MIGRATIONS OF COHO SALMON, *ONCORHYNCHUS KISUTCH*, DURING THEIR FIRST SUMMER IN THE OCEAN

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ABSTRACT

Marked juvenile coho salmon caught in fine-meshed purse seines during the summers of 1981–84 off Oregon and Washington generally demonstrated northward migrations from their rivers of ocean entrance. Northward movements in summer were preceded by southerly movements during spring, probably caused by southerly advection. Catch rates and sizes of fish caught in different months and regions of the coast also indicated northerly movements of both yearling and subyearling coho salmon. Despite this movement, the average catch of juvenile coho salmon per purse seine set along the coasts of Washington and Oregon in late summer, including marked fish from the Columbia River, was still a substantial proportion of that in May and June soon after ocean entrance, suggesting that many coho did not migrate great distances. Additionally, recoveries of marked juvenile coho salmon by sports and commercial fishermen from Alaska to California and by scientists in Alaska were generally in the region of release. These data indicate that migrations of juvenile coho are of limited extent during their first summer in the ocean and are not strong support for an earlier conclusion that juvenile coho salmon from the Columbia River, Oregon, and California may form a large proportion of the stocks of this species that migrate northward along the coastal belt in Canadian and Alaskan waters each summer.

Although there has been little research on juvenile salmon during their first summer at sea, this phase of the life history may be critical to survival and recruitment to fisheries (Hartt 1980). Highest ocean mortality is thought to occur early in marine life (Foerster 1968; Parker 1968; Ricker 1976). Production (catch and escapement) of adult coho salmon, *Oncorhynchus kisutch*, in the Oregon Production Index (OPI) Area (from Leadbetter Point, WA, to Monterey Bay, CA) is usually accurately predicted in one year by the number of precocious males (jacks) returning to index streams in the previous year (Gunsolus 1978; Oregon Department of Fish and Wildlife 1982; Pacific Fishery Management Council 1986). Hence survival from jacks to adults is fairly constant from year to year. Because survival rates from smolt to adult are variable (Nickelson 1986), however, variable year-class survival must occur before the time that jacks return, after only a few months in the ocean. This relationship, and the positive correlation between coastal upwelling and survival of OPI coho salmon (Gunsolus 1978; Scarnecchia 1981; Nickelson 1986), strongly suggest that the first few months in the ocean constitute the "critical period" in determining subsequent adult survival.

Between 1976 and 1985 the production of coho salmon in the OPI area drastically declined, despite large increases in the number of public and private smolt releases (Oregon Department of Fish and Wildlife 1982; Nickelson 1986). Reduced upwelling and ocean productivity, perhaps coupled with density-dependent mortality, is one of the hypothesized causes for this decrease in survival (Scarnecchia 1981; Peterman and Routledge 1981; McCarl and Rettig 1983; McGie 1984; Nickelson 1986). To understand the mechanisms affecting survival of juvenile salmonids at sea, we must first know where salmon reside at the time of their high and variable mortality. Are the smolts highly migratory, immediately leaving local coastal waters and migrating into waters of the Gulf of Alaska (Hartt and Dell 1986), or are they nonmigratory, spending their early ocean life in local coastal waters?

This paper summarizes research on the movements and migrations of coho salmon during their first summer in the ocean in the northeastern Pacific Ocean based on purse seine catches made mainly in coastal waters off Oregon and Washington. A few records of migrations of tagged juvenile (age .0)[2] coho salmon were given by God-

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[2]The numeral preceding and following the decimal indicate the number of winters spent in fresh water and in the ocean, respectively.

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frey (1965) and French et al. (1975), but by far the most comprehensive data were provided by Hartt (1980) and Hartt and Dell (1986). All of these studies, however, were based on recovery of mature or maturing coho in the year following tagging and on tagging in northern waters from the Strait of Juan de Fuca to the Alaska Peninsula. The only other studies of juvenile salmon in the ocean off Washington and Oregon have been restricted to within 24 km of the Columbia River (Dawley et al. 1981) or to coastal waters during 1980 (Miller et al. 1983). Our 1979–85 research, covering large areas along the coast, provides extensive and unique data on the movements of juvenile coho salmon during their first summer in the ocean.

METHODS

Purse seines, our primary sampling method, were used to sample juvenile salmonids during 1979–85 (Table 1). Cruises were in coastal waters off Oregon in 1979–80, off Oregon and southern Washington in 1981, and off Oregon and the entire Washington coast during the summers of 1982–85 (Fig. 1). During July 1984, sets were also made from northern California (lat. 40°32′N) to northern Vancouver Island (50°26′N). Except for the exploratory cruises off Oregon in 1979 and 1980, purse seine sets were usually made along east-west transect lines (Fig. 1). Sets started at the 37 m (20-fathom) contour, and continued at 9.3 km (5-mi) intervals farther offshore, usually until no salmonids were captured. Repeat sets were sometimes made when fish with missing adipose fins were common, indicating the presence of coded wire tagged (CWT) fish. In 1985, special sets were made in the vicinity of the Columbia River plume. Detailed sampling data are provided in Pearcy (1984) and our cruise reports (Wakefield et al. 1981; Fisher et al. 1982, 1983; Fisher and Pearcy 1984, 1985).

The mesh size of the seines were the same during all years, 32 mm (stretch), with 32 mm or smaller mesh in the bunts of the seines. The seine was 495 m long except in 1981 (457 m). Depths that seines fished, sometimes measured with a depth gauge on the lead line, varied among years from about 20 m to 65 m (Table 1).

Generally, purse seine sets were "round hauls", where the seiner and the skiff made a circle with the net. The seine was fully pursed after about one-half its length was aboard (half-purse sets). All sets were "blind". We attempted to use sonar on some cruises to locate concentrations of salmonids but were unsuccessful. Radar was sometimes used to determine the distance between the seiner and the skiff when a semicircle was made with the net. Each round haul encompassed about 17,000 m^2 (1981) or 19,000 m^2 (1979–85). To determine the direction of movement of fish, eight "half-round" hauls, or "semicircular" sets, were made in 1979, where the entire net formed an open semicircle. Paired sets were made in close succession, with sets open in a northern and a southern direction, at four locations. The seine was open for the same duration (15–45 minutes, depending on location) in each paired set while

TABLE 1.—Summary of number of purse seine sets and latitudinal range of sampling, 1979–85.

Year	Dates of cruises	No. of sets[1]	Latitudinal range of sampling		Purse seine Length (m)	Purse seine Depth (m)
1979	18–29 June	56	Cape Disappointment to Cape Arago	46°20′–43°18′	495	20
1980	20–28 June	36	Cape Disappointment to Alsea River	46°20′–44°30′	495	20
1981	16–25 May	63	Willapa Bay to Alsea River	46°35′–44°25′	495	20
	9–18 June	67	Willapa Bay to Cut Creek	46°35′–43°11′	495	20
	9–19 July	67	Willapa Bay to Alsea River	46°35′–44°25′	457	49
	8–19 Aug.	66	Willapa Bay to Cut Creek	46°36′–44°11′	457	49
1982	19 May–2 June	62	Waatch Point to Siuslaw River	48°21′–44°00′	495	[2]65
	7–22 June	57	Quinault River to Yachats	47°21′–44°20′	495	[2]65
	4–14 Sept.	42	Quinault River to Yachats	47°20′–44°19′	495	[2]65
1983	16–27 May	56	Waatch Point to Yachats	48°21′–44°20′	495	[2]49
	9–27 June	58	Waatch Point to Four Mile Creek	48°20′–43°00′	495	[2]49
	15–24 Sept.	53	Waatch Point to Coos Bay	48°20′–43°28′	495	[2]49
1984	4–20 June	69	Waatch Point to Coos Bay	48°20′–43°27′	495	[2]49
	9 July–3 Aug.	65	Winter Harbor, B.C. to False Cape, CA	50°26′–40°32′	495	[2]49
	1–15 Sept.	63	Waatch Point to Siuslaw River	48°20′–44°00′	495	[2]49
1985	29 May–25 June	112	Sea Lion Rock to Coos Bay	48°00′–43°27′	495	[2]25

[1]Quantitative sets.
[2]Measured with depth guage.

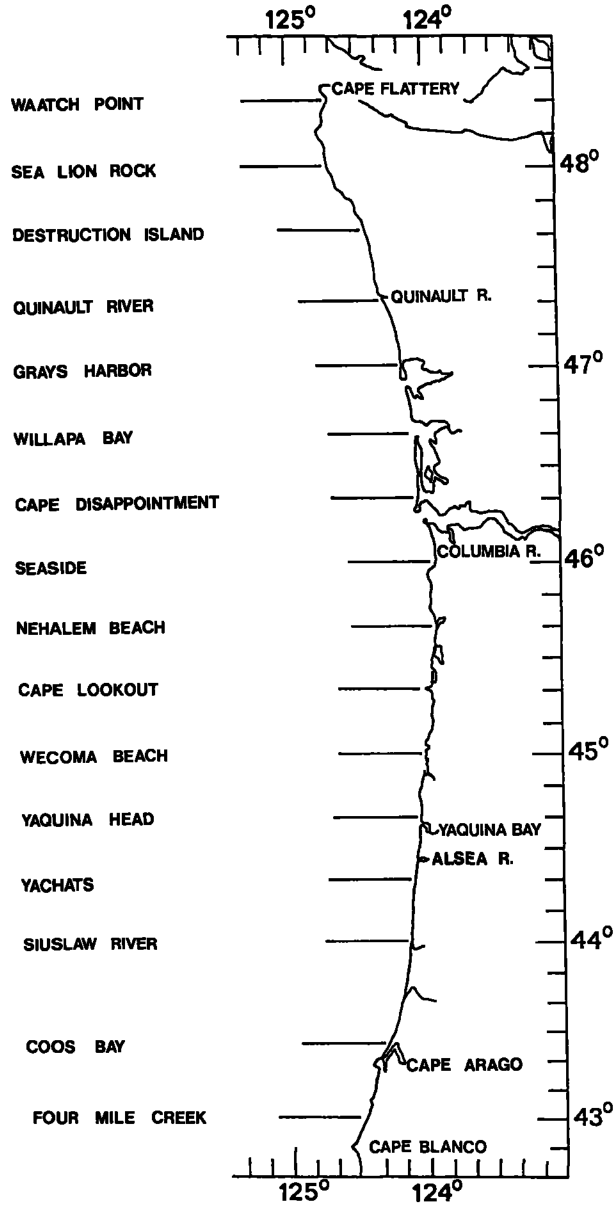

FIGURE 1.—Locations of purse seine transects off the Oregon and Washington coasts.

the vessel and skiff towed the seine only fast enough to maintain a constant net opening.

