Weight Regression slope	Length Weight Regression intercept	Correlation Coefficient (R^2)	Mean Length (mm)	Calculated Weight at 200 mm (gm)	Calculated Weight 2 at 250 mm (gm)	Calculated Weight 3 at 300 mm (gm)
June	3.178	5.420	0.982	165.3	78.3	159.1	284.1
July/August	3.014	5.004	0.976	226.7	85.1	166.7	288.7
1985	3.183	5.400	0.994	273.8	84.0	170.8	305.2
1995-1996	3.150	5.314	0.986	231.8	86.0	173.7	308.5

regression model is: log(weight) = log(length)x – a
where x = slope, a = intercept

Table 7. Broad whitefish length and weight by age group for fish caught at tapped lakes M9521 and M9625 during 2007 (ages assigned from length frequency analysis).

Fork Length (mm) at Age

	June			July			August		
Age	Mean	Standard Deviation	No.	Mean	Standard Deviation	No.	Mean	Standard Deviation	No.
0	25.0	--	1	42.6	8.6	92	71.8	9.0	192
1	87.6	9.2	665	112.0	11.3	312	135.1	8.4	529
2	140.0	9.8	41	163.8	11.0	69	173.4	11.0	59
3	185.5	8.5	183	203.2	9.9	217	219.3	12.9	138
4	222.7	10.9	274	243.8	10.6	114	259.6	11.3	52
5	257.6	11.1	293	280.3	12.5	43	303.7	12.0	23
6	303.1	13.8	167	330.0	13.2	11	353.5	13.3	10

Weight (gm) at Age

	June			July			August		
Age	Mean	Standard Deviation	No.	Mean	Standard Deviation	No.	Mean	Standard Deviation	No.
0	--	--	0	--	--	0	--	--	0
1	12.4	5.0	5	16.0	8.0	259	26.7	7.5	276
2	27.3	8.7	29	48.3	11.0	68	54.6	12.9	29
3	61.5	9.4	179	89.1	14.3	213	113.3	22.1	133
4	111.4	18.9	273	157.2	22.5	114	186.0	28.4	49
5	178.7	27.9	291	243.2	38.2	42	301.3	46.3	22
6	294.0	46.7	167	368.5	44.3	10	475.0	40.5	9

Table 8. Daily and seasonal growth of broad whitefish by age group for fish caught at tapped lakes M9521 and M9625 during 2007 (ages assigned from length frequency analysis).

Fork Length (mm) at Age

Age	June Mean Length (mm)	August Mean Length (mm)	Jun-Aug Length Increase (mm)	Rate of Length Increase (mm/day)	Jun-Aug Length Increase (percent)	Rate of Length Increase (%/day)
0	--	71.8	--	--	--	
1	87.6	135.1	47.5	0.83	54%	0.95%
2	140.0	173.4	33.5	0.58	24%	0.42%
3	185.5	219.3	33.7	0.59	18%	0.32%
4	222.7	259.6	37.0	0.65	17%	0.29%
5	257.6	303.7	46.0	0.80	18%	0.31%
6	303.1	353.5	50.4	0.88	17%	0.29%

Weight (gm) at Age

Age	June Mean Weight (gm)	August Mean Weight (gm)	Jun-Aug Weight Increase (gm)	Rate of Weight Increase (gm/day)	Jun-Aug Weight Increase (percent)	Rate of Weight Increase (%/day)
0	--	--	--	--	--	
1	12.4	26.7	14.3	0.25	115%	2.02%
2	27.3	54.6	27.3	0.48	100%	1.75%
3	61.5	113.3	51.8	0.91	84%	1.47%
4	111.4	186.0	74.6	1.30	67%	1.17%
5	178.7	301.3	122.7	2.14	69%	1.20%
6	294.0	475.0	181.0	3.16	62%	1.08%

Table 9: Total number of broad whitefish (over 200 mm) migrating downstream and upstream on a given day by lake, including untagged and previously tagged fish

	Lake M9521		**Lake M9625**	
Date	*Downstream*	*Upstream*	*Downstream*	*Upstream*
6/19/2007	4	14	9	5
6/20/2007	4	11	23	4
6/21/2007	10	32	22	2
6/22/2007	0	7	0	5
6/23/2007	7	9	8	6
6/24/2007	18	1	68	3
6/25/2007	13	5	134	15
6/26/2007	36	21	168	6
6/27/2007	53	3	34	5
7/22/2007	6	12	3	5
7/23/2007	3	12	1	6
7/24/2007	2	14	34	4
7/25/2007	0	12	5	7
7/26/2007	6	6	51	8
7/27/2007	13	5	33	4
7/28/2007	20	11	6	0
7/29/2007	3	3	2	0
8/17/2007	1	6	5	5
8/18/2007	3	1	3	3
8/19/2007	0	1	41	1
8/20/2007	1	36	19	1
8/21/2007	3	4	20	3
8/22/2007	29	10	9	1
8/23/2007			0	19
Total	**235**	**236**	**698**	**118**

Table 10: Estimated number of fish in lake M9625 and estimated mean daily emigration rate (e) during June and July sampling periods with standard deviations and percentiles of the posterior distribution for 90% and 90% confidence intervals. Estimates for August were unrealistic and are not shown here.

	June		July	
	N_1	e	N_1	e
Mean	1271	4.35%	343	4.17%
Std. err.	334	1.19%	121	1.39%
2.50%	808	2.32%	193	1.85%
5%	854	2.57%	207	2.13%
50% (Median)	1208	4.26%	317	4.04%
95%	1898	6.47%	571	6.66%
97.50%	2983	6.95%	653	7.26%

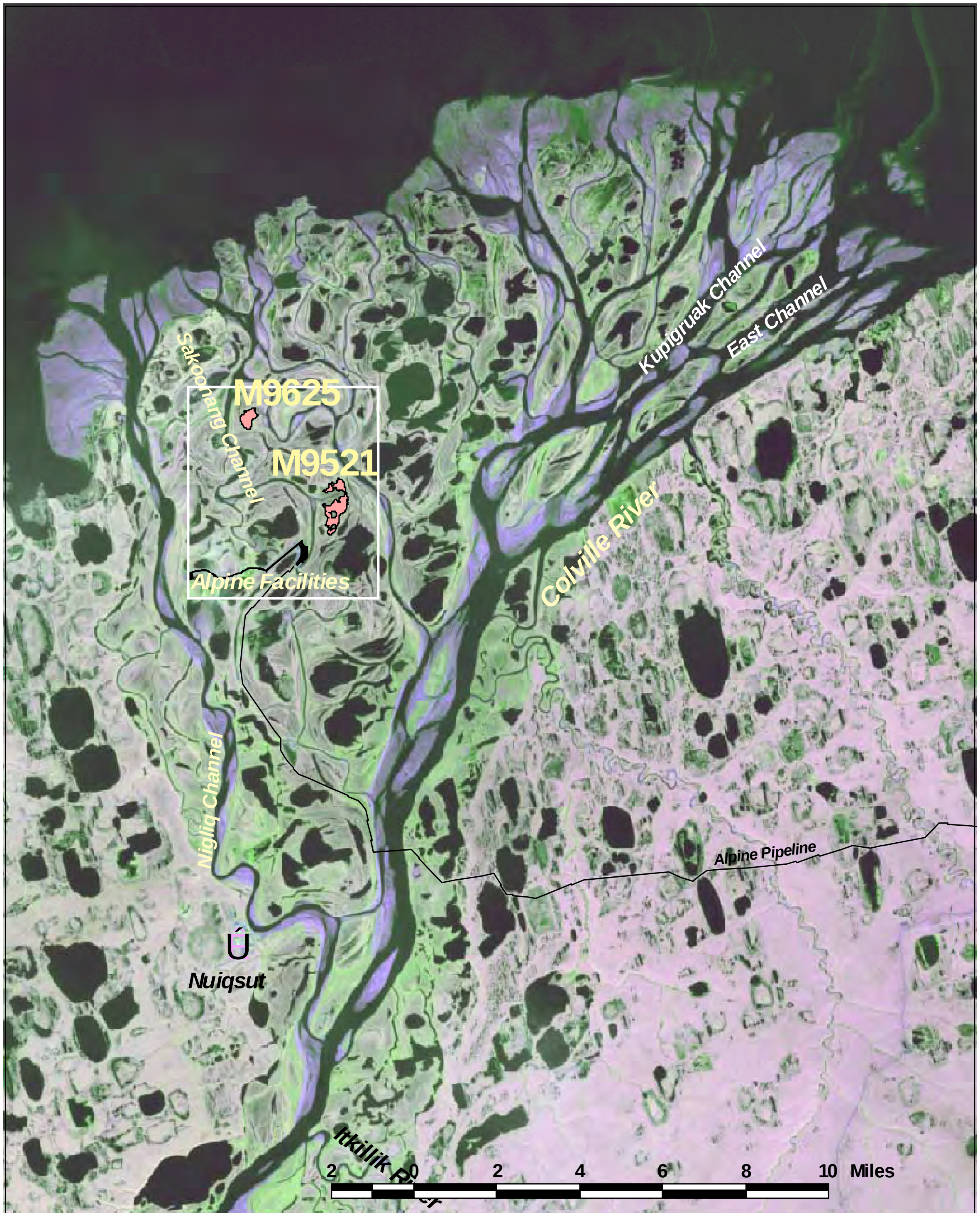


Figure 1. Location of broad whitefish study area within the Colville Delta (study lakes in red).

Figure 2. Lake M9521, a 212 acre tapped lake sampled for broad whitefish in 2007, fyke net location at yellow dot.

Figure 3. Lake M9625, a 76 acre tapped lake sampled for broad whitefish in 2007, fyke net location at yellow dot.

Figure 4. Fyke nets at tapped lakes M9521 (top) and M9625 (bottom) set to catch fish moving into and out of the lakes.

