Cultus Lake Northern Pikeminnow (*Ptychocheilus oregonensis)* Assessment and Removal Program in 2004 and 2005.

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INTRODUCTION

The Cultus Lake sockeye salmon (*Oncorhynchus nerka*) population is among the most intensively studied salmon stocks in British Columbia. Research on Cultus Lake has included spawner counts since 1925, smolt counts since 1926, and fishery catch statistics since 1952. Cultus Lake has also been the focus of two predator control studies, summarized by Ricker (1941) and by Hall (1992). Despite these efforts the Cultus Lake stock has exhibited dramatic declines in abundance over the past few decades, and was classified as "endangered" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2003.

Historically, freshwater production of approximately 60 sockeye smolts per spawner combined with a marine survival of approximately 7% yielded more than four returning adults per spawning parent (Cultus Sockeye Recovery Team 2004). In recent years, freshwater production has significantly decreased with the 1999-2000 brood years producing only 5 smolts per spawner for both years and around 20 smolts per spawner from the 2002 brood year (Schubert et al 2002, data on file).

For freshwater survival, in particular, piscivore predation has been identified as a significant component of the freshwater mortality of Cultus Lake sockeye (Ricker 1941, Steigenberger 1972). While game fish such as cutthroat trout (*O. clarki*) and char (*Salvelinus spp.*) have higher per capita predation rates, the greater abundance of northern pikeminnow (*Ptychocheilus oregonensis*) in Cultus Lake should result in overall greater numbers of juvenile sockeye being consumed by pikeminnow than other piscivorous species (Ricker 1941, Steigenberger 1972). Removal of the northern pikeminnow should therefore contribute to the improved freshwater survival of Cultus Lake sockeye.

Two predator removal programs have been conducted in Cultus Lake in the past. The first program (1935 - 1941) used gill-nets to remove piscivore predators (including thousands of trout and char). The reduction in predator population size resulted in an increase in the average egg-to-smolt survival rate from 3.1% for the eight year period prior to predator removal to 9.9% for the three year period after the start of predator removal. Egg-to-smolt survival decreased near the end of the experiment, but the benefits of predator removal may have been masked by density-dependent mortality resulting from years of very high spawner abundance (Mossop and Bradford 2004). The second predator removal program (1990-1992) that targeted exclusively northern pikeminnow resulted in 24% reduction in this predator's population size (Hall 1992). These removals did not appear to result in improved survival of juvenile sockeye (Mossop and Bradford 2004), and the smolt/spawner ratio for these years are similar to the long term average.

This report addresses the deliverables for the "Northern Pikeminnow Predation Study" as a requirement for funding by the Southern Boundary Restoration & Enhancement Fund 2004/2005. All deliverables are specifically addressed in Appendix I. The objectives of this study are to 1) to complete a northern pikeminnow mark recapture study (May 2004 to July 2005) to assess the current distribution and abundance of northern pikeminnow in Cultus Lake; 2) reduce the population size of northern pikeminnow in Cultus Lake through removal activities (mark recapture recoveries and fishing derbies); 3) model the potential effectiveness of a predator removal program in controlling northern pikeminnow; and 4) makes recommendations for future predator control programs at Cultus Lake.

METHODS

1.0 Study Design

1.1 Study Area

Cultus Lake is a small oligotrophic lake located approximately 90 km east of Vancouver B.C. This lake has a surface area of 6.3 km^2, a mean depth of 32 m, and a maximum depth of 41 m (Figure 1).

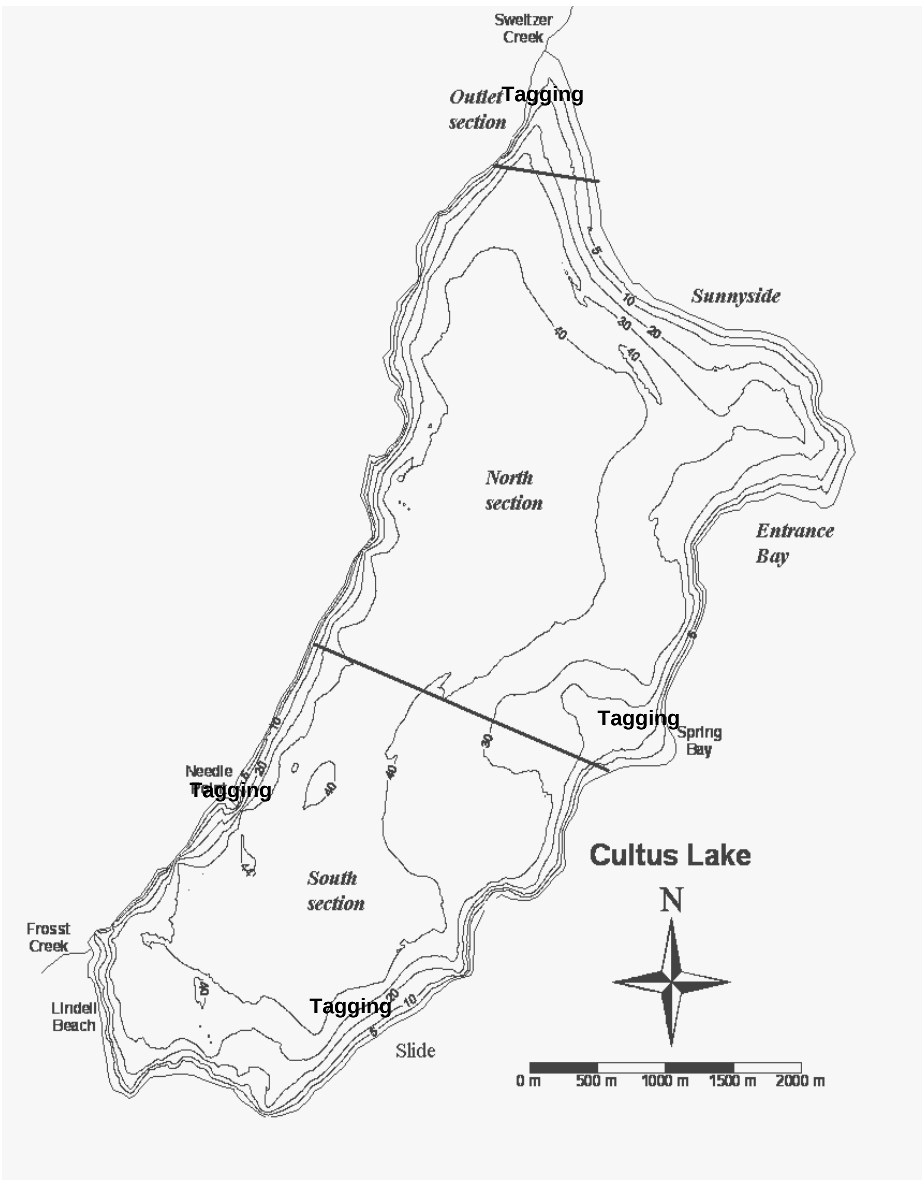


Figure 1. Map of Cultus Lake, BC. Showing lake sections and major points of interest to the 2004/2005 northern pikeminnow study.

1.2 Gear used

To determine the most effective capture methods for the tagging and removals of northern pikeminnow in Cultus Lake, we used a variety of capture methods. In both 2004 and 2005, we used angling, trap nets, and cod traps. In 2005 we also used gillnets, prawn traps, hoop nets, and long lines.

