Use of the Littoral Zone by Introduced Anadromous Salmonids and Resident Trout, Margaret Lake, Southeast Alaska

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ABSTRACT: Construction of a fish pass around a barrier falls allowed at least 5 species of anadromous salmonids to colonize the Margaret Lake watershed, more than doubling the number of fish species in the lake. Juveniles of these anadromous salmonids, primarily coho *Oncorhynchus kisutch* and sockeye *O. nerka* salmon, rapidly and successfully colonized the littoral zone of Margaret Lake. Coho salmon fry and parr were the predominant salmonid species in the littoral zone after the fish pass was opened, and sockeye salmon fry were captured in both the littoral and pelagic zones. Although relatively few cutthroat trout *O. clarki* were captured throughout the study, they were the primary resident salmonids using the littoral zone before the fish pass was opened and were continually captured in the littoral zone throughout the study. Diel catch varied among species and was inconsistent from year to year. Numbers of fish captured at each site appeared to be associated with the geographic source of recruitment: stream outlets for coho salmon and planting location for sockeye salmon. Growth rates of coho salmon juveniles appeared to be greater later in the summer, whereas growth of sockeye salmon appeared to be greater during midsummer.

INTRODUCTION

Interactions among anadromous and resident salmonids were studied following planting of sockeye salmon *Oncorhynchus nerka* fry and installation of a fish pass on Margaret Creek in Southeast Alaska (Figure 1). As a part of this large investigation, we examined use of the littoral zone by rearing sockeye and coho *O. kisutch* salmon and by young cutthroat trout *O. clarki* and Dolly Varden *Salvelinus malma*.

Fish ladders or passes are used throughout the Pacific Northwest to open new habitat to anadromous salmonids. The passes are commonly designed for pink *O. gorbuscha*, chum *O. keta*, coho, and sockeye salmon, although their life histories and habitat requirements differ. Coho and sockeye salmon are likely to exploit the littoral zone. Pink and chum salmon migrate to the ocean shortly after emergence, and their use of the littoral zone is transitory. Dolly Varden and cutthroat trout also use the littoral zones of lakes and are generally the most common resident salmonid species in nonanadromous watersheds throughout Southeast Alaska.

Pella (1968) found that sockeye salmon fry use the littoral zone extensively through midsummer in the Wood River system of Bristol Bay, Alaska, but did not report the presence of other species. Woodey (1972) reported use of the littoral zone by sockeye salmon fry as they entered Lake Washington from the Cedar River. Although juvenile coho salmon are commonly associated with stream systems, they will use ponds and lakes for rearing (Crone and Bond 1976; Peterson 1982; Bryant 1985). Species assemblages and distribution of cool-water fish species in the littoral zone are described by several authors (Andrews and Hasler 1943; Hinch et al. 1991; Bensen and Magnuson 1992). Fish in all these studies were naturally occurring, well-established populations. Introduced salmonid distribution, growth, and exploitation of littoral zones in cold, oligotrophic lakes has not been described.

The objectives of this study, as related to littoral zone use, were to (1) determine changes in species composition from spring through fall, (2) describe size and age class distribution of the salmonid populations from spring through late summer, (3) compare relative catch of juvenile salmonids by time of day and by month,

