Canadian Technical Report of

Fisheries and Aquatic Sciences 1853

1992

THE EFFECT OF COMPETITION AND PREDATION ON PRODUCTION OF JUVENILE SOCKEYE SALMON (*Oncorhynchus nerka*) IN PITT LAKE

by

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Cat. No. Fs 97-6/1853E ISSN 0706-6457

Correct citation for this publication:

Diewert, R. E. and M. A. Henderson. 1992. The effect of competition and predation on production of juvenile sockeye salmon (*Oncorhynchus nerka*) in Pitt Lake. Can. Tech. Rep. Fish. Aquat. Sci. 1853: 51 p.

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ABSTRACT

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The effect of competition for food, and predation on survival of juvenile sockeye salmon (*Oncorhynchus nerka*) in Pitt Lake was examined to determine if these factors were limiting the production of sockeye from the system. There was little overlap in distribution and diet among juvenile sockeye salmon, and stickleback (*Gasterosteus aculeatus*), and longfin smelt (*Spirinchus thaleichthys*) at the southern end of Pitt Lake. Also, the diet of juvenile sockeye salmon in the limnetic zone was different from longfin smelt and stickleback. Further, juvenile sockeye salmon caught in the limnetic zone exhibited higher levels of stomach fullness and fewer empty stomachs than stickleback or longfin smelt. It was concluded that competition with other planktivores is not limiting the production of sockeye salmon in Pitt Lake at current fish densities.

The abundance of juvenile sockeye salmon predators in Pitt Lake is lower than for other sockeye salmon nursery lakes in the Fraser River system. Also, very few of the predators captured in Pitt Lake were feeding on juvenile sockeye salmon. These results suggest that production of juvenile sockeye salmon in Pitt Lake is not limited by predation. It appears that the most important factors limiting survival and therefore production of juvenile sockeye salmon in Pitt Lake operate during the period from when the sockeye salmon fry leave the Upper Pitt River to the time they arrive at the littoral zone at the southern end of Pitt Lake. Predation on sockeye salmon fry in the Upper Pitt River, and competition for food and predation during downlake migration to the littoral area at the southern end the lake are likely factors limiting survival of juvenile sockeye salmon. We speculate that rearing a portion of sockeye salmon fry from the Upper Pitt River hatchery in lake net pens until July and then releasing them directly into the pelagic zone of the lake where they are an effective planktivore would be an appropriate strategy to increase sockeye salmon production from the Pitt Lake system.

RÉSUMÉ

Diewert, R. E. and M. A. Henderson. 1992. The effect of competition and predation on production of juvenile sockeye salmon (*Oncorhynchus nerka*) in Pitt Lake. Can. Tech. Rep. Fish. Aquat. Sci. 1853: 51 p.

Nous avons examiné les effets de la prédation et de la concurrence alimentaire sur la survie des jeunes saumons rouges (*Oncorhynchus nerka*) dans le lac Pitt pour déterminer si ces facteurs limitaient la production de cette espèce dans le bassin. Il y avait peu de chevauchement dans la répartition et le régime alimentaire entre le saumon rouge, l'épinoche (*Gasterosteus aculeatus*) et l'éperlan d'hiver (*Spirinchus thaleichthys*) à l'extrémité sud du lac Pitt. En outre, le régime alimentaire des jeunes saumons dans la zone limnétique était différent de celui de l'épinoche et de l'éperlan d'hiver. De plus, chez les jeunes saumons rouges capturés dans la zone limnétique, les estomacs étaient plus pleins et le nombre d'estomacs vides était plus faible que chez les deux autres espèces. Nous en concluons que la concurrence avec les autres planctonophages ne limite pas la production de saumon rouge dans le lac Pitt aux densités actuelles de peuplement.

L'abondance de prédateurs des jeunes saumons rouges est plus faible dans le lac Pitt que dans les autres lacs qui servent de nourriceries à l'espèce dans le réseau du Fraser. De plus, rares étaient les prédateurs capturés dans le lac Pitt qui se nourrissaient de jeunes saumons rouges. Ces résultats semblent indiquer que la production de jeunes saumons rouges dans le lac Pitt n'est pas limitée par la prédation. Il semble que les facteurs les plus importants qui limitent la survie et donc la production se manifestent pendant la période qui va du moment où les alevins de saumon rouge quittent la rivière Upper Pitt à leur arrivée sur le littoral à l'extrémité sud du lac Pitt. La prédation qui s'exerce sur les alevins dans la rivière Upper Pitt, puis celle dont ils sont l'objet pendant la migration vers le sud du lac, sont vraisemblablement des facteurs qui limitent la survie des jeunes saumons. Nous pensons qu'en élevant jusqu'en juillet une partie des alevins de la pisciculture de la rivière Upper Pitt puis en les libérant directement dans la zone pélagique du lac, où ils consomment efficacement le plancton, on aurait le moyen d'augmenter nettement la production de saumon rouge dans le bassin du lac Pitt.

1.0 INTRODUCTION

The overall objectives of the Pitt Lake Sockeye Salmon (*Oncorhynchus nerka*) Project are to determine the factors that limit the production of juvenile sockeye salmon in Pitt Lake and to determine the carrying capacity of Pitt Lake for juvenile sockeye when expressed in terms of fry inputs. Some of the results relating to these objectives have been described previously following the conclusion of the first phase of the project (Henderson *et al.* 1991). Included in the earlier report is information on i) the general biology, growth and age structure of Pitt Lake sockeye salmon, ii) the physical, chemical and biological characteristics of Pitt Lake, iii) the pelagic distribution of juvenile sockeye salmon, and longfin smelt (*Spirinchus thaleichthys*) and threespine stickleback (*Gasterosteus aculeatus*) in Pitt lake and, the diet of juvenile sockeye salmon and longfin smelt in limnetic waters of Pitt Lake. Also, inferences were made regarding the carrying capacity of Pitt Lake for juvenile sockeye salmon based on this information.

It was clear, at the conclusion of the first phase of the Pitt Lake Sockeye Salmon Project that three additional types of information were required to improve our understanding of the capacity of Pitt Lake to support juvenile sockeye salmon. These information needs were the focus of the second phase of the Pitt Lake Sockeye Salmon Project. First, it was necessary to determine the temporal and spatial distribution of juvenile sockeye salmon and longfin smelt and stickleback in a large littoral area near the outlet of Pitt Lake and in the Lower Pitt River. Previous studies (Henderson *et al.* 1991) have provided adequate information on the distribution of these fish in limnetic waters. However, the use of the littoral area of Pitt Lake, most of which is located near the outlet, by juvenile sockeye salmon and longfin smelt and stickleback was unknown. Second, it was necessary to describe in greater detail the feeding habits and diet of juvenile sockeye salmon and longfin smelt and stickleback in Pitt Lake. Results from the first phase of the study provided limited information on these two characteristics for juvenile sockeye salmon and longfin smelt in the limnetic waters. During the second phase of the study, we gathered information on the feeding habits and diet of juvenile sockeye and longfin smelt and stickleback in the littoral areas of Pitt Lake, and in the "transition" areas between the littoral and limnetic waters. In addition, more data were gathered on the feeding habits and diet of all three species in the limnetic waters. Finally, we began to explore the possible role of predation in limiting juvenile sockeye salmon production in Pitt Lake. Specifically, we identified the predators of juvenile sockeye salmon in Pitt Lake and made inferences regarding the degree to which predation contributed to their mortality.

2.0 METHODS

2.1 DISTRIBUTION AND DIET

A complete description of the location and physical characteristics of Pitt Lake is given in Henderson *et al.* (1991).

Trawl sampling was conducted at the southern end of Pitt Lake and in the Lower Pitt River (Fig. 1) between June 1989 and September 1990. Sampling gear consisted of a 2m x 2m trawl net (Gjernes 1979) deployed and retrieved using a gas powered winch mounted on the deck of a 6m boat. Fish were located at depth using a video display depth sounder and the net was towed through the depth of greatest fish concentration. All tows were thirty minutes in duration. Two of the sampling stations (T1 and T2) (Fig. 1) were located in the southern end of Pitt Lake and represented a transition area between a large littoral area, also at the southern end of the lake, and the offshore, limnetic zone. The third trawl sampling station (T3) was located in the Lower Pitt River (Fig. 1). Trawl samples from stations T1 and T2 were combined by month and the percent contribution to the catch of each species in this transition area was calculated. Trawl samples from the Lower Pitt River were summed by month and the percent contribution of each species to the catch was calculated.

Beach seine sampling was conducted between April 1990 and September 1990 at several stations within the littoral zone of the lake and along the shores of the Lower Pitt River (Fig. 1). Sampling gear consisted of a 30m x 3m beach seine deployed from a 6m boat. Beach seine samples were combined by month for all stations within the littoral zone of the lake and for all stations along the shores of the Lower Pitt River. The monthly percent contribution to the catch of each species within these two zones was calculated.

Trawl sampling was conducted during April, August and September 1990, in the limnetic zone of Pitt Lake. Sampling gear consisted of a 3m x 6m closing midwater trawl described by Enzenhofer and Hume (1989).

Fish captured during trawl and beach seine sampling were anethsetized in a solution of 2 phenoxy-ethanol to prevent the regurgitation of stomach contents and preserved in 10% buffered formalin. The esophagus and cardiac portion of the stomach were removed from fish in the laboratory. Stomach contents were identified to the lowest taxonomic level possible and counted. The volume of the stomach occupied by each food type was also estimated.

Stomach content data were combined for each species across all sampling sites and periods within each habitat zone. Average stomach fullness, percentage of empty stomachs and the average percent stomach volume occupied by each food type was calculated.

2.2 PREDATION

Predator sampling was conducted between March 22 and July 10, 1990 using gillnets. Seven sampling stations were selected in Pitt Lake and in the lower Pitt River (Fig. 1). Stations were chosen to reflect areas of high sockeye fry abundance as it has been shown that predators concentrate in these areas (McCart 1967, Ruggerone and Rogers 1984, Parkinson *et al.* 1989, Poe *et al.* 1990). Most of the sampling effort was restricted to three of the sampling stations; GN1, GN2 and GN3 (Fig. 1). Two stations (GN1&2) were located at the north end of the lake where newly emerged fry would be concentrated as they moved from the Upper Pitt River into Pitt Lake. The third station (GN3) was located near the littoral area at the southern end of Pitt Lake where large numbers of fry spend a portion of their early lake residence (Johnson 1981, Henderson *et al.* 1991).

Predator sampling was conducted using variable mesh, monofilament gillnets. Each net was made up of 8 panels with mesh sizes ranging from 2.54 cm to 11.43 cm Each panel was 15.24 m long and 2.44 m deep. Nets were generally deployed in the evening and allowed to fish overnight. The average duration of sets at the northern end of the lake (GN1&2) was 12 h. The average duration for sets made at the southern end of the lake was 4 h. Sets made in the lower Pitt River averaged 6 h in duration. All samples were removed when the gillnets were retrieved and preserved in a 10% formalin solution for later analysis.

Stomachs were removed from fish in the laboratory and dissected to examine the contents. The degree of fullness was determined for all stomachs.

3.0 RESULTS

3.1 DISTRIBUTION

3.1.1 TEMPORAL DISTRIBUTION

No juvenile sockeye salmon were captured during trawling operations in the transition zone at the southern end of Pitt Lake in 1989 (Fig. 2). This was primarily the result of a sampling program which did not begin until late in June of 1989, a time when juvenile sockeye salmon were not resident in this portion of the lake in 1990 (see below). Further, the first few weeks of sampling in 1989 were a time of experimentation with the fishing gear and developing operating procedures. Consequently, the efficiency of the fishing operations was likely low.

Juvenile sockeye salmon first appeared in trawl catches from the the transition zone at the southern end of Pitt Lake in April in 1990 (Fig. 2). The percentage of juvenile sockeye salmon in the catch increased in May and subsequently decreased through June and July. The overall contribution of juvenile sockeye salmon to the total trawl catch from this area of the lake was low and peaked at 11% in May, 1990. No juvenile sockeye salmon were captured by trawl sampling in the southern end of the lake after July.

