Abundance and Migratory Behaviour of Northern Pikeminnow (*Ptychocheilus Oregonensis*) in Cultus Lake, British Columbia and Implications for Predator Control

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ABUNDANCE AND MIGRATORY BEHAVIOUR OF NORTHERN PIKEMINNOW (*Ptychocheilus oregonensis*) IN CULTUS LAKE, BRITISH COLUMBIA AND IMPLICATIONS FOR PREDATOR CONTROL

by

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ABSTRACT

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The northern pikeminnow (*Ptychocheilus oregonensis*) has long been identified as a potential predator of sockeye salmon (*Oncorhynchus nerka*) in Cultus Lake, British Columbia. Declines in the abundance of sockeye salmon in Cultus Lake have stimulated interest in the use of predator control programs to increase juvenile salmon survival in the lake. We estimated the abundance of adult pikeminnow in Cultus Lake using mark-recapture methods. We applied >2 000 tags in 2004 and recovered tags in 2005 as part of a program that captured and removed about 4 500 pikeminnow from the lake. We estimated that there was 62-71 000 northern pikeminnow ≥200 mm in length in Cultus Lake in 2004. Analysis of recoveries indicated that northern pikeminnow have limited movements during the summer and considerable fidelity for feeding and spawning sites across years. A simple age-structured spreadsheet model was used to estimate the impact of the removal program on pikeminnow biomass, which suggested that continued removals at the 2005 level of effort for 6-8 years should reduce the biomass by 25-30%. However, the effect on salmon survival is uncertain at this stage of the study.

RÉSUMÉ

Bradford, M.J., Amos, J., Tovey, C.P., Hume, J.M.B., Grant, S. and Mossop, B. 2007. Abundance and migratory behaviour of northern pikeminnow (*Ptychocheilus oregonensis*) in Cultus Lake, British Columbia and implications for predator control. Can. Tech. Rep. Fish. Aquat. Sci. 2723: vii + 47 p.

La Sauvagesse du Nord (*Ptychocheilus oregonensis*) a longtemps été considérée comme un prédateur des populations de saumon rouge (*Oncorhynchus nerka*) du lac Cultus (Colombie-Britannique). Or, la baisse des effectifs de saumons rouges du lac Cultus a incité à mettre en place des actions de contrôle des prédateurs pour accroître le taux de survie des saumons juvéniles dans ce plan d'eau. Une campagne de recensement par marquage-recapture a été effectuée sur la population de Sauvagesse du Nord du lac Cultus en stade adulte. Plus de 2 000 étiquettes ont été posées en 2004 et récupérées en 2005 dans le cadre d'une campagne qui a consisté à prélever environ 4 500 Sauvagesses du Nord sur le lac en question. Nous avons pu établir qu'en 2004, le lac comptait entre 62 000 et 71 000 Sauvagesses du Nord ≥200 mm. L'analyse des individus récupérés a révélé que la Sauvagesse du Nord se déplaçait très peu durant l'été et restait fidèle à ses sites d'alimentation et de reproduction d'une année à l'autre. Un schéma de population selon les classes d'âge a été utilisé pour évaluer l'impact du programme de prélèvement sur la biomasse de l'espèce; on peut déduire des résultats obtenus qu'en maintenant le taux de prélèvement de 2005 sur une durée de 6 à 8 ans, la biomasse pourrait être réduite de 25 à 30%. Toutefois, l'effet d'une telle intervention sur le taux de survie du saumon rouge reste incertain.

INTRODUCTION

In 1925 two young Canadian scientists, R.E. Foerster and W.E. Ricker, embarked on an ambitious program to understand the factors limiting the production of sockeye salmon (*Oncorhynchus nerka*) in Cultus Lake, British Columbia, a small coastal lake located about 100 km east of Vancouver. They found that the losses of juvenile salmon in the lake amounted to over 95% of the potential egg deposition, and hypothesized that these losses were largely due to predation. Consequently they subjected the Cultus sockeye salmon population to two large-scale manipulations over the next 15 years: the use of a hatchery to isolate entire sockeye cohorts from predation; and the reduction of predation in the lake by the removal of as many predatory fish as possible (Foerster and Ricker 1938).

Although the hatchery efforts were not considered worthwhile and were terminated after a few years, the predator control program was conducted between 1932 and 1942, during which time nearly 22 000 northern pikeminnow *(Ptychocheilus oregonensis)* and over 7 000 salmonid predators were removed from Cultus Lake. Returns of sockeye salmon from the early part of the experiment were strong enough for Foerster and Ricker (1938, 1941) to consider the approach a cost-effective means to increase salmon abundance. The freshwater survival rates of juvenile sockeye salmon declined during the last few years of the program, however, and it was ultimately discontinued in 1942 (Ward 1960). A small scale removal program conducted between 1990 and 1992 removed over 11 000 pikeminnow but its impact on sockeye salmon production is equivocal because of deficiencies in the assessment data.

Two noteworthy legacies resulted from the Cultus Lake experiment: first, northern pikeminnow gained a significant, but not always justified, reputation as a major predator of salmonid populations (Brown and Moyle 1981), and second, predator control became identified as a viable management action to increase the abundance of desirable fish species (Jeppson and Platts 1959; Meachem and Clark 1979; Beamesderfer 2000). This is especially evident in the large-scale attempt to reduce pikeminnow populations in the Columbia River to offset some of the impacts of hydroelectric development on salmon survival (Beamesderfer 2000).

In recent years the sockeye salmon population in Cultus Lake has declined in abundance to the point that it has been categorized as *Endangered* by the Committee on the Status of Wildlife in Canada (COSEWIC). During the period of Foerster and Ricker's experiment an average of >20 000 sockeye spawned in Cultus Lake each year. In recent years the average is 2-3 000 and in some years fewer than 100 adults have returned to the lake. While the initial cause of the decline is considered to be fishing mortality, the precipitous recent decline is likely the result of poor ocean conditions and premature mortality of spawners. Predation has been identified potentially as limiting productivity when sockeye abundance is low (COSEWIC 2003). Consequently, there is a rekindled interest in removing pikeminnow from Cultus Lake as a means to increase juvenile salmon survival and ultimately assist in the recovery of the sockeye salmon population.

Beamesderfer (2000) suggests that the success of a predator control program depends on three factors: (1) how significant the target species is as a predator on the prey species of interest, (2) if the rate of removal can significantly impact the size of the predator population, and (3) if there is public, institutional and legal acceptance of this type of activity. It is currently difficult to empirically estimate the significance of pikeminnow predation in Cultus Lake because the sockeye salmon population has diminished by over 90% relative to the 1930's, when salmon juveniles were frequently found in predator stomachs (Ricker 1941). Nonetheless it is probably safe to assume that pikeminnow still prey on salmon. Predator removal programs have a long and ongoing history at Cultus Lake, and have a reasonable level of acceptance, though the removal of gamefish, such as cutthroat trout (*O. clarki*) and Dolly Varden char (*Salvelinus malma*) that was practiced by Foerster and Ricker is unlikely to be considered favourably by the public.

In this report we address the second of Beamesderfer's (2000) criteria by estimating the size of the pikeminnow population and the impact of sustained removals on pikeminnow abundance. The first estimate of pikeminnow abundance in Cultus Lake was attempted by Foerster and Ricker (1938), who used both the number of fish they caught and the decline in gillnet catch per effort to derive an estimate of about 8 400 fish ≥200mm in length. This estimate was disputed by Ward (1960) as likely low. In 1969 Steigenberger (1972) used a limited-scale mark-recapture experiment and arrived at an estimate of about 20 000 fish. Another mark-recapture study in 1991 yielded an estimate of about 40 000 fish (Hall 1992).

We also tested the hypothesis that there is an aggregation response of pikeminnow at the lake outlet during the smolt migration as was suggested by Steigenberger (1972). Such behaviour has been observed for char and other species in salmon-producing systems (Meachem and Clark 1979) and has been shown for pikeminnow in riverine environments (Collis et al. 1995). Steigenberger (1972) suggested that there may be merit in focusing predator control activities on the aggregations during the period of smolt migration to maximize the benefit to the salmon run.

Finally, after estimating population size, we used a simple model to determine the likely impacts of a sustained removal on the Cultus Lake pikeminnow population.

STUDY AREA

Cultus Lake is a small (6.3 km^2) lake at 45 m elevation located at the edge of the Coast Mountains in southern British Columbia. It is drained at the north end by Sweltzer Creek, which flows 3 km north to the Vedder River. The latter flows into the Fraser River approximately 112 km from the ocean. The lake basin is steep sided with a mean depth of 31 m and a maximum depth of 42 m (Ricker 1952). Only 12% of the lake is considered to be littoral, based on a mean euphotic zone depth of 15 m (COSEWIC 2003). Extensive Eurasian milfoil (*Myriophyllum spicatum L.*) beds occur throughout the lake in suitable locations of 1 to 7.5 m in depth: in 2004 the total area of these beds was estimated to be 30 ha or about 68% of the available bottom <7.5 m in depth. The lake's limnology and biota are reviewed in more detail in COSEWIC (2003) with references therein. We divided the lake into 3 zones - South, North, and Outlet - the latter being the shallow area at the north end of the lake that leads to Sweltzer Creek (Fig. 1).

The 2005 sockeye salmon smolt run consisted of 98,904 fish counted through a fence located 300 m downstream of the lake outlet. The median date of passage was April 26, and the 5^{th} and 95^{th} percentiles were April 18 and May 10, 2005 (DFO unpublished data). Surface water temperatures in 2005 increased from 6° C in early April to 20° C in mid-summer.

METHODS

We conducted a whole-lake mark-recapture study to estimate the abundance and distribution of pikeminnow in Cultus Lake. Pikeminnow migrate from deep waters to the littoral zone in the spring where they feed and spawn over the summer months (Foerster and Ricker 1941). In the summer of 2004, we captured, tagged and released pikeminnow in the lake's littoral zone. We assumed that after mixing of tagged and untagged fish during the winter of 2004-2005, an biased population estimate could be derived from a second sample could be taken in the summer of 2005.

In 2004, tagging took place from May 17 to August 6. In the first few weeks, pikeminnow were angled in the north end of the lake using live bait. After that, the majority of fish were captured using three trapnets that were modified from a design by Beamish (1972). Two of the trapnets had cube-shaped 19 mm stretched mesh live boxes 2.4 m x 3.3 m x 3.7 m deep with a lead net stretched perpendicular from the shore to the live box. The third trapnet had a live box that was 3.1 m on each side and had a 25 x 7.5 m lead net. The trapnets were fished from Monday to Friday (to avoid weekend recreational boat traffic) and predominately set at three locations: Needle Point and Slide in the South Zone and Spring Bay in the North Zone (Fig. 1). On occasion the traps were moved to other sites, although milfoil and bottom topography limited the number of suitable sites where they could be deployed.

A smaller number of fish were caught using circular bottom traps (a smaller version of commercial black cod traps) baited with dried cat food. These traps were 1 m in diameter at the base and 0.6 m high, and were fished on the lake bottom at 4-15 m depth.

All traps were checked once per day and the catch was enumerated by species. Previously-tagged pikeminnow were released after the tag number was noted. Untagged pikeminnow ≥200mm fork length were tagged at the base of the dorsal fin with numbered orange Floy T-bar anchor tags with a 19 mm lead and a 44 mm total length. We chose 200 mm as the cut-off for tagging because Ricker (1941) noted that pikeminnow were primarily piscivorous at this size and larger. A left pectoral fin punch was also given as a secondary mark to assess tag loss. No anaesthetic was employed. Fork length was recorded (to the nearest mm) for all tagged fish and a subset was weighed (to the nearest gram). The first 200 fish tagged were held in an aerated live well in the boat to permit a visual assessment of immediate (<1 hr) tagging stress or mortality. None was observed, so subsequently all other fish were released immediately after tagging at their capture site.

In 2005, the focus changed to the capture and removal of pikeminnow and the recovery of the tags using trapnets, commercial cod and prawn traps and angling (a hoop net and long line were tested but found ineffective). Three trapnets were fished on weekdays from April 12 to July 15, largely at the sites used in 2004. Angling occurred daily and was distributed opportunistically throughout the lake.

All fish captured in 2005 were recorded by species. Pikeminnow were recorded by sex, fork length and tag presence and except for a few that were retained for an Outlet Zone study (see below), were killed following sampling. For angling, the number of rod-hours (number of fishing rods used times hours fished) and the catch by species and lake zone (Fig. 1) were recorded each day. Most of the angling consisted of trolling with artificial lures (imitation minnow crank baits).