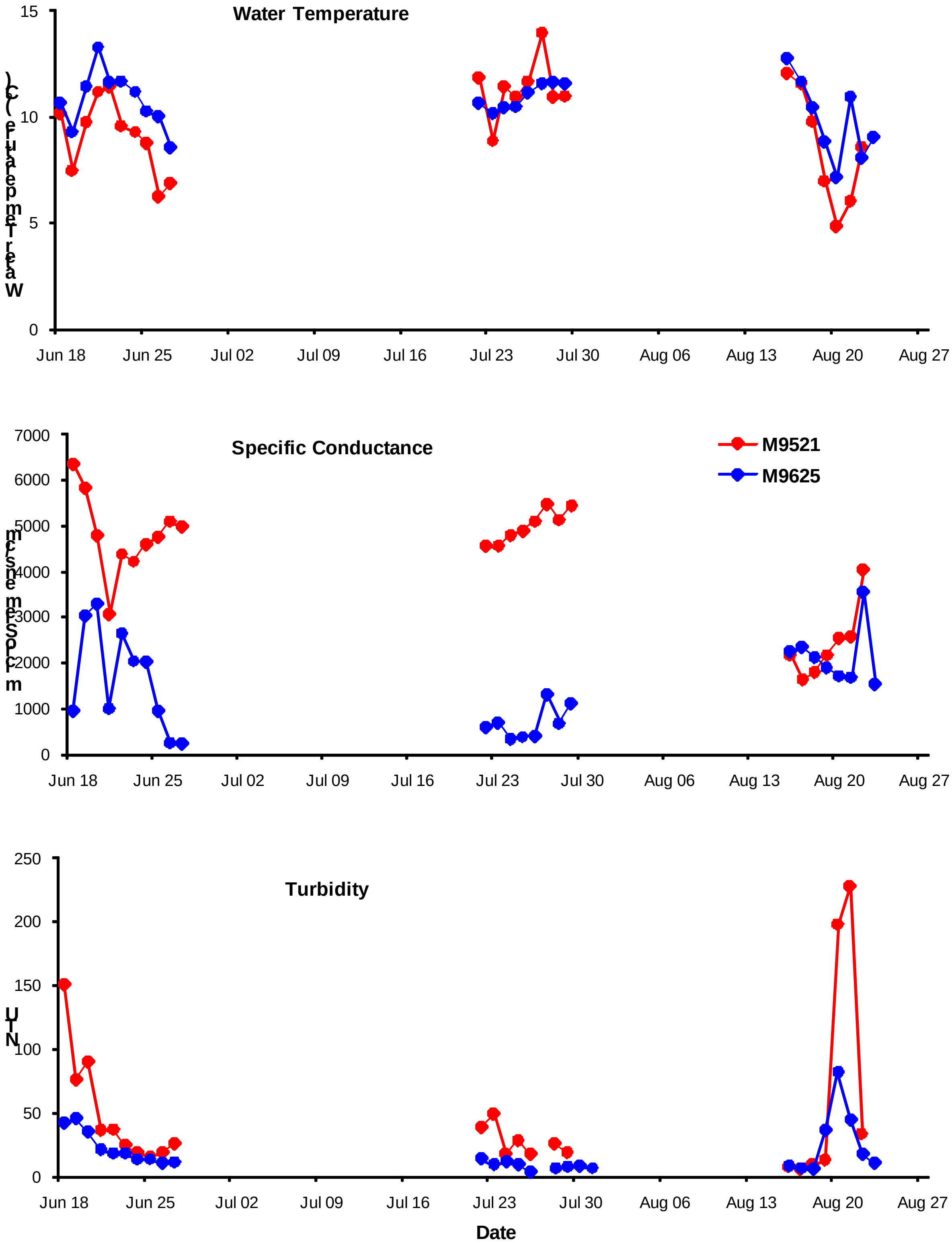


Figure 5. Water chemistry measurements at lakes M9521 and M9625 during summer 2007.

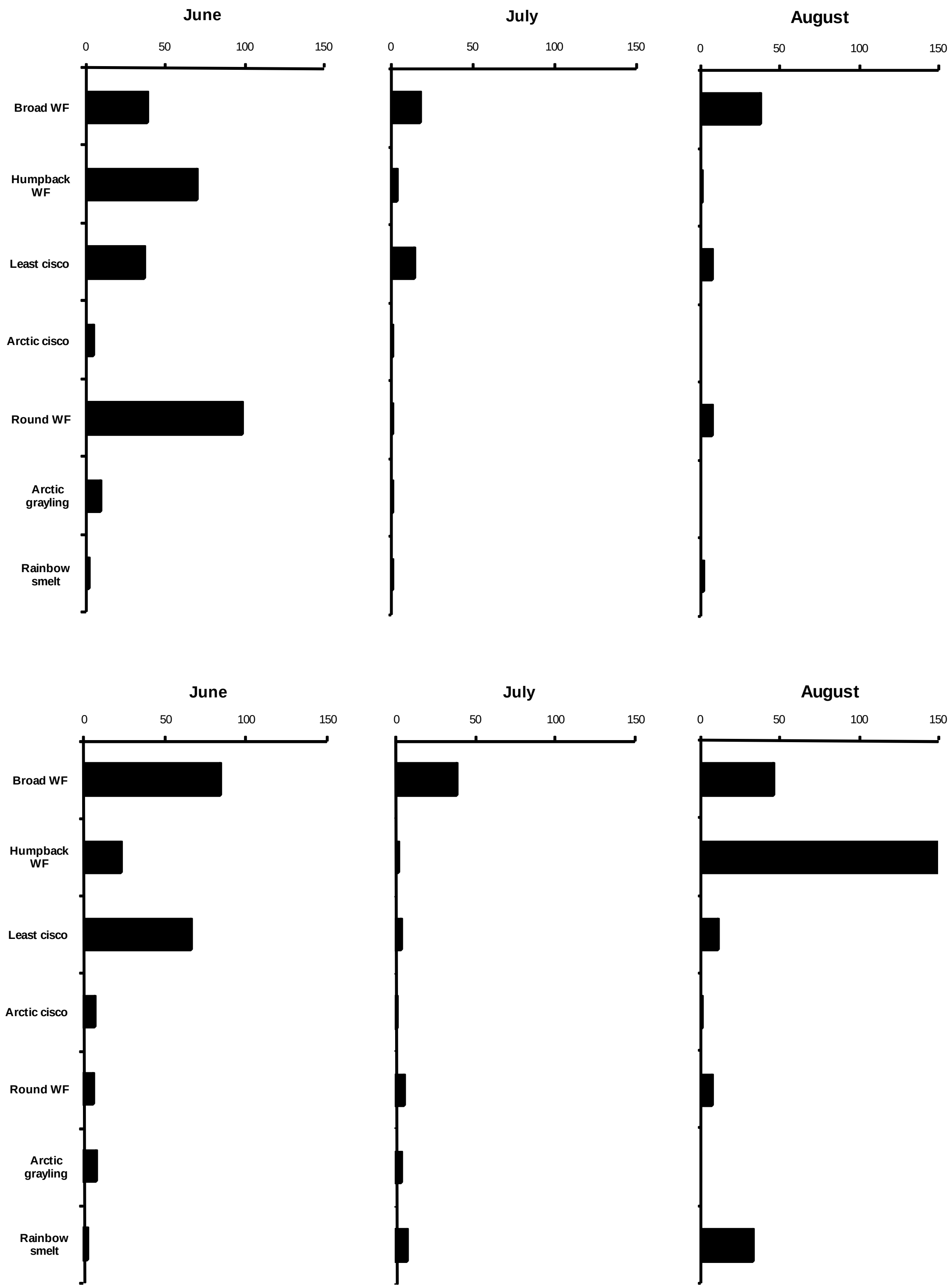


Figure 6. Catch rates (in fish per day) of dominant species at lakes M9521 (top) and M9625 (bottom) during 2007 (all sizes combined).

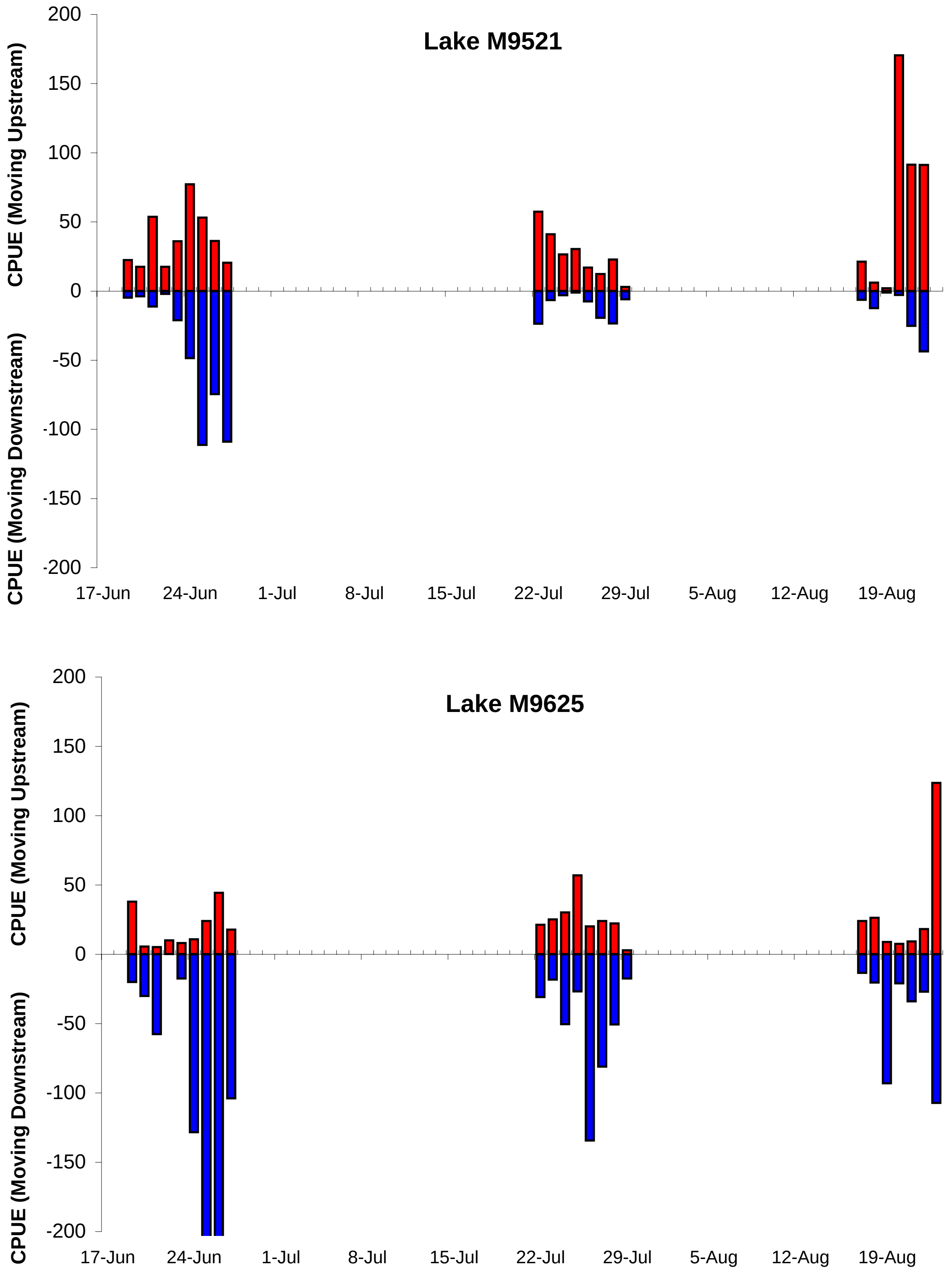


Figure 7. Daily catch rates of broad whitefish moving upstream and downstream at tapped lakes sampled in 2007 (positive values indicate fish moving upstream, negative values indicate fish moving downstream).