The contribution of stickleback and longfin smelt to trawl samples from the transition zone at the southern end of the lake averaged 41% and 59% respectively over the period from June 1989 to December 1989. Stickleback completely dominated the catch in February of 1990 (Fig. 2). Between February and July the stickleback contribution to the catch steadily decreased while the longfin smelt contribution increased and peaked in July. The pattern reversed after July with the proportion of longfin smelt in the catch declining and stickleback increasing until sampling was terminated in September.

No juvenile sockeye salmon were captured by trawl in the Lower Pitt River in 1989 for the reasons given above. Juvenile sockeye salmon first appeared in the catch in March of 1990, peaked in terms of percent contribution in May, and subsequently decreased through July (Fig. 3). No juvenile sockeye salmon were captured by trawl sampling in the Lower Pitt River after July.

The proportion of the total river trawl catch consisting of stickleback increased from June 1989 and reached a peak by August

1989 (Fig. 3). Very few stickleback were captured from September 1989 through to February 1990. Their contribution to the catch began to increase again in March and April 1990, declined in May, and then increased to peak 1990 levels in July. By the end of sampling in September 1990, the stickleback contribution to the river catch was again declining.

Longfin smelt dominated river trawl catches from September to December of 1989, were absent from February to May, 1990, and then formed an increasing proportion of the total catch through the end of the sampling program in September, 1990 (Fig. 3).

Juvenile sockeye salmon were predominant in beach seine catches from the littoral zone of Pitt Lake from April through June, 1990 (Fig. 4). The proportion of sockeye declined rapidly in July after which very few were captured in the littoral zone of Pitt Lake.

The contribution of stickleback to the catch from the littoral zone of Pitt Lake was low in the period from April to June and then increased in July remaining at a high level through to the end of the sampling program in September (Fig. 4). The observed pattern of stickleback contribution to littoral samples may indicate an onshore spawning migration of mature fish in July (Henderson *et al.* 1991) and the subsequent recruitment of juveniles to the population in September. An analysis of the average weight of stickleback samples by month revealed that size declined in July and again in September when average weight reached a minimum (Fig. 5). This likely reflects a loss of large, mature fish from the population in July due to spawning mortality followed by the recruitment of small, recently hatched juveniles in September.

Longfin smelt were not captured during beach seining operations in the littoral zone of Pitt Lake or in the Lower Pitt River.

The percent composition of beach seine catches from the Lower Pitt River for the period from April to September, 1990 (Fig. 6) were similar to that observed in the littoral zone of Pitt Lake (Fig. 4). Juvenile sockeye salmon dominated the catch in April and May, but their contribution declined through July and remained at very low levels through September. Stickleback exhibited the opposite pattern, steadily increasing in terms of their contribution to the catch as the sampling program progressed, reaching peak levels by September.

3.1.2. SPATIAL DISTRIBUTION

Differences in the spatial distribution of juvenile sockeye salmon, and stickleback and longfin smelt between the southern end of Pitt Lake and the Lower Pitt River were investigated by examining the CPUE (catch per beach seine set or trawl net tow) in each area over time.

Juvenile sockeye salmon were first captured during trawl sampling in the Lower Pitt River in March (Fig. 7). Juvenile sockeye salmon did not appear in trawl catches in the southern portion of the lake until April. This suggests that the sockeye salmon fry captured in the Lower Pitt River in March were not from the Upper Pitt River population. It is likely that these fry were the progeny of the sockeye salmon population which spawns in Widgeon Slough, a tributary system to the Lower Pitt River (Fig. 1). Juvenile sockeye salmon trawl CPUE in the river declined from March through to August while CPUE in the transition zone of the lake increased to peak levels in June and then declined to 0 in July.

Juvenile sockeye salmon captured by beach seine from the littoral zone of Pitt Lake in April and May were larger ($p < 0.05$; t test) than those captured by trawl in the transition zone during the same period. However, it does not appear that the size difference was due to differences in gear selectivity. There was no significant difference between the size of seine and trawl caught juvenile sockeye in June ($p > 0.05$; t test) indicating that the trawl gear was capable of capturing larger juveniles. Also, beach seine samples from the Lower Pitt River contained juveniles in the smallest size classes indicating that the seine gear was capable of capturing the very small fish. Finally, there was no statistically significant difference ($p > 0.05$; t test) between the size of seine and trawl caught juvenile sockeye salmon when all samples from April to June were pooled. It is likely that these smaller transition zone juvenile sockeye salmon represent late emerging wild fry or late hatchery release fry that had moved south from the north end of the lake and had not yet entered the littoral zone to begin feeding.

The abundance of juvenile sockeye salmon in the littoral zone of Pitt Lake and along the shores of the Lower Pitt River was greatest in April (Fig. 8). Beach seine CPUE from the littoral zone of the lake declined sharply in May and then gradually decreased to 0 by July. The CPUE in the Lower Pitt River declined slightly in May and then dropped sharply in June remaining at a low level until September. The observation that juvenile sockeye salmon were captured in the river in all months suggests these fish either spent some time rearing in the river or that they were continuously emigrating from the Pitt Lake system throughout the spring and summer.

Stickleback abundance in both the southern end of Pitt Lake and in the Lower Pitt River was lower in 1989 than 1990 based on trawl samples (Fig. 9). Trawl CPUE peaked in the transition zone at the southern end of the lake in October 1989 and in September 1990. Trawl CPUE peaked in July in the Lower Pitt River in both years (Fig. 9). The observation that stickleback abundance peaks in the river before peaking in the lower lake indicates there may be an anadromous component to the Pitt Lake stickleback population which returns to the littoral zone of Pitt Lake or to the Lower Pitt River to spawn.

Stickleback CPUE in beach seine samples from the littoral zone of Pitt Lake reached maximum levels in April and July, 1990 (Fig. 10). The CPUE from the river showed only one peak in July. The seine catch data suggest an onshore spawning migration in July followed by recruitment of juvenile stickleback to the southern end of the lake where they are captured in trawl operations during the month of September (Fig. 9).

Longfin smelt abundance reached maximum levels in the river in September 1989 and July 1990 based on CPUE data from trawl operations (Fig. 11). Abundance peaked in the southern end of the lake in October 1989 and in September 1990. This pattern suggests that there is an anadromous component to the Pitt Lake smelt population which returns to the lake in late summer/ early fall to spawn. Peak catches recorded in the lower lake following this period (October 1989 and September 1990) were primarily juvenile smelt. It is likely that at least a portion of these fish were the progeny of this anadromous spawning population.

Longfin smelt were not captured in beach seine sampling in the littoral zone of the lake or in the Lower Pitt River.

3.2 DIET

Juvenile sockeye salmon utilize the extensive littoral habitat near the southern end of Pitt Lake during the early portion of their life. Sockeye salmon fry emerge from the Upper Pitt River in early spring and migrate in a narrow band along the shoreline towards the lake outlet (Johnson 1981). During their migration the fry do not feed (Johnson 1981, Henderson *et al.* 1991). Juvenile sockeye were captured in the littoral zone of Pitt Lake beginning in April. By July they were completely absent from this area of the lake (Fig. 8).

During their period of residence in the littoral zone juvenile sockeye salmon shared the habitat with stickleback. Juvenile sockeye salmon and stickleback exhibited similar average gut fullness while feeding in the littoral zone (Fig. 12). For both species, gut fullness was approximately 60% and there was a low incidence of empty guts (Fig. 13).

Analysis of stomach samples of juvenile sockeye salmon collected from the littoral zone at the south end of Pitt Lake indicated they were feeding primarily on diptera which made up over 65% of their diet by volume (Fig. 14). Copepods were of secondary importance accounting for approximately 20% of the volume. Stickleback were more omnivorous than juvenile sockeye consuming copepods, diptera, and miscellaneous other food items including oligochaetes, fish eggs, larval fish and plant material.

Juvenile sockeye salmon, and stickleback and longfin smelt were actively feeding in the transition zone of Pitt Lake as indicated by percent gut fullness (Fig. 12). Juvenile sockeye salmon and stickleback showed similar levels of percent gut fullness averaging approximately 60%. The populations of both species contained very few empty guts (Fig. 13). Percent stomach fullness of longfin smelt was lower at approximately 20% (Fig. 12). Thirty percent of the longfin smelt samples from the transition zone had empty stomachs (Fig. 13).

The diet of the three species was made up primarily of copepods in the transition zone (Fig. 15). Longfin smelt showed the highest preference for copepods with over 70% of their diet consisting of this zooplankton type. However, there were differences in the species group of copepods consumed among the three species of fish. Stickleback and longfin smelt fed primarily on cyclopoid copepods while the diet of juvenile sockeye consisted mainly of calanoid copepods.

Juvenile sockeye salmon and, to a lesser degree, stickleback supplemented their diets with other food types including cladocera and diptera (Fig. 15). *Bosmina sp.* was the cladoceran being consumed by all the fish species in the transition zone. In addition, longfin smelt consumed small amounts of *Holopedium sp.*

Juvenile sockeye salmon, and stickleback and longfin smelt all utilize the limnetic zone of Pitt Lake (Johnson 1981, Henderson *et al.* 1991). Stomach content analysis revealed that sockeye were probably more effective feeders in this zone. The average percent stomach fullness for sockeye was three times greater than stickleback and four times greater than longfin smelt (Fig. 12). Also, there were no empty stomachs in the sockeye samples, while over 40% of both stickleback and smelt stomachs were empty (Fig. 13).

The diet of juvenile sockeye salmon in the limnetic zone of Pitt Lake was made up almost exclusively of cladocera (Fig. 16). Cladocera and copepoda were the primary prey types for limnetic sticklebacks. The diet of longfin smelt was made up predominantly of copepoda (Fig. 16).

Although the diets of all three planktivores contained cladocera, juvenile sockeye salmon were targeting exclusively on the large zooplankter *Hetercope sp.* Stickleback and longfin smelt fed on the smaller *Bosmina sp.* As a result, there appears to be little overlap between the diet of juvenile sockeye salmon and that of stickleback and longfin smelt in the limnetic zone of Pitt Lake.

The diet of juvenile sockeye salmon in the limnetic zone was very different from that observed in either the transition or littoral zones. The primary food type shifted from diptera in the littoral zone to copepoda in the transition zone and to a diet made up exclusively of cladocera in the limnetic zone (Figs. 14,15,16). Stickleback diet also changed with each habitat but to a much lesser degree. The diet of longfin smelt remained consistent in all samples being dominated by copepoda.

3.3 PREDATION

Thirty-two gillnet sets were made at seven different locations in Pitt Lake and the lower Pitt River (Fig. 1). The total sampling effort resulted in a catch of 107 fish of 11 different species (Table 1). Catches ranged from 0 to 12 fish per set and averaged 3.3. Fifty-one piscivorous fish were caught with a range of 0 to 7 fish per set and averaging 1.6. Thirteen sets, or approximately 40% of the total, contained no predators of juvenile sockeye salmon. The most common piscivores captured were juvenile chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*Oncorhynchus mykiss*). Redside shiner (*Richardsonius balteatus*) was the most numerous non-piscivore captured.

Catches were standardized to a set duration of 12 hours to compare catch rates between areas (Table 2). The catch per set of piscivorous fish was highest at the two sampling locations in the northern end of the lake (GN1&2). The catch of piscivorous fish averaged 2.9 fish per set at these sites. Catches of piscivorous fish at the four sampling locations near the littoral areas at the southern end of the lake (GN3,5,6&7) were lower averaging 2.0 fish per set. Three sets were made in the Lower Pitt river (GN4). The catch of predators in this area of the watershed was the lowest averaging 0.7 fish per set (Table 2).

Juvenile chinook salmon was the most abundant predator of juvenile sockeye salmon captured during gillnet sampling followed closely by rainbow trout. The least abundant predators were juvenile coho salmon (*Oncorhynchus kisutch*) and northern squawfish (*Ptychocheilus oregonensis*) (Table 3). The largest predator species captured was the cutthroat trout averaging 320.6 mm in length. Juvenile coho and chinook salmon were not significantly different in size ($p < 0.05$; t test) and were the smallest of the predators captured (Table 3).