A marking experiment was conducted in the Outlet Zone in April, 2005 to determine if there was an aggregation response of pikeminnow at the lake outlet during the sockeye smolt migration. In early April, 349 fish were captured by trapnets or angling, marked with one of three fin punches unique to their zone of capture, and released at their capture sites. Another group of 210 fish captured in the north and south zones of the lake on May 2-4 were marked with a unique fin punch and transported by boat and released in the Outlet Zone.

Three pikeminnow fishing derbies were conducted during our study. On June 19, 2004 and June 18, 2005 community-based derbies were conducted involving 100-200 anglers. All fish caught were enumerated and retained at a weigh-in station located near the lake outlet. The pikeminnow that were captured were measured for length and examined for tags. On May 8, 2005 a smaller-scale derby (about 50 anglers) was conducted in the Outlet Zone to assess pikeminnow abundance and to recover tags from this area.

ANALYSIS OF 2004 AND 2005 DATA

Catch rates for all traps were calculated as catch/trap/24h period. Angling catch rates were expressed as catch/rod•h.

The selectivity of the fishing gear was evaluated by calculating the proportion of fish tagged in 2004 that were recovered in either 2004 or 2005 in relation to their size at tagging. The data were grouped in 2 cm size classes and categorized as either caught by angling or all traps combined. We ignored any growth that may have occurred between tagging and recapture in 2004, but for fish captured in 2005 we subtracted 1 cm from their length to account for growth after tagging in 2004.

The annual growth of tagged fish was estimated as the difference in the size at tagging in 2004 to the size at capture in 2005. Because length was measured on live fish in 2004 and fish that had been dead some hours in 2005, we first estimated the shrinkage due to rigour mortis. Length was measured for 29 fish that were tagged in 2004, recaptured live for the outlet study in April and early May, 2005, then recaptured and killed 2-70 days later. The difference in length between the two capture events in early 2005 was calculated for each fish. This difference was uncorrelated with fish length ($R^2 = 0.05$, $P = 0.2$) or the time (days) that had elapsed between measurements ($R^2 = 0.02$, $P = 0.4$). The mean difference between live and dead lengths was 0.56 cm (SE 0.13). This amount was added to all 2005 length measurements made on dead fish to correct for shrinkage.

MOVEMENT MODEL

We estimated the movement of tagged individuals between the main sampling sites using a multistrata capture-recapture model (Williams et al. 2002) where the strata are fishing locations in the lake (Fig. 1). The advantage of using this model over an informal evaluation of counts of recovered tags is that it can account for both the different number of tags released at the various locations, and the different levels of recovery effort at those locations. Two analyses were conducted: for the recaptures that occurred within the 2004 trapping season, and for movements between tag application in 2004 and the removals in 2005.

The basic form of the model is:

$$(1) \qquad T_{ij} = N_i * S_i * p_j * \psi_{ij}$$

where T_{ij} is the predicted number of fish that were originally tagged in location i that were subsequently recovered in location j, N_i is the total number tagged at location i, S_i is the survival rate over the interval between tagging and recapture, p_j is the probability of capture of the gear at location j, and ψ_{ij} is the probability of an individual moving from location i to j between tagging and recapture. Note that in the case in which i=j (i.e., no movement) the probability of remaining at the same location is 1 minus the sum of the movement probabilities to the other locations: $\psi_{ii} = 1 - \Sigma\psi_{ij}$ for i≠j. However, if there are locations where fish move to that are not sampled ψ_{ii} will be overestimated. In this case estimates of p_j will be reduced, as this parameter will then account for both the capture efficiency of the gear and the probability of the fish not being in one of the recapture locations (Kendall 2004).

For the 2004 data, the strata for the model were the three locations (Needle Point, Slide, and Spring Bay) where the three trapnets were usually situated (Fig.1). For the 2005 analysis we included a fourth strata that consisted of sampling conducted on the North shore of the lake and at the outlet. Although fish were tagged here in early 2004, there was little sampling later in that year and few recaptures occurred. Sampling in this location was more extensive in 2005 as a result of our focus on the lake outlet. These strata accounted for over 90% of the total tag recoveries in both analyses.

In 2004, a number of fish were recaptured multiple times over the trapping season. To simplify the analysis we only used the last recapture of each fish, which occurred 1 to 73 days from the day of initial capture and tagging (median 14 d).

To reduce the number of parameters to be estimated and improve the estimates of the parameters of interest we used a single fixed value for S. For the 2004 tagging-2005 recapture analysis we used $S = 0.7$, the estimated annual survival rate obtained from catch curve analysis of the 1991-1992 age data (Fig. 2b). For the model that estimated in-season movement in 2004, we assumed a value for S of 0.95, as the interval between tagging and recovery was short.

In addition to fixing S we reduced the number of parameters to be estimated by assuming that ψ's were equal at each site. That is, we assumed that the probability of movement from the tag site to one of the other locations was the same for each of the other locations. The three main trapping sites were roughly equidistant in the lake (Fig. 1), which supports the use of a single parameter, however, we do not know whether fish would be more likely to travel alongshore or across the lake. Rather, we interpret the single ψ as the average probability of movement, thus ignoring any site-specific differences. Parameter estimates for the model were fit by program MARK, using maximum likelihood techniques (White and Burnham 1999).

POPULATION ESTIMATE

A two-sample Peterson population estimate was made using the tags released in 2004 and recovered in 2005. The standard formula (Ricker 1975) was used:

$$(2) \qquad \tilde{N} = MkC/R,$$

where $\tilde{N}$ is the population estimate at the time of marking, *Mk* is the number of marks or tags released, C is the number of fish in the second sample, and *R* is the number of tags in that sample. The standard error for $\tilde{N}$ was calculated using the normal approximation given by Ricker (1975, p. 78).

Obtaining an unbiased population estimate is contingent on satisfying the following assumptions (Williams et al. 2002) : (1) the population is closed, and is unaffected by immigration, emigration, mortality or recruitment; (2) tags are neither lost nor overlooked in the second sample; (3) the probability of capture of each individual is the same within each sampling period.

We addressed the closure issue by assuming that fish did not enter or leave the lake, an assumption that is likely not completely true. However, when mortality occurs between the samples, the Peterson estimate is valid since it is for the size of the population at the time the first sample was taken (i.e. 2004), under the assumption that mortality on tagged and untagged fish is the same.

We tagged fish that were ≥200 mm, and considered this to be our population of interest. To account for the recruitment of fish into the ≥200 mm population between 2004 and 2005, we only included unmarked fish ≥220 mm in 2005 in our population estimates. This assumes that 200 mm fish grew 2 cm over the year. This increase in the size threshold was based on our estimates of growth from the age data, and observed growth of tagged fish. Our results were insensitive to the exact growth increment used since relatively few fish (< 0.5 % of the total) were in the 20-22 cm size range.

We applied a secondary mark (pectoral fin punch) to all tagged fish in order to estimate the rate of tag loss, but no fish were recovered with a fin mark and no tag. This means that the tag loss rate was negligible, or that the fin punch may not have been recognized in an untagged fish.

The assumption of equal capture probability for pikeminnow was not satisfied for either sample period (see results below). The impact of unequal capture probability on $\tilde{N}$ was evaluated by calculating the population estimate using captures by different combinations of gear types. An additional bias that can affect population estimates can occur if tagged fish are not equally vulnerable to the capture gear because of their size (Ricker 1975, p. 92). To evaluate the significance of this bias we partitioned the fish tagged in 2004 into a small (< 30 cm) or large (≥ 30 cm) category. To allow for growth, the size categories in the 2005 sample were: >22 cm and <31 cm (small) and ≥ 31 cm (large). We assumed a 2 cm growth increment between 2004 and 2005 for smaller fish and a 1 cm increment for larger ones.

POPULATION MODEL

We used a simple deterministic age-structured population model (similar to that of Rieman and Beamesderfer 1990) to estimate the effects of a hypothetical removal program on the pikeminnow population. The model considered ages 5-15+ fish, and did not include sex-specific differences in size or age because those data were not available from the data we recovered from the 1990-1992 otolith age data. The annual change in the number of fish in the adult population was given by the standard equation:

$$N_{i+1,t+1} = N_{i,t}e^{-M+q_iF_t} \quad (3)$$

where N is the number at age i in year t, M is the mortality rate, F is the fishing mortality of a predator control program on fully vulnerable age classes, and q is the age-specific catchability that scales F according to the selectivity of the gear. M was set at 0.36 from catch curve analysis (see results below and Fig. 2b).

Recruitment to the adult population was derived from a Beverton-Holt recruitment function that calculated the number of age-5s in year $t+5$ from the age-6+ spawning biomass (S) in year t as:

$$N_{5,t+5} = \frac{aS_t}{1+\frac{a}{b}S_t} \quad (4)$$

where a is the "steepness" parameter describing the rate of recruitment at very small population sizes, and b the upper asymptotic recruitment level. Females were observed to be mature at age 6, and fecundity was a linear function of weight (Hall 1992), justifying the use of age 6+ biomass as an appropriate surrogate for reproductive output. Weight at age (sexes combined) was from Hall's (1992) study.

The stock-recruit model was parameterized by assuming that prior to predator control, the population was at equilibrium such that the average recruitment was balanced by mortality. An age 5 abundance of 18 000 individuals results in an adult population of about 60 000 fish, similar to our 2004 estimate for Cultus Lake (see result below). The resulting age 6+ spawning biomass is 14 000 kg. This became our pre-predator removal baseline population. No information is available on the degree of recruitment compensation (i.e., the degree of curvature or steepness in the Beverton-Holt relation between stock size and subsequent recruitment) in pikeminnow populations, so we used two values for a that resulted in weak (a = 2) and strong (a = 7) density-dependent mortality in the recruitment phase. For each value of a, a corresponding value of b that resulted in 18 000 recruits being produced by a spawning biomass of 14 000 kg was found by rearranging equation (4) and solving for b. In the Columbia River, Knutsen and Ward (1999) found no evidence of changes in adult growth, mortality or reproductive parameters in response to 5 years of removals, so we did not consider compensation in those life stages in the model.

We approximated the overall selectivity of fishing gear that might be applied in a pikeminnow removal program using the data from the 1991-1992 catch curve (Fig. 2b) and our tag recovery information (see results below). We assumed fish age 8 and older were fully vulnerable (q = 1), and used the following values for q for the younger ages (age 5: 0.1, age 6: 0.4, age 7: 0.8). These values are slightly different from those that might be derived from Hall's (1992) data (Fig. 2b) because Hall's samples were made from gillnet and purse seine collections, and gillnets are not likely to be used in future removal programs.

The model was used to simulate the effects of a removal experiment on adult pikeminnow abundance; the intensity of the removal effort and the stock-recruit parameters were varied in different model runs. The predator control program was assumed to have a constant F for 8 years (two sockeye salmon generations) before being terminated.

We do not have current information on the size or age-related daily consumption of salmon by pikeminnow for Cultus Lake. For the Columbia River, Beamesderfer et al. (1996) note that estimated daily consumption of juvenile salmon increased exponentially with predator length, with an exponent of 3.38. Since weight is exponentially related to length with an exponent of about 3, this implies that daily consumption is approximately proportional to fish weight. Therefore, we used age 5+ biomass as a proxy for predation potential for the Cultus Lake population when evaluating the impacts of control programs on salmon survival.

RESULTS

ANALYSIS OF PREVIOUSLY COLLECTED DATA

We reanalyzed over 1 000 otoliths extracted from pikeminnow that were collected from purse seine and traps (1991, N = 410) and gillnets (1992, N = 611; Hall 1992) during past sampling. The otoliths were sectioned and burnt before reading by the ageing laboratory at the Pacific Biological Station, Nanaimo, BC. The samples were biased towards females (73% in 1991, 56% in 1992), but the corresponding average lengths and standard errors by age tabularized in Hall were for both sexes combined (1992). We were unsuccessful in recovering the sex-specific length or age data. The 1991-1992 age data showed that Cultus Lake pikeminnow are relatively long lived (Fig. 2a), with a maximum age of 30 being recorded (Hall 1992).

We used the mean size-at-age data from Hall (1992) to estimate the parameters of the von Bertalanffy growth model (Fig. 2a), but note that this relation will be somewhat inaccurate because both sexes are combined in the data, and that samples taken from highly size-selective fishing gear will often sample the fastest growing fish from partially recruited age classes (Taylor et al. 2005). We combined the numbers at age for the two years of samples to derive a catch curve from which total annual mortality for the older age classes was estimated as the slope of the regression of $ln(N_i)$ on age (Ricker 1975; Fig. 2b), where N_i is the number of fish of age i in the sample. As the number of fish available differed between years, weights were used to ensure that each year had equal influence on the regression. The estimated instantaneous annual mortality rate, M, was 0.36, corresponding to an annual survival rate for age-6 and older fish of 0.70 since survival is equal to the exponent of the instantaneous mortality rate multiplied by -1 (Fig. 2b).

