Distribution, migration, and growth of juvenile chinook salmon, *Oncorhynchus tshawytscha*, off Oregon and Washington

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Abstract.—Little is known of the early ocean life of juvenile chinook salmon, *Oncorynchus tshawytscha*. During the summers of 1981 through 1985 we collected juvenile chinook salmon with fine-mesh purse seines in shelf waters off the Oregon and Washington coasts. Most coded-wire tagged (CWT) fish caught in the ocean were yearlings from Columbia River basin hatcheries. Catch per unit of effort of CWT yearling fish was much higher in the May–June period than in the August–September period, probably, for the most part, because of the migration of these fish out of the sampling area by late summer. CWT subyearling fish were more abundant in late summer than in spring and early summer. A few fish from the Columbia River Upriver Bright stock of fall chinook salmon were recovered many months after release near where they entered the ocean, indicating that northward migration of some smolts from this highly migratory stock may be delayed for several months following release, or that some individuals of the stock undertake less extensive migrations than others. Subyearling smolts were rare in our catches, despite the larger spawning populations producing these smolts than those producing the yearling smolts in this area. Subyearling fish may have been mainly distributed in shallow water inshore of our sampling. Our largest catches of small chinook salmon (≤130 mm FL) were taken in the low salinity, high-temperature waters of the Columbia River plume. CWT fished were usually recovered north of where they entered the ocean, except in May 1982 when southward currents were strong. Average net rate of migration of yearling smolts between the head of the Columbia River estuary and ocean capture was 4.1 km·d^{-1}. Average growth rate of CWT yearling fish downstream of river km 75 in the Columbia River was 1.05 mm·d^{-1}. Average instantaneous rate of growth in weight of yearling CWT Columbia River fish between hatchery release and capture in the ocean was 0.92% body wt·d^{-1}.

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The Columbia River once produced the largest runs of chinook salmon (*Oncorhynchus tshawytscha*) in the world (Van Hyning, 1973). Today, runs are only a fraction of the size they were in the late 19th and early 20th century (Chapman, 1986), and a large fraction of the present population is produced in hatcheries. Although the runs of Columbia River chinook salmon are affected by many factors (e.g. dams, freshwater habitat depredation, ocean fisheries, etc.), environmental conditions during early ocean life also may be important determinants of year-class success for these fish.

Little is known of the early ocean distribution, migration, and growth of chinook salmon during their first year in the ocean prior to becoming vulnerable to ocean fisheries. Hartt and Dell (1986) collected juvenile salmon with purse seines over a wide area of the Gulf of Alaska and the Bering Sea in the late 1950's through the early 1970's. Although relatively few juvenile chinook salmon were caught during their sampling (358 fish in 505 sets between 1964 and 1968; their Appendix Table A1), subsequent recoveries of juvenile fish tagged at sea provided information on early ocean migrations of these fish. Four juvenile fish tagged in the northern Gulf of Alaska in July and August of the fish's first summer in the ocean were recovered in later years in the spring in the Columbia River, indicating that some Columbia River spring chinook salmon migrate rapidly to the north into the Gulf of Alaska during the first three or four months of ocean life (Hartt and Dell, 1986).

Miller et al. (1983) caught juvenile chinook salmon with purse seines in the ocean off southern Washington and northern Oregon during three periods in 1980: late May through early June; July; and late August through early September. They sampled in water where the bottom depth was ≥30 m near the mouth of the Columbia River, a major source of chinook salmon smolts. Marked Columbia River spring chinook salmon (yearling smolts) were caught only during their spring cruise, and only in gillnet sets that opened to the south, suggesting that this stock group migrates rapidly to the north soon after entering the ocean (Miller et al., 1983). Very few fish <130 mm FL were found over water greater than 30 m bottom depth, in contrast to the great numbers of small fish caught in shallow marine waters near the surf zone by Dawley et al.[1]

[1] Dawley, E. M., C. W. Sims, R. D. Ledgerwood, D. R. Miller, and J. G. Williams. 1981. A study to define the migrational characteristics of chinook and coho salmon in the Columbia River estuary and associated marine waters. Coast. Zone and Estuarine Studies Div., Northwest Fish. Sci. Cent., NMFS, Seattle WA 98112.

Hence, they concluded that offshore movement of chinook salmon is size dependent, beginning when the fish are about 130 mm FL (Miller et al., 1983).

Healey (1980, 1991) studied juvenile chinook salmon in Georgia Strait, British Columbia. He found that "stream-type" chinook salmon (those spending a year in streams before entering the ocean) were only abundant in marine sampling from about late April to late May, suggesting that these fish migrated out of the protected waters of Georgia Strait soon after leaving fresh water. Conversely, "ocean-type" fish (those entering salt water as small subyearling fish) were abundant in the protected marine waters of Georgia Strait throughout the summer and early fall.

In this study we describe the abundance, distribution, migration, and growth of juvenile chinook salmon collected by purse seine during the spring and summer of 1981–85 in coastal marine waters from northern Washington to southern Oregon. This study extends the temporal and spatial scope of available information on the early ocean life of juvenile chinook salmon off Oregon and Washington. The following paragraphs include a short review of life histories, spatial and temporal patterns of hatchery releases, and seaward migrations of different stocks of chinook salmon smolts in the area from northern Washington to northern California to aid the reader in the interpretation of the distribution and movement of juvenile chinook salmon in the ocean as presented in this paper.

The majority of stocks of chinook salmon found along the coast of North America from northern Washington to northern California return to rivers to spawn in the fall (i.e. are fall-run fish), and their offspring migrate to the ocean as subyearling smolts (ocean-type) in the summer or fall of the same year during which they emerge from the gravel (Nicholas and Hankin, 1988; Healey, 1991). Although stocks that enter the ocean as yearling smolts (stream-type) are also found in this region, mainly in large river systems (e.g. the Columbia River), they are not as abundant as the ocean-type stocks (Healey, 1983, 1991; Nicholas and Hankin, 1988; Table 1, this paper). Most stream-type fish begin their upstream spawning migration in the spring (i.e. are spring-run fish), and the downstream migration of their offspring to the ocean as smolts begins earlier than that of the ocean-type fish (Healey, 1982; Dawley et al., 1985, a and b).

Total releases of yearling and subyearling fall and spring chinook salmon from coastal Washington, Columbia River, and coastal Oregon hatcheries averaged 138 million fish per year in the two-year period 1982–83 (Table 1[2]). Of these releases, about 75% were subyearling fall chinook salmon, 14% were subyearling spring chinook salmon, and 11% were yearling spring chinook salmon (Table 1). (A much smaller number of summer, winter, and late fall chinook salmon, not included in Table 1, were also released in these two years).

Fish from the Columbia River accounted for over 89% of all hatchery releases of chinook salmon in this area; Columbia River subyearling fall, subyearling spring, and yearling spring chinook salmon represented 66%, 12%, and 11% of the total, respectively. Subyearling fall chinook salmon from coastal Washington and coastal Oregon hatcheries represented 6% and 2% of the total release, respectively. Subyearling spring chinook salmon from coastal Oregon hatcheries represented 2% of the total release.

Most subyearling fall chinook salmon from the Columbia River and coastal Washington hatcheries were released from April through June at a small size (about 4 or 5 g body wt; Table 1). A smaller proportion of subyearling fall chinook salmon from these two areas was also released later in the year at a much larger size (Table 1). In contrast, most subyearling fall and subyearling spring chinook salmon from coastal Oregon hatcheries were released in late summer or fall at a large size (averaging roughly 30–60 g; Table 1). Releases of yearling Columbia River spring chinook salmon were concentrated in the April–June period, whereas releases of subyearling Columbia River spring chinook salmon were spread throughout the year.

Some of the fish released from hatcheries were marked with coded-wire tags (CWT) from which the release history of the fish could be obtained. In the two years examined, an average of 2.9% of the subyearling, and 6.5 % of the yearling fish released from January through June in the Columbia River drainage were marked with CWT's.

Releases of chinook salmon smolts from California hatcheries averaged about 30 million fish per year in 1982 and 1983, most of which were fall chinook salmon.[3] Of the California releases about 25 million were small subyearling fish in the spring and about 5 million were large subyearling fish in the fall.

