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Abstract.—The effects of ocean conditions on highly migratory species such as salmon are difficult to assess owing to the diversity of environments they encounter during their marine life. In this study, we reconstructed the initial ocean migration routes of juvenile Chinook salmon *Oncorhynchus tshawytscha* originating from Oregon to Southeast Alaska using coded wire tag recovery data from Canadian Department of Fisheries and Oceans and National Marine Fisheries Service research surveys conducted between 1995 and 2006. Over this 12-year period, 1,862 coded-wire-tagged juvenile Chinook salmon were recovered along the coasts of Oregon, Washington, British Columbia, and Alaska from March to November. Except for those from the Columbia River, most juvenile Chinook salmon remained within 100–200 km of their natal rivers until their second year at sea, irrespective of their freshwater history and adult run timing. Northward migration of most coastal stocks was initiated during their second or possibly third year at sea, whereas the Strait of Georgia and Puget Sound stocks primarily migrated onto the continental shelf after their first year at sea. In contrast, Columbia River Chinook salmon generally undertook a rapid northward migration that varied among life histories and stocks. Columbia River spring Chinook salmon were recovered as far north as Prince William Sound, Alaska, during their first summer at sea, whereas very few Columbia River fall Chinook salmon were recovered north of Vancouver Island. In addition to northern migrants, a fraction of the Columbia River spring and fall Chinook salmon actively migrated south of the Columbia River. The stock-specific initial ocean migration routes described in this study will aid in the identification of the appropriate spatial and temporal scales for assessing the processes regulating Chinook salmon recruitment in the marine environment.

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During the 1980s and 1990s, large-scale declines in the returns of Pacific salmon *Oncorhynchus* spp. from California to south-central British Columbia brought some stocks to the verge of extirpation in less than a decade, even in nearly pristine watersheds (Brown et al. 1994; NRC 1996; McKinnell et al. 2001). Adult returns have been so low for some southern stocks that severe fishing restrictions and closures have been put in place to protect and rebuild these stocks (McKinnell et al. 2001; PFMC 2008), resulting in major economic losses for some coastal communities (Beamish et al. 1999). Several southern stocks are considered threatened or endangered and have been listed under the U.S. Endangered Species Act in California, Oregon, and Washington (NRC 1996; NMFS 2006), or by the Committee on the Status of Endangered Wildlife in Canada in British Columbia (Irvine et al. 2005). Although a number of factors may be responsible for the decline of the southern stocks, the simultaneous decline of salmon originating from geographically distant watersheds suggests that a common cause is affecting these stocks in the marine environment (Beamish et al. 2000; Welch et al. 2000; McKinnell et al. 2001). Furthermore, although salmon hatchery production has remained stable over a long period, the marine survival of hatchery-released salmon has decreased drastically during this period (Beamish et al. 2000; Magnusson 2002; Logerwell et al. 2003), indicating that, in some areas, the reduction in adult returns was primarily due to changes in ocean conditions rather than salmon smolt production (Briscoe et al. 2005).

The effects of ocean conditions on salmon production have usually been assessed by correlating indices of salmon production (such as total catch, the residuals of a stock–recruitment curve, marine survival, and growth) with some environmental or climate indices that are integrated or averaged over a specific geographic area and time period (e.g., season or year; Logerwell et al. 2003; Peterson and Schwing 2003; Briscoe et al. 2005; Scheuerell and Williams 2005). The implicit assumption of these analyses is that salmon production is driven by events occurring at these spatial and time scales and that salmon are primarily distributed in or near these regions during these periods or is determined before their arrival in these regions (Scheuerell and Williams 2005). Although it is fairly well established that juvenile Pacific salmon generally undertake a northward migration along the continental shelf (Hartt and Dell 1986; Groot and Margolis 1991; Pearcy 1992), the extent of the spatial and seasonal variations in the distribution of juvenile salmon from different stocks is poorly known for most stocks (Welch et al. 2002, 2004; Morris et al. 2007). Implicit in these studies is the assumption that climate change will have little or no impact on the migratory behavior of salmon.

In this study, we examine the migratory behavior of juvenile Chinook salmon *O. tshawytscha* over a large geographic area on the West Coast of North America. Chinook salmon are broadly distributed along this coast, ranging from central California (approximately 37°N) to northern Alaska (approximately 68°N) and rear in streams during their juvenile freshwater phase (Healey 1991). Seaward migration of Chinook salmon smolts can take place within a few months after their emergence from gravel (i.e., as subyearlings) or after completing a full year in freshwater (i.e., as yearlings). Mature Chinook salmon may return to their natal river within their first or second year at sea as minijacks or jacks, respectively, though the majority of Chinook salmon return after spending 2–4 years at sea (Healey 1991). The spawning migration of mature Chinook salmon occurs at nearly any time of the year, depending on their geographic distribution: spring runs (hereafter, spring Chinook salmon) predominate in Alaska, whereas fall runs (hereafter, fall Chinook salmon) are almost exclusively distributed south of 56°N, where they predominate in all runs except those of the Fraser River (British Columbia) and the Columbia River (Washington–Oregon), in which spring and summer runs are highly abundant (Major et al. 1978; Healey 1983; Waples et al. 2004). In addition, winter runs occur in Oregon and California. Spring and fall Chinook salmon smolts typically migrate to sea as yearlings and subyearlings (Healey 1991), respectively, though alternative seaward migratory tactics have been reported for wild fall Chinook salmon (Connor et al. 2002, 2005). In addition, hatcheries sometimes alter salmon life cycles by releasing spring Chinook salmon as subyearlings or fall Chinook salmon as yearlings (Connor et al. 2004). The smolts of summer runs migrate to sea both as yearlings and subyearlings (Waples et al. 1991). Summer runs are closely related to spring runs in the Fraser River system as well as in the lower Columbia River and Snake River, but to fall runs in the upper Columbia River (Brannon et al. 2004; Waples et al. 2004; Beacham et al. 2006). Thus, for the purpose of this study, we classified juvenile Chinook salmon based on the duration of the fry stage (i.e., yearling versus subyearling) and the timing of the spawning migration (i.e., spring versus fall).

The migratory behavior of Chinook salmon has primarily been investigated using coded wire tag (CWT) recovery data obtained from immature and mature fish caught in commercial and recreational fisheries (Healey 1983, 1991) as well as from Chinook salmon tagged at sea (Major et al. 1978; Hartt and Dell 1986). Spring Chinook salmon are generally believed to undertake a rapid and directed northward migration along the continental shelf (Healey 1983, 1991; Hartt and Dell 1986), though Southeast Alaska stocks may

TABLE 1.—Research programs that contributed to this study of the ocean migration of juvenile Chinook salmon. Abbreviations are as follows: DFO = Department of Fisheries and Oceans Canada; NMFS = National Marine Fisheries Service.

Agency	Institute	Program	Study area	Years
DFO	Pacific Biological Station, Nanaimo, British Columbia	Climate and Salmon Interactions	Shelf off the west coast of Vancouver Island	1995–2004, 2006
	Pacific Biological Station, Nanaimo, British Columbia	High Seas Salmon	Shelf off British Columbia and Southeast Alaska, and inside straits of Southeast Alaska	1997–2006
NMFS	Alaska Fisheries Science Center, Juneau, Alaska	Ocean Carrying Capacity	Shelf off Southeast Alaska, south-central Alaska, central Alaska, and the Aleutian Islands	1996–2006
	Alaska Fisheries Science Center, Juneau, Alaska	Southeast Alaska Coastal Monitoring	Inside straits and coastal waters of Southeast Alaska	1997–2006
	Northwest Fisheries Science Center, Newport, Oregon	Global Ocean Ecosystem Dynamics	Shelf off northern California and southern Oregon	2000, 2002
	Northwest Fisheries Science Center, Newport, Oregon	Columbia River Plume Study	Shelf off northern Oregon and Washington	1998–2005

remain resident within local straits (Jaenicke and Celewycz 1994; Orsi et al. 2000). In contrast, fall Chinook salmon appear to establish residence in coastal waters near their ocean entry point (Healey 1983, 1991). However, very few studies have examined the migratory behavior of juvenile Chinook salmon, possibly because of the low recovery rate of coded-wire-tagged juvenile salmon at sea and the difficulty of determining the origin of untagged fish (Orsi and Jaenicke 1996). Genetic mixed-stocked analyses have recently been used to contrast the stock composition of juvenile Chinook salmon caught at sea and infer their migratory behavior (Teel 2004; Trudel et al. 2004). However, these studies generally focused on a few stocks over a relatively small area (<500–1,000 km), and may not capture the full range of migratory behaviors of juvenile Chinook salmon.

The objective of our study was to use CWT recovery data from trawl surveys conducted by Fisheries and Oceans Canada (DFO) and the National Marine Fisheries Service (NMFS) over 5,000 km of the western North American coastline to reconstruct the initial ocean migration routes and speeds of stocks of seven major origins: (1) Southeast Alaska, (2) the west coast of Vancouver Island, (3) the Strait of Georgia, (4) Puget Sound–Juan de Fuca Strait, (5) coastal Washington, (6) the Columbia River and Snake River system, and (7) coastal Oregon and California.

Methods

Sampling and data collection.—Pacific salmon were caught off the coasts of Oregon, Washington, British Columbia, and Alaska with midwater rope trawls that were towed at the surface (0–20 m) for 15–30 min at 2.5–5.0 knots on surveys conducted by DFO and NMFS in the spring (April–May), summer (June–August), fall (September–December) and winter (February–March) between 1995 and 2006 (Table 1; Figure 1). Further details can be obtained from Sweeting et al. (2003), Morris et al. (2004), Fisher et al. (2007), and Orsi et al. (2007).

Chinook salmon were measured for fork length and weight and scanned at sea or in the laboratory for CWTs. All juvenile Chinook salmon were examined for CWTs during the DFO surveys and the NMFS surveys off Oregon and Washington, but in some cases only adipose-fin-clipped salmon were examined on the NMFS surveys in Alaska. The CWTs were subsequently extracted in the laboratory and the binary or numeric codes etched on them visually decoded under a microscope.

The CWT release information, obtained by querying the Regional Mark Information System database (RMIS; www.rmpc.org), included the hatchery of origin, release site, release date, average size at release, adult run timing, brood and release years, and release region as defined by the Pacific States Marine Fisheries Commission (PSMFC). It is important to note that size at release was not available for individual Chinook smolts. Instead, when available, we used the average sizes of specific hatchery releases. While size may vary substantially among individual smolts within release groups (Nielson 1992), most smolts are expected to be close to the average size in a normally distributed sample, suggesting that the average release size is a reasonable indicator of individual size.