TAG APPLICATION

Of the 2 025 pikeminnow tagged in 2004, 78% were at the three main trapnet sites. Subsequently, 16 were removed in the 2004 pikeminnow derby, two were returned by anglers during 2004, and one was recovered at the salmon counting facility at the outlet. Consequently the total number of tags considered available for the population estimates was 2 006. The details of the 2004 tag application by date and gear type are in Appendix 1.

FISH CAPTURE RATES

The pikeminnow capture rate in the three trapnets in 2005 was highly variable (Fig. 3a), averaging 16 fish/trap/24 h over all nights and 23 fish/trap/24 h if the nights of zero capture were excluded. No strong seasonal trend was evident, although catches appeared higher from mid-June to early July. The prawn and cod traps were only used in April and May, and yielded catches of <1 pikeminnow in each trap per night.

The pikeminnow capture rate by angling increased with time and was both higher and more variable in the summer months (Fig. 3b). The average capture rate was 1.1 fish/rod-h before June 15, and increased to 2.9 fish/rod-h from June 15 onwards.

Of the 4974 northern pikeminnow that were captured in 2005, only 57 were smaller than 200 mm. The catch of pikeminnow (total number and number of marked individuals) in 2005 by date and gear type is provided in Appendix 2. The catch by sex and date for all gear types combined in 2005 is provided in Appendix 3. Effort and catch per unit of effort by date for each gear type in 2005 are tabularized in Appendix 4.

GEAR SELECTIVITY AND THE CHARACTERISTICS OF CAPTURED FISH

The proportion of tags recovered in both 2004 and 2005 increased with fish size for both major gear types (Fig 4). We considered pikeminnow 28 cm long (approximately age 8) to be fully vulnerable to the traps, although there appeared to be a decline in vulnerability at the largest sizes. Selectivity increased monotonically with size for angling; however, some of the very smallest fish that we tagged were also caught by rod and reel. There was less difference in selectivity among size classes for fish caught by angling, however, the 34 cm size class, which appears anomalously high, affected the scaling of the selectivities of the other size classes in Fig. 4.

The size distribution of all fish (tagged and untagged) captured by angling or by the various traps in 2005 was unimodal with a peak at about 30 cm fork lengths (Fig. 5). The traps tended to catch a higher proportion of fish in the 24-30 cm range, while the anglers tended to catch proportionately more very small or very large fish. These differences are consistent with the different vulnerability estimates (Fig. 4).

Both gear types caught more females than males in 2005, although the difference was most prevalent for angled catches (Angling: 70% female, traps: 54% female). The mean size of females (30.8 cm) was slightly larger than for males (27.7 cm). The largest male was 40.5 cm fork length; we captured a total of 59 females that exceeded this length, with the maximum being 52.1 cm. Comparing Figures 2a and 4 suggests that most of the fish we captured during our study were 6-12 years old.

The growth of fish tagged in 2004 and recovered in 2005 was highly variable (Fig. 6). Some of this variability was likely the result of measurement error from handling live fish in 2004, and dead ones in 2005. The average growth increment was 0.9 cm. We used a general linear model fitted by least squares and found that the growth increment was negatively related to length at tagging ($F_{1,336}$ = 38, P < .0001), was greater for females compared to males ($F_{1,336}$ = 7.7, P = 0.002, the estimated difference was 0.31 cm) and was weakly related to the number of days between tagging and capture ($F_{1,336}$ = 3.8, P = 0.052). Sex was not determined for 71 individuals: these are plotted in Fig. 6, but were not included in the regression analysis. The annual growth increments we observed from the tag recoveries were on average smaller than those calculated from the von Bertalanffy growth model fit to the 1991-92 size-at-age data (Fig. 2a).

OUTLET STUDY

In April 2005, 349 pikeminnow caught in trapnets at Needle Point, Slide, and Spring Bay were released with secondary marks to determine if there was a directed migration to the Outlet Zone during the sockeye smolt migration. During the smolt migration (April 8 to May 11), none of the 365 pikeminnow caught by angling and trapnets in the Outlet Zone had a secondary mark; however, nine of the marked pikeminnow were recovered in the southern zone during this time. An additional 17 secondary-marked fish were recovered in the north and south zones after May 11.

On May 2-6, 2005, we captured and fin clipped a further 213 fish in the trapnets at Needle Point, Slide, and Spring Bay and transported them for release at the outlet zone. None were subsequently recaptured at the outlet, however, 38 were recaptured in the trapnets (30 at the Needle Point site) later in 2005, of which 20 had also been captured in 2004 and given a numbered Floy tag. We found that 19 were caught (after the initial capture and transfer to the outlet) at the same site in 2005 where they were tagged in 2004. Nine were recaptured at the trapnet sites within 1-5 days of being released at the outlet. The recovery of these fish suggests that they had a strong affinity to their tagging sites, and left the outlet area soon after they were released there.

Finally, we evaluated whether there was an aggregation of northern pikeminnow at the lake outlet by comparing the catch rate of angling at the outlet, with that of a rest of the lake. In the May 8, 2005 fishing derby, about 50 anglers fished for 5.5 hours at the outlet and caught 50 pikeminnow - a capture rate of 0.18 fish/rod-hr. This is at the low end of the range for angling throughout the lake at this time of the year (Fig. 3b), suggesting there was not a concentration of fish in the outlet area at that time.

MOVEMENTS WITHIN THE LAKE

A total of 327 fish tagged in 2004 were recaptured later that year (16% of all tagged fish), and 114 were captured more than once. One individual was recaptured 11 times, all at the same site. Of the tags that were recovered at the three main trapnetting sites, over 90% were at the site of the original tagging (Table 1). Recaptures at the other sites, (1.0 to 1.8 km away), ranged from 1 to 21% of those that were recovered (Fig.7). Estimates of ψ, the movement parameter, were low, as relatively few fish were recovered at strata different from where they were originally captured and tagged (Table 2). Standard errors for the estimates were reasonably precise in the reduced parameter form of the model that we used.

A similar pattern was observed for the tag recoveries in 2005. Over 80% of tags were recovered in 2005 in the same strata (location) in which they were tagged in 2004 while recaptures at other sites (1.0 to 3.3 km away) ranged from 0 to 20% (Table 1, Fig. 7). The estimates of capture probability in 2005 generally were higher than those for the 2004 data reflecting the greater number of tags encountered in 2005 (Table 2). In 2005 relatively few tags were recovered from North shore strata. This stratum differed from the others in that it was not a stratum where the primary mode of capture and recapture was a single trapnet at a fixed location. Rather, most fish were captured and tagged in 2004 by angling, whereas the 2005 recoveries were made using a mixture of trapnet and angling at a number of sites within the area.

POPULATION ESTIMATES

Our original study design was to tag fish in 2004 and use the recoveries that were made during the 2005 removal program to estimate abundance using a simple Peterson estimator. We thought that the well-documented occupation of deeper habitats during the winter months (Foerster and Ricker 1941) would result in the mixing of tagged fish throughout the lake so that the probability of capture of tagged and untagged fish in 2005 would be similar, and the resulting population estimate would be unbiased. However, the analysis of fish movements and the rates of tag recovery by gear type and lake zone (Table 3) clearly show that those fish that were tagged at the main capture sites were more likely to be recovered at the same site the following year. This violates the requirement of equal capture probability among individuals in at least one of the two samples because most of the tags that were applied and recovered were from the same three trap sites. High rates of recovery of tags bias population estimates downwards.

To circumvent this problem we investigated the use of tag recoveries from the angled sample, under the assumption that this mode of capture might have a more equal probability of capture among individuals than was the case with the traps. The location of angled fish captured by our crews was recorded as being in one of the three broad zones (South, North, and Outlet), and although the effort was distributed around the lake, its distribution was not controlled and was likely a function of catch rate and not necessarily abundance. For detailed angling locations see Appendix 2, Table 2 and Fig. 1. The distribution of catch and effort was uncontrolled during the fishing derby (included in Appendix 2, Table 2 as 'Other' location). Despite these shortcomings the proportion of fish that had tags in the 2005 catches made by our crews was similar among the three zones and was also similar to the proportion of tags in the derby catch (Table 3; G-test for heterogeneity, $\chi 2\ 3 = 1.7$, $P = 0.63$). This result provides some evidence that the angling did not target a subset of the population or an area of the lake for which tags were in greater abundance, as was the case for the trapnet catches.

Population estimates for fish ≥20 cm using various combinations of the tag and recovery data are shown in Table 4. The estimate that used all of the data was low because of the relatively high rate of recovery of tags at the trap sites. Estimates based on the recoveries of all tags by angling only, or based on tags applied using one type of capture gear and recovered by another were similar, and ranged between 62 000 and 71 000 individuals (Table 4). We feel the best estimate is the one based on the tags applied by all gear types, as about one-third of the tags were applied to angled fish captured throughout the lake, and uses all the tags recovered by angling for the second sample. This estimate (62 217 ± 8 488) uses the largest number of tags and is the most precise of those that use subsets of the data to minimize the previously mentioned biases.

When we stratified the samples by fish size, the combined estimate was less than 5% greater than the unstratified estimate, indicating that size bias created by different vulnerabilities to gear did not have a large impact on the total population estimate (Table 4). The estimate was less precise because of the smaller number of tags in each stratum.

MODEL RESULTS

Beginning with a model population of about 60 000 age 5+ fish, when we simulated a predator control program with F = 0.2, the catch in the first year is predicted to be about 5 300 fish - slightly more than our actual catch in 2005. This corresponds to an overall exploitation rate on the adult population of 7%; this is much less than F (the exploitation rate on the fully exploited age classes) because the abundant younger age classes are not fully vulnerable to the gear. After 8 years with F = 0.2 catches declined to about 4 000 fish and the biomass of age 5+ fish was reduced by 27 or 31%, depending on whether strong or weak compensation was assumed for the stock-recruit relation (Fig 8). In this simulation the age 10 and older abundance declined by 55%. Doubling fishing mortality resulted in a predicted initial catch of 10 000 fish and biomass was reduced to 42 and 49% of the starting levels after 8 years. Compensation also had a strong effect on the recovery of the population once predator control was terminated; with strong compensation the population is expected to largely recover in 10 years.

We also determined the level of continued fishing mortality that would prevent the population from increasing once it was reduced by the predator control program. This depended on the stock-recruit relation: F = 0.05 was required in the case of weak compensation, and F = 0.1 was needed if strong compensation was assumed. These corresponded to yearly catches of about 1 000 and 2 000 fish, respectively.

DISCUSSION

The most surprising result of our field study was the degree of fidelity that northern pikeminnow showed to summer feeding and spawning sites within Cultus Lake, both within and across years. Although our sampling sites were only a few kilometers apart, pikeminnow were much more likely to remain in the same location than move and be captured by a different trap. Our transplantation study showed that pikeminnow returned to their home sites if moved, and that they could traverse the length of the lake in a few days to reach their home areas. Fidelity to feeding and spawning sites has been observed in a number of other lake rearing fish species; some examples include yellow perch (Aalto and Newsome 1990), smallmouth bass (Forney 1961) and pike (Miller et al. 2001). Displacement studies similar to ours for smallmouth bass have shown that fish will move back to the area of capture (Pflug and Pauley 1983), sometimes within a few days after release (Ridgway and Shuter 1996).

Fidelity to feeding and spawning sites has not been documented for northern pikeminnow. For the riverine Colorado pikeminnow, *P. lucius,* repeated long annual migrations between rearing and spawning sites have been observed, suggesting fidelity to both home range and spawning habitats (Tyus 1985; Irvine and Modde 2000). Spawning aggregations, and migrations to those aggregations, have been described for northern pikeminnow (Patten and Rodman 1969; Martinelli and Shively 1997). Aggregations in response to hatchery releases of salmonids have also been observed in the Columbia River (Collis et al. 1995).