Angling

Angling was used extensively at the lake outlet during the beginning of the 2004 season, but was used less frequently and more opportunistically as the season progressed. Angling in 2004 mainly consisted of using a hook and worm bounced off the bottom in suitable locations, but we also used live redside shiners (*Richardsonius balteatus*) and juvenile northern pikeminnow as bait. In 2005, angling mainly consisted of trolling in all areas of the lake with minnow imitation crank baits. During both seasons, angling was employed opportunistically, targeting spawning aggregations of northern pikeminnow.

Trap nets

We used three trap nets during each season, two smaller (referred to as 8"x8" trapnet, the dimensions of the live box, in feet) and one larger (10"x10" trapnet). Trap nets were typically set on Monday, checked once daily, and removed from the lake on Friday (mainly to avoid boat traffic on the weekends). Weekly removal (and occasional cleaning) of the trap nets also helped to reduce the growth of attached algae, thereby maintaining their fishing efficiency. Trap nets were set perpendicular to shore using variable length lead nets at sites with suitable substrate and slope of littoral area.

The adjustable leads on the two smaller 8"x8" trap net were 33 m long and 3.7 m deep. The floating trap section on these nets was a 2 m cube, and fished to a depth of 3.7m and the entire net was made from mesh with stretched size of 19 mm. These were the nets that were constructed for the 1990-1992 northern pikeminnow removal programs (Hall 1992). During both seasons, trap nets were used at several locations, but were mainly used at two distinct locations (Needle point and Spring Bay, Fig. 1), that were very productive in terms of catches.

The larger 10"x10" trap net had a 25 m long, 7.5 m deep lead net with stretched mesh size of 13mm. The floating trap section of this net is a 3.3 m cube and can be effectively fished to a depth of 10m (10m skirt). This net was modified for the 2005 season by removing sections of the box section and replacing them with larger mesh sized panels to allow smaller, undesired species (mainly sockeye smolts), to escape. The lead net was also modified for the 2005 season, replacing the entire lead with larger mesh material. We used the larger trap net at one location in 2004 (Slide) and at two locations in 2005 (Outlet and Slide).

Black Cod traps

We used small black cod traps in both years. These traps are a large basket or pot and consist of a steel frame with mesh walls and are designed to catch demersal fishes. They have a top diameter of 68 cm, a bottom diameter of 100 cm, a height of 60 cm, mesh size is 6 mm and has a rectangular opening 15 cm x 5 cm by which fish enter the trap. The cod traps are baited and fished on the lake bottom, and are attached with a line to a float on the lake surface. During both 2004 and 2005 we fished these traps at various depths from 4 m to 15 m and we primarily used dry cat food for bait.

Gill-nets

We used gill-nets near the lake outlet in 2005 with the expectation that this would be a good method of catching northern pikeminnow feeding at the outlet area, and by using a large enough minimum mesh size, would allow sockeye smolts to pass through the net. We fished 2 times with gill nets, once with 4 panels and once with 5 panels. Each panel was 14 m long and 2.5 m deep with stretched mesh sizes ranging between 6.3 cm to 8.9 cm. The nets were fished during dusk and dawn periods only. There was concern about capturing game fish and the nets were observed at all times and were not left in overnight. Gillnets were strung out across the outlet, in about 10 m of water, using a cannonball to anchor the ends to the bottom, and were checked within 1 hour.

Prawn traps

In 2005 we used commercially available prawn traps, as well as a modified design. The mesh size on the prawn traps was approximately 5 cm. There are three circular openings on each trap, 7.6 cm in diameter. Bait was placed in bait holders inside, and we used prawn bait, salmon roe, dog food and cat food. Traps were attached to a nylon rope which had one end tied to shore. The line was then laid out perpendicular to shore out to about 30-40 m in depth. Traps were generally spaced 10 m apart, with the first trap being about 10 m from shore. Five traps were modified by extending the top upwards in an attempt to increase the holding capacity in case of large catches.

Hoop-net

In 2005 we used a hoop net which was fished in a similar manner as the other trap nets, except that the entire trap is on the lake bottom. The hoop net had two wings that extend out from the heart approximately 7 m, and a lead net that was approximately 20 m long. The hoopnet was anchored to the bottom, perpendicular to the shore, in about 7 m of water. While easy to deploy the hoop net was not very effective for catching northern pikeminnow and was only used approximately five times.

Long lines

In 2005 we used a long line which consisted of a black nylon cord, approximately 60 m in length, with snelled single hooks attached at 3 m intervals. One end of the line was attached to a 10 lb. weight, while the other end was attached to a float. The long line was first attached to the float, and then slowly laid out straight along the bottom. We used a variety of bait, including worms, roe, and northern pikeminnow guts. The long line was only fished once, in about 10 m of water near Lindell Beach and was not very effective.

1.3 Tag Application

2004 tag application

Since the population size is unknown, the study objective in 2004 was to apply tags to as many northern pikeminnow as time and effort would permit. All captured northern pikeminnow >200 mm fork length (FL, n = 2,024) were tagged from May 17th to August 6th. Captured northern pikeminnow size was limited to fish larger than 200 mm, since fish smaller than 200 mm were not vulnerable to capture using standard methods. It has also been reported that northern pikeminnow do not prey on juvenile salmonids until their body sizes exceed 200 mm FL (Ricker 1941; Hall 1992).

The majority of the tags were applied at four locations on Cultus Lake. The first location was near the lake outlet, where most fish tagged were captured by angling in the spring. The other three locations were Spring Bay, Slide and Needle Point (Fig. 1), where most fish were captured using trap nets with some limited cod trap success at Spring Bay.

Pikeminnow were tagged using Floy® medium T-Bar Anchor Tags, FD- 94 with (19 mm) monofilament and total length of (44 mm). Tags were inserted slightly ventral to the base of the dorsal fin, on the left side. Tags used were numbered from 101 to 2,241. One side of the tag was numbered and on the opposite side a phone number was included for the public to call if they captured a tagged fish. All fish tagged during 2004 were released at the site of capture after receiving a left pectoral hole punch as a secondary mark. For all tagged fish, FL and weight were measured.

Fish were not anaesthetised while being tagged and wetted wool-like gloves were used when handling fish to prevent removal of their protective mucous layer. To assess immediate tagging and handling mortality, the first 200 tagged northern pikeminnow were held for 10 minutes prior to release, in a live well

To assess longer term tagging mortality and/or tag loss, in 2004 we ran an experiment using two circular concrete tanks with diameters of 5.5m and depths of 1.5m. All fish used in the mortality experiment were captured using trap nets and were brought back to the Cultus Lake Lab shortly after capture via live well. On July 15, 2004 we put 25 fish (13 tagged, 12 untagged) in the first tank and on July 22, 65 fish (33 tagged, 32 untagged) in the 2nd tank. The study was terminated August 11, 2004 and all fish were killed. All fish in the mortality experiments were fed live redside shiners, crayfish and juvenile (<10 cm length) northern pikeminnow, all of which were kept in a small circular tank and were captured with minnow traps at various locations on Cultus Lake.

Samples of northern pikeminnow stomach contents were also obtained in 2004 at the lake outlet and in 2005 throughout Cultus Lake (n = 438). Samples were preserved in 10% formalin.

<u>2005 mark application</u>
In 2005, two separate marking programs were conducted to further address the following objectives: 1) to determine the proportion of the northern pikeminnow population that migrates to the outlet of Cultus Lake where significant predation of migrating sockeye smolts is hypothesized to occur; and 2) to examine overall migration patterns of northern pikeminnow in Cultus Lake to address the mark recapture assumption of complete mixing of an assessed population.