The stomachs of all potential predators of juvenile sockeye salmon were examined. Sixteen of the stomachs (32%) were empty. The average percent fullness of all predator stomachs combined was 20%. Only three fish, 1 juvenile coho, 1 juvenile chinook and 1 rainbow trout, (6% of all fish examined) had consumed juvenile sockeye salmon. The coho and chinook salmon had each consumed one juvenile sockeye salmon and were captured near the southern end of the lake (GN3). The rainbow trout had consumed 4 juvenile sockeye salmon and was captured at the northern end of the lake (GN1). The overall average number of sockeye salmon fry per gut for all predators was 0.12. Insect or insect larvae appear to be the most important dietary component of the piscivorous fish with 58% of the stomachs examined contained this type of food (Table 4).

The results indicate that predators of juvenile sockeye salmon were more numerous at the northern end of the lake. During the sampling period 55.6% of all piscivorous fish captured were taken in this area of the lake. However, as only 1 fish had consumed juvenile sockeye salmon, it appears that sockeye were not a major food resource. Most fish captured at all sampling locations were either feeding on insects and insect larvae or had no food in their stomach at the time of capture.

The catch of piscivorous fish indicates a low predator density in Pitt Lake. When this is considered along with the low incidence of sockeye salmon in the diet of predators, it becomes apparent that predation is unlikely to be a major source of mortality for juvenile sockeye salmon once they enter Pitt Lake.

4.0 DISCUSSION

4.1 DISTRIBUTION AND DIET

Juvenile sockeye salmon spend the early portion of their period of lake residence rearing in the littoral habitat near the southern end of Pitt Lake. Hartman and Burgner (1972) found that when juvenile sockeye salmon are feeding in the littoral zone there is considerable potential for competition for food with other fish species. The results of our study indicate that sockeye and stickleback both utilize the littoral zone for a portion of the growing season but that the timing of peak abundance for each species in this zone does not overlap. Further, diet analysis revealed that although the diet of juvenile sockeye salmon and stickleback contained the same basic components, the proportions of each food type within those components was very different.

Juvenile sockeye salmon and stickleback samples from the littoral zone of Pitt Lake both exhibited stomach fullness levels of approximately 60% as well as a low incidence of empty stomachs. These results indicate that both species were able to utilize the food resources of the littoral zone effectively. Longfin smelt were never captured in the littoral waters of Pitt Lake implying that they do not utilize this habitat.

Juvenile sockeye salmon, and stickleback and longfin smelt captured in the transition zone of Pitt Lake were feeding primarily on copepods. Juvenile sockeye salmon and stickleback supplemented their diets to a large extent with other food types while longfin smelt fed exclusively on copepods. This feeding behaviour may explain why smelt exhibited a much higher proportion of empty stomachs and lower average stomach fullness. Juvenile sockeye salmon and stickleback were more opportunistic feeders exhibiting an ability to take advantage of a much wider range of food resources.

Juvenile sockeye salmon moved to the limnetic waters of Pitt Lake by late summer. Narver (1966) found that juvenile sockeye salmon in Chignik Lake, Alaska, were better adapted to a pelagic existence than other planktivorous species. Hartman and Burgner (1972) concluded that sockeye generally dominate in limnetic waters forcing other planktivors to alter their feeding habits. Our results support these conclusions. Juvenile sockeye salmon from the limnetic zone of Pitt Lake exhibited stomach fullness levels 3 times higher than stickleback and 4 times higher than longfin smelt. Further, while no juvenile sockeye salmon stomach samples from this area of Pitt Lake were empty over 40 % of stickleback and longfin smelt stomachs were empty. These results suggest that juvenile sockeye are the dominant and most effective planktivore in the limnetic zone of Pitt Lake.

The diet of all three planktivores in the limnetic waters of Pitt Lake was dominated by cladocera. However, while juvenile sockeye salmon fed exclusively on the large zooplankter *Heterocope sp.*, stickleback and longfin smelt consumed only the smaller *Bosmina sp.* Goodlad *et al.* (1974) found a similar situation in Fraser Lake, B.C. where sockeye selected the largest zooplankton prey available. Eggers (1978) also concluded that sockeye feeding in the limnetic zone were size selective towards the largest zooplankton. Evidently juvenile sockeye salmon feeding in the limnetic waters of Pitt Lake also feed on the largest zooplankton available.

The diet of juvenile sockeye salmon varied with each habitat zone in Pitt Lake. In the littoral zone the primary dietary component was diptera. This changed to copepoda in the transition zone and then to cladocera in the limnetic zone. The ability of juvenile sockeye salmon to feed effectively in each habitat zone of Pitt Lake must enable the species to persist in an environment that is dominated numerically by other plantivorous fish.

Our results suggest that competition between juvenile sockeye salmon and other planktivorous fish species in Pitt Lake is unlikely to be limiting sockeye production from the system at current fish densities. Burgner (1987) stated that interaction between species often results in segregation such that species are forced to magnify their differences in habitat and food selection. This may have occurred in Pitt Lake. Juvenile sockeye salmon dominated the littoral habitat in the late spring and early summer months while very few stickleback were present. By July, juvenile sockeye had dispersed from littoral waters and stickleback abundance increased dramatically. In the limnetic zone, sockeye salmon fed exclusively on the large cladoceran *Heterocope sp.* while stickleback and longfin smelt consumed only *Bosmina sp.* These differences in temporal and spatial distribution and in the feeding habits of juvenile sockeye salmon, and stickleback and longfin smelt allow for the continued coexistence and success of all three species in Pitt Lake by minimizing direct competition for resources. Changes in the size of the population of any of these members of the planktivore community may result in a change in the apparent balance of resource use that now exists.

Narver (1966) suggested that since juvenile sockeye salmon appear better adapted to the pelagic environment, intense competitive pressure should be maintained on the non-sockeye species in order to displace them from the pelagic zone. This can only be done by increasing the number of juvenile sockeye salmon that enter the pelagic zone of the lake. One way of achieving this result would be to rear a portion of the hatchery production in net pens in the lake until late July. This strategy would ensure that a large number of juvenile sockeye salmon entered the pelagic zone of the lake where they are more efficient than their potential competitors in utilizing available food resources. It would also effectively bypass the long migration of freshly emerged sockeye fry from the Upper Pitt River to the littoral area at the southern end of Pitt Lake. During this migration the young sockeye do not feed (Johnson 1981). It is likely that this stressful event results in considerable mortality which would be avoided by lake pen rearing.

4.2 PREDATION

Predation on juvenile sockeye salmon during freshwater residence can result in a significant amount of mortality. Sockeye salmon survival in Cultus Lake, British Columbia, was increased threefold as a result of the removal of a large number of predacious fish over several years (Foerster and Ricker 1941). Numerous other studies have documented high levels of predation on juvenile sockeye salmon in freshwater by an assortment of predators (Foerster 1968, Larsson 1985, Parkinson *et al.* 1989, Williams *et al.* 1989, Poe *et al.* 1990).

This study did not attempt to enumerate the predator population in Pitt Lake. However, we can make some qualitative inferences regarding the general degree of mortality caused by predation by comparing predator catch and diet data with that for other sockeye nursery lakes.

Predator studies were carried out in Shuswap Lake, British Columbia, in 1975 and 1976 (Williams *et al.* 1989). When effort was standardized with this study, the average catch of predators per gillnet set was 36 fish in 1975 and 27.6 fish in 1976 . These catch rates are 17 and 23 times higher respectively than the predator catch rate observed in Pitt Lake. In Cultus Lake, British Columbia, a predator control experiment was carried out from 1932 to 1938 (Foerster and Ricker 1941). The average catch of predators during the first few years of the removal program was 3.2 fish per gillnet set (effort standardized with this study). The catch rate of piscivorous fish in these two sockeye nursery lakes was considerably higher than the catch rate observed in Pitt Lake. This suggests that predator density in Pitt Lake is lower than in other sockeye nursery lakes in the Fraser River system.

Stomach content analysis of predators captured in Shuswap Lake indicated that 37.1% were feeding on juvenile sockeye salmon. The average number of sockeye salmon per stomach for all predators combined was 25.3. In the Cultus Lake study 19.1% of predator stomachs examined contained juvenile sockeye. The average number of sockeye per stomach ranged from 0.14 to 6.4. The occurrence of sockeye in the stomachs of predators from Shuswap and Cultus was over 6 and 3 times higher respectively when compared with samples from Pitt Lake. Further, the average number of sockeye salmon fry per predator stomach was over 200 times higher in Shuswap Lake and up to 53 times higher in Cultus Lake. When this is considered along with the comparison of predator densities it becomes evident that in-lake predation is not likely to be a major factor limiting sockeye production from Pitt Lake.

Juvenile sockeye salmon were not a major component of the diet of piscivorous fish in Pitt Lake. This may be due to the their relatively low density in the lake. Ricker (1941) found that sockeye fry consumption was proportional to their abundance and that at low densities consumption dropped dramatically. He also found that consumption of alternate food sources increased as juvenile sockeye salmon abundance decreased. This describes the situation in Pitt Lake where juvenile sockeye salmon densities in 1989 were 2,400/ha. in summer and 220/ha. in fall (Henderson *et al.* 1991). In comparison, sockeye densities in Shuswap Lake in 1975 were 11,939/ha. in summer and 3,394/ha. in fall (Williams *et al.* 1989). The relatively low juvenile sockeye salmon density in Pitt Lake has likely resulted in piscivorous fish selecting other food resources.

Predators of juvenile sockeye salmon likely move into the Upper Pitt River to feed on newly emerged wild sockeye salmon fry and on the large numbers of sockeye fry released from the Upper Pitt River hatchery. This type of in-river predation has been documented for other sockeye systems and can account for significant mortality. Larsson (1985) estimated predation rates of up to 85% on migrating Atlantic salmon (*Salmo salar*) smolts in a Swedish river. McCart (1967) found rainbow trout in the Babine River feeding exclusively on sockeye salmon fry while none of the rainbow trout sampled in the lake were eating juvenile sockeye salmon. Elson (1962) estimated a 5 fold increase in smolt production from a New Brunswick stream after the implementation of a predatory bird control program. The Upper Pitt River hatchery produces about 4 million sockeye salmon fry per year. Most of these fish are released into Corbold Creek, a small tributary to the Upper Pitt River. At the hatchery outfall, fry are concentrated in a small body of water and are a very attractive food source for predators such as Dolly Varden char (*Salvelinus malma*), rainbow and cutthroat trout, and various species of piscivorous birds. All of these predators have been observed in the area of the hatchery outfall after fry have been released (A. Stobbart, Upper Pitt River Hatchery, P.O. Box 61, 38620 Bell Road, Dewdney, B.C., V0M 1H0, pers. comm.). Larsson (1985) found that burbot reacted very quickly to hatchery releases of Atlantic salmon smolts and congregated at release sites. Poe *et al.* (1990) reported that predators were up to 30 times more abundant around dams where juvenile salmonids were concentrated. Several other reports present evidence suggesting that predators congregate in areas where sockeye salmon fry are concentrated (Petersen *et al.* 1990, Ruggerone 1986, McCart 1967). A similar situation is likely occurring in the Upper Pitt River resulting in a high level of mortality on hatchery and wild sockeye salmon fry. For these reasons, it is suggested once again that rearing a portion of hatchery fry production in net pens in Pitt Lake would be an effective way to increase juvenile sockeye salmon survival.

ACKNOWLEDGEMENTS

We are grateful to H. Enzenhofer, J. Hume, C. Mueller and S. Maclellan for assistance in collection and analysis of the data presented in this report. We would also like to thank Al Stobbart and the staff of the Upper Pitt River hatchery for their support, assistance and generous hospitality. A. Dale, T. Feakins, L. Rzen and H. Waye assisted with field sampling, data summary and analysis. We are also grateful to D. Atagi who assisted with sampling on several occasions on very short notice.

