Taseko Prosperity Gold-Copper Project

Appendix 5-3-B

PROSPERITY GOLD-COPPER PROJECT

Fish Lake Rainbow Trout Mark-Recapture Study

Report

Prepared for:

Taseko Mines Limited
1020-800 West Pender Street
Vancouver, BC
V6C 2V6

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Prepared by:

TRITON
Environmental Consultants Ltd.
120-13511 Commerce Parkway
Richmond, B.C. V6V 2L1
(604) 279-2093 Fax: (604) 279-2047

DISCLAIMER

EXECUTIVE SUMMARY

The objective of the mark-recapture study was to provide a reliable estimate of the number of rainbow trout (*Oncorhynchus mykiss*) in Fish Lake in the summer of 1997. That information was a key component of compensation planning for the Prosperity Mine project.

A simple Peterson-type mark-recapture method was used. A known number of trout were captured, marked by clipping the tip of the right maxillary bone, and released back into Fish Lake. Then, the population was resampled and the number of recaptured marked fish were counted. The ratio of the number of marked to recaptured fish, multiplied by the number of examined fish in the recapture phase, gave an estimate of population number with 95% confidence limits.

A total of 8,208 trout were captured between July 15 and September 30, 1997. Over 97% were captured with traps nets; the rest were taken with beach seines. During the marking phase (July 15 to 21), 2,059 trout were marked. During the first recapture phase (July 22 to August 3), 5,056 trout were examined for marks and 63 were found to be recaptured marked fish. During the second recapture phase (September 22 to 30), 951 trout were examined and 15 marked fish were recaptured.

The mark-recapture method could only be used to estimate the number of subadults (2-3 years old, 140-229 mm long) and adults (4-6 years old, 230-330 mm long) because the 1 year-old trout that entered the lake in spring and early summer of 1997, and small 2 year-olds that entered in 1996, were too small to be retained by trap nets in July and August. Accordingly, numbers of 1 and 2 year-old juveniles (70-139 mm long) were estimated by combining estimates of subadult and adult numbers from the mark-recapture study with counts of in-migrating 1 year-olds at the inlet and outlets of the lake from an independent fish fence study.

The ratio of marked to unmarked trout for the subadult and adult classes was significantly higher in September than in late July and August because marked trout temporarily reduced their level of activity immediately after marking and so were not caught by trap nets in July in proportion to their true abundance in the lake. Accordingly, population estimates were based only on data collected during the second recapture phase. That avoided biasing the population estimate, but at the cost of increasing the 95% confidence limits.

Six livebox survival tests were conducted to estimate the 24-hour survival of marked and examined trout. Survival ranged from 86 to 96% with a mean of 92%. Average survival of marked trout was not significantly different from average survival of examined trout. A second set of livebox tests in September confirmed that there was no variation in survival with size of fish. Therefore, the pool of marked fish was assumed to have been reduced by 8% mortality to 1,894.

The pool of marked fish was also assumed to have been reduced by a sport fishery on Fish Lake. However, creel survey data indicated that the fishing mortality rate was low enough, between 2.5 and 4.0%/year, that removal of marked fish by anglers was of negligible consequence to the population estimate.

The total number of rainbow trout in Fish Lake at the end of September 1997 was estimated to be 85,178, of which 36,121 were juveniles, 22,318 were subadults and 26,739 were adults. The approximate 95% confidence limits of the combined number of subadults and adults (49,057) were -35% and +67% or 32,097 and 82,014. That estimate was the seasonal maximum because it was calculated after the end of the juvenile in-migration period. The relatively high confidence limits of the estimate were due to basing the estimate on the relatively low sample sizes of the second recapture phase in September.

The estimate was three times greater than the estimate of 28,128 (95% confidence limits of 16,060 to 40,196) provided by a hydroacoustic survey of Fish Lake conducted on August 1, 1995. A review of the assumptions of the mark-recapture method showed no obvious methodological problems that could be responsible for the large difference in estimates. A review of the hydroacoustic survey identified several aspects of its methodology that may have led to an underestimate of trout number in 1995. The main problem was that the hydroacoustic survey could not directly survey shallow areas (<3 m deep) with dense growth of aquatic vegetation—areas of prime trout habitat.

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BC Ministry of Environment, Lands and Parks, Fisheries Branch (now the Ministry of Fisheries):
Maurice Lirette, Senior Fisheries Biologist, Williams Lake
Kenji Tsumura, Fisheries Research Biologist. Fraser Valley Trout Hatchery, Abbottsford

Taseko Mines Limited, Prosperity Camp:
Erick Bertsch, Site Coordinator
Kevin Maguire, Assistant Site Coordinator
Dean Foster, Environmental Monitor
James Combs, Environmental Monitor
Dwayne Kunz, Cook
Riley Brennan, Assistant Cook
Greg Johnson, Field Assistant

Triton Environmental Consultants Ltd.:
Roderick Bell-Irving, Manager Prosperity Mine Project, Internal Reviewer
Bruce Ford, Fisheries Biologist/Prosperity Mine Project Fisheries Coordinator
Rick Palmer, Fisheries Biologist/Crew Chief
Robin Longe, Fisheries Biologist
Ryan Liebe, Fisheries Biologist
Eva Wichmann, Fisheries Biologist
Terry Davies, Fisheries Technician
Derik Woo, GIS Specialist
Susan Labossiere and Louise Poirier, Wordprocessors

Simon Fraser University, Department of Mathematics and Statistics:
Carl Schwarz, Professor and External Reviewer

1.0 INTRODUCTION

1.1 Background

The copper-gold ore body of the proposed Prosperity Mine lies beneath the northern part of the Fish Lake-Fish Creek system. Development of the Prosperity Mine by Taseko Mines Limited will inevitably excavate part of the system, thereby reducing the amount of rainbow trout (*Oncorhynchus mykiss*) habitat. New fish habitat may have to be built to ensure that "no net loss" of fish habitat productive capacity is achieved.

The first step towards designing compensation habitat was to estimate the number of rainbow trout living in the Fish Lake-Fish Creek system. That task had two parts: estimate the number of 0 to 1 year-old juveniles that live in Fish Creek; and estimate the number of 1 to 6 year-olds that live in Fish Lake.

To estimate the number of stream-dwelling juveniles, Triton Environmental Consultants Ltd. (Triton) ran two sampling projects over the years 1996 to 1997: inlet and outlet fish fences on Fish Lake from April to August (Triton Environmental Consultants Ltd. 1997a, 1997b); and electroshocking surveys of juvenile trout density in Fish Creek during low-flow conditions in August and September (Triton Environmental Consultants Ltd. 1999).

To estimate the number of lake-dwelling juveniles and adults, a hydroacoustic survey of Fish Lake was conducted on August 1, 1995 (BioSonics Inc. 1995). Fifteen transects of the lake were run during day and night with both down- and side-looking sonar. Individual fish traces were counted on paper echograms and converted to fish densities-at-depth. Densities were expanded by lake volume-at-depth to obtain numbers of trout. Total number of trout in Fish Lake was estimated to have been 28,128 with 95% confidence limits of ±43% (16,060 to 40,196 fish).

The hydroacoustic study was controversial. The investigators stated that (BioSonics Inc. 1995: p. 5):

> "The high abundance of aquatic plants and the tendency of the fish to be near the water surface made sampling unusually difficult and affected the precision and accuracy of the survey."

A review of the hydroacoustic study by Dale Sebastian of the BC Ministry of Environment, Lands and Parks (MELP) was more critical (Sebastian 1996: p. 1):

> "when all of the uncertainties in the results are considered, it must be concluded that the acoustic population estimate for rainbow trout in Fish Lake is not reliable. Since the investigators were very conservative in all phases, I believe that the total estimate represents only a fraction of the actual trout population in this lake."

Sebastian (1996) did not suggest the degree to which the hydroacoustic study underestimated the number of trout in Fish Lake. However, if his criticisms are correct, then the degree of underestimation may have been large.

In response to those criticisms of the hydroacoustic study, Triton conducted a review of alternate methods for estimating the number of trout in Fish Lake. Two were identified:

- *a synthesis of Fish Lake trout population dynamics* based on biological data collected by the fish fence project and the electroshocking surveys, combined with information from creel surveys of the sport fishery on Fish Lake and assumptions about natural mortality rates and the proportion of adults that spawn each year; and
- *a single-census or Petersen-type mark-recapture study.* A known number of fish is captured, marked using a method that does not impair their subsequent survival, and released back into the lake to mix with the unmarked population. Then, the lake is re-sampled to estimate the ratio of marked to unmarked fish in the population. That ratio allows estimation of total fish number with statistical confidence limits.

The mark-recapture study was chosen for two reasons:

- its estimate of total population number was more accurate and reliable than that provided by a synthetic population model because it is based on fewer assumptions and because the statistical underpinnings of the mark-recapture method, including its sample size requirements and its potential sources of error, are well-known; and
- it provided statistical confidence limits for a population estimate, unlike a synthetic population model.

1.2 Objectives

The objective of the mark-recapture study was to provide a reliable estimate of the total number of rainbow trout in Fish Lake in late summer 1997.

1.3 Study Site

Fish Lake is located 246 km north of Vancouver and 127 km southwest of Williams Lake (Figure 1). It is situated at an elevation of 1,457 m in the Fraser Plateau physiographic region 10 km north of the boundary of the Fraser Plateau with the Chilcotin Ranges. The BC Ministry of Forests assigns the Fish Lake area to the very dry, cold variant of the Sub-Boreal Pine-Spruce Biogeoclimatic Zone.

Fish Lake drains an area of about 56 km^2 (Hallam Knight Piésold Ltd. 1995a) (Figure 2). Three tributaries enter the lake on its eastern and southern shores, as well as seven ephemeral streams that are water-filled only during spring freshet (not shown on Figure 2). Upper Fish Creek is the major source of inflows; its upstream terminus is Little Fish Lake. Lower Fish Creek is the only outlet of Fish Lake. It flows northwest out of Fish Lake and over a 10 m high waterfall before emptying into the Taseko River.

Fish Lake has a surface area of 111 ha. a shoreline perimeter of 7.8 km. and a volume of 3,945,400 m^3. It is a shallow lake with an average depth of 3.7 m and a maximum depth of 13.0 m (Figure 3). The extensive shallows in the southern half of the lake support high densities of aquatic plants during summer. The lake has one big island and four small islands. A public campsite, the Fish Lake Forest Recreation Site, is located on the northern shore of the lake. A small dock at the campsite provides mooring for boats and float planes.

Fish fence traps were maintained on the inlet and outlet of Fish Lake during the mark-recapture study (Figure 4). Profiles of dissolved oxygen (DO) and temperature (T) were taken every 3 to 4 days at a deep station called "DO-T" between the C1 and C3 trap stations.

1.4 Study Population

The Fish Creek-Fish Lake system supports a population of rainbow trout (*Oncorhynchus mykiss*), but no other species of fish. The population is isolated from other trout populations in the Taseko River valley by a 10-m high waterfall on Lower Fish Creek.

It is not known why only one species of fish resides in Fish Lake. There are 29 species of fish in the waters of the Cariboo-Chilcotin region and as many as 11 species co-exist in a single lake (Triton Environmental Consultants Ltd. 1997c). However, despite that diversity, rainbow trout monoculture lakes such as Fish Lake are common in the Cariboo-Chilcotin region. As of 1995, 131 of the 539 lakes (24.3%) in the region that had been surveyed by the Fisheries Branch of the Ministry of Environment, Lands and Parks (MELP) were classified as rainbow trout monocultures. Of those lakes. 65 were recorded as having been stocked by MELP with hatchery-reared trout over the 1946 to 1996 period. Trout in the remaining 66 lakes (12% of all lakes in the region), including Fish Lake, are assumed to be wild in origin.

The 1996 fish fence counts showed that pre-spawning trout migrated out of Fish Lake and into Fish Creek between May 9 and August 9, with most leaving before the end of June (Triton Environmental Consultants Ltd. 1997a). The 1997 fish fence counts showed similar timing; the first pre-spawners were counted on May 1 and the last were counted in mid-June with 90% of the total counted by June 6 (Triton Environmental Consultants Ltd. 1997b). In both 1996 and 1997, the majority of spawners entered Lower Fish Creek. That tributary contains most of the spawning and rearing habitat in the Fish Lake-Fish Creek system. Stream surveys conducted in 1996 suggested that some spawners may also have entered one of the other two tributaries of the lake, although no accurate counts were made.

In 1996, spawned-out adults returned to Fish Lake through the fences between May 11 and July 18, with the majority returning before the end of June. A similar timing was observed in 1997.

Rainbow trout eggs and alevins incubate in stream gravel for 4 to 8 weeks, depending on temperature (Scott and Crossman 1973), and then emerge as fry into the stream. Most fry spend between 6 and 18 months in Fish Creek before they migrate into Fish Lake, although a small percentage (<10%) appear to remain in Fish Creek for up to 36 months (Triton Environmental Consultants Ltd. 1999). The 1996 and 1997 fish fence projects showed that the majority of juveniles enter Fish Lake as 1 year-olds, having spent one summer, one winter, and one spring in the creek. In 1996, juveniles entered Fish Lake between May 12 and July 28 with the majority entering between mid-June and mid-July. In 1997, most juveniles entered the lake between June 5 and July 31.

Rainbow trout usually begin to mature sexually by age 3 (Scott and Crossman 1973). In Fish Lake, the majority of spawners counted at the fence traps were between 4 and 5 years old with only a few 6 year olds. Mature rainbow trout can spawn repeatedly over several years, but survival is often low and the number of repeat spawners, as indicated by the presence of spawning checks on scales or otoliths, can be less than 10% (Scott and Crossman 1973). The frequency of repeat spawners in the Fish Lake population is not known.

The length-age relationship of Fish Lake trout was well described by the conventional von Bertalanffy growth model (Figure 6). The model was fit to data using weighted nonlinear regression (SPSS Inc. 1994). The model is shown in this report because it was used to calculate the age (t, years) of fish captured in the mark-recapture study from their fork length (L, mm), i.e.

(1) $t = t_0 - (1/K)\log_e(1 - L/L_\infty)$

The values of the parameters t_0, K and L_∞ and their standard errors (SE) are shown in Figure 6.

Fish Lake trout have an unusually low physical condition, as indexed by their relative weight or W_r. W_r is the percent of "standard weight" or W_s. W_s is defined as the average weight for a given length that is equal to the 75th percentile of weights measured for that length for that species. Simpkins and Hubert (1996) recently proposed a W_s equation for lake-resident populations of rainbow trout based on 50 North American populations. Based on that equation, the average W_r of Fish Lake trout with lengths greater than 120 mm is 66.5 (SD = 9.5, n = 1,217). A comparison of this average W_r for Fish Lake trout with W_r for other lake-resident rainbow trout populations in BC (Triton, unpublished data), Washington State (Liss et al. 1995) and California (Zardus et al. 1977), showed that the Fish Lake population fell within the lowest 20% of all populations.

Low physical condition is most likely the result of food limitation due to high population density. Thus, the relative weight data suggests that the Fish Lake trout population has high numerical densities (number/hectare of lake surface area) relative to other rainbow trout populations.

Fish Lake trout are also heavily parasitized (Rick Palmer, Triton, personal communication). Quantitative studies on parasite burden are in preparation.

A sport fishery is conducted on Fish Lake from May to October. Relatively few sportfishers make use of the campsite because of the remote location of Fish Lake, difficult road access, and small size and low quality of trout. The Province has set a catch limit of 8 trout/day/person for Fish Lake. All other lakes in the Cariboo-Chilcotin region have a catch limit of 5 trout/day/person.

Hallam Knight Piésold Ltd. (1995b) reported that in 1995 anglers caught 1,615 trout of which 400 were kept and 1,215 were released live. Hallam Knight Piésold Ltd. (1997a) reported that in 1996 anglers caught 2,137 trout of which 651 were kept and 1,486 were released. Those numbers are underestimates of the total catch because Hallam Knight Piésold Ltd. excluded all records of fishers that they were not able to interview because fishers were on the lake at the time the creel surveyors visited the campsite. Also, they did not audit their creel surveyors to determine what proportion of the total number of visitors were actually interviewed.

Those numbers were recalculated to account for non-interviewed and missed anglers, using data collected in 1997 (Triton Environmental Consultants Ltd. 1998). In 1995, anglers caught a corrected total of 4,150 trout of which 1,009 were kept and 3,141 were released. In 1996, anglers caught a corrected total of 4,900 trout of which 1,602 were kept and 3,287 were released.

The numbers of trout kept by sport fishers are equivalent to a fishing mortality rate of between 2.5 and 4.0%/year, which is a very low exploitation rate. That range of rates was based on the assumptions that:

- only trout longer than 200 mm were kept by anglers instead of being returned live to the lake (Triton Environmental Consultants Ltd. 1998). That lower limit of trout size is supported by information from other angler fisheries on lake-resident salmonids. For example, Rieman and Maiolie (1995) reported that 200 mm was the lower limit of kokanee (*Oncorhynchus nerka*) lengths taken by anglers in seven lakes of Idaho and Oregon. Korman et al. (1994) used that lower limit in their simulation model of rainbow trout population dynamics in small British Columbia lakes;
- there were 37,898 of those subadult and adult trout in Fish Lake (see Table 7: the sum of adults and half the number of subadults calculated in 1997); and
- mortality of trout caught and then released is, on average, 5% or less. That assumption allows capture mortality to be ignored for all practical purposes. Korman et al. (1994) assumed an average loss of 5% of released rainbow trout in their simulation model.

Since only 2.5 to 4.0% exploitation occurs each year, natural mortality is more important than fishing mortality in controlling the number of trout in Fish Lake.

1.5 Study Plan

Timing of the mark-recapture study was based on the requirements of the method. One of the key assumptions of a Petersen mark-recapture study is that the population under study has zero immigration and emigration during the recapture phase of the study. In 1996, the annual migration of juvenile trout into Fish Lake from Fish Creek ended by July 10 and the return of spawners to the lake ended by July 18 (Triton Environmental Consultants Ltd. 1997a). Therefore, the mark-recapture study was planned to begin in the second half of July 1997.

The duration of the study was based on three considerations: sample size, logistics and the need to detect possible differences in vulnerability to capture between marked and unmarked trout. Robson and Regier (1964) calculated the combination of marked and sampled fish that are necessary to provide estimates of population number with error no greater than 50%, 25% or 10% of the true value 19 times out of 20. The first error level is appropriate for preliminary population surveys, the second for population management, and the third for scientific research. Following Ricker's (1975) recommendation, the error level appropriate for population management was adopted. A 25% error level and an assumed trout population of 30,000 (based on the BioSonics Inc. (1995) study) requires a minimum sample size of 1,000 marked fish and 2,000 examined fish. Those numbers had to be increased to account for a population that may have been much greater than 30,000. In the absence of any reliable estimate of the upper bound of the true population, the sample size requirements were doubled to 2,000 marked fish and 4,000 examined fish.

To capture and process 6,000 fish within a study period of a few weeks required processing several hundred fish each day. Net traps are the only fishing gear that allow capture of such large numbers of trout in a non-destructive manner (Hubert 1996; Triton Environmental Consultants Ltd. 1992, 1994). All other methods are either too slow (angling) or too lethal (gill nets) or do not sample a wide range of sizes (beach seines). A 1 day test of a net trap in Fish Lake in October 1996 showed that it could capture 150 fish in a 24-hour period. Therefore, the study plan was based on the simultaneous use of two net traps installed at opposite ends of Fish Lake. If catches in July 1997 were similar to those in October 1996, then approximately 300 fish could be captured and processed each day. At that rate, 2,000 trout could be marked in 7 days, and 4,000 fish could be examined for marks in the following 14 days for a total of 21 days. Thus, the first (marking) phase of the field program was planned to begin in mid-July, and the second (recapture) phase was planned to begin one week later and end after the first week in August.

A third phase of the field program was included in the study plan to test for possible differences in vulnerability to capture between marked and unmarked trout in Fish Lake. Ratios of marked to unmarked fish measured immediately after the marking phase may have underestimated true marked-unmarked ratios because marked fish may have temporarily reduced their activity level and so may not have been caught by passive gear in proportion to their true abundance. To detect this phenomenon, if it existed, we planned to wait at least 1 month after the end of the first recapture phase, and then return to Fish Lake, re-install one trap net, and measure marked-unmarked ratios for an additional 1 week. That was long enough to capture and examine approximately 1,000 trout. That number was large enough to provide reliable estimates of marked-unmarked ratios.

Thus, the third and last phase of the field program was planned to begin after the first week of September and end by mid-September. Logistic requirements delayed this final field phase until the period of September 22 to 30.

A variety of marks and tags were available (Guy et al. 1996). A mark was chosen rather than a tag because the additional information that could be provided by tags was judged to be not worth the additional problems involved in applying tags. Individually-numbered tags are commonly used in fisheries research where the objective is to delineate a migration route, identify discrete breeding populations, and estimate population size and exploitation rate. However, they are unnecessary for studies such as this one that seek only to estimate population size. Tags would require more effort and time to apply than a mark. They would cause greater mortality than a mark because attaching a tag involves puncturing a fish's skin, with the attendant dangers of blood loss and infection, whereas marking involves clipping external structures such as fins or bones that are less vascularized than internal musculature. Unlike marks, a proportion of the tags would inevitably be shed and lost, and there was the possibility of entanglement of the tags in the mesh walls of the net traps (Ricker 1975; Guy et al. 1996).

The first choice of an external mark was to remove the adipose fin because its removal is permanent in salmonids and it has little effect on subsequent survival. However, adipose fin clips had previously been used as part of the 1996 fish fence program, and preliminary results of the 1997 fish fence program showed that at least one adipose-clipped fish had survived to be counted again at the fences. Partial clips of the caudal fin also had to be rejected because previous sampling of Fish Lake trout for genetic purposes had involved clipping the caudal fin of over 100 fish. There was also a danger that partial clips of any fin could be confused with natural fin injuries. Many Fish Lake trout have damaged fins. To avoid this problem, a partial clip of the maxillary bone on the surface of the upper right jaw of a trout was chosen. Rainbow trout have long maxillary bones (Scott and Crossman 1973), thereby providing enough material for an obvious clip. It would be difficult to confuse a clip of a maxillary bone with natural jaw injuries. Although the maxillary regenerates after clipping (Wydoski and Emery 1984), the study duration was short enough that the mark would remain visible throughout the two recapture phases.

2.0 METHODS

2.1 Water Temperature

At least once each day during the marking phase and the first recapture phase, surface water temperature was measured with a hand-held thermometer at each of the campsite (C1) and island (I1) working sites and at each of the inlet and outlet fish fences. During the second recapture phase, surface water temperature was measured several times daily at C1 and I2, but no temperatures were taken at the fences because they were not operating at that time due to a lack of flows. Every 3 to 4 days during all three phases, temperature profiles from the surface to the bottom of the lake at 1-m intervals were made at the DO-T station (depth = 12 m) with a YSI Model 51B dissolved oxygen-temperature meter.

2.2 Inlet and Outlet Fish Fences

The ice covering Fish Lake did not completely break up until early May 1997. Fences could not be installed in the inlet and outlet streams while ice was on the lake. To count the number of trout that were migrating into and out of the lake under the ice, underwater video cameras were installed in both the inlet and outlet streams from April 20 to May 14 (Proulx et al. 1997). The cameras covered the entire stream width, operated 24 hours a day and took one picture every 0.2 seconds. The number of fish that passed by each camera was counted by viewing the film. The length of each fish was estimated from landmarks of known size placed in the camera field.

On May 12 fish fences were installed in both the inlet and outlet of Fish Lake. The fences were monitored twice daily until August 17 when flows in both Upper and Lower Fish Creek were so low that no movement of fish was possible. Flows remained low during the rest of August and September. Fences were finally removed from the streams on September 29.

Each fence was a "W" design, incorporating an upstream and a downstream live box (Conlin and Tutty 1979). Triton Environmental Consultants Ltd. (1997a, 1997b) includes a detailed description of the construction and operation of the fences during 1996 and 1997. Each fence was visited at least once each day during the period of monitoring. At each visit, surface water temperature was measured. Then, the number of fish in the upstream and downstream boxes were counted, their fork lengths were measured in 50 mm intervals (i.e. 50 to 100 mm, 101 to 150 mm, etc.) and they were released to continue their migration.