The information from each decoded fish was linked to capture date, location (latitude and longitude), and size (fork length, mass, or both). The combined capture and release data were grouped into the seven regions noted in the previous section. Recoveries of Chinook salmon released from California (n = 7), the central

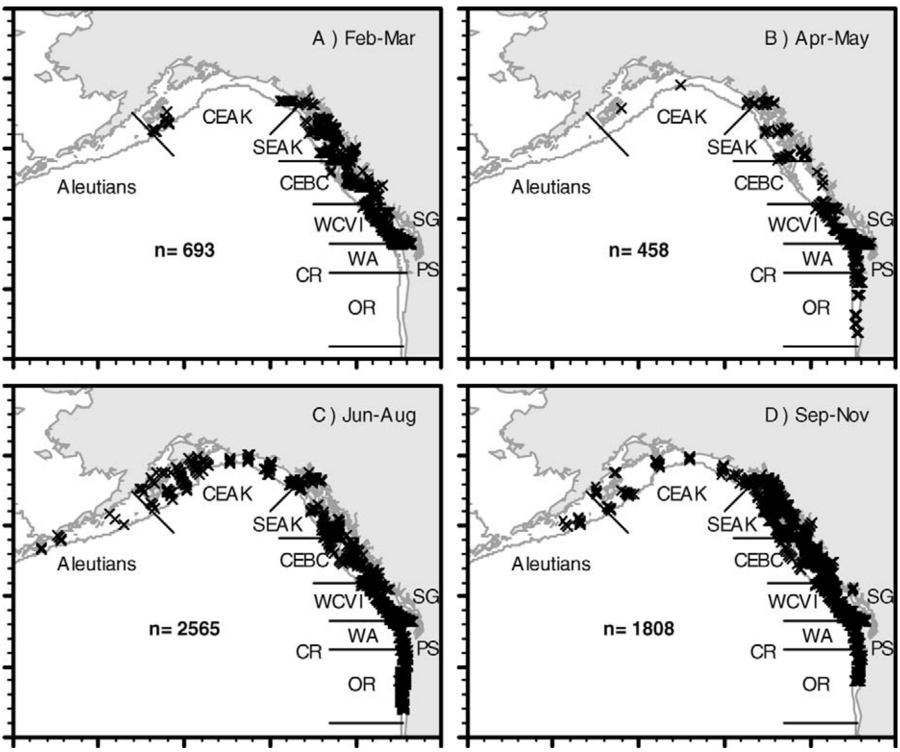

FIGURE 1.—Sampling stations surveyed by Fisheries and Oceans Canada and the National Marine Fisheries Service off the west coast of North America during **(A)** February–March, **(B)** April–May, **(C)** June–August, and **(D)** September–November 1995–2006. The solid line beyond the margin of the continent represents 1,000 m depth. For the purpose of this study, the 500-m isobath was used to define the limit of the continental shelf. Abbreviations are as follows: CEAK = central Alaska, SEAK = Southeast Alaska, CEBC = central British Columbia, WCVI = the west coast of Vancouver Island, WA = Washington, CR = the Columbia River, OR = Oregon and California, PS = Puget Sound (Puget Sound and the Strait of Juan de Fuca), and SG = the Strait of Georgia (the Fraser River and the east coast of Vancouver Island).

coast of British Columbia ($n = 6$), the northern coast of British Columbia ($n = 6$), and central Alaska ($n = 5$) were excluded from this study as there were insufficient recoveries to assess migratory behavior, either because few fish were released in these regions or the regions were not adequately sampled in this study.

Selection criteria.—The following criteria were used to select the fish for our analyses: (1) smolts had to have been released over a period of less than 100 d, (2) fish had to be in their first (ocean age 0) or second year at sea (ocean age 1), (3) stations had to be located within the 500-m isobath, (4) net hauls had to be ones in which the headrope was kept above 15 m, and (5) fish recovery dates had to occur after release dates. In addition, we excluded smolts released in September–February in Alaska and the Columbia River, as some smolts appear to remain in freshwater until the following spring before migrating to sea. Thus, overall, 139 CWTs or 6.9% of the recoveries were excluded from our analyses, including 43, 66, 26, 3, and 1 ocean-age 0, 1, 2, 3, and 4 Chinook salmon, respectively. It is noteworthy that approximately two-thirds of the Chinook salmon that were caught in deeper tows were in their second year at sea, possibly because larger and older fish forage in deeper waters (Orsi and Wertheimer 1995).

Migratory behavior and dispersal rates.—The timing, direction, and extent of region-specific migrations of juvenile Chinook salmon along the continental shelf off the West Coast of North America were determined by plotting CWT recoveries by release region and season or year onto electronic charts. All the distribution maps were generated using the PBSMapping package in R (R Development Core Team 2008; Schnute et al. 2008). Ocean migration distances were calculated by summing the great circle distances between a series of points along the continental shelf from the point of ocean entry to the capture location. Total migration distances for the Columbia–Snake River system and the Fraser River system releases included both the ocean migration distance and the downstream river distance, which was the sum of the

TABLE 2.—Sampling effort by season and capture location. Winter = February–March, spring = April–May, summer = June–August, and fall = September–December. Abbreviations are as follows: CEAK = central Alaska, SEAK = Southeast Alaska, CEBC = central British Columbia, and WCVI = the west coast of Vancouver Island.

Sampling location	Winter	Spring	Summer	Fall	All seasons
Number of stations					
Aleutian Islands	0	0	11	10	21
CEAK	15	2	160	41	218
SEAK	158	60	892	417	1,527
CEBC[a]	174	24	295	313	806
WCVI[b]	341	187	464	612	1,604
Washington	5	84	199	193	481
Columbia River Plume	0	46	92	61	199
Oregon	0	55	452	161	668
All regions	693	458	2,565	1,808	5,524
Surface area (km^2)					
Aleutian Islands	0	0	3.1	1.2	4.3
CEAK	1.8	0[c]	35.4	5.4	42.6
SEAK	23.3	4.0	49.8	53.7	130.8
CEBC[a]	25.6	3.3	44.8	45.6	119.3
WCVI[b]	53.2	44.4	66.9	96.1	262.6
Washington	1.5	11.5	19.5	18.9	51.4
Columbia River Plume	0	3.8	8.5	5.2	17.5
Oregon	0	5.1	40.2	14.8	60.1
All regions	105.4	72.1	268.2	240.9	686.6

[a] Includes the west coast of the Queen Charlotte Islands.
[b] Includes Juan de Fuca Strait and Queen Charlotte Strait.
[c] The surface area covered by the two sampling events was not reported in the original study.

distance from the estimated release location to the nearest point on the river system and the distance along the river system from this point to its mouth (Morris et al. 2007). As it was not possible to identify the Snake River Chinook salmon that had been transported below Bonneville Dam, we assumed that all the Snake River Chinook salmon were released in the Snake River. As a result, the dispersal rates of these fish may be somewhat overestimated.

Geographic coordinates for release locations were found by searching the Geographic Names Information System provided by the U.S. Geological Survey for U.S. releases (geonames.usgs.gov) and the Geographical Names of Canada Web site provided by Natural Resources Canada for Canadian releases (geonames.nrcan.gc.ca). It was not always possible to determine the exact release location when releases were not at a hatchery. In those cases, position coordinates were selected either at the midpoint of the release stream or from geographic references provided by RMIS. Any potential errors in the release coordinates selected by these means were judged to be minor in relation to the combined downstream and alongshore migration distances (Morris et al. 2007).

Dispersal rates were calculated by dividing the total migration distance by the number of days at liberty, and thus included the downstream migration speed for Columbia River and Fraser River Chinook salmon (Welch et al. 2002; Morris et al. 2007). The median date of release was used to determine the number of days at liberty in cases in which releases took place over a range of dates that did not exceed 14 d. Smolts that were released over a period that exceeded 14 d were excluded for the estimation of dispersal rates. Migratory behavior and dispersal rates were compared in terms of release region, run timing (spring versus fall), and freshwater rearing duration (yearling versus subyearling). Summer runs were pooled with spring runs for all stocks except the upper Columbia River summer runs, which were included with fall runs based on DNA analyses (Brannon et al. 2004; Waples et al. 2004; Beacham et al. 2006). We also included winter runs ($n = 1$) with fall runs.

Results

Sampling and Release Effort

Fishing effort varied among regions and seasons (Table 2; Figure 1). On a regional level, it was highest off the west coast of Vancouver Island and Southeast Alaska and lowest off the Aleutian Islands. On a seasonal level, the highest fishing effort was during the summer, while the lowest was during the spring. No sampling was conducted for a few combinations of regions and seasons. Overall, a total of 5,524 fishing events covering an area of 687 km^2 contributed to the data set used for this study (Table 2).

Release effort also varied substantially among stocks (Table 3). Over the 12-year time period 1995–2006, hatcheries released approximately 15–25 times more coded-wire-tagged fish in the Columbia River (199

TABLE 3.—Releases and recapture success of coded-wire-tagged ocean-age-0 and ocean-age-1 Chinook salmon from seven areas that produce this species on the west coast of North America, 1995–2006. See Table 2 for abbreviations.

Release location	Number of releases	Number caught	Catch per million fish
SEAK	9,918,426	122	12.3
WCVI	7,395,865	73	9.9
Strait of Georgia[a]	20,269,243	27	1.3
Puget Sound[b]	76,678,156	182	2.4
Washington	8,265,276	37	4.5
Columbia River	198,754,363	1,331	6.7
Oregon	11,719,897	90	7.7
All regions	333,601,226	1,862	5.6

[a] Includes the Fraser River, the east coast of Vancouver Island, and the lower mainland of British Columbia.

[b] Juan de Fuca stocks were pooled with Puget Sound stocks based on DNA analysis.

million) than any other coastal system, the annual releases approaching 17 million tagged smolts (Table 3). The second-highest release occurred in Puget Sound, with a total of 77 million tagged smolts being released over the same time period, or about 6 million per year (Table 3). Approximately 0.6–1.0 million tagged smolts were released on an annual basis in the other regions (Table 3).

A total of 1,862 tagged juvenile Chinook salmon originating from the Oregon coast (42°21′N) to Southeast Alaska (59°22′N) were recovered on the continental shelf during the juvenile salmon surveys conducted between 1995 and 2006 (Table 3; Table A.1 in the appendix). Overall, approximately six tagged fish were recovered per million released. However, the number of tagged fish recovered relative to the number released varied tenfold among production areas (Table 3). For instance, 72, 10, and 7% of the tagged Chinook salmon captured in this study originated from the Columbia River, Puget Sound, and Alaska, respectively (Table 3). Yet typically less than three fish per million releases were recovered from Puget Sound, while more than nine fish per million releases were recovered for the west coast of Vancouver Island and Southeast Alaska stocks (Table 3).