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sampling in Pitt Lake.

DAY	MONTH	SITE	SOCKEYE SMOLT	LONGFIN SMELT	CHINOOK SMOLT	COHO SMOLT	REDSIDE SHINER	STEELHEAD TROUT	CUTTHROAT TROUT	CHUB	SQUAWFISH	EULACHON	SURF SMELT	TOTAL
22	3	GN1			3							1		4
27	3	GN3			2									2
29	3	GN1										1		1
29	3	GN2												0
2	4	GN3										2		2
6	4	GN2	5		4			2					1	12
6	4	GN1	1					3	1			3	1	9
10	4	GN3			1									1
12	4	GN1			3			1						4
18	4	GN3										1		1
18	4	GN4					8							8
21	4	GN1		1		1		6				1		9
21	4	GN2			2		1		1			2		6
26	4	GN1						1						1
26	4	GN1		9										9
2	5	GN2	1		2	1	1	1						6
2	5	GN1			2			1	1					4
9	5	GN3			1			1				1		3
10	5	GN2			1									1
10	5	GN1						3						3
14	5	GN3				1	2							3
29	5	GN3					1							1
5	6	GN3					1							1
12	6	GN5					1							1
19	6	GN6									1			1
19	6	GN5												0
26	6	GN7							2					2
26	6	GN6												0
5	7	GN6					3							3
5	7	GN4		1			2			2				5
10	7	GN4					1				1			2
10	7	GN5					1				1			2
TOTAL			7	11	21	3	22	19	5	2	3	12	2	107

Table 2. Catch distribution of piscivorous fish in Pitt Lake and the Lower Pitt River.

LOCATION	# OF 12-h SETS	TOTAL CATCH	% OF TOTAL CATCH	CPUE
Lake - N. End (GN1&2)	14	40	55.6	2.9
Lake - S. End (GN3,5,6&7)	15	30	41.7	2.0
L. Pitt River (GN4)	3	2	2.8	0.7

Table 3. Average length and weight of predators caught by gillnet in Pitt Lake between March 22 and July 10, 1990.

SPECIES	SAMPLE SIZE	AVERAGE LENGTH (mm)	AVERAGE WEIGHT (g)
Squawfish	3	161.7	53.1
Chinook Smolt	21	111.9	15.7
Coho Smolt	3	111.7	15.1
Rainbow Trout	19	201.5	76.5
Cutthroat Trout	5	320.6	---

Table 4. Stomach content data for predators caught by gillnet in Pitt Lake between March 22 and July 10, 1990.

SPECIES	AVERAGE % FULLNESS	% GUTS EMPTY	% GUTS INCLUDING SOCKEYE	INSECTS	AVERAGE NUMBER OF SOCKEYE PER GUT
Squawfish	3.3	66.7	0.0	N/A	0.0
Chinook	20.0	27.8	5.5	55.6	0.1
Coho	33.3	33.3	33.3	66.7	0.3
Rainbow	21.5	26.3	5.3	73.7	0.2
Cutthroat	22.0	60.0	0.0	40.0	0.0

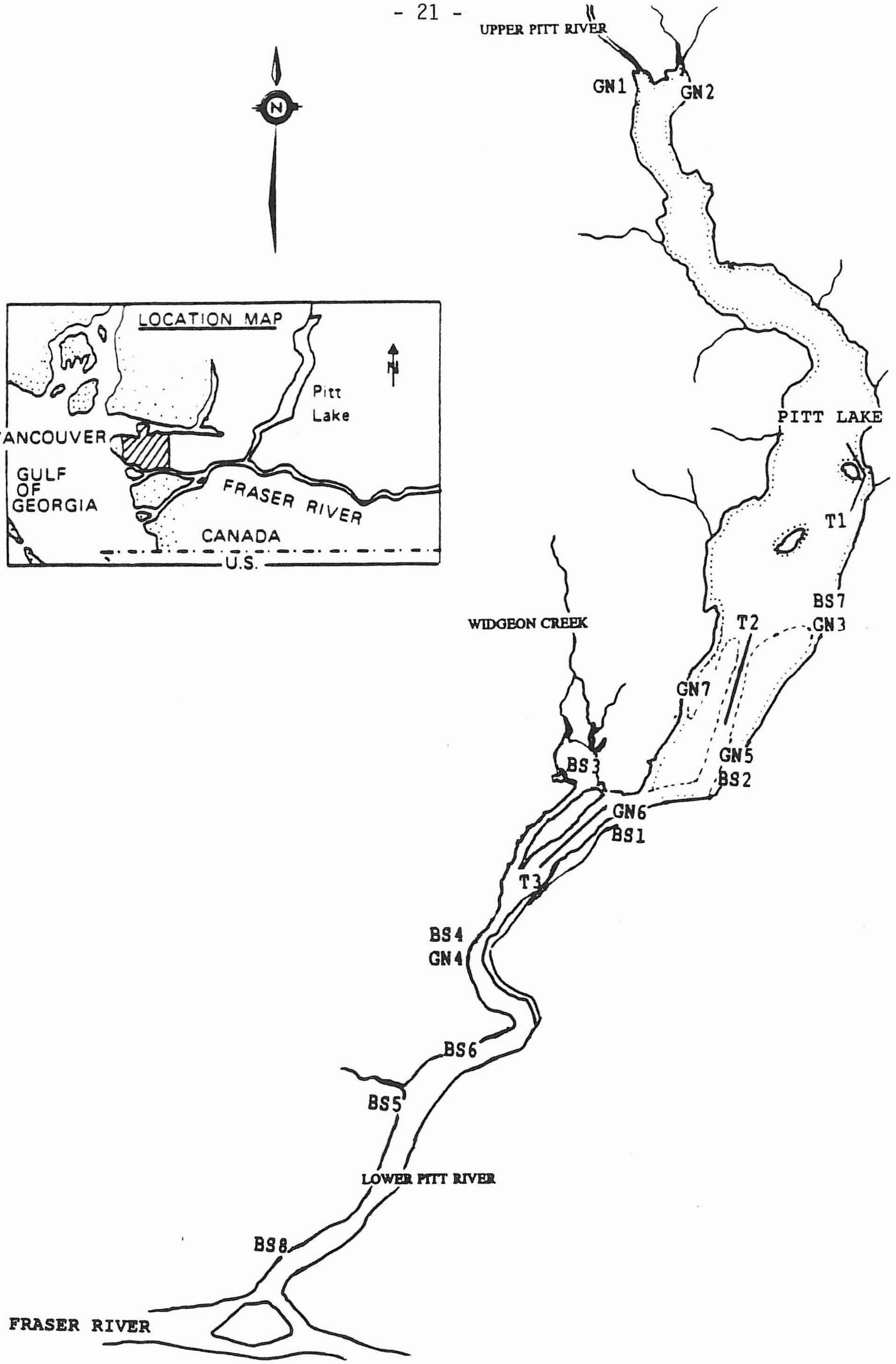


Fig. 1. Map of Pitt Lake showing beach seine (BS), gillnet (GN) and trawl (T) sampling stations.

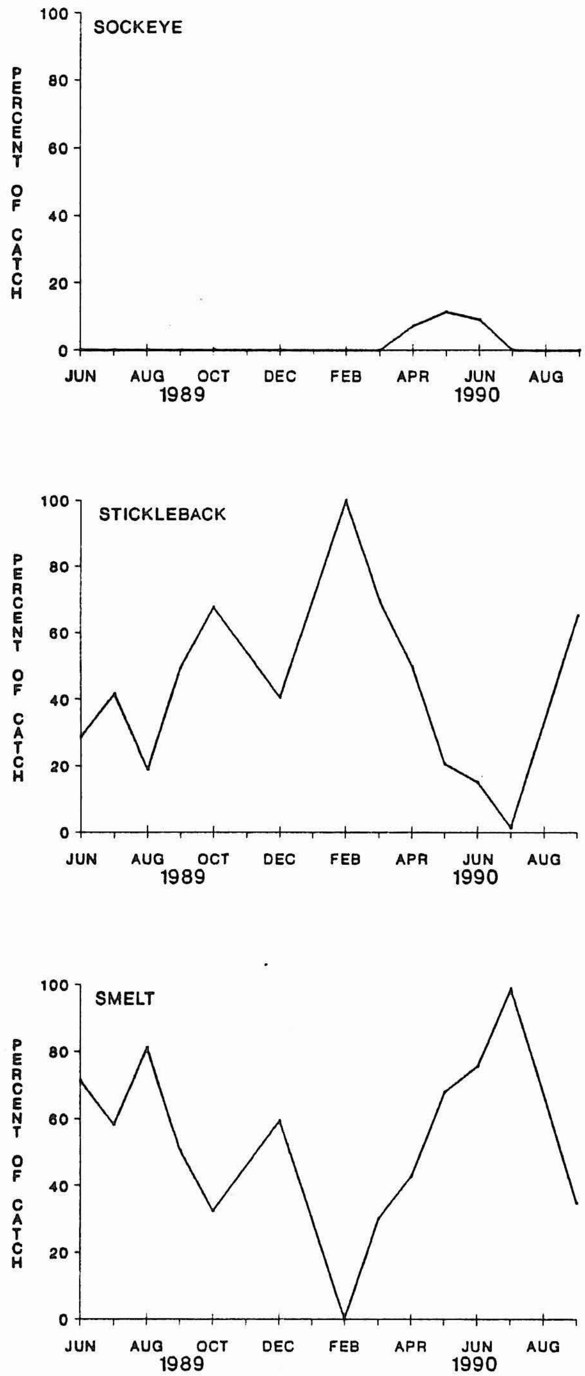


Fig. 2. Contribution of juvenile sockeye salmon, and stickleback and longfin smelt to trawl catches from the transition zone at the southern end of Pitt Lake for the period June 1989 to September 1990.

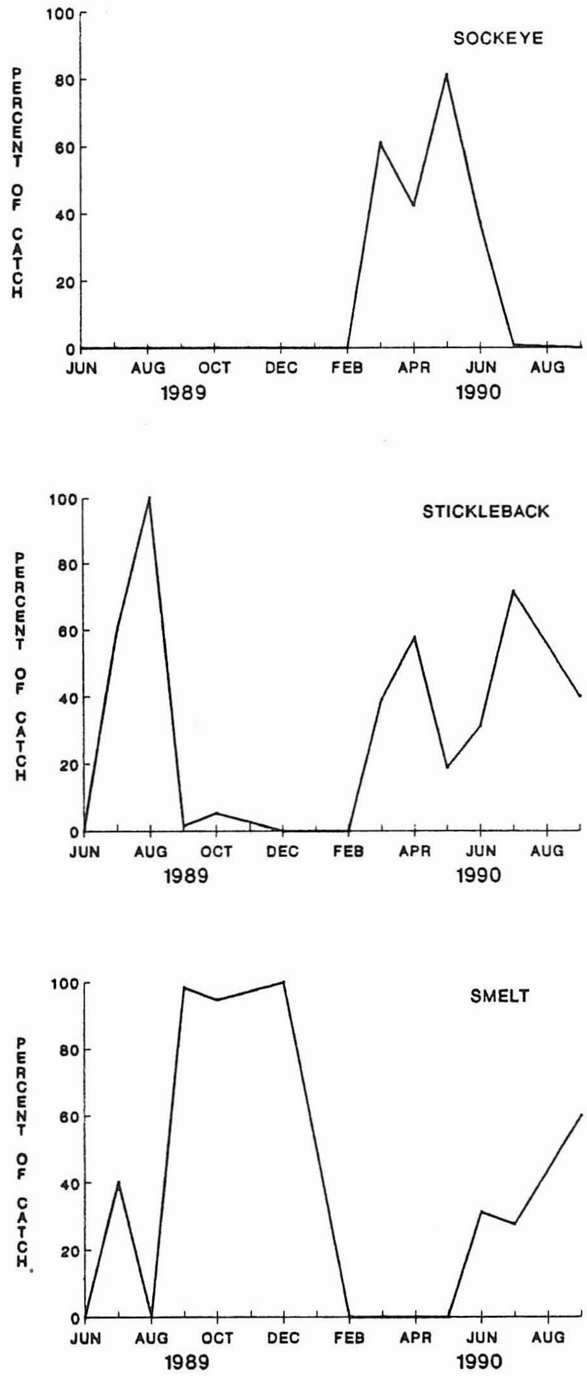


Fig. 3. Contribution of juvenile sockeye salmon, and stickleback and longfin smelt to trawl catches from the Lower Pitt River for the period June 1989 to September 1990.