Lengths, weights and scale samples (for aging purposes) of a randomly-chosen subsample of fish were individually measured at each daily visit to each fence. Those measurements ceased after June 29 because sample sizes for length-weight and length-age analyses had been satisfied.

2.3 Creel Survey

A survey of the number of visitors to the campsite at Fish Lake and of their fish catch began in May 1997 and continued throughout the mark-recapture study period. Each day at 1100 and 1800 h, an environmental monitor visited the campsite and recorded the number of parties, the number of individuals in each party, the amount of time they spent fishing, the number of fish captured, released and kept by each party, and other information. To ensure that sportfishers reported any marked fish that were killed and removed from the lake, a one-page leaflet with a figure of a trout showing a clipped maxillary was distributed to all visitors to the campsite during the marking phase and the first recapture phase.

Effort and catch statistics of the 1997 creel survey were corrected for two sources of error: anglers seen on the lake but not interviewed, and anglers missed by environmental monitors because the twice-daily schedule of visits did not match the timing of angler arrivals and departures. The first type of error was corrected by multiplying the number of anglers seen on the lake on a daily basis by the average effort/day and the average number of fish killed/day, both averages being calculated over the entire year. The second type of error was corrected using the results of an audit program. For each of 9 days scattered over the fishing season in 1997 the number of visitors at the campsite were monitored on a half-hour basis. The ratio of the average daily number of visitors counted by auditors to the average daily number counted by environmental monitors for those 9 days was used to expand effort and catch statistics. Thus, the total corrected number of trout killed over one week was the sum of the number recorded from interviews plus the number calculated from anglers seen but not interviewed (= number of anglers seen x mean number of trout killed/angler/day) plus the number missed by monitors (= estimated number of anglers not seen x mean number of trout killed/angler/day).

2.4 Capture Techniques

All marked trout and the great majority of trout examined during the two recapture phases of this study were captured with two fish traps. Each trap consisted of three components: a 40 m long and 3 m deep guide or "leader" net, a square mesh box with a surface area of 4 m^2 and a depth of 3 m, and two mesh wings attached to the sides of the box that were each 8 m long and 3 m deep. The knotless mesh was dark green in color with a 3/4 inch stretched mesh size. Hubert (1996) and Triton Environmental Consultants Ltd. (1992, 1994) describe trap nets that are similar in design to those used in the mark-recapture study.

The leader net was set perpendicular to shore with the ends of the cork and lead lines securely tied to a tree. The cork and lead lines of the other end of the leader net were tied to the cork and lead lines of the trap box. The box was anchored in place by cinder block weights attached by ropes to the two outer corners of the box. The top of the box was kept from collapsing on itself by tying four 2 m long pieces of wood called "spreaders" to the four corners of the box's cork line. The wings attached to the sides of the box were anchored in place by cinder block weights attached by ropes to the ends of the cork lines from each wing. The wings were angled in towards the leader net so that the trap appeared from the surface as a giant arrowhead pointing offshore.

During the first phase of the study, traps were installed for periods of 2 to 9 days at four stations in the northern half of the lake (Figure 4). They were labeled C1 to C4 because the first trap to be installed (C1) was set next to the campsite dock. (The campsite dock was also one of two fish processing areas for the mark-recapture study.) Traps were also installed for periods of 2 to 13 days at three stations along the shores of the big island in the southern half of the lake. They were labeled I1 to I3. (I1 was the second processing area of the study.)

During the third phase in September, a trap was installed at C1 for 5 days and then moved to I1 for another 2 days.

Once a trap had been closed by tying off the mouth in the top of the box and tying the spreaders to the top of the box, it was left to soak overnight. During that time, fish that encountered the leader net while swimming in an alongshore direction were forced to move along the leader net up to the box. The oblique slant of the wings forced fish to enter a small space between the leader net and the box. In the center of that space was a metal-framed mouth about 0.3 m deep and 0.15 m wide. Fish that entered the box through that mouth tended to stay inside the box, either because they could not find the mouth again or because they did not recognize the mouth as an exit.

Each trap was moved several times during the study to ensure that location was not biasing catch rate or the size distribution of fish. Locations were chosen so that the trap box reached from the lake surface to the lake bottom.

The other type of gear used to collect fish was a 45 m long beach seine with a stretched mesh size of 1/4 inch in the bunt and 1/2 inch in the wings. This net was set at several locations around the lake during the first recapture phase. However, it was not widely used because it collected mainly juvenile trout—those that tended to congregate in shallow inshore areas where beach seines are useable—and because it tended to hang up on the woody debris that litters the shores and bottom of Fish Lake.

2.5 Marking and Examining

This section provides a detailed description of how trout were handled during capture, marking and examination. This detail was necessary to show the type and level of injury that trout sustained during the study, and thus the effect of handling fish on their survival and population estimation.

Each morning the box of a trap was opened by untying the mesh opening in the top and untying the spreaders. Then fish were brailed with a long-poled dipnet out of the box into

20 L buckets full of fresh lake water. The buckets were quickly driven by boat to a work site at either the campsite dock (C1) or at the big island (I1), depending on which work site was closest to a trap. At a work site, fish were released into a wooden, fiberglass-lined holding tank with dimensions of 0.9 x 0.9 x 1.2 m. A bilge pump powered by a car battery directed a continuous stream of clean lake water through a plastic hose into the tank, thereby allowing the live fish to be held safely for several hours at relatively low water temperatures until they could be processed.

In two cases, a trap collected so many fish that it had to be temporarily closed after brailing out several hundred fish. After processing the first batch of fish, the trap was re-opened later that day and the remaining fish were processed.

During the marking phase of the study, all fish collected by the traps that appeared healthy and in good condition were marked. Fish that were dead or injured were not marked. The first step in the process was to brail about 10 to 30 fish with a dipnet out of the holding tank into a 20 L bucket. Any fish that were dead or that showed signs of injury such as large surface lesions caused by an avian predator or a broken jaw caused by previous capture and release by a sportfisher were removed from the bucket and their fork length (the distance from the tip of the snout to the fork in the tail) was measured to the nearest millimeter with a measuring board and recorded. Dead fish were buried on land, live fish were released back into the lake.

All of the healthy, intact fish remaining in the bucket were marked. A biologist grasped a fish with two hands and placed it on a measuring board where fork length was read out loud. This length was recorded by a second biologist who also assigned the measurement a unique identification number. Without releasing the fish, it was lifted off the board and presented head-first and right-side up to a third biologist who quickly snipped several millimeters off the tip of the fish's right maxillary bone with sharp scissors. The success or failure of a clip was recorded by the second biologist. The fish was then released into a 20 L bucket of clean water. Measurement and marking of a fish usually took 5 seconds or less. Any fish that required more that 5 seconds to process was temporarily returned to the bucket so that it would not asphyxiate.

After processing, the batch of trout were examined to determine if they had suffered handling or marking injuries. Any fish that could not swim in an upright position or that showed any bleeding was killed to prevent it from being released into the population. However, few fish showed such injuries. Fish were then released live into the lake. To ensure mixing of marked fish with the rest of the population, batches of marked fish were released at sites throughout the lake (Figure 5).

Processing was similar during the two recapture phases with the exception that the fish's right maxillary was not clipped but was instead examined for the presence or absence of a mark. All fish were examined for a mark regardless of their physical condition. Examined fish were released into the center of the lake mid-way between the campsite dock and the big island.

2.6 Survival Tests

Two sets of tests were made to assess the effect of capture in a trap, handling, and marking on survival of trout. The first set were made during July and August, and the second set were made during late September.

In the first set, six batches of trout were not released directly into Fish Lake, but were instead placed into a livebox for 24 hours. The plywood box was 1 m deep, 1.2 m long and 0.65 m wide with four mesh windows and a hinged lid. The box was placed in shallow water about 0.95 m deep, and was weighted with three cinder blocks to prevent it from being overturned or swept along the shore by wind or waves. After overnight soaking, the box was opened and the survivors were counted and released into the lake. Those fish that had died or were obviously in poor condition because they could not maintain an upright position were measured for fork length and then buried on land. The survival tests were not run longer than 24 hours because mortality related to handling and marking usually occurs soon after processing (Guy et al. 1996). We were also concerned that imprisonment in the box and lack of food for periods greater than 24 hours would cause mortality that was not related to handling or marking.

In the second set of tests, another six batches of trout that had been examined for marks were held in liveboxes for 24 hours before being returned to Fish Lake. However, each batch was split into three length groups corresponding to juveniles (70 to 139 mm), subadults (140 to 229 mm), and adults (230 to 330 mm) and placed into their own separate livebox. This study design allowed survival to be explicitly compared between length groups.

2.7 Population Estimate

The total number of rainbow trout in Fish Lake was the sum of the numbers of 1-2 year-old juveniles, 2-3 year-old subadults, and 4-6 year-old adults. Mark-recapture techniques could only be applied to estimating numbers of subadults and adults because trap nets sampled subadults and adults in proportion to their abundance in the lake population, but underestimated the relative abundance of juveniles. The youngest and smallest juveniles were able to escape through the mesh walls of the traps. Number of juvenile trout was estimated using a combination of data from this study and the 1997 fish fence study.

Numbers of subadult and adult were estimated with Chapman's version of Petersen's method (Ricker 1975):

(2) $N = [(M + 1)(C + 1)]/(R + 1)$

where N = number of fish in a population class at the end of the marking period, M = number of marked fish in that class at the end of the marking period that survived handling and marking, C = number of fish in that class examined for marks during the recapture phases, and R = number of recaptured marked fish in that class counted during the recapture phases.

Capture, handling and marking are stressful to fish and can be expected to cause some mortalities. Thus, a conservative estimate of N must be based on the assumption that some portion of the total number of marked fish did not survive to be recaptured. In this study, M was assumed to be a fraction of the total number of marked fish released back into Fish Lake (M') or

(3) $M = sM'$

where s = handling/marking survival.

Following Ricker's (1975) recommendation, 95% confidence limits of N were calculated by assuming that recaptures follow a Poisson distribution. Lower and upper 95% confidence limits of the number of recaptures were taken from Ricker's (1975: Appendix II) table of confidence limits for a Poisson distribution and substituted into equation (2) to obtain 95% confidence limits of N. The true confidence limits of N are greater than those estimated by Ricker's (1975) table because not all marked fish are assumed to have survived. However, the difference is negligible because average survival was assumed to be high, i.e. 92%, based on 24-hour survival studies.

3.0 RESULTS

3.1 Water Temperature

Average surface water temperature during the first phase of field work increased from 14.5°C on July 14 to a peak of 19.4°C on July 20, and then fell to 14.6°C by July 25 (Figure 7 and Appendix A). From July 26 to August 3, average surface temperature varied within a narrow range of 15.9 to 17.8°C. This daily variation in mean surface temperature is assumed to have been driven by daily variation in environmental variables such as air temperature, solar radiation, precipitation, and water flow into and out of the lake.

Surface temperatures at most dates were lowest at the inlet, intermediate at the island site and the campsite, and highest at the outlet, indicating heating of surface water as it passed through the lake.

Average surface water temperature during the second phase of field work decreased continuously from a peak of 14.4°C in the afternoon of September 22 to 9.5°C in the morning of September 29 (Figure 8). There was a clear daily temperature cycle at station C1 with low temperatures in the morning, higher temperatures in the afternoon, and lower temperatures again in the evening. A similar daily cycle is presumed to have occurred at station I1 and at all other places in the lake.

The seven vertical temperature profiles taken between July 14 and August 3 at the DO-T station showed roughly similar shapes: constant temperature in the upper mixed layer, a strong thermocline between 6 and 8 m depth, and constant temperature below the thermocline (Figure 9). If one defines the thermocline of a profile as the depth at which the temperature change is greatest, then the mean thermocline was at 7.3 m with a standard deviation (SD) of 0.6 and a sample size (n) of 7.

The two temperature profiles taken during the second recapture phase in September showed that the lake was in the process of overturning at that time. The thermocline was at 9.5 m on September 24 and then it dropped a further 1 m to 4 days later. There was little change in temperature with depth in the upper mixed layer above the thermocline.

In summary, surface temperatures of Fish Lake increased in a south-north axis from the inlet to the outlet, and there was a daily cycle at each station with the highest temperatures in late morning and early afternoon. The depth of the thermocline was constant at 7.5 m during the second half of July, but it sank to 10.5 m by late September as the lake cooled. This spatial and temporal variation in temperature of the upper mixed layer may have influenced the temporal and spatial distribution of trout in Fish Lake and thus the location and magnitude of rainbow trout catches and sizes. This issue was examined in section 3.4.

3.2 Inlet and Outlet Fish Fence Counts

One of the key assumptions of the mark-recapture study was zero immigration and emigration from the study population during the study period. In this section, the fence count data was examined to test that assumption.

From the beginning of the marking phase on July 15 to the end of the daily monitoring of the fish fences on August 22, 1997, a total of 3,273 rainbow trout were counted leaving upper and lower Fish Creek and entering Fish Lake (Figure 10, Table 1 and Appendix B). Over 97% were juveniles, defined for the purposes of this study as those fish with fork lengths less than or equal to 140 mm. Over the same time period, only 63 trout left Fish Lake and entered Fish Creek. Over 71% were juveniles and the remaining 29% were sub-adults and adults (151 to 350 mm).

Flows remained at zero levels during the remainder of August and September and the fences were not monitored. Thus, there was no recorded immigration or emigration of fish into Fish Lake during the second recapture phase in late September.

The length frequency distribution of trout subsampled for size at the inlet and outlet traps in May showed three modes: a small one at 95 mm, a larger one at 135 mm, and a major mode at 275 mm (Figure 11). The June distribution showed three similar modes, but there was a clear change in the average size of the smallest trout that entered the lake—those that entered in June were much smaller than those that entered in May.

According to the length-age relationship developed from the 1996 and 1997 fish fence studies (Figure 6), the three modes of Figure 11 correspond to 1 year-old juveniles, 2 year-old subadults and 4 to 6 year-old adults. When lengths were converted to ages with equation (1) and grouped into age classes 0.5 to 1.4, 1.5 to 2.4, etc., the age frequency distributions were found to be dominated by 2 and 4 year-olds in May and 1 and 4 year-olds in June (Figure 12).

In summary, all immigration ceased 1 month before the start of the second recapture phase. If immigration occurs between the marking and recapture phases of a Petersen mark-recapture study but little or no emigration, as was the case for the Fish Lake-Fish Creek system in 1997, then the population estimate is unbiased and refers to the population number at the end of the recapture phases. The population estimate derived in this study was based, in part, on the second recapture phase (see section 3.11). Therefore, that estimate was not biased by immigration or emigration.

3.3 Creel Survey

Another key assumption of the mark-recapture study was that fishing did not remove a significant number of marked fish from the study population. This section tested that assumption using creel data.

A total of 4,869 rainbow trout were captured by anglers from Fish Lake from May 30 to September 27, 1997, of which 3,680 were released and 1,189 were killed and kept (Triton Environmental Consultants Ltd. 1998). Most kept trout were between 200 and 300 mm long. Those fish were caught by a total of 1,275 angler-hours and 388 angler-days (where an angler-day was an average of 3.3 angler-hours/day). The average number of fish caught/angler-day was 12.7 and the average number of fish kept/angler-day was 3.2. If an angler-day is standardized to the 4-hour day used by MELP, then those statistics rise to 15.7 and 4.0 trout/standard angler-day. Angler success, regardless of how it is calculated, was considerably less than the maximum creel limit of 8 fish kept/angler-day that has been set for Fish Lake by provincial fishing regulations.

The distribution of catch was bimodal with one mode in early July and a second mode in late August (Figure 13).

A total of 864 trout were estimated to have been caught and removed from Fish Lake during the mark-recapture study: 60 during the marking phase (July 15-21), 76 during the first recapture phase (July 22 to August 3), 656 between August 4 and September 21, and 72 during the second recapture phase (September 22-30). None of the fish killed between July 15 and August 3 were reported as marked, but one party reported the capture of a marked trout that was returned live to the lake.

The most important issue for purposes of population estimation was that 76% of all fish killed during the mark-recapture study period were taken between the first and second recapture phases. It is reasonable to assume that some marked trout were removed from the pool of marked fish by angling during that period. Unfortunately, there is no simple way of correcting for the loss in the absence of any independent information on the number of marked fish in the creel.

The simplest method of estimating the possible bias introduced by those catches is to assume that:

- all killed trout were 200 mm long or greater; and
- the probability of a marked trout being removed by anglers was the ratio of the number killed to the estimated number of fish vulnerable to capture or 0.023 (= 876/37,898). The vulnerable population was assumed to be all adults plus half the number of subadults (see Table 7). Thus, a total of 26 marked trout (= 0.023 x 1,140) may have been removed by anglers, of which most would have disappeared from the pool of marked trout between the first and second recapture periods. That number is small in relation to the 99 trout of that vulnerable population that were assumed to have died from an 8% handling and marking mortality. We conclude that the sport fishery on Fish Lake resulted in an upward bias on the estimate of adult trout number, but the bias was negligible compared to other sources of error.

3.4 Trap Net Catches

From July 15 to September 30, a total of 7,926 trout were captured in 46 trap net sets (Table 2). The number of fish caught in a trap ranged from 7 to 439, and soak time ranged from 9.3 to 42.6 hours. Catch-per-unit-effort or CPUE, defined as the number of fish caught for each hour of soak time, ranged from 0.3 to 23.9 fish/hour with an average of 7.9 fish/hour (SD = 4.7, n = 46).

CPUE for the marking phase and first recapture phase decreased with time after installation of a trap at 2 of the 7 sites (C1 and C3), but not at the other 5 sites (Figure 14). The correlation coefficient (r) between all estimates of CPUE and the number of days after installation of a trap was not significant (r = 0.30, P = 0.064).

CPUE was also not significantly correlated with distance from the inlet fence trap to a trap site (r = 0.05, P = 0.752) or with the average surface water temperature of the lake on the day that a trap was closed (r = 0.24, P = 0.139) or on the day that a trap was opened (r = 0.25, P = 0.118).

However, the three greatest measurements of CPUE, those for C1 on July 15 and for C3 on July 23 and 24, were all obtained on dates when the mean lake-wide surface water temperature was less than 16°C. This observation suggested that CPUE varied inversely with average temperature of the upper mixed layer of the lake during July or with another environmental variable that was linked to sudden changes in temperature of the upper mixed layer.

Comparison of September CPUE and average temperatures did not support the inverse-temperature hypothesis—all CPUE fell within the range of 3.5 to 7.0 fish/hour and none approached the high levels measured in July (Figure 15).

We concluded that CPUE was not varying directly with temperature, but was following another environmental variable that was associated with sudden decreases in temperature of the upper mixed layer during mid-summer. That unknown variable attracted trout to the surface of the lake resulting in unusually high surface aggregations of trout and unusually high CPUE for brief periods of time.

3.5 Beach Seine Catches

A total of 5 beach seine sets were made during the recapture phase: two on the afternoon of July 25 and three in the early morning of July 27 (Table 2). The first set was made on the gravel beach near the campsite dock, but only 3 trout were captured. The second set was made later that day just south of the C2 trap net site. A total of 245 trout were captured of which 90% were juveniles less than 140 mm long. Of those 248 fish, 2 were recaptures.

Two days later the third set was made at dawn at the I3 site on the big island. The seine hung up on woody debris that covers most of the shorelength of the lake and fewer than 30 fish were caught. Two more sets were then made off the campsite dock. However, a total of only 34 fish were collected that day for 4 hours of difficult labor. Of those 34 fish, 1 was a recapture.

In summary, seines were not effective for catching large numbers of trout in Fish Lake, and were not used after July 27.

3.6 Marking Phase

A total of 2,196 trout were captured by trap nets during the 7 day marking phase, of which 2,059 were marked, 89 were not marked because they were dead or moribund at time of marking, 28 were not marked because the maxillary was missing due to a jaw injury or because the maxillary had grown into the mouth instead of along the outside of the upper jaw, 5 escaped the net traps or the holding tanks before they could be measured or marked, and 15 had been marked earlier in the marking phase (Table 3 and Appendix C).

The marked fish ranged in length from 74 to 315 mm with an average length of 202 mm (SD = 63, n = 2,059) (Figure 16). The length frequency distribution of the marked fish showed three modes at 100, 170 and 260 mm.

There were relatively few marked fish less than 90 mm long. That was due to escape of small trout through the meshes of the trap walls, rather than to avoidance of traps, because beach seine catches showed that juvenile trout are common in the inshore areas where trap nets were installed. Several juveniles less than 100 mm long were usually found gilled in the box walls in each trap opening, indicating that juveniles attempted to move through the mesh walls of the trap (see section 3.7).

In contrast, the rapid decrease in the number of fish longer than 270 mm was not a gear-related phenomenon, but reflects the relative abundance of those fish in the population. Few trout longer than 315 mm have ever been captured in Fish Lake despite several years of sampling with a variety of gear types (Hallam Knight Piésold Ltd. 1995a; Triton Environmental Consultants Ltd. 1997a, 1997b, 1998, 1999).

The three modal lengths correspond to age classes 1 to 2, 2 to 3, and 4 to 6 years, according to the length-age curve developed from the 1996 and 1997 fish fence studies (Figure 6). In this report, those length classes are called juveniles (70-139 mm), subadults (140-229 mm) and adults (230-330 mm).

It is important to recognize that those names are used for convenience only and are not based on detailed knowledge of relationship between size and sexual maturation in the Fish Lake population. For example, although the adult size class is the largest of the three size classes, and most spawners are certainly contained within that class, not all fish in the adult size class will necessarily spawn each year—some may have too low a physical condition to allow sexual maturation. Also, some precocious males may engage in spawning activity even though they are small enough to fall within the subadult or juvenile size classes.

The age frequency distribution of marked trout shows that trout aged 1 to 2 years old were not sampled by trap nets in proportion to their true abundance in the population (Figure 17A). In any stable self-reproducing population of fish, the youngest fish are most abundant and the oldest are least abundant. However, the most abundant age classes of marked fish were the 3 and 4 year-olds, indicating that the abundance of 1 and 2 year-old juveniles was underestimated.

We concluded that only the subadults and adults were marked in proportion to their true abundance in the population.

3.7 Recapture Phases

A total of 6,012 fish were captured during the two recapture phases: 5,059 during the first recapture phase and 953 during the second recapture phase (Table 3 and Appendix D). Of those, 6,007 were examined for marks and 5 escaped before they could be examined. A total of 78 of the examined fish were found to be marked with a clip on the right maxillary.

The examined fish ranged in length from 74 to 323 mm with an average length of 182 mm (SD = 65, n = 6,007) (Figure 16). The length frequency distribution of examined trout showed approximately the same three modes as were observed in the length frequency distribution of marked fish. The age frequency distribution of examined fish showed that 2 year-olds were the most abundant age class (Figure 17B).

In contrast to traps, seines showed selection for juvenile trout, for example over 90% of all seine-caught fish were less than 130 mm long and 94% were 1 or 2 year-olds (Figure 16). Seine-caught trout ranged in length from 74 to 290 mm, with an average length of 113 mm (SD = 30, n = 282). That average length was highly significantly lower than the average length of trap-caught marked and examined fish (t_{6005} = 18.798, P<0.001).

A Kolmogorov-Smirnov two-sample test showed that the length frequency distributions of marked and recaptured trout were highly significantly different from each other (Kolmogorov-Smirnov Z statistic = 5.8049, P<0.001) (Figure 19 and 21). There was a lower proportion of adult fish, and a greater proportion of juvenile fish, in the two recapture phases than in the marking phase. The proportions of juveniles in the trap catches also increased between the two recapture phases (Figure 18). That pattern was also shown in the age frequency distributions—the most common age of examined fish was 2 years old instead of 3 to 4 years old for marked fish (Figure 17B).

Those differences in size and age between marking and recapture phases have the potential to substantially affect population estimates. There were four possible explanations:

Size and age distributions of the Fish Lake population changed between the marking and recapture phases because of immigration of juveniles into the lake. The patterns shown in Figures 16 to 18 may have been the result of continuous immigration of juveniles into the lake throughout the study period combined with no change in the number of subadults and adults. That explanation required a source for juvenile immigrants. Only 1,039 juveniles were counted into Fish Lake from Fish Creek from July 22 to August 22, and none were counted into the lake from Fish Creek after August 22 (see section 3.2). Therefore, for that possibility to be correct, large numbers of undocumented juveniles would have had to enter Fish Lake from tributaries other than Fish Creek, and they would have had to continue moving into the lake after flows in Fish Creek were too low to allow fish movement. Immigration of undocumented juveniles was unlikely for two reasons: small tributaries have much less spawning and juvenile rearing habitat than either upper or lower Fish Creek, and all tributaries of the Fish Creek watershed share the same precipitation regime and so would be expected to run dry at roughly the same time each summer.