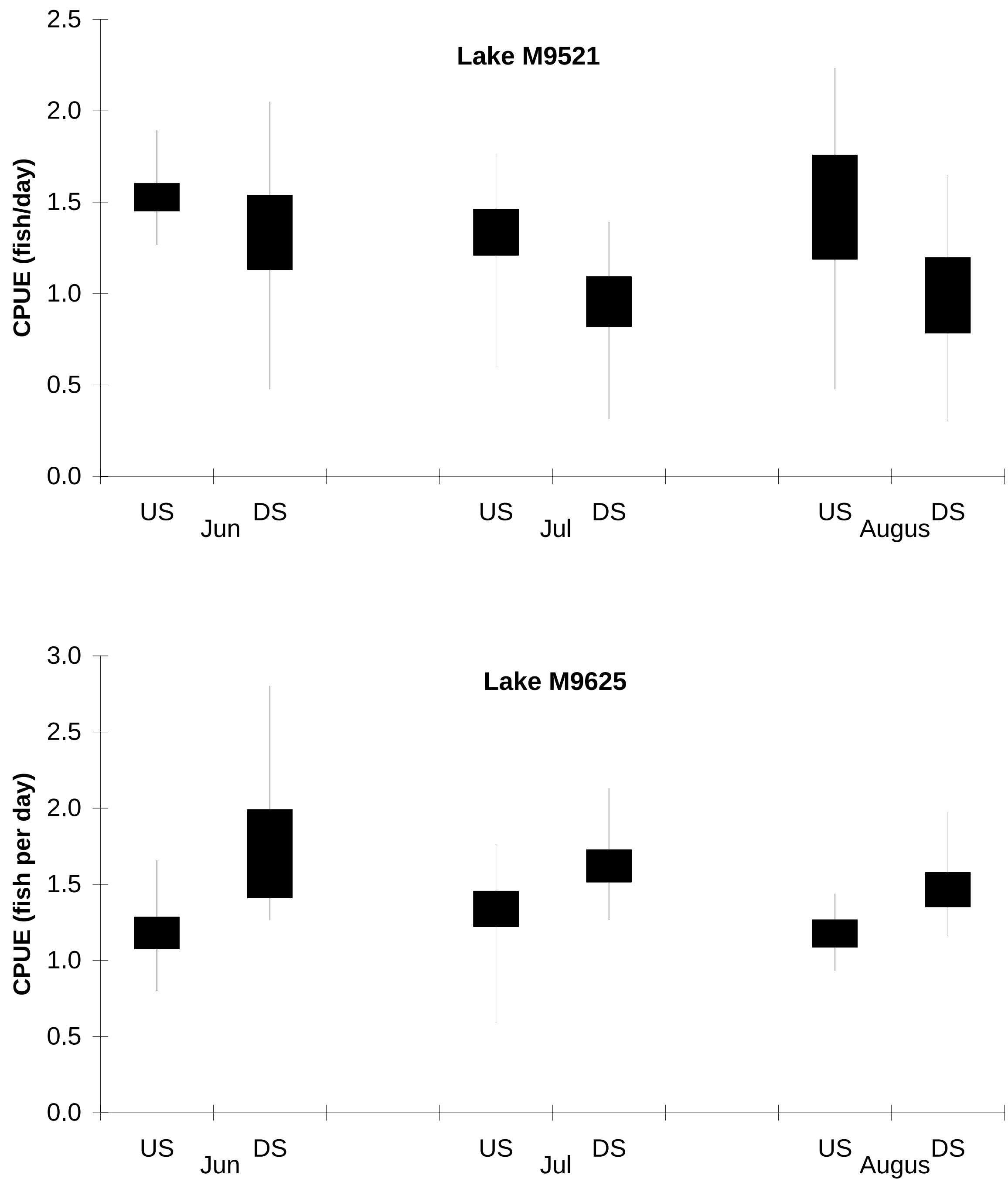
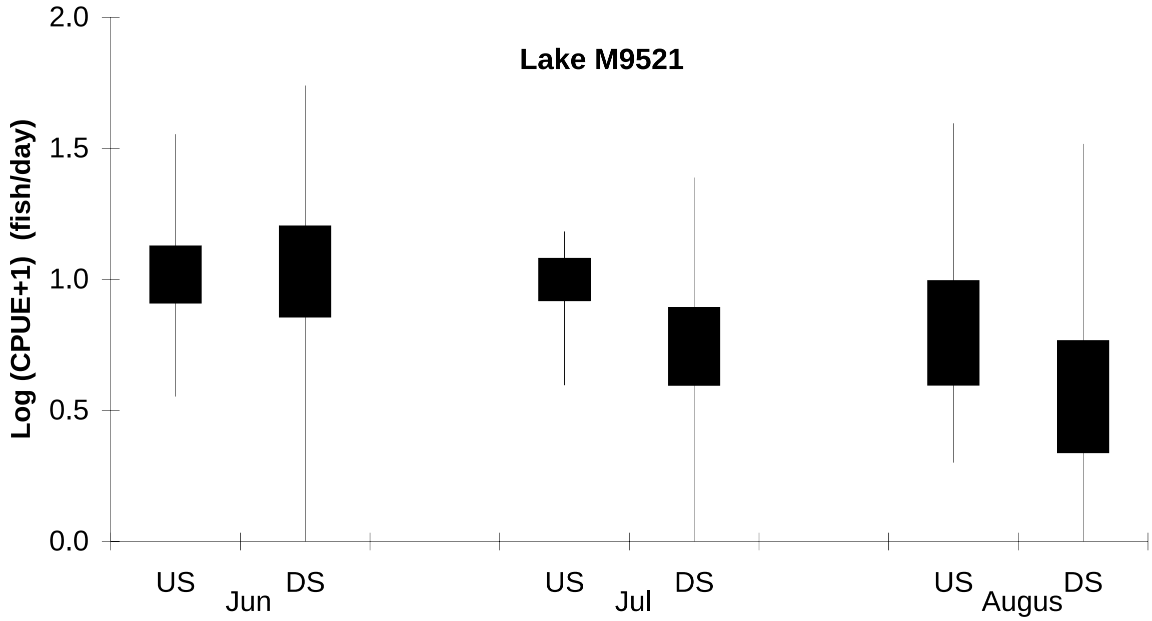


Figure 8. Patterns of broad whitefish movements (all sizes) in lakes M9521 and M9625 during 2007 (black boxes indicate 2 standard errors of the mean, vertical lines indicate range of values, US = fish moving upstream, DS = fish moving downstream



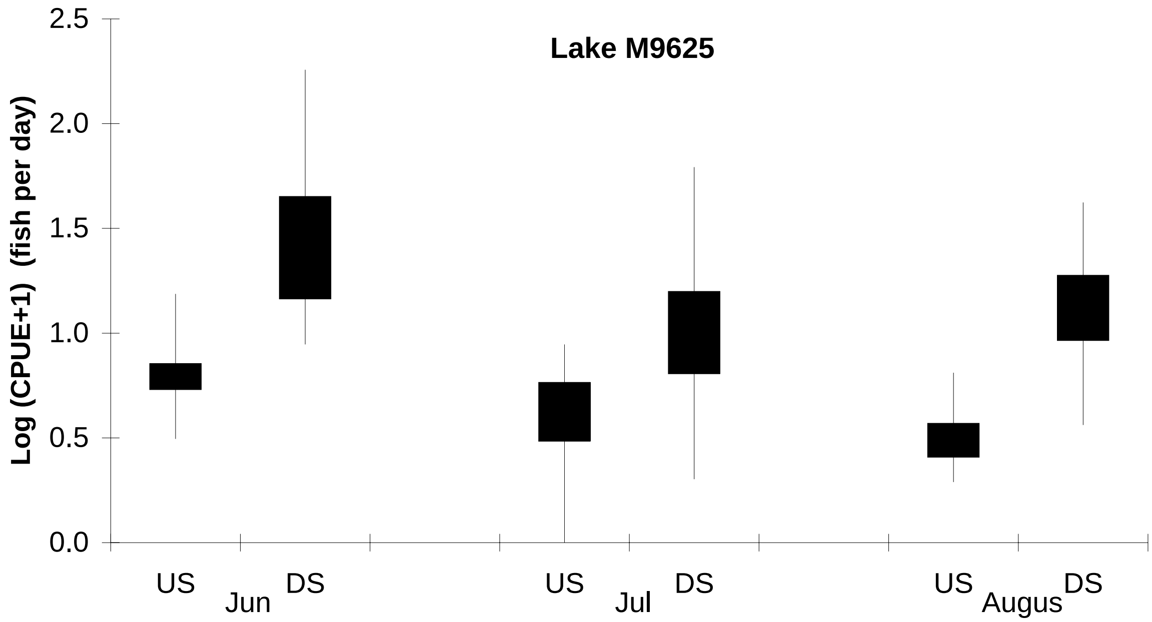


Figure 9. Patterns of large (200 mm or greater) broad whitefish movements in lakes M9521 and M9625 during 2007, black boxes indicate 2 standard errors of the mean, vertical lines indicate range of values, US = fish moving upstream, DS = fish moving downstream

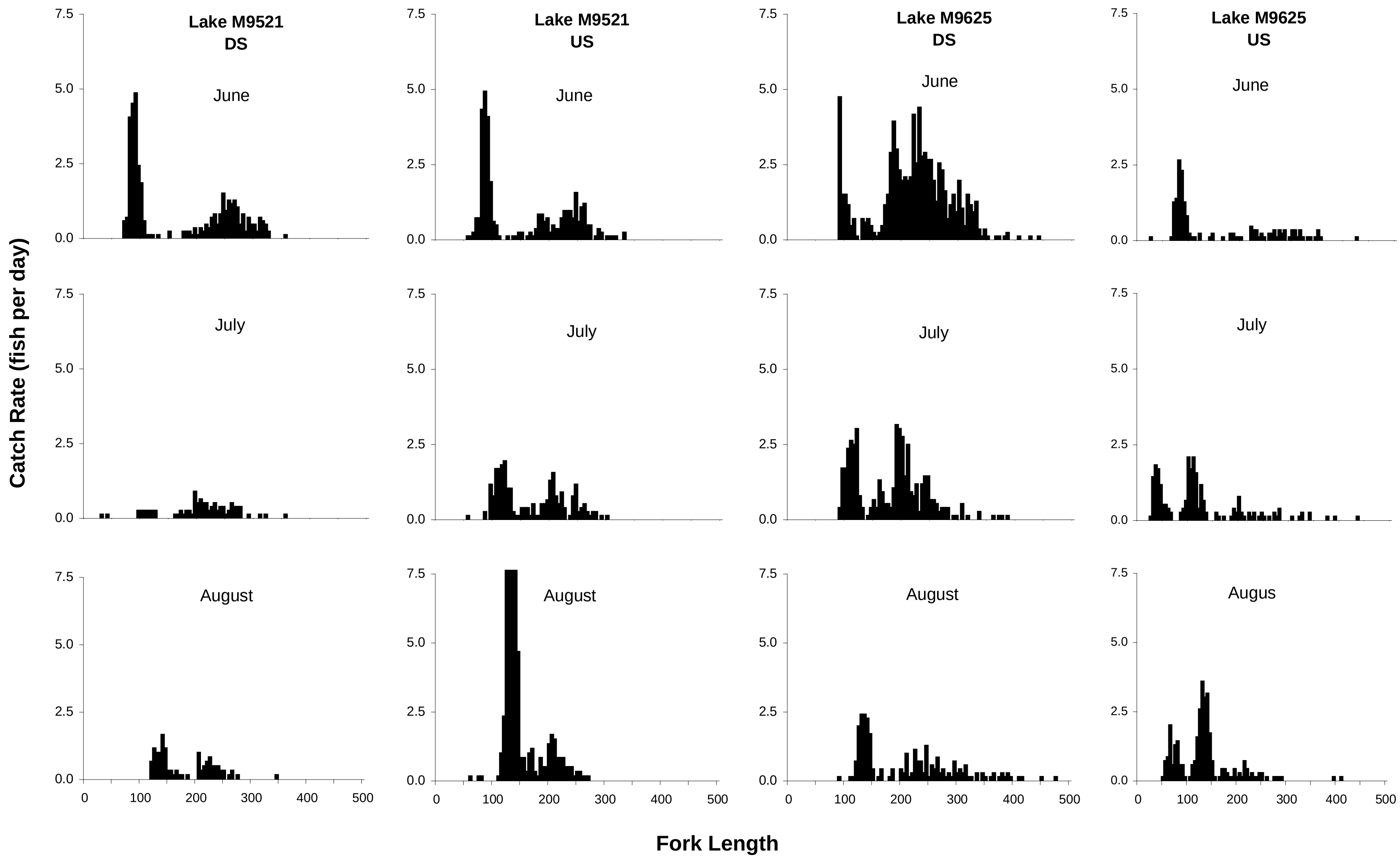


Figure 10. Sizes of broad whitefish caught moving upstream (US) and downstream (DS) in lakes M9521 and M9625, by month.