Tagged Chinook salmon were recovered from the Oregon coast to Kodiak Island in central Alaska (Tables 4, A.1, A.2; Figures 2–4). No tagged juvenile Chinook salmon were recovered along the Aleutian Islands (Tables A.1, A.2; Figures 2–4), though sampling effort was low and limited to the summer and fall in this region (Table 2). The recovery of tagged Chinook salmon per unit effort varied among regions, seasons, and age-classes (Table 4). The catch per unit effort (CPUE) of ocean-age-0 fish was higher than that of ocean-age-1 fish for all combinations of season and region except during winter and spring along the west coast of Vancouver Island, central British Columbia, and Southeast Alaska (Table 4). The CPUE of ocean-age-0 Chinook salmon generally decreased from spring through fall and continued to decrease from winter through fall when the fish were ocean age 1 (Table 4). The highest CPUE of ocean-age-0 Chinook salmon was observed in the Columbia River plume in the spring, followed by the coast of Washington in the summer

TABLE 4.—Catch per unit effort (number of fish recovered per 10 km^2) of coded-wire-tagged ocean-age-0 and ocean-age-1 Chinook salmon by season and capture location. See Tables 2 and 3 for abbreviations and other details.

Sampling location	Winter	Spring	Summer	Fall	All seasons
Ocean age 0					
Aleutian Islands			0	0	0
CEAK	0		2.8	0	2.3
SEAK	0	0	11.8	11.4	9.2
CEBC[a]	0	0	8.5	2.0	3.9
WCVI[b]	3.8	3.6	29.9	11.4	13.3
Washington	0	87.8	168.2	53.4	102.9
Columbia River Plume		613.2	80.0	19.2	178.7
Oregon		15.7	19.9	41.9	25.0
All regions	1.9	49.7	29.2	14.6	22.1
Ocean age 1					
Aleutian Islands			0	0	0
CEAK	0		3.1	0	2.8
SEAK	3.0	10.0	2.6	0.6	2.1
CEBC[a]	0	3.0	0.7	0.4	0.5
WCVI[b]	23.7	17.3	8.4	1.0	10.3
Washington	0	16.5	1.5	1.1	4.7
Columbia River Plume		2.6	5.9	0.0	3.4
Oregon		2.0	0.5	0.7	0.7
All regions	12.6	14.4	3.5	0.7	5.1

[a] Includes the west coast of the Queen Charlotte Islands.

[b] Includes Juan de Fuca Strait and Queen Charlotte Strait.

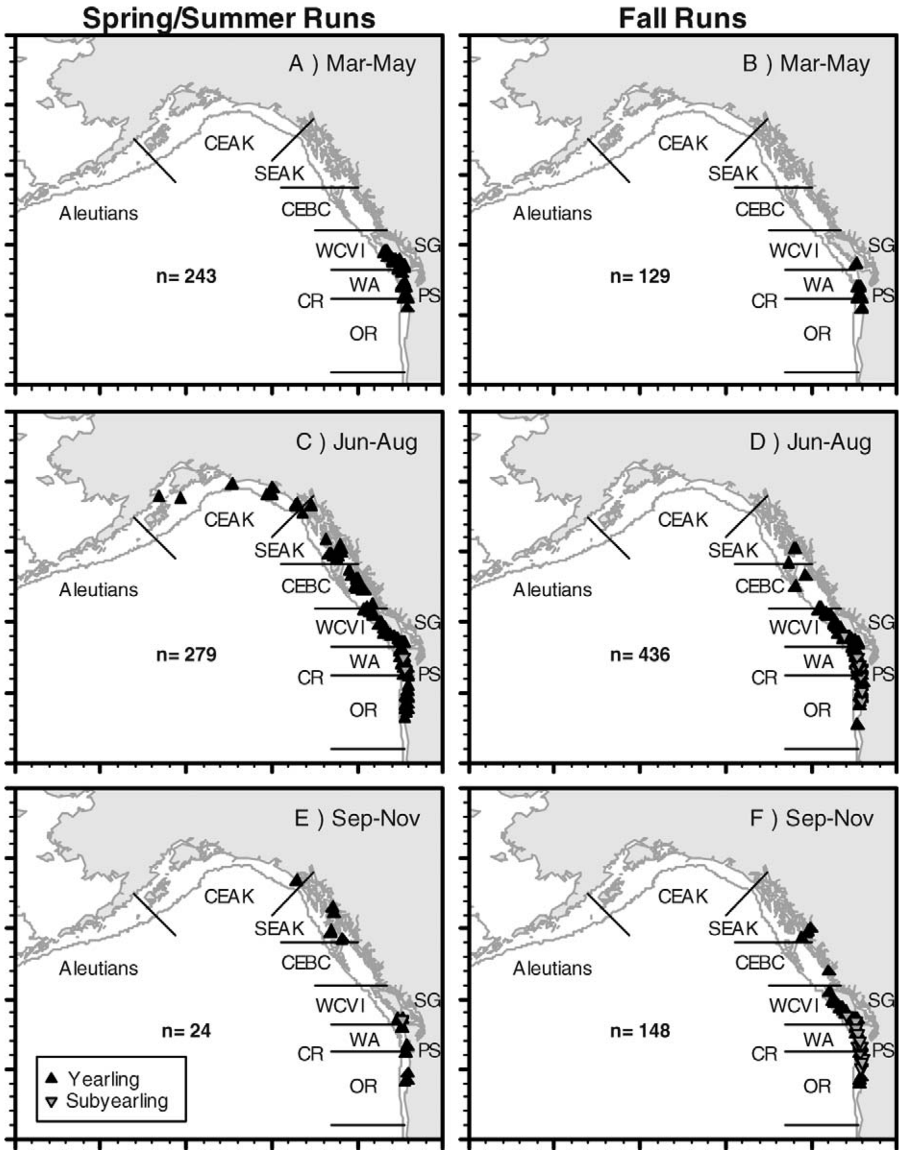

FIGURE 2.—Recovery locations of coded-wire-tagged juvenile (ocean-age-0) Columbia River spring–summer and fall Chinook salmon released as yearlings or subyearling and recovered in **(A)–(B)** March–May, **(C)–(D)** June–August, and **(E)–(F)** September–November 1995–2006. Upper Columbia River summer runs were included with fall runs based on DNA analysis (Brannon et al. 2004; Waples et al. 2004; Beacham et al. 2006). See Figure 1 for abbreviations.

(Table 4); this is probably due to the larger number of tagged Chinook salmon smolts released in the Columbia River than in other coastal areas (Table 3).

Release Size and Date

The release size and date of the juvenile Chinook salmon recovered in this study varied substantially within and among regions and between yearlings and subyearlings (Table 5). Average release dates ranged from early February to late August for certain Oregon and Columbia River stocks, whereas they were generally in April and May for other stocks (Table 5). Average release size ranged from 78 to 150 mm among subyearlings and from 106 to 169 mm among yearlings (Table 5). Overall, yearling Chinook salmon smolts were generally released earlier and at larger sizes than subyearling smolts, although subyearling fish released late in summer in the Columbia River

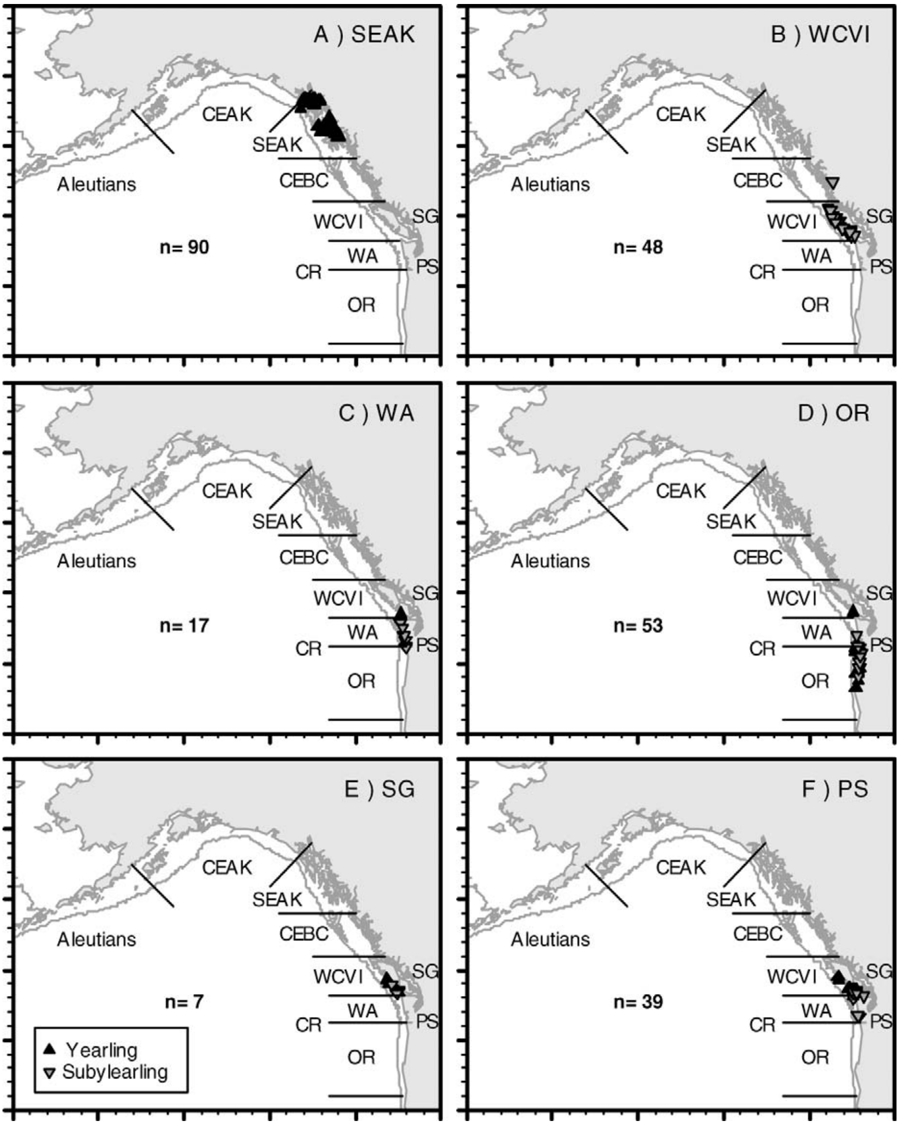

FIGURE 3.—Recovery locations of coded-wire-tagged ocean-age-0 yearling and subyearling Chinook salmon originating from **(A)** Southeast Alaska, **(B)** the west coast of Vancouver Island, **(C)** the coast of Washington, **(D)** the coasts of Oregon and California, **(E)** the Strait of Georgia, and **(F)** Puget Sound in 1995–2006. See Figure 1 for abbreviations.

basin were also large (Table 5). In addition, smolts were generally released earlier in the year and at larger sizes at southern latitudes; the exceptions were subyearling Washington, Oregon, and Columbia River spring Chinook salmon (which were released late in the summer) and yearling Puget Sound Chinook salmon (which were the largest smolts) (Table 5).

