Movement of Tagged Lingcod *Ophiodon elongatus* at Neah Bay, Washington

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Lingcod *Ophiodon elongatus* is an important component of Washington's coastal commercial and sport fisheries (Jagielo 1989). Female lingcod comprise most of the offshore commercial landings, grow faster than males, and attain a larger size. Males predominate in the nearshore sport catch, are typically smaller than females, and perform a nest guarding role during reproduction. These characteristics of the coastal lingcod population suggest the need for an integrated stock assessment which addresses males and females separately and takes the geographic distribution and migratory behavior into account.

This paper reports the movement of lingcod tagged nearshore in the western Strait of Juan de Fuca near Neah Bay, Washington, during 1986–89. Results are presented for tags recovered through 1989 and analyzed by sex and size for extent and direction of movement. I also evaluated tag retention of a wire spaghetti tag applied on the preopercular plate as an alternative to strap, anchor, or dart tags used previously for lingcod tagging (Chatwin 1958, Forrester 1973, Cass et al. 1983, Mathews and LaRiviere 1987).

Methods

From 1986 to 1989, 3478 lingcod were tagged using a chartered commercial vessel trolling with 6–10 jigs from a hydraulic gurdy. Each year fishing occurred from mid-March to mid-April in advance of the sportfishery opening on 15 April. Only fish not injured by capture were tagged and released. All tagged fish were measured to the nearest millimeter, and sex was determined by noting the presence of anal papillae in males.

The tagging area was within 3 miles of the shoreline in the vicinity of Neah Bay, Washington, and extended from the Sekiu River to Makah Bay (Fig. 1). In 1986, the tagging effort was distributed evenly among areas NB-1, NB-2, and NB-3. Area NB-4 was added in 1987, and effort was distributed evenly among the four areas from 1987 to 1989. Most of the tagging occurred at depths between 15–25 m.

In 1986 two tag types were released: 481 fish were tagged with a large dart tag (Floy FT-1) applied dorsally, and 487 fish were tagged with a wire spaghetti tag (Floy FT-4) twist-tied to the preopercular plate. Fish were alternately tagged with one of the two tag types and were released back into the population. Recaptures from 1986 to 1989 for the two tag types are shown in Table 1. In 1987 and 1988, 207 fish were double-tagged with the spaghetti tag to evaluate tag shedding. Through September of 1989, 20 of the double-tagged fish were recovered, all with both tags in place. Since tag shedding appeared to be negligible for the spaghetti tag, only fish released with the spaghetti tag (2997 lingcod) were analyzed for movement trends in this paper.

Recapture information, including the date and location of capture, was obtained both by direct interviews with fishermen and by voluntary returns submitted by fishermen. A $10 reward was paid for the return of tags, which was available directly on landing at Neah Bay.

Migratory and nonmigratory lingcod were defined as fish recaptured at distances greater than or less than 8.1 km (5 miles) from the tagging location, respectively. This reference distance was selected to enable comparisons with previous tagging studies. Chi-square contingency-table analysis was used for comparing release length-frequency distributions of migratory and nonmigratory recoveries and migrational tendency by sex. A chi-square goodness-of-fit test was used to test the null hypothesis that the release length distribution of recaptured lingcod was the same as the release length distribution of all tagged lingcod. Length-frequency distributions were grouped into 5-cm intervals and pooled at the tails so that no expected cell frequency was <1.0 and no more than 20% of the expected cell frequencies was <5.0 (Zar 1974, p. 50). One-way analysis of variance was used to test the null hypothesis that the mean time at liberty was the same for fish that had migrated different distances.

Results

Through September 1989, 393 (13.1%) tagged lingcod were recaptured (Table 2). The percent recaptured for each release group ranged from 9.96% in 1989 to 18.89% in 1986. The lower recovery rate for the 1989 release is probably a reflection of fewer recovery years as compared with releases from 1986 to 1988.