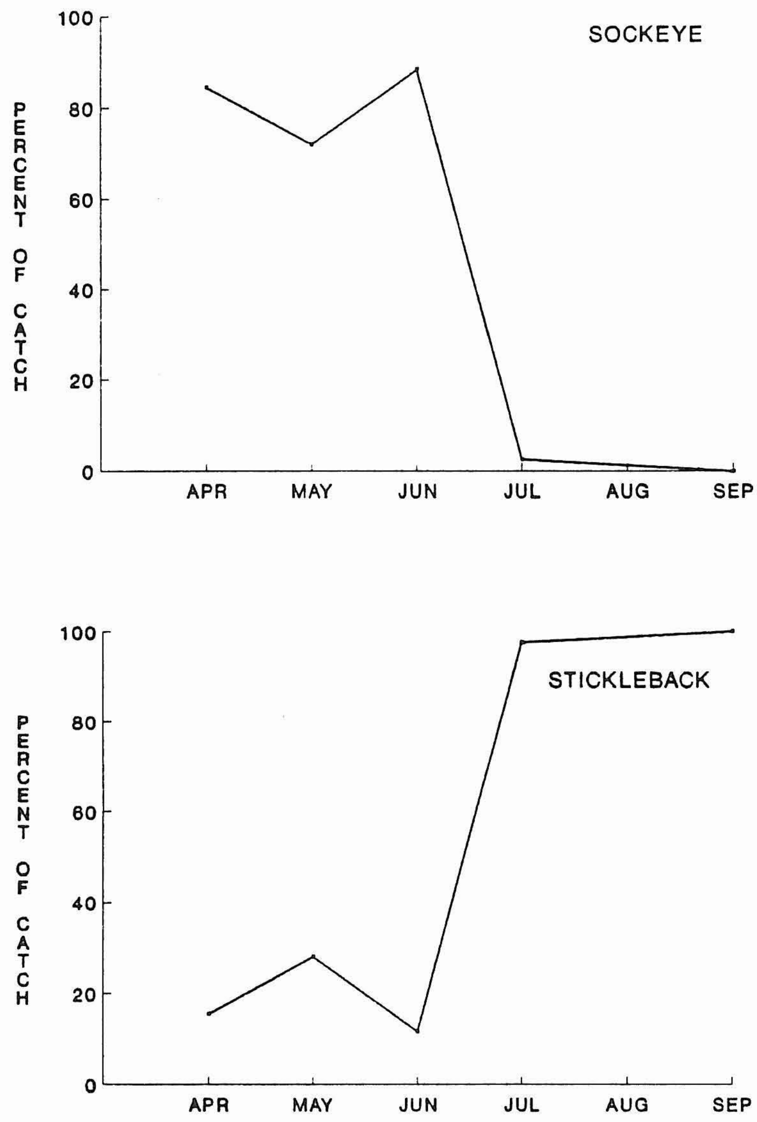


Fig. 4. Contribution of juvenile sockeye salmon and stickleback to beach seine catches from the littoral zone of Pitt Lake for the period April to September 1990.

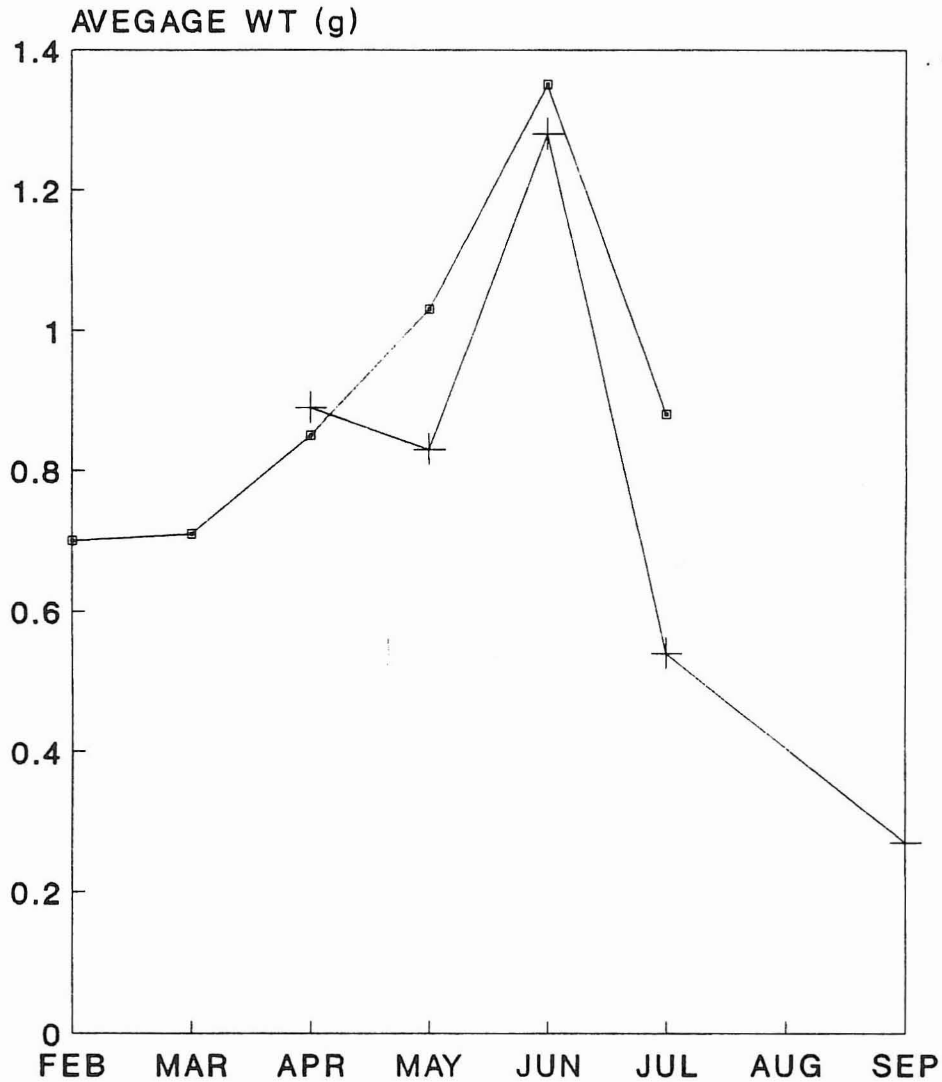


Fig. 5. Average weight of stickleback from trawl (—▪—) and beach seine (—+—) samples for the period February to September 1990.

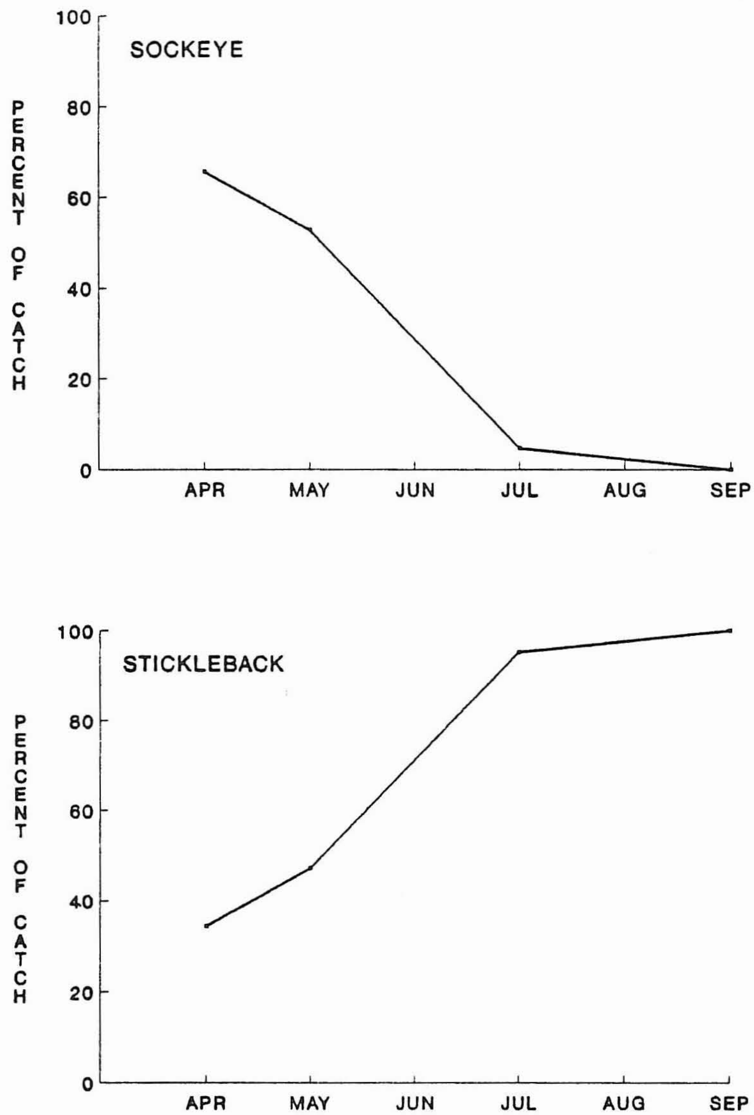


Fig. 6. Contribution of juvenile sockeye salmon and stickleback to beach seine catches from the Lower Pitt River for the period April to September 1990.

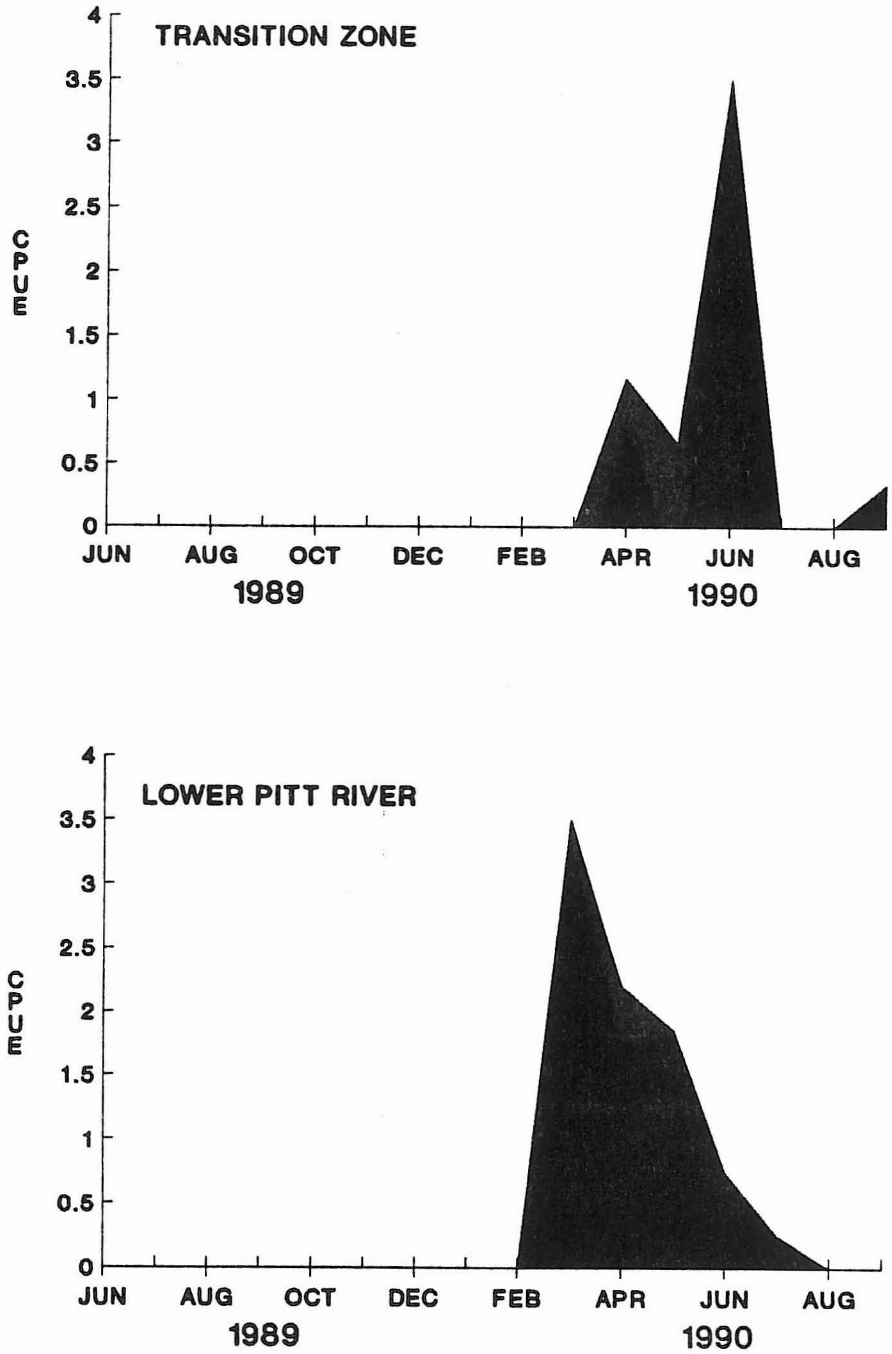


Fig. 7. Catch per unit effort (CPUE) of juvenile sockeye salmon from trawl sampling in the transition zone at the southern end of Pitt Lake and in the Lower Pitt River for the period June 1989 to September 1990.