Northern pikeminnow in Cultus Lake are found offshore during the winter months, and move to shallow areas between May and September (Foerster and Ricker 1941). For the Needle Point trapnet site the littoral zone is very small, and the deep waters of the lake are within 200 m of the shore. It is possible that pikeminnow might have correspondingly small winter habitat ranges in the region just offshore from the trapnet site, which would tend to result in a low rate of movement from this region to other parts of the lake. The bathymetry is less extreme for the Slide and especially the Spring Bay trapnet site, such that deeper water is further offshore at these sites. The larger distances required to move to offshore sites in the winter may be the cause for the higher likelihood of fish at these sites to be captured at other trapnet sites the next year, resulting in the larger ψ estimates for Slide and Spring Bay movements. A telemetry study would be a useful way to determine the actual ranges of pikeminnow during both the shallow and deep water periods of habitat use (e.g., Ridgway and Shuter 1996).

The finding of restricted movements in summer and strong site fidelity between years presents particular challenges for estimating abundance. Foerster and Ricker (1938) estimated there were 8 400 pikeminnow in Cultus Lake in 1936 based on their gillnet catches and the consequent decline in catch-per-effort between 1935 and 1936. This may be a considerable underestimate. Although details about the deployment of their nets are not provided in the original reports, if the same or nearby sites were used in each year the local aggregations of pikeminnow may have become depleted as a result of their site fidelity. The localized depletion effect would tend to both underestimate the total population and overestimate the impact that the removal program was having on the population, a possibility later acknowledged by Foerster and Ricker (1953).

Site fidelity will also affect mark-recapture estimates of population size as the critical assumption of equal catchability of tagged and untagged fish (often achieved by mixing in unstructured populations) will be violated. In the fall of 1968 Steigenberger (1972) tagged and released 103 pikeminnow from the northwest shore of Cultus Lake. 16 tags were recovered a few months later, and a population estimate of about 20 000 fish $\geq$ 20 cm was derived. However, 13 of the 16 recoveries were made within 2 km of the release site, where most of the fishing effort also occurred. Our finding of site fidelity suggests that Steigenberger's estimate is probably significantly low, as it was unlikely that the tagged fish distributed themselves throughout the population. His estimate is only applicable to the population in the north end of the lake, although the boundaries of the population that he estimated are unclear. A more extensive tagging study was conducted by Hall (1992) that resulted in an estimate of about 40 000 pikeminnow in Cultus Lake, but details on the spatial distribution of tagging and recoveries were not provided.

We attempted to reduce the bias in our population estimates by using only fish captured by angling as our second sample, under the assumption that the widespread distribution of angling would result in a more even probability of capture of tagged and untagged fish throughout the lake. We did find that the incidence of tagged fish was similar in different components of the angled sample, which supports our assumption of equal capture probability. We cannot rule out the possibility that angling targets a different component of the population than the trapnets, however, which would cause the estimates to be biased upwards if the fish tagged by the trapnets were less likely to be captured by angling than unmarked fish.

Nonetheless, the similarity in the population estimates generated by using three methods: (1) using all tags released and only the tags recovered by angling; (2) using all tags released by one gear and captured by another; and (3) by the stratification of the recoveries by size suggests that a 2004 abundance of 60-70 000 fish ≥20 cm in length is reasonably robust. This estimate is larger than those obtained in earlier work, but as noted earlier, those studies may have resulted in substantial underestimation of the population. With a total population of 60-70 000 pikeminnow, the average density over the whole lake is approximately 100 fish/ha, considerably higher than estimated for Columbia River reservoirs (15 fish/ha, Beamesderfer et al. 1996).

We did not find evidence for a directed migration of northern pikeminnow to the outlet of the lake during the period of smolt migration. Aggregations of predators at lake outlets and in migratory corridors have been observed in other systems presenting an opportunity to potentially increase salmon production through a directed predator control program during the smolt run (Meacham and Clark 1979). Steigenberger (1972) concluded that there was a significant aggregation at the outlet at Cultus Lake, but his conclusion was based on his observation that tagged fish that were captured and tagged at the outlet and moved to various regions of the lake quickly returned to the outlet area. Our results suggest that this is not necessarily aggregation behaviour, but rather a return to home ranges after displacement. Pikeminnow are certainly present at the outlet, but this might be just one of the many local aggregations that exist within the lake. Directed migrations to the outlet, however, may have occurred in the past when smolt runs were 1-2 orders of magnitude larger than in recent years.

MANAGEMENT IMPLICATIONS

The number of sockeye smolts leaving Cultus Lake each spring from 2001-2005 has ranged from 6 000 to 110 000 fish (9 to 175 smolts /ha); fry abundance during the preceding summer have been estimated by hydroacoustic methods to be 4-5 times these values (JMB Hume unpublished data). Our estimates of pikeminnow abundance suggest that in two of the four most recent years the adult pikeminnow population is larger than the juvenile sockeye population. Thus a very low rate of per-capita consumption of salmon by pikeminnow on an annual basis could have significant consequences for salmon survival. This is a very different situation than in the Columbia River where the juvenile salmon population has been estimated to be 100 times larger than the pikeminnow populations, and salmon are migrating through the rivers and reservoirs over only a portion of the year (Beamesderfer et al. 1996). Besides the 4 974 pikeminnow removed in 2005 we did catch other piscivorous fish during our sampling. The low catch rates (we caught a total of 65 resident coho salmon (*O. kisutch*), cutthroat trout (*O clarki*), and rainbow trout (*O. mykiss*), in 2005) suggest that these species are not nearly as abundant as pikeminnow. Sculpins (*Cottus spp.*) are likely a common and significant predator of sockeye fry and alevins that we did not sample. The catch by date for each of the bycatch species is provided in Appendix 5.

The ultimate impact of a pikeminnow removal program on salmon survival depends not only on the extent of the removals, but on the significance of the targeted species among all the potential predators of salmon in the lake. The limited seasonal and spatial overlap between pikeminnow and sockeye salmon, and the low rate of consumption during the winter when they do overlap spatially have lead others to suggest that pikeminnow may not be the most important predator of sockeye salmon (Ricker and Foerster 1941; Vigg and Burley 1991; Beauchamp et al. 1995). However, in the current context of a very depleted sockeye population the numerical superiority of the pikeminnow does suggest that they have at least the potential to make a substantial contribution to sockeye mortality.

The removals we achieved in 2005 (4 974 fish), and the predicted impact on the pikeminnow population in Cultus Lake are similar to the system-wide predator control program in the Columbia River (Friesen and Ward 1999). Friesen and Ward (1999) estimated that a sustained exploitation rate of 10-15% could lead to a 10-30% decrease in pikeminnow predation on salmon, largely through the cumulative effects of exploitation in reducing the number of larger older fish in the population. Estimating the benefits of predator control on salmon survival in Cultus Lake requires a better understanding of the actual predation rates for pikeminnow, and should consider the potential impacts on the Cultus Lake food web as a result of the removal of the top predator. Fishing effort could be increased in Cultus Lake to affect a larger impact, although there are a limited number of sites where trapnets can be deployed because of milfoil presence, bathymetric conditions, and public acceptance. Our finding of fidelity to specific inshore feeding and spawning sites means that the abundance of pikeminnow near the useable trapnet sites may become depleted once a multi-year removal effort is initiated. Purse-seining has been used to catch pikeminnow in Cultus Lake in the past, and this method would make it possible in future removal programs to access more areas than with the trapnets.

The predictions on the impact of predator control are based on our simple deterministic model that assumes no variability in survival or productivity. If the experiment was executed as suggested, the results could be quite different than predicted by the model if there was a concurrent sequence of anomalous recruitment events, or unusual survival conditions. Mass spawning fish such as pikeminnow often have highly variable recruitment rates (Rieman and Beamesderfer 1990), and the populations can be supported by the occurrence of occasional very strong year classes. Strong recruitment events could easily swamp modest predator control efforts such as the current Cultus Lake program.

RECOMMENDATIONS FOR FUTURE STUDIES

Since this project was completed, a large-scale pikeminnow removal project using a modified commercial fishing vessel was initiated in 2006 and is expected to continue through 2007 and onwards. To evaluate the efficacy of the expanded activities and their impact on the survival of sockeye salmon a number of studies will be required:

- Continued assessment of wild smolt/spawner ratios based on counts of spawners in the lake and wild smolts emigrating from it to compare the survival of broods possibly affected by pikeminnow control to the wild smolts/spawner time series for this population.
- Another population estimate for pikeminnow should be initiated in 2008 or 2009 to evaluate the cumulative effects of the intensive removal program. The results of the current study and those of the acoustic tagging program that started in 2006 should be used to ensure that the tagging program meets the assumptions of the mark-recapture methodology as best as possible. However, some consideration may have to be given to using as similar protocol as was used in 2004-2005 to ensure the results are comparable in order to evaluate the change in population estimates.
- Consideration should be given to sampling for age and growth of the population if abundance has been significantly reduced from 2004 levels. A pikeminnow population response in terms of increased growth or recruitment could lead to greater productivity, potentially negating any initial successes of the removal program.

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Table 1. Data used in the estimation of movement parameters for tagged northern pikeminnow for the four main trapnet sampling sites. Upper section is for fish tagged and recovered in 2004; lower section is for tags applied in 2004 and recovered in 2005. No recovery data are listed for the North End in 2004 because there was little sampling effort there after May and few recoveries were made. The number of tags applied by site is slightly lower in the lower section as some tags were removed from the lake in 2004, largely by angling.

		Tags Recovered in 2004			
Site	Tags Applied	Needle Point	Spring Bay	Slide	North End
Needle Point	794	151	2	2	-
Spring Bay	398	10	70	10	-
Slide	391	1	1	43	-
		Tags Recovered in 2005			
Needle Point	791	197	2	6	1
Spring Bay	394	13	68	12	0
Slide	382	8	9	26	1
North End	303	1	0	1	15

Table 2. Parameter estimates (SE in parentheses) for multistrata movement model for northern pikeminnow in Cultus Lake, based on the data in Table 1 and estimated by program MARK. Survival (*S*) was fixed in the model; *P* is the capture probability for each site, and ψ is the probability of an individual moving from the tagging site listed to one of the other sampling sites. The first column of estimates is for fish tagged and recaptured in 2004, the second column is for fish tagged in 2004 and recaptured in 2005.

Parameter	Site	2004	2004-05
S	All	0.95	0.7
P	Needle Point	0.20 (0.02)	0.38 (0.03)
	Spring Bay	0.27 (0.04)	0.38 (0.06)
	Slide	0.13 (0.02)	0.18 (0.03)
	North End	-	0.06 (0.02)
ψ	Needle Point	0.013 (0.007)	0.02 (0.01)
	Spring Bay	0.16 (0.04)	0.13 (0.02)
	Slide	0.012 (0.008)	0.10 (0.03)
	North End	-	0.01 (0.007)

Table 3. Distribution by gear and location of: the number of tags applied in 2004, the number of fish caught in 2005, the number of tagged fish recovered in 2005 and the proportion of fish caught in 2005 that were tagged. The last column indicates the fish that were captured by angling for which the location in Cultus Lake was unknown. Most of these fish were captured by volunteer anglers during the pikeminnow derby.

	Outlet		North		South		Unspecified
	Angled	Traps	Angled	Traps	Angled	Traps	Angled
Tags applied (*Mk*)	-	-	363	429	133	1081	-
Total caught (*C*)	79	507	727	503	184	1975	590
Tags recovered (*R*)	1	7	25	80	7	276	17
% tags in catch	1.3%	1.4%	3.4%	15.9%	3.8%	14.0%	2.9%

Table 4. Peterson population estimates for northern pikeminnow in Cultus Lake for 2004, using different segments of the data to generate the estimates. The tags that were applied in 2004 (*Mk*) are categorized by the gear used for capture, or their size at capture. For the 2005 recapture data the data source, the total number of fish captured (*C*) and the number of tags (*R*) in the sample is indicated. The large size category was incremented by 1 cm and the small by 2 cm to account for growth between 2004 and 2005.