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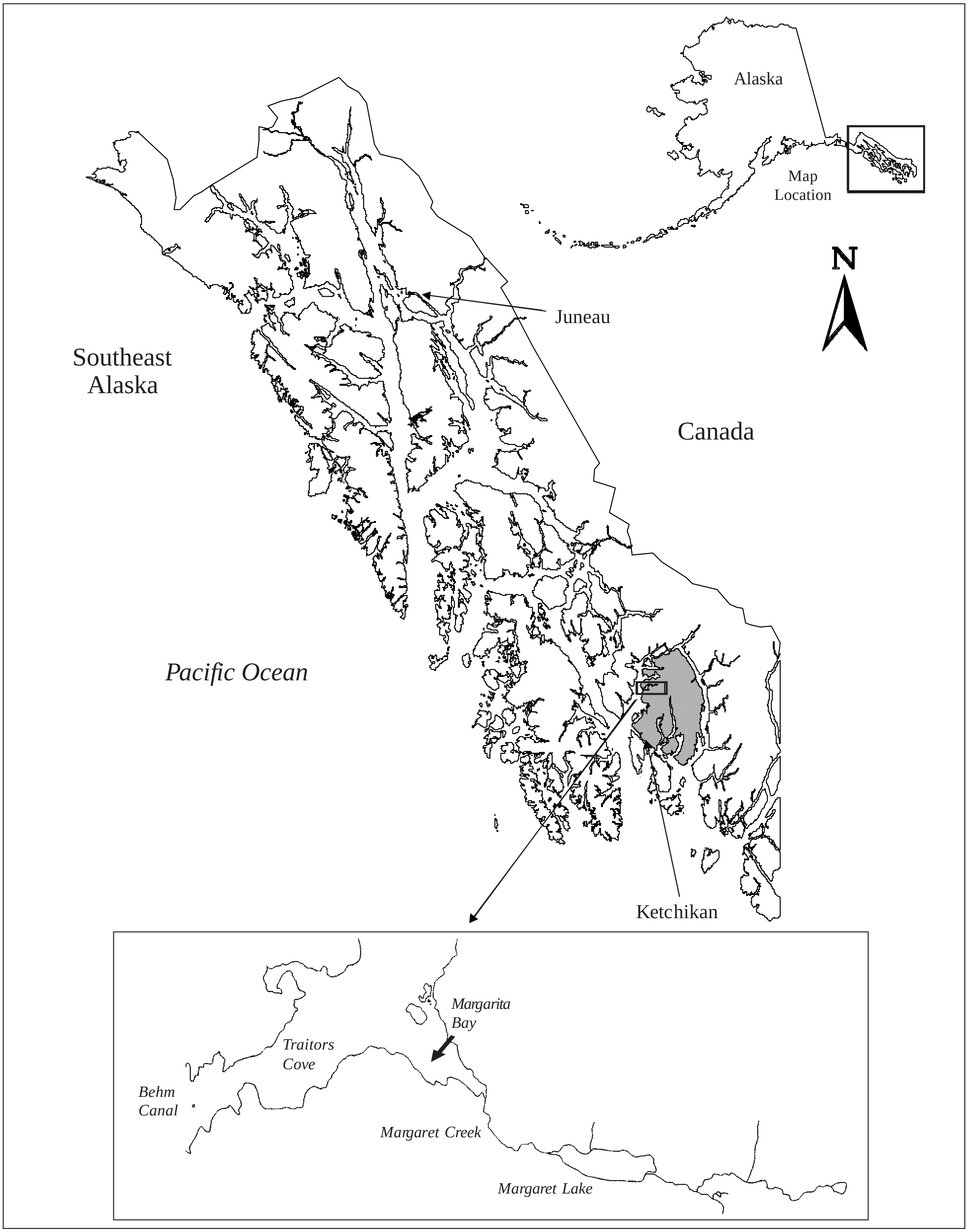

Figure 1. Location of the Margaret Lake watershed in Southeast Alaska.

and (4) relate number of salmonids to physical aspects of the littoral zone.

STUDY AREA

Margaret Lake is a 54.6-ha lake about 42 km north of Ketchikan in Southeast Alaska (Figure 1). The maximum depth of the lake is 37 m and 40% is <20 m deep. Though there is a small tributary (Sprout Fork) that enters Margaret Lake from the north, Margaret Creek is the lake's primary inlet and outlet. A 7-m waterfall about 900 m downstream from the lake and about 900 m from tidewater formed a complete barrier to upstream movement of fish.

Before July 1990, fish species in the lake were restricted to resident cutthroat trout, Dolly Varden, kokanee *O. nerka*, threespine sticklebacks *Gasterosteus aculeatus*, and sculpins *Cottus*. When the fish pass was opened in 1990, anadromous salmonids moved into Margaret Lake: pink, chum, and coho salmon, steelhead *O. mykiss*, searun cutthroat trout, and anadromous Dolly Varden. Sockeye salmon fry were planted in the pelagic zone of the lake in 1988 and each year from 1990 to 1994 (none were planted in 1989). None of the 518,000 fry planted in 1988 were observed in 1989. Nearly 1 million sockeye salmon fry were planted from 1990 to 1992 (Table 1). In April 1991, 25,000 near-smolt coho salmon were planted; hydroacoustic surveys and sampling in the lake throughout the summer revealed that nearly all had emigrated (Alaska Department of Fish and Game, Ketchikan, unpublished data). Annual population estimates of cutthroat trout from 1989 through 1993 ranged from 1,418 in 1989 to 3,182 in 1991 and for Dolly Varden (>140 mm fork length) from 939 in 1992 to 1,752 in 1991 (Frenette and Bryant 1993). No estimates were made for kokanee salmon. Few cutthroat trout fry were observed during surveys of Margaret Creek and Sprout Fork, or during sampling in the lake before the fish pass opened in 1990.

Table 1. Time and number of sockeye salmon fry planted in Margaret Lake from 1988 to 1992 (M. Haddix, Alaska Department of Fish and Game and Southern Southeast Regional Aquaculture Association, Ketchikan, personal communication).

Year	Date	Number
1988	no record	518,000
1989	NA	none
1990	4 April	300,200
1991	27 June	450,000
1992	5 May	200,000
1993	19 May	200,100
1994	19 May	120,000