Extensive sampling of juvenile salmon in the lower Columbia River (rkm 75) between 1977 and 1983 determined that yearling chinook salmon smolts entered the Columbia River estuary (at rkm 75) mainly from April through June and that peak migration

[2] This table was compiled from data received in 1994 from the salmonid release data files of the Regional Mark Information System of the Pacific States Marine Fisheries Commission, 45 SE 82nd Drive, Suite 100, Gladstone, OR 97027-2522.

[3] Calculated from data supplied in 1994 by Frank Fisher, Calif. Dep. Fish. and Game (CDFG), 2440 North Main St., Red Bluff, CA; Gary Ramsden, CDFG, Trinity River Hatchery, Lewiston, CA; and Kim Rushton, Iron Gate Hatchery, 8638 Lakeview Rd. Hornbrook, CA.

Table 1

Total number, percent coded-wire tagged fish, and average fish size for hatchery releases of different age and run groups of chinook salmon, *Oncorhynchus tshawytscha,* for the Columbia River drainage, coastal Oregon, and coastal Washington areas by quarter (average of releases in 1982 and 1983).

Total	Jan–Mar	Apr–Jun	Jul–Sept	Oct–Dec
Columbia River				
Fall run (subyearlings)	3,595,917	77,520,135	8,366,243	1,567,369
91,049,664	2.1%	3.2%	7.1%	23.5%
	1.9 g	5.9 g	5.8 g	24.5 g
Fall run (yearlings)	694,978	622,582		
1,317,560	17.1%	8.0%	0	0
	63.0 g	53.9 g		
Spring run (subyearlings)	2,476,963	6,248,487	3,606,772	3,478,973
15,811,195	0%	1.3%	1.5%	8.2%
	1.0 g	3.4 g	12.1 g	57.6 g
Spring run (yearlings)	2,988,851	11,820,322		76,310
14,885,483	14.9%	3.7%	0	0%
	40.8 g	26.2 g		6.6 g
Coastal Oregon				
Fall run (subyearlings)	180,984	40,032	1,312,591	1,478,026
3,011,633	0%	0%	14.8%	23.7%
	0.6 g	2.5 g	34.0 g	48.1 g
Spring run (subyearlings)	177,518	25,134	1,055,342	1,500,590
2,758,584	14.5%	0%	13.9%	22.5%
	2.9 g	2.1 g	40.3 g	58.7 g
Spring run (yearlings)	118,731			
118,731	41.7%	0	0	0
	89.4 g			
Coastal Washington				
Fall run (subyearlings)		7,659,325	869,200	
8,528,525	0	3.0%	22.7%	0
		5.3 g	11.7 g	
Fall run (yearlings)		27,625		
27,625	0	49.9%	0	0
		64.9 g		
Spring run (subyearlings)			43,987	
43,987	0	0	0%	0
			10.1 g	
Spring run (yearlings)		120,575		
120,575	0	15.6%	0	0
		71.2 g		

was in May (Dawley et al., 1985a, Dawley et al.[4]). Downstream migration of subyearling chinook salmon smolts into the Columbia River estuary took place somewhat later, mainly from May through July, with a peak in late June or early July (Dawley et al.[4]). The average length of subyearling chinook

[4] Dawley, E. M., R. D. Ledgerwood, T. H. Blahm, C. W. Sims, J. T. Durkin, R. A. Kirn, A. E. Rankis, G. E. Monan, and F. J. Ossiander. 1986. *Migrational characteristics, biological observations,* (continued) and relative survival of juvenile salmonids entering the Columbia River estuary 1966–1983. Final Res. Rep., Bonneville Power Admin., Div. Fish Wildl., Portland, OR 97208.

salmon at the time they entered the Columbia River estuary was usually under 100 mm FL, whereas that of yearling chinook salmon was about 130–150 mm FL (Dawley et al., 1985a). Between January and July 1981–83 about eight times as many subyearling fish as yearling fish were caught at rkm 75 (purse and beach seines combined, Dawley et al., 1985a). During the same period an average of 2.3% of subyearling fish and 2.5% of yearling fish caught at rkm 75 were CWT'd (calculated from data in Dawley et al., 1985, a and b). Large numbers of subyearling chinook salmon, the mean lengths of which ranged from 91 mm in May to 135 mm in September, were caught in shallow (<4 m water depth) marine waters outside of the river mouth in some years (Dawley et al.[1]).

Most naturally reared chinook salmon from coastal Oregon river systems also enter the ocean as subyearling smolts (Nicholas and Hankin, 1988). Peak abundance of subyearling chinook salmon in Oregon estuaries generally occurs from late June through August (Reimers, 1973; Nicholas and Hankin, 1988). Although peak abundance in estuaries is earlier, juvenile chinook salmon are often caught in estuaries in the late fall (Myers and Horton, 1982; Nicholas and Hankin, 1988). By September, subyearling chinook salmon smolts caught in beach seines in the lower estuaries were generally from 100 to 130 mm mean FL (Nicholas and Hankin, 1988).

Ocean migrations of stocks originating in northern California and in Oregon south of Cape Blanco are limited in extent, and few maturing fish of these stocks are caught outside of the California and Oregon ocean or freshwater fisheries (Nicholas and Hankin, 1988; Garrison[5]). However, some northern coastal Oregon and Columbia River stocks (both spring and fall runs) undertake very extensive migrations and are caught in large numbers in the ocean fisheries of Alaska and northern British Columbia (Nicholas and Hankin, 1988; Garrison[5]; Hansen and Johnson[6]; Howell et al.[7]; Vreeland[8]).

[5] Garrison, R. L. 1986. Stock assessment of anadromous salmonids. Oregon Dep. Fish Wildl., Annual Prog. Rep., Portland, OR 97207, 47 p.

[6] Hansen, H. L., and R. L. Johnson. 1987. An evaluation of fishery contribution from fall chinook salmon reared in Oregon hatcheries on the Columbia River, coded-wire-tag recovery program. Oregon Dep. Fish Wildl., Annual Prog. Rep., Portland, OR 97207, 47 p.

[7] Howell, P., K. Jones, D. Scarnecchia, L. LaVoy, W. Kendra, and D. Ortmann. 1985. Stock assessment of Columbia River anadromous salmonids. Vol. 1: chinook, coho, chum and sockeye salmon stock summaries. Final Rep., U.S. DOE, Bonneville Power Admin., Div. Fish Wildl., Portland, OR 97208.

[8] Vreeland, R. R. 1986. Evaluation of the contribution of chinook salmon reared at Columbia River hatcheries to the Pacific salmon fisheries. Annual Rep., U.S. DOE, Bonneville Power Admin., Div. Fish Wildl., Portland, OR 97208.

