Discussion

Although lunar rhythmicity in marine organisms, particularly marine invertebrates, has long been recognized (Palmer 1974), lunar rhythms in which a single peak of activity occurs each month in fishes appear to be rare (Gibson 1978). Most accounts of variations in catch rate of commercially important species which correlate with moon phase refer to clupeids (Gibson 1978). Blaxter and Holliday (1963) suggested several possible explanations for the apparent lunar rhythmicity of clupeid catches including: 1) intensity of moonlight, 2) effect of tides, and 3) fishermen behavior.

Gulf butterfish are normally trawled during daylight when they concentrate near bottom following nocturnal vertical migration. However, this migration is difficult to describe because conventional echo sounding equipment poorly tracks gulf butterfish movement owing to atrophy of the swim bladder in gulf butterfish over 100 mm standard length (Horn 1970). Differences in catch rates between lunar phases may be attributed to changing vertical movements of gulf butterfish in the water column. The lunar pattern is probably not due to onshore-offshore movement out of the fishery's area of operation. In the three research cruises, sampling was stratified by bottom depth (36-585 m) and data do not suggest horizontal movements of gulf butterfish outside these depths.

In conclusion, further work on lunar rhythmicity relationships of gulf butterfish is needed. Results may greatly enhance commercial and scientific efforts in harvesting and surveying gulf butterfish, respectively, by identifying alternate fishing methods (e.g., midwater trawling) that successfully target gulf butterfish during all moon phases.

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MOVEMENTS OF COHO, *ONCORHYNCHUS KISUTCH*, AND CHINOOK, *O. TSHAWYTSCHA*, SALMON TAGGED AT SEA OFF OREGON, WASHINGTON, AND VANCOUVER ISLAND DURING THE SUMMERS 1982-85

Knowledge of the migration patterns of salmonids in the ocean is an important consideration in developing fishery management plans. Catches of coded-wire tagged salmon in the ocean have yielded much information on general distribution patterns of different stocks and species of salmon (see for example Hunter [1985], Garrison [1985], and Howell et al. [1985]). Other studies have dealt with movements of salmon tagged in offshore waters of the northern North Pacific Ocean (Hartt 1962, 1966; French et al. 1975; Godfrey 1965; Godfrey et al. 1975) and in coastal waters of British Columbia, Washinton, Oregon, and California (Milne 1957; Vernon et al. 1964; Kauffman 1951; Van Hyning 1951; Fry and Hughes 1951). Movements of juvenile salmon in coastal waters of the Gulf of Alaska were studied by Hartt and Dell (1986); in Georgia Strait, British Columbia, by Healey (1980); and in coastal waters off Oregon and Washington by Pearcy and Fisher (unpubl. manuscr.)[1].

[1]W. C. Pearcy and J. P. Fisher. Migration of coho salmon (*Oncorhynchus kisutch*) during their first summer in the oceans. Unpubl. manuscr. College of Oceanography Oregon State University, Corvallis, OR 97331.

Movements of individual maturing salmon off Oregon and Washington are still poorly known. In this paper we examine migration after tagging of salmonids collected during purse seine cruises off the Oregon and Washington coasts from 1982 to 1985 and off the west coast of Vancouver Island, B.C., in 1984.

Methods

Maturing and juvenile salmon were collected by purse seine during May 1982, 1983, and 1985; June 1982-85; July 1984; and September 1982-84. Coho salmon, *Oncorhynchus kisutch*, were classified as maturing or juvenile, based on the length-frequency distribution of the catch in each month. The distribution was usually bimodal and the division between juvenile and maturing coho salmon was about 300 mm FL in May and June, 360 mm FL in July, and 420 mm FL in August and September. Chinook salmon, *O. tshawytscha*, ≤400 mm in all months were arbitrarily classified as juveniles.