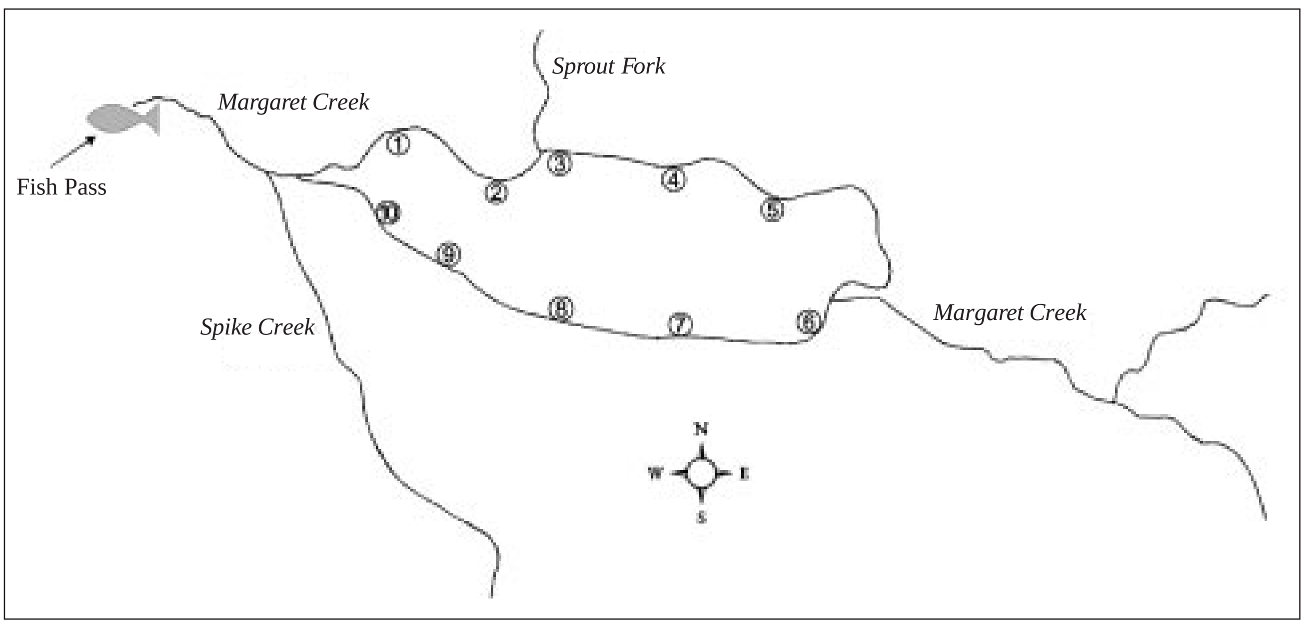

Figure 2. Margaret Lake shoreline sample sites used from 1992 through 1994 and the tributaries and outlets of the lake.

Table 2. Characteristics of sites sampled along the littoral zone of Margaret Lake.

Site	Substrate	Aquatic Vegetation	Woody Debris	Slope Break[a] (m)
1	Sand	Present	Absent	3–5
2	Sand	Absent	Absent	0–3
3	Rocks/silt	Absent	Slash	>12
4	Silt	Absent	Slash	>13
5	Silt	Present	Slash	3–6
6	Silt	Dense	Absent	>12
7	Silt	Absent	Slash	0–3
8	Sand	Present	Absent	9–12
9	Sand	Present	Absent	9–12
10	Sand/organic	Present	Whole tree/slash	>12

[a] Distance from the shore to the slope break; at the slope break, the depth (generally ≥1.5 m) exceeded the depth of the seine used to sample the littoral zone.

METHODS

Sampling

Beach seine samples were taken at 10 permanent sites along the shoreline of Margaret Lake during 1992, 1993, and 1994 (Figure 2). Sample sites 3 and 4 were located near the outlet of the 2 streams entering the lake; other sites were distributed along the shoreline of the lake to sample representative areas of the lake's littoral zone (Table 2).

At each site, morning (sunrise) and evening (1 h before sunset) samples were taken once a month from May through August 1992, a sample consisting of the combined catch from 2 beach seine passes. In 1993, samples were taken once a month in the evening from June through September; morning and evening samples were taken in May. In 1994 the monthly morning and evening samples were taken in May and July only. All fish were identified and counted, and all salmonids were measured for fork length to the nearest millimeter. Ages were estimated from length-frequency distributions.

The beach seine was 30 m long, 1.5 m deep, and had a bar mesh size of 6.3 mm. The net was set from shore using a boat and was pulled in a semicircle around the littoral zone. The area swept was about 300 m^2, but this varied depending on the slope break (Table 2), i.e., the point at which the slope of the bottom increases dramatically. In Margaret Lake the slope break was at 1.5 m or more depth, which generally was too deep to sample with the beach seine. Weaver et al. (1993) stated that beach seines are selective by species for cool-water fish assemblages; they did not examine selectivity among juvenile salmonid species. We assumed similar efficiencies for juvenile coho and sockeye salmon and similarly sized cutthroat trout; a lower efficiency was assumed for cutthroat trout >120 mm. Pierce et al. (1990) showed that littoral habitat complexity (i.e., woody debris and aquatic vegetation) will affect seine efficiency, greater efficiency occurring in aquatic vegetation than in open bottom or woody debris. Although we tried other capture methods — minnow traps and fyke nets — they did not effectively capture juvenile fish in the littoral zone. As a result, we did not include those data in this study.