The length distribution of tagged lingcod by sex are shown in Figure 2a. Of all tagged lingcod, 99% were sexed; 84% of this sample were

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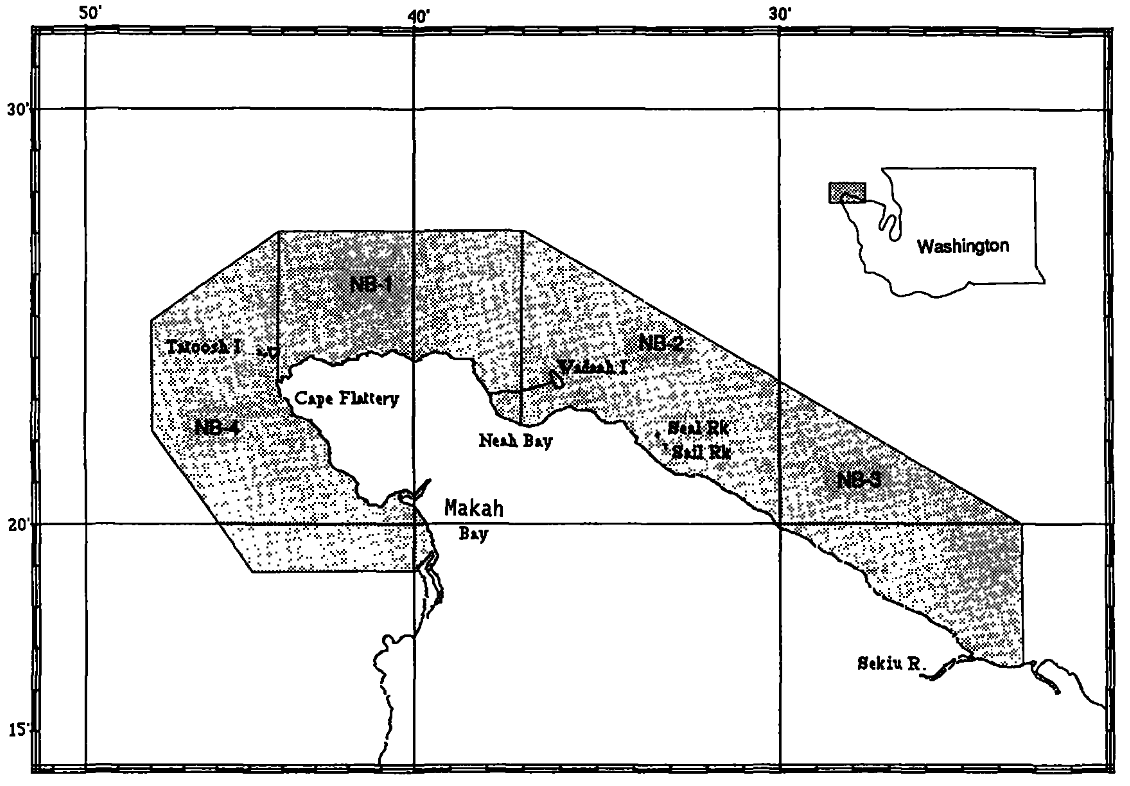

Figure 1
Lingcod tagging area at Neah Bay, Washington.

Table 1
Rates of recapture of tagged lingcod for two types of tags released in 1986.

Tag type	No. tagged	No. tags returned by fishermen 1986	1987	1988	1989	Total	% returned
Large dart (Floy FT-1)	481	41	25	7	1	74	15.38
Spaghetti (Floy FT-4)	487	47	29	13	3	92	18.89

Table 2
Number of lingcod tagged, 1986–89, and recaptured through 1989 by year of recapture.