To address these objectives, northern pikeminnow were marked and released (n = 349) in April, 2005 from three different general locations in Cultus Lake. The following marks were applied to indicate the area of the lake the fish originated from: 1. South End-left pectoral punch; 2. North End-right pectoral punch; and 3. Outlet-upper caudal hole punch.
To further examine migration patterns of pikeminnow we moved fish captured from around the lake to the outlet area. From May 2-5, 2005 northern pikeminnow were captured from the north and south ends of the lake, marked with a lower caudal punch and re-released at the outlet (n = 210). Their recapture sites were subsequently recorded.

1.4 Tag Recovery and pikeminnow removal

Recapture and consequent removal of northern pikeminnow was conducted in 2005 using the gear described in section 1.

Northern pikeminnow fishing derbies were also held annually to assist with recovery and removal efforts. A total of three derbies were held, one in 2004 (June 19th) and two in 2005 (May 8th and June 18th). During these derbies, the number of fish captured by anglers and the length (FL), weight, and sex were recorded by Department of Fisheries and Oceans observers.

1.5 Analytical procedures

<u>Population estimate</u>
The northern pikeminnow (>200 mm FL) population size was calculated from the mark-recapture data using the simple Petersen method (Ricker 1975, pg. 77):

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

M = number of fish tagged in 2004
C = number of fish recovered in 2005 (tagged and untagged)
R = number of fish recovered in 2005 with tags

Confidence limits for N were calculated by treating R as a Poisson variable, obtaining limits and substituting the limits from Appendix II in Ricker into the above equation (1975, pg. 343).

Potential biases were evaluated and statistical tests were performed to assess whether key mark recapture assumptions were violated.

Pikeminnow removal model

To assist with future predator control programs in Cultus Lake, a model was constructed to assess the effectiveness of alternative northern pikeminnow removal strategies. This model is a tool for assessing alternative enhancement strategies and does not attempt to produce specific predictions about the impacts of a control program on the Cultus Lake northern pikeminnow population or subsequent effects on the sockeye salmon population.

A population of long-lived fish consists of an adult population, and the juvenile or pre-recruit stages. The adult population is usually dominated by younger-aged fish, as the cumulative effects of natural mortality reduces the number of older fish. The adult population contributes annually to reproduction, producing large numbers of eggs, larvae and juvenile fish. Mortality on these stages is high, and those that do survive and enter the adult population annually is referred to as the recruitment.

The northern pikeminnow model presented here is based on the assumption that the adult population is stable (i.e. at equilibrium); recruitment and mortality are balanced, and there is no change in the population over time. No natural variation in survival and recruitment is included, however, this variation will play an important role in the actual effects of predator control on the Cultus Lake northern pikeminnow population. Biological data provided by Hall (1992) provide the basis for parameterizing the model. The following simplifying assumptions were made:

1. The ages modeled are from age 5 (226 mm mean length) to age 15 (360 mm). Hall found fish age 20+ in his samples, but there will only be a few fish older than 15 and we chose to ignore these.

2. Maturity occurs at age 6, so the biomass of age-6 and older fish are included in the spawning biomass. Hall’s data showed that fecundity was a linear function of weight (55 eggs/g) so biomass is a useful estimate of reproductive potential.

3. Hall’s catch curve analysis resulted in an estimated total mortality rate of 0.36 for age-6 and older fish. This estimate includes natural mortality and mortality caused by recreational fishing on the lake.

4. Hall (1992) mainly used traps to capture fish, although some data were obtained from other gear types. These gear are inefficient for capturing small fish. We estimated the catchability of younger ages (relative to age 6+) as: ages 2-3: 0.10, age-4: 0.18, and age-5: 0.4. In this preliminary analysis the catch of ages 2-4 fish was not included in the evaluation of predator control, however, relatively few fish of this size have been caught in the current control efforts.

The annual change in the number of fish by age is given by the standard equation:

$$N_{i+1,t+1} = N_{i,t}\, e^{-M+qF} \qquad \text{Equation 2}$$

where N is the number at age i in year t, M is the mortality rate (0.36), F is the fishing mortality on age 6+ fish associated with a predator control program, and q is the age-specific catchability that scales F according to the selectivity of the gear.

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

$$N_{5,t+5} = \frac{aS_t}{1+\frac{a}{b}S_t} \qquad \text{Equation 3}$$

where *a* is the "steepness" parameter, and *b* upper asymptotic recruitment level. No data exist on lacustrine northern pikeminnow stock-recruitment relations, so the parameters were approximated as follows. For *a*, values of 2 and 7 were used that correspond to weak and higher levels of compensation or density dependence. Higher values for *a* mean that survival from egg to recruit decreases substantially as the population becomes larger, perhaps because of competition for food and space. For *a*=2, the recruitment is only weakly limited at high spawner abundance.

Values of *b* were found by trial using the model. For a given total population size, under the age structure and mortality schedule described above, there is an abundance of recruits that will result in a stable population. We found that a recruitment of 15,000 age-5 fish will result in a steady-state population of about 50,000 age 5 to 20+ fish, which is close to the current estimate from the field studies. A total population of 50,000 age-5+ fish has an age-6+ spawning biomass of 11,118 kg. Thus *b* is found by trial so that the Beverton-Holt function will produce 15,000 recruits from a spawning biomass of 11,100 kg. The trial-and-error process resulted in two parameter sets for the recruitment model representing high (*a*=7, *b*=18,600) and low (*a*=2, *b*= 46,200) compensation (Figure 1).

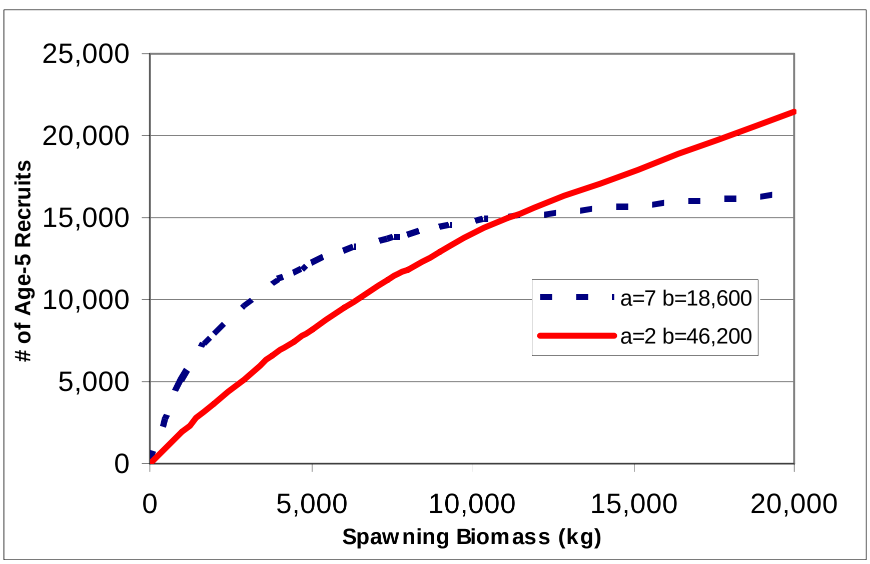


Figure 2. Northern pikeminnow stock-recruitment curves.