Tags applied		Recaptures			Estimate	
Source	*Mk*	Source	*C*	*R*	$\tilde{N}$	SE
All	2006	All	4565	413	22 135	1036
All	2006	Angled	1580	50	62 217	8488
Traps	1510	Angled	1960	33	70 669	15 014
Angled	496	Traps	2985	20	70 662	11 748
All <30cm	1290	Angled <31cm	861	23	46 368	10 702
All ≥30cm	715	Angled ≥31cm	719	27	18 411	7073
Sizes combined					64 780	12 828

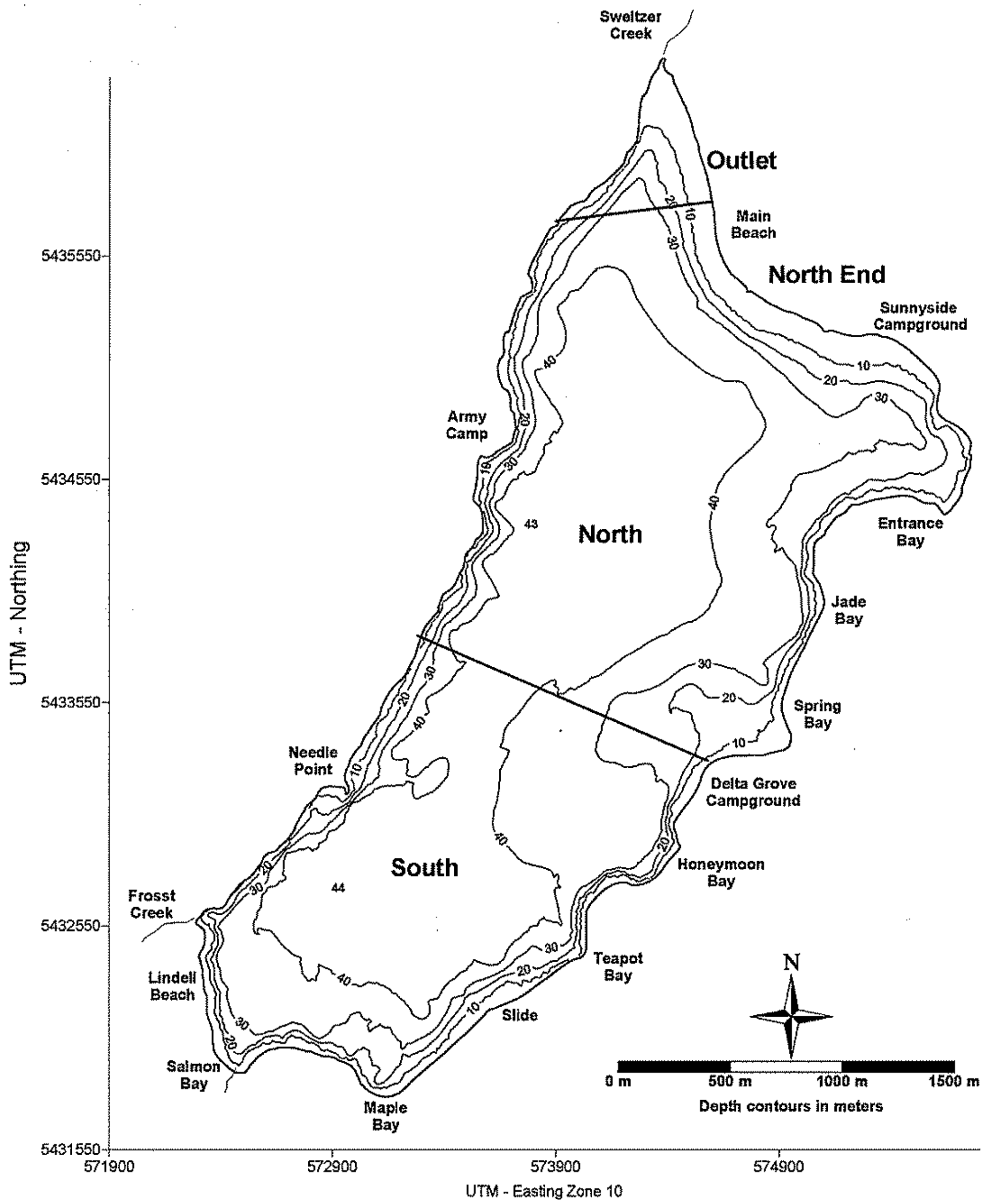

Figure 1. Map of Cultus Lake showing the three lake zones (Outlet, North, and South), the four main trapnet sites (North End, Spring Bay, Slide and Needle Point) as well as other locations.

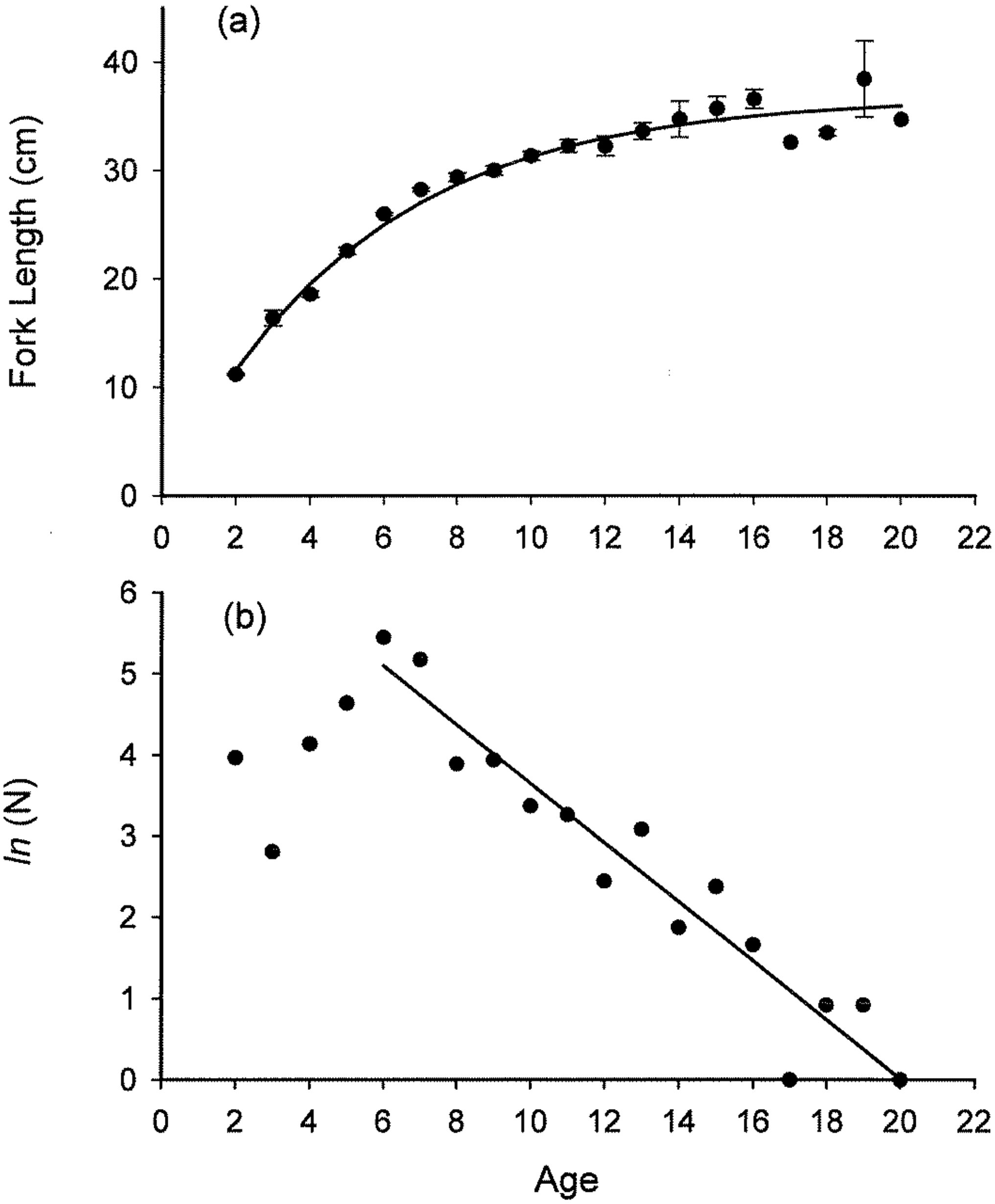

Figure 2. a) Size and age and fitted von Bertalanffy growth curve for Cultus Lake pikeminnow. Data are for both sexes combined although most fish were female. b) Catch curve for pikeminnow caught in gillnets and purse seine. Slope of the regression line (0.36) is an estimate of total annual mortality for age 6+ fish. Data from Hall (1992)

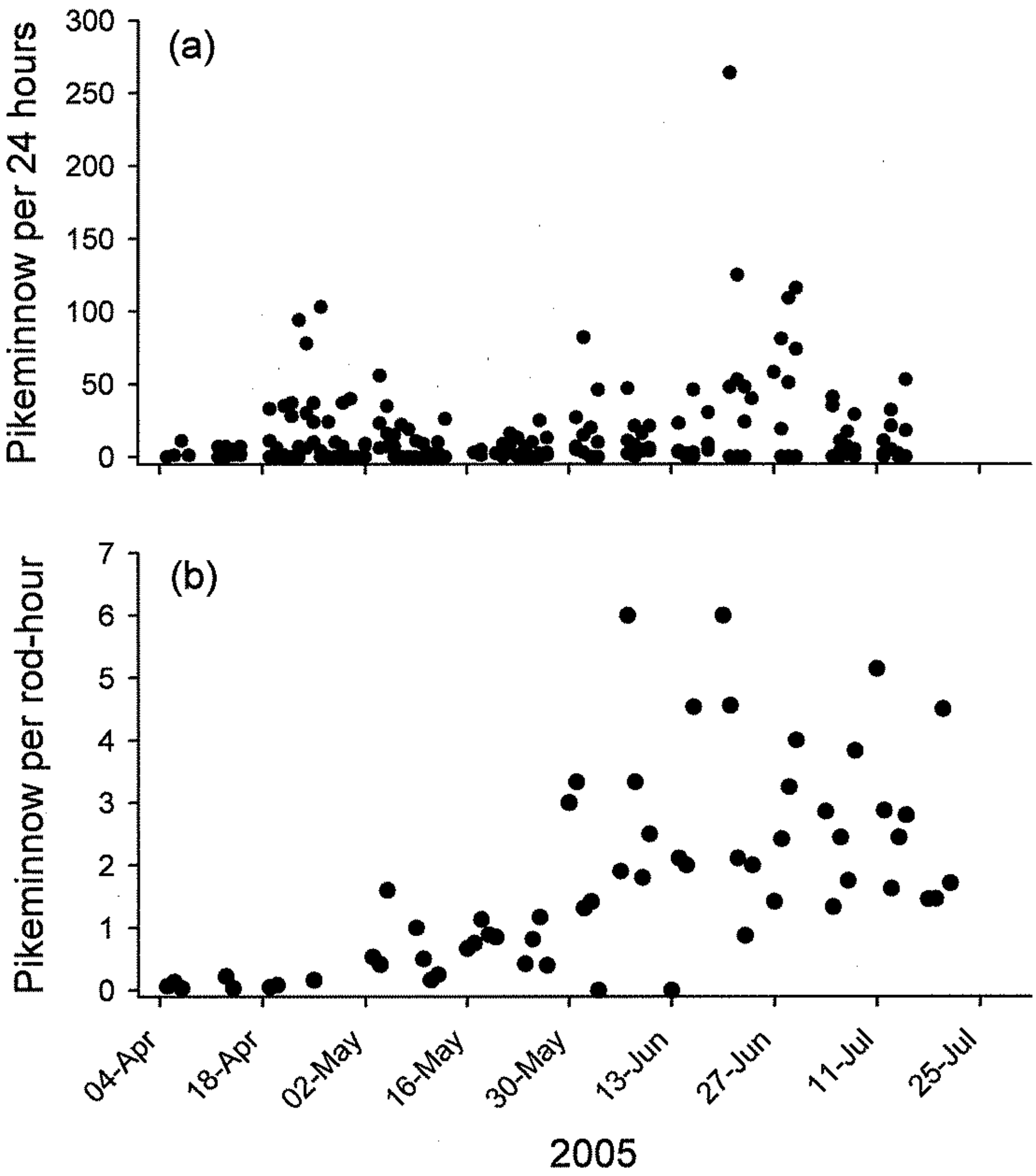

Figure 3. Daily catch per unit effort of northern pikeminnow for (a) three trapnets, and (b) angling at Cultus Lake in 2005.