Year tagged	No. tagged	1986	1987	1988	1989	Total	% recaptured
1986	487	47	29	13	3	92	18.89
1987	564	0	36	20	15	71	12.59
1988	982	0	0	79	55	134	13.64
1989	964	0	0	0	96	96	9.96
Total	2997	47	65	112	169	393	13.11

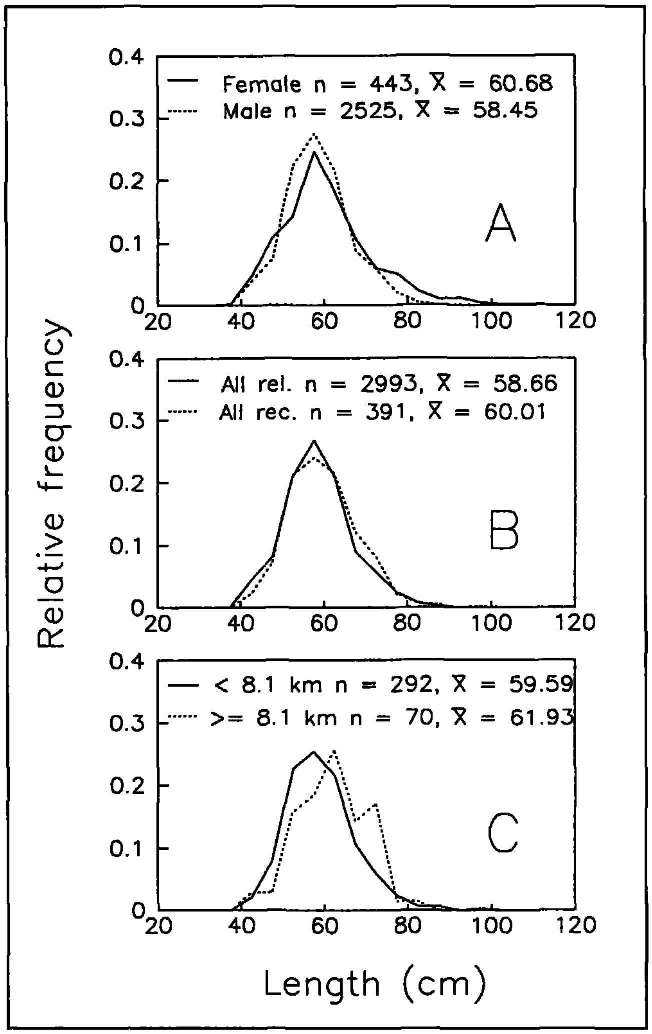

Figure 2
Length-frequency distributions of tagged lingcod. (A) Known male and female lingcod tagged; (B) release length distribution of all lingcod released and all lingcod recovered; (C) release length distribution of all lingcod recovered <8.1 km from release location and all lingcod recovered ≥8.1 km from release location.

males. The average size of tagged males (58.45 cm) was less than the average size of females (60.68 cm). Based on the length-at-maturity values of 46 cm for males and 76 cm for females (Mathews and LaRiviere 1987), approximately 95% of the tagged males were mature, and approximately 10% of the tagged females were mature at the time of tagging.

The average size of all tagged fish recaptured (60.01 cm) was greater than the average size of all tagged fish released (58.66 cm) (Fig. 2b). The null hypothesis that the length distribution of all recaptured lingcod is the same as that of all tagged lingcod was rejected (χ^2 = 14.91 with 7 df; $P = 0.0371$).

The average size of fish considered migratory (61.93 cm) was greater than those considered nonmigratory (59.59 cm) (Fig. 2c). The null hypothesis that migratory fish had the same length distribution as nonmigratory fish was rejected (χ^2 = 51.42 with 5 df; $P<0.00001$).

Of the 363 lingcod with known tagging and recapture locations, 70 (19.3%) were recaptured >8.1 km (5 miles) from the tagging location and were considered migratory, while the remaining 293 were recaptured within 8.1 km of the tagging location and were considered nonmigratory (Table 3). Of those that migrated, 46 were recaptured from 8.1 to 50 km from the tagging site, and 24 were recaptured >50 km from the tagging site.