Analysis

Each morning or afternoon sample at a site consisted of 2 combined seine hauls. Samples were stratified by site, time of day, month, and year. Three separate *t*-tests, 1 each for coho salmon, cutthroat trout, and sockeye salmon, were used to test for differences in abundance between 1992 and 1993. Between-year comparisons for all sites were made for the evening samples only. We used the Bonferroni adjustment to account for multiple tests ($\alpha = 0.05$; SAS Institute 1988). Length-frequency distributions were developed from the combined catch of each species from all locations for each month.

The number of salmonids caught per sample was analyzed using a nested analysis of variance (SAS Institute 1988) to determine the proportion of the total variance attributable to site, year, month, and time of day. Class variables were year, site, month, and time of day. For the 1992 and 1993 samples, the test was done for cutthroat trout and for coho and sockeye salmon. Similar analysis was used for the limited data set collected during 1994.

RESULTS

During evening samples more coho salmon fry (age 0) were caught in 1993 than in 1992, but fewer sockeye salmon fry were captured in 1993 than in 1992 (Figure 3). Year-to-year differences in the number of coho and sockeye salmon were significant ($P = 0.01$) but not significant for cutthroat trout ($P > 0.05$). The number of coho salmon captured was greater in 1993 than in 1992 because of an escapement of >2,000 spawners in 1992 compared to <500 in 1991. The same number of sockeye salmon were planted in 1992 as in 1993.

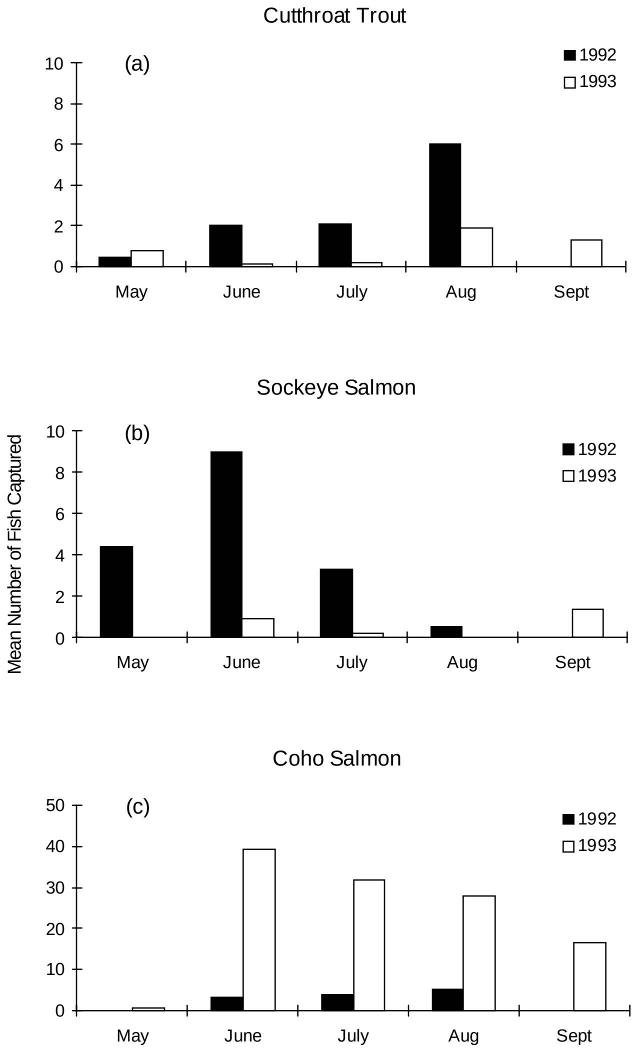

Figure 3. Monthly mean number of coho and sockeye salmon and cutthroat trout captured during evening samples at all sites, 1992 and 1993.

Time of day accounted for the largest percentage of the variation in number of sockeye salmon fry caught in the 1992 and 1993 samples, the greatest number captured in the morning samples (Table 3). Time of day also accounted for the largest variance component for cutthroat trout (60.1%; Table 3). During 1992 more cutthroat trout were captured in the morning than in the evening samples. Time of day accounted for a small percentage (6.1%) of the variation in the number of coho salmon caught. Month (55.8%), followed by year (38.1%), accounted for the greatest percentage of variation in the number of coho salmon caught. Few coho salmon were caught in May. In 1993, as fry were recruited into the lake in June, the number caught increased and then decreased from July through September (Figure 3a). Although monthly changes accounted for a small part of the variation for other species, a marked decrease in the catch of sockeye salmon was observed between June and July in both 1992 and 1993 (Figure 3b); the number of cutthroat trout, however, more than doubled from July to August in both years.

Table 3. Site, year, month, and time-of-day contributions to total variance for the beach seine catch of juvenile coho salmon, cutthroat trout, and sockeye salmon, 1992–1993.