Columbia River Spring Chinook Salmon

Yearling Columbia River spring Chinook salmon were typically released in March–April (Table 5). Upon ocean entry, they quickly dispersed over nearly 3,000 km along the continental shelf, ranging from Cape Arago, Oregon, in the south (43°12′N) to Kodiak Island, Alaska, in the north (Figures 2, 5A). In the spring, the limit to the northward migration of juvenile Columbia River spring Chinook salmon appeared to be near the northern tip of Vancouver Island, as they were not recovered in the surveys conducted farther north along the central coast of British Columbia and in Southeast Alaska (Figures 1, 2A). Northern migrants undertook a rapid migration in a counterclockwise

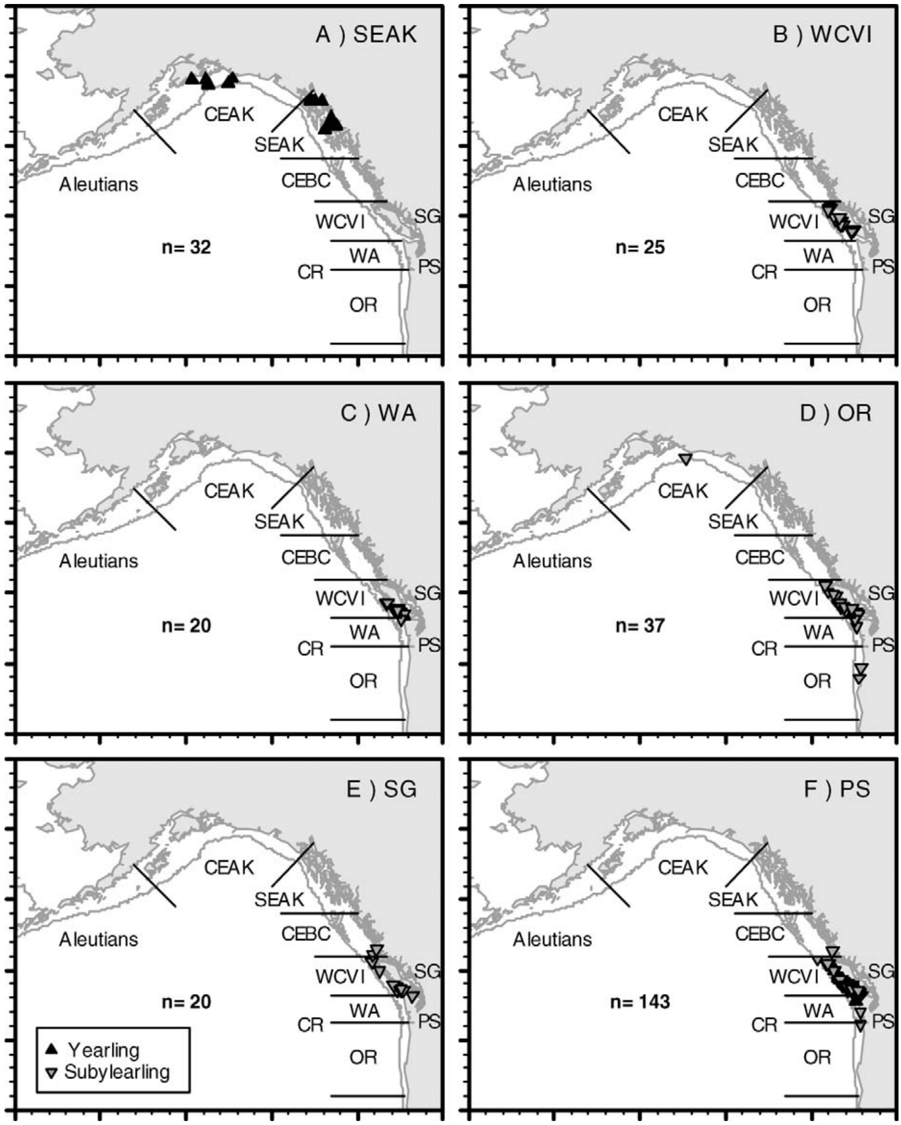

FIGURE 4.—Recovery locations of coded-wire-tagged ocean-age-1 yearling and subyearling Chinook salmon originating from **(A)** Southeast Alaska, **(B)** the west coast of Vancouver Island, **(C)** the coast of Washington, **(D)** the coasts of Oregon and California, **(E)** the Strait of Georgia, and **(F)** Puget Sound in 1995–2006. See Figure 1 for abbreviations.

direction on the shelf around the Gulf of Alaska and reached Southeast Alaska as early as June (after 1,200–1,600 km of ocean travel) and central Alaska as early as July (after 1,800–2,100 km of ocean travel) (Figures 2C, 5A). The combined river and ocean dispersal rates of northern migrants were highly variable, ranging from 1.8 to 36.5 km/d, with a modal speed around 10–20 km/d (Figure 6A). Juvenile Columbia River spring Chinook salmon moving slower than 10 km/d or faster than 20 km/d were not uncommon (Figure 6A).

Juvenile Columbia River spring Chinook salmon were observed as far as 340 km south of the Columbia River in the summer and fall (Figure 2C, E). However, the extent of their southward migration during spring could not be established in this study owing to the lack of sampling effort south of the Columbia River plume at this time of the year. Southern migrants were generally moving at slower speeds than northern migrants, their combined river and ocean dispersal rates averaging 5.2 and 14.0 km/d, respectively (Figure 6A). The majority

TABLE 5.—Release dates and fork lengths (mm) of the coded-wire-tagged ocean-age-0 and ocean-age-1 Chinook salmon recovered by Fisheries and Oceans Canada and the National Marine Fisheries Service off the west coast of North America in 1995–2006. When direct measurements were not available for fork length, it was estimated from weight using stock-specific length–weight relationships.

	Release date			Release fork length		
Origin	Mean	SD	*n*	Mean	SD	*n*
Yearlings						
SEAK	26 May	11.6	122	131.4	20.6	119
WCVI						
Strait of Georgia	11 Apr	4.0	3	106.3	5.7	3
Puget Sound	11 Apr	21.0	35	169.1	19.8	10
Washington	16 Apr	0	2			
Columbia River, spring–summer	30 Mar	22.9	543	146.8	23.5	412
Columbia River, fall	21 Apr	12.2	623	159.6	18.2	399
Oregon	14 Feb	27.0	12	150.0	7.4	12
Subyearling						
SEAK						
WCVI	28 May	11.4	73	82.8	7.9	73
Strait of Georgia	18 May	9.8	24	78.3	7.1	24
Puget Sound	17 May	11.3	147	87.0	9.5	75
Washington	10 Jul	31.9	35	100.5	16.2	34
Columbia River, spring–summer	24 Aug	76.9	21	150.2	31.7	15
Columbia River, fall	28 May	23.3	143	95.4	23.0	115
Oregon	17 Aug	30.8	78	134.0	9.9	78

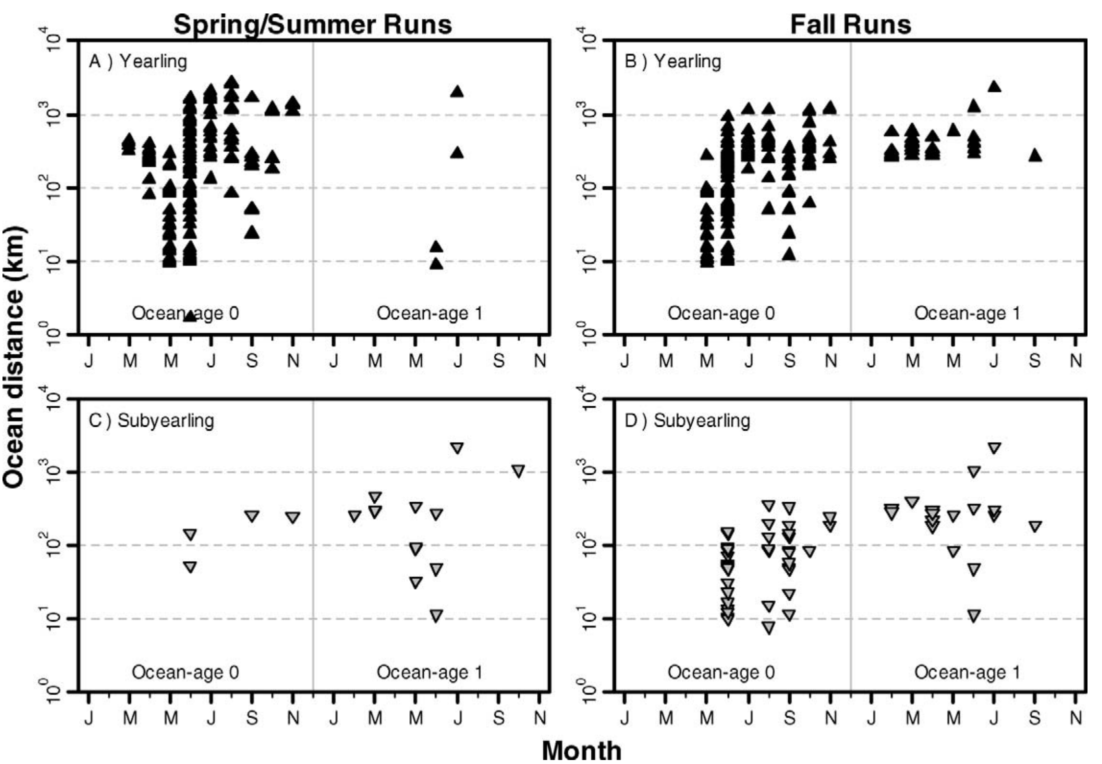

FIGURE 5.—Ocean migration distances of ocean-age-0 and ocean-age-1 Columbia River spring–summer and fall Chinook salmon released as **(A)–(B)** yearlings or **(C)–(D)** subyearlings, by recovery month in 1995–2006. Upper Columbia River summer runs were included with fall runs based on DNA analysis.