The purse seine catches were either dip-netted from the bunt of the seine while it was alongside the vessel, brailed aboard, or hauled aboard in the bunt, depending on the composition and size of the catch.

In 1979 and 1980, juvenile salmon preserved in formalin were identified ashore. In 1981–85, juvenile salmon were identified to species at sea, fork length (FL) was measured to the nearest millimeter and then they were individually wrapped in labelled plastic bags and frozen. All salmonids with marks or missing adipose fins were frozen. When large numbers of juvenile salmonids were caught in a set, most unmarked fish were released after they were measured.

In order to increase the numbers of marked fish released into our study area we marked about 1.5 million coho smolts in 1981 and 835,000 in 1982 using fluorescent pigment propelled by compressed air (see Phinney et al. 1967) prior to their transport from Oregon Aqua-Foods, Inc. (OAF) hatchery to their ocean release facilities at Yaquina Bay or Coos Bay, OR.

In the laboratory ashore, species identifications were confirmed and individuals remeasured and reexamined for both fluorescent marks (under ultraviolet light 1981–82) and missing adipose fins or other marks (1979–85). Coded-wire tags from the heads of salmonids with missing adipose fins were decoded by personnel from the Oregon Department of Fish and Wildlife, Clackamas Laboratory.

Juvenile or age .0 (first year in the ocean) coho salmon were distinguished from adult or age .1 (second year in the ocean) coho salmon by examination of size-frequency histograms and scales. The division between age .0 and .1 coho progressed from approximately 300 to 420 mm FL from May to September, in most years. Most coho salmon migrated to the ocean a little over one year after hatching (age 1.0), but OAF released large numbers of subyearling (age 0.0) smolts into Yaquina Bay and Coos Bay. These two age groups of smolts were distinguished by the radial distance to the 21st circulus on scales removed from the preferred area (Clutter and Whitesel 1956) of the fish. The accuracy of this method for distinguishing known age 0.0 and 1.0 fish was approximately 85–90%. In the years 1981–85, scales from 52% of the 4,222 juvenile coho sampled were analyzed. The estimated numbers of age 0.0 and 1.0 fish represented in different geographic areas and cruises were then extrapolated from their proportions in each 10 mm length interval.

Distances traveled and movement rates were estimated from actual distances between sites of release and entry into the ocean, and from straight-line distances between ocean entry and recapture locations for CWT or fluorescent marked juvenile coho salmon that were recovered in the ocean within 10 days of release. These distances and swimming speeds are minimal estimates.

In addition to purse seining, fine-meshed monofilament gill nets were used off the Oregon coast (ca. lat. 45°00′N, long. 124°21′W) during 24 and 25 July 1985, from the training vessel *Oshoro Maru*, to determine depth and direction of swimming of juvenile salmonids. Surface and subsurface nets were used. The surface gill nets were 2,050 m long, and fished from depths of 0–6 m with 11 mesh sizes ranging from 29 to 121 mm (stretch). The subsurface nets were 500 m long and consisted of four mesh sizes ranging from 29 to 42 mm; they were suspended below large (300–400 mm) mesh to fish at depths of 5–12 m. Four sets were made in an east-west direction with soak-times of about 4–9 hours. As the gill nets were hauled, the direction that each juvenile salmonid was heading when caught, and its depth in the net (upper, middle, or lower section) were noted. Each juvenile salmonid was given a consecutive number and frozen for later identification. Comparisons of catch rates in the surface and subsurface nets were based on equal lengths of the four mesh sizes of the subsurface net, standardized to 10 hours of fishing time.

Information on the location of landings of marked juvenile coho by commercial and sports fishermen was provided by the Pacific Marine Fisheries Commission (PMFC), (PMFC 1980, 1981, 1984a, b, c, 1985a, b), from lists of nonstandard recoveries (Johnson PMFC unpubl. data), and from state agencies. The actual numbers of tagged fish, and the total numbers of tagged fish estimated from the proportions of the catch sampled are reported.

To determine if juvenile coho salmon were sexually precocious "jacks", we examined testes from 542 juvenile males caught in July 1981 and 1984, in August 1981, and in September 1982, 1983, and 1984. All developed and some undeveloped testes (ribbonlike, with no thickening), as determined by visual inspection, were weighed (123) and gonadal-somatic indices (GSI = testes wt./body wt. × 100) were determined.

RESULTS AND DISCUSSION

Swimming Direction

Of the 106 juvenile coho salmon captured during June in paired, half-round purse seine sets, all but two were in the sets open to the south (Table 2). This suggests that juvenile coho salmon

TABLE 2.—Catches of coho salmon in semicircular purse seine sets open to the south (S) and north (N) off Oregon, June 1979.

Location	Km offshore	Age .0 S	Age .0 N	Age .1 S	Age .1 N
Clatsop Spit	12.6	57	0	2	6
Clatsop Spit	18.5	37	0	15	37
Clatsop Spit	18.5	7	0	6	8
Newport	9.4	3	2	0	9
		98%	2%	28%	72%

were swimming to the north during this sampling period. Maturing fish over 300 mm FL (age .1 coho) showed the opposite trend.

Miller et al. (1983) made several hundred paired purse seine sets open to the south and north during three cruises off the northern Oregon-southern Washington coasts in 1980. During their May-June cruise, they caught 76% of the juvenile coho salmon, 80% of the chinook salmon, and almost all the steelhead trout in sets open to the south, indicating northward movement. We note a positive relation between the proportion of juvenile salmon caught in south-facing sets in their three cruises and strength of upwelling during these cruises (mean daily Bakun indices of 52, 39, and 19 $m^3\ s^{-1}\ 100\ m^{-1}$ coastline at 45°N, 125°W in May, July, and August, respectively (Mason and Bakun 1986)), suggesting that surface currents to the south resulting from Ekman transport may be cues for orientation of salmon smolts.

Hartt (1980) and Hartt and Dell (1986) found that 83% of the combined species of juvenile salmonids caught in 19 paired purse sets along the coast from Cape Flattery, WA to Yakutat, AK were caught in sets held open to the southeast and only 17% in sets open to the northwest and north. They concluded that juvenile salmonids tended to migrate in a northwest direction along the coast during July–September.

Of the 100 juvenile coho salmon (135–315 mm FL) caught in the gill nets set in an east-west direction off the Oregon coast in July 1985, 90 coho were caught as they approached the southern face of the gill net (heading north) and 10 in the northern face (heading south). Jaenicke et al. (1984) reported that 63% of the juvenile coho caught in a surface gill net fished off southeastern Alaska in July moved north at night, but only 6% moved to the north during the day.

Available data indicate that most juvenile coho salmon caught off Oregon and southern Washington, as well as juveniles farther to the north, are predominantely swimming in a northerly direction during summer months.

Depth Distribution

One-half of the juvenile coho salmon caught in gill nets set off the Oregon Coast in 1985 were in the upper 2 m of the surface gill net (Table 3). Catches in the surface net exceeded those in the subsurface net, except for the last set that fished during daylight hours, indicating that juvenile coho salmon were most common in the upper 4 m of the water column.

Other information on the vertical distribution of maturing coho and other species of salmon caught in gill nets or with longlines in oceanic waters also indicates that they usually swim near the surface, between 0 and 20 m (Manzer 1964; Godfrey 1965; Godfrey et al. 1975). Machidori (1966), for example, fished gill nets from the surface to 50 m and caught 79% of the coho salmon in the upper 10 m of the gill net. Although catches in gill nets at different depths may be biased by vertical differences in avoidance reactions to the net or swimming speeds (Hartt 1975), acoustical methods have also shown that salmon are usually distributed near the surface (Susuki and Sonoda 1972; Lord et al. 1976). We conclude that most juvenile coho salmon in coastal waters and maturing coho in oceanic waters reside at depths above 20 m, the minimum depth that our purse seine fished. We recognize, however, that maturing coho and other species of salmon may feed in deeper water. Some salmon (including coho salmon) caught in surface gill nets in the oceanic waters of the Gulf of Alaska contained prey in their stomachs characteristic of mesopelagic depths (200–1,000 m), suggesting that some individuals may feed well below the thermocline (Pearcy et al. in press).

TABLE 3.—Catches of juvenile coho salmon in four gill net sets in 50 m lengths of 29, 33, 37, and 42 mm mesh at different depths and times 24–25 July 1985, each set adjusted to 10-h fishing duration.

	Depth in meters					
	Surface net			Subsurface net		
Times of set	0–2	2–4	4–6	5–7	7–9	9–12
0913–1702	2.5	3.8	0	1.3	1.3	0
2001–0104	25.0	11.5	0	0	0	1.9
0248–0701	42.8	2.4	2.4	9.5	16.6	0
0830–1737	1.1	0	0	6.6	7.7	5.5
Total catch	51	16	1	11	15	6
Percent of total catch	50.3	12.5	1.7	12.3	18.0	5.2

North-South Trends in Catch per Set and Sizes of Juvenile Coho

Variations in the average catches and sizes of juvenile coho salmon in purse seine sets in different regions of the Oregon-Washington coast during the summer provide indirect evidence for north-south coastal movements. Histograms showing average catches per set for 10 mm size groups of juvenile coho, classified as age 0.0 or 1.0 from scale analysis, are shown in Figure 2, for 1981–84 in three regions: (A) Cape Flattery, WA to Grays Harbor, WA (called Washington), (B) Willapa Bay, WA to Nehalem Bay, OR (Columbia River region), and (C) Cape Lookout, OR to Coos Bay, OR (Oregon) (Fig. 1). In May of 1981, 1982, and 1983, average catch per set of yearling (age 1.0) coho generally decreased from the southern to the northern regions. Catches were highest off Oregon (Area C) or the Columbia River (Area B) and lowest off Washington (Area A) in May of 1982 and 1983. This trend was reversed later in the summer. In June of 1981, 1983, and 1984, lowest catches were found in the Oregon region. By August or September 1981–84, highest catches consistently occurred off the Columbia River or Washington and few yearling fish were caught off Oregon. These shifts in abundance suggest a northerly movement of age 1.0 smolts during the summer. Highest catch rates occurred in May and June of 1981 and 1982 when an average of over 10 juvenile coho salmon were caught in most sets.