In summary, the change in size and age of Fish Lake trout between the marking and recapture phases was not due to immigration of juveniles during the study period.

Size distribution of the Fish Lake population changed between the marking and recapture phases because of growth recruitment of lake-resident juveniles into net traps. If there was little or no additional immigration of juveniles from non-monitored tributaries, then juveniles must have recruited from a population that was already resident in the lake by late July, but they had to grow to a minimum length before they could be retained by traps and be counted and measured. As juveniles grew in length over July to September, an ever larger proportion of the juveniles in the lake became vulnerable to capture in net traps. That phenomenon is called growth recruitment.

If growth recruitment occurred, then mean length and age of juveniles caught in the traps should have been significantly greater than mean length and age of juveniles counted through the fences. Comparison of length frequency distributions (Figures 11 and 16) and age frequency distributions (Figures 12 and 17) confirmed that prediction. Average length of juveniles in the traps was greater than 100 mm, whereas average length of juveniles passing through the fences in June, the month of peak juvenile immigration, was at least 30 mm shorter. The dominant age of juveniles in the traps was 2 years, but it was 1 year old in juveniles measured at the fences in June. Clearly, net traps did not sample the entire juvenile size range, but instead retained only the largest juveniles in the lake.

In summary, the available data on fish sizes supports the scenario of growth recruitment as a cause of changes in size and age between marking and recapture phases.

Size distribution of the sampled population changed between marking and recapture phases because of a difference in the spatial coverage of sampling between phases. This was possible because marking was done only at 3 of the 7 sites (C1, C2 and I1), and all of those sites are classified as eastern sites, whereas fish examined for marks were caught at all 7 sites covering both eastern and western sides of Fish Lake. Average size of trout in Fish Lake varied along east-west and north-south gradients with the largest trout in the southeastern quadrant and the smallest trout in the northwestern quadrant (Figure 22; see section 3.8). Thus, the fish examined during the recapture phases would have tended to include a greater proportion of juveniles than would marked fish.

However, it was unlikely that differences in spatial coverage in sampling could have been solely responsible for the steady increase with time in the percent of the catch made up of juveniles. It was more likely to have been a contributing factor rather than a primary factor.

The schedule of mortality with body size was different for marked fish than for unmarked fish as a result of the marking process. This was possible only if one assumed that adult marked fish had a greater mortality rate than adult non-marked fish or of juvenile and subadult marked fish. However, the 24-hour survival tests showed that there was no significant difference in survival between marked and unmarked fish, and no evidence to support a change in survival with fish size (see section 3.10).

In summary, the differences in length frequency distribution between recaptured and marked trout were due primarily to growth recruitment of juveniles during the study period and, secondarily, to differences in the spatial coverage of sampling between marking and recapture phases. The first factor is more important than the second factor.

The conclusion that growth recruitment occurred meant that the number of juveniles could not be reliably estimated using the same mark-recapture techniques that were applied to subadults and adults. This subject is examined in detail in sections 3.9 and 3.11.

3.8 Spatial Variation of Trout Size

Rainbow trout of different sizes often reside in different habitats. If there are large differences in trout size distribution among areas in Fish Lake, then it may affect interpretation of mark-recapture ratios and estimation of population number. In this section of the report, spatial variation in trout size was examined to determine its possible effects on the results of the mark-recapture study.

Trends in trap net CPUE with time suggested a possible separation of trout into east- and west sub-groups (see section 3.4). To test this hypothesis, the seven stations were divided into an east group (stations C1, C2, I1 and I2) and a west group (stations C3, C4, I3) and their length frequency distributions were compared. Both distributions showed the same three modes described in Sections 3.6 and 3.7, but the western distribution was dominated by juveniles while the eastern distribution was dominated by adults (Figure 22A).

The distribution of sampling stations naturally lends itself to separating length data into north (stations C1, C2, C3 and C4) and south (stations I1, I2 and I3) groups. Length frequency distributions of the two groups also showed the three modes observed previously, but the northern group was dominated by juveniles while the southern group was dominated by adults (Figure 22B).

In summary, there were east-west and north-south gradients of trout length with the largest fish in the southeastern quarter of the lake and the smallest fish in the northwestern quarter. Those findings support anecdotal observations reported by sportfishers, and by Triton employees who used angling to capture trout for biological samples (T. Davies, personal communication), that the largest trout are usually caught south and east of the big island.

The most likely explanation for the observed distribution of trout was a combination of the location of origin of most juveniles and of competition for habitat. The greatest concentration of juveniles was in the northwestern quarter of the lake in part because the majority of juvenile recruits migrate into the lake from Lower Fish Creek. Trout also compete among each other for desirable habitat—a competition that adults would be expected to win because of their greater size. During July and August in Fish Lake there were north-to-south gradients of decreasing surface water temperature and average depth and increasing shoal area and aquatic plant cover. Thus, during summer adults tend to occupy the best available trout habitat (shoal area, cool, abundant cover) in the southeastern quarter of the lake whereas juveniles tend to occupy less desirable habitat (less shoal area, warmer, lacking in cover) in the northwestern quarter of the lake. That pattern holds only for the July to September period—it can be expected to change seasonally in response to seasonal changes in water temperature and in the area covered by aquatic plants.

We conclude that there was spatial variation in trout density and mean size, but that it did not affect the results of the mark-recapture study because the lake traps were moved around Fish Lake during both the marking phase and the two recapture phases.

3.9 Ratios of Recaptured to Sampled Trout

A total of 78 marked trout were recaptured: 63 in the first recapture phase and 15 in the second recapture phase (Table 3). The corresponding ratios of number recaptured (R) to number examined for marks (C) were 0.013, 0.012 and 0.016. The differences between these ratios were small, but their consequences for population estimation were large. Therefore, it was important to establish whether R/C ratios varied significantly between the two recapture phases and, if so, why they varied.

There were also substantial differences in R/C ratio among the three length classes for both recapture phases (Table 4 and Figure 23). For example, there were no recaptures of juveniles in the second recapture phase, and R/C ratios for subadults and adults were both greater in the second recapture phase than in the first recapture phase. Therefore, it was important to establish whether R/C ratios varied significantly among the three length classes for each of the two recapture phases.

A χ^2 test for equality of proportions showed that there was no significant difference among R/C ratios for the three length classes for the first recapture phase ($\chi_2^2 = 3.785$, P = 0.151). However, there was a significant difference among R/C ratios for the three length classes for the second recapture period ($\chi_2^2 = 10.984$, P = 0.004) due to the absence of any juvenile recaptures.

There was no significant difference between R/C ratios of the first and second recapture phases ($\chi_1^2 = 0.685$, P = 0.408). That result was misleading because there are obvious large differences in R/C ratios for adults and subadults between the two recapture phases. The finding of non-significance is due to an absence of juvenile recaptures in the second recapture phase. When a juvenile September R/C ratio of zero was combined with relatively high subadult and adult September R/C ratios, then the pooled R/C ratio for September was lowered to the point that it was not significantly different from the pooled R/C ratio for July and August.

To confirm those results, R/C ratios were analyzed on an individual catch basis. A total of 48 separate catches were available to calculate R/C ratios: 46 trap catches and 2 beach seine catches (Tables 2 and 3 and Appendix D). Eleven of those 48 catches were taken during the marking phase, leaving 37 catches from which true R/C ratios could be calculated. Each catch was divided into three length classes, producing 111 R/C ratios.

An analysis of covariance of those 111 ratios in which C was the covariate showed that R did not vary significantly between the two recapture phases ($F_{1,104} = 0.38$, $P = 0.538$). However, R varied significantly with length class ($F_{2,104} = 6.28$, $P = 0.003$) and with the interaction of recapture phase and length class ($F_{2,104} = 3.51$, $P = 0.033$). That finding supported the results of the χ^2 tests.

In summary, two independent methods supported the conclusion that there was significant heterogeneity in the R/C ratios among length classes and between recapture phases. There were two reasons for that heterogeneity.

Marked fish were less vulnerable to capture than unmarked fish during the first recapture period due to temporary reductions in activity caused by the trauma of capture and marking. The R/C ratio of subadults in the second recapture phase was 65% greater than their R/C ratio in the first recapture phase, and the R/C ratio of adults in the second recapture phase was 160% greater than their R/C ratio in the first recapture phase. The most likely reason for those differences was that marked trout reduced their activity immediately after marking and so were less vulnerable than unmarked trout to capture in passive gear such as net traps. The result was an underestimation of the subadult and adult R/C ratios in July and August. By September, marked subadults and adults had recovered their normal activity level and were caught in proportion to their true abundance in the lake.

Similar findings have been reported by other researchers enumerating trout populations in British Columbia. For example, Sean Cox (Fisheries Center, University of British Columbia, personal communication) reported preliminary results of a mark-recapture study of rainbow trout numbers in hatchery-supplemented lakes in the Cariboo region. R/C ratios were very low immediately after marking, but began to increase within one week of marking and eventually stabilized one month after marking.

Similar findings have also been reported for other species of fish in marine as well as freshwater systems. For example, Ricker (1975) reported a mark-recapture study of chum salmon (*Oncorhynchus keta*) in Johnstone Strait, BC, in which tagging delayed migration timing of chum by several days.

Ricker (1975) commented (p. 87):

> "A more insidious source of error is a tendency for marked or tagged fish to be either more, or less, vulnerable to fishing ... Effects of these sorts will generally be hard to detect, and hard to distinguish from actual mortality due to tagging."

There are no studies in the scientific literature than offer guidelines for predicting the duration of the refractory period between marking and recapture phases for rainbow trout or for any other species of fish. Some researchers have avoided the problem by using a different type of gear for recapturing than for marking, but that was not possible in this case because lake traps were the only method that could collect large numbers of trout in Fish Lake with minimal injury.

Assuming that a refractory period existed, then only the September R/C ratios for subadults and adults can be used for population estimation, and not the pooled R/C ratios shown in Table 3. Correcting the R/C ratios of subadults and adults observed in July and August by using the R/C ratios measured in September does not provide any more information than is provided by using the September R/C ratios alone.

Vulnerability of juveniles to capture in the net traps changed over the study period as they grew into the size range that was catchable by traps. The length and age frequency analyses of section 3.7 showed that only the subadult and adult size classes were completely vulnerable to capture in net traps throughout the study period. Most of the 1 year-olds that immigrated to Fish Lake in the spring and summer of 1997 and some of the small 2 year-olds that immigrated in 1996 were too small to be retained in the traps. Therefore, the R/C ratios of juveniles were too unreliable to be used.

Unlike subadults and adults, it was not possible to compare R/C ratios for juveniles between the two recapture phases because no juveniles were recaptured in September. Growth recruitment between July-August and September had diluted the number of marked juveniles that were vulnerable to recapture in net traps to such a degree that not a single juvenile recapture was found in the 951 fish that were examined. That means that mark-recapture techniques alone cannot be used to calculate reliable estimates of the number of juveniles. We must turn to the fence project to help us calculate estimates of juvenile number. (See section 3.11.2.)

3.10 Survival Tests

A total of six live box tests were conducted in July and August, 1997, to estimate the 24-hour survival of trout processed during this study. Survival ranged from 86 to 96% with an average of 92% (Table 5). The average survival of marked trout was 93% (SD = 4, n = 3), which was not significantly different ($t_4 = 0.812$, $0.50<P<0.40$) from an average survival of 90% (SD = 5, n = 3) for examined trout.

Mean length of survivors was 208 mm (SD = 61, n = 173) and mean length of mortalities was 182 mm (SD = 50, n = 16). There was no significant difference in mean fork length between fish that survived the tests and those that died during the tests ($t_{187} = 1.653$, $0.05<P<0.10$). However, a Kolmogorov-Smirnov two-sample test showed that the two length distributions were significantly different (K-S Z = 1.450, P = 0.028). The difference was due to a greater proportion of sub-adults in the dead class than in the live class (Figure 24). This was assumed to be due to random influences operating on small sample sizes because the alternative was to assume that survival was high for juveniles and adults but low for sub-adults, a conclusion that had no other evidentiary support.

To confirm that there was no change in survival with size of fish, a second set of livebox tests was conducted during the second recapture phase in September. The design of the tests was altered to reflect new objectives. Instead of placing all fish into a single livebox after measurement and examination, fish were instead sorted into three size classes corresponding to juvenile, sub-adult and adult, and then each class was placed into its own separate livebox. After overnight soaking, the three liveboxes were opened, the live trout were released into Fish Lake and the dead trout were counted and their lengths were measured.

A total of 613 trout were placed in liveboxes and 602 survived overnight soaking for an average survival of 0.98 (Table 6). Survival on an individual livebox basis ranged from 0.94 to 1.00 with an average of 0.98 (SD = 0.02, n = 18). Survival of juveniles was lower than survival of sub-adults or adults, mainly because juveniles tended to be gilled more often in the net traps than sub-adults or adults. However, the difference in survival between length classes was less than 2%, which was of negligible importance for all practical purposes.

The 6% difference in average survival between the two sets of livebox experiments was most likely due to the 5°C difference in average water temperature between the two time periods: 16.6°C (SD = 1.8, n = 88) for July-August compared to 11.6°C (SD = 1.5, n = 21) for September (Appendix A). Temperatures greater than 15°C are known to stress salmonids (Brett 1995).

In summary, an average survival of 92% was used to correct the total number of marked trout to the actual number of marked trout in Fish Lake.

3.11 Population Estimate

3.11.1 Subadults and Adults

Section 3.9 showed that mark-recapture techniques can only be reliably used to estimate numbers of subadult and adults. Juveniles were not sufficiently vulnerable to capture in trap nets during the study for their R/C ratios to be used in population estimation. Instead, we must use juvenile fence counts to estimate juvenile abundance (see section 3.11.2).

Section 3.9 also showed that only the data from the second recapture phase can be used for Petersen estimates of subadult and adult numbers because the R/C ratios of the first recapture phase were underestimates of the true R/C ratios.

If a marking survival of 92% was assumed, and if the observed numbers of recaptured and examined subadult and adult trout for the second recapture phase were used, then equations (2) and (3) give a total population of subadults and adults of 49,058 with 95% confidence limits of -35% and +67% (Table 7). Summing separate population estimates for subadults and adults gives 49,057, which was exactly one fish less than the estimate based on pooling the two size classes.

3.11.2 Juveniles

Traps were not effective in capturing juveniles. Therefore, several estimates of the number of juveniles in the lake at the end of the second recapture phase were obtained by combining information from the mark-recapture study and the 1997 fish fence project, and by making a series of assumptions about the proportion of the juveniles that were available to be marked.

The first estimate was obtained by assuming that juveniles caught in net traps were a mixture of 2 year-olds and large 1 year-olds. We further assumed that those juveniles were caught at the same rate as subadults and adults. That was a reasonable assumption because we were dealing with those juveniles that were large enough to be trapped, not the total number of juveniles in the lake. Then, the number of those large juveniles was equal to the number caught during the marking phase expanded by the R/C ratio of subadults and adults estimated from the second recapture phase. A total of 441 juveniles between the lengths of 70 and 139 mm were marked during the marking phase, of which 406 were expected to survive marking (Table 7). Expanding that number by an R/C ratio of 0.027 gave 406/0.027 or 15,037. Thus, the total number of juveniles in the lake was the number of 1 year-olds counted through the fences plus the number of 2 year-olds and large 1 year-olds caught in net traps. The 1997 fence project found that 20,110 juveniles between the lengths of 50 and 150 mm entered in the spring and summer (Triton Environmental Consultants Ltd. 1997b). Therefore, the total number of juveniles was the sum of 20,110 and 15,037 giving 35,147.

Those calculations can be verified by a second method. At the end of the second recapture phase, the ratio of juveniles examined to total fish examined was 397/951 or 0.417. Thus, the ratio of the number of juveniles (N_J) to the total population number at the end of the second recapture phase was:

$$N_J/(N_J + 49{,}058) = 0.417$$

which can be solved to give an estimate of N_J of 35,090. That was only 57 fish or 0.2% lower than the first estimate of juvenile number.

A similar calculation can be made for the end of the marking phase, i.e. the ratio of marked juveniles to total marked trout was 441/2,059 or 0.214. Thus, the ratio of N_J to the total population number at the end of the marking phase was

$N_J/(N_J + 49{,}058) = 0.214$

which can be solved to give an estimate of N_J of 13,357.

The difference between these two estimates of N_J was 21,733. That was the number of juveniles that grew large enough to become catchable in trap nets between the end of the marking phase on July 22 and the end of the second recapture phase on September 30, 1997. It was only 1,623 fish more (or 8% more) than the total number of 1 year-old juveniles that were counted into Fish Lake in the spring and summer of 1997. That suggested that most 1 year-olds had grown large enough to be vulnerable to trap nets by the end of the study in late September.

A third method of estimating the total number of juveniles was to, first, reconstruct number-at-age of the population using the number of 1 year-olds counted through the fences and the numbers of subadults and adults that are 3 to 6 years old. Then, extrapolate the number-at-age between ages 1, 3 and 4, thereby obtaining an estimate of the number of 2 year-olds. Total juvenile number was the sum of the known number of 1 year-olds and the estimated number of 2 year-olds.

Numbers of 2 and 3 year-olds were calculated by multiplying the mark-recapture estimate of the number of subadults by the fractions of the total number of subadults that were in each 10 mm length interval over the length range of 140 to 229 mm. The number of 2 year-olds calculated by this method was an underestimate of the total number of 2 year-olds because it did not include those small 2 year-olds that were classified as juveniles on the basis of their length. In contrast, the number of 3 year-olds was reasonably accurate because 3 year-olds were completely vulnerable to capture in net traps. Numbers of 4, 5 and 6 year-olds were calculated by multiplying the mark-recapture estimate of the number of subadults by the fractions of the total number of adults that were in each 10 mm length interval over the length range of 230 to 330 mm.

A plot of the $\log_e$-transformed numbers on age showed that numbers decreased slowly between ages 1 and 4 (Figure 25). (The numbers of 2 year-olds were ignored in that comparison because it was an underestimate of the true number of 2 year-olds.) The plot also showed that there was a rapid decrease in numbers of 4, 5 and 6 year olds with age, undoubtedly reflecting the influence of spawning-related mortality on those age classes. Therefore, two separate three-point regressions were calculated: one for immature age classes and a second for sexually mature age classes.

The regression of $\log_e$(number) on age for ages 1, 3 and 4 was not statistically significant ($r^2 = 0.08$, $P = 0.480$), mainly because of its low sample size. The slope of the regression, which is equivalent to total instantaneous mortality rate, was 7%/year. Such a low mortality rate was expected for those age classes because there are few natural predators of trout in Fish Lake other than birds such as eagles and ospreys, and because trout of those ages do not experience spawning-induced stress and injury.

The regression of $\log_e$(number) on age for ages 4, 5 and 6 was also not statistically significant because of low sample size ($r^2 = 0.80$, $P = 0.220$). Total instantaneous mortality rate was 164%/year, which was more than 20 times greater than the mortality rate of age classes 1 to 4. Such a high mortality rate explains why there are only three spawning age classes in the population—extrapolating the regression to age 7 predicts only 172 7 year-olds in the population or 0.4% of the total number of subadults and adults.

The regression of $\log_e$(number) on age for 1 to 4 year-olds predicted that there were 18,016 2 year-olds in the population. Thus, the total number of trout in the juvenile length class was the sum of the 1 year-olds counted at the fence plus the number of 2 year-olds predicted by the regression or 20,110 + 18,016 = 38,126.

In summary, three separate methods show that juvenile number ranged from 35,909 to 38,126. In the absence of any other criteria to assess those estimates, the arithmetic average of 36,121 was taken as the best estimate of juvenile number.

<u>3.11.3 Total Number</u>

The total population of rainbow trout in Fish Lake at the end of September 1997 was estimated to be 85,178, of which 36,121 were juveniles, 22,318 were subadults, and 26,739 were adults. 95% confidence limits of the total population number cannot be accurately estimated because the number of juveniles was not estimated using equation (2).

The number of rainbow trout in Fish Lake changes seasonally in response to immigration of juveniles and natural mortality of juveniles, subadults and adults. Total number is expected to be greatest in early August after the peak of the juvenile in-migration, and lowest in late May prior to the period of juvenile in-migration. Therefore, this study provides an estimate of the maximum number of trout in Fish Lake in 1997.

4.0 DISCUSSION

The results of this mark-recapture study supported Sebastian's (1996) contention that the true number of trout in Fish Lake was underestimated by the 1995 hydroacoustic survey. The mark-recapture estimate was three times greater than the hydroacoustic estimate. That difference was highly statistically significant, as can be seen by comparing the 95% confidence limits of the two estimates—both estimates exclude the other.

To assess the validity of the mark-recapture estimate, this section of the report first reviewed the underlying assumptions of the mark-recapture method as they apply to Fish Lake. Then, the hydroacoustic survey was reviewed in light of Sebastian's (1996) review of BioSonics Inc. (1995) and of the findings of this study.

4.1 Assumptions of Mark-Recapture Methodology

4.1.1 Statistical Bias

Equation (2) provided a biased estimate of population number, but the bias was negligible if the number of recaptures was 4 or greater (Ricker 1975). The number of recaptures in the second recapture phase was 15. When divided into subadult and adult size classes, they ranged from 6 to 9. Thus, statistical bias was negligible for this study.

4.1.2 Sample Size and Sampling Error

The study plan aimed for 2,000 marked trout and 4,000 examined trout. Those numerical targets were exceeded during the marking phase and the first recapture phase. Unfortunately, the unexpected temporary reduction in vulnerability of marked trout to capture during the first recapture phase meant that we were forced to use only the statistics of the second recapture phase: 951 fish examined and 15 recaptured. As a result, the approximate 95% confidence limits of -35% and +67% were greater than the planned ±25% error level.

4.1.3 Mortality Rate of Marked and Unmarked Trout

The Petersen method assumed that marked fish suffered the same natural mortality as unmarked fish. It was not possible to strictly verify this assumption because there was no method of collecting fish for survival experiments that did not involve handling them. Thus, the 24-hour survival experiments were only capable of comparing the acute mortality caused by handling with the acute mortality caused by handling plus marking.

The first set of survival experiments showed that survival was not significantly different among marked and examined fish, which indicated that marking did not contribute additional mortality to that generated by capture in a trap and by handling. The second set of survival experiments confirmed that mortality did not significantly vary with trout size. We concluded that acute mortality rates were the same for both marked and unmarked trout of all sizes.

Chronic effects of marking on survival were impossible to detect. The length frequency distributions of marked and examined trout were significantly different from each other, but that was due to growth recruitment rather than to differential mortality rates (see section 3.7).

4.1.4 Vulnerability to Capture of Marked and Unmarked Trout

The Petersen method assumed that marked and unmarked fish had equal vulnerability to capture. That is, the process of capture, marking and handling did not make the marked trout more or less inclined to move about than unmarked fish, thereby affecting their probability of encountering a trap and being captured, or more or less "trap-shy" than unmarked trout.

The first effect was tested by comparing the R/C ratios between the first and second recapture phases. The analyses described in section 3.9 showed that there were significant differences in R/C ratios of subadults and adults between the two time periods. Accordingly, the population estimate was based on the assumption that marked and unmarked trout did not have equal probabilities of capture during the first recapture phase, but that they did so during the second recapture phase.

It was not possible to test for trap-shyness because if it existed it would affect both marked and unmarked fish alike. A different study design incorporating multiple marks, multiple recapture times, or radiotagging would have been necessary to test for that effect. However, there was no reason to expect that trap-shyness existed during this study. That is, there was no indication from CPUE or mean length or any other measurable variable that trap-shyness operated.

In summary, bias due to temporary decreases in trap vulnerability of marked trout was avoided by basing the analysis only on the results of the second recapture phase. The incidence of trap-shyness could not be investigated, but was assumed to be of negligible importance.

4.1.5 Loss of Marks and Recognition of Marks

The Petersen method assumed that all marks were retained throughout the study, that there was no loss of marks due to regeneration of clipped tissue, that there were no other natural processes that would create new marks or remove old marks, and that all marks were recognized.