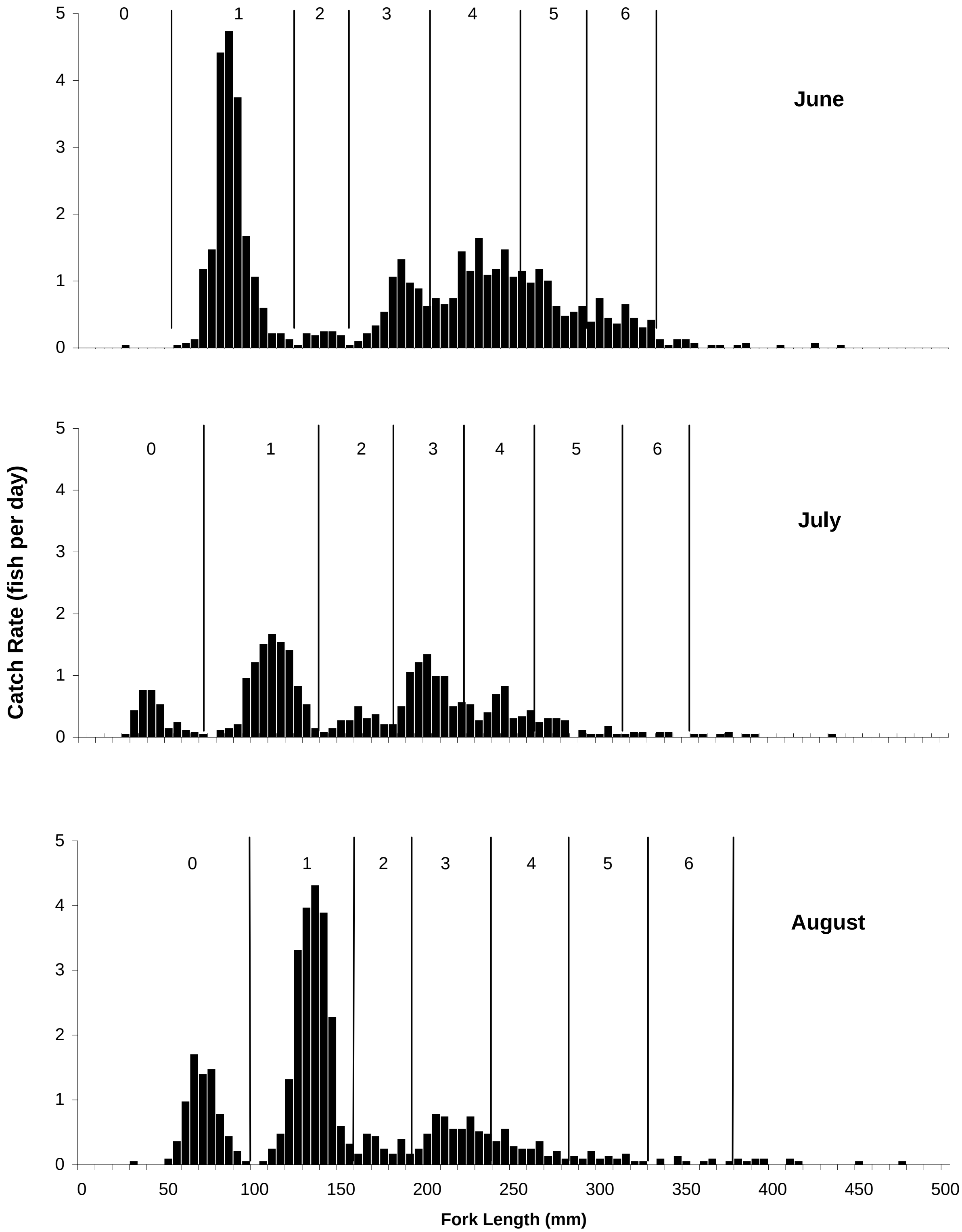


Figure 11. Length frequencies of broad whitefish captured at lakes M9521 and M9625 during 2007, showing ages assigned to designated length intervals.

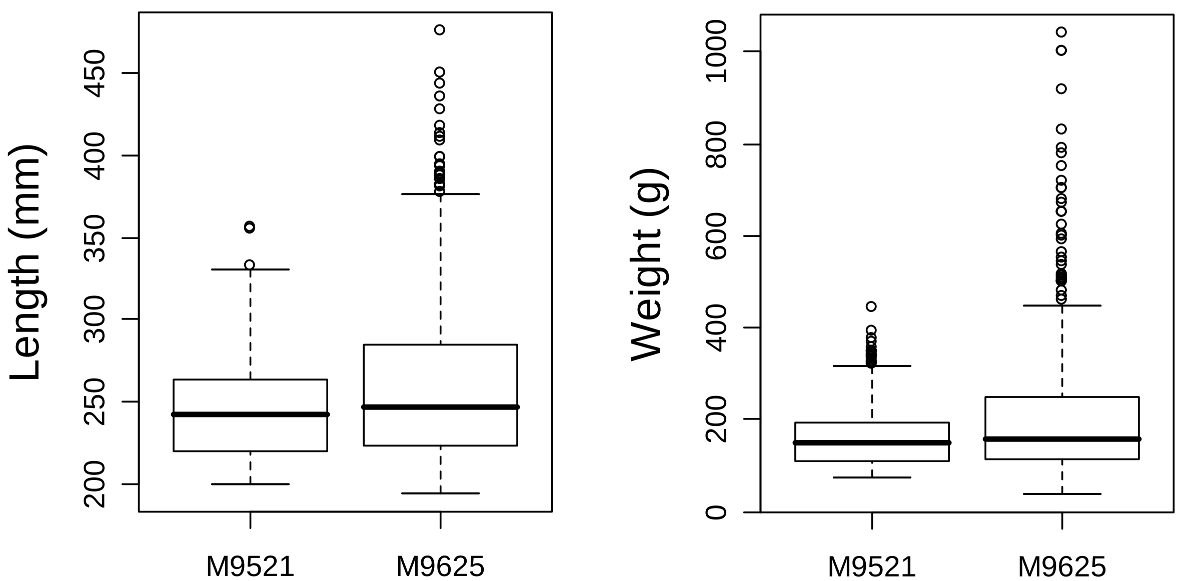


Figure 12. Distribution of lengths and weights by lake for tagged broad whitefish. Note larger fish at M9625.

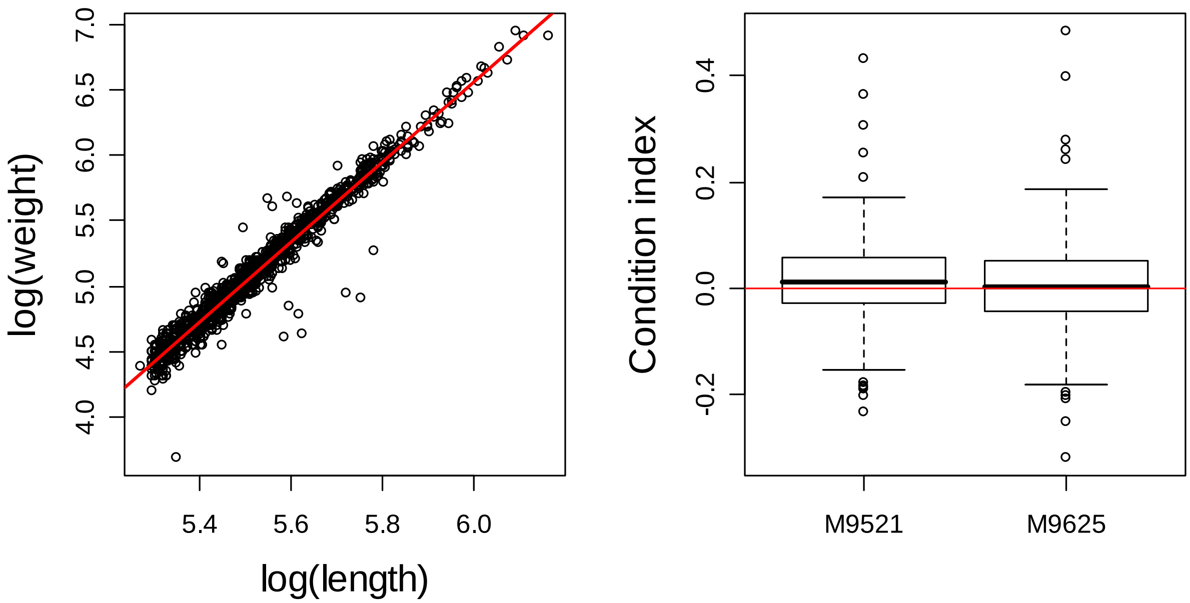
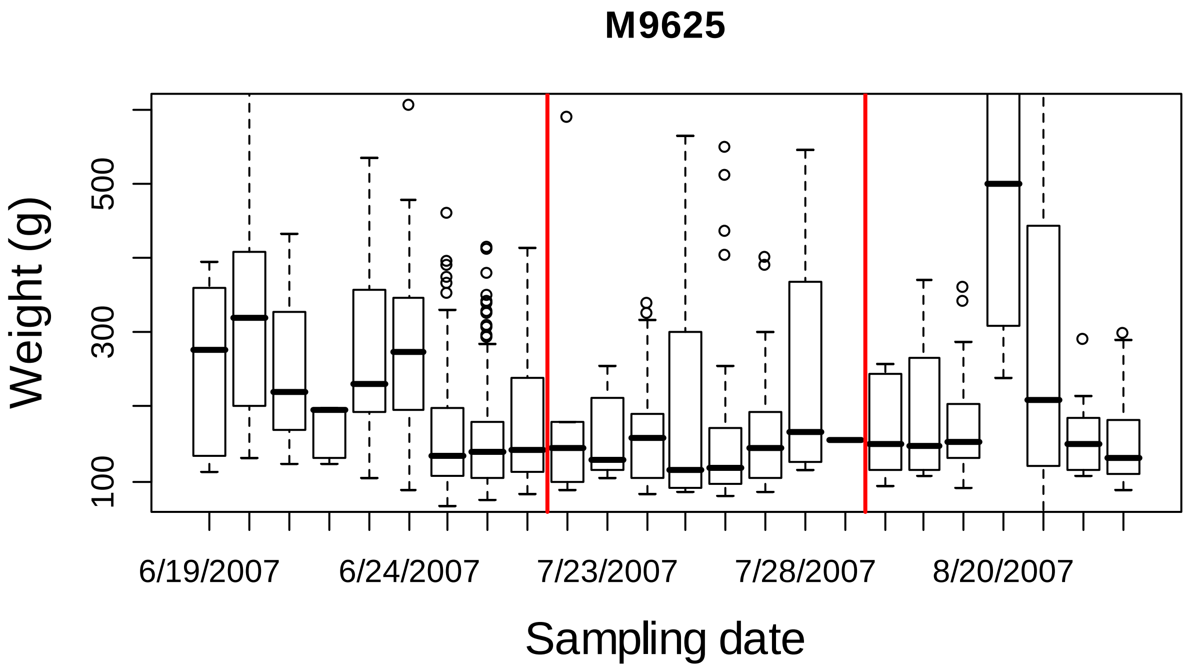


Figure 13. Length-weight relationship for tagged broad whitefish and comparison of length-weight residuals between lakes.