Subyearling or age 0.0 coho salmon released from private facilities at Yaquina and Coos Bays provide more direct evidence on movements. Subyearling coho salmon clearly demonstrated northward dispersal. They were most common in our catches of July 1981 and September 1982, 1983, and 1984 (Fig. 2). They were apparently more numerous than age 1.0 coho salmon in the Oregon region during June–August 1981 and September 1982, and in the Oregon and Columbia River regions in September 1983. The catches and proportions of age 0.0 coho salmon increased off Oregon during the summer because they were released from hatcheries later in the summer than yearling coho salmon. They were found in the most northern region sampled late in the

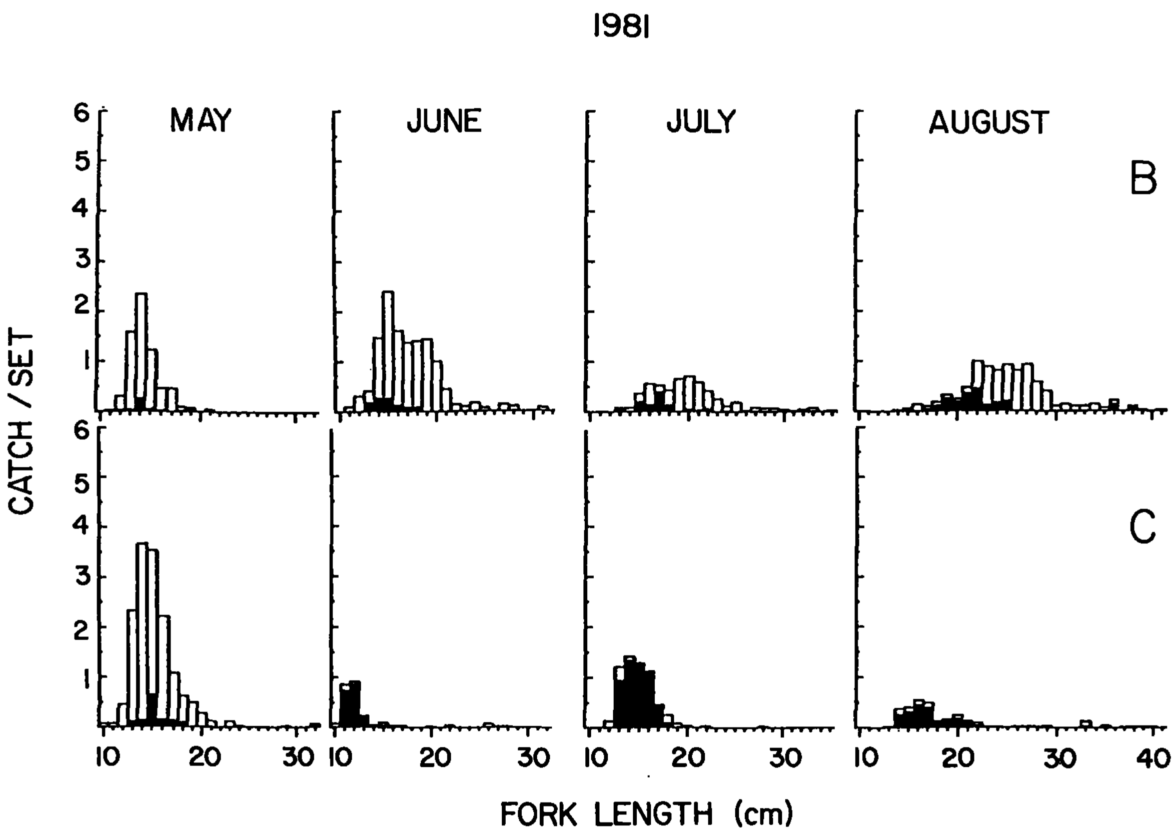

FIGURE 2.—Catch per purse seine set of age 1.0 (open) and age 0.0 (shaded) juvenile coho by 10 mm length groups during different months, 1981–84, for three regions of the Oregon-Washington coast: (A) Cape Flattery to Grays Harbor, WA, (B) Willapa Bay, WA to Nehalem Beach, OR, (C) Cape Lookout to California.

summer of all years. Their abundance, as that of age 1.0 coho salmon, also increased during the summer off Washington where they intermingled with age 1.0 coho salmon. Because the Oregon region included the release locations of all age 0.0 coho salmon, our figures provide no information on southward movements of these fish.

The mean lengths of both age 0.0 and 1.0 coho salmon increased from the southern to the northern areas during most months. Larger age 0.0 and 1.0 coho salmon were caught off Washington than Oregon during the late summer, 1981–84 (Fig. 2), providing corroborative evidence for northward migration of coho salmon. Larger, and presumably older, fish were found farther to the north than smaller fish.

Despite northward movements, many yearling coho salmon did not migrate out of the sampling area, but remained in coastal waters off Oregon and Washington during the entire summer. Mean coastwide catch per set of yearling coho salmon in August 1981 and September 1982, 1983, and 1984

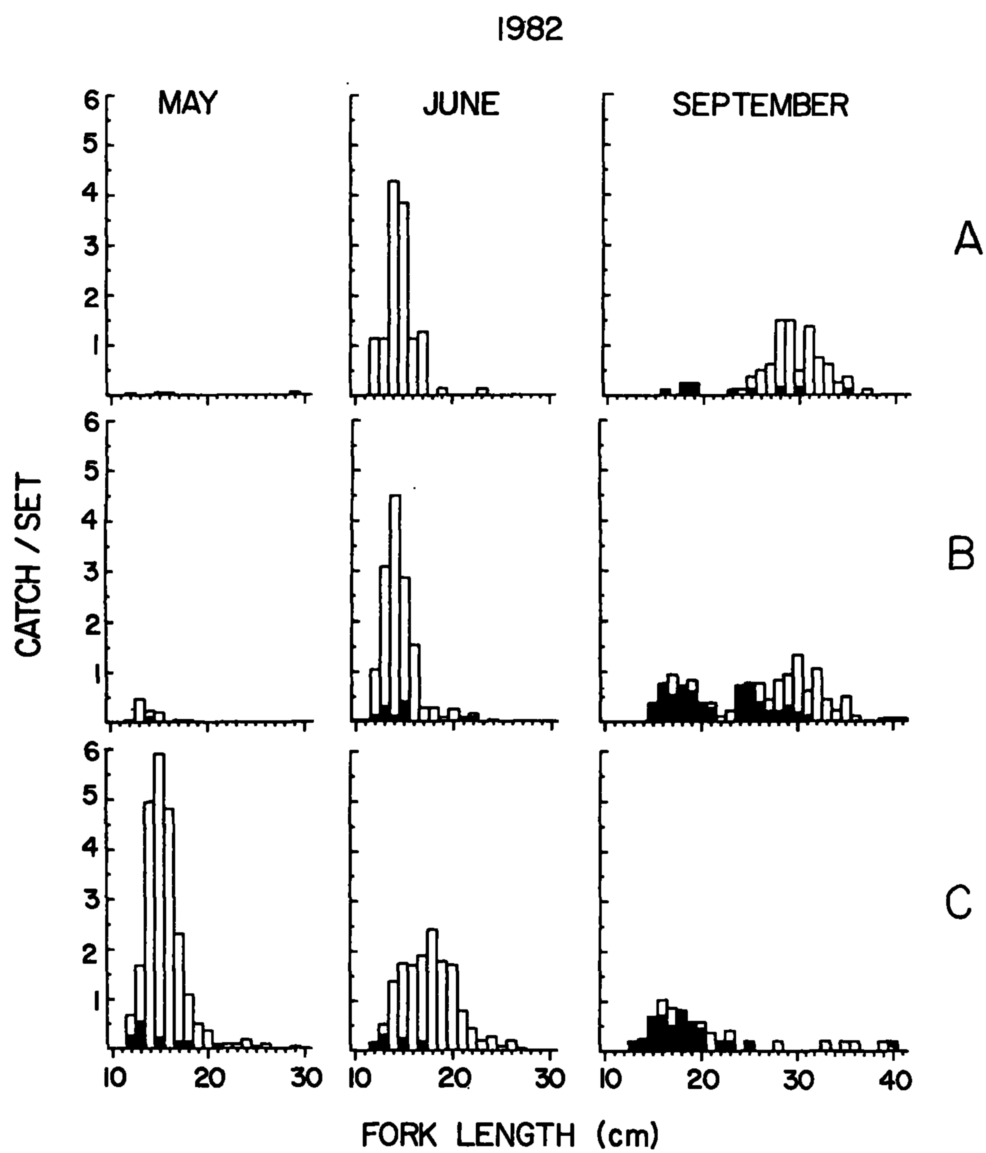

FIGURE 2.—*Continued*.