Variance Component	Percent: Coho Salmon	Cutthroat Trout	Sockeye Salmon
Site	0.0	3.5	0.0
Year	38.1	36.4	0.0
Month	55.8	0.0	2.2
Time of day	6.1	60.1	97.8
Total	100.0	100.0	100.0

Site differences accounted for the least amount of variation in catch during 1992 and 1993 among all species, but species composition between sites was inconsistent. For example, relatively high numbers of sockeye salmon and relatively few coho salmon were captured at site 2 and high numbers of coho salmon and few sockeye salmon were captured at sites 6 and 10. The number of a particular species captured at the sites did not appear to be related to a single or combination of physical factors, including area. Logging slash was present at site 4, but that site showed relatively high numbers of sockeye salmon fry. Geographic location of the sites could have been the reason for this variation: sites 2, 3, and 4 had higher numbers of sockeye salmon fry than other sites during both 1992 and 1993. These sites were located at the north end of the lake where sockeye salmon were planted during both years. Site 6, near the inlet to the lake, consistently had more coho salmon than the other sites.

Unlike 1992 and 1993, site differences accounted for more than 70% of the abundance variation for all species in the samples taken during 1994 (Figure 4). The largest number of fish were caught at sites 3 and 6 (Figure 4); those sites were located near the outlets of the 2 tributaries to Margaret Lake, which may account for the high numbers of juvenile coho salmon caught there. Proximity to the source of recruitment may be a more important factor in littoral zone use than specific habitat type. The stream outlet may provide an additional source of food, which could attract drift-feeding juvenile coho salmon.

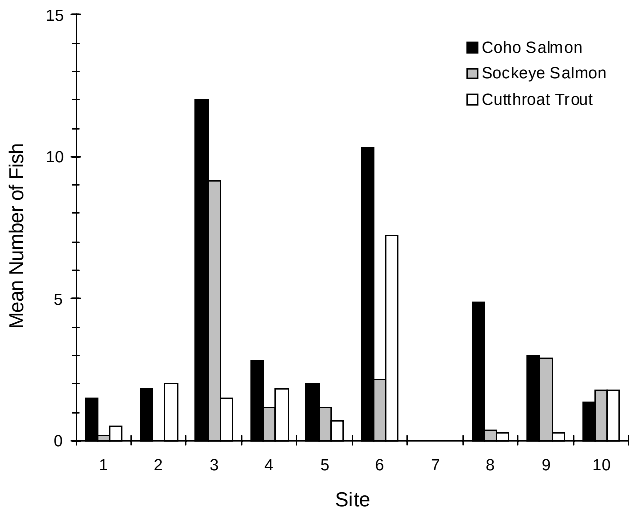

Figure 4. Mean number of fish captured in beach seines at the 10 sample sites combined during 1994.

In 1992 few coho salmon <70 mm were captured; in 1993 large numbers of fry <40 mm were caught in May, a distinct mode occurring around 48 mm (Figure 5). By August 1993 the number of fish in size intervals from about 50 through 90 mm was evenly distributed. The seasonal changes in distribution of length frequencies from May through September could have been due to the high number of fry recruited from an escapement of over 2,000 spawners in 1992. The distribution observed in August 1993 may reflect a density-dependent response, smaller fish being forced into less favorable feeding locations. The result would be a wider range of fish lengths later in the summer, such as that observed in August 1993.

The median length of age-0 coho salmon recruited into the littoral zone in May 1993 was 32 mm; insufficient numbers were captured in 1992 to estimate the median length of fry (Table 4). By September 1993 the median length was 60 mm. The August median length of age-1 coho salmon (89 mm) was slightly higher in 1992 than in 1993 (84 mm; Table 4). Growth rates for age-0 coho salmon decreased from July through September 1992; those for age-1 were highest in September (Table 4), indicating the later part of the summer provides the best growth factors. Although greater recruitment into the lake may have reduced growth rates of age-1 coho salmon in 1993, the median lengths were similar to those observed elsewhere in the Margaret Lake watershed.

For all 3 years sockeye salmon fry were about 35 mm when they were planted in May (Figure 6). Although few sockeye salmon were caught in 1993, the median fork length in September 1993 was 66 mm, which was only slightly greater than the median length of 62 mm observed in August 1992 (Table 5). In 1992 highest growth rates at 0.667 mm/d occurred from June through July (Table 5). Too few fish were captured in 1993 to identify trends in growth, but in July 1994 the apparent growth rate from May through July was about 50% of that observed in July 1992.

Sticklebacks generally composed >70% of the total catch during all 3 years but were not included in the computation of percent of total catch in Figure 7. In 1992 sockeye salmon abundance varied in the monthly samples (Table 5), although percent contribution decreased (Figure 7). This probably reflects increased abundance of other fish species in the littoral zone as the summer progressed. No trend like

Table 4. Monthly median length and apparent growth rate by age group for coho salmon captured in beach seine samples at all locations combined, 1992 and 1993.