Predator control was assumed to begin in 2005 and is initially a 6 year program. The intensity of the removals is set by varying F, the annual exploitation rate on fully recruited ages. The exploitation rate on the younger ages (q_iF) is much lower. The efficacy of the predator control program is measured in terms of the change in the total northern pikeminnow biomass (age 5+). We considered total predator biomass to be the simplest index of the risk of predation for juvenile salmon.

Results

2.1 Tag Application

A total of 2,002 tags were available for recapture (not incorporating mortality and tag loss) due to 16 identified tag removals during the 2004 northern pikeminnow derby, two observed mortalities of tagged pikeminnow, and the removal of four tagged pikeminnow reported by the general public.

No short term mortality of tagged fish was observed in the holding tanks. The fish appeared to be healthy and in behaving normally. Consequently, after the first 200 tagged fish were assessed all subsequent fish were released immediately and not held for observation.

The longer-term mortality and tag loss study did not produce reliable results that could be applied to correct the value for the number of fish tagged in the simple Peterson estimator equation (equation 1). Northern pikeminnow retained in holding tanks for this study experienced excessively high water temperatures (16-18°C), fungal disease, and predation by a terrestrial predator (minks). These effects preclude the interpretation of tagging and handling effects on northern pikeminnow.

In addition to the longer-term mortality and tag loss study, the loss of the primary Floy tag was assessed by the application of a secondary mark (left pectoral fin punch). This secondary mark was observed to regenerate within two months of its application but it did leave a distinguishable scar which was used as an indicator of tag loss. All recovered fish with a Floy Tag had a noticeable scar on the left pectoral fin, while no scars were observed on untagged northern pikeminnow indicating a 0% tag loss. Hall's report (1992) previously documented a 4% tag loss and we chose to use this more conservative value to reduce the effective number of tags (corrected n = 1,923) in our mark-recapture estimate

2.2 Catch summary

Over two years, the Cultus Lake northern pikeminnow assessment and removal program captured a total of 9,105 northern pikeminnow and killed 5,933. A number of other species were also captured (and mostly released) but are not reported here They are recorded in the database and are available from J. Hume, DFO, Cultus Lake Lab (humej@dfo-mpo.gc.ca@dfo-mpo.gc.ca, 604-824-4705)

In 2004, a total of 3,552 individual northern pikeminnow were captured; of these 1,526 northern pikeminnow were killed and 2,026 were tagged and released. A total of 4,132 northern pikeminnow (including recaptures of fish tagged and released earlier) were captured in Cultus lake from May 12 to Aug 6, 2004 (Table 1). Four tagged fish were reported caught and killed by recreational anglers from August 12th to November 5th, 2004.

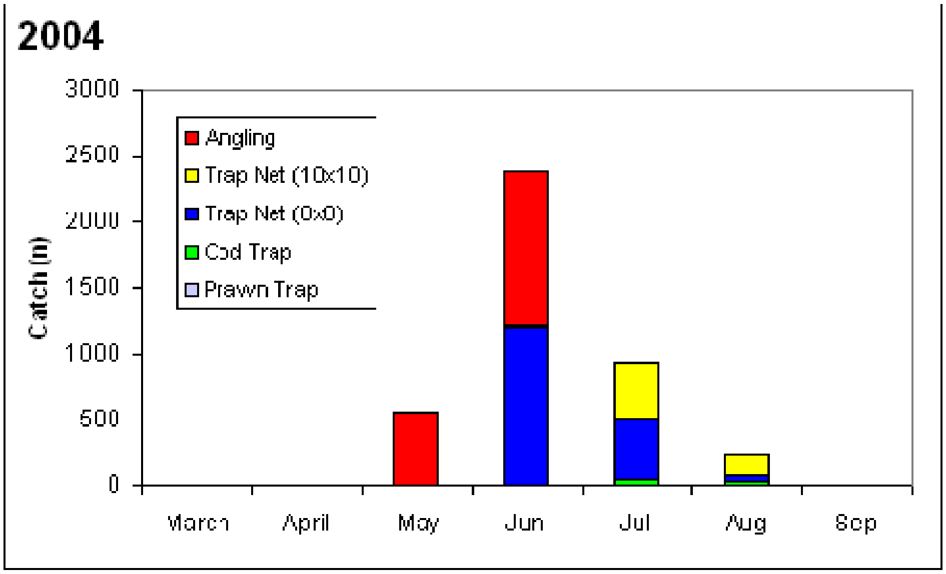
In 2005, a total 4,407 northern pikeminnow were killed and 567 were released as part of the outlet studies, for a total capture of 4,974 northern pikeminnow. A total of 452 Floy tagged fish were recaptured. Appendix 2 and 3 provide a detailed summary of the northern pikeminnow catch, by gear type, for each year of the study.

Table 1. Summary of northern pikeminnow catch and tagging data for 2004 and 2005.

	Tagged	Total Recaptures	Unique Recaptures	Killed	Released	Total	% of total
2004							
Angler	508	23	23	1199	531	1,730	42
Cod Trap	74	4	4		78	78	2
Trap Net (10"X10")	255	132	55	225	387	612	15
Trap Net (8"X8")	1,189	421	248	102	1,610	1,712	41
2004 Total	2,026	580	330	1526	2,606	4,132	
2005							
Angling			52	1,624	43	1,667	34
Cod Trap			4	45	55	100	2
Trap Net (10"x10")			50	1,073	161	1,234	25
Trap Net (8"x8")			333	1,580	212	1,792	36
Prawn Trap			13	79	96	175	4
Hoop Net			0	3	0	3	0
Long Line				3		3	0
2005 Total		0	452	4,407	567	4,974	
Grand total	2,026			5,933	3173	9,106	

Overall, the northern pikeminnow catch for the various gear types was similar in both years, with the majority of northern pikeminnow captured with the two trapnet sizes and by angling (Table 1, Figure 3). Angling was somewhat more effective in 2004 probably because of a larger turnout and a larger catch by the 2004 northern pikeminnow derby. The 10"X10" trap net was more effective in 2005 because of more fishing effort with this gear. The four other gear types (cod trap, hoop net, prawn trap and long line) were relatively ineffective and contributed very little to the overall catch of northern pikeminnow.

All gear types were most effective in June when water temperatures were warming up and northern pikeminnow moved onshore to feed and spawn. In 2004 angling did not start until May 8th, the 8"X8" trapnets were not fished until June 2nd, and the 10"X10" wasn't continuously fished until July 20th. In 2005 all three gears were fished more or less continuously from early April. The trap nets were somewhat effective in April and May of 2005 but were most effective in June. Over 50% of the catch was caught in June by angling and the trapnets in both years. Catches from all gear types declined considerably in July and August.