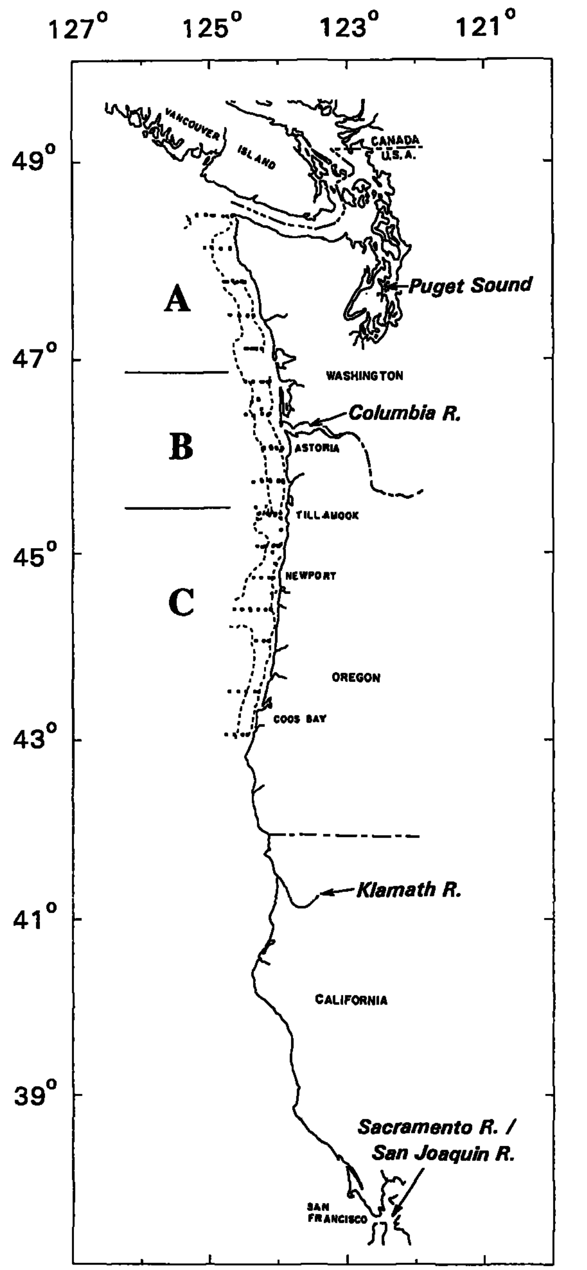

Figure 1

Sampling areas (**A**, **B**, **C**) where juvenile chinook salmon, *Oncorhynchus tshawytscha*, were collected in purse seines, 1981–85. Sampling sites occupied in 1983 are shown (dots) along with the 40 and 120 m depth contours (dashed lines). Basins which are major sources of chinook salmon in this region are indicated by arrows. Latitudinal extent of sampling varied in the different months and years (see Fig. 5).

Methods

Chinook salmon were collected with a fine-mesh purse seine between May and September, 1981–85, along a series of east-west transects off Oregon and

Washington (Fig. 1; Pearcy and Fisher, 1988, 1990). The sampling area was divided latitudinally into three sections (A, B, and C in Fig. 1). Additional sampling in July 1984 occurred off northern California as far south as 40°32'N and off the west coast of Vancouver Island as far north as 50°26'N, and in May 1985 in a concentrated area off the mouth of the Columbia River. The months sampled in each year are shown in Table 2. The latitudinal range of sampling varied among years and months (Pearcy and Fisher, 1988; see also Fig. 5, this paper). Transects were generally 37 km apart and collecting stations along each transect were 9.3 km apart starting at about the 37 m depth contour and continuing out to 37 or 46 km offshore. Occasionally stations farther offshore were sampled.

For this study we considered all chinook salmon less than 401 mm fork length (FL) to be juvenile fish. This was based on the sizes of known age coded-wire tagged (CWT) fish in our catches. This length range included those fish that entered the ocean as yearlings or subyearlings in the same year in which they were caught in the ocean (age 1.0 or age 0.0, respectively[9]) and those that entered the ocean as subyearlings in the year prior to capture in the ocean (age 0.1[9]).

[9] The number before the period indicates winters spent in freshwater after hatching and before migration to the sea, and the number following the period indicates winters spent at sea (Koo, 1962).

Fork length (FL) of most fish was measured at sea to the nearest mm. CWT fish were measured at sea, then frozen, and later weighed in the laboratory. Tags were decoded by personnel at the Oregon Department of Fish and Wildlife laboratory in Clackamas, Oregon.

Growth rates of CWT chinook salmon between release from hatcheries and capture in the ocean were estimated by $(FL_1 - FL_0)/d$; where FL_0 = mean length of fish in the tag group at release, FL_1 = length of the individual fish when caught in the ocean, and d = the number of days between release and capture ($d \geq 10$). Often only mean weight at release was readily available for a tag group. For these groups we converted mean weight at release to mean FL by using the geometric mean functional relationship (Ricker, 1973) between average weight (g) and average FL (mm) for CWT groups released in California and the Columbia River for which both mean weight and mean length at release were measured: $\ln(FL) = 0.3122(\ln(wt)) + 3.8233$, n=311, r^2=0.94. Average instantaneous rates of growth in weight (% body wt/d) between release and ocean capture were estimated by $(\ln(Wt_1) - \ln(Wt_0))/d$; where Wt_1 = weight at capture in the ocean, Wt_0 = average weight at release, and d = the number of days ($\geq$10) between release from the hatchery and capture in the ocean (Ricker, 1975).

Growth rates of chinook salmon in the Columbia River estuary and in the ocean prior to capture in

Table 2

Catch (n), mean catch per set (CPUE, in parentheses), and percentage of coded-wire tagged fish in the catch of juvenile chinook salmon, *Oncorhynchus tshawytscha*, for different months and years.

	May		June		July		Aug		Sept	
Year	n (CPUE)	% CWT	n (CPUE)	% CWT	n (CPUE)	% CWT	n (CPUE)	% CWT	n (CPUE)	% CWT
1981	68 (1.08)	5.9%	37 (0.55)	2.7%	73 (1.09)	4.1%	51 (0.77)	2.0%	— —	—
1982	217 (3.50)	7.8%	228 (4.07)	7.0%	— —	—	— —	—	15 (0.39)	6.7%
1983	128 (2.32)	5.5%	52 (0.90)	3.8%	— —	—	— —	—	213 (4.18)	0.0%
1984	— —	—	104 (1.58)	12.5%	72 (1.20)	2.8%	— —	—	59 (0.93)	10.2%
1985	533[1] (19.04)	15.6%	282 (3.52)	10.3%	— —	—	— —	—	— —	—

[1] Late May and early June sampling off the mouth of the Columbia River.

1981, 1982, and 1983 for individuals from groups of CWT fish sampled 75 km upstream from the ocean (rkm 75) during their downstream migration were estimated by $(FL_1 - FL_0)/d$; where FL_0 = mean FL of the tag group when sampled in the river (from Dawley et al., 1985b), FL_1 = length of the individual fish when caught at sea, and d = days (≥10) between the date when half the fish in the tag group had passed rkm 75 and the date of capture in the ocean. (See Dawley et al., 1985, a and b; Dawley et al.[4] for detailed information on in-river sampling.)

Net migration speed of individual CWT smolts in the lower Columbia River estuary, downstream of rkm 75, and in the ocean prior to capture was estimated by dividing the distance between rkm 75 and the point of capture in the ocean (straight line segments) by the number of days (≥10) between the date when half the fish in the CWT group had passed rkm 75 during downstream migration (Dawley et al., 1985b), and the date when the individual CWT fish was caught in the ocean.

In September 1983 we caught a large number of juvenile chinook salmon, none of which were CWT'd. We examined scales from 128 of these fish in order to estimate their size at time of ocean entry and the length of time they had been in the ocean. Scale radii were measured from the focus to what we interpreted to be the ocean entrance mark (the last abrupt change in circulus spacing, often accompanied by a few narrowly spaced circuli). Fork length of fish at ocean entry was backcalculated by using a geometric mean regression (Ricker, 1973) of FL and scale radius for juvenile chinook salmon (length range approximately 100–350 mm FL) caught by us in the ocean (1981–84) and in four Oregon estuaries by the Oregon Department of Fish and Wildlife ($FL_{(mm)} = 2.3772 \times Scale\ radius_{(mm\ at\ 88\times)} + 0.08, n=202, r^2=0.88$). We roughly estimated the length of time these fish had been in the ocean by dividing their ocean growth (FL at capture minus back-calculated FL at time of ocean entry) by an assumed ocean growth rate of 1.5 $mm \cdot d^{-1}$; a growth rate common for juvenile coho salmon during their first summer in the ocean (Fisher and Pearcy, 1988) and similar to the estimated mean growth rate downstream of rkm 75 of five CWT Columbia River chinook salmon in the same year (this study).

Results

Catch per unit of effort

A total of 2,132 juvenile chinook salmon were caught in 880 purse-seine sets during our ocean sampling 1981–85. A consistent seasonal trend among years in mean CPUE (all sampling areas combined) of juvenile chinook salmon was lacking (Table 2). In 1982, CPUE was considerably higher in May and June than in September, but in 1983, CPUE in September was higher than it was earlier in May and June. In 1981 and 1984 little change occurred in CPUE between early and late summer. By far the largest CPUE was during latitudinally restricted sampling off the Columbia River mouth in May 1985 (Table 2).