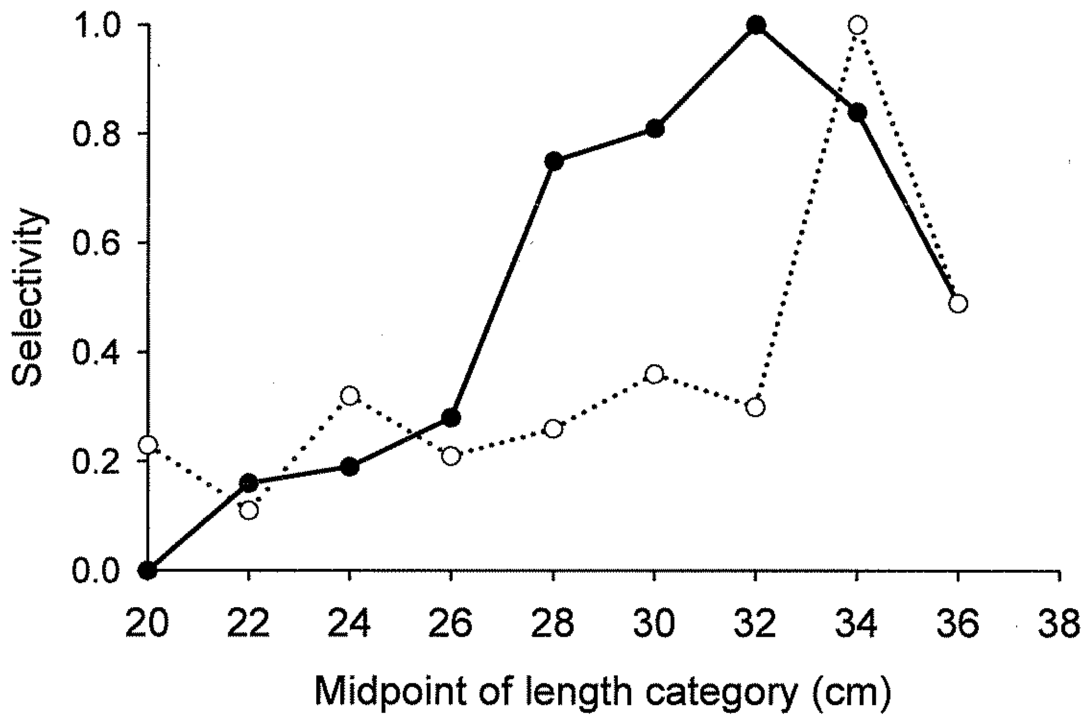

Figure 4. Size-dependent selectivity of trapnets (solid line) and angling gear (dashed line), scaled such that the maximum value is 1.0. Vulnerability at length based on the recovery rates of tagged fish recaptured in 2004 or 2005.

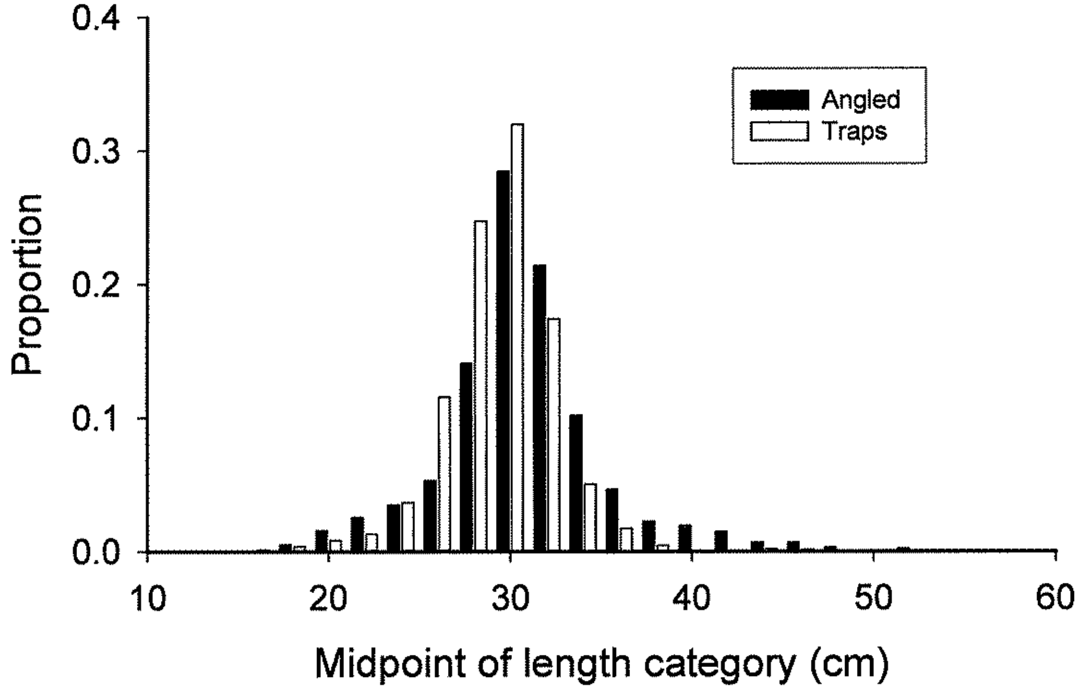

Fig. 5. Size frequency distribution of northern pikeminnow captured by angling or traps. 2004 and 2005 are combined.

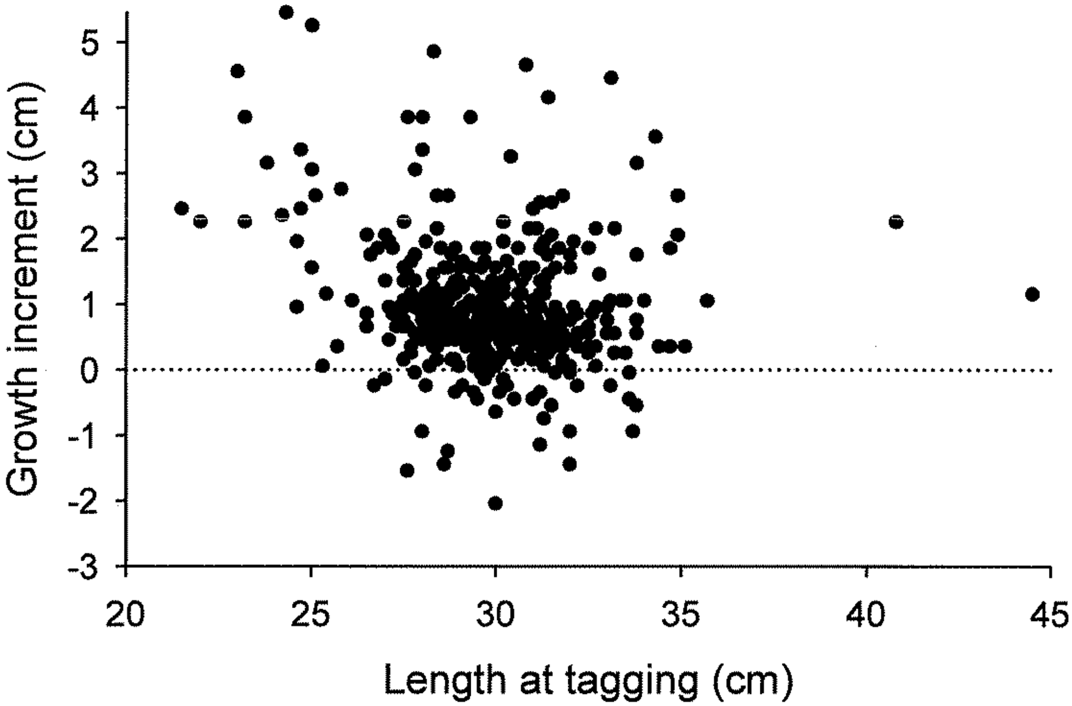

Figure 6. Change in length of Cultus Lake northern pikeminnow between the initial capture and tagging in 2004 and subsequent recovery in 2005. In 2005 the lengths were measured on dead fish, and 0.56 cm was added to the measured length to account for shrinkage.

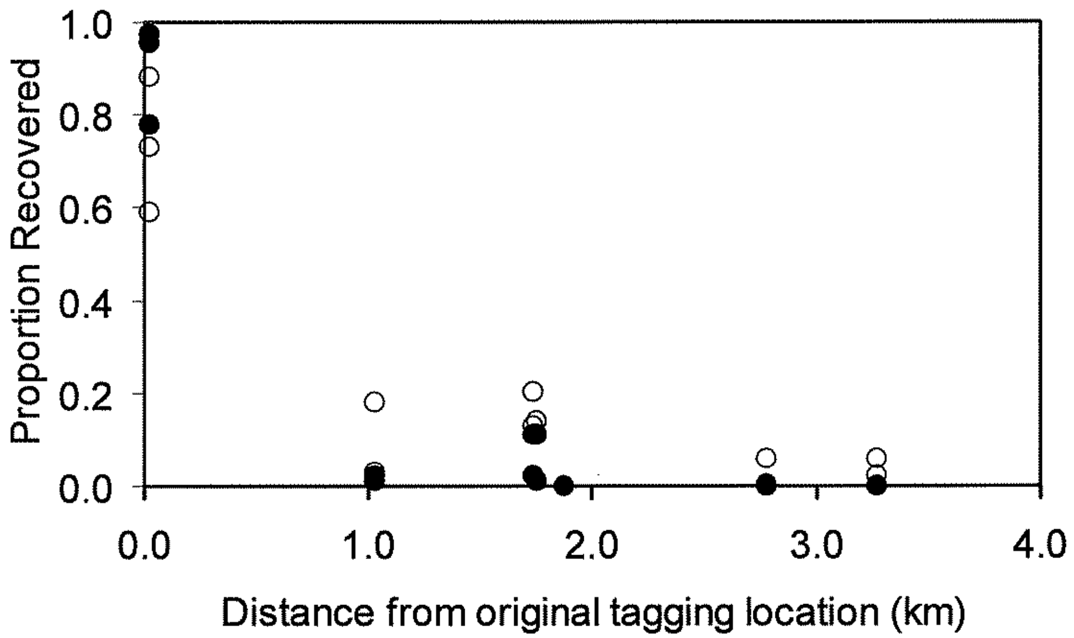

Figure 7. The distribution of recovered tags among recovery sites as a function of the distance between the original tagging site and the location of recovery. Filled symbols are fish tagged and recovered in 2004, open symbols are fish tagged in 2004 and recovered in 2005.

Appendix 5. The number of bycatch fish species caught by date in 2005 for all gear types.

Date	Rainbow Trout	Char	Cutthroat	Residual Coho	Peamouth Chub	Sucker Sp.	Whitefish Sp.	White Sturgeon	Total
14-Jun	1								1
15-Jun						5			5
16-Jun						21			21
18-Jun			1			15	2		18
20-Jun				1					1
21-Jun						196			196
22-Jun									0
23-Jun									0
24-Jun	1								1
27-Jun									0
28-Jun						48			48
29-Jun						26			26
30-Jun						16			16
04-Jul									0
05-Jul						15			15
06-Jul						10			10
07-Jul						20			20
08-Jul			1			11			12
11-Jul				1					1
12-Jul						14			14
13-Jul						23			23
14-Jul									0
15-Jul						12			12
18-Jul									0
19-Jul									0
20-Jul									0
21-Jul									0
Total	20	2	27	18	3	1113	7	1	1191

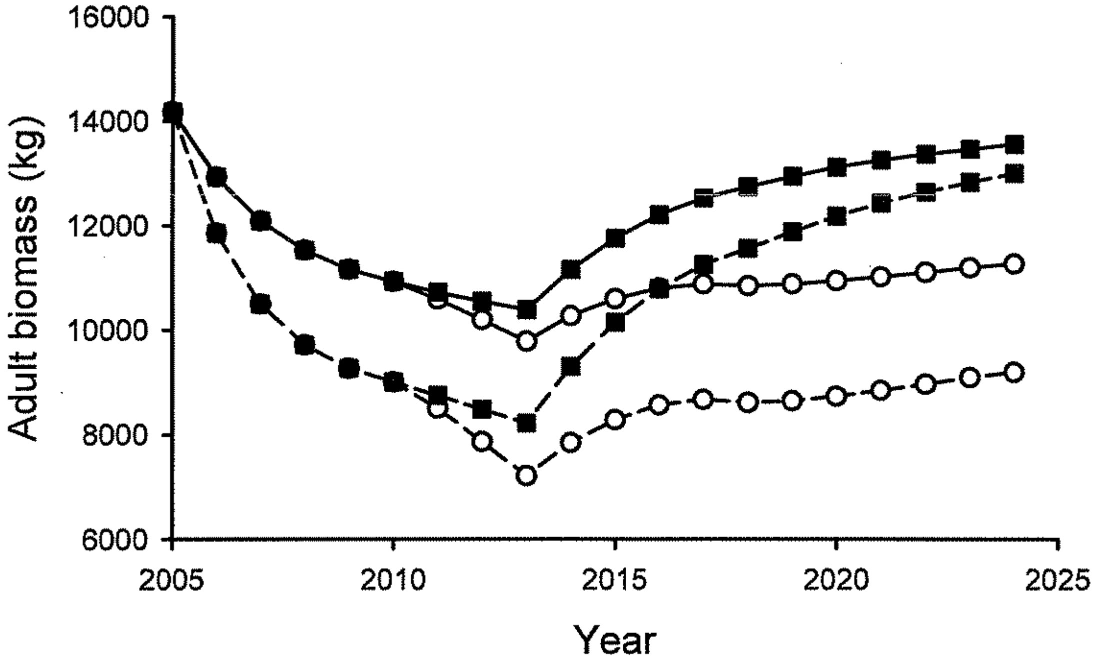

Figure 8. Predicted time series of northern pikeminnow age 5 and older biomass from the age-structured simulation model for two scenarios of fishing mortality (F = 0.2, solid line, F = 0.4 dashed line), and for weak (open circles) and strong (filled squares) compensation in the stock-recruit relations. In each simulation predator control is simulated for 8 years and then terminated, allowing the population to recover.