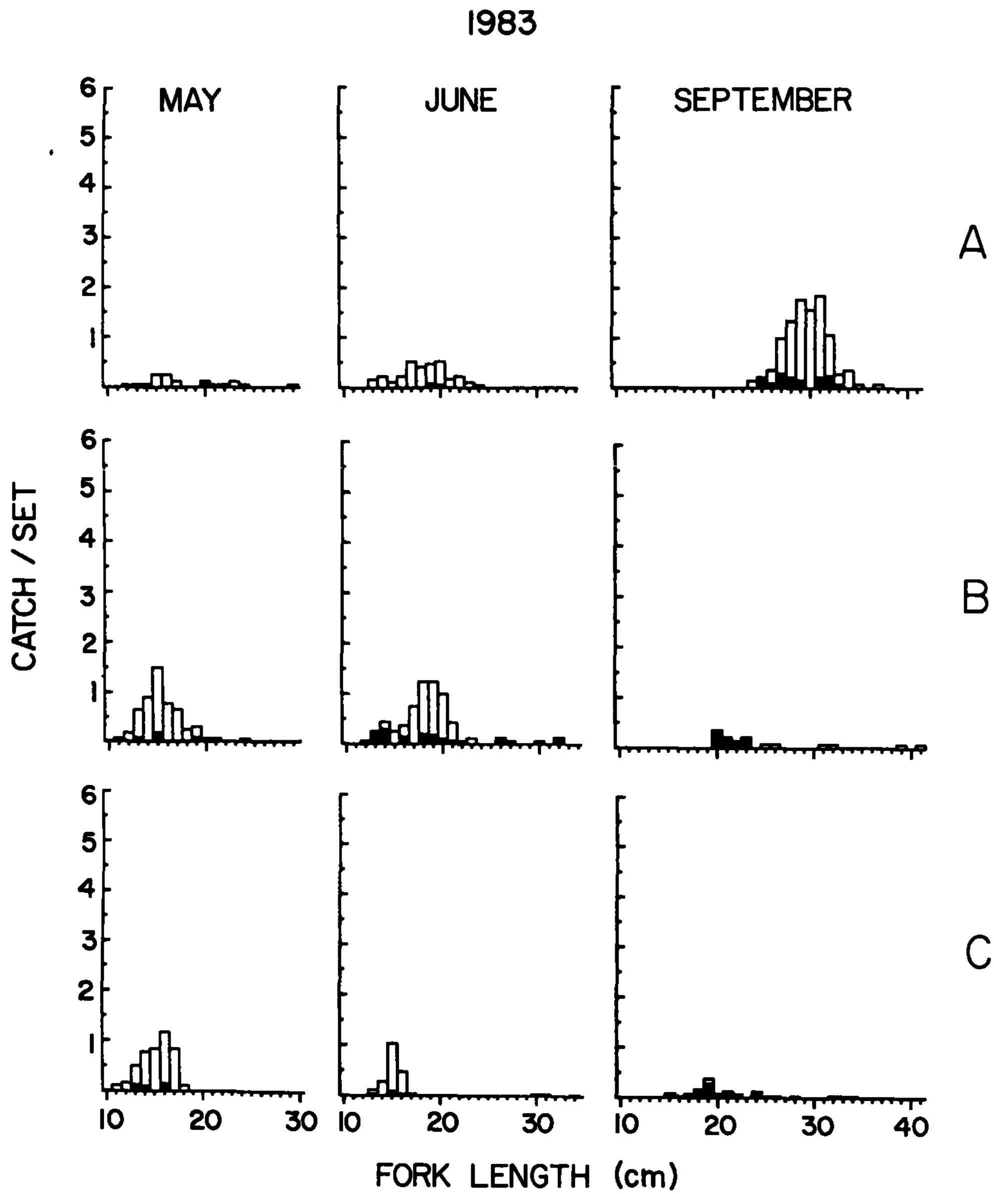

FIGURE 2.—*Continued*.

was 61%, 42%, 81%, and 77% respectively, of that in June of the same years. In September 1983, a strong El Niño year (Pearcy and Schoener 1987), almost all yearling juvenile coho salmon were caught at the extreme northern transect off Cape Flattery, but in August or September of other years they were more evenly distributed off the Columbia River and the Washington coast.

In July 1984, we sampled both north (15 sets off the west coast of Vancouver Island) and south (5 sets off northern California) of Washington and Oregon. Catches per set of yearling and subyearling juvenile coho salmon were higher off the Columbia River (5.1), the area of greatest smolt production, and off Washington (3.5) than off Vancouver Island (1.8), Oregon (1.7), and California (1.2). This shows that as late as July juvenile coho salmon occurred in coastal waters of all regions and were not concentrated off Vancouver Island or California.

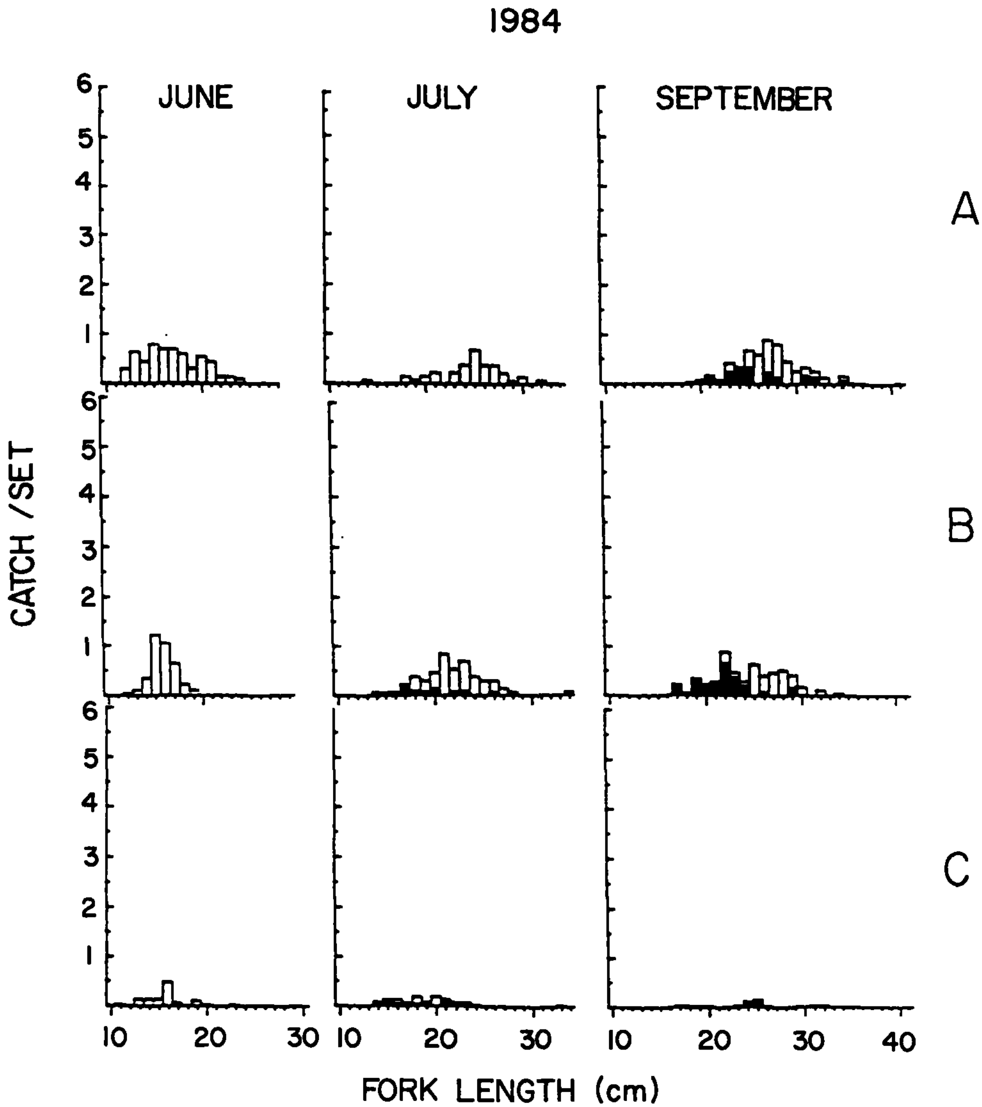

FIGURE 2.—*Continued.*

The Question of "Jacks"

Are the juvenile coho salmon off Oregon and Washington in late summer relatively nonmigratory because they are sexually precocious? GSI were almost always <0.1% for those fish visually classified as "undeveloped". GSI's from fish with "developed" testes ranged from 0.2% to 1.0% in July 1981 and 1984 in fish >250 mm FL; from 0.3% to 5.6% in August 1981, mostly in fish >280 mm FL; and from 2.4% to 6.6% (except for one value at 0.6) in September 1982, 1983, and 1984 in fish >300 mm FL (Fig. 3). In August 1981, and clearly in September 1982, 1983, and 1984, two distinct groups of fish were evident: "jacks", with developing testes (GSI >0.3% August or GSI >2.0% September), and "nonjacks", which showed no development (GSI <0.1%).

The total numbers of jacks and nonjacks in each 50 mm length group were estimated for the catch during August 1981 and September 1982, 1983, and 1984 from the ratio of jacks and nonjacks in the sample (Table 4). Only 8.4%, 4.8%, 5.2%, and 2.8% of all juvenile fish (male and female) were "jacks" in August 1981 and September 1982, 1983, and 1984, respectively. However jacks com-

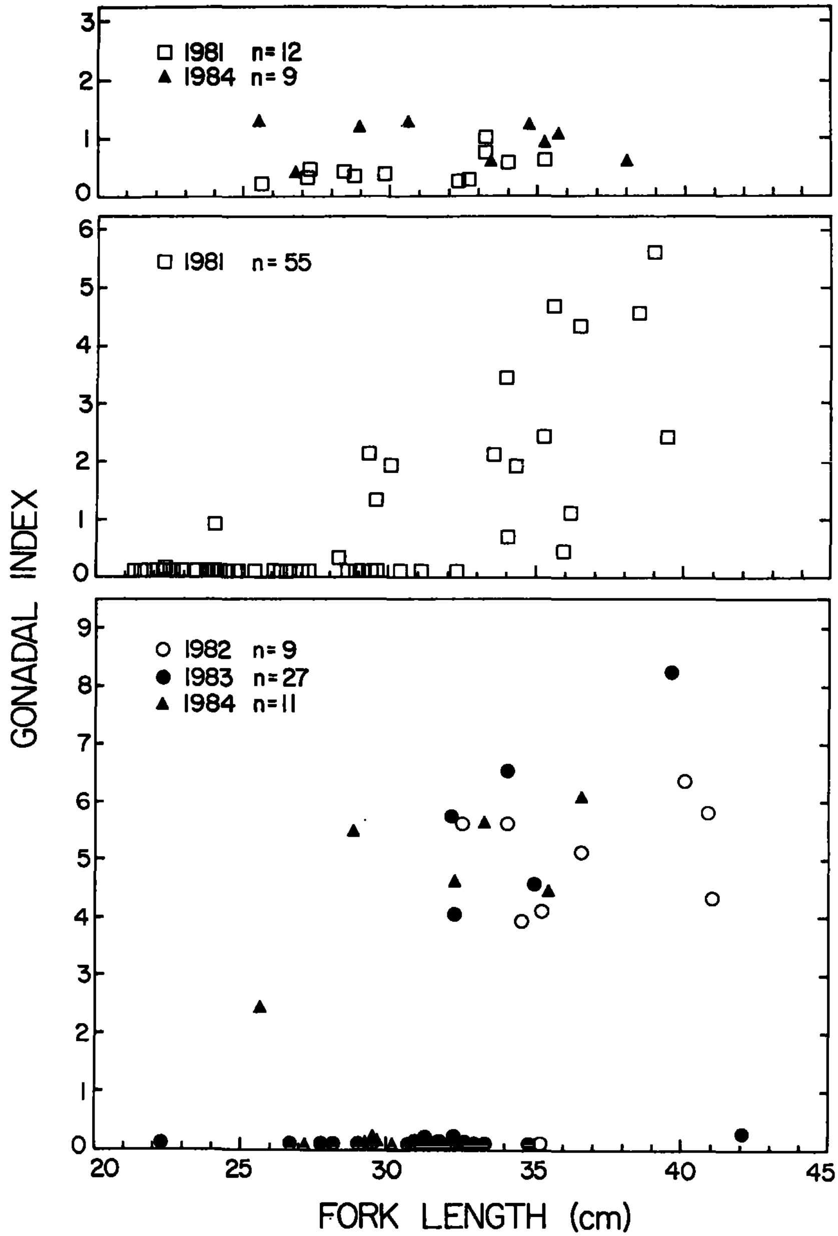

FIGURE 3.—Gonadal-somatic index (testis wt/total body wt) × 100 of juvenile coho salmon vs. length of fish for July, August, and September 1981–84. Only data for those testes actually weighed are shown.

prised a higher percentage of fish larger than 300 mm FL in August 1981 and larger than 350 mm FL in September 1982, 1983, and 1984. These results indicate that most juvenile coho salmon caught off Oregon and Washington were not sexually precocious. Thus, the relatively large catches of juvenile coho salmon in late summer are explained by lack of strong migrational tendencies of juvenile coho salmon in this region and not by a high proportion of precocious "jacks" that resided in this region as a prelude to re-entry of streams for spawning.