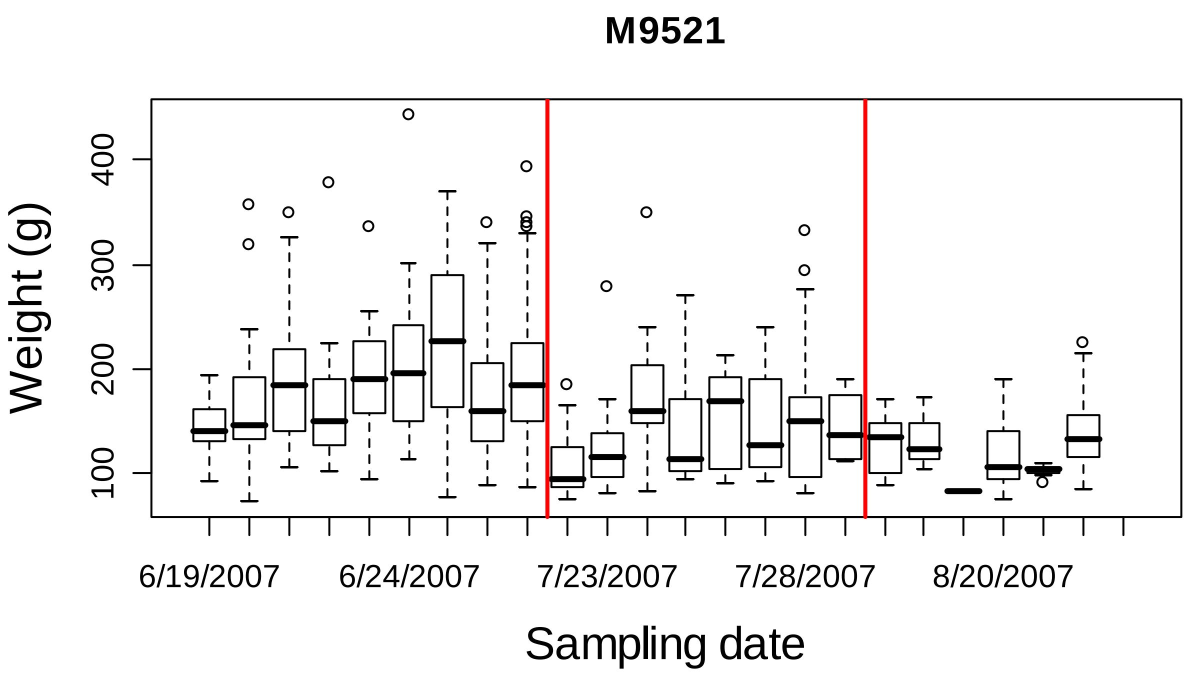


Figure 14. Distribution of weight for tagged broad whitefish by lake and sampling date for three sampling periods (separated by vertical bars)

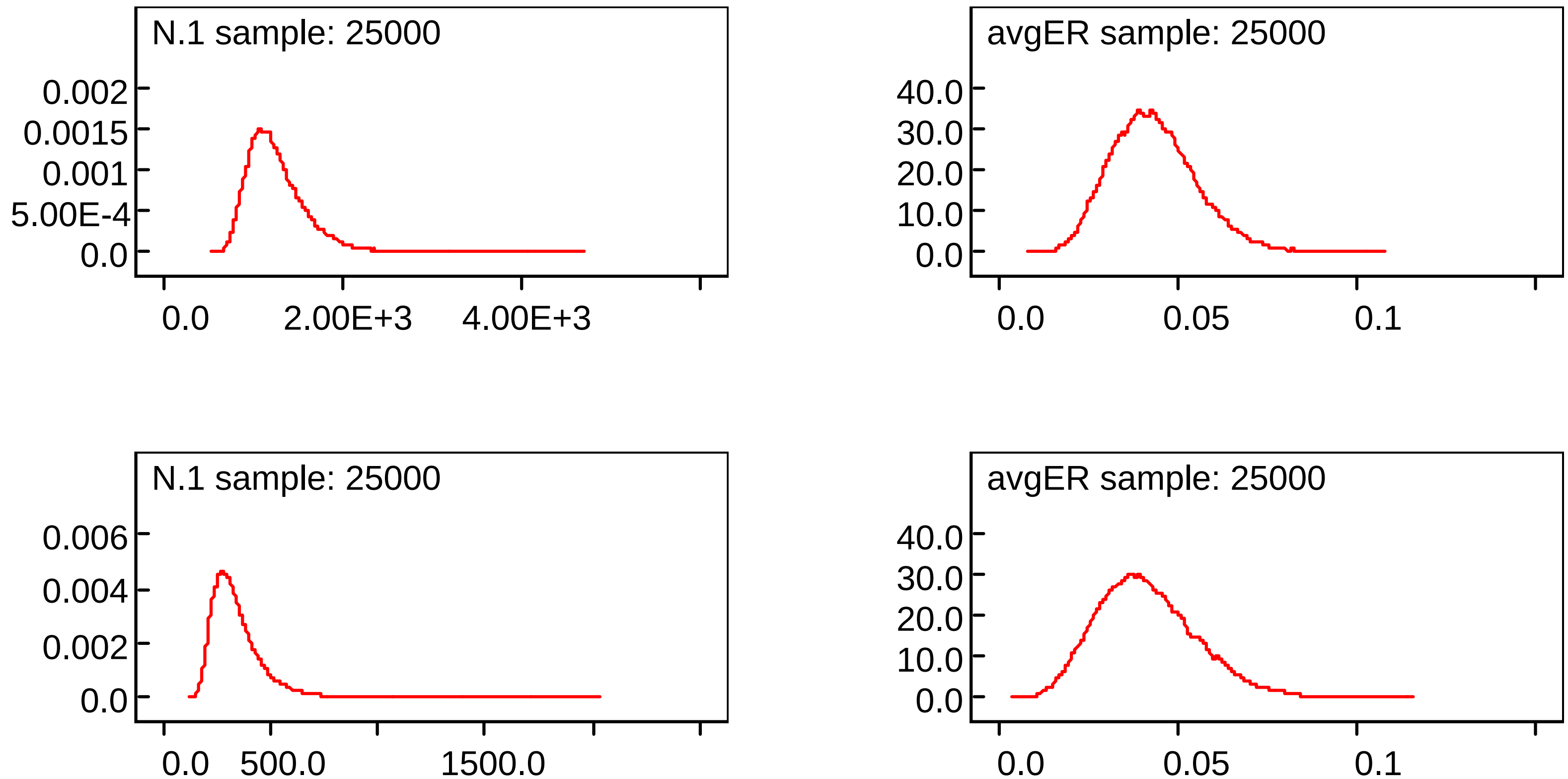


Figure 15. Full posterior probability distributions of estimated broad whitefish abundance (left) and average daily net emigration rates in June (top) and July (bottom).

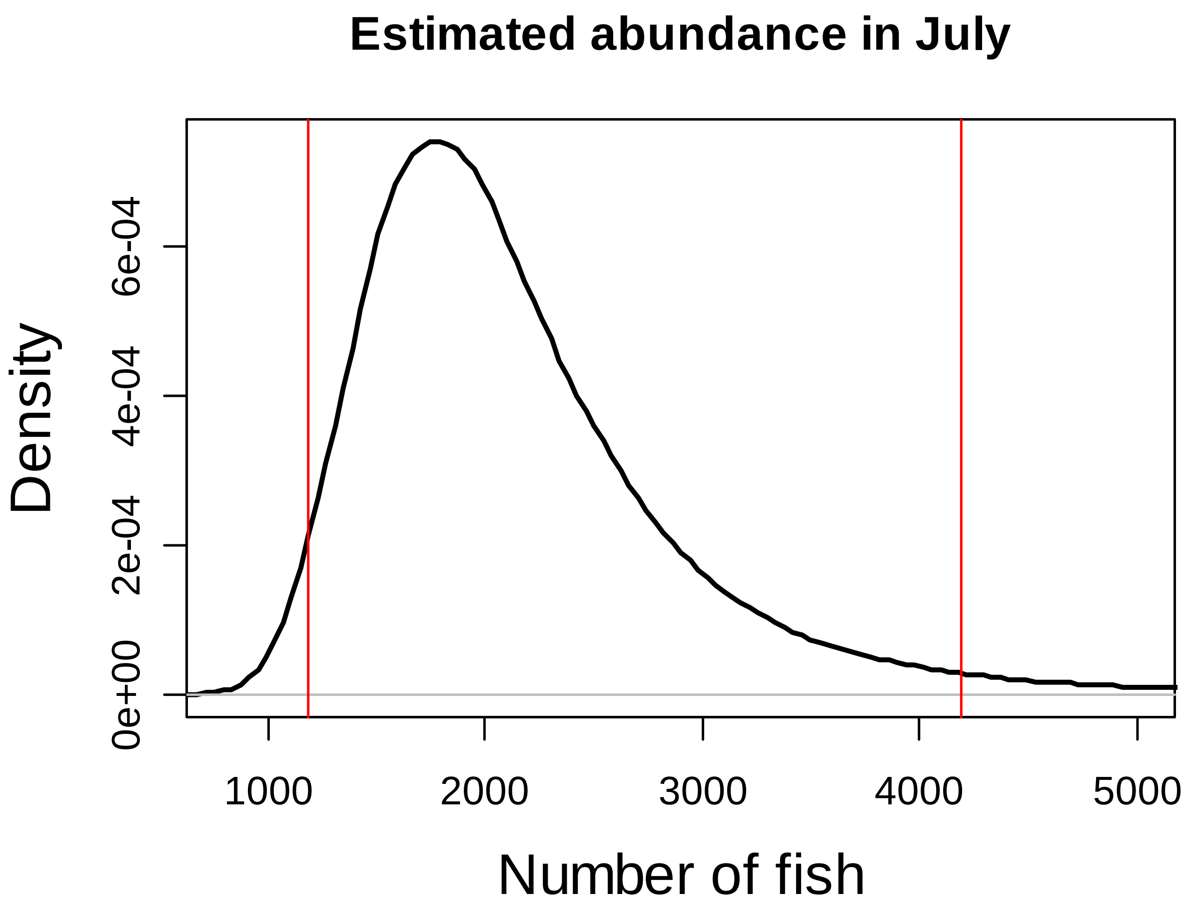
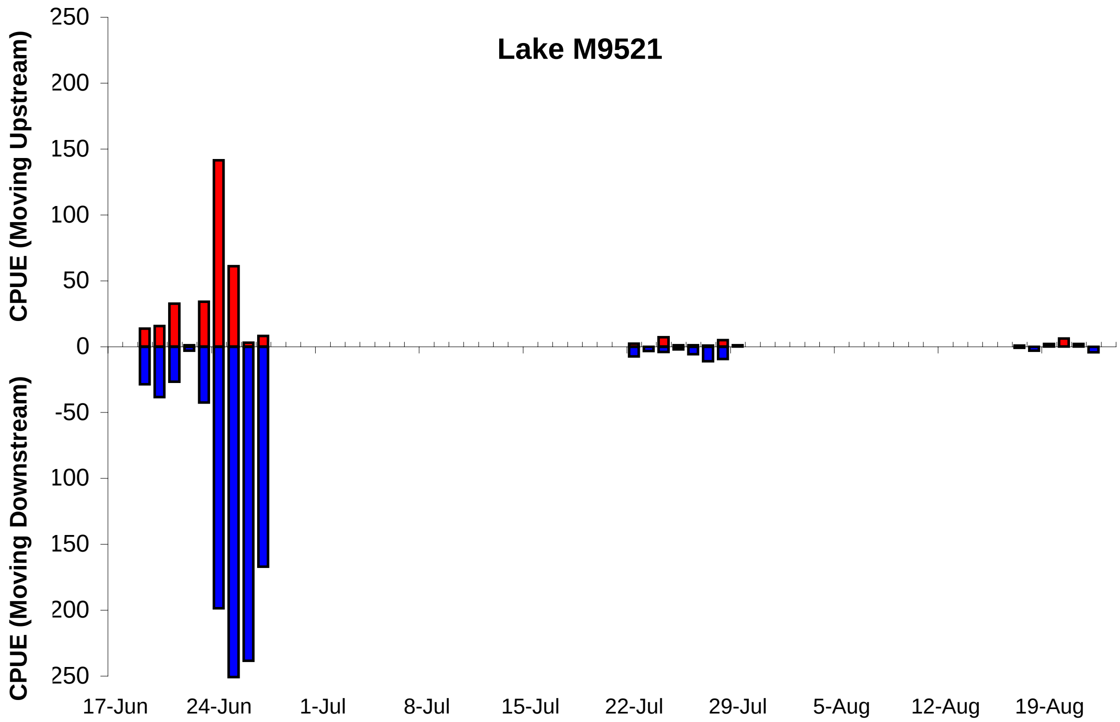


Figure 16. Estimated number of broad whitefish utilizing the lake and channel region below lake M9625 in July with 95% credibility region (red lines).