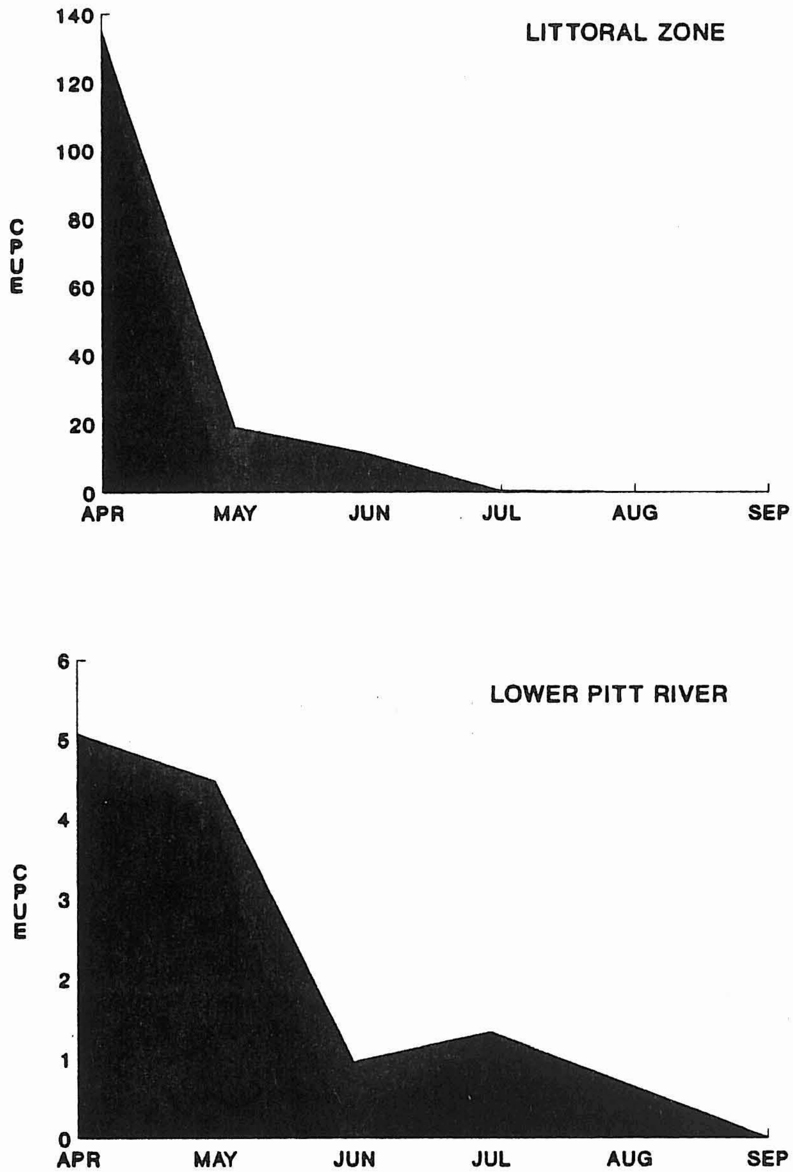
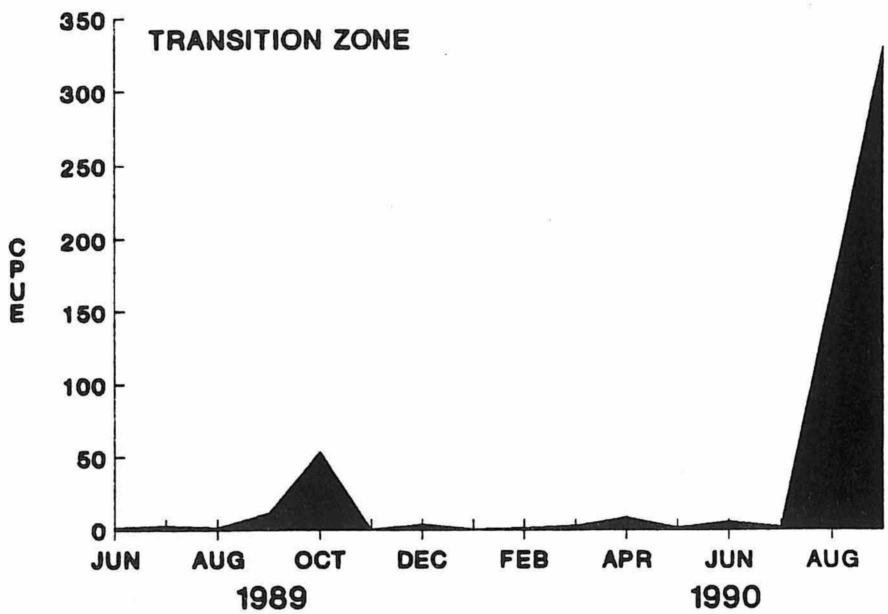


Fig. 8. Catch per unit effort (CPUE) of juvenile sockeye from beach seine sampling in the littoral zone of Pitt Lake and in the Lower Pitt River for the period April to September 1990.



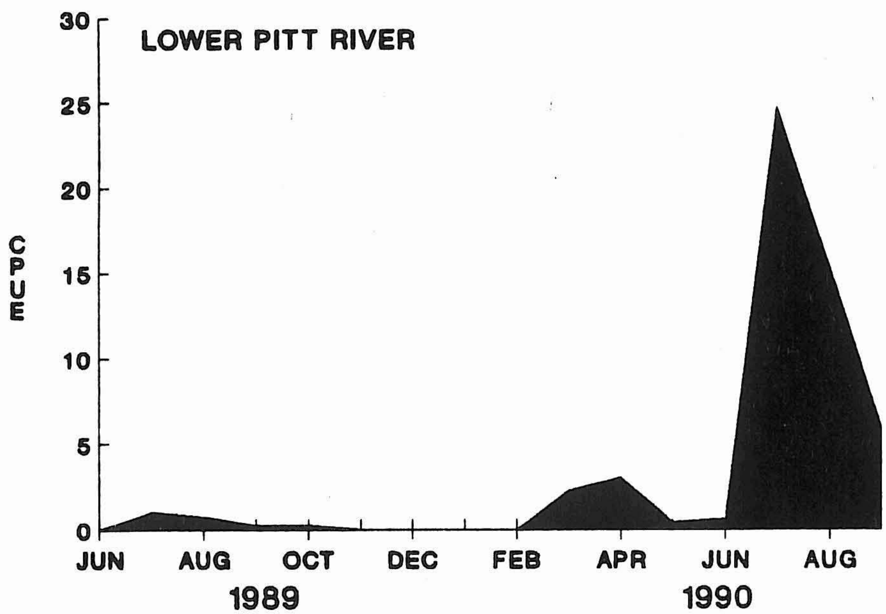
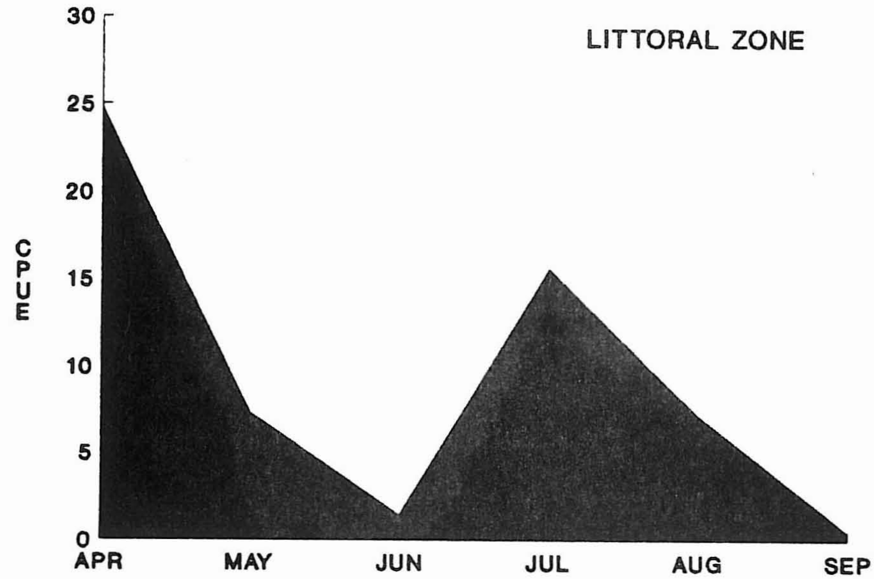


Fig. 9. Catch per unit effort (CPUE) of stickleback from trawl sampling in the transition zone at the southern end of Pitt Lake and in the Lower Pitt River for the period June 1989 to September 1990.



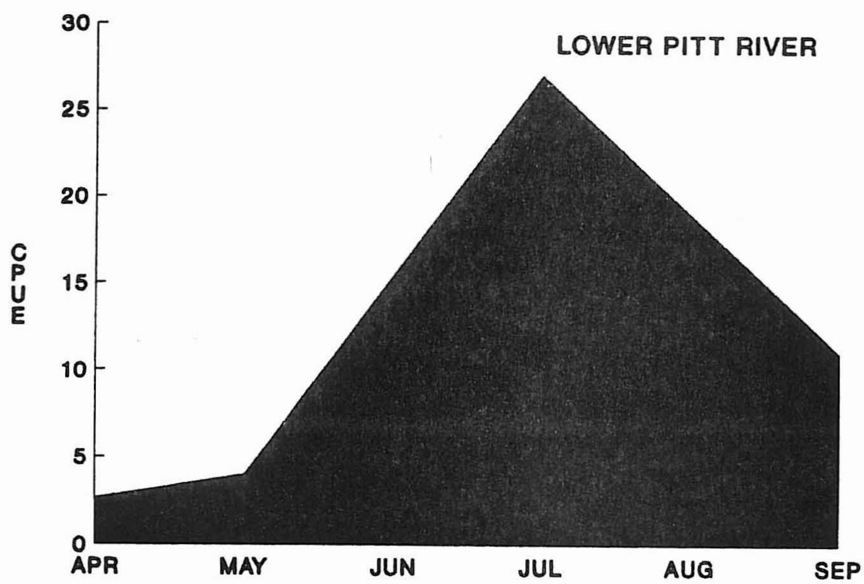


Fig. 10. Catch per unit effort (CPUE) of stickleback from beach seine sampling in the littoral zone of Pitt Lake and in the Lower Pitt River for the period April to September 1990.