TABLE 4.—The percent of coho salmon jacks and males, by length groups, in the total catch, August 1981 and September 1982–84.

Date	Fork length (mm)	Number of fish examined	% males	Number of jacks[1]	Total catch	Est. total jacks	Est. % jacks of total
Aug. 1981	<200	71	60.6	0	111	0	0
	201–250	63	60.0	1	115	2	1.7
	251–300	55	47.3	4	104	8	7.7
	301–350	16	81.3	4	22	6	27.3
	351–420	10	80.0	8	19	15	78.9
	Total	215	59.5	17	371	31	8.4
Sept. 1982	<200	56	55.4	0	125	0	0
	201–250	21	76.2	0	54	0	0
	251–300	22	63.6	0	109	0	0
	301–350	33	69.7	3	97	9	9.3
	351–420	13	53.8	5	28	11	39.3
	Total	145	62.8	8	413	20	4.8
Sept. 1983	<200	16	62.5	0	18	0	0
	201–250	23	47.8	0	25	0	0
	251–300	23	56.5	0	71	0	0
	301–350	39	61.5	4	77	8	10.4
	351–420	2	0	1	3	2	66.7
	Total	103	58.3	5	194	10	5.2
Sept. 1984	<200	6	33.3	0	15	0	0
	201–250	38	47.4	0	69	0	0
	251–300	90	50.0	2	128	3	2.3
	301–350	27	55.6	12	31	2	6.5
	351–420	6	33.3	2	7	2	28.6
	Total	167	49.1	16	250	7	2.8

[1]Jack is defined as a male whose testes wt./total body wt. × 100 > 0.3% in August and >2.0% in September.

Movements of Marked Fish

Direct evidence of movements of juvenile coho salmon was obtained from capture of marked fish containing coded wire tags or marked with fluorescent pigment. The generalized pattern of movements that emerges for 1981–85 is an initial movement of most juvenile coho salmon to the south soon after ocean entry in May and June and then a reversal of movement with most fish migrating to the north by August and September (Figs. 4–8). These trends are discussed for fish originating from the Columbia River, Oregon coastal, Washington coastal, and private hatcheries.

Columbia River

Juvenile coho salmon originating from hatcheries on the Columbia River were usually recovered south of the Columbia River in May. This trend was especially obvious in May 1982 when all 22 marked fish which were recovered moved south, some as far as 175 km (Fig. 5). In May 1981, all but one of 14 marked Columbia River fish were caught to the south, three as far as 180 and 204 km (Fig. 4). In May 1983, all four fish were taken south of the mouth of the Columbia River (Fig. 6).

During June and July of all years, marked Columbia River coho salmon were recovered in nearly equal proportions both north and south of the river mouth, except in June 1982 when 15 of 17 fish were found to the south (Figs. 4–8). By September, all marked Columbia River coho salmon were captured north of the river, including fish captured off the Quinault River in September 1982 and off Cape Flattery in September 1984. Fish were also caught close to the mouth of the Columbia River in July, August, and September, indicating that some marked juvenile coho salmon did not undertake extensive migrations at sea.

In two sets on the Wecoma Beach Transect on 1 June 1982 we caught 17 marked juvenile coho salmon released between 30 April and 6 May from six hatcheries on the Columbia River. Based on downstream migration rates for these groups to Jones Beach (Dawley et al. 1985) and assuming similar rates from Jones Beach to the ocean, these fish had probably been in the ocean for <10 days before recapture. This indicates that some juve-

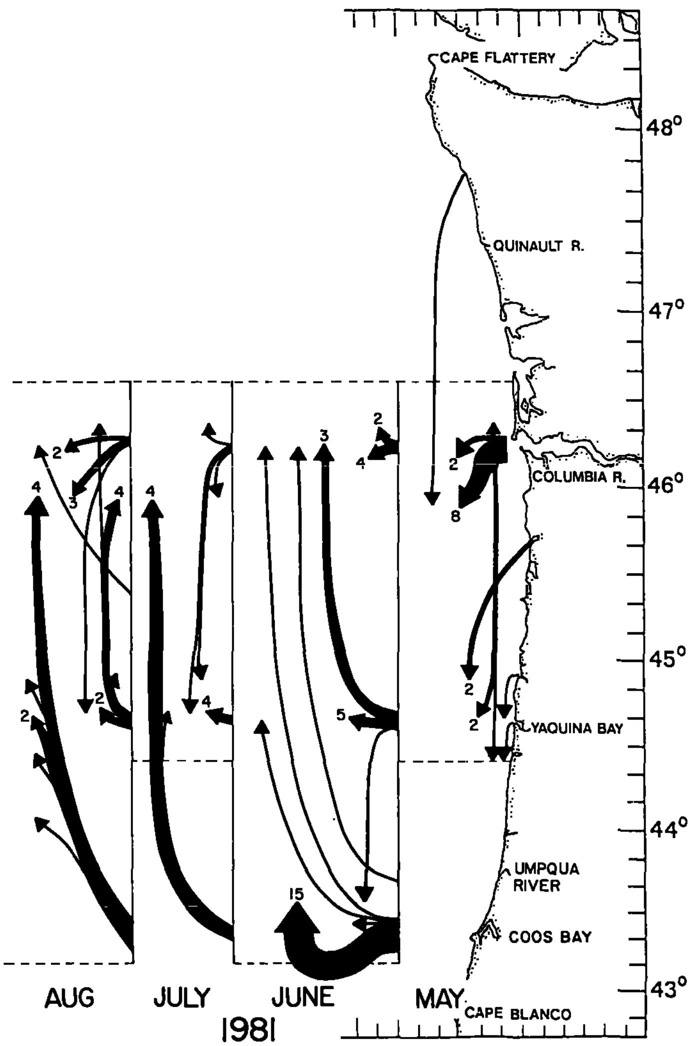

FIGURE 4.—North-south movements of marked juvenile coho salmon captured in purse seines, May–August 1981. The width of the lines are approximately proportional to the number of fish. Numbers at end of arrows indicate number of fish captured. Arrows without numbers and thin lines represent single fish. Inshore-offshore movements are not shown. Dashed lines indicate latitudinal extent of sampling.

nile coho salmon released from hatcheries at about the same time tended to stay together during their downstream migration in the Columbia River and during early residency in the ocean.

Oregon Public Coastal Hatcheries

We captured marked fish originating from public Oregon coastal hatcheries both north and south of the latitude of ocean entrance in May. A total of five fish were found to the south, while 11 fish were found to the north in May (Figs. 4–8). With the exception of one coho salmon from the Umpqua River in June 1983 and two from the Rogue River in July 1984 (Figs. 6, 7), the other 25 fish taken after May were captured north of where they entered the ocean. Northerly movements into Washington waters occurred by June 1983 and 1985 (Figs. 6, 8).

The southward movements of two juvenile coho salmon released from the Rogue River (south of Cape Blanco) and captured off northern Califor-

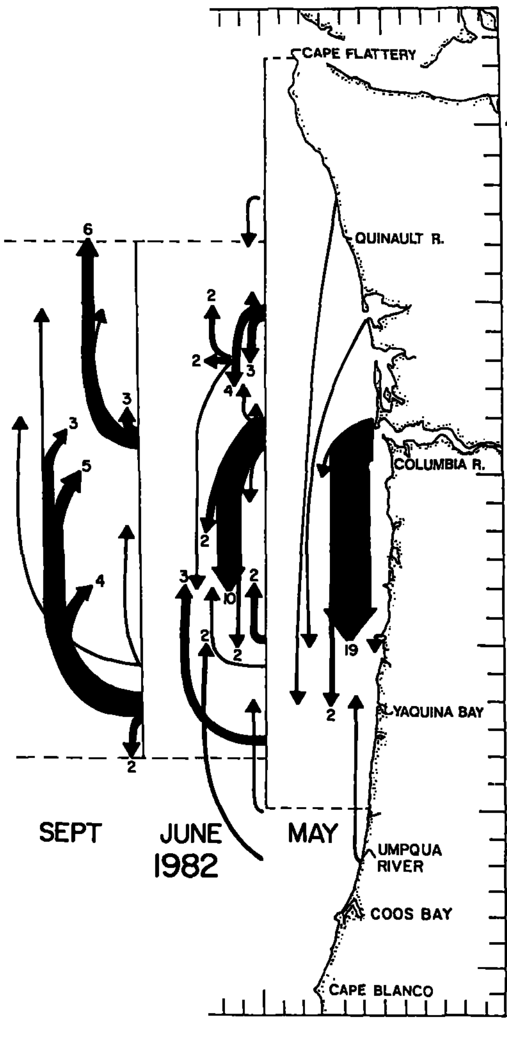

FIGURE 5.—North-south movements of marked juvenile coho salmon captured in purse seines, May, June, and September 1982. The width of the lines are approximately proportional to the number of fish. Numbers at end of arrows indicate number of fish captured. Arrows without numbers and thin lines represent single fish. Inshore-offshore movements are not shown. Dashed lines indicate latitudinal extent of sampling.