Some marked fish were undoubtedly lost from the pool of marked fish due to fishing mortality, particularly between the first and second recapture phases. That resulted in an upward bias to the number of adults. It was not possible to estimate the exact amount of bias, but it was expected to be low relative to other sources of error because fishing mortality rate on Fish Lake trout was low compared to natural mortality rate and because the duration of the study period was short—only 3 months.

Maxillary bones regenerate (Wydoski and Emery 1983). However, it is unlikely that Fish Lake trout could have regenerated several millimeters of maxillary length and re-grown the rounded outer edge of the maxillary over a period of only 2.5 months. All of the workers in this study reported that the clipped right maxillary was clearly visible in all recaptured fish as a shortened bone with a sharp, straight outer edge. The clips were as visible on September 28 as they were on July 15. Moreover, all of the examinations were conducted by the same workers who had clipped the fish.

In summary, bias due to loss of marks was assumed to be of negligible importance.

4.1.6 Random Mixing of Marked and Unmarked Trout

All single-census mark-recapture methods assume that the marked and unmarked trout are randomly mixed together during the recapture phase. In this study, the marked fish were evenly distributed over the lake during each day of the marking phase because the duration of the first recapture phase was too short to guarantee that the fish would have time to randomize their own distribution within the lake by natural movements.

4.1.7 Immigration and Emigration

If immigration occurs between the marking and recapture phases of a Petersen mark-recapture study, but no emigration, then the population estimate is unbiased and refers to the population number at the end of the recapture phases. If emigration occurs between the marking and recapture phases, but no immigration, then the population estimate is also unbiased but it refers to the population number at the end of the marking phase. If both emigration and immigration occur simultaneously, then the population estimate is a weighted average of the population number before emigration occurred and after immigration occurred.

Fortunately for this study, immigration was so much greater than emigration that we can assume that immigration operated alone. However, because we were forced to use only the statistics of the second recapture phase, the population estimate refers to the population at the end of the second recapture phase.

4.1.8 Summary of Assumptions

A review of the seven critical assumptions of the Petersen mark-recapture method showed that all but two were satisfied by the Fish Lake study. The single most important assumption that was not satisfied was equal vulnerability of marked and unmarked trout during the first recapture phase. However, that assumption was eventually satisfied by using only the data of the second recapture phase.

The next most important unsatisfied assumption was no loss of marks due to anglers. No corrections were possible for that factor, but its upward bias on adult number was very low compared to other sources of bias because of the very low exploitation rate on the Fish Lake population.

4.2 Why was the Mark-Recapture Estimate Greater than the Hydroacoustic Estimate?

There are three possible reasons why the number of trout estimated by the mark-recapture study is three times greater than the number estimated by the hydroacoustic survey:

- the hydroacoustic survey missed a large portion of the trout population because it was not able to cover the shallow, weedy areas where the majority of trout resided:
- hydroacoustic methods were biased towards the detection of relatively large trout. and underestimated the true number of smaller trout. Immature trout make up a large portion of total trout numbers in any self-reproducing trout population; and
- the number of trout in the lake in August 1995 may have been lower than the number in the lake in July- 1997 due to annual variation in the number of 1 year-old juveniles that recruit to the lake population each summer.

Sebastian (1996) identified four reasons why the hydroacoustic survey may have underestimated population number in Fish Lake:

- the hydroacoustic survey was not able to reliably survey areas of the lake that were less than 3 m deep because of dense growth of aquatic vegetation at those depths. Trout prefer such habitat over open water because it provides cover from predators. It is possible that the 27% of the surface area of the lake that the BioSonics team could not survey contained the majority of the trout population in the lake;
- the down-looking sonar underestimated fish density because the beam was too narrow to reliably illuminate every fish below it. At a depth of 2 m. with the reported beam angle, ping rate and boat speed, each ping covered an area with a diameter of only 220 mm. Any fish that was not directly in the center of that illuminated area would not produce an interpretable trace on an echogram. Small trout with lengths of 50 to 100 mm would be less likely to produce a trace than larger trout because effective beam angle decreases with decreasing fish length;
- the investigators underestimated fish density because they were conservative in their identification of echogram traces and may have classified a substantial number of fish traces as non-fish traces; and
- there are unexplained anomalies in the results of the side-looking sonar survey. More fish counts were made in the 8.5 to 18.5 m range than in the 18.5 to 28.5 m range, even though the sampled volume in the latter range is twice as great as in the former range.

A plot of the lake volume-below-depth on depth shows that 167.73×10^4 m^3 of the total lake volume of 394.54×10^4 m^3 is below 3 m depth (Figure 26). In other words, 57.5% of the total volume of the lake is contained within the 0 to 3 m depth stratum, and 42.5% of the volume is contained within the 3 to 12 m depth stratum. Thus, over half of the volume of the lake is contained within the areas that the hydroacoustic team could not survey. Considered from this viewpoint, it does not seem unreasonable to propose that the hydroacoustic survey may have missed a large part of the trout population.

5.0 SUMMARY

The mark-recapture study provided an estimate of rainbow trout number in Fish Lake of 85,178 as of the end of September 1997. That was three times greater than the estimate of 28,128 (95% confidence limits: 16,060 to 40,196 fish) provided by a hydroacoustic survey conducted on August 1, 1995. A review of the assumptions of the mark-recapture method showed that methodological problems were not responsible for the large difference in numbers. A review of the hydroacoustic survey identified several aspects of sonar methodology that may have led to an underestimate of trout number in 1995.

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Table 1. Total numbers of rainbow trout moving into and out of Fish Lake during the mark-recapture study: July 15 to August 22, 1997.

Length classes (mm)	Into Fish Lake:				Into Fish Creek:			
	Inlet trap/ downstream	Outlet trap/ upstream	Total	Percent of total	Inlet trap/ upstream	Outlet trap/ downstream	Total	Percent of total
0-50	11	2	13	0.4	9	0	9	14.3
51-100	253	2781	3034	92.7	13	16	29	46.0
101-150	11	159	170	5.2	4	3	7	11.1
151-200	5	22	27	0.8	0	1	1	1.6
201-250	2	9	11	0.3	1	6	7	11.1
251-300	5	11	16	0.5	0	10	10	15.9
301-350	2	0	2	0.1	0	0	0	0.0
Total	289	2984	3273	100.0	27	36	63	100.0

Note: Flows in both upper and lower Fish Creeks fell to zero by late August

Table 2. Catches, CPUE, mean lengths, and ratios of marked (R) to examined (C) rainbow trout, Fish Lake, 1997

Phase	Site	Trap closed:		Trap opened:		Hours	Numbe	CPUE	Fork length (mm):			C:				R:				R/C:			
		date	hour	date	hour	soaked	of trout	(fish/h	mean	SD	n	j[a]	sa	a	total	j	sa	a	total	j	sa	a	total
marking	C1	14-Jul	1550	15-Jul	0915	17.4	416	23.9	220	56	415	43	152	220	415	0	0	0	0	0.000	0.000	0.000	0.000
marking	C1	15-Jul	0930	16-Jul	0900	23.5	211	9.0	211	68	211	44	59	108	211	0	0	0	0	0.000	0.000	0.000	0.000
marking	C1	16-Jul	0930	17-Jul	0845	23.3	266	11.4	194	65	264	70	93	101	264	0	2	1	3	0.000	0.022	0.010	0.011
marking	C1	17-Jul	0900	18-Jul	0845	23.8	234	9.9	193	62	233	56	93	84	233	1	2	0	3	0.018	0.022	0.000	0.013
marking	I1	17-Jul	1500	18-Jul	1315	22.3	128	5.8	203	58	128	24	53	51	128	0	0	0	0	0.000	0.000	0.000	0.000
marking	C1	18-Jul	0900	19-Jul	0900	24.0	147	6.1	192	65	147	43	49	55	147	2	1	1	4	0.047	0.020	0.018	0.027
marking	I1	18-Jul	1330	19-Jul	1330	24.0	210	8.8	191	57	210	47	100	63	210	0	1	0	1	0.000	0.010	0.000	0.005
marking	C1	19-Jul	0930	20-Jul	0830	23.0	7	0.3	148	62	7	4	2	1	7	0	0	0	0	0.000	0.000	0.000	0.000
marking	I1	19-Jul	1550	20-Jul	1100	19.2	224	11.7	197	66	223	60	73	90	223	1	0	0	1	0.017	0.000	0.000	0.004
marking	C2	20-Jul	1000	21-Jul	0835	22.6	141	6.2	164	68	141	71	35	35	141	0	0	2	2	0.000	0.000	0.057	0.014
marking	I1	20-Jul	1115	21-Jul	1325	26.2	213	8.1	221	50	213	15	94	104	213	0	1	0	1	0.000	0.011	0.000	0.005
recapture 1	C2	21-Jul	0900	22-Jul	0830	23.5	40	1.7	168	79	40	20	7	13	40	0	0	0	0	0.000	0.000	0.000	0.000
recapture 1	I1	21-Jul	1409	22-Jul	0935	19.4	101	5.2	220	52	101	11	39	51	101	1	1	0	2	0.091	0.026	0.000	0.020
recapture 1	C3	22-Jul	1400	23-Jul	0830	18.5	408	22.1	146	51	408	221	143	44	408	1	4	0	5	0.005	0.028	0.000	0.012
recapture 1	I2	22-Jul	1600	23-Jul	1335	21.6	215	10.0	201	55	215	39	109	67	215	2	1	0	3	0.051	0.009	0.000	0.014
recapture 1	C3	23-Jul	0900	24-Jul	0835	23.6	439	18.6	162	61	439	204	152	83	439	0	4	0	4	0.000	0.026	0.000	0.009
recapture 1	I2	23-Jul	1350	24-Jul	1045	20.9	183	8.7	208	55	183	28	79	76	183	0	2	0	2	0.000	0.025	0.000	0.011
recapture 1	C3	24-Jul	0855	25-Jul	0845	23.8	272	11.4	178	65	272	100	95	77	272	0	3	0	3	0.000	0.032	0.000	0.011
recapture 1	I2	24-Jul	1100	25-Jul	1045	23.8	180	7.6	217	54	178	23	74	81	178	1	1	1	3	0.043	0.014	0.012	0.017
recapture 1	C1/C2[b]	25-Jul	1345	25-Jul	1345	-	248	-	108	16	248	242	5	1	248	2	0	0	2	0.008	0.000	0.000	0.008
recapture 1	C3	25-Jul	0900	25-Jul	1930	10.5	58	5.5	209	60	58	10	25	23	58	0	0	1	1	0.000	0.000	0.043	0.017
recapture 1	I2	25-Jul	1100	25-Jul	2015	9.3	45	4.9	225	52	45	3	21	21	45	0	0	1	1	0.000	0.000	0.048	0.022
recapture 1	C3	25-Jul	1945	26-Jul	1415	18.5	228	12.3	194	64	228	58	88	82	228	1	0	1	2	0.017	0.000	0.012	0.009
recapture 1	I2	25-Jul	2030	26-Jul	1625	19.9	193	9.7	206	61	192	41	64	87	192	1	2	2	5	0.024	0.031	0.023	0.026
recapture 1	I3/C1[b]	27-Jul	0430	27-Jul	0430	-	34	-	150	66	34	21	7	6	34	1	0	0	1	0.048	0.000	0.000	0.029
recapture 1	C3	26-Jul	1430	27-Jul	0815	17.8	178	10.0	165	65	178	85	50	43	178	3	0	0	3	0.035	0.000	0.000	0.017
recapture 1	I2	26-Jul	1640	27-Jul	0917	16.6	202	12.2	202	62	202	43	77	82	202	0	1	0	1	0.000	0.013	0.000	0.005
recapture 1	C3	27-Jul	0830	28-Jul	0820	23.8	258	10.8	171	63	257	97	98	62	257	2	0	0	2	0.021	0.000	0.000	0.008
recapture 1	I2	27-Jul	0937	28-Jul	1000	24.4	202	8.3	204	57	202	33	91	78	202	0	2	1	3	0.000	0.022	0.013	0.015
recapture 1	C3	28-Jul	0840	29-Jul	0830	23.8	219	9.2	176	68	219	87	68	64	219	1	0	1	2	0.011	0.000	0.016	0.009
recapture 1	I2	28-Jul	1020	29-Jul	1005	23.8	213	9.0	197	59	213	49	90	74	213	0	3	0	3	0.000	0.033	0.000	0.014
recapture 1	C3	29-Jul	0850	30-Jul	0900	24.2	34	1.4	138	53	34	21	10	3	34	0	0	0	0	0.000	0.000	0.000	0.000
recapture 1	I2	29-Jul	1035	30-Jul	0930	22.9	147	6.4	209	61	147	31	41	75	147	0	1	1	2	0.000	0.024	0.013	0.014
recapture 1	C4	30-Jul	1215	31-Jul	0830	20.3	147	7.3	131	56	147	110	21	16	147	2	0	0	2	0.018	0.000	0.000	0.014
recapture 1	I2	30-Jul	1000	31-Jul	0930	23.5	103	4.4	207	60	103	20	40	43	103	0	0	1	1	0.000	0.000	0.023	0.010
recapture 1	C4	31-Jul	0900	1-Aug	0830	23.5	55	2.3	176	75	55	24	12	19	55	0	1	0	1	0.000	0.083	0.000	0.018
recapture 1	I2	31-Jul	0950	1-Aug	0915	23.4	154	6.6	210	58	154	21	69	64	154	0	2	1	3	0.000	0.029	0.016	0.019
recapture 1	I2	1-Aug	0930	2-Aug	0830	23.0	154	6.7	205	63	154	34	55	65	154	0	0	1	1	0.000	0.000	0.015	0.006
recapture 1	I3	1-Aug	1100	2-Aug	0945	22.8	129	5.7	209	62	129	25	44	60	129	1	0	2	3	0.040	0.000	0.033	0.023
recapture 1	I2	2-Aug	0900	3-Aug	0830	23.5	111	4.7	218	53	111	15	38	58	111	0	1	1	2	0.000	0.026	0.017	0.018
recapture 1	I3	2-Aug	1015	3-Aug	0930	23.3	110	4.7	212	59	110	16	40	54	110	0	0	0	0	0.000	0.000	0.000	0.000
recapture 2	C1	22-Sep	1440	24-Sep	0915	42.6	261	6.1	166	60	261	133	74	54	261	0	3	2	5	0.000	0.041	0.037	0.019
recapture 2	C1	24-Sep	0930	25-Sep	0900	23.5	100	4.3	168	61	99	49	30	20	99	0	2	1	3	0.000	0.067	0.050	0.030
recapture 2	C1	25-Sep	0930	26-Sep	0810	22.7	152	6.7	176	65	152	63	47	42	152	0	1	1	2	0.000	0.021	0.024	0.013
recapture 2	C1	26-Sep	0950	27-Sep	0830	22.7	101	4.4	182	64	100	39	35	26	100	0	1	2	3	0.000	0.029	0.077	0.030
recapture 2	C1	27-Sep	0940	28-Sep	0815	22.6	158	7.0	195	61	158	38	65	55	158	0	2	0	2	0.000	0.031	0.000	0.013
recapture 2	I1	28-Sep	0945	29-Sep	0830	22.2	78	3.5	168	55	78	33	31	14	78	0	0	0	0	0.000	0.000	0.000	0.000
recapture 2	I1	29-Sep	0840	30-Sep	0830	23.8	103	4.3	187	102	103	42	37	24	103	0	0	0	0	0.000	0.000	0.000	0.000

[a] j = juvenile (70-139 mm), sa = subadult (140-229 mm), a = adult (230-330 mm)

[b] seine catches

Table 3. Summary of marked, examined and recaptured fish, Fish Lake Rainbow Trout Mark-Recapture Study, 1997.

	Number in study phase:			
	Marking	First recapture	Second recapture	Total
Marked (M)	2059	0	0	2059
Dead or Moribund[a]	89	0	0	89
No Right Maxillary[a]	28	0	0	28
Escaped[b]	5	3	2	10
Recaptured in marking phase	15	0	0	15
Examined (C)	0	5056	951	6007
Total	2196	5059	953	8208
Recaptured in recapture phases (R)	-	63	15	78
R/C ratio	-	0.012	0.016	0.013

[a]fish were not marked if they were dead, moribund or had no right maxillary to clip

[b]fish that jumped out of net traps or holding tanks before being measured, marked or examined

Table 4. Ratios of recaptured (R) to examined (C) rainbow trout for three length classes and two recapture phases.

	Juvenile (70-139 mm):			Subadult (140-229 mm):			Adult (230-330 mm):			Total:		
Phase	R	C	R/C	R	C	R/C	R	C	R/C	R	C	R/C
1st	19	1732	0.011	29	1752	0.017	15	1572	0.010	63	5056	0.012
2nd	0	397	0.000	9	319	0.028	6	235	0.026	15	951	0.016
total	19	2129	0.009	38	2071	0.018	21	1807	0.012	78	6007	0.013

Table 5. Survival of rainbow trout in a livebox, Fish Lake, July-August, 1997.

	In-box:			Out-box:			Numbe	Hours	Percent
Site	date	hour	umber	date	hour	umber	dead	in-box	survival
Marking									
C1	18-Jul	0945	33	19-Jul	0845	31	2	23.0	94
C2	19-Jul	0950	34	20-Jul	0815	33	1	23.8	97
I1	20-Jul	1100	35	21-Jul	1030	31	4	23.5	89
Recapture									
I1	25-Jul	1120	35	26-Jul	1600	30	5	29.5	86
I1	26-Jul	1730	26	27-Jul	1030	23	3	17.0	88
I1	27-Jul	1030	26	28-Jul	1100	25	1	23.5	96
sum			189			173	16		
mean			32			29		23.4	92
SD			4			4		4.0	5
n			6			6		6	6

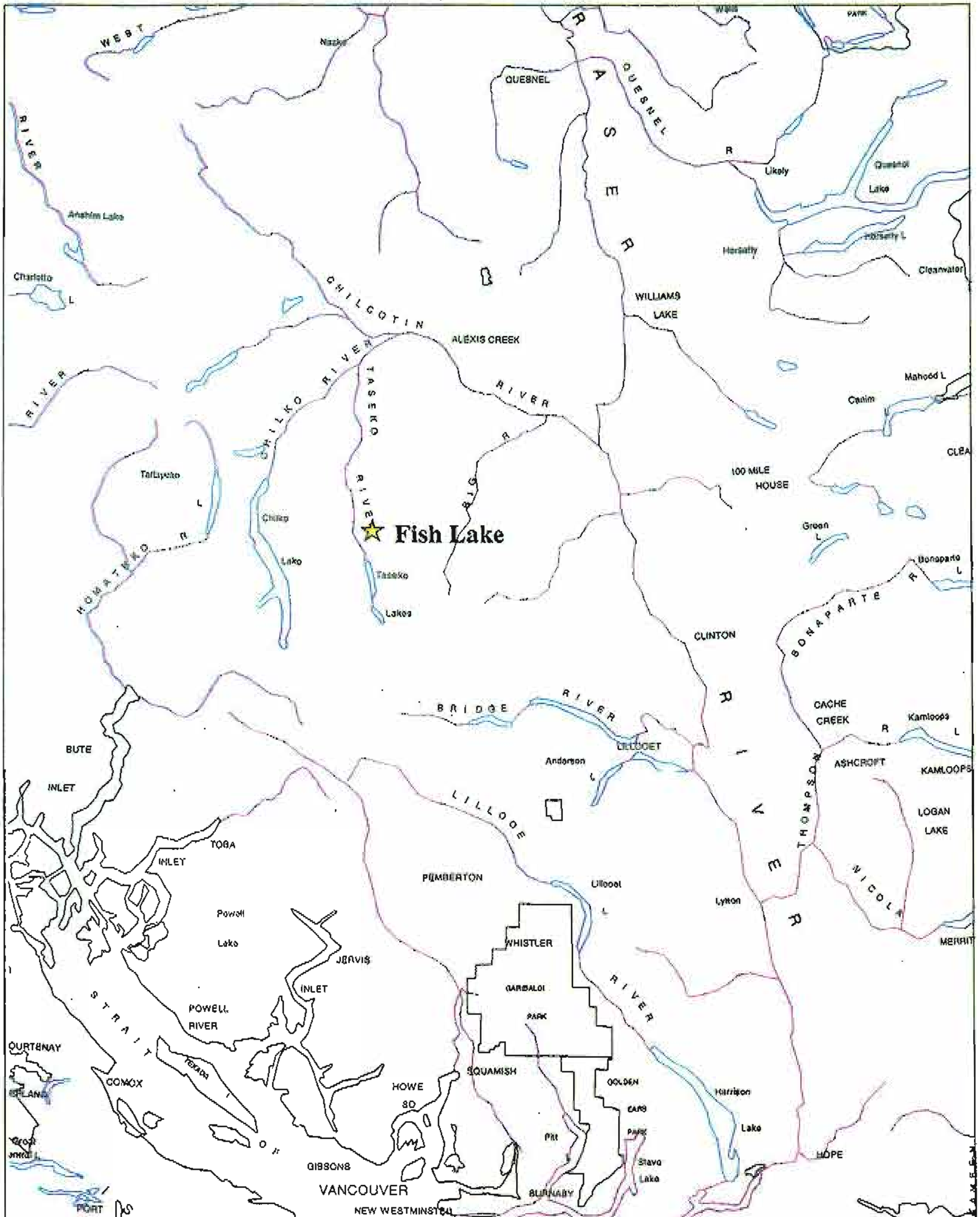
Table 6. Survival of rainbow trout in liveboxes, September 1997.