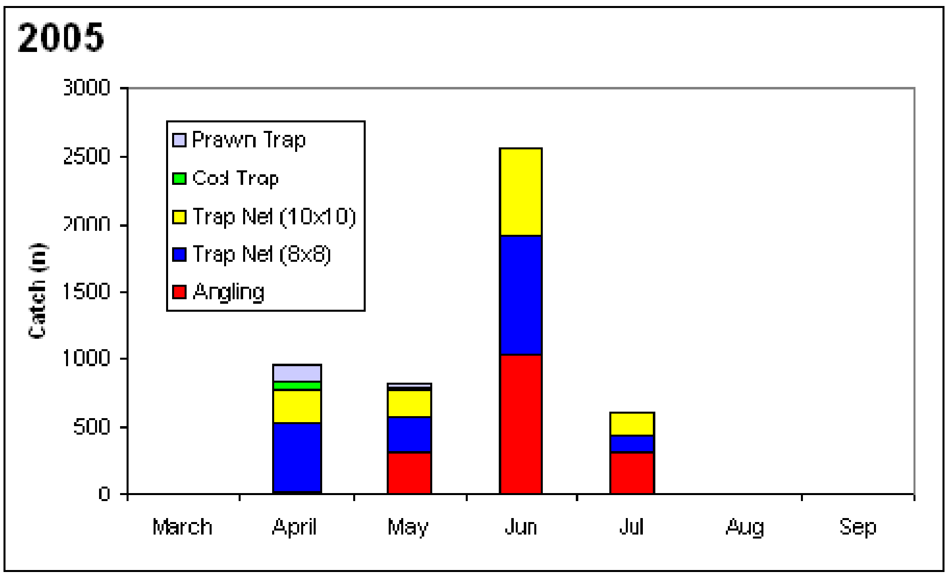


Figure 3. Northern pikeminnow catch by month and gear type in 2004 and 2005.

2.3 Bias Estimation

Spatial bias

One of the key assumptions of the Peterson mark-recapture estimate is that the marked fish become randomly mixed with unmarked fish throughout a survey area. We examined this assumption using two methods: recovery in 2005 of fish marked in 2004 with Floy tags relative to their known initial capture and release point, and the recovery of fish marked and released in 2005 in each of the lake sections (Fig. 1).

We found that northern pikeminnow in Cultus Lake exhibit remarkable site fidelity. Even after one year, over 80% of the Floy tagged fish (*n*= 452) were recovered at their original release location.

Two locations, in particular, illustrate this high site fidelity. Seventy five percent of the recaptures in 2005 were caught Spring Bay and Needle Point. At Spring Bay, 72 of the 86 recaptures caught in 2005 were tagged and released at Spring Bay in 2004. At Needle Point, 231 of the 255 recaptures caught were tagged and released at Needle point in 2004.

The 2005 northern pikeminnow migration study also showed a lack of movement within the lake. Of the 352 northern pikeminnow marked with fin clips in early April, we recovered 25 (Table 2). None of these fish were recovered at the outlet and many were recaptured within the same lake area as where they were marked, suggesting no movement of fish to the outlet.

Of the 213 northern pikeminnow marked with a lower caudal fin punch and released at the outlet between May 2nd and May 6th, 118 were from the south section of the lake and 95 were from the north. There were no marked fish caught during an intensive angling effort at the outlet on May 8th and only one of these fish was recovered at the outlet during 2005. Although their original capture location could not be determined, many fish were recaptured within a few days in either the north or south sections of the lake suggesting that they were possibly returning to their original capture site.

Table 2. Results of the 2005 northern pikeminnow migration study in Cultus Lake. The lower caudal clipped fish were capture in either the south (118) or north (95) sections and released at the outlet.

Mark Type	**Number marked**	**Recaptured at**				
(Lake section)		**North**	**South**	**Outlet**	**Unknown**	**Total**
Left Pectoral (South)	155	1	17		2	20
Right Pectoral (North)	185	3	1			4
Upper Caudal (Outlet)	12		1			1
Lower Caudal	213	6	32	1		39

<u>Size bias</u>

Northern pikeminnow FL exhibited some differences between different gear types (Figure 4). Although, distributions were significantly different between fish angled and recaptured in 2005 (Kolmogorov-Smirnov test, $D = 0.115$, p-value = 0.0007), these differences are attributed to differences in their variance (F test, $F = 3.5997$, p-value < 0.001), the longer tails of the angling distribution particularly for smaller size classes. However, since we only used fish larger than 230 mm in our Petersen estimate calculations, the catchable portion of the population through angling in 2005 are representative of the tagged fish in the lake.

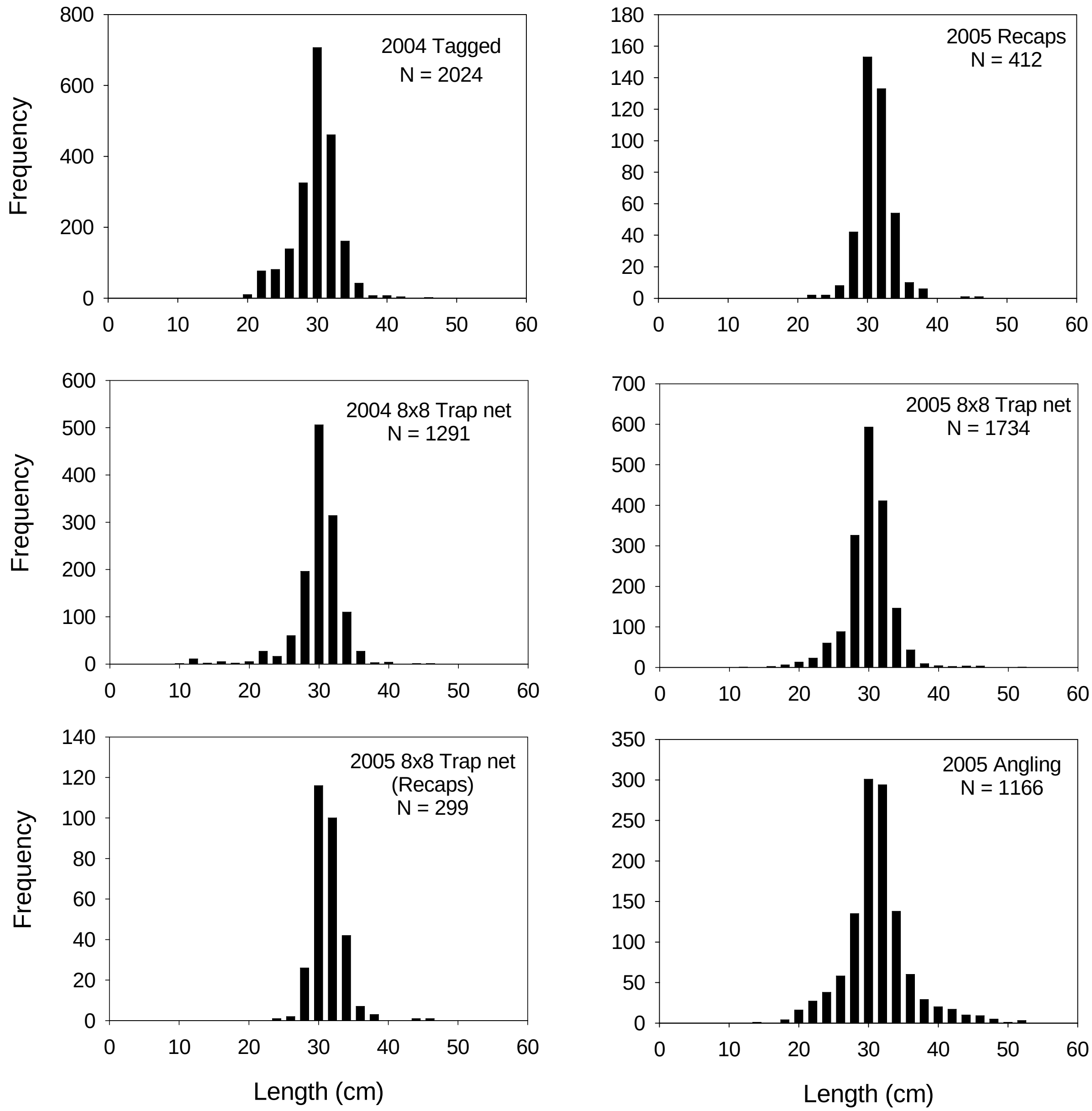


Figure 4. Length frequency distribution of Cultus Lake pikeminnow capture in 2004 and 2005

2.4 Population estimate

Site fidelity of northern pikeminnow was observed in our study. Therefore, incomplete mixing of marked and unmarked fish throughout the study area violated a key assumption of the Petersen mark-recapture estimator. However this assumption can be met if the recovery data is collected with random and evenly distributed effort (Ricker 1975 pg. 90). In order to meet this assumption we used data from two separate 2005 recovery periods.