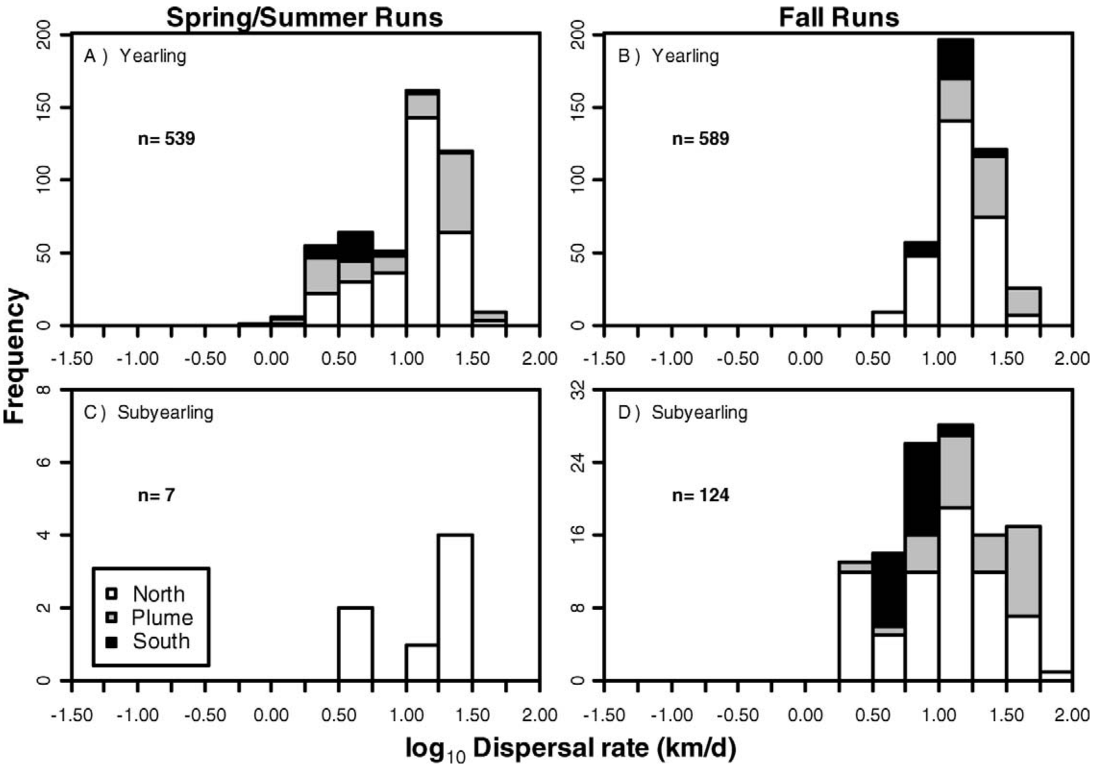

FIGURE 6.—Frequency distributions of $\log_{10}$ transformed dispersal rates (freshwater plus ocean migration) of juvenile (ocean-age-0) Columbia River spring–summer and fall Chinook salmon released as **(A)**–**(B)** yearlings or **(C)**–**(D)** subyearlings, by recovery location north or south of the Columbia River or near its mouth (plume) in 1995–2006. Upper Columbia River summer runs were included with fall runs based on DNA analysis.

(63%) of the yearling spring Chinook salmon that were caught south of the Columbia River originated from the Cowlitz River (Table A.1).

Overall, recoveries of yearling Columbia River spring Chinook salmon decreased by an order of magnitude between summer and fall (Figure 2C, E). Yet sampling effort only decreased by 10% during that time (Table 2B). Furthermore, very few ($n = 4$) yearling Columbia River spring Chinook salmon were recovered during their second year at sea (Figure 5A). These results suggest that yearling Columbia River spring Chinook salmon leave the continental shelf in late summer or fall (see Discussion). In contrast, the few subyearling ($n = 21$) Columbia River spring Chinook salmon that were recovered in this study were primarily (67%) caught during their second year at sea (Figure 5C) and north of the Columbia River, possibly because they were released relatively late in the summer.

Columbia River Fall Chinook salmon

Yearling Columbia River fall Chinook salmon were released on average about 3 weeks after the yearling spring Chinook salmon (Table 5). Upon ocean entry, they quickly dispersed over 1,500 km along the continental shelf, ranging from Island Rock, Oregon, in the south (42°41′N) to Clarence Strait, Southeast Alaska, in the north (Figures 2, 5B). However, relatively few yearling Columbia River fall Chinook salmon were recovered north of Vancouver Island during their first year at sea (Figure 2D, F). During summer and fall, the highest concentration of juvenile yearling Columbia River fall Chinook salmon occurred off the Washington coast and the Columbia River, followed by the west coast of Vancouver Island and northern Oregon (Figure 2D, F). In contrast, they were recovered primarily off the west coast of Vancouver Island—after traveling 300–600 km at sea—during their second year at sea (Figure 5B). Southern migrants were observed as far as 400 km south of the Columbia River in the summer and fall (Figure 2D, F) and originated primarily (67%) from the Snake River (Table A.1; Fisher et al., unpublished data). The combined river and ocean dispersal rates of yearling

Columbia River fall Chinook salmon were relatively uniform at around 10–30 km/d (Figure 6B).

Subyearling Columbia River fall Chinook salmon were typically released in May–June (Table 5). They were primarily recovered off the Washington coast, the Columbia River, and northern Oregon during their first year at sea (Figure 2D, F), but off the Washington coast and the west coast of Vancouver Island during their second year at sea (Figure 5D). The combined river and ocean dispersal rates of northern migrants were highly variable, ranging from 2.0 to 67.8 km/d (Figure 6D). Three modal speeds were apparent for subyearling Columbia River fall Chinook salmon, the slow, intermediate, and fast components swimming at 0–5, 5–15, and 15–55 km/d, respectively (Figure 6D). Southern migrants generally moved at slower speeds than northern migrants, their migrations averaging 6.4 and 15.3 km/d, respectively (Figure 6D).

The CPUE of yearling Columbia River fall Chinook salmon decreased from 1.4 fish/km^2 in the summer to 0.4 fish/km^2 in the fall (Figure 2D, F), and continued to decrease during the following year (Figure 5B). In contrast, the CPUE of subyearling Columbia River fall Chinook salmon remained relatively constant at 0.2–0.3 fish/km^2 during the summer and fall (Figure 2D, F) but decreased by an order of magnitude the following year (Figure 5D).

Coastal Stocks

Both yearling and subyearling releases of Chinook salmon originating from the coastal systems of Oregon, Washington, the west coast of Vancouver Island, and Southeast Alaska were generally recovered within 200–400 km of their ocean entry point during their first year at sea (Figures 3, 7). Thus, coastal stocks were comprised of slow migrants, movement rates typically ranging from nearly 0 to 10 km/d and averaging 0.4–1.2 km/d for subyearlings and 1.0–2.4 km/d for yearlings (Figure 8). Northward migration appeared to be initiated primarily in the second year at sea except for Chinook salmon from the west coast of Vancouver Island, which remained near their ocean entry points during both their first and second ocean years (Figures 3, 4, 7). A few Southeast Alaska and Oregon Chinook salmon were recovered near Prince William Sound during their second year at sea (Figure 4A, D), whereas nearly all coastal Washington stocks were recovered off the west coast of Vancouver Island during their second year at sea (Figure 4C). Fewer ocean-age-1 than ocean-age-0 fish were recovered from all these stocks except for coastal Washington stocks, possibly because the latter migrated mainly to an area (the west coast of Vancouver Island) where sampling effort was intensive (Table 2; Figures 3, 4).

Salish Sea

Few Strait of Georgia and Puget Sound Chinook salmon were recovered on the continental shelf during their first year at sea (Figures 3, 7). The majority of these fish were caught in Juan de Fuca Strait and at the southern end of the west coast of Vancouver Island (Figure 3E, F). Salish Sea stocks were comprised of slow migrants, their movement rates typically ranging from 1 to 10 km/d and averaging 1.5–2.6 km/d for subyearlings and 2.3–5.4 km/d for yearlings (Figure 8E, F).

Strait of Georgia and Puget Sound Chinook salmon were primarily recovered off the west coast of Vancouver Island during their second year at sea (Figure 4E, F). However, unlike Columbia River and coastal Chinook salmon stocks, catches of Strait of Georgia and Puget Sound Chinook salmon on the continental shelf increased by a factor of 2.9 and 3.7, respectively, between their first and second year at sea (Figures 3–4).

Discussion

Migratory Behavior

Two races of Chinook salmon have generally been recognized based on their freshwater life history strategy, ocean migration, and adult run timing (Gilbert 1913; Healey 1983, 1991). "Stream-type" Chinook salmon produce fry that remain in freshwater for one or more years before migrating to sea and are believed to undertake a rapid and extensive migration along the continental shelf, then rear in offshore waters before returning to their natal rivers in the spring and summer of subsequent years to spawn. "Ocean-type" Chinook salmon, which migrate to sea as subyearlings after rearing in freshwater for a few weeks or months, are believed to establish residence on the continental shelf before returning to their natal rivers in the summer and fall of subsequent years to spawn. Hence, based on the terminology used in this study, "stream-type" corresponds to yearling spring Chinook salmon and "ocean-type" corresponds to subyearling fall Chinook salmon.