Trout length (mm)	Date: closed	Date: opened	Hour: closed	Hour: opened	Hours soaked	Number: in-box	Number: dead	Number: survived	Survival
70-139	24-Sep	25-Sep	1000	0845	22.8	65	1	64	0.98
140-229	24-Sep	25-Sep	1000	0850	22.8	40	0	40	1.00
230-330	24-Sep	25-Sep	1000	0855	22.9	23	0	23	1.00
70-139	25-Sep	26-Sep	1030	0755	21.4	49	2	47	0.96
140-229	25-Sep	26-Sep	1030	0800	21.5	29	1	28	0.97
230-330	25-Sep	26-Sep	1030	0805	21.6	20	0	20	1.00
70-139	26-Sep	27-Sep	0905	0810	23.1	42	2	40	0.95
140-229	26-Sep	27-Sep	0905	0815	23.4	38	1	37	0.97
230-330	26-Sep	27-Sep	0905	0818	23.3	30	0	30	1.00
70-139	27-Sep	28-Sep	0915	0800	22.8	39	2	37	0.95
140-229	27-Sep	28-Sep	0915	0805	22.8	35	0	35	1.00
230-330	27-Sep	28-Sep	0915	0810	22.9	26	0	26	1.00
70-139	28-Sep	29-Sep	0830	0816	23.8	22	0	22	1.00
140-229	28-Sep	29-Sep	0830	0814	23.8	42	0	42	1.00
230-330	28-Sep	29-Sep	0830	0812	23.8	35	0	35	1.00
70-139	29-Sep	30-Sep	0928	0802	22.5	33	2	31	0.94
140-229	29-Sep	30-Sep	0928	0805	22.5	31	0	31	1.00
230-330	29-Sep	30-Sep	0928	0807	22.5	14	0	14	1.00
					sum	613	11	602	
					mean				0.98
					SD				0.02
					n				18

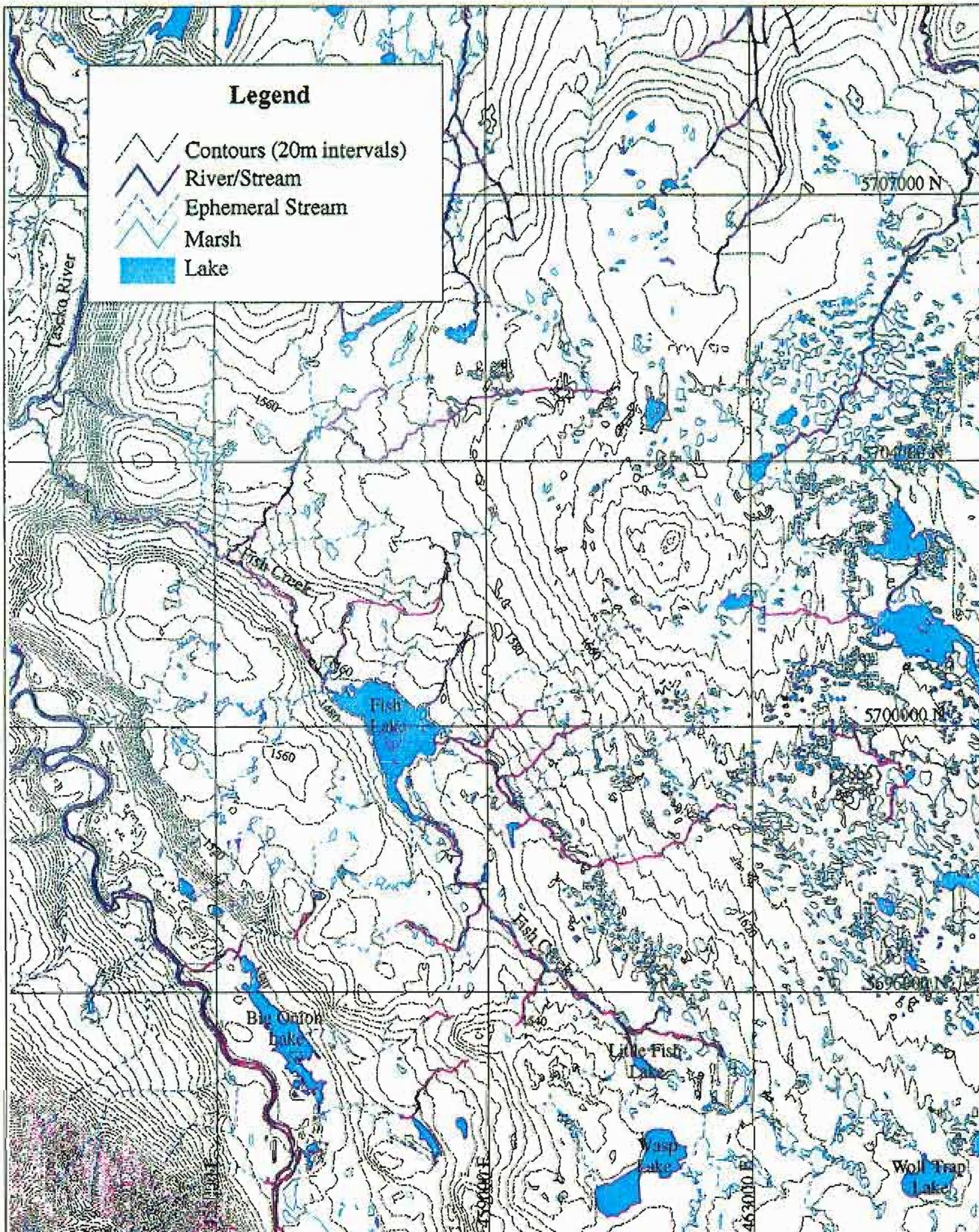
Table 7. Petersen estimates of the number of subadult and adult rainbow trout in Fish Lake, 1997.

Sub-population (Length range, mm)	Juveniles (70-139)	subadults (140-229)	adults (230-330)	combined (140-330)
Initial number marked (M')	441	757	861	1618
Marked after 24 hours (M)[a]	406	696	792	1489
Total number examined in 2nd recapture phase (C)	397	319	235	554
Recaptured in 2nd recapture phase (R)	0	9	6	15
R/C ratio	-	0.028	0.026	0.027
Population (N)	-	22318	26739	49058
lower 95% confidence limits	-	12318	13270	32093
upper 95% confidence limits	-	39004	50123	82014

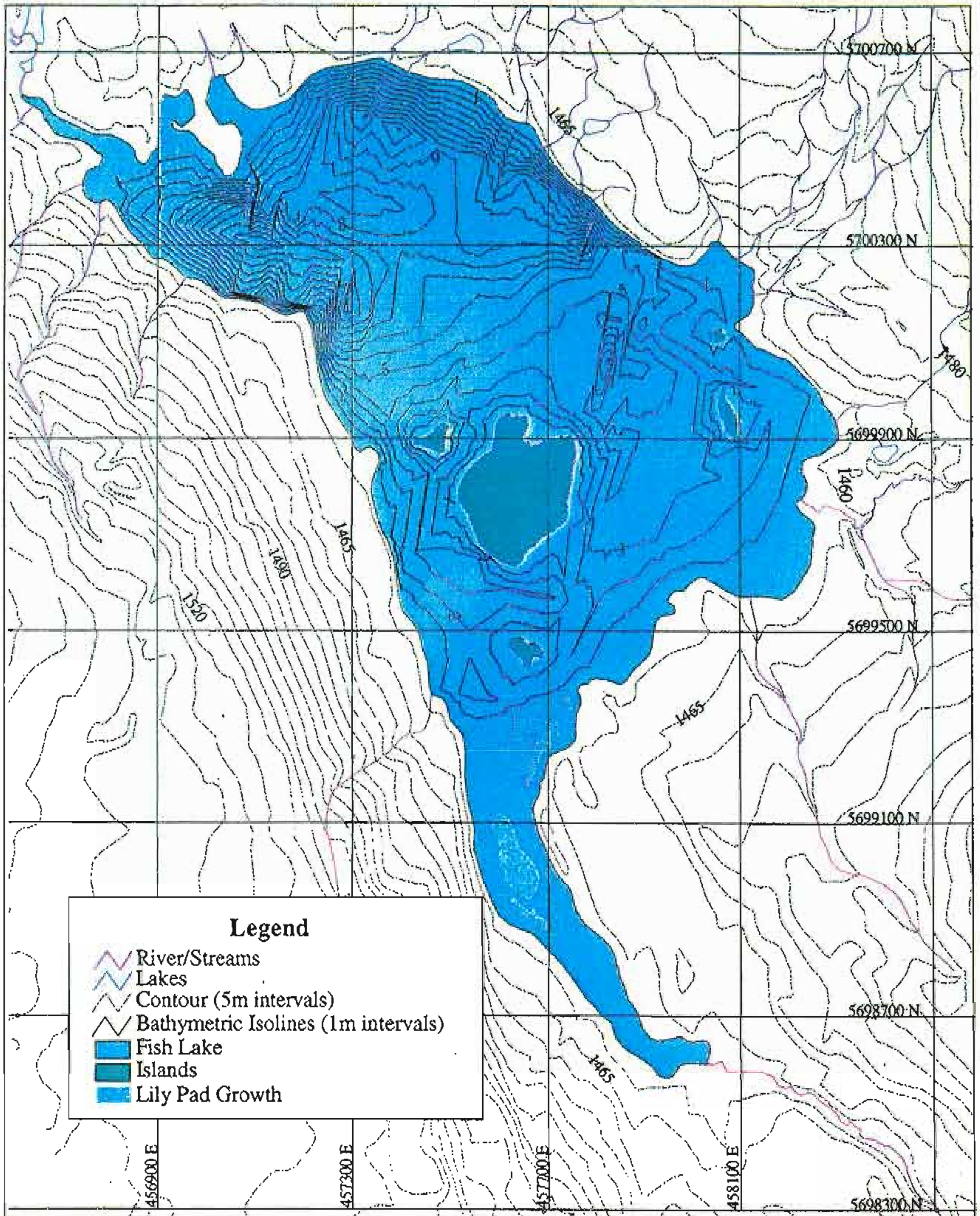
[a]survival was assumed to be 92%. Losses due to angling were assumed to be negligible.



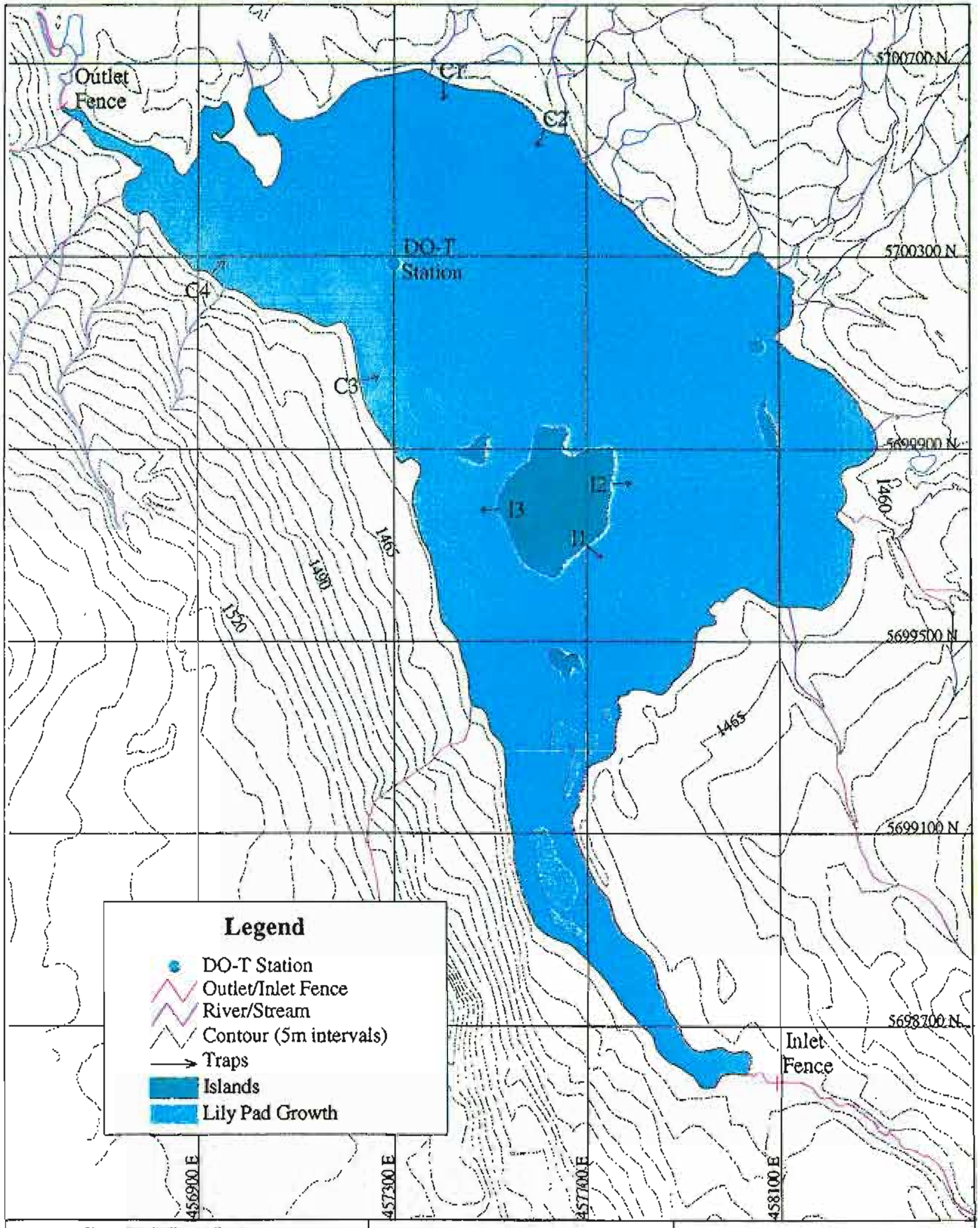
Taseko Mines Ltd. Prosperity Gold - Copper Project	Map 255512136	20 0 20 40 Kilometers 1:2100000
Figure 1. Location of Fish Lake in Southwestern British Columbia		TRITON Environmental Consultants Ltd.



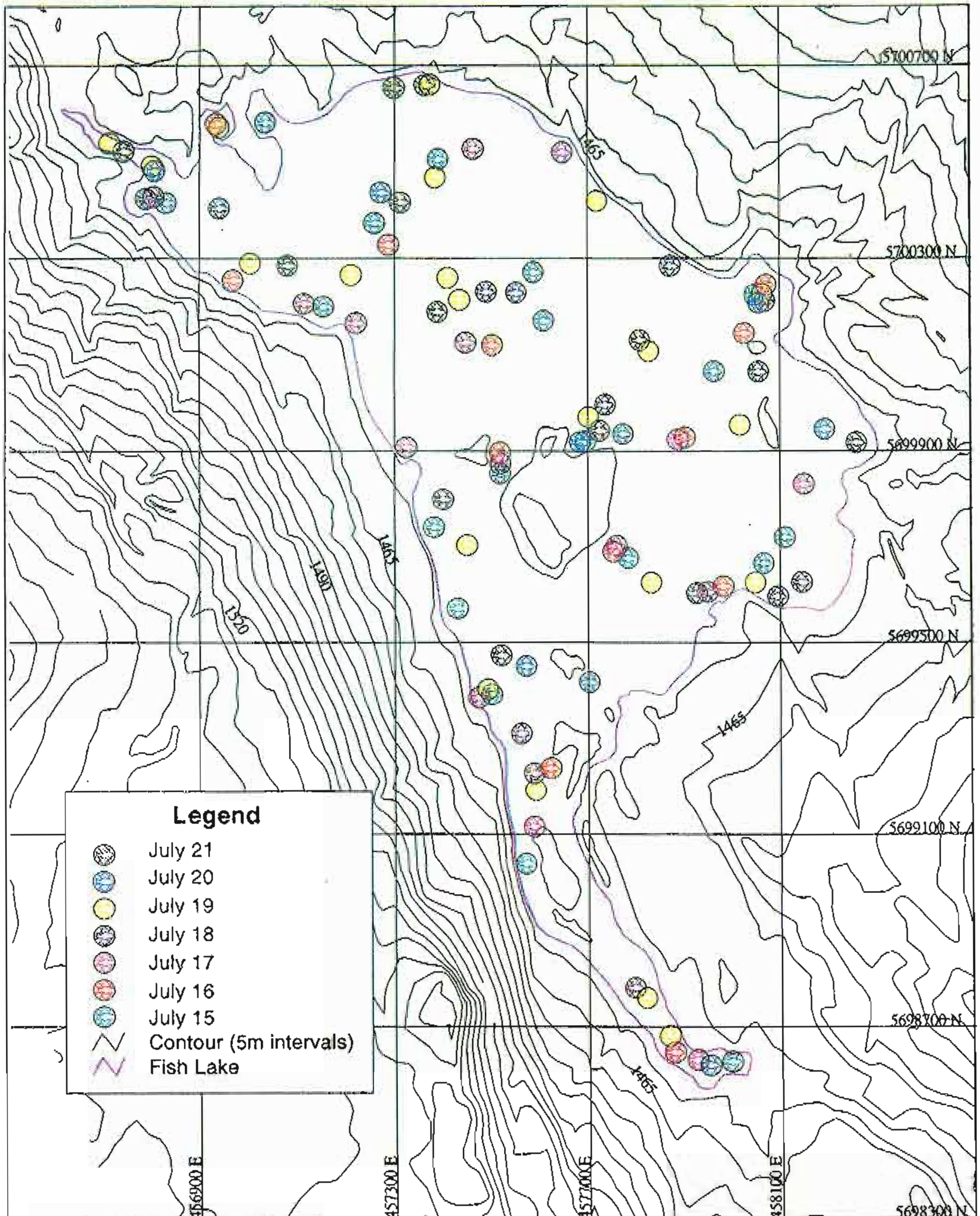
Taseko Mines Ltd. Prosperity Gold - Copper Project	Map 255512137	1000 0 1000 2000 Meters 1:88000
Figure 2. Map of Fish Lake Watershed		TRITON Environmental Consultants Ltd.



Taseko Mines Ltd. Prosperity Gold - Copper Project	Map 255512138	100 0 100 200 300 Meters 1:12000
Figure 3. Bathymetric Map of Fish Lake		TRITON Environmental Consultants Ltd.



Taseko Mines Ltd. Prosperity Gold - Copper Project	Map 255512136	100 0 100 200 300 Meters 1:12000
Figure 4. Sampling Stations in Fish Lake		TRITON Environmental Consultants Ltd.



Taseko Mines Ltd.
Prosperity Gold - Copper Project

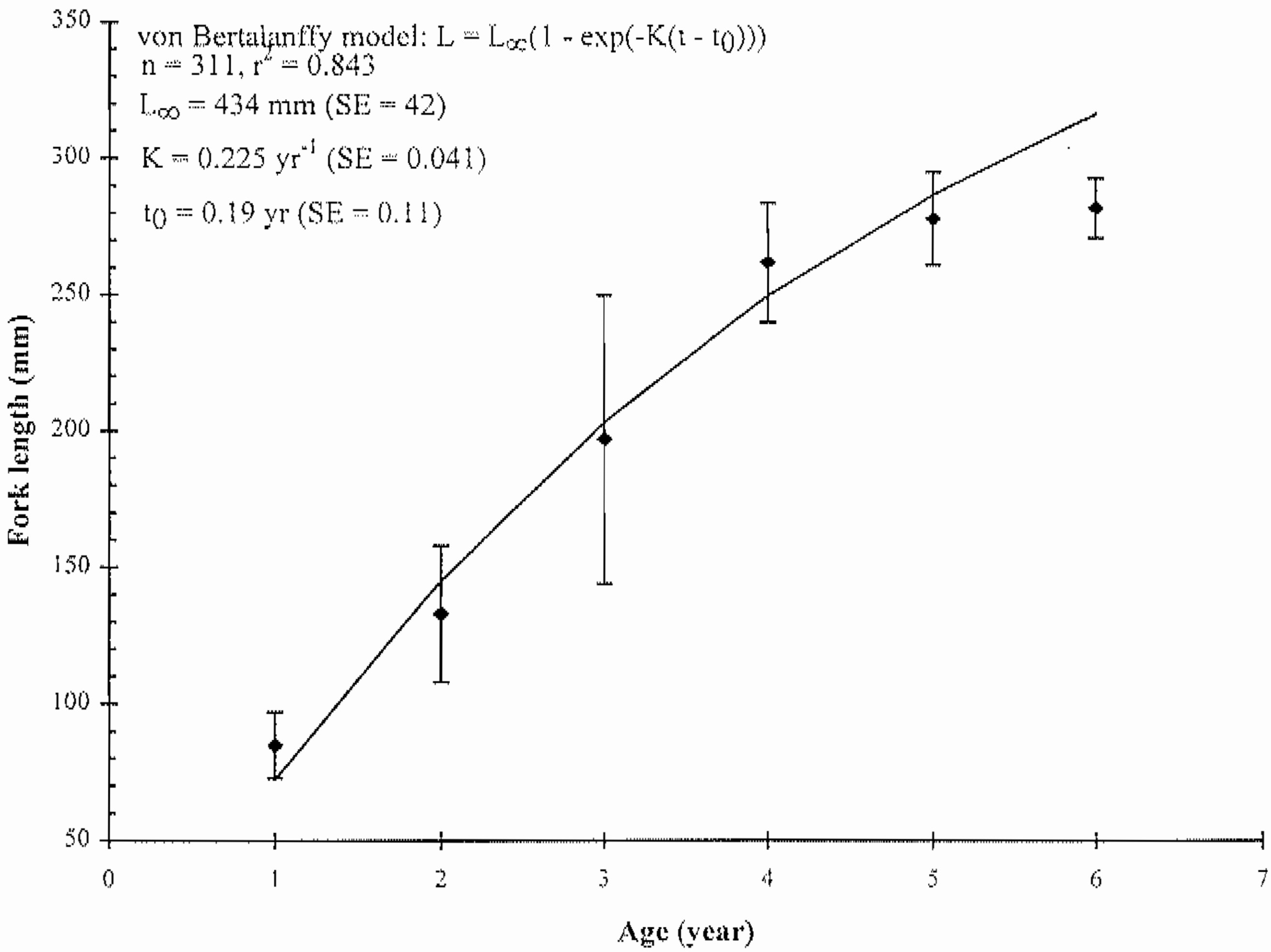
Map 255512139

100 0 100 200 300 Meters
1:12000

Figure 5. Locations of Release of Marked Trout in Fish Lake

TRITON
Environmental Consultants Ltd.

Figure 6. Mean (±1 SD) length-at-age of Fish Lake rainbow trout based on scale samples taken at inlet and outlet fences in 1996 and 1997, fit with a von Bertalanffy growth model



Triton Environmental Consultants Ltd.
April 14, 1999 *2555.12/agetot[meansize].xls*

Figure 7. Surface water temperature of Fish Lake, July-August 1997, measured at five stations. The solid line is the daily mean of all stations and the broken lines are the 95% confidence limits of the daily mean

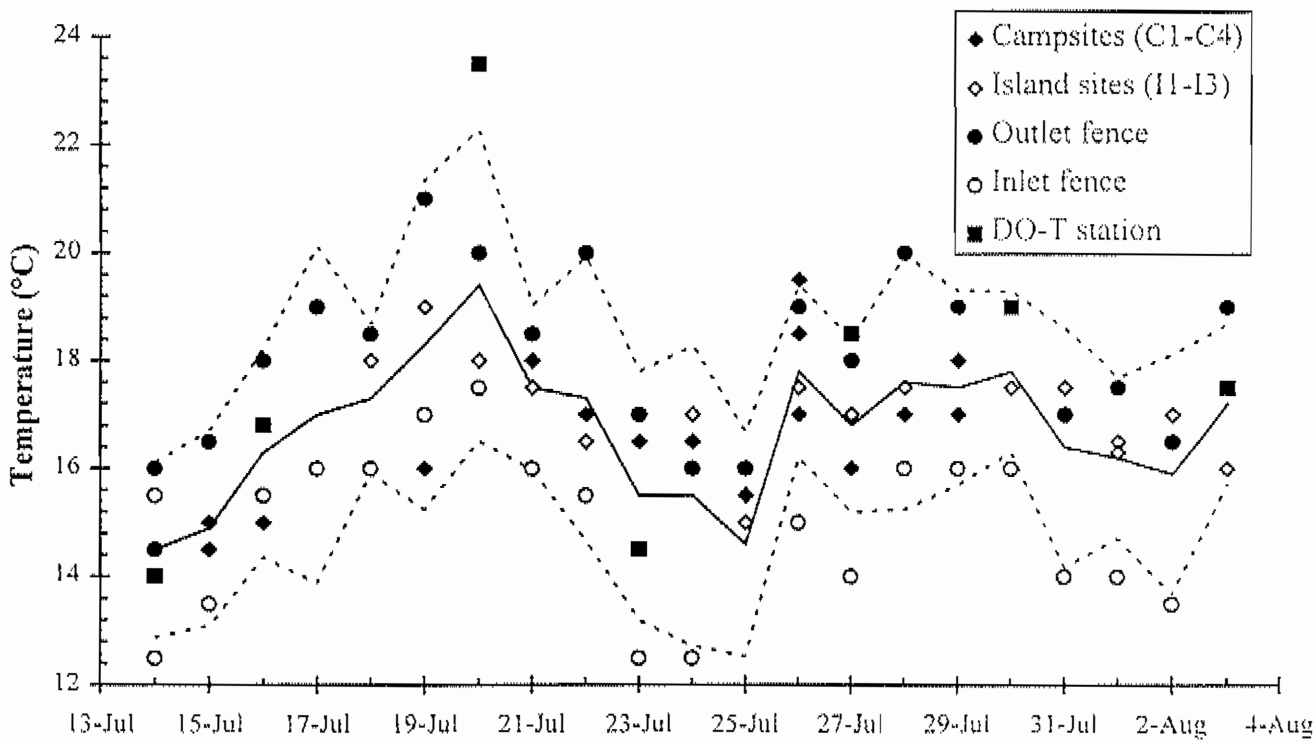
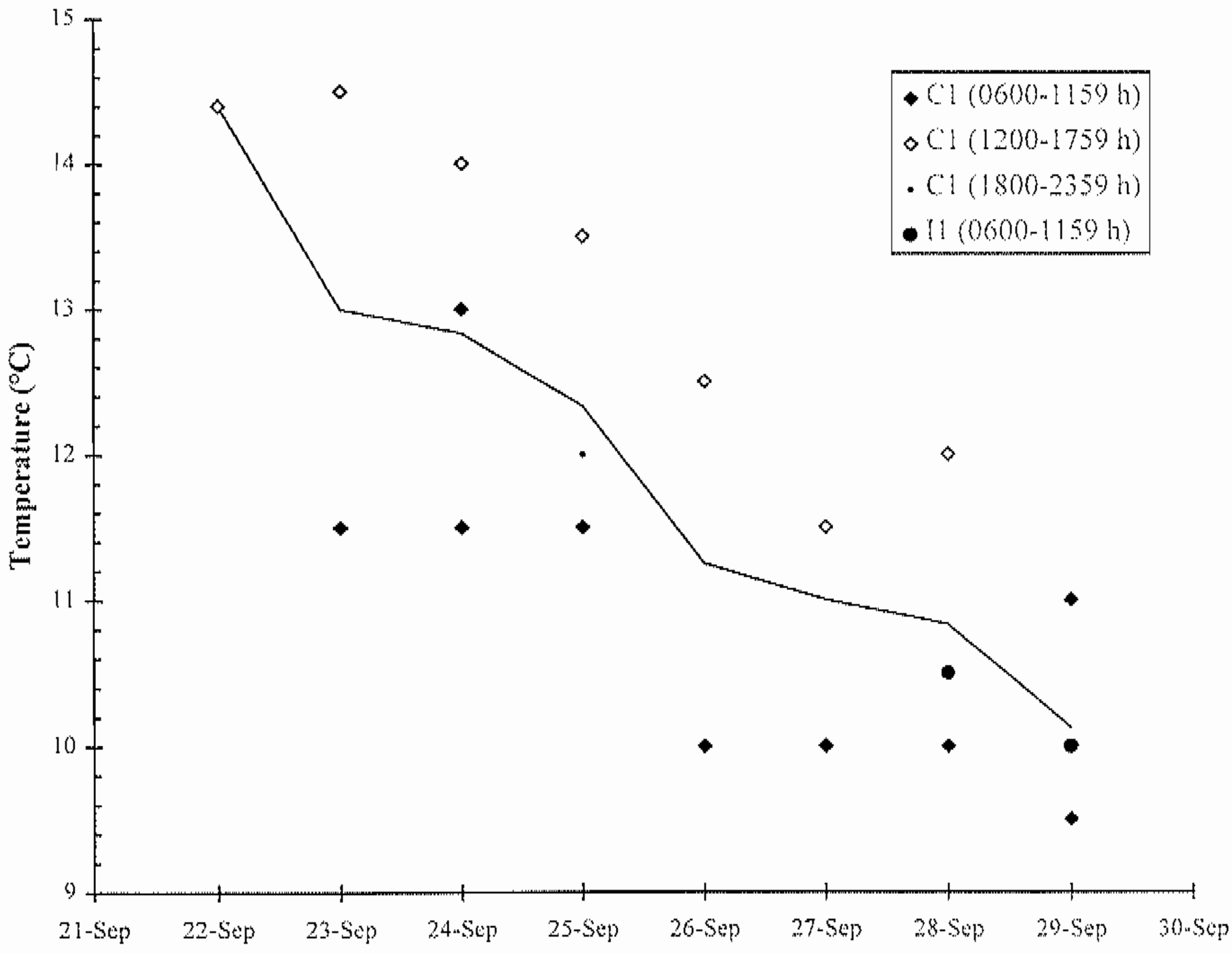