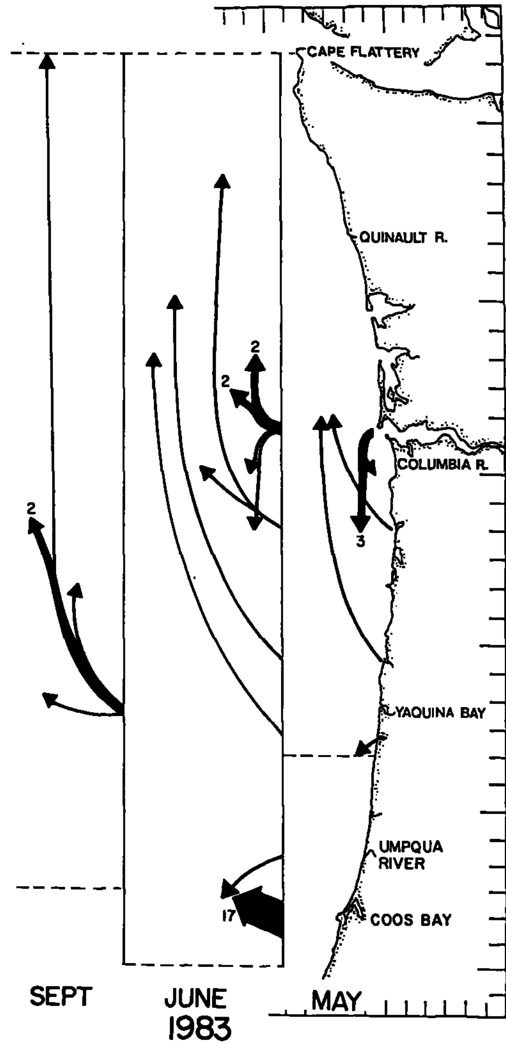

FIGURE 6.—North-south movements of marked juvenile coho salmon captured in purse seines, May, June, and September 1983. The width of the lines are approximately proportional to the number of fish. Numbers at end of arrows indicate number of fish captured. Arrows without numbers and thin lines represent single fish. Inshore-offshore movements are not shown. Dashed lines indicate latitudinal extent of sampling.

nia during July 1984 are notable (Fig. 7). They were captured in our only cruise into California waters and represent the only recoveries of marked juvenile coho salmon originating from hatcheries south of Cape Blanco in all six years of sampling. Although ocean sampling was limited south of Coos Bay, if juvenile coho salmon from southern Oregon and northern California hatcheries had migrated north of Coos Bay, we would expect them to be represented in our catches. The fact that they were not caught in this northern region, but two were caught after swimming to the south, suggests that juvenile coho salmon originating in streams south of Cape Blanco may migrate south, possibly occupying the region of intense coastal upwelling off northern California during their first summer in the ocean. The catch of over 70% of the adult coho

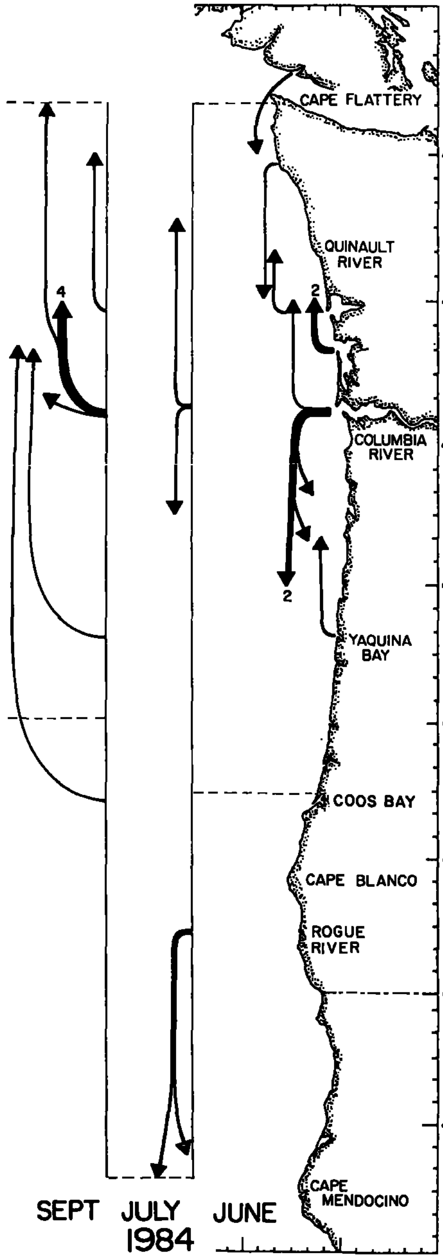

FIGURE 7.—North-south movements of marked juvenile coho salmon captured in purse seines, June–September 1984. The width of the lines are approximately proportional to the number of fish. Numbers at end of arrows indicate number of fish captured. Arrows without numbers and thin lines represent single fish. Inshore-offshore movements are not shown. Dashed lines indicate latitudinal extent of sampling.

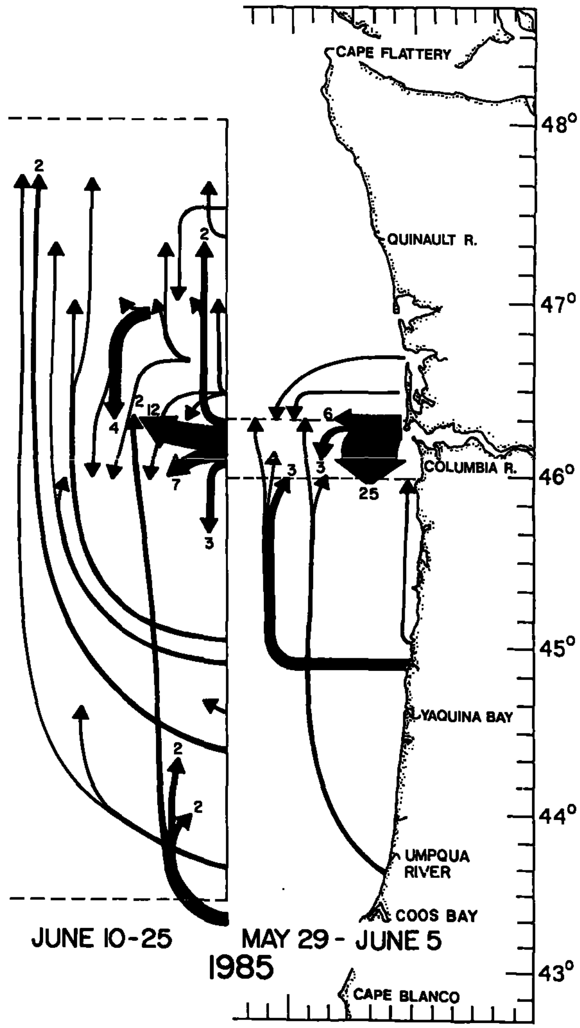

FIGURE 8.—North-south movements of marked juvenile coho salmon captured in purse seines, 29 May–5 June and 10–25 June. The width of the lines are approximately proportional to the number of fish. Numbers at end of arrows indicate number of fish captured. Arrows without numbers and thin lines represent single fish. Inshore-offshore movements are not shown. Dashed lines indicate latitudinal extent of sampling.

salmon from the Rogue River in the troll fishery off California (R. Garrison[3]) is further evidence for a southern distribution of this stock. Marked juvenile coho salmon from California hatcheries were reported from the sports fishery off southern Oregon, however, as will be shown later.

Washington Coastal Hatcheries

Juvenile coho salmon from Washington public hatcheries demonstrated southerly movements, sometimes into Oregon waters, during May 1981 and 1982 (Figs. 4, 5). During June 1982, 1984, and 1985, Washington coastal fish were found both north and south of ocean entry. Except for one fish that moved north in September 1984, no Washington coastal fish were taken in August or September of other years, suggesting that most Washington fish may have migrated out of our sampling area by late summer.

Oregon Private Hatcheries

All marked juvenile coho salmon originating from Yaquina and Coos Bays that we captured at sea were from private hatcheries. Those from Yaquina Bay were mainly age 0.0 smolts from OAF, those from Coos Bay were either age 1.0 smolts from Anadromous, Inc. or age 0.0 smolts from OAF. Forty-one recoveries of marked OAF fish released from Yaquina Bay were caught to the north while only 4 were to the south of Yaquina Bay. In general, more juvenile coho salmon from Yaquina Bay were captured in late than early summer, and distances traveled to the north were largest (up to 413 km) for fish caught in later summer (Figs. 4–8). All recoveries of marked Anadromous, Inc. and OAF fish released into Coos Bay were to the north in all years. Large northerly movements were demonstrated by some of these fish (Figs. 4, 6, 8). Since our sampling in the ocean usually did not extend south of Coos Bay, recoveries of these fish are biased to the north; however, strong northward movements of these stocks were indicated.

Rates of Movement

Recoveries of marked juvenile coho salmon in the ocean provided information on the minimum rates of movement from hatchery release to capture in the ocean. Some fish moved rapidly through estuaries into the ocean. We captured some tag-groups in the ocean only a few days after the median date of capture at Jones Beach (75 km from the ocean) as reported by Dawley et al. (1985): 5 fish after 2 days in 1981, 6 fish after 3–11 days in 1981, 8 fish after 1–14 days in 1982, and 5 fish after 3–8 days in 1983. Dawley et al. (1986) found average rates of movement of 14–23 km d^{-1} for marked groups of coho smolts from areas of release on the Columbia River to river km 75, and rates of movement that were 40% faster from river km 75 to the lower Columbia River estuary and to the ocean plume. These recoveries and those reported by Miller et al. (1983) for yearling chinook salmon and steelhead trout indicate rapid movements of juvenile salmonids of over 20 km d^{-1} through the Columbia River estuary.

Some juvenile coho salmon released from Yaquina Bay and Coos Bay also demonstrated rapid movements into and in the ocean, e.g., 17 Anadromous, Inc. fish were captured 11 km north of Coos Bay only two days after release in June 1983 (Table 5). Myers (1980) described an exponential decrease in the catches of juvenile coho salmon released from the OAF facility into Yaquina Bay; about one-half the fish from marked groups remaining in the bay after 1.7–9.0 days. Juvenile coho salmon apparently emigrate rapidly from estuaries into the ocean.