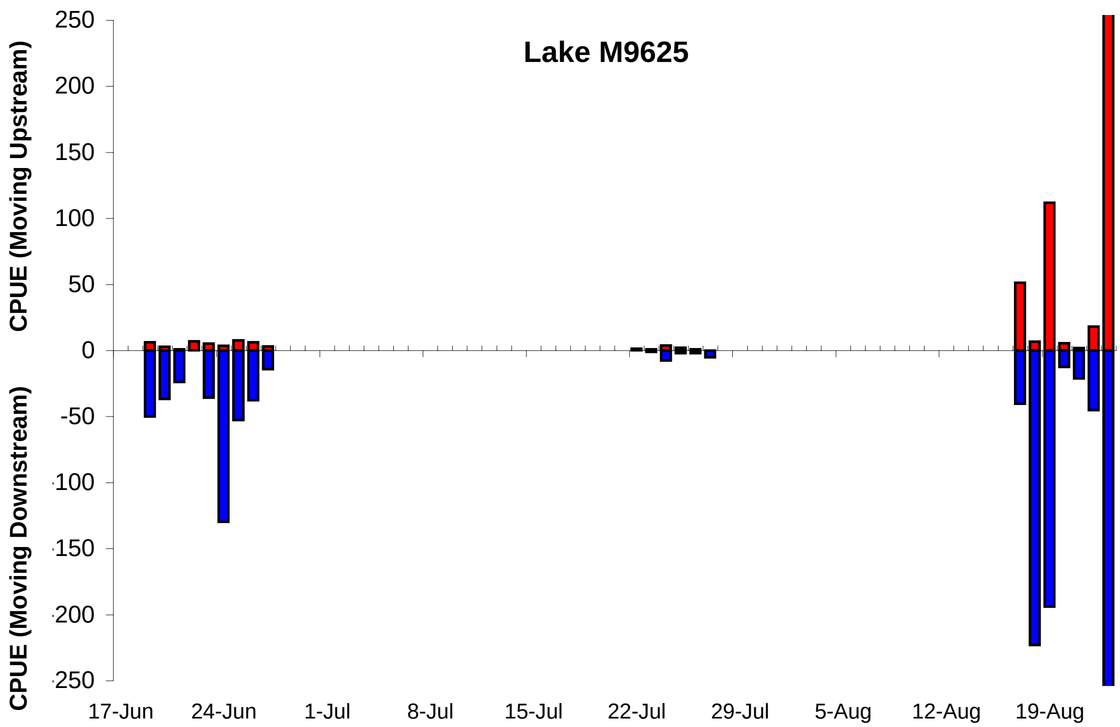


Figure 17. Daily catch rates of humpback whitefish moving upstream and downstream at tapped lakes sampled in 2007 (positive values indicate fish moving upstream, negative values indicate fish moving downstream).

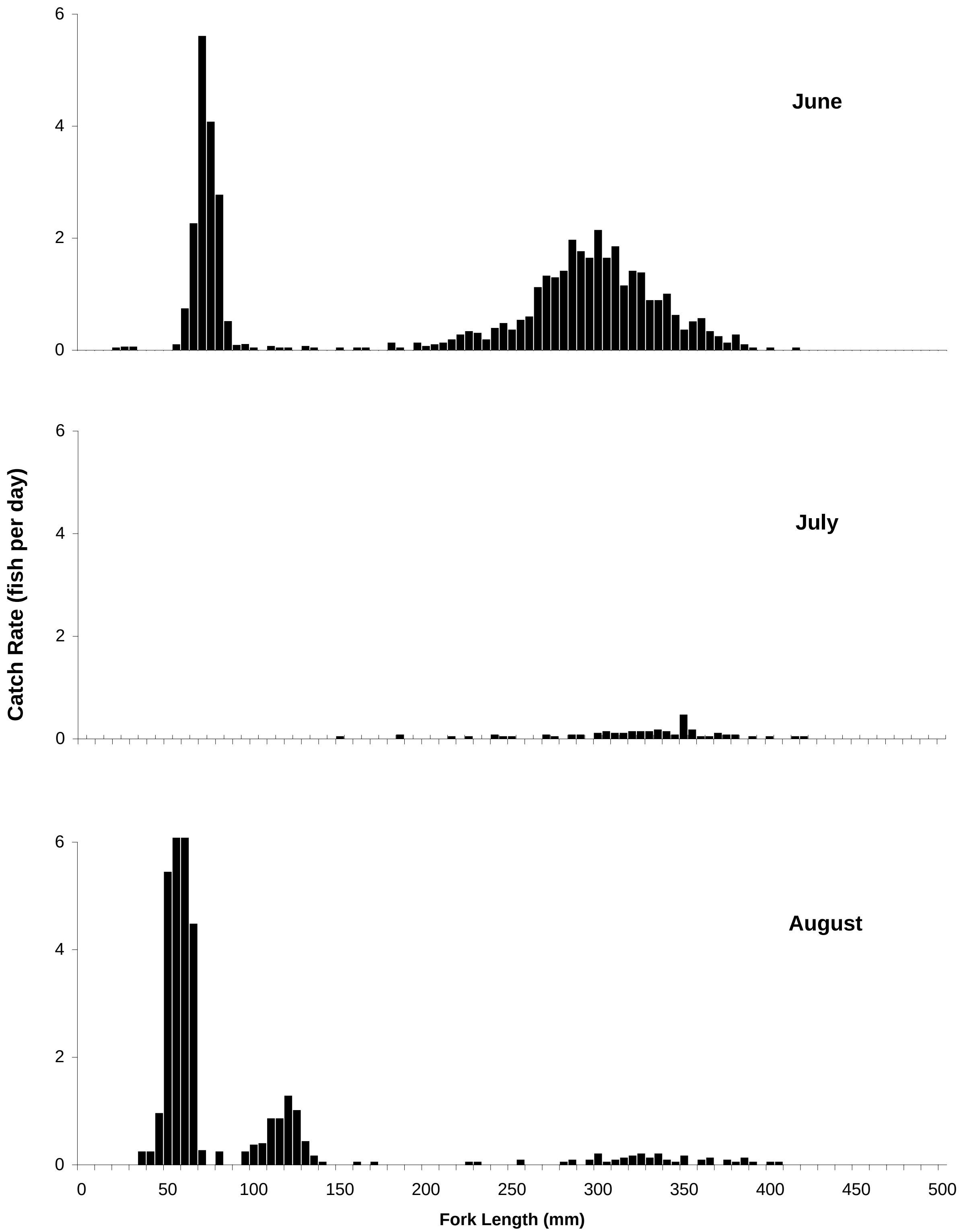
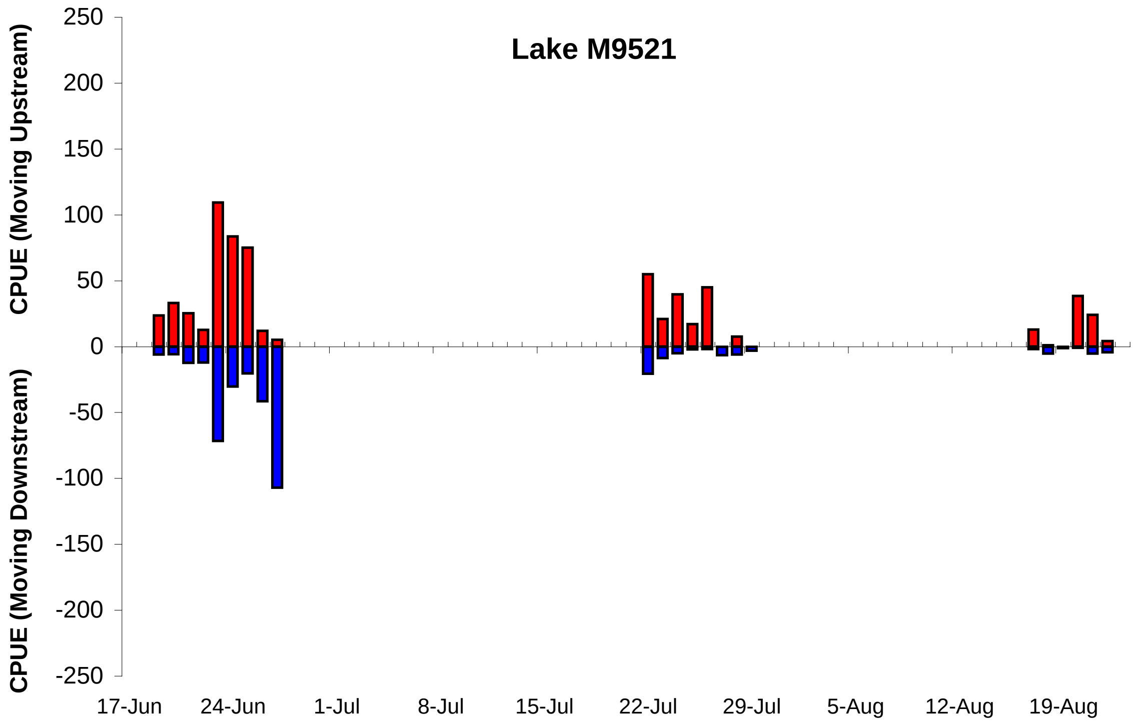


Figure 18. Length frequencies of humpback whitefish captured at lakes M9521 and M9625 during 2007.