Numbered orange Floy[2] tags were applied with a Dennison Mark II tagging gun between the pterygiophores just below the dorsal fin of fish anesthetized with MS-222. Fish were allowed to recover for a few minutes in tanks with circulating saltwater and then were released into the ocean. Date and location of release was recorded for each tagged fish. Condition of the fish after handling varied, but most swam vigorously in the recovery tank and rapidly swam away when released. However, some scale loss almost always occurred and for some individuals was extensive.

Information on movements of coho and chinook salmon was obtained from subsequent recoveries in ocean and terminal fisheries and on spawning grounds or at hatcheries. No reward was offered

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 1.—Summary of mark and recovery data for coho and chinook salmon tagged in the ocean off Oregon, Washington, and the west coast of Vancouver Island.

Year	Maturing coho No. tagged	Maturing coho No. rec. (%)	Juvenile coho No. tagged	Juvenile coho No. rec. (%)	Maturing chinook No. tagged	Maturing chinook No. rec. (%)	Juvenile chinook No. tagged	Juvenile chinook No. rec. (%)
1982	194	21 (10.8)	0	—	73	3 (4.1)	0	—
1983	142	17 (12.0)	0	—	5	1 (20.0)	0	—
1984	162	10 (6.2)	86	3 (3.5)	56	4 (7.1)	27	0 (0)
1985	215	13 (6.0)	18	0 (0)	37	8 (21.6)	46	1 (2.1)
All years	713	61 (8.6)	104	3 (2.9)	171	16 (9.4)	73	1 (1.4)

Other studies:	Maturing coho No. tagged	Maturing coho No. rec. (%)	Maturing chinook No. tagged	Maturing chinook No. rec. (%)
Fry and Hughes (1951) Tagging off California in 1939-42, 1948, 1949	954	26 (2.7)	6,144	483 (7.9)
Boydston (unpubl.) Tagging off California in 1971 and 1972	3,341	409 (12.2)		
Van Hyning (1951) Tagging off Oregon in 1948 and 1949	506	29 (5.7)	221	11 (5.0)
Kauffman (1951) Tagging off Washington and W. coast Vancouver Is. in 1948 and 1949	65	16 (24.6)	635	33 (5.2)
Milne (1957)	5,458	476 (8.7)	7,194	970 (13.5)

for return of tags. The straight line distance between release and recovery locations indicated the minimum distance travelled (called "net movement") for fish recovered in the ocean. A series of connected straight line tracks were used to estimate net movement of fish recovered in locations where a single line could not be used (e.g., recoveries in Puget Sound). Straight line distance travelled in the ocean was added to distance travelled upstream to estimate net movement for fish recovered in river systems. Approximate latitudinal change was used to estimate net movement of fish for which an accurate recovery location was not known (e.g., "recovered off Coos Bay"). Net migration rate was estimated by dividing net movement by days between release and recovery.

Results and Discussion

Numbers of fish tagged and percentages recovered are summarized in Table 1 for coho and chinook salmon released in different years. Recovery rates were similar for maturing coho (mean 8.6%, range 6-12%) and chinook (mean 9.4%, range 4-22%) salmon. These are similar rates to those found for these two species in other studies (Table 1).

Numbers of fish recovered in different areas from releases off Oregon, Washington, and Vancouver Island are given in Table 2. Simplified migration patterns are shown in Fig. 1. Recoveries of coho salmon released off Oregon were mainly (81%) from the Columbia River and Oregon. Only 11% were recovered in the Strait of Juan de Fuca or Puget Sound. This distribution differs from Van Hyning's (1951) finding that 47% of coho salmon tagged between June and August from Cape Lookout, OR, to the Columbia River were recovered in Puget Sound. Recoveries of coho salmon released off Washington were more widely distributed and 46% were recovered from the Columbia River to Cape Flattery, 20% in Oregon, 23% in the Strait of Juan de Fuca or Puget Sound areas, and 11% in British Columbia.

Estimated net migration of coho salmon between release and recovery (including upstream migration for those recovered in freshwater) averaged 181 km and ranged from 7 to 657 km (Fig. 2A.) Most coho salmon were recovered within 150 days of release. The two fish recoverd after 330 and 380 days were released as juveniles and recovered the following year as adults.