	1992			1993		
Age Group and Month	*n*	Median Length (mm)	Growth Rate (mm/d)	*n*	Median Length (mm)	Growth Rate (mm/d)
Age 0						
May				49	32.0	
June				79	37.0	0.128
July				222	44.0	0.467
August				134	56.0	0.279
September				93	60.0	0.190
Age 1						
June	28	70.5		12	62.0	
July	54	74.0	0.167	30	65.0	0.200
August	84	89.0	0.500	143	84.0	0.349
September				72	94.0	0.479

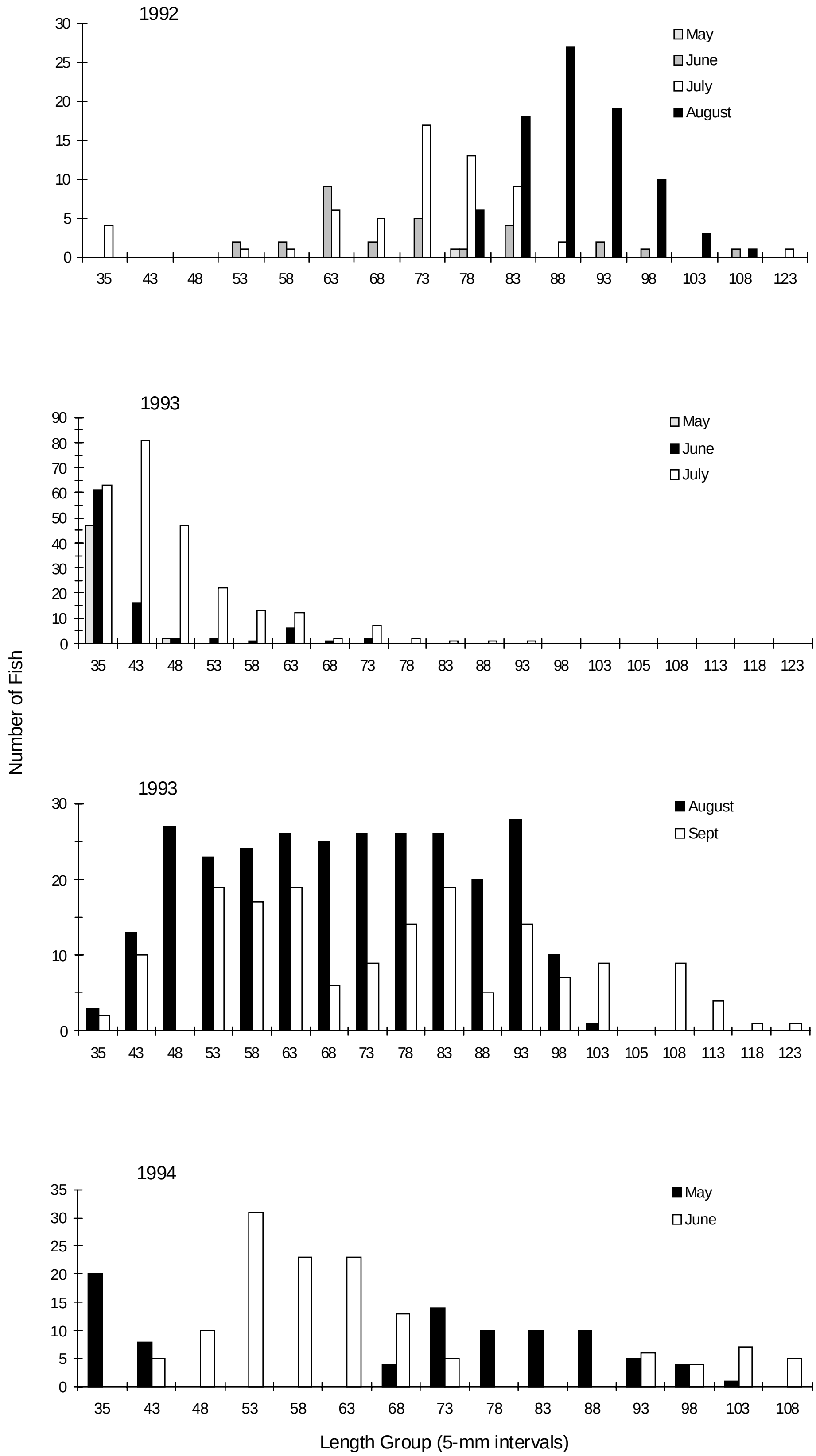

Figure 5. Monthly length-frequency distributions of coho salmon captured at all sites, 1992, 1993, and 1994.