Appendix 1, Table 1. 2004 northern pikeminnow tag application by date and location for angling.

Date	Army Camp	Delta Grove	Frosst Creek	Main Beach	Needle Pt.	Slide	Sunnyside	Teapot Bay	Other	Total
17-May			2	18						20
18-May			17	39						56
19-May				42						42
20-May			4	31						35
21-May				37						37
25-May				32						32
26-May				18			2			20
27-May	56									56
01-Jun			3							3
02-Jun	14									14
03-Jun	5									5
04-Jun						88				88
07-Jun	15		1			1				17
08-Jun		1		9				1		11
11-Jun			3							3
17-Jun					1		18		6	25
18-Jun			3			8				11
23-Jun							11			11
24-Jun							10			10
Total	90	1	33	226	1	97	41	1	6	496

Appendix 1, Table 2. 2004 northern pikeminnow tag application by date and location for trapnets.

Date	Needle Pt.	Slide	Spring Bay	Other	Total
01-Jun				3	3
02-Jun			62	3	65
03-Jun			63		63
04-Jun			61		61
08-Jun			26		26
09-Jun		14	65		79
10-Jun		11	34		45
11-Jun		3	39		42
15-Jun	74				74
16-Jun	289				289
23-Jun	60				60
24-Jun	120				120
25-Jun	58				58
06-Jul	17				17
07-Jul	2				2
08-Jul	31				31
09-Jul	10				10
13-Jul	2	1		4	7
14-Jul	3			3	6
15-Jul		1			1
20-Jul	15	111			126
21-Jul	15	57			72
22-Jul	17				17
23-Jul	5	3			8
27-Jul	9	11			20
28-Jul	16				16
29-Jul	16	11			27
30-Jul	17	3			20
04-Aug	8	18			26
05-Aug	6	26			32
06-Aug		14			14
Total	790	284	350	13	1437

Appendix 1, Table 3. 2004 Northern Pikeminnow tag application by date and location for cod traps.

Date	Main Beach	Spring Bay	Sunnyside	Total
20-Jul	2	1		3
21-Jul		21		21
23-Jul		2		2
27-Jul		19		19
04-Aug			13	13
05-Aug			7	7
06-Aug			8	8
Total	2	43	28	73

Appendix 2, Table 1. The total number of northern pikeminnow as well as the number of marked (M) individuals captured by trapnet in 2005 by location.

	Needle Pt.		Slide		Spring Bay		North End		Outlet		Other		Total		
Date	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	% M
06-Apr										1			0	1	0%
07-Apr										10			0	10	0%
08-Apr										1			0	1	0%
12-Apr										7			0	7	0%
13-Apr					1	7				3			1	10	10%
14-Apr		5				4				1			0	10	0%
15-Apr		2				1				7			0	10	0%
19-Apr		11								33			0	44	0%
20-Apr	2	6			1	3							3	9	33%
21-Apr	6	35								1			6	36	17%
22-Apr	7	28								37			7	65	11%
23-Apr	9	93				7							9	100	9%
24-Apr		30				6			3	118			3	154	2%
25-Apr	2	24			7	37				10			9	71	13%
26-Apr	17	98				3							17	101	17%
27-Apr		24											0	24	0%
28-Apr	3	10											3	10	30%
29-Apr	5	37								7			5	44	11%
30-Apr	7	40											7	40	18%
02-May	3	9			3	8							6	17	35%
04-May	6	23			2	6			1	46			9	75	12%
05-May	13	35				7				16			13	58	22%
06-May	3	15				7							3	22	14%
07-May	8	22											8	22	36%
08-May	8	19											8	19	42%
09-May	3	11											3	11	27%
10-May	4	9											4	9	44%
11-May	1	2											1	2	50%
12-May		3								10			0	13	0%
13-May	6	25											6	25	24%
17-May	1	2						3					1	5	20%
18-May								5		1			0	6	0%
20-May	3	7											3	7	43%
21-May								1		26			0	27	0%
22-May	4	9						3		16			4	28	14%
23-May		1								13			0	14	0%
24-May	5	7								4			5	11	45%
25-May										10			0	10	0%
26-May	2	2							1	25			3	27	11%
27-May	1	3						1		13			1	17	6%
31-May	8	27								5		6	8	38	21%
01-Jun	16	79								15	1	3	17	97	18%
02-Jun	4	20											4	20	20%
03-Jun	12	46								10			12	56	21%
07-Jun	16	47			9	11				2			25	60	42%
08-Jun	4	21								8			4	29	14%

continued

Appendix 2, Table 1. The total number of northern pikeminnow as well as the number of marked (M) individuals captured by trapnet in 2005 by location.

	Needle Pt.		Slide		Spring Bay		North End		Outlet		Other		Total		
Date	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	% M
09-Jun	6	16			1	4				5			7	25	28%
10-Jun	6	21				4				6			6	31	19%
14-Jun	5	23			3	4				3			8	30	27%
15-Jun		2								2			0	4	0%
16-Jun	10	45			1	3							11	48	23%
18-Jun	10	61			2	9			2	24			14	94	15%
21-Jun			12	264	19	48							31	312	10%
22-Jun			4	53	15	125							19	178	11%
23-Jun			4	23	8	48							12	71	17%
24-Jun					9	39							9	39	23%
28-Jun	3	19	3	58									6	77	8%
29-Jun	2	51	4	81									6	132	5%
30-Jun	8	116	6	103									14	219	6%
05-Jul	2	41	1	35									3	76	4%
06-Jul	1	4	1	11									2	15	13%
07-Jul	1	7	1	17		1							2	25	8%
08-Jul	1	5		30									1	35	3%
12-Jul	1	2	1	11									2	13	15%
13-Jul	1	21	3	32	1	5							5	58	9%
14-Jul				2									0	2	0%
15-Jul	4	52	3	18									7	70	10%
Total	250	1373	43	738	82	397	0	13	7	496	1	9	383	3026	13%

Appendix 2, Table 2. The total number of northern pikeminnow as well as the number of (M) individuals captured by angling in 2005 by location.

	Army Camp		Entrance Bay		Frosst Cr.		Honeymoon Bay		Jade Bay		Lindell Beach		Maple Bay		Marina		Needle Pt.		Outlet		Slide		Spring Bay		Sunnyside		Other		Total		
Date	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	% M
05-Apr								1																					0	1	0%
06-Apr																										4			0	4	0%
07-Apr																												1	0	1	0%
13-Apr																												4	0	4	0%
14-Apr																												1	0	1	0%
19-Apr																										1			0	1	0%
20-Apr																										1			0	1	0%
25-Apr																				2									0	2	0%
03-May						8																							0	8	0%
04-May						2																3							0	5	0%
05-May		4				10								8						1		1							0	24	0%
06-May						5																							0	5	0%
08-May																				50								46	0	96	0%
09-May				4											1	4										2			1	10	10%
10-May				2		1						4				1				2									0	10	0%
11-May						2																							0	2	0%
12-May	1	1																		1									1	2	50%
16-May		6																											0	6	0%
17-May		1		2				3										1				5							0	12	0%
18-May				3		1	1	1				2								2		3		2		3			1	17	6%
19-May																												16	0	16	0%
20-May				2				1		2				2						7				1		2			0	17	0%
24-May		1		2																3								1	0	7	0%
25-May		2	1	4																1				3		1			1	11	9%
26-May				1																1							1	12	1	14	7%
27-May																										1	1	1	1	2	50%
30-May																												15	0	15	0%
31-May																				2								23	0	25	0%
01-Jun		3				3																2						13	0	21	0%
02-Jun	1	2																								3		12	1	17	6%
06-Jun				5			1	1		6																4		4	1	20	5%
07-Jun																									3	77		4	3	81	4%
08-Jun																				5					1	30			1	35	3%
09-Jun				6																						17		4	0	27	0%
10-Jun																										15			0	15	0%
14-Jun				3																					1	16			1	19	5%
15-Jun		3		5				3		4												7	1	3		10			1	35	3%
16-Jun															2	52					1	15							3	67	4%
18-Jun																											15	482	15	482	3%
20-Jun																					1	21				27			1	48	2%
21-Jun										2											2	18	1	3	1	18			4	41	10%
22-Jun																						19							0	19	0%
23-Jun																						7							0	7	0%
24-Jun																	1	2								4			1	6	17%

continued

Appendix 2, Table 2. The total number of northern pikeminnow as well as the number of marked (M) individuals captured by angling in 2005 by location.

	Army Camp		Entrance Bay		Frosst Cr.		Honeymoon Bay		Jade Bay		Lindell Beach		Maple Bay		Marina		Needle Pt.		Outlet		Slide		Spring Bay		Sunnyside		Other		Total		
Date	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	otal	M	Total	M	Total	M	Total	M	Total	% M
27-Jun				2					1	2												2	1	1		7	1	3	3	17	18%
28-Jun				4						4														5		16			0	29	0%
29-Jun										7										2		1			1	16			1	26	4%
30-Jun										4															1	12		8	1	24	4%
04-Jul																				4					1	26			1	30	3%
05-Jul																										12			0	12	0%
06-Jul																									2	31	1	2	3	33	9%
07-Jul				4					1	4																1		5	1	14	7%
08-Jul																										23			0	23	0%
11-Jul																										54			0	54	0%
12-Jul																			1	1		12				10			1	23	4%
13-Jul				1					1	4																8			1	13	8%
14-Jul		6		3														5						4		4			0	22	0%
15-Jul																										13		1	0	14	0%
18-Jul																												16	0	16	0%
19-Jul																												19	0	19	0%
20-Jul																											1	27	1	27	4%
21-Jul																											1	12	1	12	8%
Total	2	29	1	53	0	32	2	10	3	39	0	6	0	10	3	57	1	8	1	84	4	##	3	22	11	469	21	732	52	1667	3%

Appendix 2, Table 3. The total number of northern pikeminnow as well as the number of marked (M) individuals captured in 'other traps' (hoop, prawn, and cod) in 2005 by location.

	Army Camp		Honeymoon Bay		Lindell Beach		Maple Bay		Marina		Needle Pt.		Outlet		Slide		Spring Bay		Sunnyside		Other		Total		
Date	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	M	Total	% M
28-Feb		4																						4	0%
06-Mar		5																						5	0%
05-Apr			1	7								2		2				3					1	14	7%
06-Apr				8								5		2				1						16	0%
07-Apr				2								2		1										5	0%
08-Apr		2	1	3										2				2					1	9	11%
11-Apr				1							1	2								15		7	1	25	4%
13-Apr																				1	2	20	2	21	10%
15-Apr		2	1	1		1				1		2				2		1		2			1	12	8%
18-Apr				6						1		3		1		1		1				12		25	0%
20-Apr				1								3				3		1				5		13	0%
21-Apr				2								3										1		6	0%
25-Apr				3						8	2	11				5					1	15	3	42	7%
28-Apr				10					1	3						3							1	16	6%
29-Apr								1																1	0%
04-May				5						4					1	2		1					1	12	8%
08-May																2								2	0%
11-May			2	7						1	1	3				4	1	2					4	17	24%
13-May			1	6					1	4								2					2	12	17%
17-May				2						1		2		2				1				1		9	0%
25-May				1								3		2										6	0%
26-May										2				1										3	0%
30-May										2														2	0%
01-Jun								1																1	0%
Total	0	13	6	65	0	1	0	2	2	27	4	41	0	13	1	22	1	15	0	18	3	61	17	278	6%

Appendix 3. The number of female (F) and male (M) or sex unspecified (U) northern pikeminnow captured by date using all methods in 2005.