Origin and age of CWT fish

CWT fish represented 8.7% (185) of juvenile chinook salmon caught in purse seines 1981–85. The percentage of CWT fish during the different cruises ranged from 0.0% in September 1983 to 15.6% in late May 1985 off the mouth of the Columbia River (Table 2).

Most CWT fish caught in the ocean originated in the Columbia River basin (Table 3). CWT Columbia River fish represented 92% (170) of all CWT fish caught in the ocean 1981–85. CWT fish from coastal Oregon hatcheries and from coastal Washington hatcheries represented 6.4% (12) and 1.1% (2) of the total catch of CWT fish, respectively. No CWT fish that originated in British Columbia or Puget Sound, Washington, and only one CWT fish that originated in a California hatchery (Klamath R. system) was caught.

Most of the CWT fish that we caught in the ocean were released from hatcheries as yearling fish the same year we recovered them in the ocean (age 1.0, Table 3). In addition, two CWT fish caught in the ocean were released from hatcheries as subyearling fish, but overwintered in freshwater before entering the ocean (based on their size and scale characteristics at time of capture). Age-1.0 fish represented 90.8% (168) of the catch of CWT fish 1981–85. Subyearling fish released from hatcheries in the spring or summer, a few months or less prior to capture in the ocean (age 0.0 at ocean capture), accounted for only 3.7% (7) of the catch of CWT fish between 1981 and 1985. Fish that overwintered in the ocean after being released as subyearlings in the summer, fall, or winter of the year prior to capture in the ocean (age 0.1 at ocean capture) accounted for only 5.4% (10) of the catch of CWT fish 1981–85 (Table 3).

Yearling (age-1.0) chinook salmon smolts from the Columbia River basin were the predominant group of CWT fish in the May and June samples in most years. Most of these were spring run fish, but fall run yearling fish were also abundant in May and June 1985, and fall, summer, and mixed stock yearlings were also present in some years (Table 3).

Age-1.0 CWT fish from the Columbia River basin (all runs combined) accounted for 4.4%, 5.1%, 5.5%, and 15.5% of the total ocean catch in May 1981, 1982,

Table 3

Number of coded-wire tagged (CWT) fish of different stock groups and ages and their percentage of the total catch (in parentheses) of chinook salmon, *Oncorhynchus tshawytscha*, caught during ocean sampling in different months and years, 1981–85. Absence of sampling is indicated by —. No CWT fish were caught in September 1983.

				Month				
Year	Release area	Age	Run	May	June	July	August	Sept
1981	Columbia River	1.0	spring	3 (4.4%)		2 (2.7%)		
1981	Columbia River	0.0	mixed				1 (2.0%)	
1981	Columbia River	0.0	fall			1 (1.4%)		—
1981	Coast of Oregon	1.0	spring		1 (2.7%)			
1981	Klamath River	0.1	fall	1 (1.5%)				
1982	Columbia River	1.0	spring	11 (5.1%)	9 (3.9%)			1 (6.7%)
1982	Columbia River	1.0	fall		2 (0.9%)			
1982	Columbia River	1.0	summer	1 (0.5%)	2 (0.9%)			
1982	Columbia River	0.1	fall	2 (0.9%)		—	—	
1982	Columbia River	0.1	mixed		1 (0.4%)			
1982	Coast of Oregon	1.0	spring	1 (0.5%)				
1982	Coast of Oregon	0.1	fall	2 (0.9%)	1 (0.4%)			
1982	Coast of Washington	1.0	spring	1 (0.5%)				
1983	Columbia River	1.0	spring	5 (3.9%)				
1983	Columbia River	1.0	fall	1 (0.8%)				
1983	Columbia River	1.0	summer	1 (0.8%)		—	—	
1983	Columbia River	0.0	spring		1 (1.9%)			
1983	Coast of Washington	1.0	fall		1 (1.9%)			
1984	Columbia River	1.0	spring		9 (8.7%)			
1984	Columbia River	1.0	fall		2 (1.9%)	1 (1.4%)		
1984	Columbia River	1.0	summer	—	2 (1.9%)		—	2 (3.4%)
1984	Columbia River	0.0	spring			1 (1.4%)		
1984	Coast of Oregon	0.1	fall					1 (1.7%)
1984	Coast of Oregon	0.0	spring					3 (5.1%)
1985	Columbia River	1.0	spring	50 (9.4%)	5 (1.8%)			
1985	Columbia River	1.0	fall	23 (4.3%)	17 (6.0%)			
1985	Columbia River	1.0	summer	6 (1.1%)				
1985	Columbia River	1.0	mixed	4 (0.8%)	3 (1.1%)	—	—	—
1985	Columbia River	0.1	fall		2 (0.7%)			
1985	Coast of Oregon	1.0	spring		2 (0.7%)			

1983, and 1985, respectively, and 5.7%, 12.5%, and 7.8% of the total ocean catch in June 1982, 1984, and 1985, respectively (Table 3). These percentages of CWT fish were much higher than those of downstream migrant yearling chinook salmon entering the Columbia River estuary, which averaged 2.3% CWT fish during the period January–June, 1981–83 (calculated from Dawley et al., 1985, a and b), and were comparable to the CWT percentages of hatchery yearling Columbia River spring and fall chinook salmon released during the period April–June 1982–83 (3.7 and 8.0%, respectively, Table 1). The high proportion of CWT yearling (age 1.0) chinook salmon from the Columbia River basin in the May and June ocean catches indicates that most unmarked fish caught in the ocean during these months probably were also yearling hatchery fish from the Columbia River basin.

Five stocks from the Columbia River basin dominated our catch of age-1.0 smolts: Snake River summer, Upriver Bright (URB) and Snake River fall chinook salmon, and Cowlitz River and Willamette River spring chinook salmon (Table 4). These stocks are caught in ocean fisheries as maturing fish mainly to the north of Oregon (Howell et al.[7]).

Catch per unit of effort of CWT Fish

Some distinct seasonal trends were apparent in the abundance of the different age classes of CWT fish. Age-1.0 fish were most abundant in catches in May

Table 4

Coded-wire tagged chinook salmon, *Oncorhynchus tshawytscha*, stocks caught during ocean purse-seine sampling, 1981–85.

Stock group	Recovery age	Number recovered	Mean FL (mm)
Columbia River Fall Chinook Salmon			
Lower river hatchery	0.0	1	91
	1.0	1	147
Upriver Bright	1.0	20	202
	0.1	4	292
Snake River	1.0	26	208
Columbia River Summer Chinook			
Salmon River (Snake R.)	1.0	13	163
Upper Columbia River	1.0	1	189
Columbia River Spring Chinook			
Cowlitz River	1.0	29	214
Carson NFH	1.0	16	169
Deschutes River	1.0	6	242
	0.0	1	124
Willamette River	1.0	34	190
Upper Columbia River	1.0	7	161
	0.0	1	138
Rapid River (Snake R.)	1.0	2	152
Mid-Columbia River Mixed	0.0	1	137
	0.1	1	355
	1.0	7	158
Coastal Oregon Fall Chinook			
Domsea Inc. (Siuslaw R.)	0.1	2	290
Elk River	0.1	1	316
Rogue River	0.1	1	389
Coastal Oregon Spring Chinook			
Anadromous Inc.	0.0	3	214
Umpqua River	1.0	4	279
Coastal Washington			
Fall Chinook	1.0	1	238
Spring Chinook	1.0	1	203
Klamath River			
Fall Chinook	0.1	1	290

and June, when they dominated the catch of CWT fish. They were much less abundant in July, August, and September. (Table 5). The few age-0.1 fish were also more common in the May–June period than in the July–September period. Conversely, recoveries of CWT subyearling (age 0.0) fish were mainly in the July–September period (Table 5).

Size-frequency distributions

Mean FL of age-1.0 CWT fish was 183 mm, 215 mm, 214 mm, and 281 mm in May, June, July, and September, respectively, for all years combined (Table 5). Age-0.1 fish were generally larger than the age-1.0 fish, averaging 294 mm, 310 mm, and 389 mm FL in May, June, and September, respectively (Table 5). Except for three fish caught in September, age-0.0 fish were considerably smaller than the other two age classes, averaging 124 mm, 115 mm, and 137 mm FL in June, July, and August, respectively (Table 5).