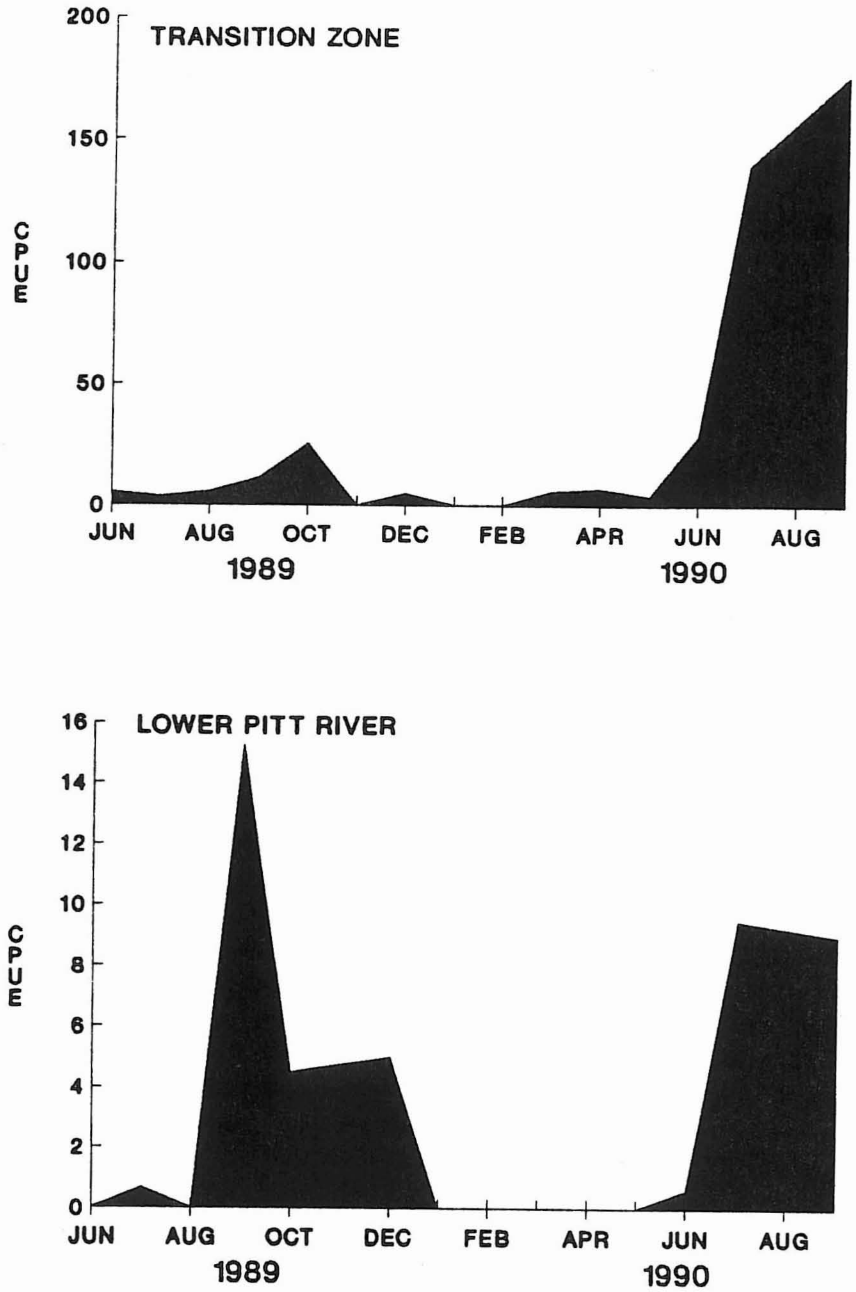


Fig. 11. Catch per unit effort (CPUE) of longfin smelt from trawl sampling in the transition zone at the southern end of Pitt Lake and in the Lower Pitt River for the period June 1989 to September 1990.

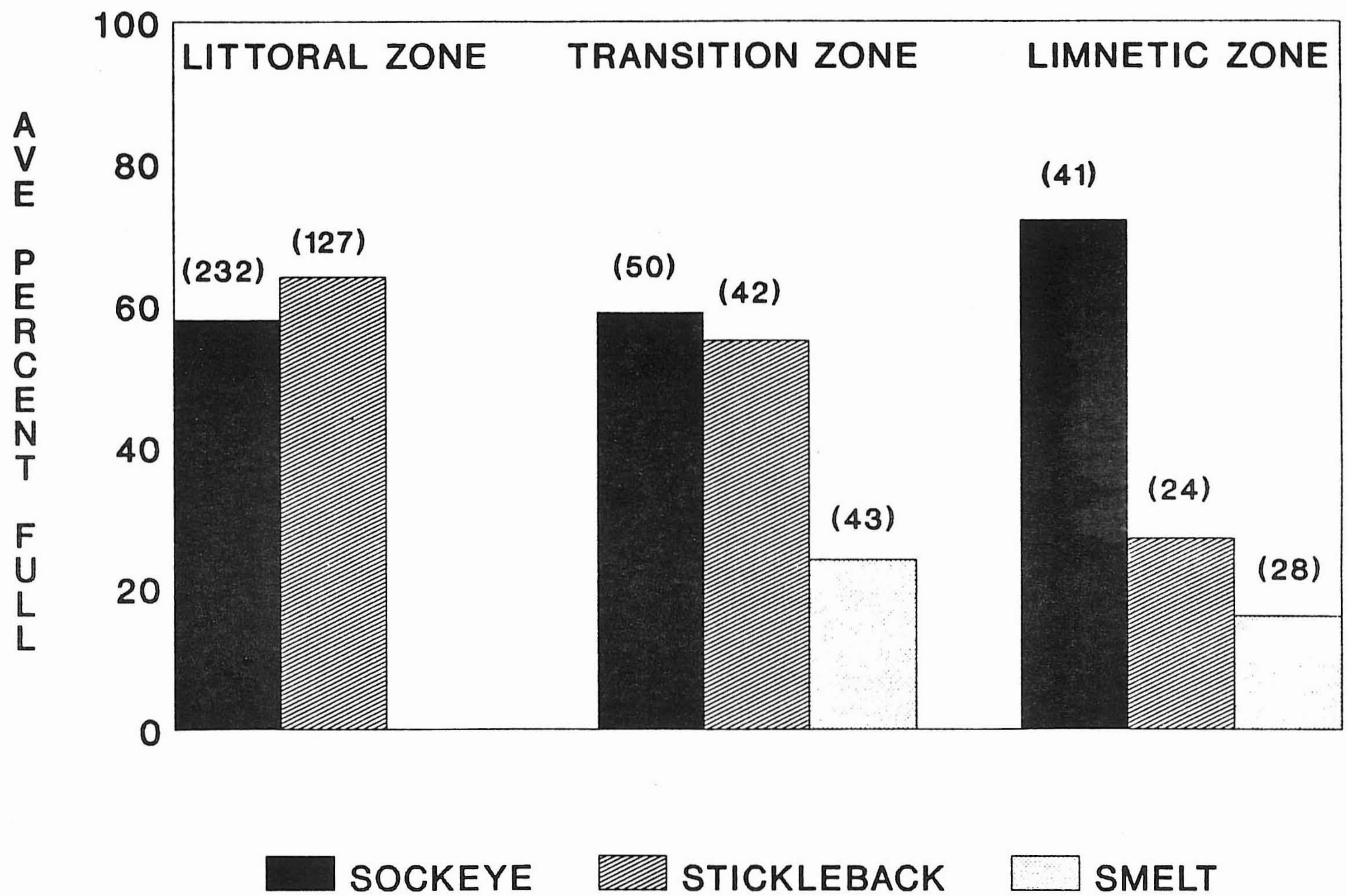


Fig. 12. Average percent stomach fullness for juvenile sockeye salmon, and stickleback, and longfin smelt by habitat zone in Pitt Lake (sample size shown in parentheses).

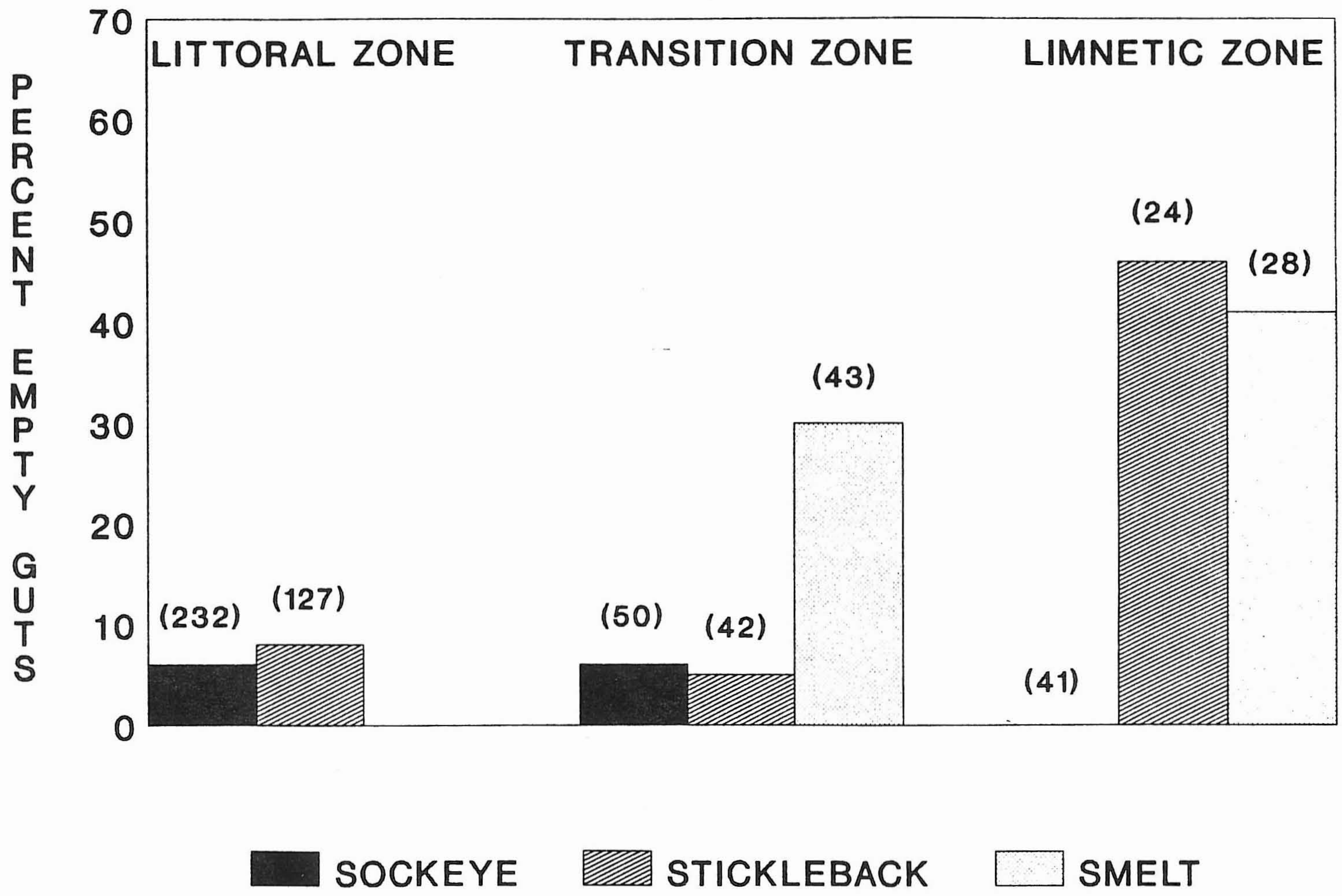


Fig. 13. Percentage of empty stomachs for juvenile sockeye salmon, and stickleback, and longfin smelt by habitat zone in Pitt Lake (sample size shown in parentheses).