Figure 8. Surface water temperature of Fish Lake, September 23 to 30, 1997. The solid line is the daily mean of all stations and times of day



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2555.12/appa[temp2].xls

Figure 9. Temperature profiles, Fish Lake, 1997

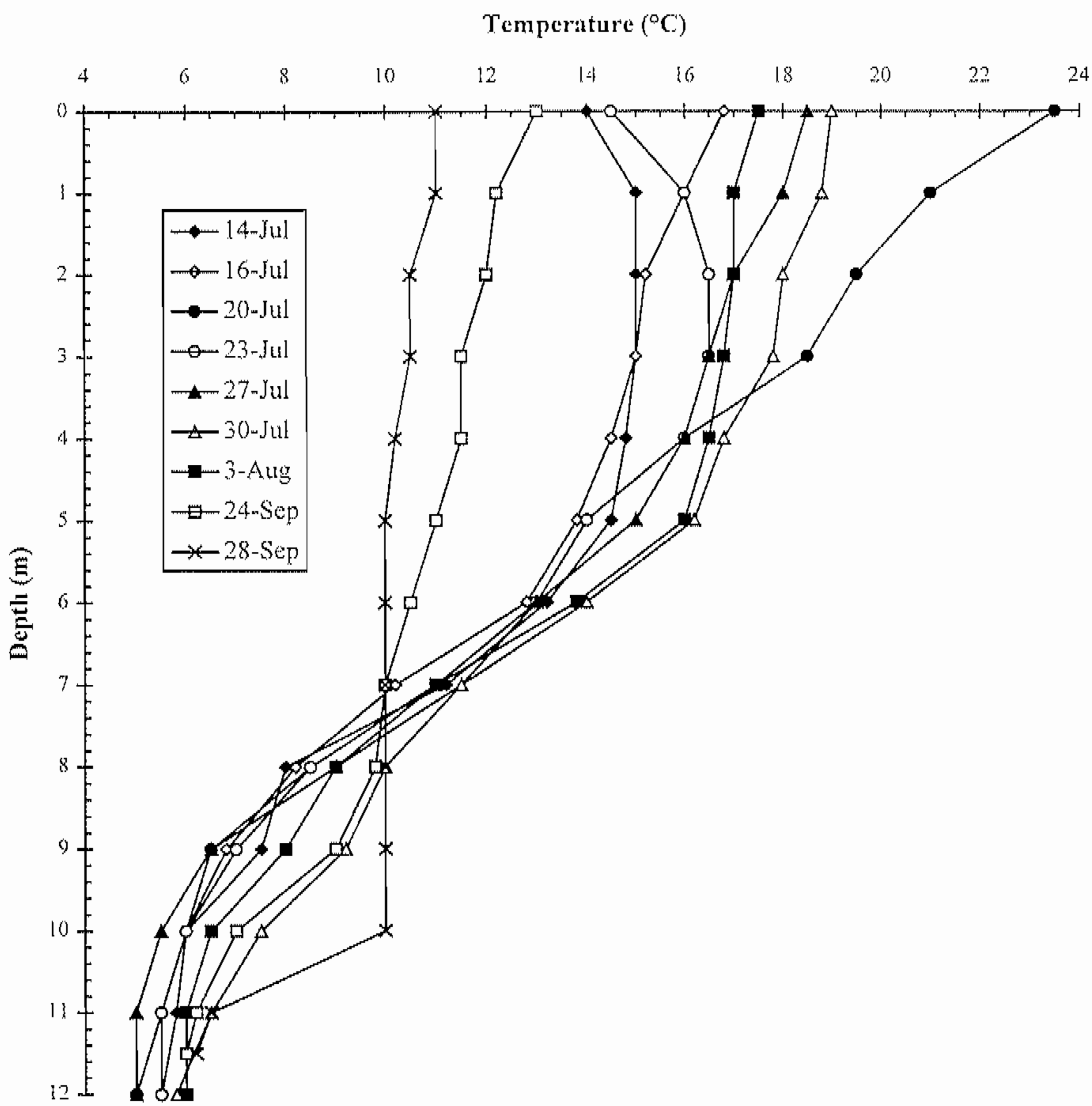

Figure 10. Numbers of rainbow trout entering and leaving Fish Lake, July-September, 1997

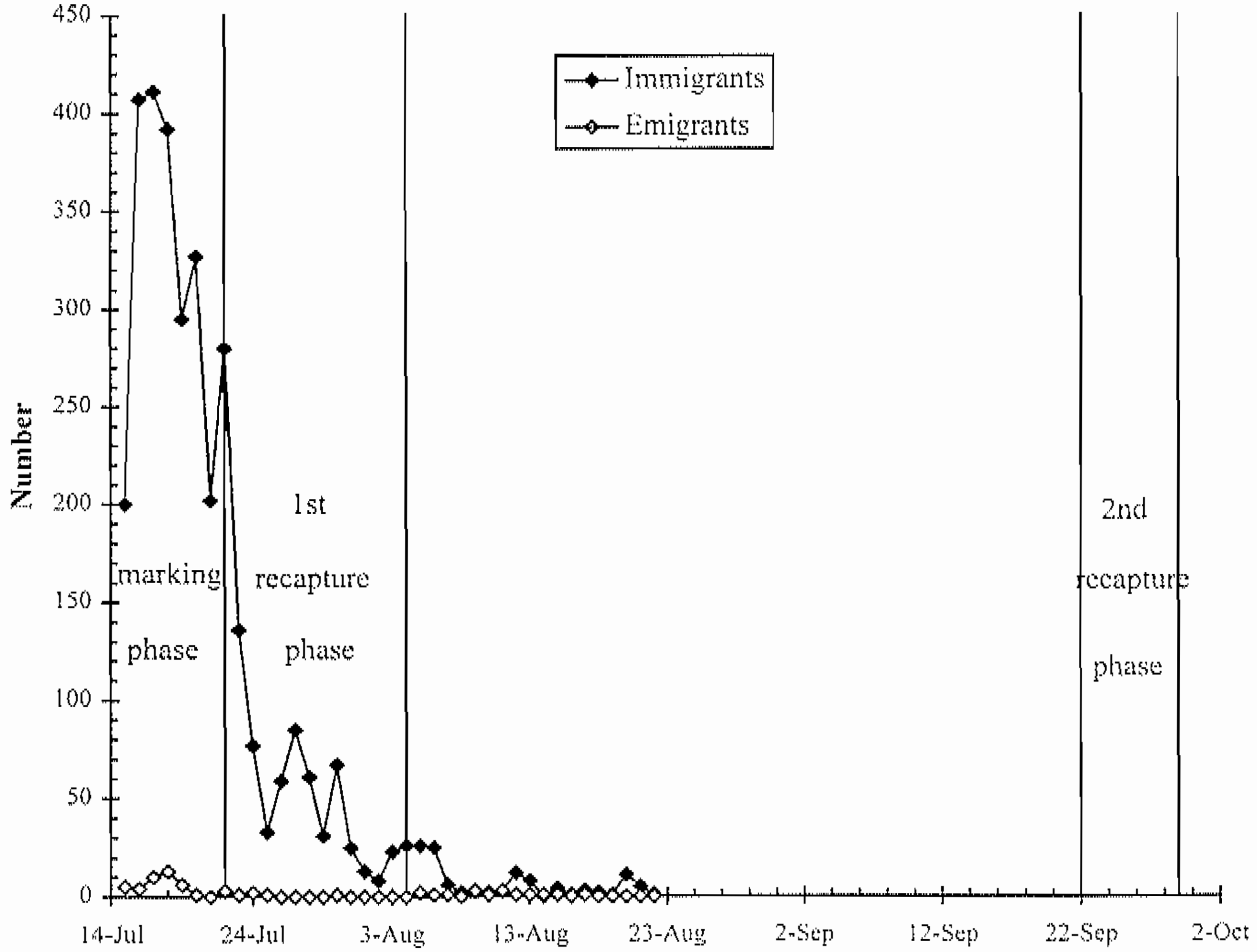

Figure 11. Length frequency distribution of rainbow trout migrating into Fish Lake from Fish Creek, 1997

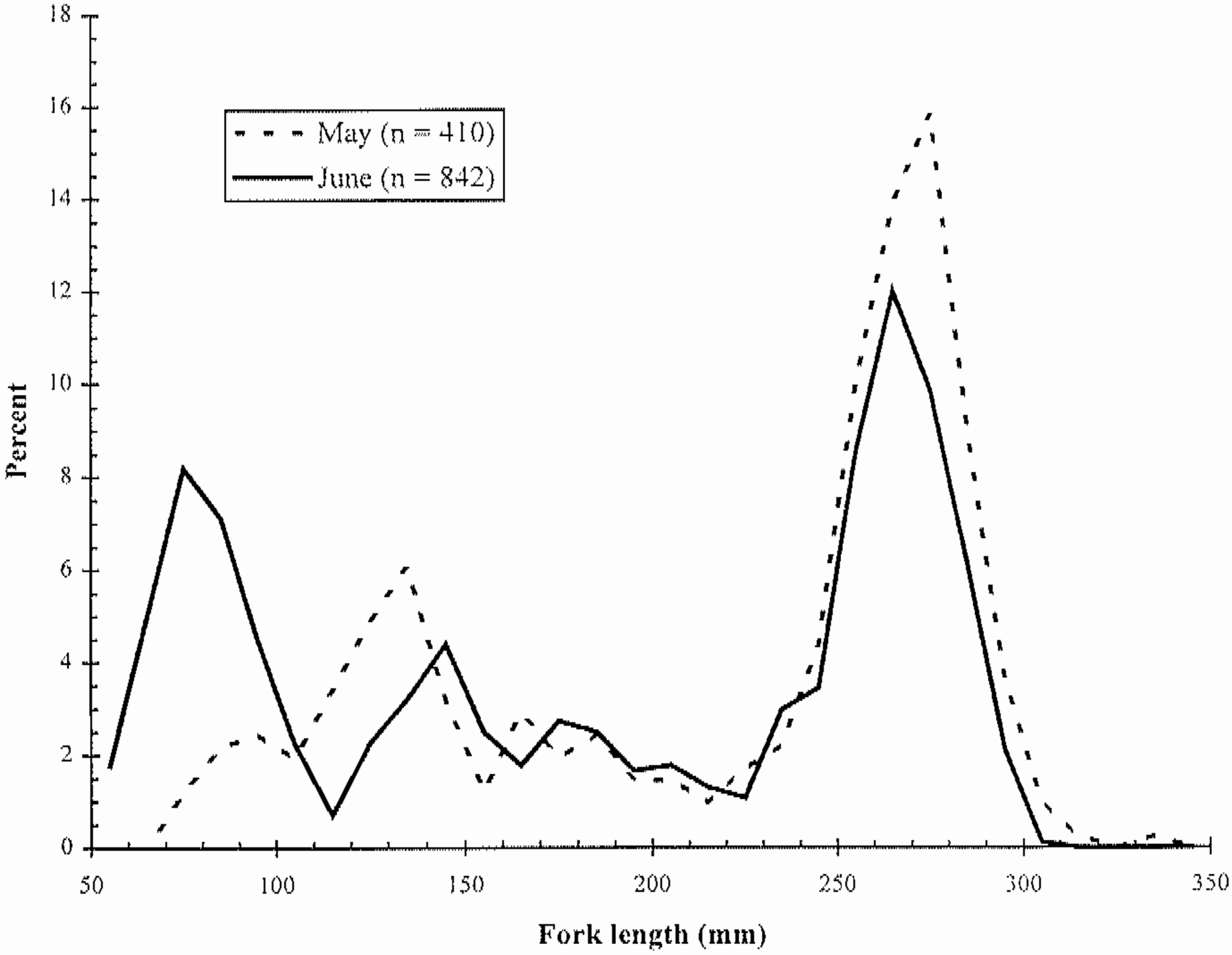

Figure 12A. Age frequency distribution of rainbow trout migrating into Fish Lake from Fish Creek, May 1997

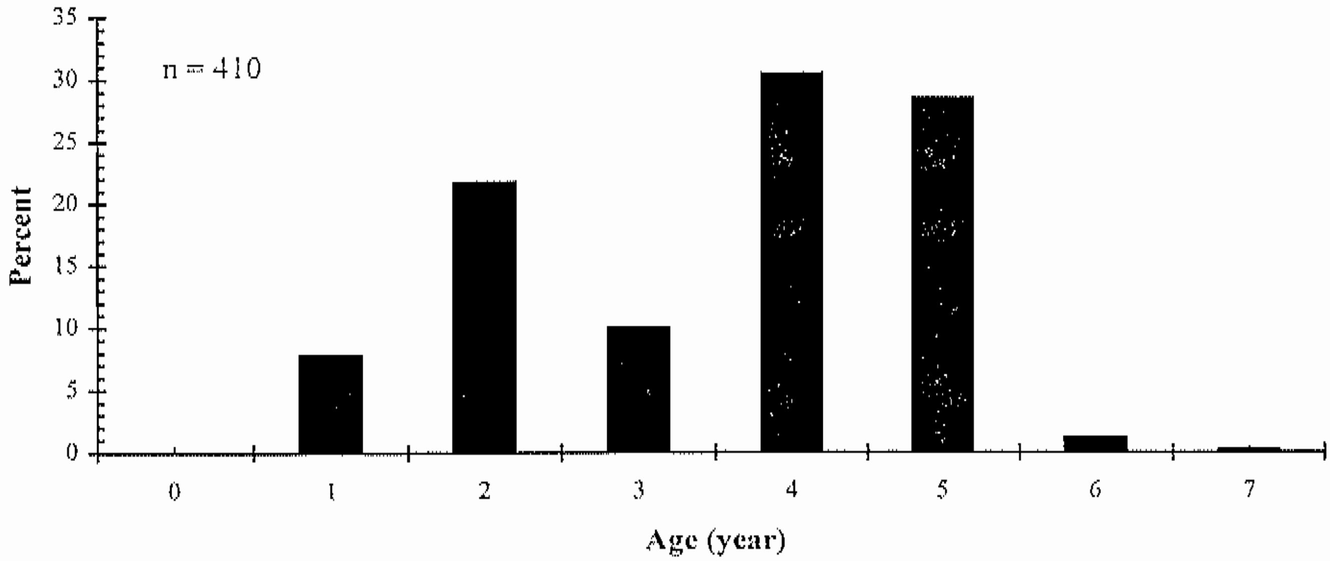

Figure 12B. Age frequency distribution of rainbow trout migrating into Fish Lake from Fish Creek, June 1997

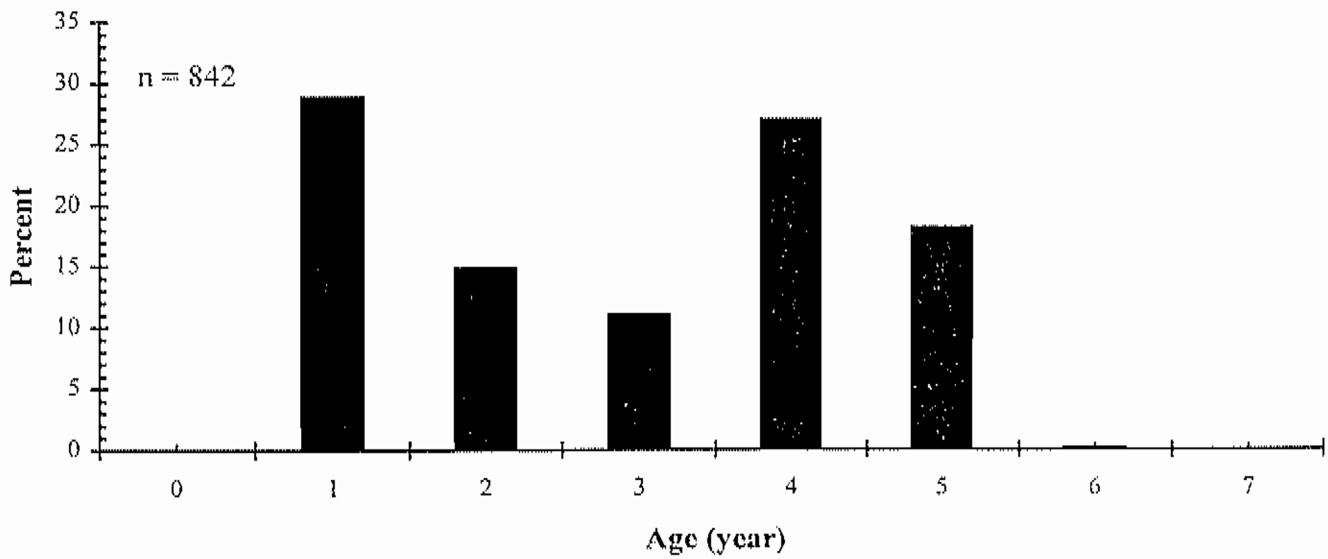

Figure 13. Number of rainbow trout caught and killed in Fish Lake, 1997, by week. All numbers corrected for non-interviewed and missed anglers

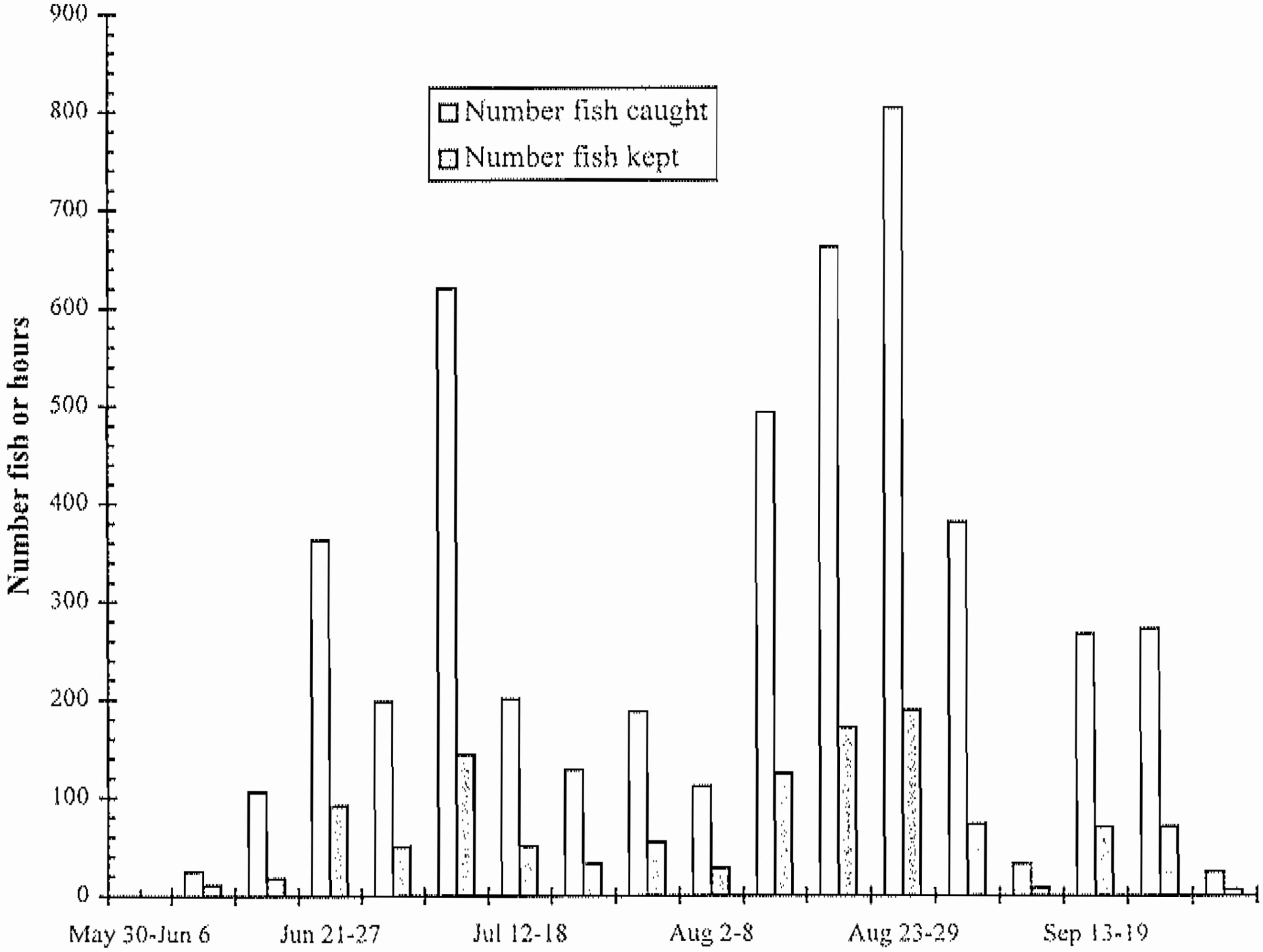

Figure 14. Plot of trap net CPUE of seven sites and mean surface temperature (T) on the date of trap opening, Fish Lake, July-August 1997