Net migration rates of the maturing coho salmon tagged in coastal waters were generally very low and ranged from 0.1 to 20.4 km/day with a mean rate of 3.6 km/day (Fig. 2B). Coho salmon recovered in the open ocean off Oregon, Washington, or Vancouver Island (circles) had only slightly higher mean rates of movement than those recovered in the Strait of Juan de Fuca or Puget Sound areas (triangles) or those recovered

TABLE 2.—Recovery areas of tagged coho and chinook salmon released off Oregon, Washington, and the west coast of Vancouver Island.

	Recovery areas										
Release areas	Ocean off N. California	Ocean off Oregon	Coastal Oregon bays & rivers	Columbia River	Ocean off Washington	Coastal Washington bays & rivers	Ocean off W. Vancouver Island	Strait of Juan de Fuca	Puget Sound	British Columbia Rivers	Other British Columbia
Coho											
Off Oregon		11	7	3		2		2	1		
Off Washington		6	1	7	8	1	2	3	5	1	1
Off west Vancouver Island							1				
Chinook											
Off Oregon	1	2	2	1	1						
Off Washington		3		3	2					1	
Off west Vancouver Island								2			

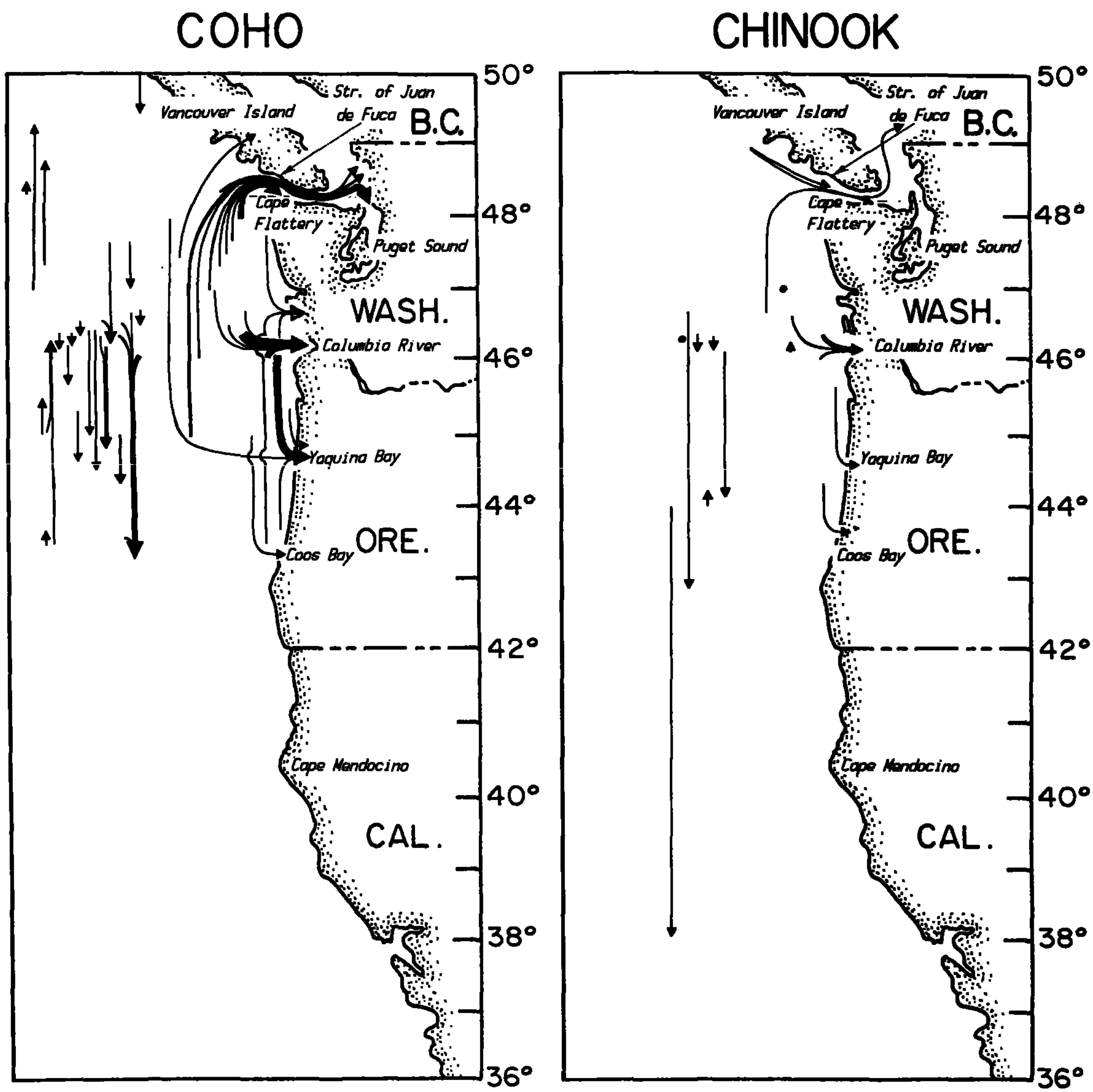

FIGURE 1.—Migration patterns of tagged coho and chinook salmon released at sea. For fish recovered in the ocean off Oregon, Washington, or Vancouver Island, release latitude is indicated by the tail of the arrow and recovery latitude by the head of the arrow. For fish recovered in inland waters or river systems the head of the arrow points to the system in which the fish was recovered. Solid dots indicate fish released and recovered at the same latitude. Numbers of fish are approximately proportional to thickness of arrows. Most releases and recoveries were within 50 km of the coast and the positions of arrows do not represent true distances from shore.

in coastal bays or river systems, including the Columbia River (squares) (4.4, 3.5, and 2.7 km/day, respectively, Fig. 2B). Similar low net movement rates were found for coho salmon in coastal waters by Van Hyning (1951) off Oregon (3.0 km/day), by Kauffman (1951) off Washington and Vancouver Island (3.9 km/day), and by Milne (1957) also off Vancouver Island (9 km/day).

In all studies the stresses related to capture and tagging may cause some mortality and weaken some surviving fish, affecting speed of migration. Hartt (1966) suggested that tagging retards migration by at least 1 day. However, movements of fish immediately after release in sonic tagging experiments were often rapid (Madison et al. 1972; Stasko et al. 1973).