Length-frequency distributions (on a catch/set basis) of juvenile chinook salmon are shown for the three standard sampling areas (A, B, and C) for all years combined (Fig. 2, top), for sampling in July 1984 off northern California (CA) and Vancouver Island (BC) and for sampling off the mouth of the Co-

Table 5

Number, catch per unit of effort (CPUE) and fork length (FL) of coded-wire tagged age-1.0, age-0.0 and age-0.1 chinook salmon, *Oncorhynchus tshawytscha*, by cruise for all years combined, 1981–85.

			Age 1.0				Age 0.0				Age 0.1			
Cruise	Years	Sets	*n*	CPUE	Mean FL	FL Range	*n*	CPUE	Mean FL	FL Range	*n*	CPUE	Mean FL	FL Range
May	81–83	180	23	0.13	200	139–302	0	0.00	—	—	5	0.03	294	270–316
May	85[1]	28	83	2.96	178	118–261	0	0.00	—	—	0	0.00	—	—
June	81–85	327	56	0.17	215	140–295	1	<0.01	124	—	4	0.01	310	220–355
July	81, 84	107	3	0.03	214	206–223	2	0.02	115	91–138	0	0.00	—	—
Aug.	81	66	0	0.00	—	—	1	0.01	137	—	0	0.00	—	—
Sep.	82–84	152	3	0.02	281	236–340	3	0.02	214	211–217	1	0.01	389	—

[1] Sampling restricted to an area immediately off the Columbia River.

lumbia River (CO) in May 1985 (Fig. 2, bottom). For each month and area the effort (number of purse-seine sets) and total CPUE are also shown. The length-frequency distributions of CWT age-1.0 Columbia River fish are shown in black, and lengths of other CWT fish are indicated by letters (Fig. 2).

In the May and June samples, most CWT age-1.0 fish from the Columbia River were between 130 mm FL and 250 mm FL. As discussed earlier, from the percentages of CWT fish in the catches, most unmarked fish in this size range were probably also age-1.0 hatchery fish from the Columbia River. On the basis of CWT's and scale characteristics, we concluded that larger fish (about 220–400 mm FL) in May and June were a mixture of age-1.0 and age-0.1 fish. CPUE of fish in May was greatest in Area B, which straddles the mouth of the Columbia River, and was about half as great in areas to the south (C) and to the north (A). Relative to May, CPUE in June decreased in Area C, remained about the same in Area B, and increased in Area A. CPUE in June was much higher in the two northern areas than in Area C.

Age-1.0 Columbia River fish were much rarer in all areas in the July–September period than in the May–June period, based both on the catches of CWT fish and the length-frequency distributions of unmarked fish. Generally, CPUE of fish between 150 mm FL and 330 mm FL was low in July and August in all areas. In September only a few age-1.0 and age-0.1 fish were caught in Area A. Only one CWT age-1.0 fish (340 mm FL) was caught in Area C in September.

The most abundant fish in July and August were less than 150 mm FL (Fig. 2). Catches of these small fish were highest off northern California (CA), the Columbia River (B), and the Washington coast (A). The few CWT fish caught in July and August in this size range were age-0.0 fish from the Columbia River (Fig. 2). The catches in the ocean in July and August of these small fish coincided with the time of peak abundance of subyearling chinook salmon in Oregon estuaries (Nicholas and Hankin, 1988) and with the later half of the peak migration of subyearling chinook salmon in the Columbia River estuary (Dawley et al.[4]) and was well after the time when most yearling chinook salmon enter the ocean (in May, Dawley et al.[4]). Therefore, it is most likely that the unmarked fish <150 mm FL caught in the ocean in July and August were age-0.0 fish.

Catches of chinook salmon in September in Areas B and C occurred mainly in 1983 and 1984. In September 1984, 32 moderately large (range 160–260 mm FL) fish were caught off Oregon (Area C). These were mainly age-0.0 fish released in August from the Anadromous Inc. release facility on Coos Bay (this conclusion was based on associated CWT fish and their percentage of the catch).

During September 1983 we caught 207 unmarked juvenile chinook salmon in areas B and C off Oregon. Fish caught in area B were smaller (mean FL=185, n=35) than those caught to the south in area C (mean FL=227 mm, n=172; Fig. 2). Estimated mean FL at time of ocean entry backcalculated from scales was 138 mm and 173 mm for fish caught in areas B and C, respectively. Growth while in the ocean averaged 48.5 mm for fish caught in area B and 52.2 mm for fish caught to the south in area C. Dividing by a growth rate of 1.5 mm/d, we estimated time since ocean entry to be just over one month for both these groups.

The estimated date of ocean entry of these fish (sometime in mid or late August) indicates that these were subyearling rather than yearling chinook salmon, since both naturally and hatchery produced yearling fish generally enter the ocean in the spring or early summer (see the introduction to this study).