Angling was used as one recovery data set. The field crew suggested that angling was not targeted on any one area and was conducted over a larger area than other sampling methods. The second recovery data set used was obtained from the pikeminnow derby. Derby anglers were distributed around the lake and used a variety of gear. We found that tag incidence in both data sets was similar (DFO angling: 3.4% tags in 1089 fish, derby catch 3.0% of 497 fish) suggesting that the angling datasets were similar, and unbiased. To estimate population size we combined both datasets. As not all derby captured fish were measured we could not estimate numbers greater than 230 mm and this data was discarded resulting in 38 recaptures from a total angled catch of 1,103) The Petersen population size estimate for northern pikeminnow in Cultus Lake is 54,436 (39,831-76,642 95% CI)

2.5 Model results

When the pikeminnow population is in equilibrium (recruitment and mortality are balanced), the biomass is approximately 11,100 kg (50,000 individuals age 5 and older), and is sustained by an annual average recruitment of about 15,000 age 5 fish. Assuming that all females spawn each year, and a 1:1 sex ratio, the adult population is predicted to produce about 321 million eggs; the egg-recruit survival rate is about 0.005%.

For level of exploitation, the model predicts that catches will decline over the 6 years of the each experiment as the population gets smaller. An exploitation rate of 0.1 results in removals of about 2,000-3,000 per year, 0.2 corresponds to 4,000-5,000 per year, and 0.3 results in a removal of 5,000-7,000 year from a northern pikeminnow population that is initially 50,000 age 5+ fish. At the end of the 6 year removal period the population biomass is reduced by the following: F=0.1, 14%, F=0.2, 24%, F=0.3, 32%.

At the cessation of the experiment the population is predicted to increase in size. Under the assumption of weak compensation in the stock-recruit relation, the recovery is slow, likely taking in excess of 30 years (Fig. 2). In the situation in which density dependence is much stronger, the population is predicted to recover in about 10 years (Fig. 3). Since the age of recruitment (to a size >200mm) is age 5, in the first 5 years of the removal experiment there is no impact of removals on the number of fish recruiting to the population, as these were spawned prior to the onset of the predator control program. If the removal experiment extends beyond 5 years, then there is a slight additional effect of both the removals on the adult population, and reduced recruitment resulting from a smaller spawning biomass size.

The cumulative effect of a 6-year removal trial on the age 5+ biomass is relatively small. Based on a predicted annual catch of 4,000-5000, a value for F of 0.2 appears to be similar to the fishing mortality exerted during the 2005 program (the 2005 total catch was 4974). Yet 6 years of this level of effort only reduced the age 5+ population by about 25%. Part of the reason for this is that age 5 and 6 fish are not very vulnerable to the fishing gear, and so these ages classes (which are the most abundant in the population) are largely unaffected by removal efforts. The abundance of the older fish is more impacted by the cumulative effect of fishing, the number of age 10 and older fish is reduced by 50% after 5 years of F=0.2 removals.

Once a population is suppressed by a 6 year predator control program, it is useful to determine what level of effort is required to keep the population from rebounding. Under the scenario of weak compensation in the recruitment function, a sustained F of 0.05, corresponding to an annual catch of 1,000 fish is adequate to prevent recovery. If there is strong compensation, then an F of 0.15 (catch 3,000/yr) is needed. To reduce the northern pikeminnow population to half of the starting biomass after 6 years a fishing mortality of >0.7 is required, which is equivalent to removing one-half of the fully exploited age classes each year. Annual catches of >10,000 in the first few years of the removal program would be required to impose this level of fishing mortality.

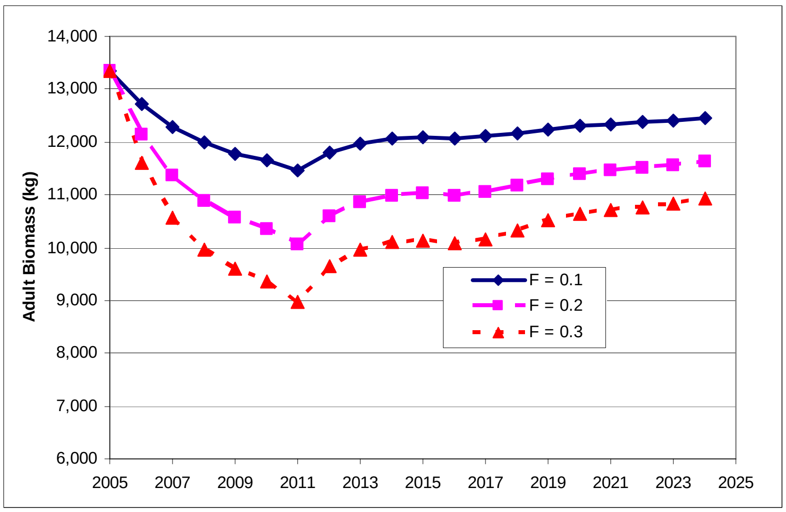


Figure 5. Predicted changes in adult biomass for a 6 year removal experiment for 3 different levels of removal intensity. Weak compensation (see Figure 3) is assumed in this example which results in the protracted period of recovery at removal cessation.

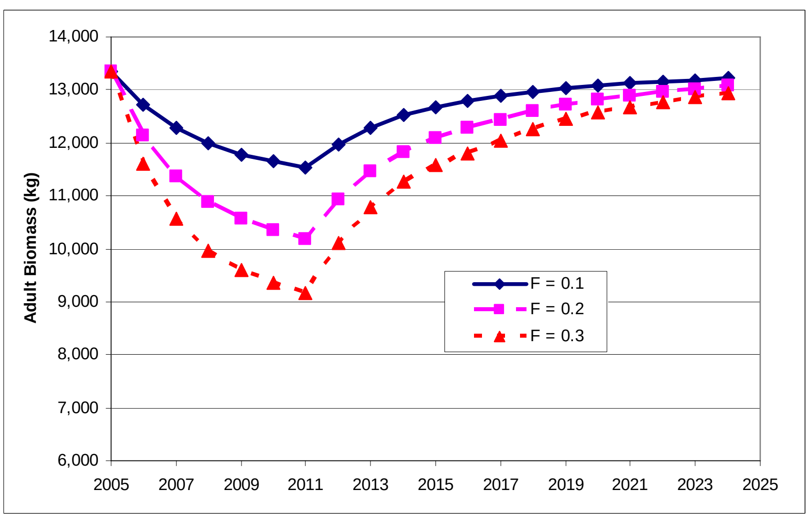


Figure 6. Effects of a 6-year removal experiment. In this case strong compensation is assumed, and the population recovers more quickly after removal cessation.