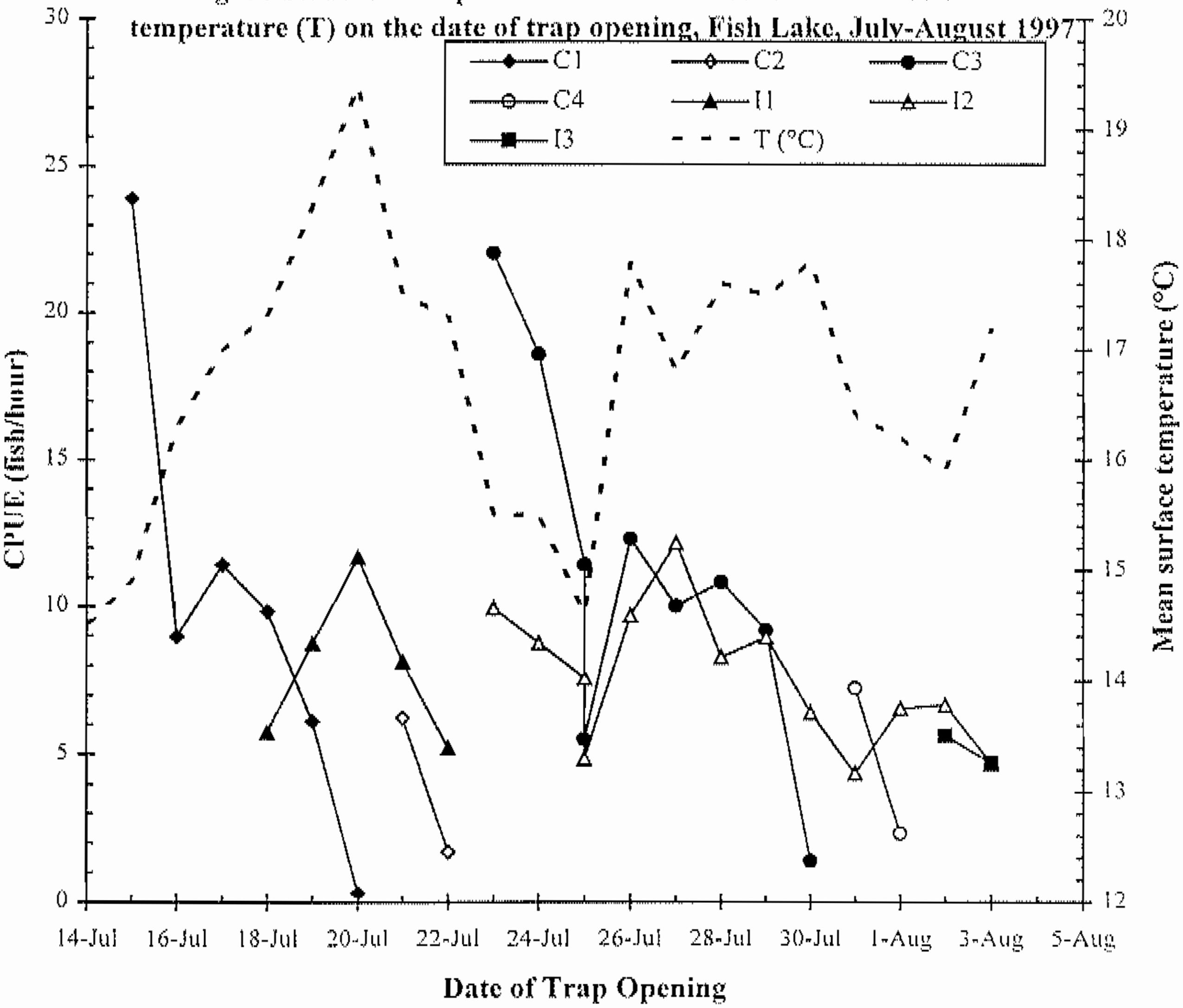

Figure 15. Plot of trap net CPUE of two sites and mean surface temperature (T) on the date of trap opening, Fish Lake, September 1997

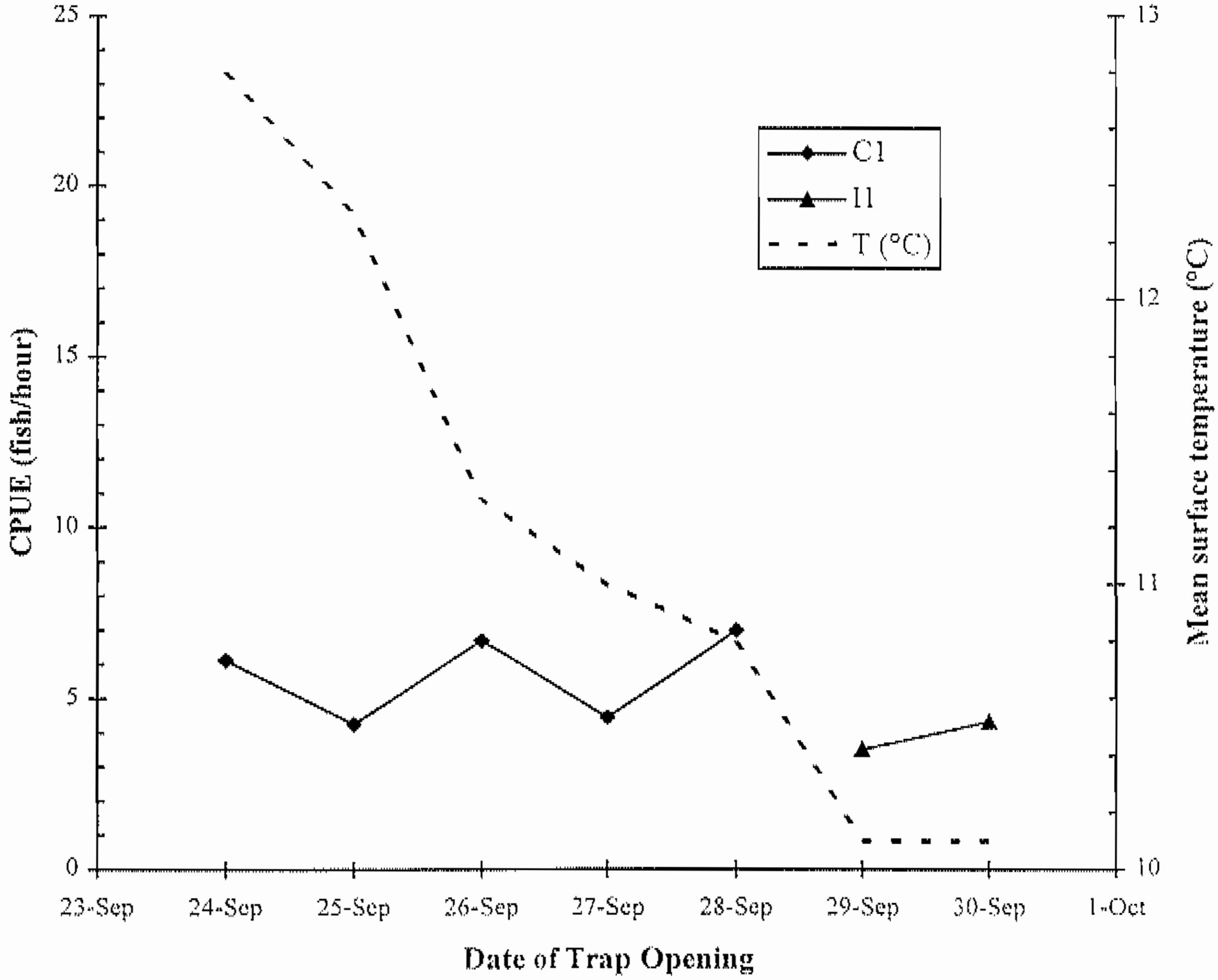

Figure 16. Length frequency distribution of marked rainbow trout and of trout examined for marks during the two recapture phases, collected in 10 mm length intervals, Fish Lake, July-September 1997

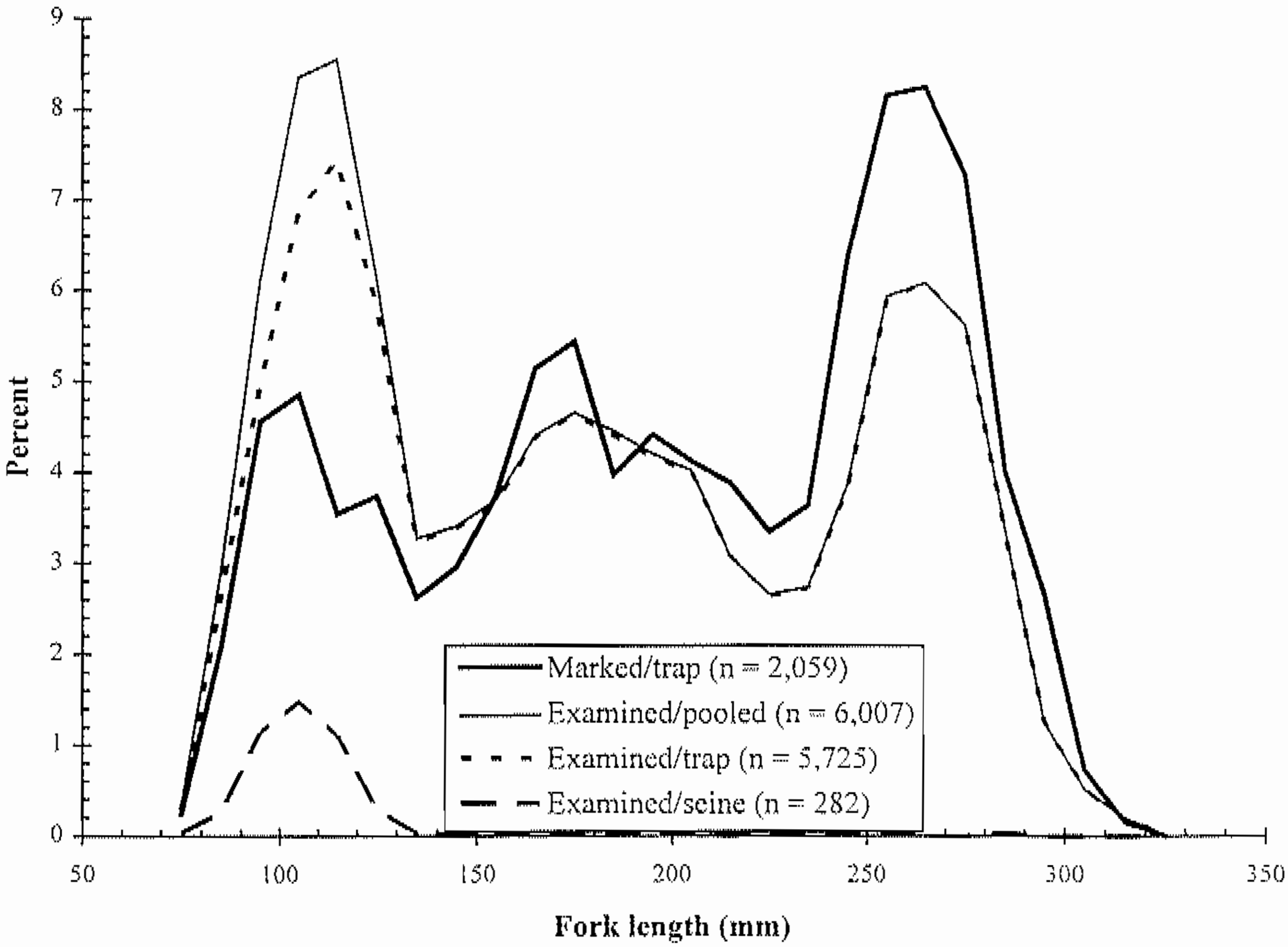

Figure 17A. Age frequency distribution of marked rainbow trout, Fish Lake, 1997

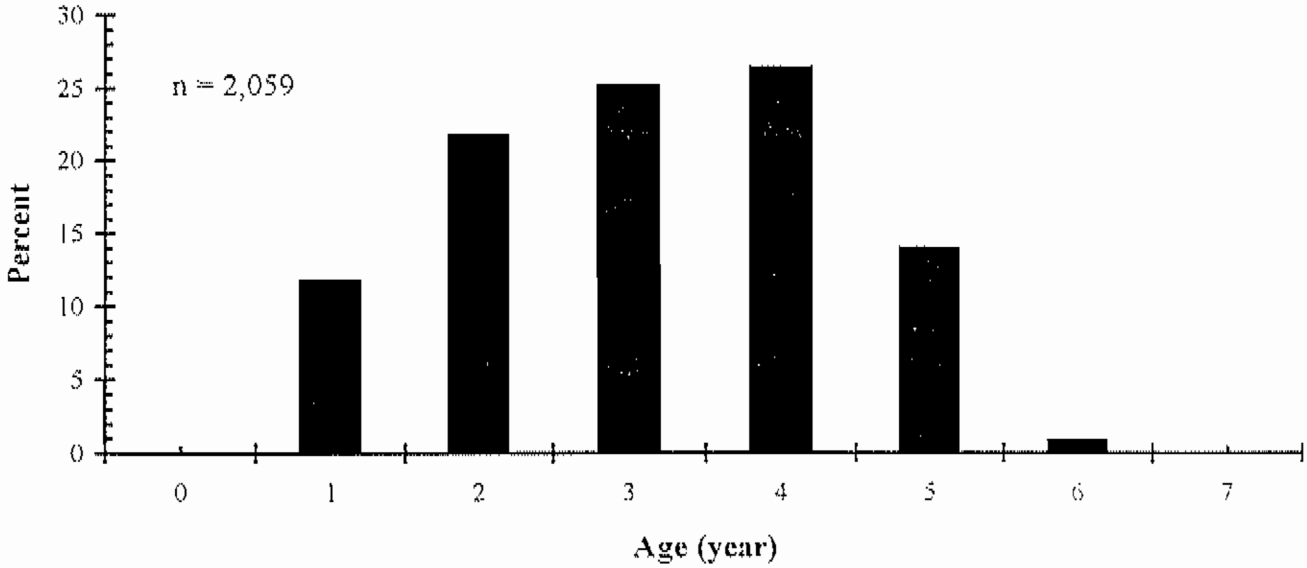

Figure 17B. Age frequency distribution of examined rainbow trout, Fish Lake, 1997

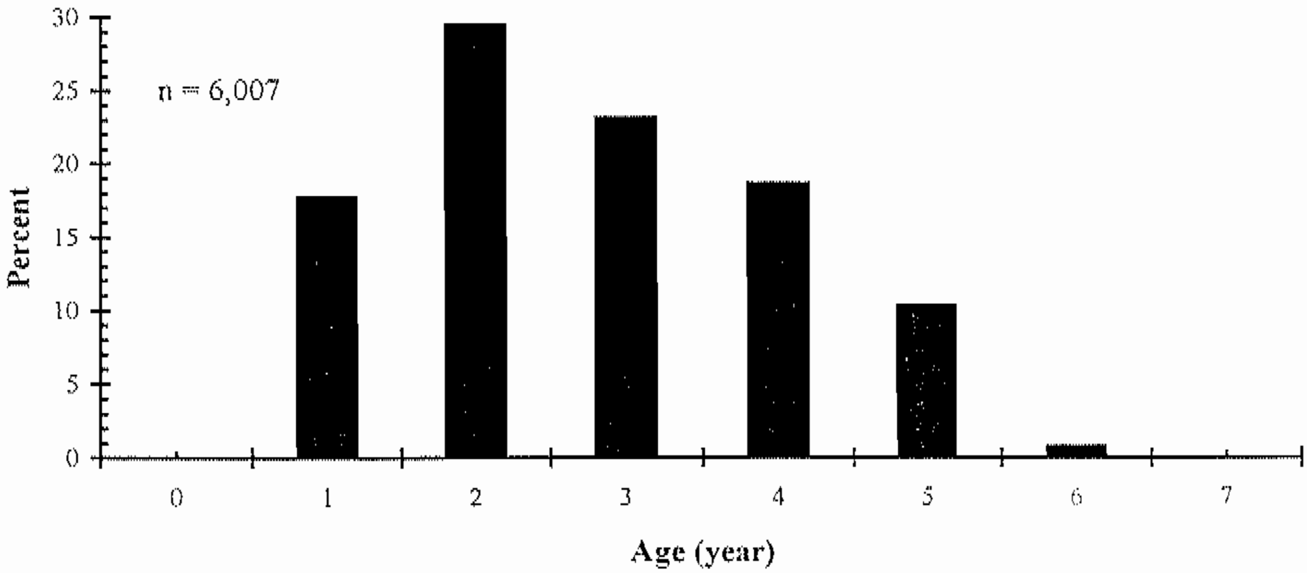

Figure 18. Percent of rainbow trout examined in each study phase that belonged to three length classes, Fish Lake, 1997

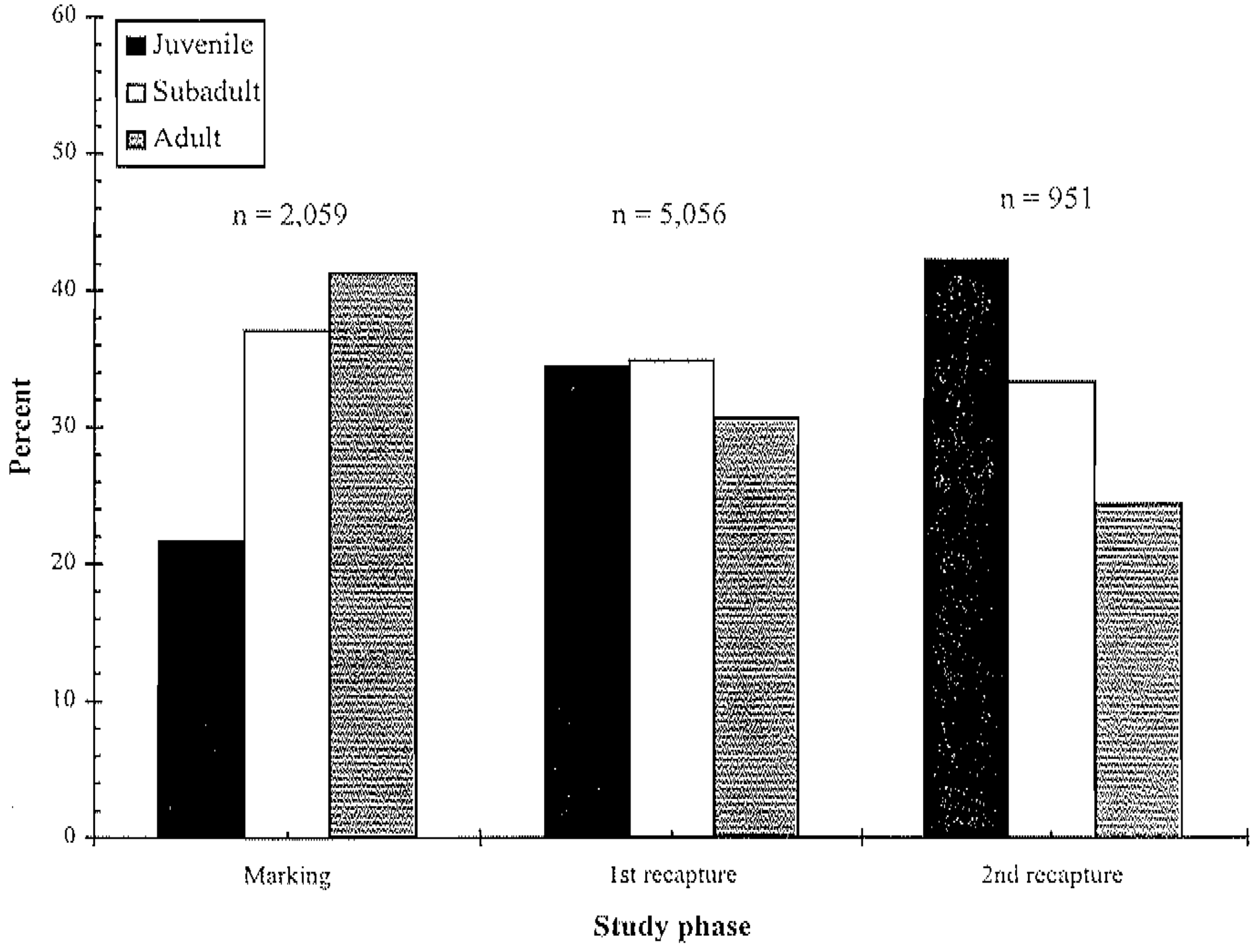

Figure 19. Length frequency distributions of marked and recaptured rainbow trout, collected in 20 mm length intervals, Fish Lake, July-September 1997

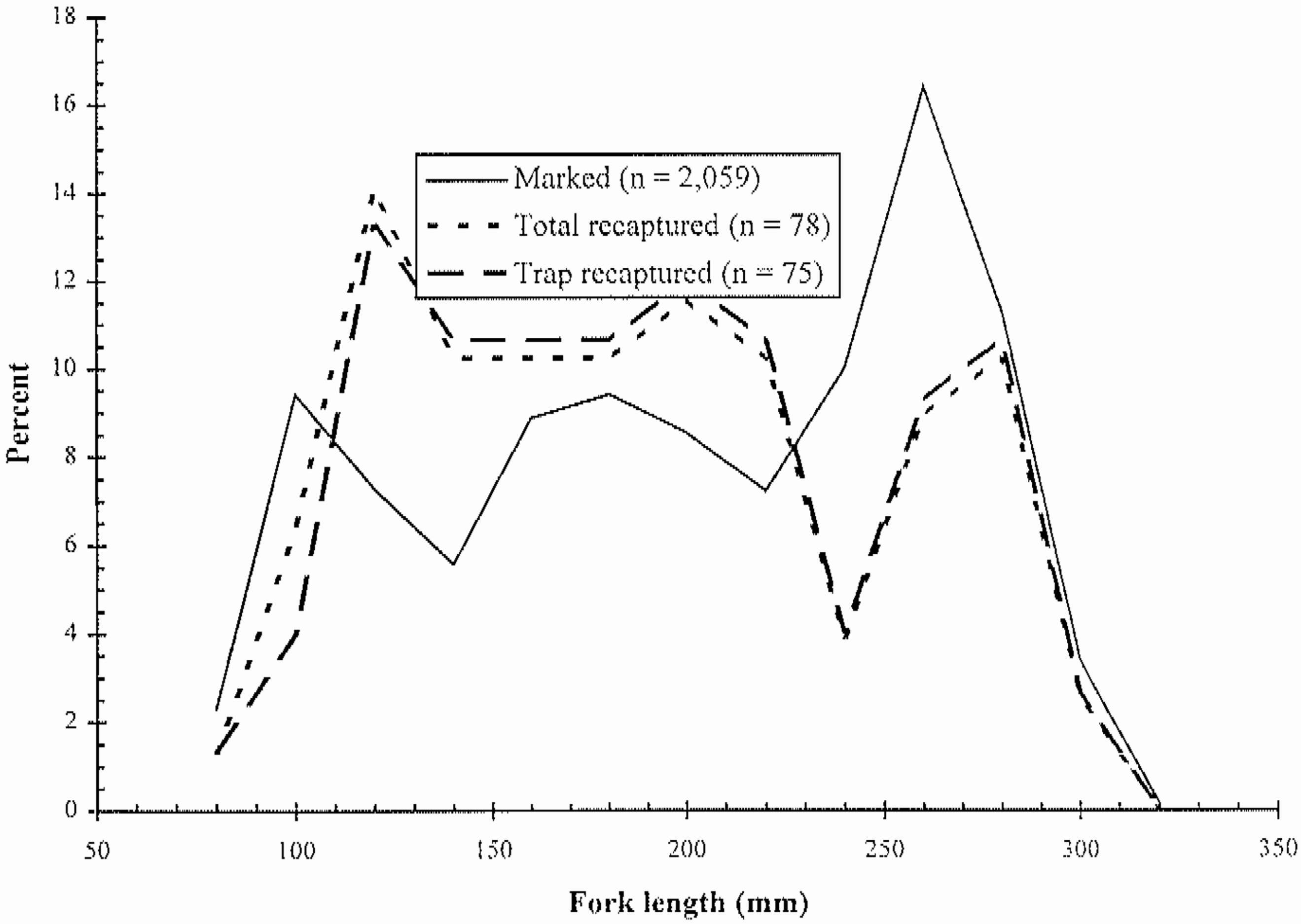

Figure 20A. Age frequency distribution of recaptured rainbow trout, Fish Lake, July to August 1997