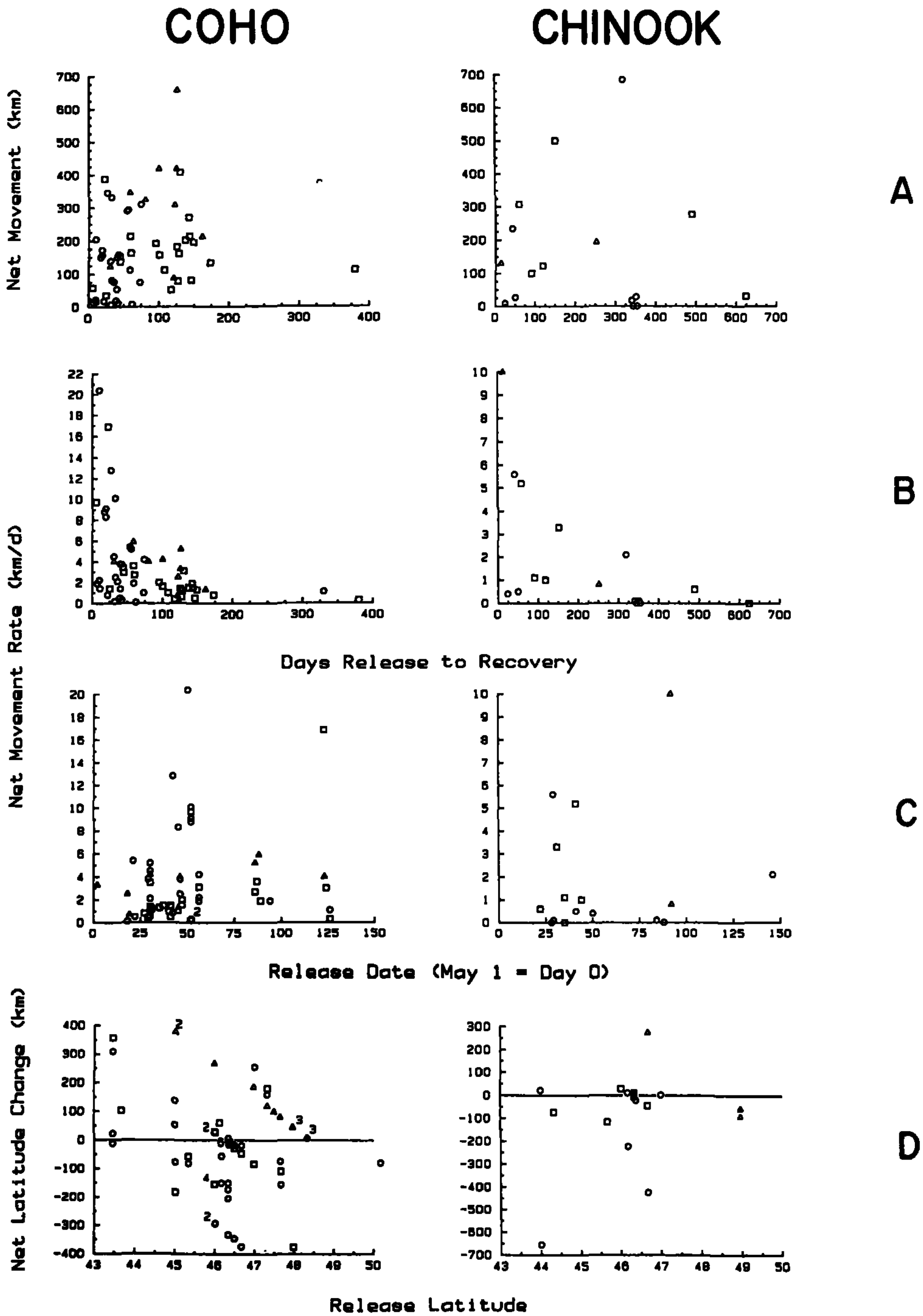

FIGURE 2.—A) net movement vs. days between release and recovery, B) net movement rate vs. days between release and recovery, C) net movement rate vs. release date, and D) net latitude change (+ = north and − = south) vs. release latitude for tagged coho and chinook salmon. Recoveries in inland waters (Strait of Juan de Fuca, Puget Sound, Georgia Strait, and associated river systems) are indicated by triangles, those in the open ocean from the west coast of Vancouver Island to northern California by circles, and those in coastal bays or river systems by squares. For fish released off Oregon or Washington and later recovered in Puget Sound, net latitudinal change (D) is given as the change between the release location and Cape Flattery.

In contrast to the low movement rates observed for coho salmon in coastal waters off Oregon, Washington, and Vancouver Island, net migration rates reported for salmon tagged in offshore waters of the North Pacific were generally much higher. Godfrey et al. (1975) calculated an average rate of 24 km/day for tagged coho salmon recovered in the Japanese high seas fishery and 30 km/day for coho recovered in coastal waters. Hartt (1962, 1966) estimated that the migration rates of sockeye salmon into Bristol Bay averaged 44-50 km/day, whereas those of maturing sockeye salmon caught on the high seas averaged about 32 km/day. Chum salmon had migration rates at sea of 23-50 km/day; pink salmon had average rates of 43 km/day for coastal returns and 50 km/day for high seas returns.

Rapid migrations in coastal waters of British Columbia and Washington were also found for pink salmon (Vernon et al. 1964; Stasko et al. 1973) and for sockeye salmon (Madison et al. 1972) and off the Kurile Islands for chum salmon (Ichihara et al. 1975). However, migration rates slowed greatly as fish neared their home river systems (Vernon et al. 1964; Groot et al. 1975).