The analyses performed in this study indicate that the migratory behavior of juvenile Chinook salmon we observed did not conform to the stream-type and ocean-type classifications proposed by Healey (1983, 1991). Juvenile Chinook salmon from coastal and Salish Sea stocks remained within 200–400 km of their natal rivers until their second year at sea, irrespective of their freshwater history (i.e., whether released as subyearlings or yearlings) or adult run timing (spring or fall). Orsi and Jaenicke (1996) also showed that Southeast Alaska and northern British Columbia stream-type Chinook salmon remained within the inside waters of Southeast Alaska for an extended

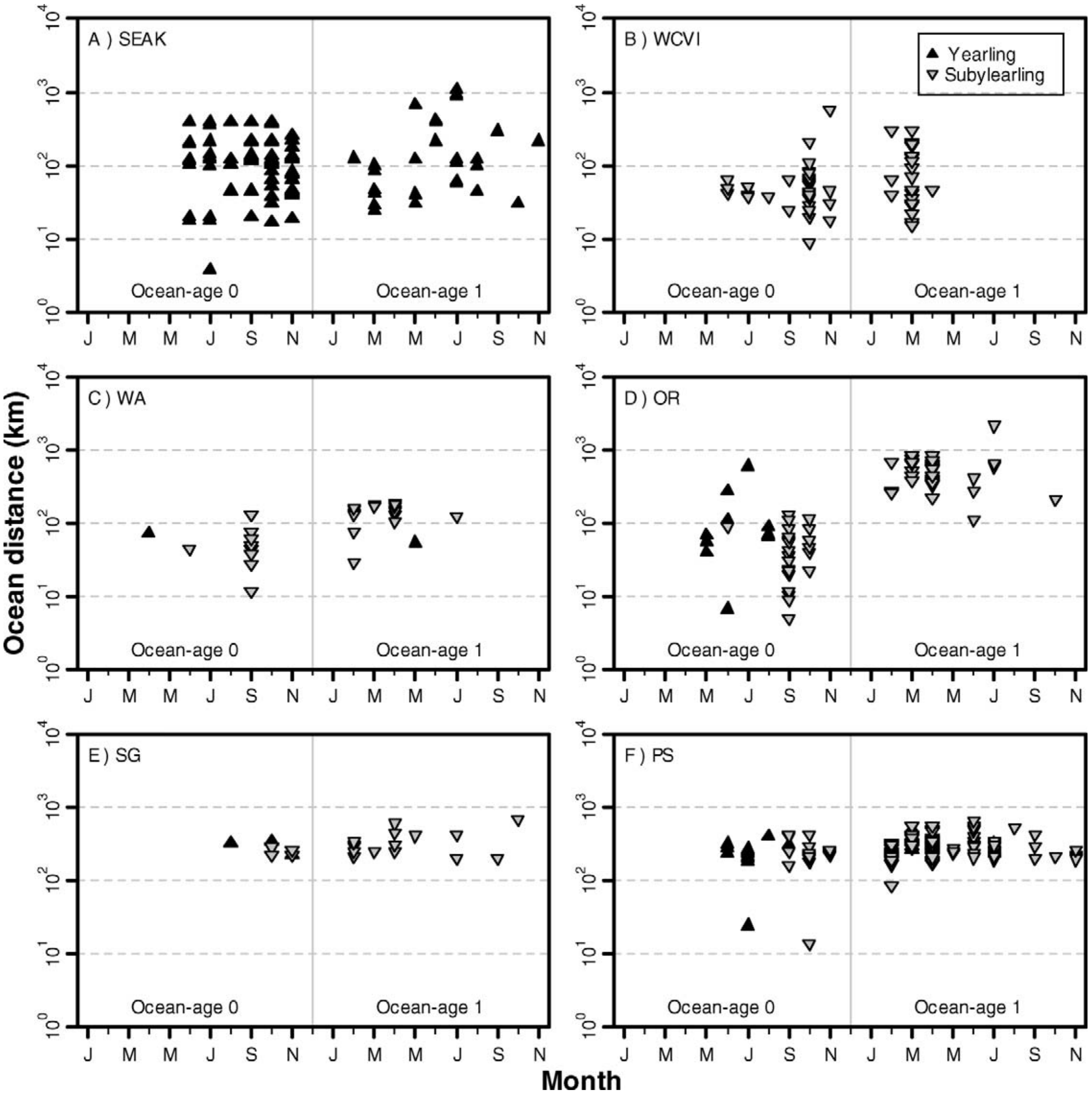

FIGURE 7.—Ocean migration distances of ocean-age-0 and ocean-age-1 yearling and subyearling Chinook salmon originating from **(A)** Southeast Alaska, **(B)** the west coast of Vancouver Island, **(C)** the coast of Washington, **(D)** the coasts of Oregon and California, **(E)** the Strait of Georgia, and **(F)** Puget Sound, by recovery month in 1995–2006.

period before migrating offshore. Although Chinook salmon released from California were not included in this study, as this region was poorly sampled (only northern California was in 2000 and 2002) and too few fish ($n = 7$) were recovered from it to properly assess their migratory behavior, they were generally recovered south of the Columbia River as ocean-age-0 and ocean-age-1 fish, suggesting that these coastal stocks also remain near their natal rivers during their first year at sea. Our analyses also showed that the northward migration of coastal stocks was initiated during their second year at sea for Southeast Alaska, Washington, and Oregon stocks or possibly during their third year at sea for west coast of Vancouver Island stocks, whereas Salish Sea stocks primarily migrated out of the Strait of Georgia and Puget Sound after their first year at sea, as CPUE increased by a factor of 3–4 between ocean ages 0 and 1 for these stocks. This increase is particularly significant considering the high mortality that can occur over winter in juvenile Pacific salmon (Beamish and Mahnken 2001). Salish Sea stocks appeared to migrate through Juan de Fuca Strait, as these fish were primarily recovered off the west coast of Vancouver Island rather than in Queen Charlotte Sound. It is

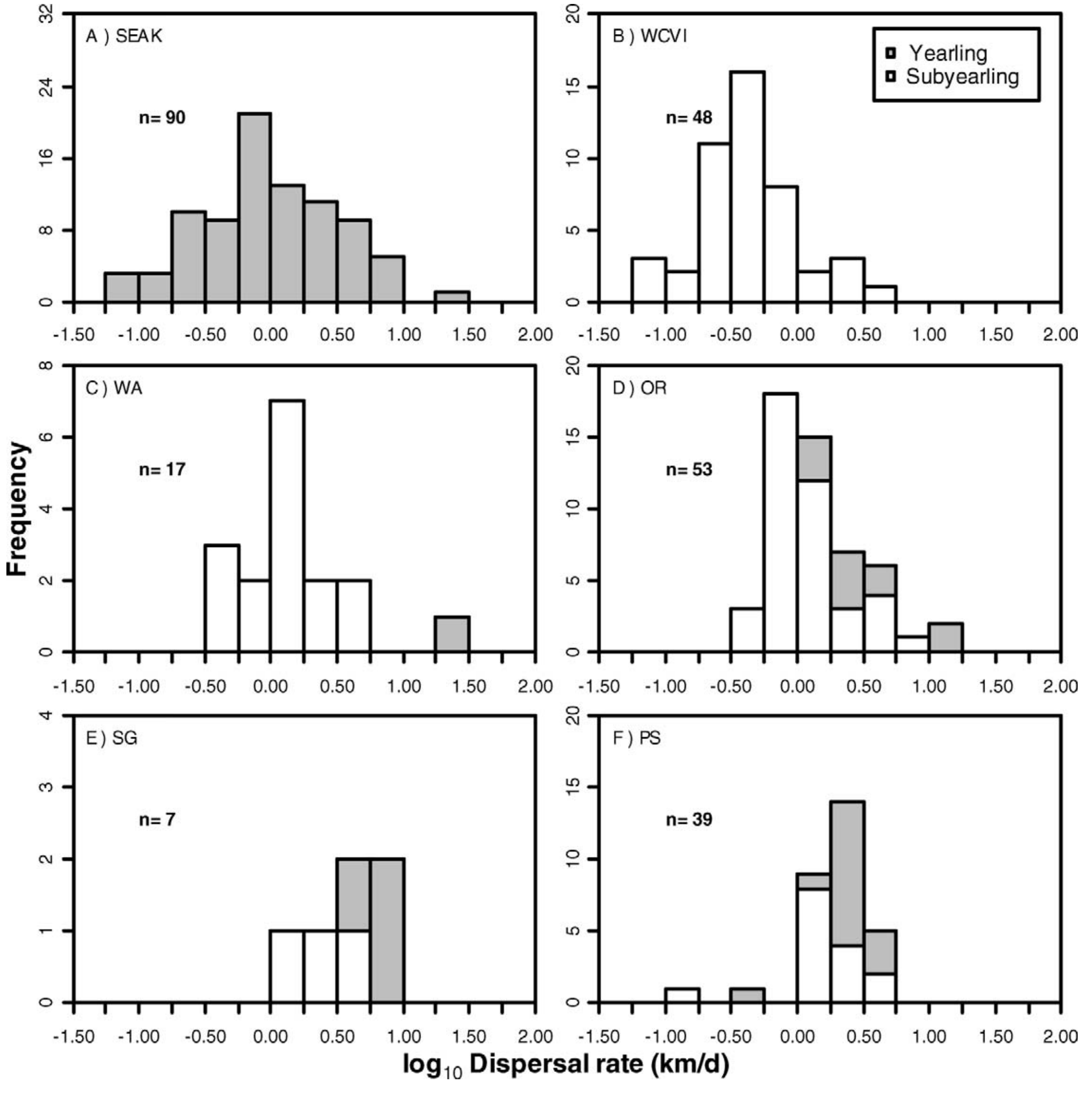

FIGURE 8.—Frequency distributions of $\log_{10}$ transformed dispersal rates (freshwater plus ocean migration) of juvenile (ocean-age-0) yearling and subyearling Chinook salmon originating from **(A)** Southeast Alaska, **(B)** the west coast of Vancouver Island, **(C)** the coast of Washington, **(D)** the coasts of Oregon and California, **(E)** the Strait of Georgia, and **(F)** Puget Sound, by recovery month in 1995–2006.

noteworthy that, with the exception of a few Puget Sound Chinook salmon, none of the juvenile Chinook salmon originating from coastal and Salish Sea stocks were recovered south of their region of origin. Yet older Chinook salmon are often caught south of their natal river (Healey 1983; Healey and Groot 1987; Weitkamp, in press), suggesting either that some juvenile Chinook salmon migrate south after their first year at sea or that adults that migrated offshore land on the continental shelf south of their natal river.

In contrast to coastal and Salish sea stocks, Columbia River Chinook salmon exhibited a diversity of migratory behavior. As expected for stream-type Chinook salmon, Columbia River spring Chinook salmon generally undertook a rapid northward migration that quickly brought them well beyond the Columbia River estuary and plume to expose them to the ocean conditions prevailing on the west coast of British Columbia and subsequently those in Alaska. As with Columbia River coho salmon *Oncorhynchus kisutch*, the combined downriver and northward ocean dispersal rates of Columbia River spring Chinook salmon were highly variable, with both fast and slow migrants (Morris et al. 2007; Fisher et al., unpublished data) and ocean dispersal rates that varied among the different Columbia River stocks (Fisher et al., unpublished data). Columbia River spring Chinook salmon did not establish residence on the continental shelf. Instead, they appeared to leave the continental shelf sometime late in the summer or in the fall, as CPUE decreased by a factor of ten between summer and fall and very few Columbia River spring Chinook salmon were recovered on the continental shelf during their second year at sea or reached the continental shelf off of the Bering Sea or Aleutian Archipelago. However, the data collected in this study are insufficient to determine where the northern migrants leave the continental shelf, as sampling in central Alaska and the Aleutian Islands was limited during both summer and fall and no sampling occurred in this region during winter.