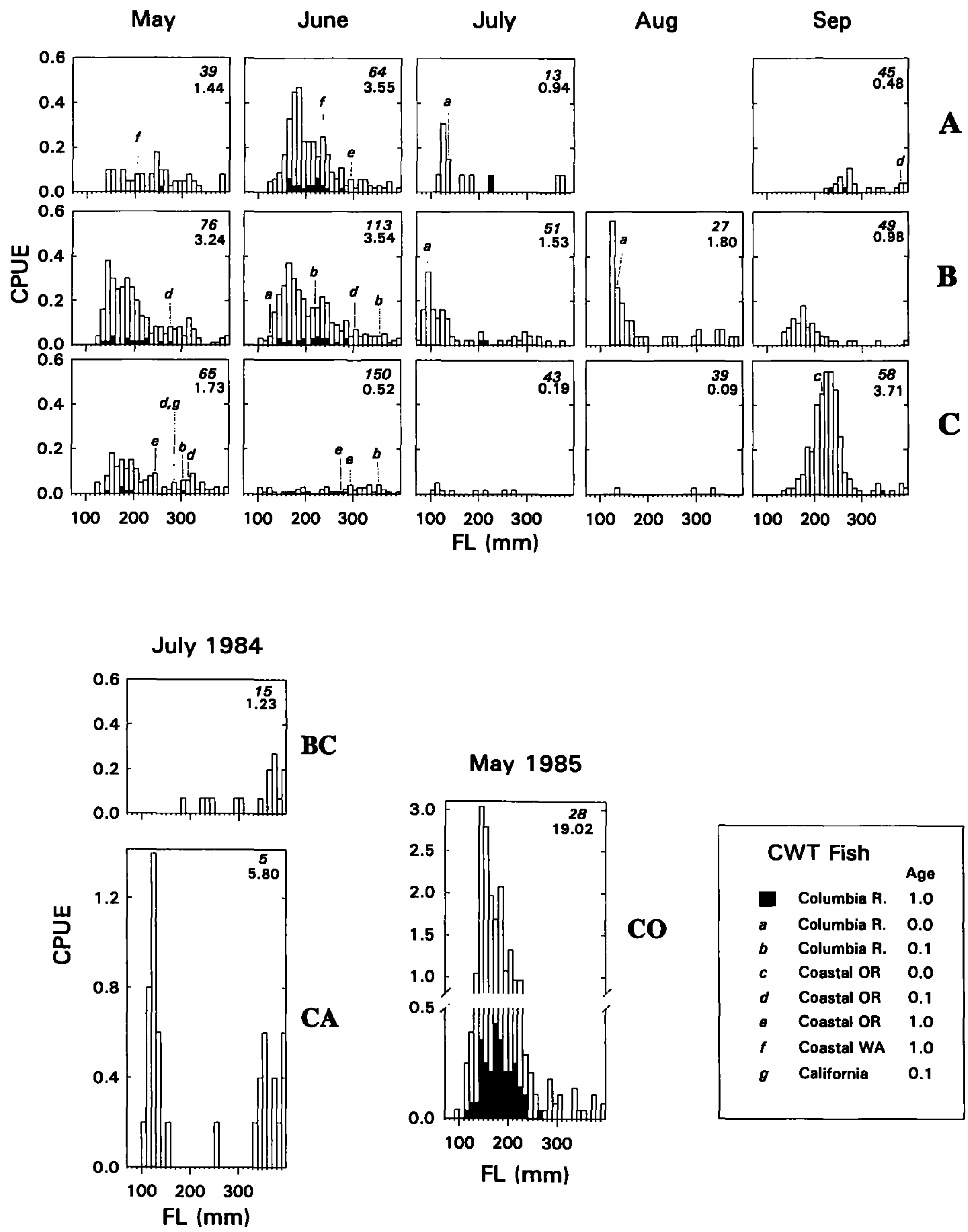

Figure 2

Length-frequency distributions of juvenile chinook salmon, *Oncorhynchus tshawytscha*, by month and area (**A**, **B**, and **C** in Fig. 1) for all years combined, for July 1984 off northern California (CA) and the west coast of Vancouver Island (BC) and for May 1985 off the mouth of the Columbia River (CO). Total effort (number of sets, in italics) and total catch per unit of effort (CPUE) are indicated for each month and area. The size-frequency distributions of coded-wire tagged (CWT) age-1.0 Columbia River fish are indicated in black, lengths of other CWT fish are indicated by letters.

However, the mean size at ocean entry backcalculated from scales (173 mm FL) of the fish caught in Area C was much larger than the mean sizes of naturally produced fall chinook salmon reported by Nicholas and Hankin (1988) in Oregon estuaries in the late summer (100–140 mm FL by mid-September, depending on the river system).

Since the estimated average size at time of ocean entry of the fish caught in Area C in September (173 mm FL) was much larger than the average size at which age-0.0 wild smolts enter the ocean (Nicholas and Hankin, 1988; Dawley et al.[1]; Dawley et al.[4]), it is probable that these fish were released from a hatchery. The only releases in the study area (excluding California) of large smolts in groups not represented by CWT's during the July–August period were from the Oregon Aqua Foods (OAF) saltwater rearing and release facility on Yaquina Bay, Oregon, which is located within 5 km of the ocean. Almost 800,000 unmarked subyearling fall chinook and 55,000 unmarked subyearling spring chinook salmon were released from this facility between 28 August and 5 September 1983[10], about three weeks before our sampling in the ocean (22–24 September). The mean weight at time of release for these groups ranged from 47 to 57 g for the fall chinook salmon and was 100 g for the spring chinook salmon. From a regression of FL and body weight (this study) we estimated that the mean lengths of these OAF-released fall chinook salmon at time of release ranged from 152 to 162 mm, close to the mean size at ocean entrance (backcalculated from scales) of the fish we caught in Area C in September 1983 (173 mm). If these OAF-released fish were the source of the unmarked fish caught in the ocean in September 1983, then they were in the ocean about three weeks before capture. If fish size at ocean entrance that we backcalculated from scales was accurate, then their growth rate since entering the ocean was slightly over 2 $mm \cdot d^{-1}$, considerably higher than the mean growth rate (1.05 $mm \cdot d^{-1}$) estimated for age-1.0 Columbia River fish downstream of rkm 75 (see below), and about one and a third times that estimated for juvenile coho salmon, *Oncorhynchus kisutch*, caught in the ocean in late summer (Fisher and Pearcy, 1988).

Inshore-offshore distributions

The inshore-offshore distributions of very small fish (≤130 mm FL), which were mainly age-0.0 fish, and of larger fish (>130 mm FL) were similar; the median offshore distance of the catch of each size category was about 13 km (Fig. 3A). However, small fish were strongly associated with warm, brackish waters (mainly the Columbia River plume), whereas larger fish were not (Fig. 3, B and C). Fully 38% of the small fish, but only 2% of the large fish, were caught in waters ≤17‰ (Fig. 3B). Over 40% of small fish, but only 4% of large fish were caught where sea-surface temperature was ≥15°C (Fig. 3C). These data indicate that, at least over the depths sampled (mainly >37m), the smallest chinook salmon juveniles were much more likely to be found in the warm, low salinity waters of the Columbia River plume than in the colder, more saline adjacent waters.

Our largest catches of juvenile chinook salmon in late summer were taken in September 1983. On the basis of their scale characteristics we concluded that these were hatchery subyearling chinook salmon that had been in the ocean about a month (see section on Size-Frequency Distributions). Almost all of these fish were captured within 4 km of the shoreline, in depths of <40 m (Fig. 4). This is a much more restricted inshore-offshore distribution than was found in general for the juvenile chinook salmon (mainly age-1.0 fish) caught during all months and years of our sampling combined (Fig. 3A). Since daily upwelling indices during September 1983 at both 42°N and 45°N were almost all positive (Mason and Bakun, 1986), the restricted inshore distribution of juvenile chinook salmon in this month does not appear to have been caused by onshore transport of water. The difference in offshore distribution between this group of large age-0.0 hatchery chinook salmon and the mainly age-1.0 fish caught in early summer may be due to behavioral differences between these groups of fish; the age-0.0 fish appear to prefer shallower, more nearshore areas.

Migration

Several trends are apparent in the migrations of CWT juvenile chinook salmon between ocean entry and capture in purse seines (Fig. 5). In 1983, 1984, and 1985 most fish originating in the Columbia River basin were caught north of where they entered the ocean. In May 1982, however, all Columbia River fish were caught south of the river mouth, but by the following month most were caught to the north. All but one of the ten tagged chinook salmon originating from coastal Oregon hatcheries were caught north of where they entered the ocean.

Thirteen fish were caught more than 190 km north of where they entered the ocean. Seven of these were age-1.0 fish from the Columbia River drainage (three Snake River fall, two Snake River summer, one URB fall, one Deschutes River spring), one was an age-1.0 fish from a coastal Oregon River system (Umpqua

[10] Information obtained from the Pacific States Marine Fishery Commission's salmon release data base.