Because net migration rates of coho salmon in coastal waters off Oregon, Washington, and Vancouver Island are so much lower than movement rates found for other salmon stocks, these coho are probably spending less time migrating in a single direction compared to meandering and feeding. Similarly, Milne (1957) concluded that coho salmon in coastal waters of British Columbia probably meander during both feeding and spawning migrations. Slow, feeding movements off Oregon and Washington are also suggested by the long time period (3-4 months) during which individual stocks are available in the ocean fisheries (Hunter 1985). The relatively fast net migration rates observed for some coho salmon recaptured within 33 days of release (Fig. 2B) suggest that actual movement rates over short time periods may be quite high but that meandering courses over time produce low net migration rates. Higher migration rates for fish tagged in late summer, to be expected if movements were changing from predominantly feeding to homing, were not apparent (Fig. 2C).

Roughly equal numbers of coho salmon were recovered to the north (27) and to the south (35) of release sites, although most (8 of 11) coho released from lat. 45°N and south were recovered to the north (Fig. 2D). Van Hyning (1951) also found that most coho tagged south of 45°N travelled to the north after release; however, he found that most coho released off northern Oregon and the Columbia River (46°15′N) were recovered to the north as well. Fry et al. (1951) and L.B. Boydston (California Department of Fish and Game, unpubl. data) reported that most recoveries of maturing coho salmon tagged off northern California were to the north, off Oregon or Washington.

Northward migration by most of the maturing coho salmon tagged at sea south of 45°N during their final summer in the ocean is consistent with the distributional patterns of coastal Oregon and early run Columbia River stocks in the ocean fisheries. Peak catches of coastal Oregon coho salmon stocks are off northern California in May and June and shift to waters off Coos Bay in July and August (compiled from Hunter 1985). Relatively high percentages (24-37%) of the ocean catch of coastal Oregon coho salmon stocks (all combined) are off northern California (Garrison 1985; Hunter 1985; Oregon Department of Fish and Wildlife 1982). Similarly, between 62 and 65% of early run Columbia River stocks are caught south of the Columbia River (Hunter 1985; Howell et al. 1985; Oregon Department of Fish and Wildlife 1982). Therefore, many fish from these two stock groups, which make up a substantial fraction of the coho catch off California and Oregon, migrate south and then migrate north sometime later during the summer to return to their natal systems. Southward migration into waters off northern California and southern Oregon may be advantageous to these coho salmon stocks because of the potentially high food production fueled by strong coastal upwelling during the summer in this area.

Other stocks of coho salmon are caught to the north of where they entered the ocean during their final summer in the ocean. About 47% of the late run Columbia River coho are caught north of the Columbia River in Washington and British Columbia (Howell et al. 1985). Smaller, but significant percentages of other stock groups from the south (early Columbia River, private hatchery, and other coastal Oregon groups) are also caught as maturing adults north of their natal streams. Thus, these fish would eventually have to migrate to the south to return to their natal streams. Therefore, the subsequent southward movement of many of the maturing coho salmon we tagged north of 45°N (Fig. 2D) is not surprising.

The slow net migration rates, prolonged residence in coastal waters, and mixed north and south net movements suggest that maturing coho salmon in coastal waters of Oregon and Washington, unlike stocks of salmon from the Gulf of Alaska and Bering Sea regions, are not highly migratory with precisely directed and timed movements. Many juvenile coho salmon off Oregon and Washington also reside in coastal waters and do not appear to undertake rapid or long migrations out of this region (Pearcy and Fisher fn. 1).

Of the 7 recoveries of chinook salmon released off Oregon, 5 were off Oregon, in the Columbia River, or in coastal Oregon rivers; 1 was off northern California; and 1 was off Washington. Of the 9 recoveries of chinook salmon released off Washington, 3 were in the Columbia River, 3 off Oregon, 2 off Washington, and 1 in British Columbia. Two chinook salmon tagged off the west coast of Vancouver Island were recovered in the Strait of Juan de Fuca (Fig. 1, Table 2).