Columbia River fall Chinook salmon also generally undertook a rapid downriver and northward migration, but very few were recovered north of Vancouver Island and their ocean dispersal rates appeared to be age-related, with the subyearling releases migrating considerably more slowly (Fisher et al., unpublished data). Although their distribution extended over a broader geographic area than those of the coastal and Salish Sea stocks (1,600 km versus 200 km), Columbia River fall Chinook salmon remained on the shelf for an extended period of time well into their second year at sea, suggesting that they also established residence on the shelf (Fisher and Pearcy 1995). Columbia River fall Chinook salmon released as subyearlings appeared to migrate over shorter distances than those released as yearlings (600 km versus 1,600 km; Fisher et al., unpublished data), possibly because the yearlings are released at a larger size (160 cm versus 95 cm) and earlier in the year (April 20 versus May 28).

In addition to the northern migrants, a fraction of the Columbia River spring and fall Chinook salmon migrated south of the Columbia River. Fisher and Pearcy (1995) argued that southern migrants had been advected south of the Columbia River by strong southward flows. The results obtained in this study also suggest that this southward migration was, at least in part, active. First, some juvenile Columbia River Chinook salmon were recovered more than 300 km south of the Columbia River and, in some cases, several months after ocean entry. Second, the release size of the juvenile Chinook salmon that were recovered south of the Columbia River was generally similar to that of those that were caught further north (M. Trudel, unpublished data), suggesting that the swimming capacity to overcome the southward flows of the California Current was similar for both northern and southern migrants, though the southern migrants were generally larger at capture. And finally, although most of the Columbia River Chinook salmon smolts entered the ocean in April–September, when the southward flows of the California Current are strongest (Strub and James 2000; Huyer et al. 2005), the proportion of southern migrants varied among basins and life history strategies within the Columbia River. The majority of the southern migrants were spring-run fish from the Cowlitz River and fall-run fish from the Snake River, whereas no Snake River spring Chinook salmon migrated south of the Columbia River (Tables A.1, A.2; Fisher et al., unpublished data). With the exception of the Cowlitz River stock, most of the spring Chinook salmon stocks that migrated south of the Columbia River were also recovered in Alaska, suggesting that they undertook a northward migration along the continental shelf before moving offshore or into the Bering Sea or Aluetian Islands. In contrast, none of the Cowlitz River spring Chinook salmon were recovered north of the west coast of Vancouver Island. Interestingly, Cowlitz River spring Chinook salmon that were released as subyearlings were all ($n = 5$) recovered in their second year at sea off the Oregon and Washington coasts, suggesting that they establish residence on the continental shelf.

Overall, these results indicate that migratory behavior may differ among stocks within a large river system such as that of the Columbia and Snake rivers (Fisher et al., unpublished data), possibly owing to the diversity of habitats and environmental conditions to which Chinook salmon are exposed as fry and adults in such systems. However, this interpretation is inconsistent with the migratory behavior observed among Chinook salmon originating from the Fraser River system (also a large-river system), as these fish appeared to remain within the Strait of Georgia during their first year regardless of age (yearling or subyearling) and migration timing (fall or spring). In addition to providing a diversity of habitats, the Columbia River system was also a refugium during the last glaciation (Waples et al. 2004; Beacham et al. 2006). Thus, selection may have operated over a longer time scale for this system and thereby favored the evolution of alternative migratory tactics.

Coded wire tags were particularly useful in this study of the migratory behavior of juvenile Chinook salmon, as they provide unequivocal information as to fish origins. However, the low recovery rate of tagged fish (approximately six per million releases) precluded interannual comparisons of juvenile Chinook salmon migratory behavior as well as the inclusion of stocks for which relatively few tagged fish are released, such as those from the central and northern coasts of British Columbia. In addition, nearly all of the tagged juvenile Chinook salmon recovered in this study were of hatchery origin. Thus, the extent to which the migratory behavior described in this study is applicable to wild Chinook salmon is currently unknown. Analyses of DNA offer a promising way to overcome these difficulties (Teel 2004; Trudel et al. 2004), as the origin of all the juvenile Chinook salmon that are collected at sea during any given survey can be determined with a high degree of accuracy (Beacham et al. 2006), provided the DNA baseline is extensive and rigorously tested.

Migration and Salmon Production

The effects of climate and ocean conditions on highly migratory species like Pacific salmon are usually difficult to predict owing to the diversity of environmental conditions that fish encounter during their marine life. As the recruitment dynamics of Pacific salmon are expected to be set within the first year of their marine life (Pearcy 1992; Beamish and Mahnken 2001), the processes regulating Pacific salmon production should be examined at the spatial scale at which juvenile salmon occur. The analyses performed in this study indicate that the effects of ocean conditions on Chinook salmon are expected to be manifested at a local scale for coastal and Salish Sea stocks (i.e., within 200–400 km of the natal river) and on the scale of the northern California Current (i.e., from Oregon to the west coast of Vancouver Island) for Columbia River fall Chinook salmon. The appropriate spatial scale for Columbia River spring Chinook salmon is currently difficult to determine owing to the diversity of migratory behavior and ocean entry timing observed in these fish, with both fast and slow northward migrants, southern migrants, and late and early migrants (this study; Fisher et al., unpublished data). As ocean conditions vary both among regions and months, different stocks of spring Chinook salmon originating from the Columbia and Snake River system may be exposed to different ocean conditions and may thus respond differently to climate change. A more specific description of the migratory behavior of individual Columbia and Snake River stocks is thus required to understand their responses to ocean conditions (Fisher et al., unpublished data).

A number of studies have attempted to assess the effects of climate and ocean conditions on Chinook salmon production (i.e., Beamish et al. 1995; Ruggerone and Goetz 2004; Scheuerell and Williams 2005; Wells et al. 2006, 2007, 2008). However, the results obtained in some of these studies are difficult to interpret, either because the authors relied on large-scale climate indices or because the ocean and climate indices were not calculated for the areas where Chinook salmon occur or at the time they migrated into these areas. For instance, Scheuerell and Williams (2005) used spring and fall upwelling indices measured at an offshore station (45°N, 125°W) to predict the marine survival of Snake River spring Chinook salmon. Yet none of the juvenile Snake River spring Chinook salmon were observed south of the Columbia River (~46°12′N) and undertook a rapid northward migration, such that by October none of them appeared to be on the continental shelf east of the Aleutian Islands. Similarly, as part of a study designed to examine the effects of local and large-scale environmental conditions on the growth of numerous Chinook salmon stocks, Wells et al. (2008) correlated the marine growth of Puget Sound (i.e., Salish Sea) and Taku River (i.e., Southeast Alaska) Chinook salmon to ocean conditions measured on the continental shelf off the west coast of Vancouver Island and Southeast Alaska, respectively. While these conditions may be appropriate for these stocks during their second or third year of life at sea, they may not reflect the environmental conditions experienced by juvenile Puget Sound and Taku River Chinook salmon, as these stocks appear to migrate onto the shelf primarily during their second year at sea. Thus, the results obtained in these studies must be interpreted cautiously, at least with respect to the survival and growth of juvenile Chinook salmon from these stocks.

Historically, the marine phase of the life cycle of Pacific salmon has often been treated as a black box, the assumption being that the marine environment is homogeneous. Yet the ocean conditions experienced by Pacific salmon are highly heterogeneous both in space and time (Mackas et al. 1998, 2001, 2007; McGowan et al. 1998, 2003; Orsi et al. 2007). The fate of individual salmon populations may thus depend on where they migrate in the ocean and the amount of time they spend in different regions of the ocean (Levin 2003; Welch et al. 2000). Hence, an understanding of stock-specific migration behavior is required to determine how climate and ocean conditions regulate Pacific salmon production. By describing the stock-specific migration routes used by juvenile Pacific salmon on the continental shelf, this study will aid in the identification of the appropriate spatial and temporal scales for assessing the processes regulating Chinook salmon production in the marine environment.

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Appendix: Recovery Locations

TABLE A.1.—Numbers of age-0 coded-wire-tagged Chinook salmon released from 12 areas along the west coast of North America, by recovery location. Asterisks denote yearling releases. Abbreviations are as follows: CEAK = central Alaska, SEAK = Southeast Alaska, CEBC = central British Columbia, WCVI = the west coast of Vancouver Island, WA = the coast of Washington, CR = the Columbia River, and OR = the coasts of Oregon and California.

	Recovery location						
Stock (latitude)	CEAK	SEAK	CEBC	WCVI[a]	WA	CR	OR
Southeast Alaska spring runs							
Tahini River* (59°14′)		5					
Taku River* (58°26′)		3					
Hidden Falls* (57°13′)		22					
Medvejie Hatchery* (57°01′)		3					
Whitman Lake* (56°47′)		4					
Crystal Creek* (56°44′)		14					
Macaulay Hatchery* (56°44′)		20					
Stikine River* (56°40′)		2					
Chickamin River* (56°20′)		10					
Little Port Walter* (56°18′)		1					
Unuk River* (56°17′)		4					
Ketchikan Creek* (55°20′)		1					
Tamgas Creek* (55°04′)		1					
West coast of Vancouver Island fall runs							
Marble River (50°30′)				2			
Conuma River (49°47′)				11			
Burman River (49°37′)				1			
Robertson Creek (49°19′)			1	16			
Tranquille Creek (49°07′)				1			
Sarita River (48°53′)				6			
Nitinat River (48°48′)				8			
San Juan River (48°35′)				2			
Fraser River spring–summer runs							
Shuswap River (50°43′)				1			
Salmon River* (50°42′)				2			
Fraser River fall runs							
Dome Creek* (53°45′)				1			
Capilano River (49°19′)				1			
Harrison River (49°16′)				1			
Chilliwack River (49°11′)				1			
Puget Sound spring–summer runs							
Nooksack River (48°54′)				2			
Skagit River* (48°30′)				1			
Skykomish River* (47°52′)				7			
White River (47°17′)				1			
White River*				1			

TABLE A.1.—Continued.