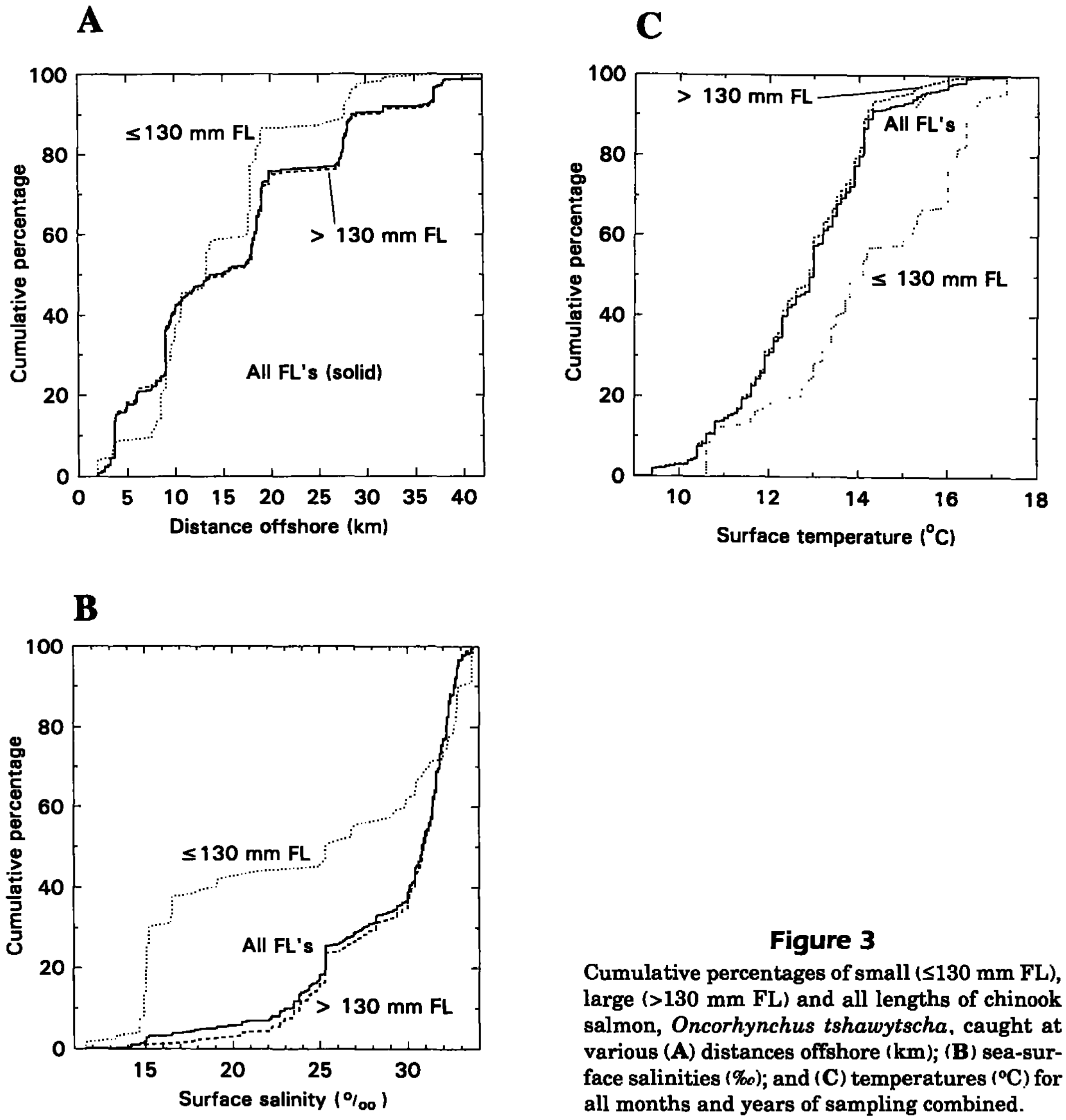

Figure 3

Cumulative percentages of small (≤130 mm FL), large (>130 mm FL) and all lengths of chinook salmon, *Oncorhynchus tshawytscha*, caught at various (**A**) distances offshore (km); (**B**) sea-surface salinities (‰); and (**C**) temperatures (°C) for all months and years of sampling combined.

R. spring chinook salmon), and five were age-0.1 fish from coastal Oregon and California hatcheries (two Siuslaw R. fall, one Elk R. fall, one Rogue R. fall, and one Trinity R. (Klamath R. system) fall chinook salmon). The two farthest northward migrations were made by an age-1.0 spring chinook salmon from the Umpqua River, Oregon, caught 481 km to the north off northern Washington in June 1985, and by an age-0.1 fall chinook salmon from the Trinity River, California, caught 317 km to the north in May 1981.

Speed of migration

Average net migration rate of CWT age-1.0 Columbia River juvenile chinook salmon between rkm 75 and their ocean capture locations was 4.1 km·d^{-1} (range 1.1–14.2 km·d^{-1}, n=31; 1981, 1982, and 1983 data combined). This net migration rate was equivalent to 0.3 body lengths·sec^{-1} (where body length is the average between the mean length of the CWT group at rkm 75 and the length of the individual fish at capture in the ocean).

Growth of juvenile chinook salmon

Estimated mean growth rates of age-1.0 CWT Columbia River juvenile chinook salmon between hatchery release and capture in the ocean and between

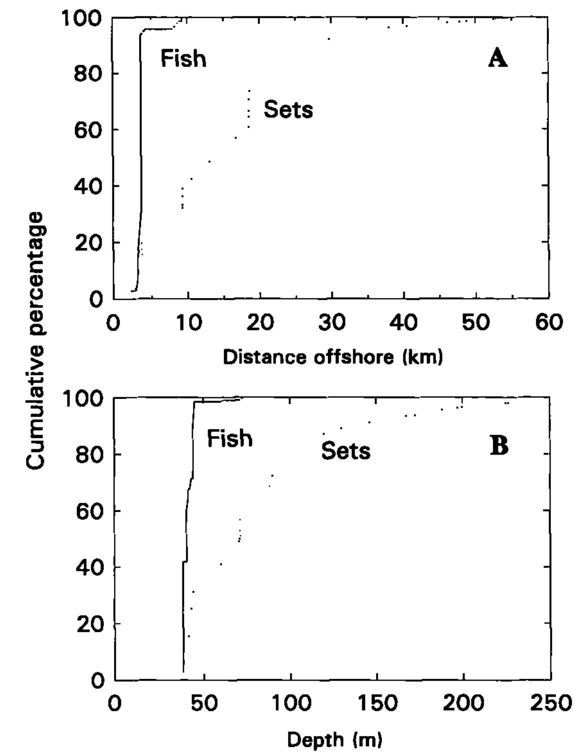

Figure 4
Cumulative percentages of number of sets (effort) and number of chinook salmon, *Oncorhynchus tshawytscha*, caught at various (**A**) distances offshore (km) and (**B**) bottom depths (m), in September 1983.

rkm 75 and capture in the ocean were 0.75 mm·d^{-1} (n=152) and 1.05 mm·d^{-1} (n=31), respectively, for all years combined. The higher estimated growth rates for fish downstream of rkm 75 suggest that growth rates of fish in the Columbia River Estuary and ocean were higher than growth rates in the areas upstream in the Columbia River. Growth rates between rkm 75 and ocean capture were 0.98 (n=5), 0.98 (n=21), and 1.41 mm·d^{-1} (n=5) in 1981, 1982, and 1983, respectively. Average instantaneous rate of growth in weight of age-1.0 CWT Columbia River juvenile chinook salmon between hatchery release and ocean capture was 0.92% body wt·d^{-1} (n=152), for all years combined.

Discussion

Age-1.0 chinook salmon smolts from the Columbia River basin migrate rapidly to the north after entering the ocean in the spring. Evidence for this rapid northward migration is found in the sharp decrease between early and late summer in CPUE of CWT age-1.0 fish in the area off Oregon and Washington (Table 5); in the much higher CPUE of age-1.0 fish in the area north of the Columbia River than south of the Columbia River in June (Fig. 2); in the low CPUE of age-1.0 fish in late summer (Fig. 2); and in the predominantly northward migrations of CWT Columbia River fish (Fig. 5). These results are consistent with those of Miller et al. (1983), who found CWT age-1.0 fish only in their late spring sampling in 1980 off southern Washington and northern Oregon, and who caught CWT age-1.0 fish only in purse-seine sets that were open to the south (sets that catch northward swimming fish). Our results are also consistent with those of Hartt and Dell (1986) who caught juvenile Columbia River spring chinook salmon in the northern Gulf of Alaska in August of their first year in the ocean. Only in May 1982 were many CWT age-1.0 Columbia River fish found to the south of the Columbia River (Fig. 5). This was a period of strong northerly winds and southward flowing surface currents which may have transported the juvenile salmon to the south by advection (Pearcy and Fisher, 1988).

Unlike age-1.0 chinook salmon, age-1.0 coho salmon were fairly abundant in late summer off the Columbia River mouth and off Washington (Pearcy and Fisher, 1988). The Columbia River is the major source for both of these species in the study area, and yearlings of both enter the ocean at about the same time (April through June). The continued presence in late summer of age-1.0 coho salmon off the Columbia River and Washington coast suggests that they are less migratory than yearling Columbia River chinook salmon during their first summer in the ocean. As maturing fish, these two species of salmon generally also have different ocean distributions. A major part of the ocean catch of several stocks of Columbia River spring chinook salmon occurs far to the north in British Columbia and Alaska ocean fisheries (e.g. Willamette R. and Klickitat R. stocks); conversely, Columbia River and coastal Oregon coho salmon stocks are mainly caught in Washington, Oregon, and California ocean fisheries (Garrison[5]; Howell et al.[7]). This divergence in the ocean distributions of these two species is already apparent in the first few months of their ocean life.