DISCUSSION

Early estimates of the population size of northern pikeminnow ranged from 8,400 and 840 fish in 1935 and 1938, respectively (Ricker 1938), to approximately 20,000 fish and 40,000 fish in 1969 and 1991, respectively. Despite inconsistencies in assessment methods between years, Hall's (1992) analysis indicated that there was an increase in northern pikeminnow abundance over the 50-60 year period between 1935 and 1991. Our estimate for the 2004/2005 northern pikeminnow population assessment is similar to the most recent 1991 estimate and was 54,436 (95% CI: 39,831-76,642). Based on previous year's assessments this population size is at the high end of the reported northern pikeminnow population size for Cultus Lake.

Our study provided evidence for significant site fidelity of northern pikeminnow in Cultus Lake. This required a change in our population size analyses methods to compensate for the lack of complete mixing of marked and unmarked fish throughout a system required in standard Petersen mark recapture methods (Ricker 1975). A large percentage of northern pikeminnow (80%) were captured at identical sites in 2004 and 2005. As a result of our observations on northern pikeminnow site fidelity, previous year's population estimates are also likely to be biased since mixing between tagged and untagged fish would be incomplete and not considered in past analyses.

Although previous studies have suggested that two populations (littoral and pelagic populations) of northern pikeminnow occupy Cultus Lake (Hall 1992), our results indicate that population aggregations are site-specific rather than habitat-specific. Using the recapture data we were able to document three northern pikeminnow aggregations at Spring Bay, Slide and Needle Point. More aggregations may exist but remain undocumented by the current study. We did obtain qualitative information from our differential marking study in three different broad lake areas that indicated that northern pikeminnow exhibited site fidelity; most differentially marked fish were recovered later in the season in the same areas they were initially marked.

It has been suggested that northern pikeminnow aggregate at the outlet of the lake where Cultus Lake sockeye smolt concentrate during their migrations from March to June. If northern pikeminnow concentrated at this site in response to high prey concentrations, then sockeye smolts might be particularly vulnerable to predation at this time of year. Our results, from differentially marking fish at four broad locations in Cultus Lake and from caudal fin marked fish released at the outlet, indicated that most fish remained or returned to their initial marking location. No northern pikeminnow were observed to concentrate at the lake outlet. Similarly, our results on angling success at the outlet also indicated that northern pikeminnow did not aggregate at the outlet of the lake during the 2005 sockeye smolt out-migration period. Therefore, spring smolt migration to the lake outlet might not represent a particularly vulnerable time period for northern pikeminnow predation as previously suggested.

A key component of this study was to remove northern pikeminnow from Cultus Lake and effectively reduce predation on the juvenile sockeye population. In 2004/2005, using a variety of capture methods (predominantly traps and angling methods), a total of 5,933 northern pikeminnow were removed from Cultus Lake (~10% of the estimated population size).

The application of model runs using a similar level of effort to 2004/05 over a 6 year period is predicted to reduce the northern pikeminnow population biomass by about 25%. The magnitude of the reduction is relatively modest because the gear is selective for age-7 and older fish and has only small impact on the younger, more abundant, age classes. These predictions are based on the assumption of no variability in survival or productivity of the northern pikeminnow population over the 6 year period. The actual population size removed could deviate from the model run predictions if recruitment and survival conditions deviated from the typical conditions used in the model. If 2004/05 methods are not altered in subsequent years, the removal program should have only modest impacts on the northern pikeminnow population in Cultus Lake.

Recommendations for future work

The most effective removal methods identified by our study are trap nets and angling. These methods should be applied to some of the key aggregations we identified including Spring Bay, Slide and Needle Point. To improve subsequent year's removals, other key aggregations should be identified and focused on for removal effort. New trap net sites need to be identified for depth, slope and absence of debris and aquatic vegetation. In our study we did not identify and use all available sites in the system for trap deployment. Additional angling and trap net effort should also be applied particularly in June when catch is greatest during northern pikeminnow spawning. It is at this time of year when northern pikeminnow are most vulnerable to capture.

Northern pikeminnow derbies should be continued, particularly during northern pikeminnow spawning periods. Based on 2005 removal results, the derbies have proven to be fairly effective at removing large numbers of northern pikeminnow. The application of a sport fishing reward program might also be beneficial, similar to the one used in the lower Columbia and Snake River systems. This sport reward program has been very successful, capturing more than 85% of the 1.1 million northern pikeminnow removed from the lower Columbia and Snake Rivers during 1991 – 1996 (Friesen and Ward 1999).

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Appendix 1. Deliverables for the Southern Boundary Restoration & Enhancement Fund 2004/2005 for Cultus Lake Sockeye

1. **Compilation of information from published reports and data from the archives of the IPSFC and DFO. Synthesis of these reports and data into a database and preparation of a report summarizing the available information (partially complete from 2003/4 funding)**
   - These reports are summarized and synthesized in Mossop et al. (2004). A detailed database proved to be too difficult and was not compiled.

2. **Collect creel information and biological samples from Annual Pikeminnow Derby. Analyze data and incorporate into database.**
   - this information has been incorporated into a database currently managed by J. Hume, DFO, Cultus Lake Lab (humej@dfo-mpo.gc.ca@dfo-mpo.gc.ca, 604-824-4705)
   - the results and analyses are documented in this report (methods/results/discussion)

3. **Development of a model to predict the effects of reducing predation on the survival of juvenile sockeye salmon and the subsequent effects on overall stock rebuilding**
   - this model has been constructed and managed by M. Bradford, DFO, Simon Fraser University (BradfordM@dfo-mpo.gc.ca@dfo-mpo.gc.ca, 604-666-7912)
   - the results of this model are documented in this report (methods/results/discussion)

4. **A pilot removal experiment will be conducted on pikeminnow.**
   - this was conducted in 2005 and is documented in this report .

5. **Reporting of the model results and if a predator removal program is recommended.**
   - documented in the discussion section of this report

6. **Preparation of a report on pikeminnow removal activities integrating all program elements**
   - this report represents this deliverable

Appendix 2. 2004 Tag application and recovery data by gear type.