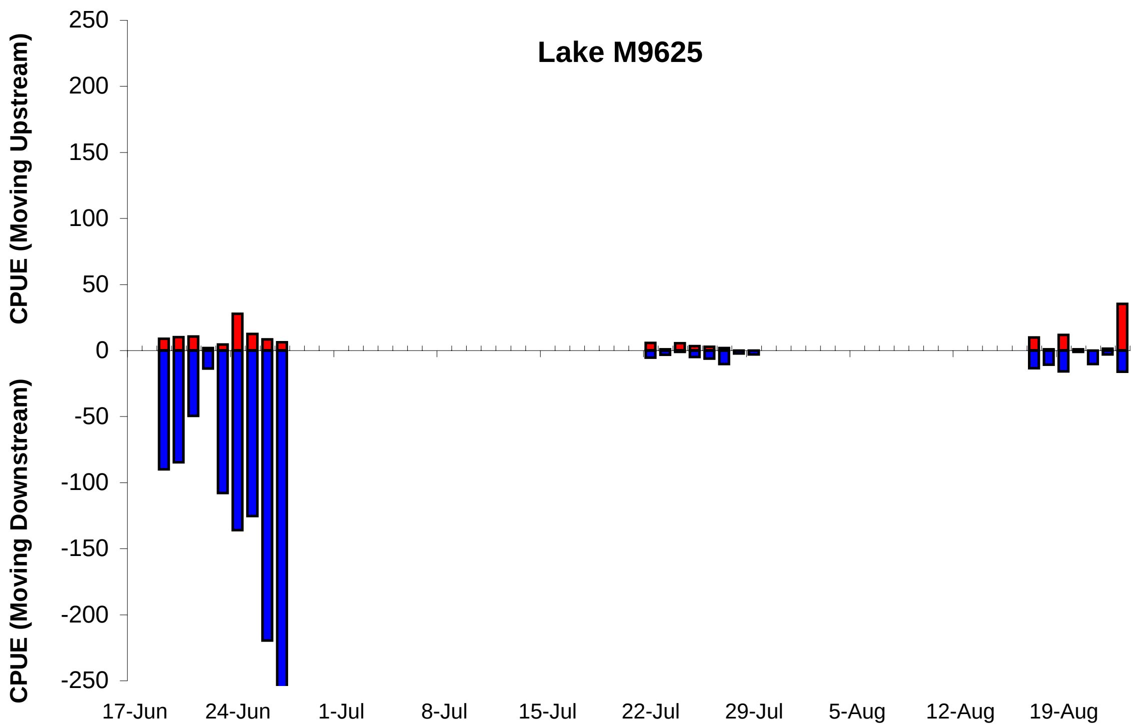


Figure 19. Daily catch rates of least cisco moving upstream and downstream at tapped lakes sampled in 2007 (positive values indicate fish moving upstream, negative values indicate fish moving downstream).

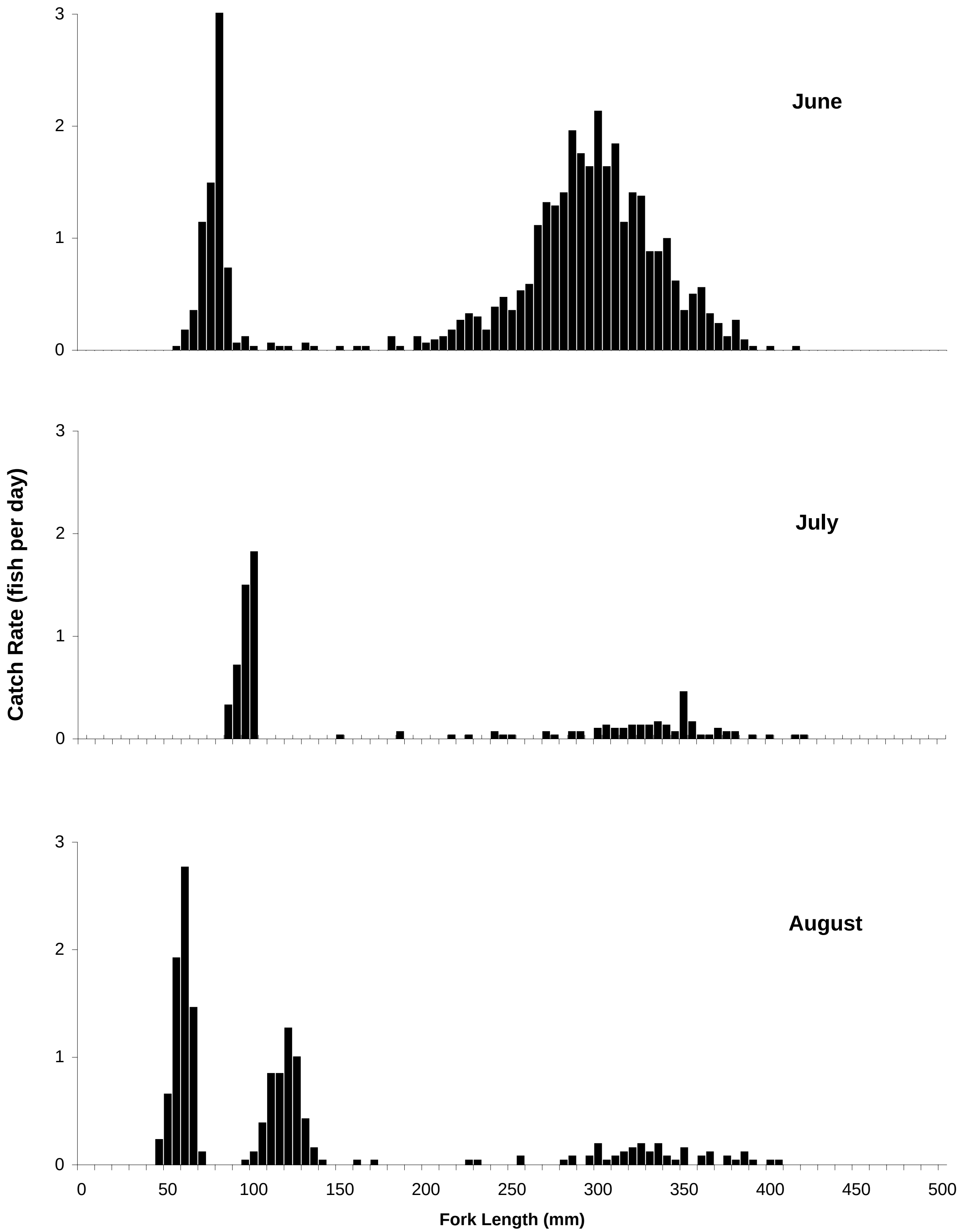
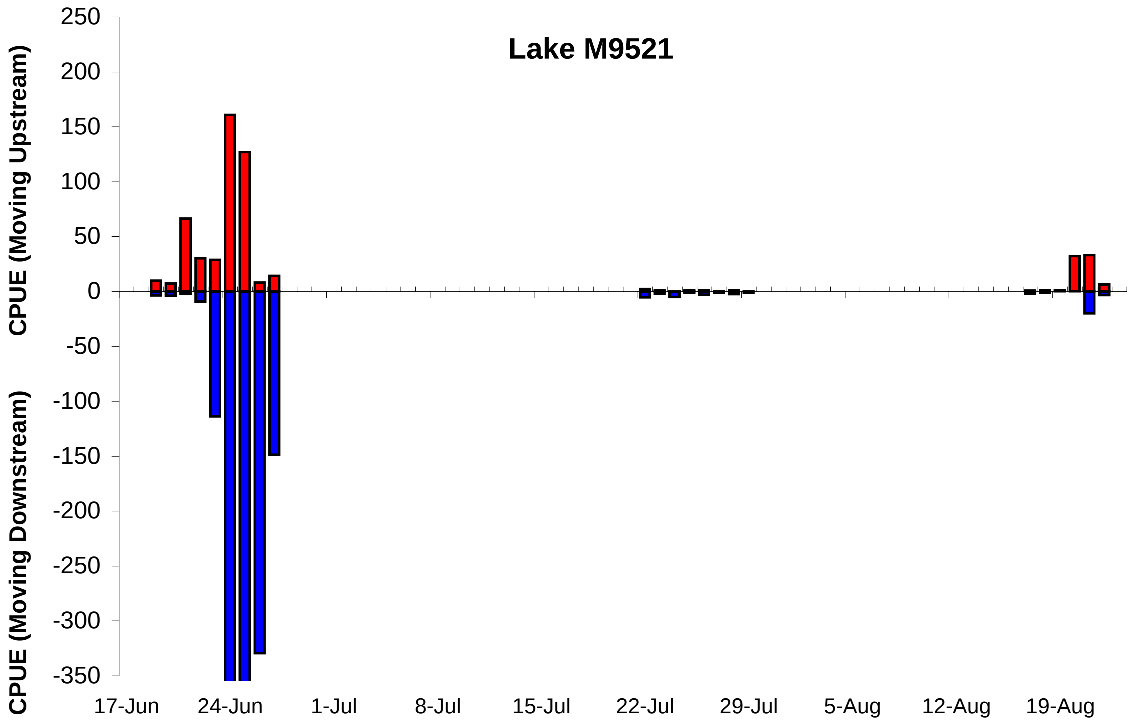


Figure 20. Length frequencies of least cisco captured at lakes M9521 and M9625 during 2007.



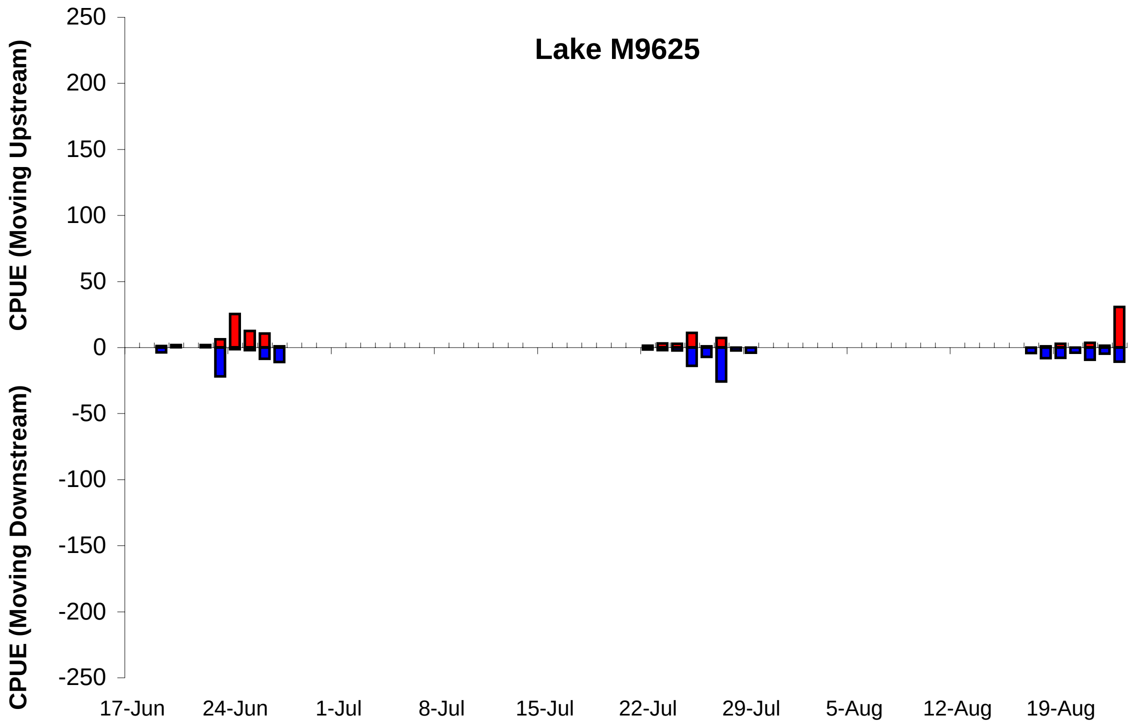


Figure 21. Daily catch rates of round whitefish moving upstream and downstream at tapped lakes sampled in 2007 (positive values indicate fish moving upstream, negative values indicate fish moving downstream).