Date	F	M	U	% Female	Total Caught
28-Feb	3		1	100%	4
06-Mar	1		4	100%	5
05-Apr			15		15
06-Apr	1		20	100%	21
07-Apr			16		16
08-Apr			10		10
11-Apr	1		24	100%	25
12-Apr			10		10
13-Apr	1		34	100%	35
14-Apr			11		11
15-Apr			22		22
18-Apr			25		25
19-Apr			45		45
20-Apr			23		23
21-Apr			42		42
22-Apr			65		65
23-Apr	40	59	1	40%	100
24-Apr	60	94		39%	154
25-Apr	53	24	38	69%	115
26-Apr	37	63	1	37%	101
27-Apr	13	11		54%	24
28-Apr	10	16		38%	26
29-Apr	22	23		49%	45
30-Apr	21	19		53%	40
02-May			17		17
03-May	5	3		63%	8
04-May			92		92
05-May			82		82
06-May			27		27
07-May			22		22
08-May	93	24		79%	117
09-May	15	6		71%	21
10-May	15	4		79%	19
11-May	12	6	3	67%	21
12-May	1	1	13	50%	15
13-May	22	15		59%	37
16-May	5	1		83%	6
17-May	15	10	1	60%	26
18-May	15	3	5	83%	23
19-May	10	6		63%	16
20-May	20	4		83%	24
21-May	9	18		33%	27
22-May	14	14		50%	28
23-May	8	6		57%	14
24-May	9	9		50%	18

continued

Appendix 3. The number of female (F) and male (M) or sex unspecified (U) northern pikeminnow captured by date using all methods in 2005.

Date	F	M	U	% Female	Total Caught
25-May	9	18		33%	27
26-May	25	19		57%	44
27-May	5	3	11	63%	19
30-May	8	8	1	50%	17
31-May	46	17		73%	63
01-Jun	71	45	3	61%	119
02-Jun	29	8		78%	37
03-Jun	29	16	11	64%	56
06-Jun	13	7		65%	20
07-Jun	103	37	1	74%	141
08-Jun	35	29		55%	64
09-Jun	32	18	2	64%	52
10-Jun	21	19	6	53%	46
14-Jun	34	11	4	76%	49
15-Jun	28	10	1	74%	39
16-Jun	79	34	2	70%	115
18-Jun	64	23	489	74%	576
20-Jun	19	28	1	40%	48
21-Jun	116	34	203	77%	353
22-Jun	125	69	3	64%	197
23-Jun	48	28	2	63%	78
24-Jun	22	22	1	50%	45
27-Jun	7	9	1	44%	17
28-Jun	70	31	5	69%	106
29-Jun	66	85	7	44%	158
30-Jun	104	116	23	47%	243
04-Jul	17	10	3	63%	30
05-Jul	29	59		33%	88
06-Jul	32	16		67%	48
07-Jul	23	16		59%	39
08-Jul	23	12	23	66%	58
11-Jul	45	8	1	85%	54
12-Jul	27	6	3	82%	36
13-Jul	21	48	2	30%	71
14-Jul	9	4	11	69%	24
15-Jul	34	9	41	79%	84
18-Jul	13	3		81%	16
19-Jul			19		19
20-Jul	18	9		67%	27
21-Jul	4	8		33%	12
Total	2034	1391	1549	59%	4974

Appendix 4, Table 1. The total amount of effort and the CPUE (catch per trap-day) for northern pikeminnow by date for trapnet gear type in 2005.

Capture Date	# Traps	Hours Fished	Pikeminnow Catch	Pikeminnow CPUE
06-Apr	1	24	1	1
07-Apr	1	24	11	11
08-Apr	1	24	1	1
12-Apr	1	24	7	7
13-Apr	3	24	10	3
14-Apr	3	24	10	3
15-Apr	3	24	9	3
19-Apr	3	24	44	15
20-Apr	3	24	9	3
21-Apr	3	24	36	12
22-Apr	3	24	65	22
23-Apr	3	24	101	34
24-Apr	3	24	154	51
25-Apr	3	24	71	24
26-Apr	3	24	103	34
27-Apr	3	24	24	8
28-Apr	3	24	10	3
29-Apr	3	24	45	15
30-Apr	3	24	40	13
02-May	3	48	17	3
04-May	3	24	76	25
05-May	3	24	59	20
06-May	3	24	27	9
07-May	3	24	22	7
08-May	3	24	19	6
09-May	3	24	11	4
10-May	3	24	9	3
11-May	3	24	2	1
12-May	3	24	16	5
13-May	2	24	26	13
17-May	2	24	6	3
18-May	3	24	6	2
20-May	3	24	7	2
21-May	3	24	27	9
22-May	3	24	28	9
23-May	3	24	14	5
24-May	3	24	11	4
25-May	3	24	10	3
26-May	3	24	27	9
27-May	3	24	7	2
31-May	3	24	38	13
01-Jun	3	24	97	32
02-Jun	3	24	20	7
03-Jun	3	24	56	19
07-Jun	3	24	60	20
08-Jun	3	24	29	10

continued

Appendix 4, Table 1. The total amount of effort and the CPUE (catch per trap-day) for northern pikeminnow by date for trapnet gear type in 2005.

Capture Date	# Traps	Hours Fished	Pikeminnow Catch	Pikeminnow CPUE
09-Jun	3	24	25	8
10-Jun	3	24	31	10
14-Jun	3	24	30	10
15-Jun	3	24	4	1
16-Jun	3	24	48	16
18-Jun	3	48	88	15
21-Jun	3	24	312	104
22-Jun	3	24	178	59
23-Jun	3	24	72	24
24-Jun	1	24	40	40
28-Jun	3	24	77	26
29-Jun	3	24	132	44
30-Jun	3	24	225	75
05-Jul	3	24	76	25
06-Jul	3	24	15	5
07-Jul	3	24	25	8
08-Jul	3	24	34	11
12-Jul	3	24	13	4
13-Jul	3	24	58	19
14-Jul	3	24	2	1
15-Jul	3	24	70	23
Total			3033	

Appendix 4, Table 2. The total amount of effort and the CPUE (catch per rod-hour) for northern pikeminnow by date for angling gear type in 2005.

Date	Rods Fished	Hours Fished	Pikeminnow Catch	Pikeminnow CPUE
04-Apr	4	3	0	0.00
05-Apr	4	3.45	1	0.07
06-Apr	6	5	4	0.13
07-Apr	6	5	1	0.03
13-Apr	6	3	4	0.22
14-Apr	5	6	1	0.03
19-Apr	5	4	1	0.05
20-Apr	4	3	1	0.08
25-Apr	4	3	2	0.17
03-May	3	5	8	0.53
04-May	4	3	5	0.42
05-May	3	5	24	1.60
08-May	60	7	96	0.23
09-May	2	5	10	1.00
10-May	4	5	10	0.50
11-May	4	3	2	0.17
12-May	4	2	2	0.25
16-May	3	3	6	0.67
17-May	4	4	12	0.75
18-May	3	5	17	1.13
19-May	3	6	16	0.89
20-May	4	5	17	0.85
24-May	3	5.5	7	0.42
25-May	3	4.5	11	0.81
26-May	3	4	14	1.17
27-May	2	2.5	2	0.40
30-May	2	2.5	15	3.00
31-May	2	2.5	25	5.00
01-Jun	4	4	21	1.31
02-Jun	3	4	17	1.42
03-Jun	3	1	0	0.00
06-Jun	3	3.5	20	1.90
07-Jun	3	4.5	81	6.00
08-Jun	3	3.5	35	3.33
09-Jun	3	5	27	1.80
10-Jun	3	2	15	2.50
14-Jun	2	4.5	19	2.11
15-Jun	3	5	30	2.00
16-Jun	4	3	68	5.67
18-Jun	181	7	482	0.38
20-Jun	2	3	48	8.00
21-Jun	2	4.5	41	4.56
22-Jun	2	4.5	19	2.11
23-Jun	2	4	7	0.88
24-Jun	2	1.5	6	2.00
27-Jun	3	4	17	1.42

continued

Appendix 4, Table 2. The total amount of effort and the CPUE (catch per rod-hour) for northern pikeminnow by date for angling gear type in 2005.

Date	Rods Fished	Hours Fished	Pikeminnow Catch	Pikeminnow CPUE
28-Jun	3	4	29	2.42
29-Jun	2	4	26	3.25
30-Jun	2	3	24	4.00
04-Jul	3	3.5	30	2.86
05-Jul	3	3	12	1.33
06-Jul	3	4	33	2.75
07-Jul	2	4	14	1.75
08-Jul	3	2	23	3.83
11-Jul	3	3.5	54	5.14
12-Jul	2	4	23	2.88
13-Jul	2	4	13	1.63
14-Jul	2	4.5	22	2.44
15-Jul	2	2.5	14	2.80
Total			1584	

Appendix 4, Table 3. The total amount of effort and the CPUE (catch per trap-day) for northern pikeminnow by date for "other traps" (hoop, prawn, and cod) gear type in 2005.

Date	# Traps	Hours Fished	Pikeminnow Catch	Pikeminnow CPUE
28-Feb	5	72	0	0.00
06-Mar	10	72	0	0.00
05-Apr	29	24	14	0.48
06-Apr	29	24	16	0.55
07-Apr	29	24	5	0.17
08-Apr	34	48	9	0.13
11-Apr	29	72	25	0.29
13-Apr	34	96	21	0.15
15-Apr	34	96	13	0.10
18-Apr	34	144	25	0.12
20-Apr	34	96	13	0.10
21-Apr	34	48	6	0.09
25-Apr	34	144	44	0.22
28-Apr	34	96	16	0.12
04-May	34	96	12	0.09
08-May	29	48	2	0.03
11-May	29	48	17	0.29
13-May	34	96	13	0.10
17-May	34	192	9	0.03
25-May	26	328	6	0.02
26-May	31	256	3	0.01
30-May	27	192	2	0.01
01-Jun	16	96	1	0.02
02-Jun	10	72	0	0.00
14-Jun	4	16	0	0.00
Total			272	

Appendix 5. The number of bycatch fish species caught by date in 2005 for all gear types.

Date	Rainbow Trout	Char	Cutthroat	Residual Coho	Peamouth Chub	Sucker Sp.	Whitefish Sp.	White Sturgeon	Total
28-Feb									0
06-Mar									0
05-Apr									0
06-Apr						2			2
07-Apr	1					18			19
08-Apr	1		1		1				3
11-Apr									0
12-Apr			1			2			3
13-Apr	2			9		4			15
14-Apr			1			1			2
15-Apr	1					2			3
18-Apr						6			6
19-Apr			3			16			19
20-Apr						5			5
21-Apr						2			2
22-Apr						3			3
23-Apr									0
24-Apr						5			5
25-Apr						2			2
26-Apr						7	2	1	10
27-Apr						1			1
28-Apr						5			5
29-Apr				1		3			4
30-Apr						1			1
02-May			1						1
03-May									0
04-May		2	1			109			112
05-May	2			1		57			60
06-May						16			16
07-May			1			30			31
08-May				1		31			32
09-May			1			31			32
10-May									0
11-May									0
12-May	3					14			17
13-May						7			7
16-May									0
17-May			4	1		3			8
18-May	1		1			16			18
19-May	1		1						2
20-May			1						1
21-May			1			71			72
22-May						36			36
23-May						8			8
24-May	1		2			16			19
25-May	2			1		22			25
26-May						28			28
27-May	2		1			12	1		16
30-May									0
31-May						24			24
01-Jun			1	2		13			16
02-Jun			2			1			3
03-Jun						14			14
06-Jun			1						1
07-Jun						8	1		9
08-Jun					1	14			15
09-Jun					1	10			11
10-Jun	1					5	1		7

continued

Appendix 5. The number of bycatch fish species caught by date in 2005 for all gear types.

Date	Rainbow Trout	Char	Cutthroat	Residual Coho	Peamouth Chub	Sucker Sp.	Whitefish Sp.	White Sturgeon	Total
14-Jun	1								1
15-Jun						5			5
16-Jun						21			21
18-Jun			1			15	2		18
20-Jun				1					1
21-Jun						196			196
22-Jun									0
23-Jun									0
24-Jun	1								1
27-Jun									0
28-Jun						48			48
29-Jun						26			26
30-Jun						16			16
04-Jul									0
05-Jul						15			15
06-Jul						10			10
07-Jul						20			20
08-Jul			1			11			12
11-Jul				1					1
12-Jul						14			14
13-Jul						23			23
14-Jul									0
15-Jul						12			12
18-Jul									0
19-Jul									0
20-Jul									0
21-Jul									0
Total	20	2	27	18	3	1113	7	1	1191