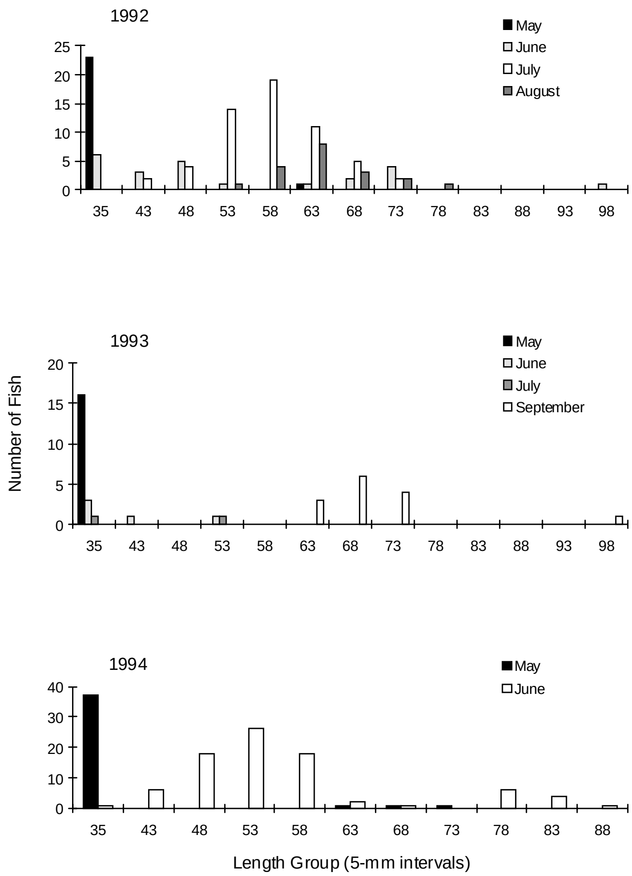

Figure 6. Monthly length-frequency distributions of sockeye salmon captured at all sites, 1992 and 1993.

this was evident in 1993 and 1994 (Figure 7). Excluding sticklebacks, age-0 and -1 coho salmon were predominant in 1993 and 1994, and though no monthly patterns appeared, sculpins also were a consistent component of the catch, composing from 5 to 35% during the 3 years (Figure 7). The percentage of cutthroat trout in the catch was greatest during 1992. Steelhead were not caught until 1993, and then in relatively low numbers. Two kokanee were captured during the 3 years but were not included in Figure 7.

DISCUSSION

In this study recently recruited juvenile coho and sockeye salmon colonized the littoral zone. As for cutthroat trout, few fry were captured in the littoral zone, but younger, age-1 cutthroat trout were present in the littoral zone during the summer months. Larger cutthroat trout (>140 mm) were also taken in the littoral zone with fyke nets during seasonal population sampling from 1989 through 1995 (Bryant and McCurdy 1995).

At least for coho salmon, year-to-year differences reflected abundances observed elsewhere in the watershed. In 1993, coho salmon fry were the predominant species in the littoral zone, and this strong year class contributed to the higher numbers observed in 1994. Coho salmon fry and parr were not captured in mid-water townets used in conjunction with hydroacoustic surveys to estimate pelagic fish abundance (M. Cartwright, Alaska Department of Fish and Game, Ketchikan, personal communication), which suggests that coho salmon fry and parr occupy the littoral zone but do not make extensive use of the pelagic zone, as do sockeye salmon fry. Coho salmon growth rates in this study appeared to be higher than for other locations reported in Southeast Alaska (Dolloff 1983; Bryant 1984). All coho salmon fry in a set of streams on Prince of Wales Island in Southeast Alaska were <65 mm in September and had a mode near 50 mm (Cardinal 1980). The growth rates and mean sizes of coho salmon in the littoral zone of Margaret Lake also tended to be greater than those found elsewhere in the

Table 5. Monthly median length and apparent growth rate by age group of sockeye salmon captured in beach seine samples at all locations, 1992 and 1993.

	1992			1993			1994		
Age Group and Month	*n*	Median Length (mm)	Growth Rate (mm/d)	*n*	Median Length (mm)	Growth Rate (mm/d)	*n*	Median Length (mm)	Growth Rate (mm/d)
Age 0									
May	24	32.0		16	33.0		37	37.0	
June	16	43.0	0.306	5	38.0	0.126			
July	55	57.0	0.667	2	43.0	0.333	69	53.0	0.326
August	19	62.0	0.167						
September				14	66.0	0.359			

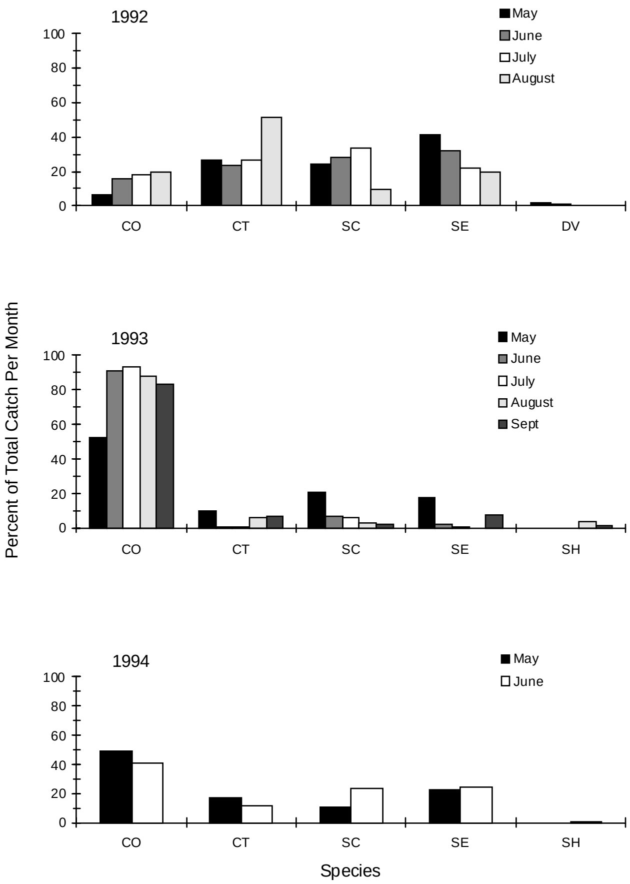

Figure 7. Species composition of fish captured (excluding sticklebacks) during monthly samples from 1992 through 1994, where CO = coho salmon, CT = cutthroat trout, SC = sculpins, SE = sockeye salmon, and SH = steelhead.

watershed (Frenette and Bryant 1993). These results are consistent with studies that showed coho salmon are not only abundant in beaver ponds but tend to be larger than the fish found in adjacent stream sections (Bryant 1985; Sampson 1994).