	Angler					Cod Trap				Smolt Fence	Trap Net (10X10)(always 1 net)			Trap Net (10X10)	Trap Net (8X8)					Grand Total
Date	Recap	Tagged	Killed	Angler Total	angler hours	Recap	Tagged	Cod Trap Total	# of traps	Recap	Recap	Tagged	Killed	Total	Recap	Tagged	Killed	Trap Net (8X8) Total	# of 8x8 nets	
May 8, 2004			54	54	4															54
May 12, 2004			88	88	14															88
May 17, 2004		24		24	10															24
May 18, 2004		57	5	62	15															62
May 19, 2004	1	42	12	55	15															55
May 20, 2004		36	18	54	20															54
May 21, 2004		39	11	50	9															50
May 25, 2004		33	13	46	18															46
May 26, 2004		22	18	40	13															40
May 27, 2004		57	25	82	17															82
June 1, 2004		3*	12	15	9											3	1	4	1	19
June 2, 2004		14		14	20											66	13	79	2	93
June 3, 2004		5*	15	20	6					1					1	63		64	1	85
June 4, 2004		88	4	92	6										13	62		75	1	167
June 7, 2004		17	10	27	9															27
June 8, 2004		11	7	18	8										7	26	1	34	1	52
June 9, 2004															13	80	4	97	1	97
June 10, 2004															24	45	3	72	2	72
June 11, 2004		3		3	3										28	42	1	71	2	74
June 15, 2004															1	75	2	78	2	78
June 16, 2004													26	26	10	291	2	303	2	329
June 17, 2004		25		25	8															25
June 18, 2004		11		11	3															11
June 19, 2004	16		902	918																918
June 23, 2004		11	3	14	6										14	60		74	1	88
June 24, 2004		10		10	6										44	120		164	2	174
June 25, 2004															17	58	1	76	2	76
July 6, 2004															10	17		27	1	27
July 7, 2004															34	2	28	64	2	64
July 8, 2004	1			1											14	31	1	46	2	47
July 9, 2004															14	10	17	41	2	41
July 13, 2004															5	7	3	15	2	15
July 14, 2004															3	6		9	2	9
July 15, 2004															15	1	25*	41	2	41
July 20, 2004							3	3	5		7	111	89	207	15	15		30	1	240
July 21, 2004						1	21	22	5		3	58		61	17	15		32	1	115
July 22, 2004									4		12		65*	77	18	17		35	1	112
July 23, 2004							2	2	3		7	3		10	10	5		15	1	27
July 27, 2004			1	1	3	2	19	21	2		9	11		20	14	9		23	1	65
July 28, 2004			1	1	3	1	1	2	2						15	16		31	1	34
July 29, 2004									4		16	11		27	17	16		33	1	60
July 30, 2004									4		13	3		16	12	17		29	1	45
August 4, 2004	1			1			13	13	4	1	23	18		41	14	8		22	1	77
August 5, 2004							7	7	4		21	26	26	73	20	6		26	1	106
August 6, 2004							8	8	4		21	14	19	54	2			2	1	64
August 12, 2004	1			1																1
September 4, 2004	1			1																1
September 12, 2004	1			1																1
November 5, 2004	1			1																1
Total	23	508	1199	1730		4 (4)	74	78		2	132 (55)	255	225	612	421 (248)	1189	102	1712		4133

Appendix 3. 2005 Tag application and recovery data by gear type.

Date	Angling			Angling	Cod Trap			Cod Trap	Prawn Trap			Prawn Trap	Trap Net (10x10)			Trap Net	Trap Net (8x8)			Trap Net (8x8)	
	Killed	Recaps	Released	Total	Killed	Recaps	Released	Total	Killed	Recaps	Released	Total	Killed	Recaps	Released	(10x10) Total	Killed	Recaps	Released	Total	Grand Total
28-Feb-05									4			4									4
6-Mar-05									5			5									5
5-Apr-05			1	1						1	14	14									15
6-Apr-05	1		3	4							16	16			1	1					21
7-Apr-05			1	1					1		4	5			10	10					16
8-Apr-05							2	2		1	7	7			1	1					10
11-Apr-05					3		19	22	1	1	2	3									25
12-Apr-05															7	7					7
13-Apr-05	1		3	4			7	7		2	14	14			3	3		1	7	7	35
14-Apr-05			1	1											1	1			9	9	11
15-Apr-05							4	4	1	1	7	8	2		5	7			3	3	22
18-Apr-05							13	13			12	12									25
19-Apr-05			1	1											33	33			11	11	45
20-Apr-05			1	1			5	5	1		7	8						3	9	9	23
21-Apr-05							1	1			5	5			1	1		6	35	35	42
22-Apr-05															37	37		7	28	28	65
23-Apr-05																	100	9		100	100
24-Apr-05													118	3		118	36			36	154
25-Apr-05	2			2	32	3		32	10			10	10			10	61	9		61	115
26-Apr-05																	101	17		101	101
27-Apr-05																	24			24	24
28-Apr-05									16	1		16					10	3		10	26
29-Apr-05													7			7	37	5		37	44
30-Apr-05																	40	7		40	40
2-May-05																		6	17	17	17
3-May-05	8			8																	8
4-May-05			5	5			4	4		1	8	8		1	46	46		8	29	29	92
5-May-05	2		22	24											16	16		13	42	42	82
6-May-05			5	5														3	22	22	27
7-May-05																	22	8		22	22
8-May-05	96			96					2			2					19	8		19	117
9-May-05	10	1		10													11	3		11	21
10-May-05	10			10													9	4		9	19
11-May-05	2			2					17	4		17					2	1		2	21
12-May-05	2	1		2									10			10	3			3	15
13-May-05					4	1		4	8	1		8					25	6		25	37
16-May-05	6			6																	6
17-May-05	12			12	2			2	7			7					5	1		5	26
18-May-05	17	1		17									1			1	5			5	23
19-May-05	16			16																	16
20-May-05	17			17													7	3		7	24
21-May-05													26			26	1			1	27

Appendix 3 Ctd. 2005 Tag application and recovery data by gear type.

	Angling			Angling	Cod Trap			Cod Trap	Prawn Trap			Prawn Trap	Trap Net (10x10)			Trap Net	Trap Net (8x8)			Trap Net (8x8)	
Date	Killed	Recaps	Released	Total	Killed	Recaps	Released	Total	Killed	Recaps	Released	Total	Killed	Recaps	Released	(10x10) Total	Killed	Recaps	Released	Total	Grand Total
22-May-05													16			16	12	4		12	28
23-May-05													13			13	1			1	14
24-May-05	7			7									4			4	7	5		7	18
25-May-05	11	1		11					4			4	10			10					25
26-May-05	14	1		14	2			2	1			1	25	1		25	2	2		2	44
27-May-05	2	1		2									13			13	4	1		4	19
30-May-05	15			15	2			2													17
31-May-05	25			25									5			5	33	8		33	63
1-Jun-05	21			21					1			1	15			15	82	17		82	119
2-Jun-05	17	1		17													20	4		20	37
3-Jun-05													10			10	46	12		46	56
6-Jun-05	20	1		20																	20
7-Jun-05	81	3		81									2			2	58	25		58	141
8-Jun-05	35	1		35									8			8	21	4		21	64
9-Jun-05	27			27									5			5	20	7		20	52
10-Jun-05	15			15									6			6	25	6		25	46
14-Jun-05	19	1		19									3			3	27	8		27	49
15-Jun-05	35	1		35									2			2	2			2	39
16-Jun-05	67	3		67													48	11		48	115
18-Jun-05	482	15		482									24	2		24	70	12		70	576
20-Jun-05	48	1		48																	48
21-Jun-05	41	4		41									264	12		264	48	19		48	353
22-Jun-05	19			19									53	4		53	125	15		125	197
23-Jun-05	7			7									23	4		23	48	8		48	78
24-Jun-05	6	1		6													39	9		39	45
27-Jun-05	17	3		17																	17
28-Jun-05	29			29									58	3		58	19	3		19	106
29-Jun-05	26	1		26									81	4		81	51	2		51	158
30-Jun-05	24	1		24									103	6		103	116	8		116	243
4-Jul-05	30	1		30																	30
5-Jul-05	12			12									35	1		35	41	2		41	88
6-Jul-05	33	3		33									11	1		11	4	1		4	48
7-Jul-05	14	1		14									17	1		17	8	1		8	39
8-Jul-05	23			23									30			30	5	1		5	58
11-Jul-05	54			54																	54
12-Jul-05	23	1		23									11	1		11	2	1		2	36
13-Jul-05	13	1		13									32	3		32	26	2		26	71
14-Jul-05	22			22									2			2					24
15-Jul-05	14			14									18	3		18	52	4		52	84
18-Jul-05	16			16																	16
19-Jul-05	19			19																	19
20-Jul-05	27	1		27																	27
21-Jul-05	12	1		12																	12
Grand Total	1624	52	43	1667	45	4	55	100	79	13	96	175	1073	50	161	1234	1580	333	212	1792	4968