Estimated net migration of chinook salmon averaged 201 km and ranged from 0 to 685 km (Fig. 2A). Unlike coho salmon, which spend only 1 year in the ocean and which were mostly recovered within 150 days of release; almost half of the chinook salmon, which may spend several years in the ocean, were recovered after more than 200 days at liberty. Mean net migration rate of chinook salmon was 1.9 km/day (n = 16, Fig. 2B). As was found for coho salmon, net migration rates of chinook salmon were many times lower than rates found for salmon tagged in offshore waters of the North Pacific Ocean. Therefore, some chinook salmon also appear to undertake meandering feeding movements in coastal waters off Oregon, Washington, and Vancouver Island. There was no evidence for acceleration of migration rate late in summer (Fig. 1C).

Tagged maturing chinook salmon differed from coho salmon in that most moved to the south after release (Fig. 2D). Columbia River and many coastal Oregon stocks of chinook salmon are caught in the ocean fisheries predominantly to the north of Oregon, i.e., north of their natal systems (Wahle et al. 1981; Garrison 1985). Some of the maturing chinook salmon that we tagged may have been moving slowly toward their natal systems from the north. One chinook salmon was recovered 319 days after release over 656 km to the south, off northern California (Figs. 1, 2D).

Other species of salmonids tagged off Oregon and Washington were recovered only in very low numbers. There were only 2 recoveries from 164 tagged pink and 36 tagged chum salmon. The greatest net movement was by a chum salmon tagged on 1 June 1985 off Seaside, OR, just south of the Columbia River and recovered on 8 August 1985 in Hecate Strait, B.C. (great circle distance 830 km). This fish was at liberty for 68 days and its minimum movement rate as 12.2 km/day.

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DAILY GROWTH INCREMENTS IN OTOLITHS OF JUVENILE BLACK ROCKFISH, *SEBASTES MELANOPS*: AN EVALUATION OF AUTORADIOGRAPHY AS A NEW METHOD OF VALIDATION

Investigations into the temporal periodicity of growth increment formation in otoliths of larval and juvenile fishes have produced conflicting accounts. Taubert and Coble (1977), Barkman (1978), Wild and Foreman (1980), and Campana and Neilson (1982), among others, have confirmed daily increment formation in otoliths from various species of larval and juvenile fishes. There have been a few studies, however, in which increment counts were not representative of actual age of the fish (Wild and Foreman 1980; Geffen 1982; Neilson and Geen 1982). Nondaily increment formation has been explained by the inclusion of subdaily rings in age estimates as well as by methodological errors in preparing and viewing the otoliths (Campana 1983a; Campana and Neilson 1985). Since size and age of fish, food limitations, and environmental conditions have been suggested to affect increment formation, validation is necessary in each study where fish age is estimated.

Several techniques have been used to validate daily growth increments in larval and juvenile fish otoliths. Fish of known age, raised from fertilization or birth under controlled laboratory conditions, provide the best material to determine frequency of increment formation (Taubert and Coble 1977; Barkman 1978; Tanaka et al. 1981; Miller and Storck 1982). For many species, however, rearing the larvae from birth through the juvenile stage is difficult or impossible. An alternate method of age validation introduces a chemical mark onto those calcified structures which exhibit periodic growth zones, such as otoliths, scales, and spines. The antibiotic oxytetracycline hydrochloride (OTC) has been used most successfully in this manner (Wild and Foreman 1980; Campana and Neilson 1982; Ralston and Miyamoto 1983; Dabrowski and Tsukamoto 1986). The OTC is taken up at the site of calcification and fluoresces bright yellow under ultraviolet light, compared with the blue autofluorescence of normal tissue. Most recently, stable strontium has been used to demonstrate daily increment formation in squid statoliths (Hurley et al. 1985) and in mass marking of coho salmon (Yamada et al. 1979). For some species, a timemark may also be induced on the otolith by stress,

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