Seasonal migration patterns were not observed for sockeye salmon fry in Margaret Lake. In contrast, Burgner (1958) and Pella (1968) reported that sockeye salmon fry tend to remain in shallow water during the early part of summer and move into the pelagic zone later in summer. Sockeye salmon fry entering Lake Washington were observed in the littoral zone near the outlet of the major spawning tributary in the early summer but moved into the pelagic zone by midsummer (Woodey 1972). All of these studies reported movement into the pelagic zone as the sockeye salmon fry grew, and some reported low catches in littoral zones later in summer.

The number of fry caught in the littoral zone in Margaret Lake from June through September varied, showing no trend (Table 5; Figure 7). The population size in the pelagic zone decreased during this period, based on hydroacoustic measurements in 1992 (DeCino 1992; M. Haddix, Alaska Department of Fish and Game, Ketchikan, personal communication). Vertical diel movements of sockeye salmon fry in response to light and predation were reported from hydroacoustic surveys (Narver 1970; Eggers 1978; Clarke and Levy 1988) but provide no evidence of diel movements to or from the littoral zone. Although differences between the catch of sockeye salmon fry during the morning and evening were observed at Margaret Lake, the data do not suggest lateral movement between the pelagic and littoral zones. In contrast to juvenile coho salmon, sockeye salmon fry were found in both the littoral and pelagic zones.

Although cutthroat trout were captured in the littoral zone, we did not note extensive littoral zone use by cutthroat trout fry. They may, however, have occupied areas <10 cm deep along the shore that we were not able to sample efficiently. Some cutthroat trout fry were observed near the delta of the small tributary, Sprout Fork, in late July, but few were captured. Data from the Sprout Fork and Margaret Creek weirs, used to monitor migration into and out of Margaret Lake, indicated that cutthroat trout tend to recruit into the lake at ages of 1 to 4 years and at lengths of 70 to 140 mm (Frenette and Bryant 1993). We suspect that most remain in the streams the first summer.

Coho salmon fry and juveniles were the largest component of the salmonid community in the littoral zone in 1992–1994 and are likely to have the greatest influence on available resources. They also may be a significant competitor with smaller cutthroat trout. Although young coho salmon may be susceptible to predation by larger cutthroat trout, none have been observed as food items in stomachs of cutthroat trout captured in the lake (M. Cartwright, Alaska Department of Fish and Game, Ketchikan, personal communication). Resource partitioning among the littoral zone species has not been investigated but would contribute to our understanding of the productivity of littoral zone habitat. Sticklebacks are common residents of the littoral zone, but they also use the pelagic zone for foraging. Their resource use, food, and space are closely aligned with those of sockeye salmon (Rogers 1968; Ruggerone 1991).

Though beach seine sampling imposed some limitations on the data set, its limitations did not seem to affect our observations of anadromous salmonid distribution in and use of the littoral zone. Juvenile coho salmon recruited into the lake via the fish pass and sockeye salmon planted in the lake were both found throughout the littoral zone. Midday samples were taken before this study began, and though the samples were not systematic, they were taken in areas where we suspected young-of-year cutthroat trout would be found. Few fish of any species, however, were captured. It is apparent that samples taken close to sunset and sunrise were more successful than those taken at midday. Evening samples might have been more successful, but beach seining in difficult terrain at night can be hazardous.

RECOMMENDATIONS

The role and relative importance of littoral zones in lakes throughout Southeast Alaska in the production of anadromous salmonids is poorly understood. Although this study has identified the colonization and use of the littoral zone of Margaret Lake by anadromous salmon, the factors that affect its productivity or the significance of lakes as rearing and refuge habitat in other watersheds remain to be determined. Well-developed littoral zones may provide a significant buffer to habitat disturbance, both natural and anthropogenic. More extensive studies that emphasize the role of the littoral zone are needed to determine how these areas affect watershed productivity of lake systems throughout Southeast Alaska,

The early life history of cutthroat trout fry remains largely unknown. Although few cutthroat trout fry were captured in the littoral zone of Margaret Lake, shallow areas of the lake that were not sampled could have been important. In addition, interactions that include resource partitioning (food and space) between anadromous salmonids and resident species, such as cutthroat trout, in lakes are important considerations for managers when determining whether to open non-anadromous watersheds to anadromous fish populations. More intensive studies are needed to provide a better understanding of these effects on the early life history of cutthroat trout in lakes.

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