Some of the marked fish recovered within 10 days of release demonstrated rapid movements down-rivers or in the ocean. Twenty-four fish traversed 10 km d^{-1} or more largely in the ocean, in both north and south directions (Table 5). Four fish released in bays or in the ocean moved over 18.8 km d^{-1}. Two of these swam to the north, presumably against coastal currents. These speeds are equivalent to 1.7 body lengths (BL) per second or more and suggest that some fish must be traveling nearly straight courses during 24-h days, since 1–3 BL s^{-1} are thought to be optimal cruising speeds for small (<20 cm) pelagic fishes (Weihs 1973; Ware 1978). These maximum rates of movement for purse seine caught juvenile coho salmon are similar to those estimated by Hartt (1980) and Hartt and Dell (1986) for tagged sockeye salmon during their first summer in the ocean: 14–27 km d^{-1} for 11 Fraser River fish and 6–14 km d^{-1} for 10 Skeena River fish that were between about 8 and 23 cm in length during the migration period.

[3]R. Garrison, Oregon Department of Fish and Wildlife, Corvallis, OR 97330, pers. commun. December 1983.

TABLE 5.—Release information and mean travel speeds in kilometers per day and body length (BL) per second for CWT and fluorescent-pigment marked age .0 coho salmon recovered in the ocean within 10 days of release. CR = Columbia River; OAF = Oregon Aqua Foods, Inc., (OAF Yaquina is 3.7 km from ocean; OAF Coos is 14 km from the ocean), Anad. = Anadromous Inc. (7.4 km from the ocean).

Year	No.	Release location	Date released	Median days to recovery	Mean FL	Mean km/d	Mean BL/s	Direction of movement
1981	1	Big Cr. (CR)	8 June	3	153	22.2	1.7	S
	1	Tanner Cr. (CR)	6 July	6	138	41.0	3.4	N
	1	OAF Yaquina	11 May	7	140	4.0	0.3	S
	1	OAF Yaquina	12 June	2	124	14.5	1.4	N
	2	Anad. Coos	8 June	9	179	2.3	0.2	N
	2	OAF Yaquina	10–15 June	2	124	3.7	0.3	N
	1	OAF Yaquina	10–15 June	2	123	10.2	1.0	N
	1	OAF Yaquina	10–15 June	2	126	18.8	1.7	N
	11	OAF Coos	5–9 June	10	122	1.9	0.2	N
	1	OAF Yaquina	10–15 June	5	124	24.0	2.2	S
	1	OAF Coos	5–9 June	7	136	20.1	1.7	N
1983	17	Anad. Coos	26 June	2	156	11.2	0.8	N
1984	1	OAF-Offshore	7 June	7	143	11.3	0.9	N
1985	6	Tongue Pt. (CR)	24 May	6	151	9.5	0.7	S
	1	Offshore-22 km	30 May	0.9	134	22.0	1.9	S
	1	Naselle River	20 May	9	143	7.8	0.6	S
	1	Cowlitz River	31 May–6 June	2.5	144	88.0	7.1	N

Effects of Ocean Currents

The tendency for juvenile coho salmon to move to the south early in the summer and to the north later in the summer (Figs. 4–8) may be related to advection of water and the size, orientation, and swimming speeds of fish. Generally, surface currents are to the south off Oregon and Washington in the early summer owing to prevailing northwesterly winds (Hickey 1979; Huyer 1983). Southward flow averaging 17–34 km d^{-1} (Huyer et al. 1975, 1979) has been measured near the surface. May and June are periods of peak outflow of the Columbia River, so fish entering the ocean at this time, especially in the Columbia River plume, may be displaced to the south by advection of surface waters. Southward flow is at a maximum in the coastal jet which is strongest (~22 km d^{-1}) during the spring about 15–20 km from shore (Kundu and Allen 1976; Huyer et al. 1979). Since currents can be equivalent to 1.7 BL s^{-1} for a 15 cm smolt, advection alone could explain the southward movement of most marked Columbia River fish during May and June but not the rapid northward movement of fish during this period (see Figures 4–7).

Coastal Oregon fish were often found to the north in May and June, but these fish were usually substantially larger and generally released much earlier in the spring than Columbia River fish, and were presumably better able to swim against the current. Later in the summer when Columbia River hatchery fish had grown larger, movement was also predominately northward. In August and September southward velocities of surface coastal currents are diminished and the mean may be near zero (Huyer et al. 1975). Northward movements during the summer off Oregon and Washington generally cannot be explained by passive drift and in most years must entail active, oriented swimming.

The northern El Niño of 1982–83, which had severe effects on the growth and survival of adult and jack coho salmon (Pearcy et al. 1985; Johnson 1984; Pearcy and Schoener 1987; Fisher and Pearcy in press), also appeared to affect the distribution of juvenile coho salmon. During September of 1983 nearly all the seine-captured juvenile coho were taken along our northernmost transect, off Cape Flattery, WA (Fig. 2). In other years juvenile coho salmon during late summer were common and more equally distributed from the Columbia River northward. In the summer of 1983 juvenile coho salmon may have moved farther north, or more likely those to the south may have experienced higher mortality, as a result of northerly currents (Huyer and Smith 1985), warm temperatures and low productivity (Pearcy et al. 1985; Chung 1985) that prevailed off Oregon.

Recoveries of CWT Juvenile Fish in Ocean Fisheries

Data on ocean location of landings of juvenile CWT coho salmon reported in sports and commercial fisheries in the ocean along the west coast of North America, 1977–83, provide valuable information on ocean migrations of marked fish, although these data are biased by differences in legal minimum sizes, time and duration of open season, and effort in the different regions. The summary of all years shows that, except for California, most of the recoveries of juvenile coho salmon during their first summer in the ocean were in the general region of their ocean entry location (Table 6). Both the actual number of fish reported and the estimated total numbers (in parentheses) support our earlier conclusion that many juvenile coho salmon off Oregon and Washington are not highly migratory. All (20) of the actual recoveries of marked juvenile coho salmon that were released in southeastern Alaskan waters were from southeastern Alaska. Ninety-seven percent of the recoveries of marked fish released in British Columbia waters were landed in British Columbia; only two were landed in Alaska. Most (86%) marked juvenile fish from Puget Sound hatcheries were caught in the Sound, and more were recovered in British Columbia fisheries (13%) than in coastal Washington fisheries (<1%), probably due to the smaller size limits for coho in British Columbia as well as migratory patterns. Half of the actual numbers of recoveries of juvenile coho salmon liberated into Washington coastal waters were landed in Washington coastal ports, followed by British Columbia (29%) and the Columbia River region (17%). Only one was landed in Alaska and two in Oregon ports (Garibaldi and south). Juvenile coho salmon originating from Columbia River hatcheries had a broader distribution of recoveries in other regions. Only 40% of Columbia River fish were caught in this region, 41% were taken in northern regions, including two (1%) in Alaska. The remaining 19% were captured off Oregon. The majority (73%) of Oregon coastal fish were recovered off Oregon, followed by the Columbia River region, Washington coast, and British Columbia. None was reported from Alaska, but 10 (2%) were from California ports. All marked California fish were recovered from the Columbia River region and farther south. Most (87%) were landed in Oregon. The few recoveries of California fish off California is undoubtedly influenced by the larger size limits in this than other fisheries.

TABLE 6.—Recoveries of coded wire tagged juvenile coho in the ocean fisheries 1977–83. Estimated total numbers are in parentheses.

	Landing area						
Release area	S.E. Alaska	British Columbia[1]	Puget Sound	Washington Coast (Areas 2–4)	Columbia River (Area 1 + Astoria)	Oregon Coast (Garibaldi and south)	California
S.E. Alaska	20 (39)	0	0	0	0	0	0
British Columbia	2 (2)	1,086 (1,735)	24 (90)	2 (8)	0	0	0
Puget Sound	0	201 (729)	1,352 (5,262)	9 (40)	1 (2)	2 (9)	0
Washington Coast	1 (5)	71 (316)	7 (42)	125 (451)	42 (151)	2 (77)	0
Columbia River	2	24 (133)	4 (14)	39 (162)	67 (310)	31 (164)	0
Oregon Coast	0	18 (107)	3 (13)	21 (83)	62 (213)	308 (1,137)	10 (45)
California	0	0	0	0	1 (4)	138 (552)	19 (200)

[1]Sports catches are not expanded. The estimated total number = expanded commercial catch + actual number CWT's recovered in the sports fisheries. Preliminary data.

In general, the legal size limits increased from north to south, which could result in more recoveries of juvenile coho salmon in northern than southern regions. Thus, these data do not provide evidence that a large proportion of juvenile coho salmon from British Columbia and waters to the south made northward migrations into Alaskan waters before or during the commercial and sports salmon seasons. Movements of Washington, Columbia River, and Oregon fish into British Columbian waters were common however.

Hunter (1985) expanded the catches of CWT juvenile coho salmon caught along the west coast of North America during 1978–80 to the total landed plus estimated "drop-off" mortality (fish that were hooked and died without being landed) of both tagged and untagged hatchery groups. Calculations of the percentage returns from different release and recapture areas are similar to ours (Table 6). The highest percentage of returns were from the areas of release for all areas except for California, and a higher proportion of the catches of Washington coastal, Puget Sound, Columbia River, and Oregon coastal stocks were reported north than south of the area of release.

Are Juvenile Coho Highly Migratory?

Based on our observations on movements of marked fish, north-south and seasonal trends in abundance and size, and directional purse seine sets during the summer, we conclude that many juvenile coho salmon from Oregon and Washington coastal streams and the Columbia River are transported by currents to the south in May and June but then migrate north later in the summer. The mean catches per set of yearling coho salmon in August and September are a large fraction of those in June, indicating that in the years studied many juvenile coho salmon in coastal waters of Oregon and Washington were not highly migratory. Moreover, more marked juvenile hatchery coho salmon were caught in ocean fisheries in the region of release than in distant waters. Recoveries of juvenile coho salmon released from hatcheries south of Cape Flattery were rare in northern waters off Alaska and relatively few were recovered in British Columbia (Table 6). In addition, the positive correlation between upwelling off Oregon and survival of hatchery coho salmon from the Columbia River, Oregon, and California (Nickelson 1986) also argues for a close coupling of OPI coho salmon with a local, not a distant, environmental event during the time that year-class survival is determined. All of these trends suggest that most juvenile coho salmon from this area are not highly migratory and that many usually remain in coastal waters near their sites of ocean entry during their first summer in the ocean, and perhaps during their entire ocean life. In years of unfavorable ocean conditions, however, movements may be more extensive or mortality may be higher, as suggested by the very low catches of juvenile coho salmon in purse seine sets south of Cape Flattery during September 1983, the year of the recent strong El Niño.