On the basis of estimated growth rates of CWT fish, we concluded that both age-1.0 coho and chinook salmon appear to grow at fairly similar rates during the first few months they are in the ocean. Estimated mean growth rates of CWT age-1.0 Columbia River chinook salmon between release and capture in the ocean (0.75 mm·d^{-1}) and between rkm 75 and capture in the ocean (1.05 mm·d^{-1}) were similar to the estimated mean growth rate of juvenile coho salmon

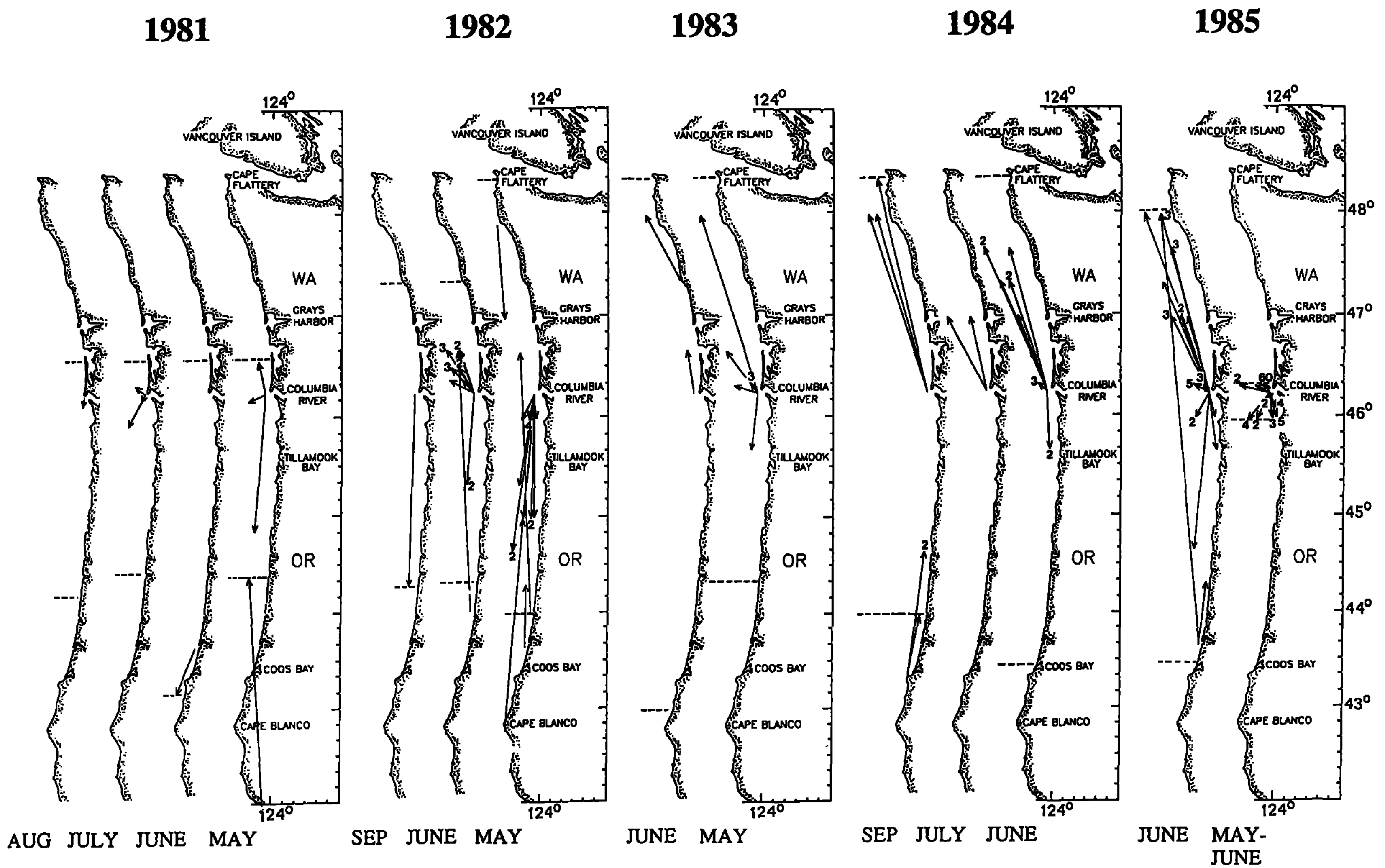

Figure 5

Net migration of coded-wire tagged juvenile chinook salmon, *Oncorhynchus tshawytscha*, from point of ocean entry to capture in purse seines. When more than one fish followed a particular net migration path, the number of fish is indicated at the head of the arrow. Dashed lines indicate the latitudinal extent of purse-seine sampling in each month in each year caught in the ocean in May and June (0.93 mm·d^{-1}, n=142; Fisher and Pearcy, 1988). Mean growth rates of CWT juvenile coho salmon caught in the ocean in the July–September period were higher (1.43 mm·d^{-1}, n=69) than growth rates in early summer. Unfortunately, we caught too few CWT age-1.0 chinook salmon in late summer to compare their growth rates with those of coho salmon in late summer. Our estimates of growth rates of CWT age-1.0 Columbia River chinook salmon based on mean size of fish in the CWT group at time of release or during downstream migration may be biased by size-related differences in mortality rates or migration rates out of the sampling area.

The ratio of age-1.0 to age-0.1 chinook salmon in our ocean purse-seine samples was disproportionately high compared with the relative numbers of these two age classes entering the ocean. Although subyearling chinook salmon were much more numerous than yearling chinook salmon among downstream migrating smolts in the Columbia River (Dawley et al., 1985a), and many more subyearling than yearling chinook salmon were released from hatcheries (Table 1), yearling fish predominated in our catches in the ocean. The high catches in the ocean in May and June of age-1.0 fish coincided with the period of peak downstream migration and ocean entry of these yearling fish. However, no similarly large catches of the more numerous age-0.0 fish occurred in the June, July, and August ocean samples, following their peak period of downstream migration in the Columbia River. In fact, CPUE of age-0.0 fish during July and August in Areas A and B, was not nearly as great as the CPUE of age-1.0 fish earlier in May and June (Fig. 2).

The relatively low numbers of small age-0.0 chinook salmon caught in water >37 m bottom depth support the hypothesis of Miller et al. (1983) that offshore movement of subyearling chinook salmon is size dependent; few fish move offshore until they reach a size of around 130 mm FL. Many of the small age-0.0 fish caught over deep water in July and August appeared to have been carried offshore in the Columbia River plume, since they were found in waters of high temperature and low salinity (Fig. 3). During June, July, and August large numbers of small age-0.0 chinook salmon may have been present in shallow nearshore waters inshore of our sampling. Subyearling smolts of those stocks caught in ocean fisheries far to the north as maturing fish (e.g. Columbia River Upriver Bright Fall chinook, Howell et al.[7]) may migrate to the north while they are still in shallow waters near the surf zone and thus may not be available to sampling over deeper water. Even large age-0.0 fish may prefer shallow water habitats. In late summer, when many age-0.0 fish should be quite large, this age class was rare in our samples. Our only large catches of age-0.0 fish (in September 1983) were inshore of 4 km (Fig. 4).

The apparent difference in inshore-offshore distribution between age-0.0 and age-1.0 chinook salmon suggests that these two age groups are exposed to different environmental conditions in the ocean and that different factors may be critical in determining their survival in the ocean. Small subyearling chinook salmon may be more susceptible than yearling chinook salmon to processes affecting the nearshore environment, such as storms that cause heavy surf conditions, concentrations of nearshore predators, or nearshore dredging and other habitat modifications. On the other hand, by staying in shallow nearshore waters, where southward currents in the summer tend to be slower than 15–20 km farther offshore (Kundu and Allen, 1976; Huyer, 1983), the northward movement of the small subyearling fish may be facilitated.

In contrast to stream-type age-1.0 chinook salmon from the Columbia River, some ocean-type fish may overwinter in areas near where they enter the ocean. We found four age-0.1 CWT fish of the Columbia River URB fall chinook salmon stock, which is harvested mainly in Alaska and British Columbia ocean fisheries (Howell et al.[7]), near or south of the Columbia River many months following their release from hatcheries. Apparently, some individuals of this highly migratory ocean-type stock may delay their northward migration for a long period of time. Alternatively, the extent of the migrations of individuals of this stock may vary. Those that mature at younger ages (jacks for example) may undertake less extensive migrations than those that spawn at older age.[5]

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