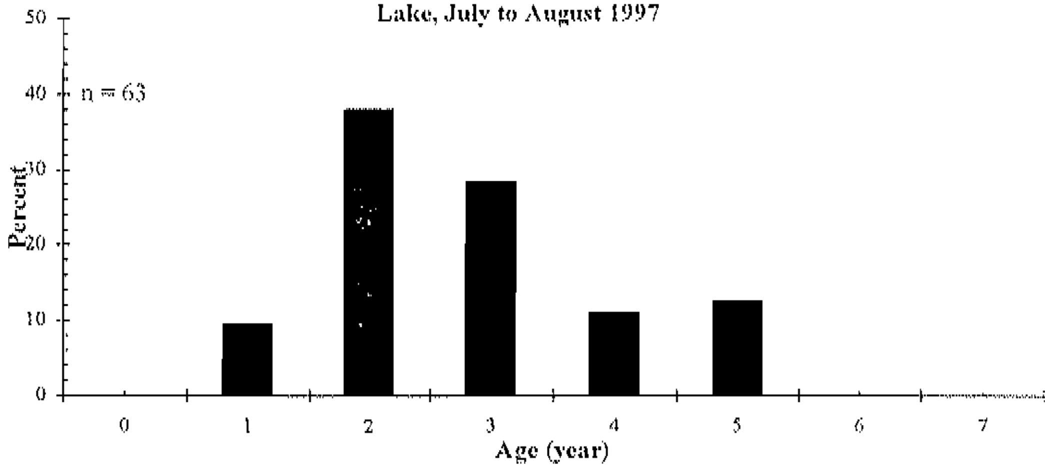

Figure 20B. Age frequency distribution of recaptured rainbow trout, Fish Lake, September 1997

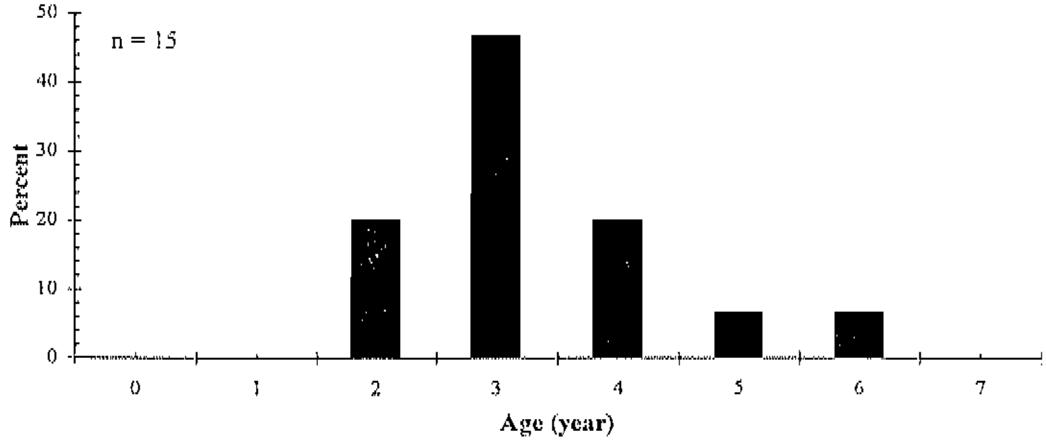

Figure 20C. Age frequency distribution of all recaptured rainbow trout, Fish Lake, July to September 1997

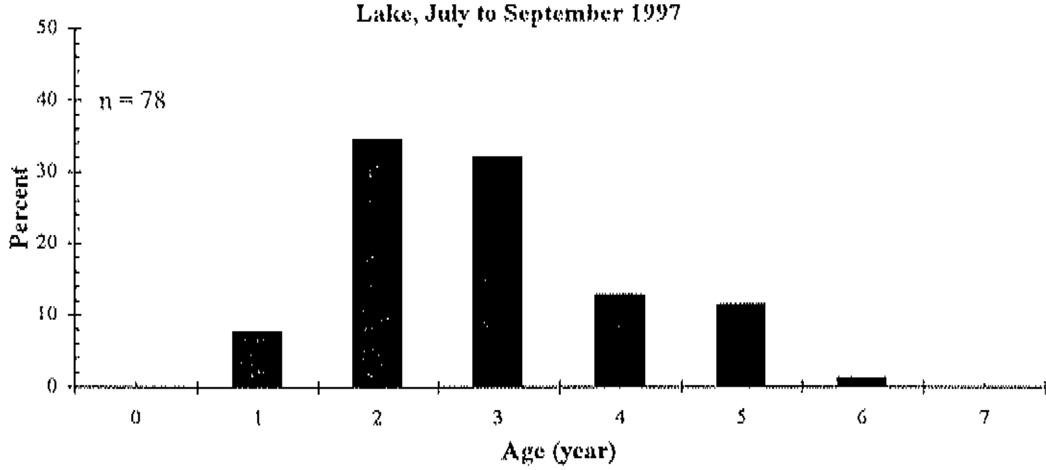

Figure 21. Length frequency distributions of rainbow trout recaptured with trap nets during the first and second recapture phases, collected in 20 mm length intervals, Fish Lake, July-September 1997

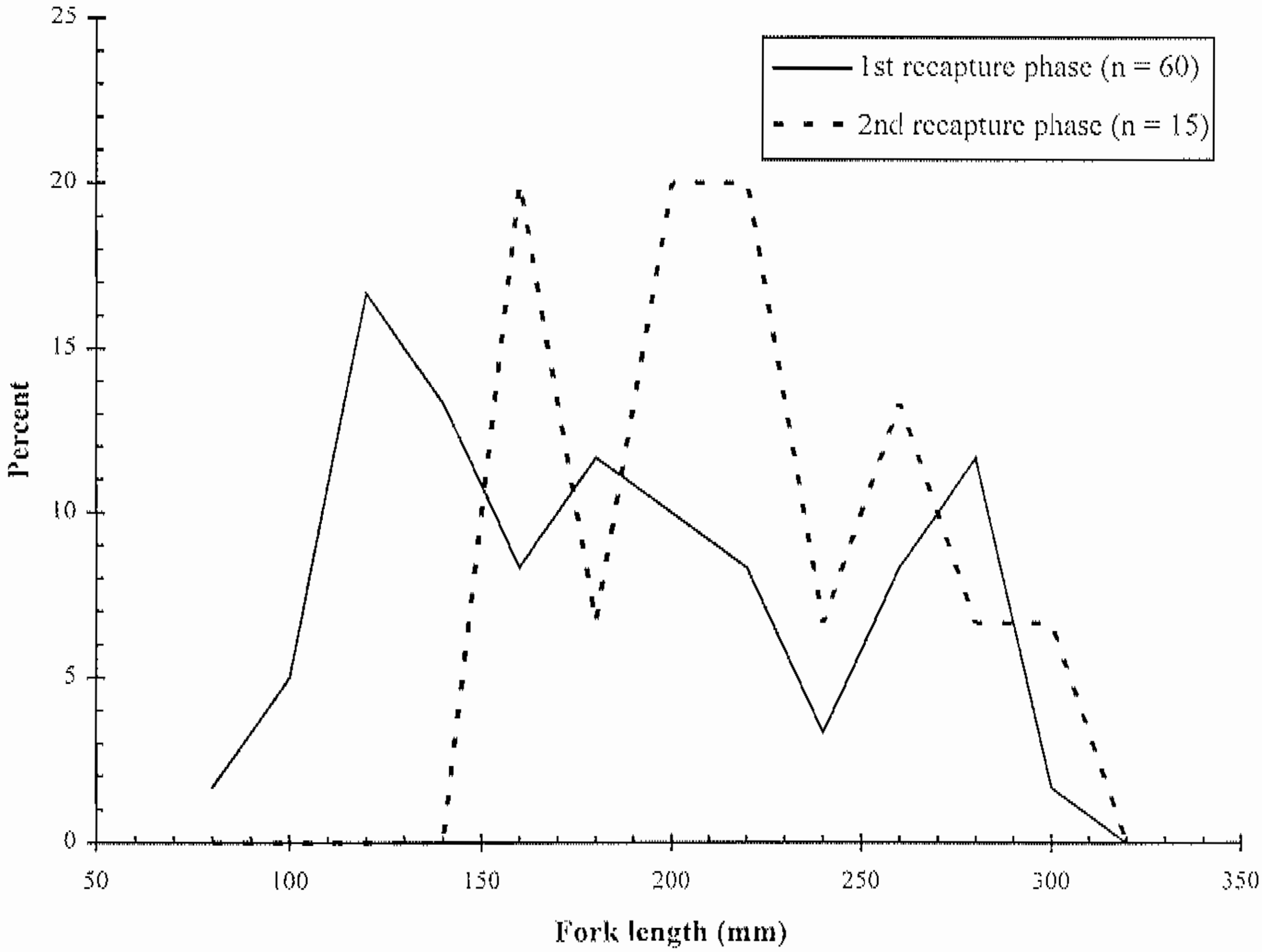

Figure 22A. Length frequency distributions of trap-caught rainbow trout from the eastern and western sides of Fish Lake, July to September 1997

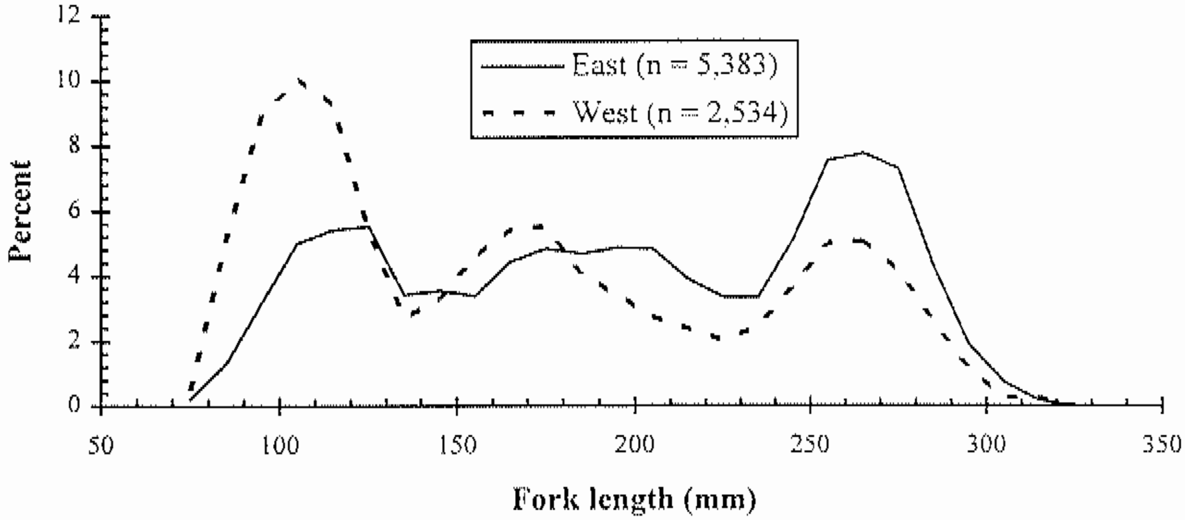

Figure 22B. Length frequency distributions of trap-caught rainbow trout from the northern and southern parts of Fish Lake, July to September, 1997

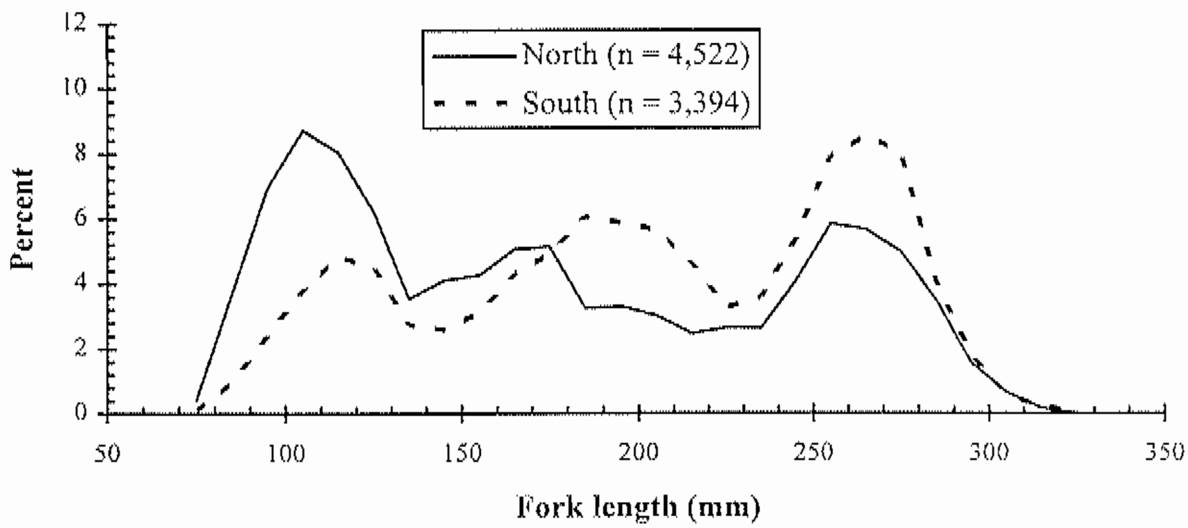

Figure 23. Ratios of recaptured (R) to examined (C) rainbow trout for three length classes and two recapture phases, Fish Lake, 1997

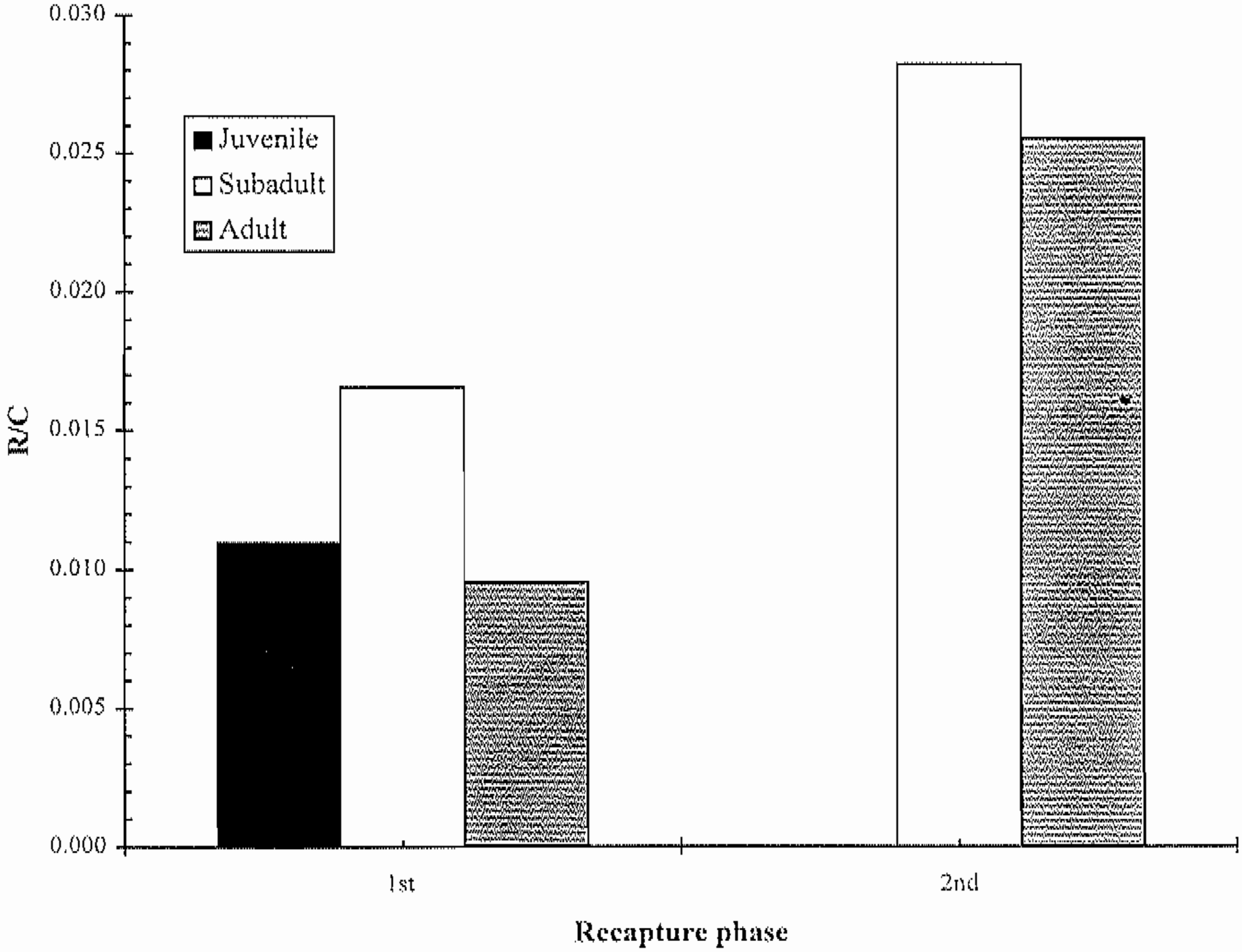

Figure 24. Length frequency distributions of trout held in a livebox for 24 hours, collected in 20 mm intervals, Fish Lake, July-August 1997

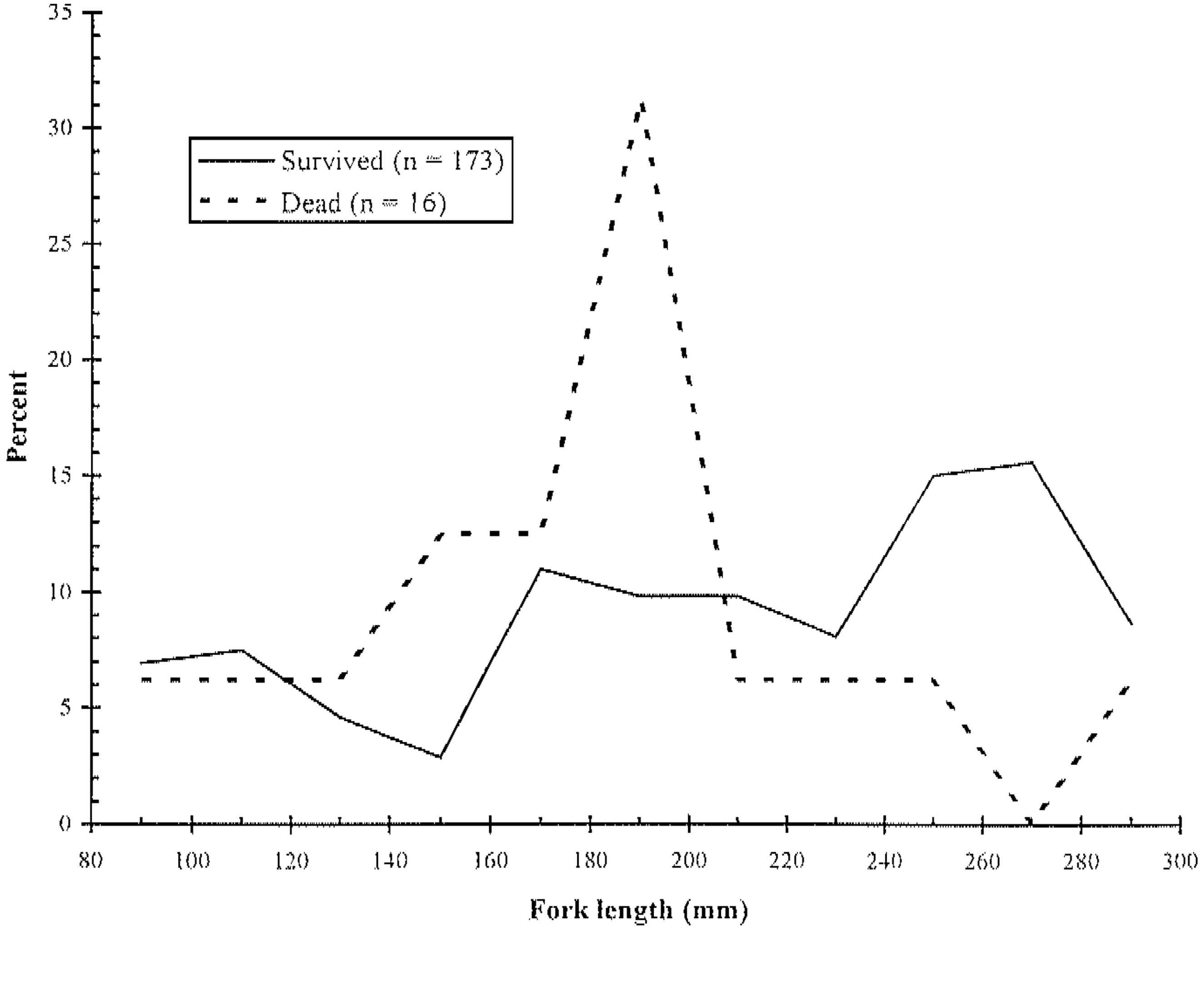

Figure 25. Numbers-at-age of rainbow trout in Fish Lake, 1997

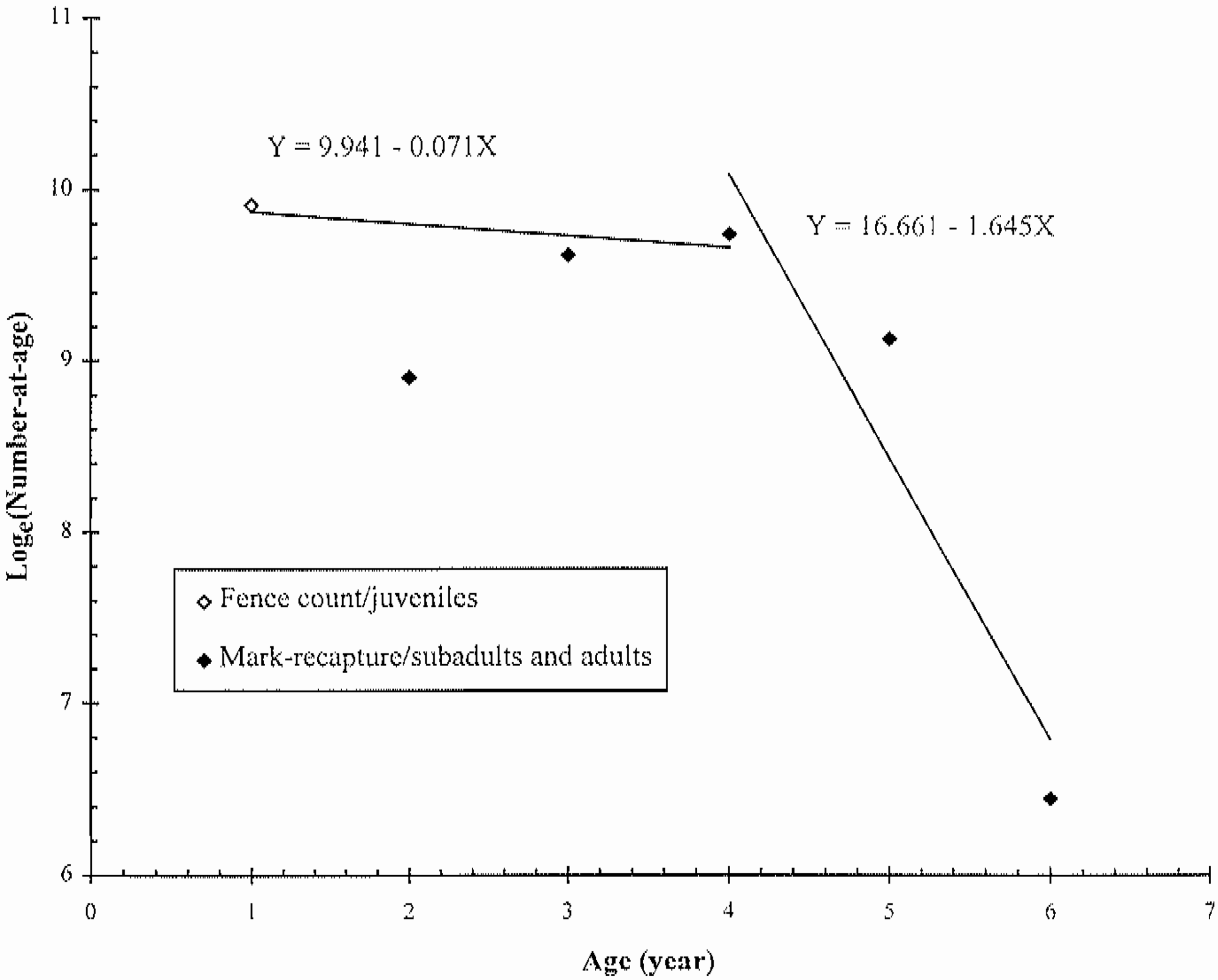

Figure 26. Volume-below-depth of Fish Lake