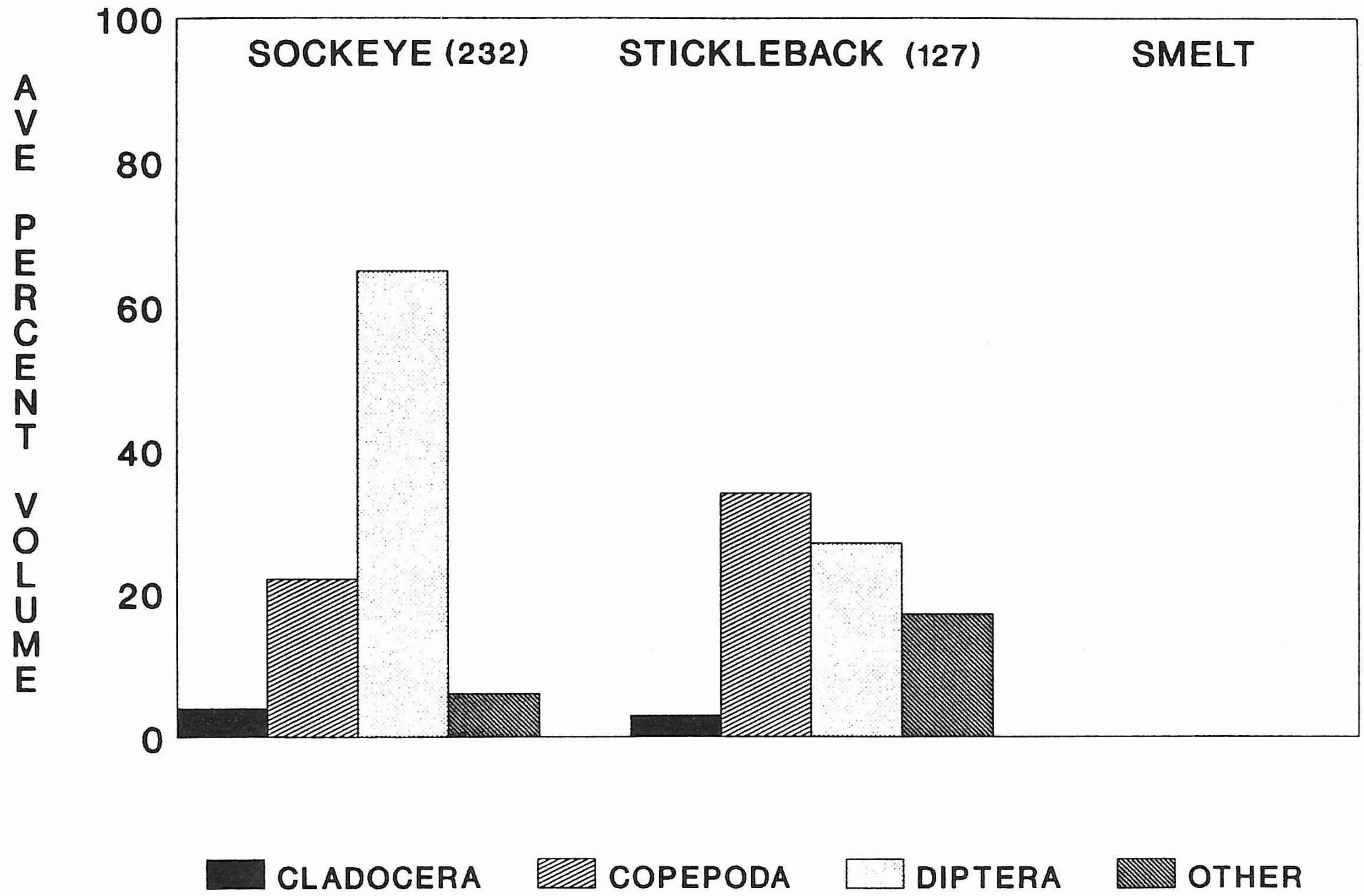


Fig. 14. Average percent stomach volume occupied by each food type for juvenile sockeye salmon, stickleback, and longfin smelt in the littoral zone of Pitt Lake (sample size shown in parentheses).

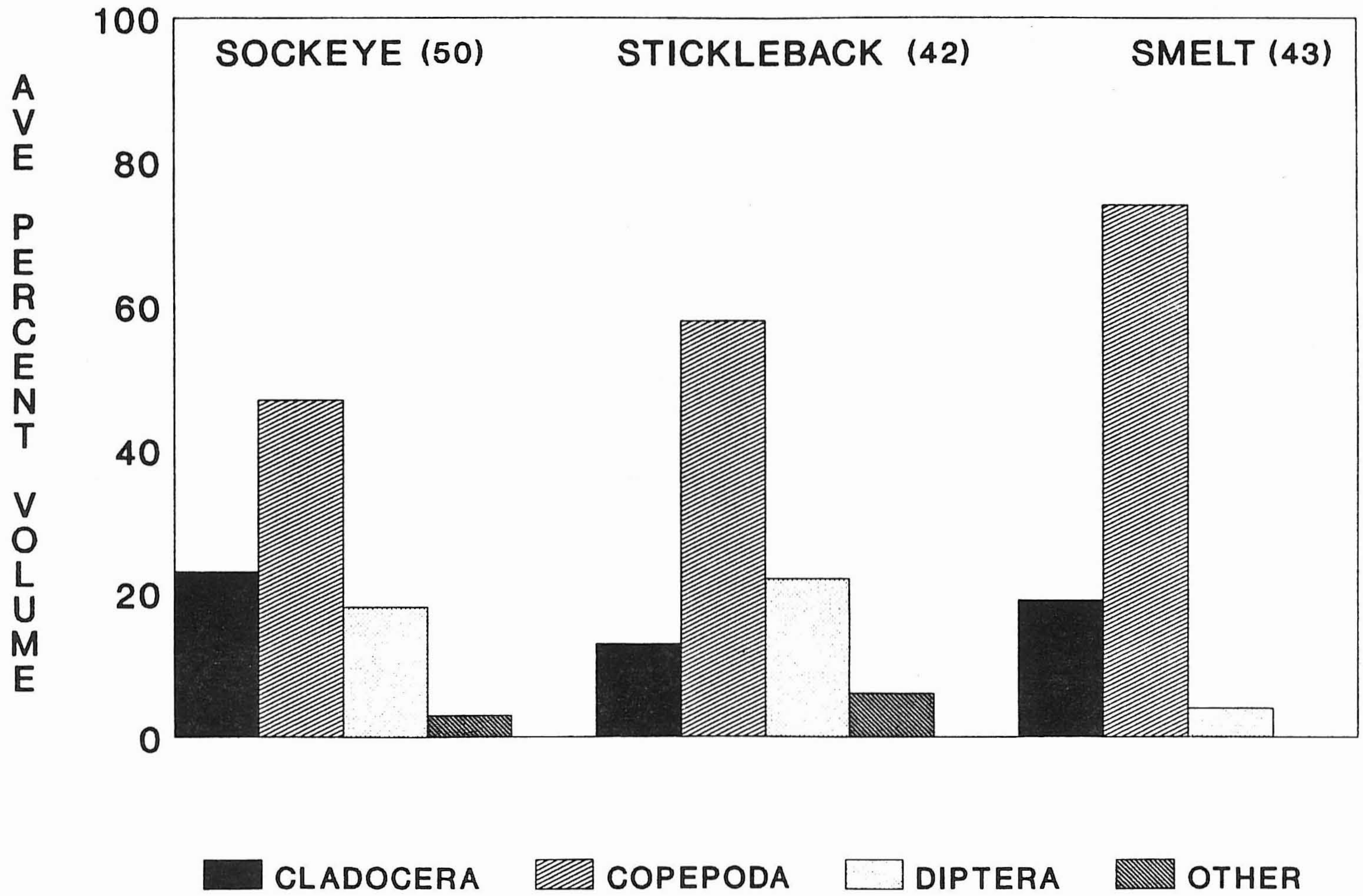


Fig. 15. Average percent stomach volume occupied by each food type for juvenile sockeye salmon, and stickleback, and longfin smelt in the transition zone at the southern end of Pitt Lake (sample size shown in parentheses).

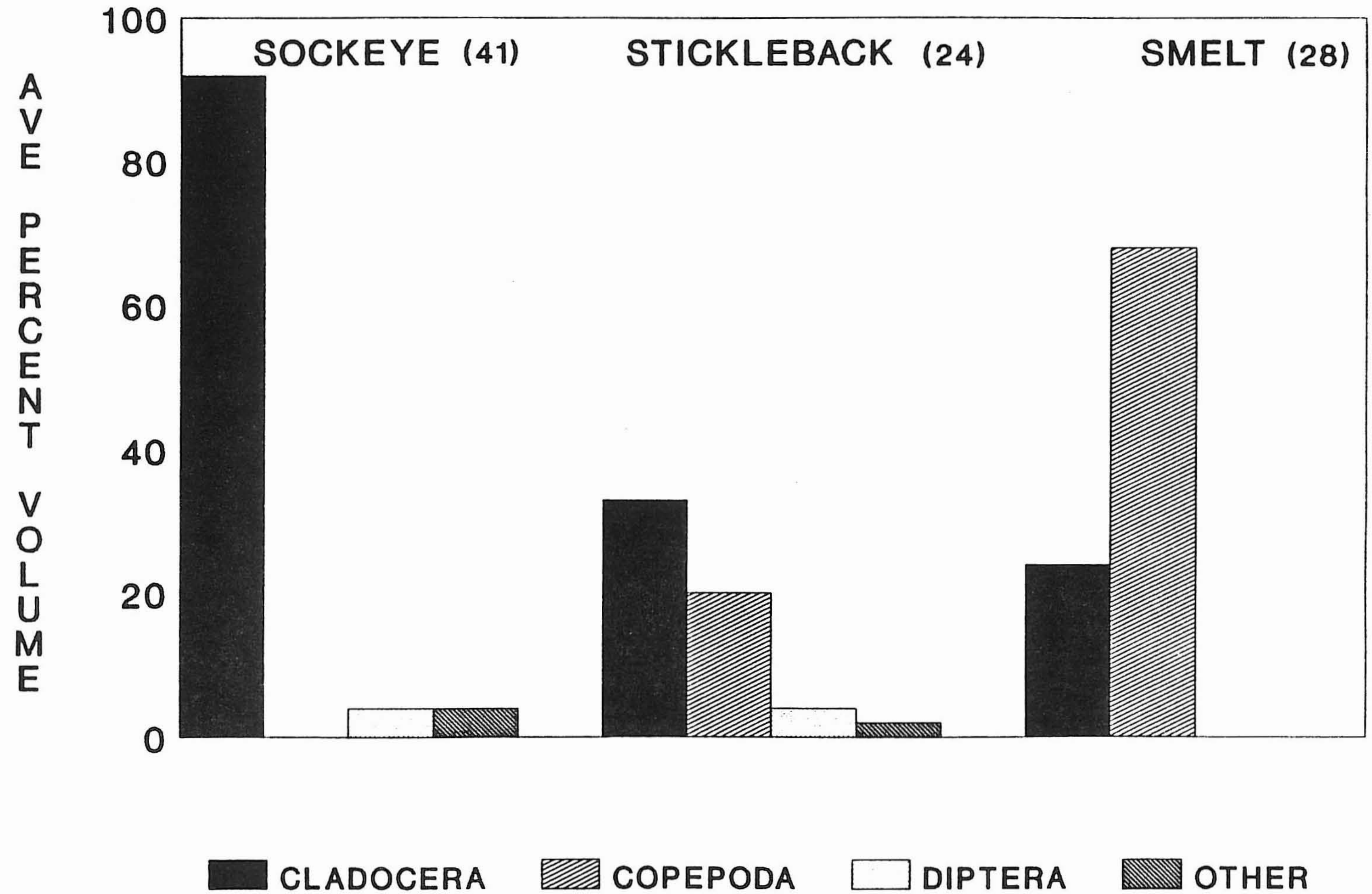


Fig. 16. Average percent stomach volume occupied by each food type for juvenile sockeye salmon, and stickleback, and longfin smelt in the limnetic zone of Pitt Lake (sample size shown in parentheses).