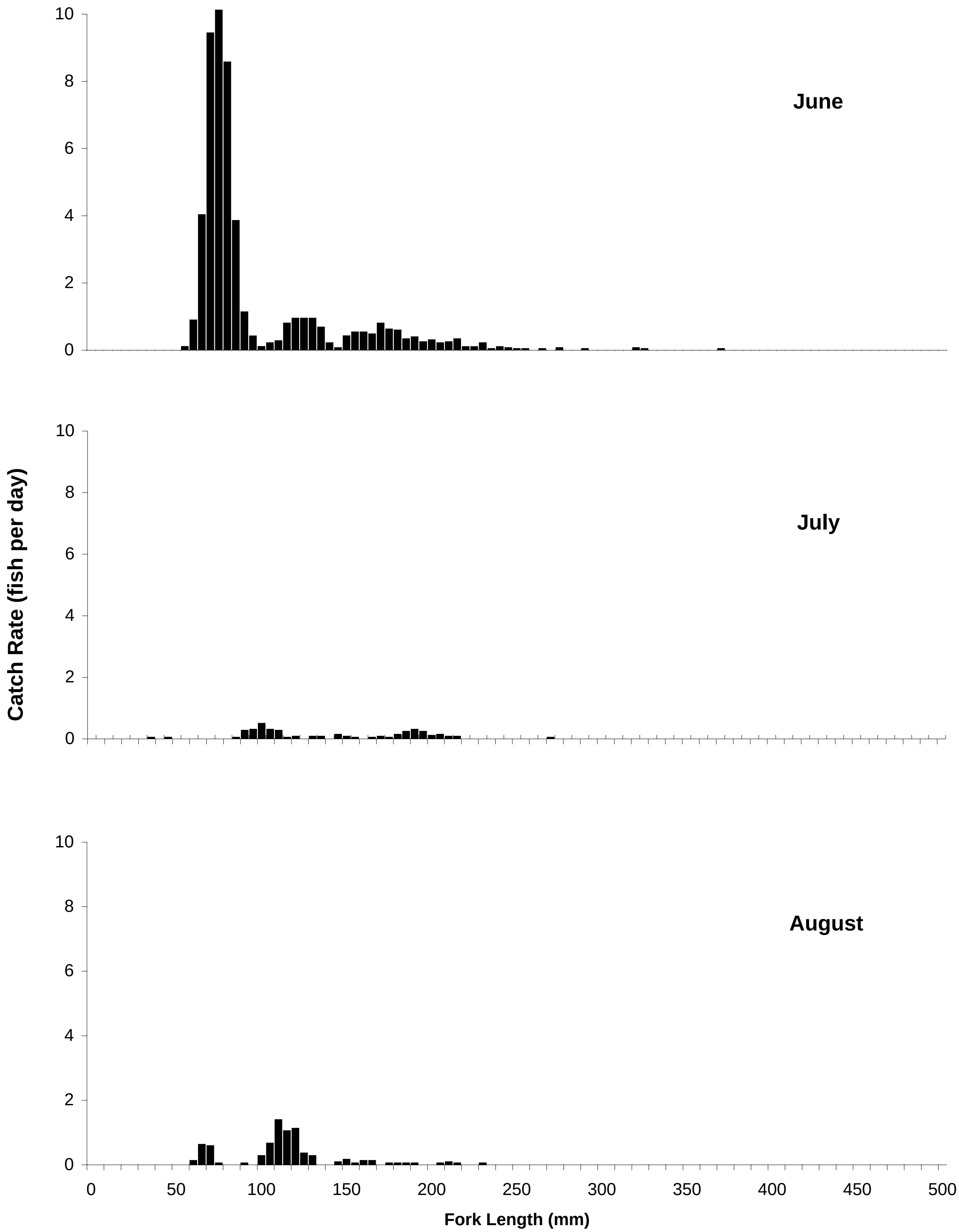


Figure 22. Length frequencies of round whitefish captured at lakes M9521 and M9625 during 2007.

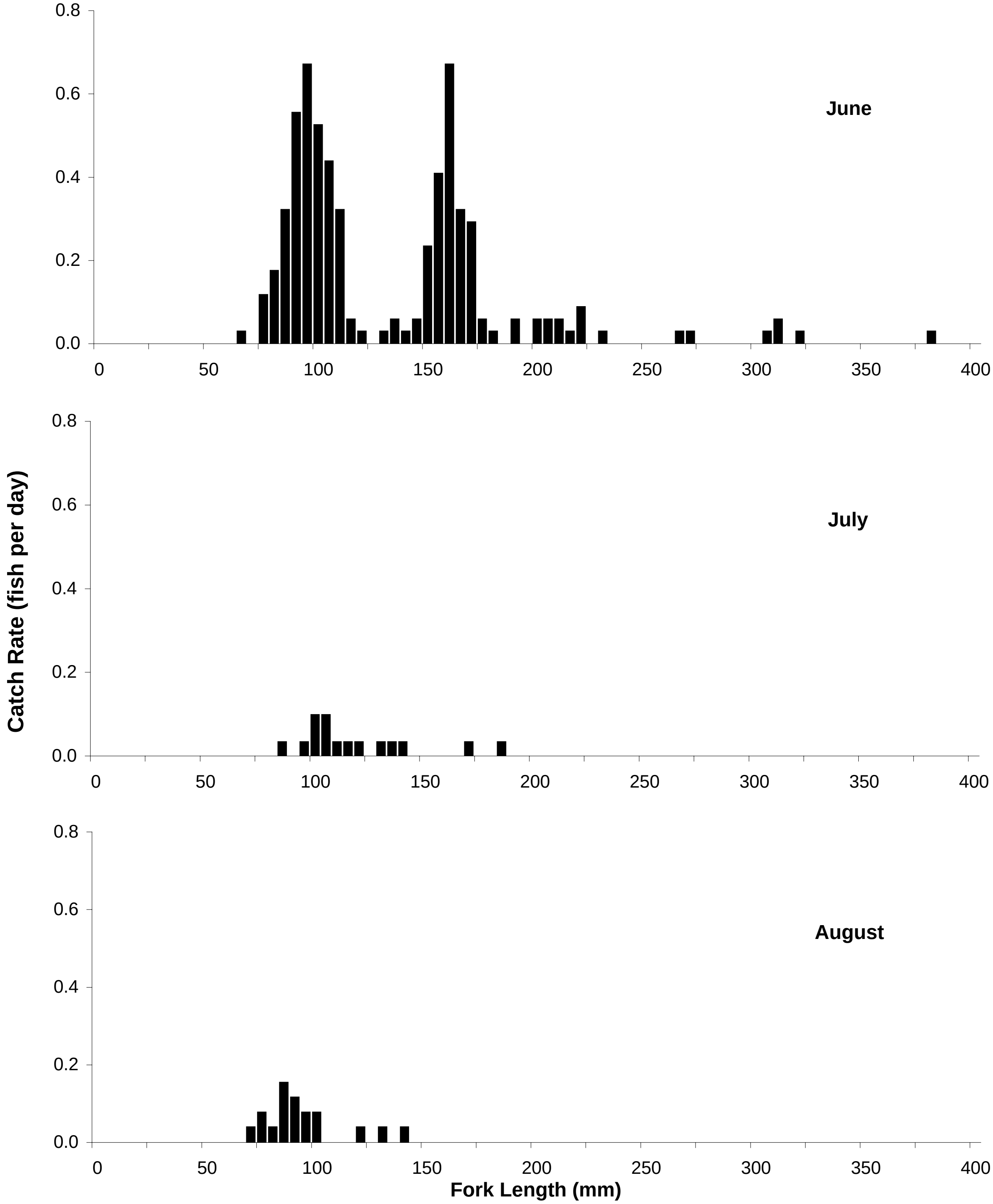


Figure 23. Length frequencies of Arctic cisco captured at lakes M9521 and M9625 during 2007.

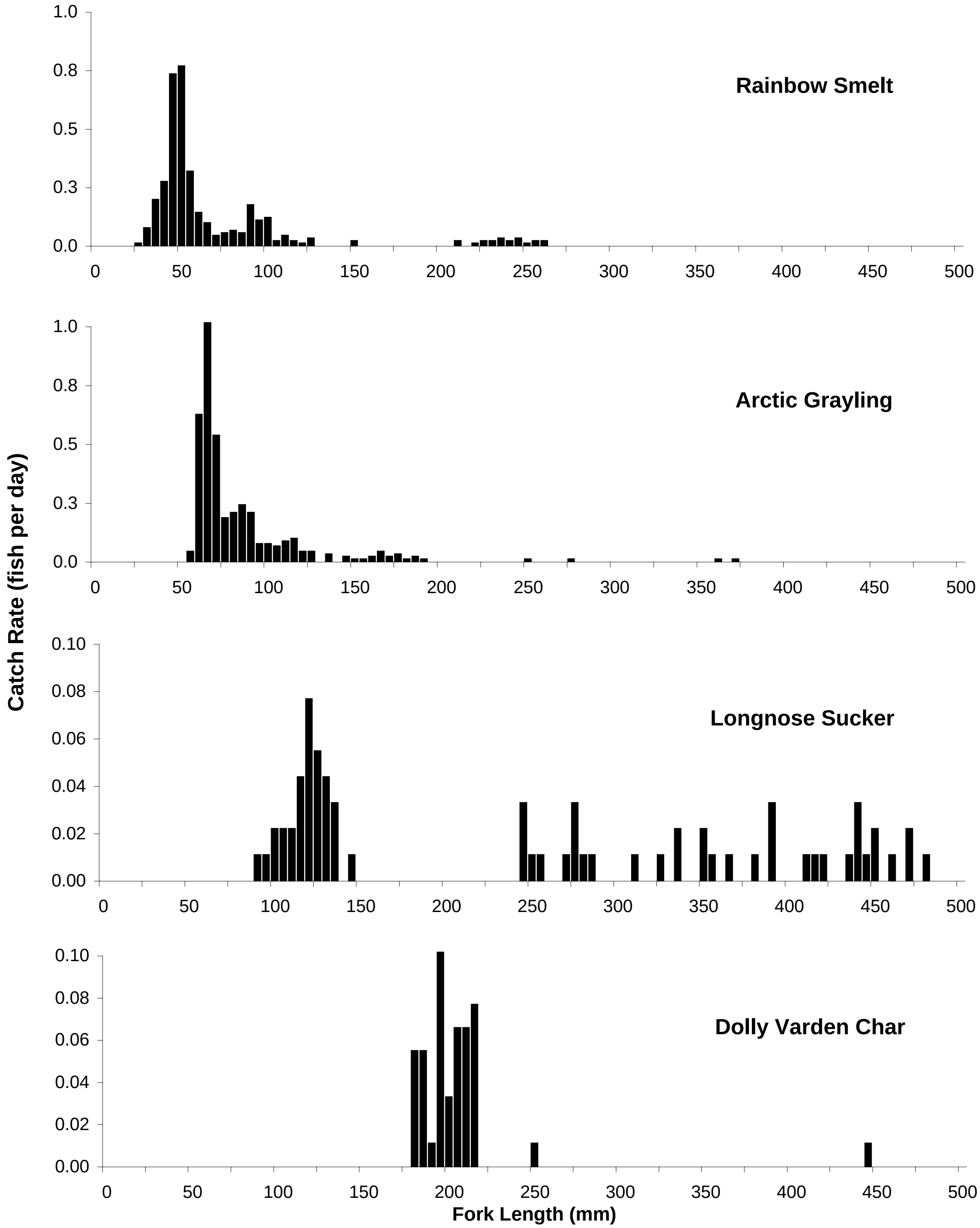


Figure 24. Length frequencies of rainbow smelt, Arctic grayling, longnose sucker, and Dolly Varden char captured at lakes M9521 and M9625 during 2007.