Although Pacific salmon are renown for their long foraging migrations in the subarctic Pacific, coho salmon demonstrate both nonmigratory and highly migratory behavior. Milne (1950) found immature coho salmon almost year-round in Georgia Strait and concluded that two types of coho salmon exist in British Columbia waters: "ocean" and "inshore" types, the "ocean" type spending most of its ocean life in coastal and offshore waters and the "inshore" type in inside waters such as Georgia Strait. Healey (1978) caught "inshore" juvenile coho salmon in purse seines in Georgia Strait during summer, fall, and winter months. Similarily, large numbers of coho salmon originating from streams of Puget Sound remain in the Sound throughout their marine life (Haw et al. 1967). Young coho salmon have also been found in the winter and spring, many months after seawater entry in Yaquina Bay (Myers 1980) and other Oregon estuaries (J. Nicholas[4]). Hartt and Dell (1986), in their impressive study of juvenile salmonids of the northeastern Pacific during 1956–70, recognized these two migratory patterns of coho salmon. They found juvenile coho salmon in waters off Vancouver Island and in the Strait of Juan de Fuca throughout the summer and fall, and concluded that some coho salmon spend their entire marine life in "inside" waters and make only limited ocean migrations.

What Proportion of Juvenile Coho from Oregon and Washington Migrate North?

The tagging experiments reported by Hartt and Dell (1986) and Godfrey (1965) provide convincing evidence for long-distance migrations of coho

[4]J. Nicholas, Oregon Department of Fish and Wildlife, Corvallis, OR, 97331, pers. commun. May 1986.

salmon during their first summer in the ocean. Based on recoveries of maturing coho salmon that were tagged a year earlier at sea during April–October 1956–70, Hartt and Dell (1986) concluded that juvenile coho salmon from the Columbia River, Oregon, and California may form a large proportion of the coho stocks that migrate north along the coast each summer. Of the 70 recoveries of tagged fish that were released between Kodiak Island and 56°N, 37% were recovered the following year in the area of the Columbia River and Oregon-California; of the 59 recoveries of fish released between 56°N and Cape Flattery, 47% were recovered in these southern regions. In all, 25% of the recoveries were from Oregon-California, 16% from the Columbia River, 14% from Washington, 33% from British Columbia, and 12% from Alaska.

Loeffel and Forster (1970) concluded that patterns of radioactive ^{65}Zn in juvenile coho salmon collected in the northeastern Pacific supported the concept of a northerly migration from Oregon and Washington into the Gulf of Alaska during the summer. They found that juvenile coho salmon captured off the west coast of Vancouver Island in June and July 1967 contained ^{65}Zn, presumably originating from neutron activation of Columbia River water used to cool the nuclear reactors at Hanford, WA. ^{65}Zn levels decreased in fish caught farther to the north (54°42′N–58°24′N) in July–September of 1967. The authors thought the low concentrations in northern samples represented background levels and that fish with relatively high levels of ^{65}Zn had associated with the Columbia River plume and subsequently migrated north from the Oregon-Washington region. They found low ^{65}Zn levels in 1968, however, and no pronounced latitudinal gradients. Furthermore, they reported none of the many finmarked juvenile coho salmon released from Oregon and Washington hatcheries in 1967 and 1968 north of Juan de Fuca Strait. Hence their evidence for northward movements of Columbia River or Oregon-Washington coho salmon was equivocal.

During June and July 1984, research was conducted with the NMFS Auke Bay Laboratory in waters from northern California to southwest Alaska from the FV *Pacific Warwind* and *Bering Sea*, both making round hauls with the same size of purse seine, to sample juvenile coho in waters north of Oregon and Washington: 37 sets were made in coastal waters of British Columbia, and 39 were made in coastal waters and 29 in inland waters (bays, inlets, and fjords) of southeastern Alaska. Of the 371 juvenile coho salmon captured in these regions, 77% were caught in inland waters of southeastern Alaska. The seven CWT juvenile coho salmon captured were all from Alaska inland waters and all originated from Alaska hatcheries (Auke Bay Laboratory 1984a). A later cruise in southeast Alaska by the Auke Bay Laboratory in August 1984 caught eight CWT coho salmon, also all from inland waters and from Alaskan hatcheries (Auke Bay Laboratory 1984b).

Of the 14 CWT juvenile coho salmon collected in other purse seines, gill nets, and special troll gear in waters of southeastern Alaska during 1982, 1983, and 1985, 12 originated from Alaska hatcheries and 2 originated from Washington hatcheries (Auke Bay Laboratory 1983; Jaenicke et al. 1984; Orsi et al. 1987). Table 6 shows that only 5 of 25 CWT juvenile coho salmon caught in Alaskan waters during 1977–83 were from hatcheries south of Alaska, indicating that most juvenile coho salmon caught in southeastern Alaska during the summer originated from Alaska and not from southern regions.

Hartt (1980) and Hartt and Dell (1986) recognized that their data did not indicate the proportion of southern stocks that made northerly migrations, but they concluded that a large proportion is probable, since juvenile coho salmon were consistently caught in most seine sets throughout the area sampled. They estimated that the average density of juvenile salmonids in coastal waters between 56°N and 60°N off southeastern Alaska during August and September 1964–68 was 1,500 km^{-2}. The average density of juvenile coho salmon in this area during these two months was only 82 km^{-2} (Hartt and Dell 1986, app. A). During August and September 1981–84, the average density of juvenile coho salmon in our round hauls between Cape Flattery, WA and Cape Arago, OR to 37 km offshore was 350 km^{-2}, several times the estimates of Hartt and Dell for the same months of the year. This suggests that juvenile coho salmon may be found in higher densities off Oregon and Washington than southeastern Alaska during late summer, assuming that distributions and abundances in the late 1960s and early 1980s were similar. This trend for higher abundances of juvenile coho salmon off Oregon and Washington than in coastal waters farther north was also found during July 1984 (Table 7), although average catches off Washington and Oregon were not as

TABLE 7.—Average catches of juvenile coho salmon in purse seines sets in coastal waters along the west coast of North America during July 1984[1,2]

Area	No. per set	No. per km²
Sitka-Juneau	1.29	68
Ketchikan-Sitka	0.58	3
Cape Scott-Dixon Entrance	1.90	100
Vancouver Is.	1.80	95
Washington	3.76	198
Oregon/No. California	2.59	136

[1]Cruise Report, Drum Seiner FV *Bering Sea*, Coastwide NWAFC/OSU Cooperative Study, Ecology of Juvenile Salmon in Coastal and Inside Waters of Southeast Alaska, 28 June–26 July 1984. NWAFC Auke Bay Laboratory, National Marine Fisheries Service, NOAA, P.O. Box 115, Auke Bay, AK 99821.
[2]Fisher and Pearcy (1984).

large as in some earlier years owing to low survival (Fig. 2; Pearcy 1984; Fisher and Pearcy in press).

Comparisons of the estimates of total juvenile yearling coho salmon abundances off Oregon and Washington with the production of coho smolts in the Oregon Production Area (Columbia River to California) also suggests that many juvenile coho resided off Oregon and Washington during the summer. By expanding our catches per m^2 to the region sampled, we estimated that the numbers of juvenile yearling coho salmon in areas surveyed by our purse seine sampling during August or September 1981–84 were 6.3%, 6.5% 5.1%, and 5.2%, respectively, of the numbers of hatchery and wild smolts released in the Columbia River and in Oregon (T. Lichatowich[5]). The areas included in these estimates were roughly 83%, 62%, 51%, and 68% of the total area from Cape Flattery to Cape Arago out to 37 km offshore. Recognizing that the entire area was not sampled, that year-class strength of coho salmon in this region is probably established soon after ocean entrance (Fisher and Pearcy in press), and that early marine mortality may be inversely related to size (Parker 1968; Ricker 1976) so that much of the ocean mortality has occurred by late summer, these percentages probably represent a substantial portion of the surviving OPI coho smolts. In fact, they are several times higher than the smolt-to-adult survival of 1.3–2.8% for OPI public hatchery coho salmon (excluding Rogue River and California hatcheries) during 1981–84 (R. Kaiser[6]).

We conclude, therefore, that a major fraction of the juvenile coho salmon from Oregon and Washington hatcheries did not undertake distant migrations into the Gulf of Alaska in recent years. This is not necessarily in conflict with Hartt and Dell's (1986) data, since they established the presence of Oregon and Washington coho salmon in northern waters but not the proportion of total production that undertakes this migration. On the other hand, neither the stocks of coho nor oceanographic conditions have remained constant over the period from 1956 to 1985 when these two studies were conducted. Wild coho smolts exceeded hatchery smolts in the Oregon Production Area before 1961 (Nickelson 1986) but comprised <12% of the smolts in 1980–85 (R. Kaiser fn. 6). Perhaps wild smolts from the OPI area had different migratory patterns than hatchery smolts do today and migrated rapidly into northern waters soon after ocean entrance. This may explain Nickelson's (1986) finding that survival of hatchery, but not wild coho smolts, was significantly correlated with coastal upwelling off Oregon.

Ocean conditions have also changed over this period. The late 1960's were accompanied by strong upwelling along the coast compared to weak upwelling in the early 1980's (Nickelson 1986; Mason and Bakun 1986). McLain (1984), Norton et al. (1985), and Royer (1985) illustrated that sea surface temperatures and sea levels increased in the northeastern Pacific between 1976 and 1984. These factors and associated changes in ocean circulation could explain differences in migratory behavior of coho salmon between 1960's and 1980's. If currents provide orientational cues to migration, cues facilitating northerly movements may be reduced during years of weak upwelling and weak Ekman transport from the north. Ocean conditions may have modified migratory patterns, as they possibly have for the migration of Fraser River sockeye salmon around Vancouver Island (Groot et al. 1984; Hamilton 1985).

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[5]T. Lichatowich, Oregon Department of Fish and Wildlife, P.O. Box 59, Portland, OR 97207, pers. commun. September 1987.
[6]R. Kaiser, Oregon Department of Fish and Wildlife, Hatfield Marine Science Center, Newport, OR 97265, pers. commun. September 1987.

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