Stock (latitude)	Recovery location						
	CEAK	SEAK	CEBC	WCVI[a]	WA	CR	OR
Puget Sound fall runs							
Glenwood Springs* (48°42′)				1			
Friday Creek (48°33′)				1			
Issaquah Creek (47°33′)					1		
Grovers Creek (47°30′)				6			
Grovers Creek*				1			
Finch Creek (47°27′)				2	2		
Finch Creek*				1	1		
Purdy Creek (47°25′)				2			
Big Soos Creek (47°18′)				2	1		
Big Soos Creek*				2			
Clear Creek (47°11′)				1			
Juan de Fuca Strait spring–summer runs							
Dungeness River* (48°17′)				1			
Juan de Fuca Strait fall runs							
Elwha River* (49°20′)				1			
Hoko River (48°17′)				1			
Coastal Washington spring–summer runs							
Sol Duc River* (47°55′)				1			
Coastal Washington fall runs							
Sooes River (48°18′)					4		
Queets River (47°32′)					5		
Quinault Lake–River (47°26′)					5	1	
Cook Creek (47°22′)						1	
Lower Columbia River spring–summer runs							
Cowlitz River* (46°15′)				7	24	16	22
Kalama River* (46°04′)		2		1	2	4	2
Lewis River* (45°54′)		2	3	4	9	7	1
Lower Columbia River fall runs							
Elochoman River (46°16′)						1	
Cowlitz River (46°15′)						1	
Big Creek (46°09′)					7		
Abernathy Creek (45°57′)							1
Lewis River (45°54′)				1			
Spring Creek (45°44′)				1	12		
Willamette River spring–summer runs							
Sandy River* (45°24′)				1			
Clackamas River (45°20′), early				1			
Clackamas River, early*	1	2	2	5	5	7	1
Clackamas River, late*					2	6	2
Santiam River (44°59′)				1			
Santiam River*	2	2	3	6	10	7	2
McKenzie River (44°51′)				1			
McKenzie River*	2	1		4	11	3	1
Willamette River (44°32′)				1			
Willamette River*		1		21	9	2	1
Mid-Columbia River spring runs							
Carson River* (45°55′)		1	2				
Umatilla River* (45°55′)				1		1	
Klickitat River (45°47′)				1			
Klickitat River*				1	3	1	1
Little White Salmon River* (45°46′)		1		2	3		
Hood River* (45°36′)		1	2	1	1	4	
Warm Springs* (44°52′)		2	1	2	5	3	
Round Bute Hatchery* (44°52′)					1	2	
Deschutes River* (44°47′)	1	2	1		12	7	

TABLE A.1.—Continued.

Stock (latitude)	Recovery location						
	CEAK	SEAK	CEBC	WCVI[a]	WA	CR	OR
Mid-Columbia River summer–fall runs							
Mid-Columbia River (46°42′)					1		2
Bonneville Pool (46°02′)					2	2	1
Umatilla River (45°55′)					7		
Umatilla River*					1		
Little White Salmon River (45°46′)					2		
Upper Columbia River spring runs							
Chewuch River* (48°32′)				2	1		1
Twisp River* (48°26′)				2		1	
Methow River* (48°18′)		2	2	5	16	15	1
Chiwawa River* (47°47′)		2	2	7	10	5	
Entiat River* (47°42′)				1	1	3	
Leavenworth Hatchery* (47°35′)			1	5	14	14	
Yakima River* (47°14′)			1	3	3	1	
Wind River* (45°42′)	1	1	1	2	3	2	1
Upper Columbia River summer–fall runs							
Methow River* (48°18′)		1	4	31	55	20	2
Wells Hatchery (47°52′)					3	5	2
Wells Hatchery*		1	5	33	92	36	8
Wenatchee River* (47°27′)			2	30	77	29	6
Priest Rapids (45°58′)				1	3	6	3
Washington Brights (45°55′)					14	3	1
Upper Columbia River (45°51′)					1	3	6
Snake River spring–summer runs							
Dworshak Hatchery* (46°30′)	1		2	2	4	2	
Powell Rearing Ponds (46°29′)					1		
Powell Rearing Ponds*	1			1	2	3	
Tucannon River (46°29′)					1		
Tucannon River*				1		1	
Kooskia Creek* (46°08′)		1	1	1	1	2	
Grande Ronde River* (46°05′)				1		2	
Clearwater River* (45°47′)						2	
Rapid River* (45°41′)		1	6	7	11	17	
Lostine River* (45°34′)						1	
Imnaha River* (45°25′)		3	1	3	1	3	
Catherine Creek* (45°17′)			1			1	
Salmon River* (45°15′)	1	1	2	9	4	6	
Johnson Creek* (44°58′)						1	
Pahsimeroi Channel* (44°41′)				1	1	1	
Snake River fall runs							
Lower Snake River (46°22′)					1	1	1
Lower Snake River*			1	30	21	18	14
Lyons Ferry Hatchery (46°04′)					15	7	1
Lyons Ferry Hatchery*				13	21	20	18
Snake River (45°52′)				1	3		
Snake River, mixed stocks (45°52′)					1		1
Coastal Oregon spring–summer runs							
Nehalem River*[b] (45°55′)						1	1
Trask River (45°35′)							3
Nestucca River (45°13′)							3
Umpqua River* (43°20′)				1		1	7
Coastal Oregon fall runs							
Cole Rivers[b] (46°11′)						2	5
Nehalem River[b] (45°55′)					1		
Trask River (45°35′)							2
Salmon River (45°01′)							23
Yaquina River (44°37′)							1
Gardiner Creek (43°28′)							1
Umpqua River* (43°20′)							1

[a] Includes Juan de Fuca and Queen Charlotte straits.
[b] Released in the Columbia River.

TABLE A.2.—Numbers of age-1 coded-wire-tagged Chinook salmon released from 12 areas along the west coast of North America, by recovery location. Asterisks denote yearling releases. See Table A.1 for recovery location abbreviations.

	Recovery location						
Stock (latitude)	CEAK	SEAK	CEBC	WCVI[a]	WA	CR	OR
Southeast Alaska spring runs							
Jerry Myers Hatchery* (59°22′)		1					
Chilkat River* (59°15′)		1					
Taku River* (58°26′)		1					
Hidden Falls* (57°13′)		3					
King Salmon River* (57°13′)		1					
Whitman Lake* (56°47′)		1					
Crystal Creek* (56°44′)	2	11					
Macaulay Hatchery* (56°44′)	1	3					
Stikine River* (56°40′)		2					
Chickamin River* (56°20′)		2					
Unuk River* (56°17′)	2						
Tamgas Creek* (55°04′)	1						
West coast of Vancouver Island fall runs							
Marble River (50°30′)				2			
Conuma River (49°47′)				7			
Robertson Creek (49°19′)				10			
Kennedy River (49°08′)				1			
Sarita River (48°53′)				1			
Nitinat River (48°48′)				4			
Strait of Georgia fall runs							
First Lake (50°03′)				1			
Big Qualicum River (49°24′)				2			
Little Qualicum River (49°22′)				1			
Nanaimo River (49°08′)			1				
Cowichan River (49°48′)			1	3			
Fraser River spring–summer runs							
Salmon River (54°04′)				1			
Chilliwack River (49°11′)				1			
Fraser River fall runs							
Shuswap River (50°43′)				2			
Capilano River (49°19′)				1			
Harrison River (49°16′)				2			
Chilliwack River (49°11′)				4			
Puget Sound spring–summer runs							
Nooksack River (48°54′)				11			
Skagit River (48°30′)				13			
Skagit River*				8	1		
Stillaguamish River (48°15′)				8			
Wallace River (48°04′)				1			
Skykomish River (47°52′)				1			
Skykomish River*				2			
White River (47°17′)			1	4			
White River*					1		
Puget Sound fall runs							
Friday Creek (48°33′)				5			
Skagit River (48°30′)				1			
Wallace River (48°04′)			1	2			
May Creek* (47°52′)				1			
Skykomish River* (47°52′)				1			
Portage Bay (47°39′)				3	1		
Issaquah Creek (47°33′)				1			
Grovers Creek (47°30′)				19			
Grovers Creek*				2			
Finch Creek (47°27′)				4			
Purdy Creek (47°25′)				12	1		
Big Soos Creek (47°18′)				9	1		
Big Soos Creek*				2			
Nisqually Creek (47°13′)				10			
Clear Creek (47°11′)				4	2		
Kalama Creek (47°07′)							1
Voight Creek (47°06′)				8			

TABLE A.2.—Continued.

Stock (latitude)	Recovery location						
	CEAK	SEAK	CEBC	WCVI[a]	WA	CR	OR
Juan de Fuca Strait fall runs							
Hoko River (48°17′)				1			
Coastal Washington spring–summer runs							
Sol Duc River* (47°55′)				1			
Coastal Washington fall runs							
Sooes River (48°18′)				4			
Queets River (47°32′)				5			
Quinault Lake–River (47°26′)				7	2		
Cook Creek (47°22′)				1			
Lower Columbia River spring–summer runs							
Cowlitz River (46°15′)					2	1	2
Cowlitz River*						1	
Kalama River* (46°04′)				1			
Lower Columbia River fall runs							
Toutle River (46°22′)				1			
Elochoman River (46°16′)	1						
Columbia River (46°14′)				1			
Big Creek (46°09′)				2			
Abernathy Creek (45°57′)				1			
Spring Creek (45°44′)				1	2	1	
Willamette River spring–summer runs							
Santiam River (44°59′)	1			2			
McKenzie River (44°51′)				2	1		
McKenzie River*	1						
Willamette River (44°32′)	1						
Upper Columbia River spring runs							
Methow River* (48°18′)	1			1			
Upper Columbia River summer–fall runs							
Wells Hatchery (47°52′)				2	1		
Wells Hatchery*		1		11			
Wenatchee River* (47°27′)				5			
Hanford Reach (46°40′)			1				
Priest Rapids (45°58′)				1			
Washington Brights (45°55′)					1		
Upper Columbia River (45°51′)				1	1		
Upper Columbia River*				1			
Snake River spring–summer runs							
Powell Rearing Ponds (46°29′)						1	
Grande Ronde River (46°05′)			1				
Salmon River* (45°15′)						1	
Snake River fall runs							
Lower Snake River* (46°22′)				9			
Lyons Ferry Hatchery (46°04′)				1	1		
Lyons Ferry Hatchery*				5			
Coastal Oregon spring–summer runs							
Nestucca River (45°13′)	1						
Umpqua River (43°20′)				2			1
Coastal Oregon fall runs							
Cole Rivers[b] (46°11′)				4	2		
Trask River (45°35′)				3			
Salmon River (45°01′)				7	2		
Gardiner Creek (43°28′)					1		
Cow Creek (43°16′)				2			
Elk River (42°44′)				9			
Cole River (42°42′)					1		
Rogue River (42°42′)							1
Hunter Creek (42°21′)				1			

[a] Includes Juan de Fuca and Queen Charlotte straits.
[b] Released in the Columbia River.