Relative to the tagging location, most of the migratory recaptures were westward and out of the Strait of Juan de Fuca as opposed to eastward and inside the Strait. Of the 70 lingcod judged to be migratory, 54 were recaptured west and north/south of the tagging location, while only 16 were recaptured east and north/south of the tagging location (Table 3). The null hypothesis that male and female tagged lingcod were as likely to be recaptured east and north/south as opposed to west and north/south) of the tagging location was rejected (χ^2 = 20.62 with 1 df; $P<0.00001$). Recaptures came from as far north as Queen Charlotte Sound (241 miles), as far south as Cape Falcon (149 miles), and as far east in the Strait of Juan de Fuca as Crescent Bay (36 miles). Most of the migratory fish (25) were recovered on trawl grounds off the Washington coast and included those in the vicinity of Cape Flattery (5), the Cape Flattery Spit (9), Umitilla/La Push (4), Destruction Island (4), and Cape Elizabeth (3).

Table 3
Distribution of recoveries of tagged lingcod by distance and direction of migration.

		8.1–50 km			>50 km			Recaptured	
No. tagged	<8.1 km	East	West	Total	East	West	Total	No.	%
2997	293	15	31	46	1	23	24	393*	13.11

* Includes 30 recaptures with unknown recapture location.

Table 4
Distribution of recaptured lingcod by sex and distance of migration.

Sex	Total released	Number recaptured			Unknown distance	Recaptured	
		<8.1 km	8.1–50 km	>50 km		Total	%
Male	2526	245	42	24	23	334	13.22
Female	443	47	4	0	6	57	12.87
Unknown	28	1	0	0	1		
Total	2997	293	46	24	30	393	13.11

Thirteen were recovered on Canadian trawl grounds including La Perouse Bank (8) and Swiftsure Bank (4). Twenty of the migratory recaptures occurred within the tagging area between Makah Bay and the Sekiu River (Fig. 1), and 12 recaptures were made east of the study area in the Strait of Juan de Fuca.

Of fish with known sex and recapture location, a higher proportion of male lingcod were migratory as compared with female lingcod. Of 311 male recaptures, 66 (21.2 %) were judged to be migratory, while 4 of 51 female recaptures (7.8%) were considered migratory (Table 4). The null hypothesis that male and female recaptures were equally likely to be migratory was rejected ($\chi^2 = 4.20$ with 1 df; $P = 0.0402$ with Yates correction).

The time span between tagging and recapture for all recaptured lingcod averaged 237.6 days and ranged from 6 to 1197 days (Table 5). The null hypothesis that the average time span between tagging and recapture was the same for fish recaptured at different distances was not rejected ($F_{2360} = 1.50$; $P = 0.2240$).

Table 5
Time span between date of tagging and date of recapture of tagged lingcod with known date of recapture.

Distance between release and recapture	No. recaptured	Time span (days)	
		Mean	Range
<8.1 km	293	224.91	18–1197
8.1–50 km	46	251.85	36–1122
>50 km	24	306.63	78–770
Total	393*	237.61	6–1197

*Includes 30 fish with unknown distance traveled.

Discussion

This study gives qualitative evidence that a portion of the nearshore lingcod population in the vicinity of Neah Bay is vulnerable to the offshore trawl fishery; however, fishery tag recapture data, unadjusted for differential fishing effort, are inadequate to make quantitative statements about the net mixing rates of fish between areas. Clearly, from a harvest management perspective, it is important to know whether offshore stocks of lingcod contribute to nearshore recruitment, or vice versa, since valued fisheries operate in both areas.

Previous studies in the Strait of Juan de Fuca and Strait of Georgia have reported variable lingcod movement and indicate some exchange between inside and outside waters. Hart (1943) observed that fish tagged in the vicinity of the Strait of Juan de Fuca and Seymour Narrows made more extensive migrations than fish tagged in other adjacent inside waters. Of 1993 fish released during 1939–43, 209 were recovered of which 34 (16%) traveled distances >8.1 km (5 miles). For 342 recoveries from tags released in the Strait of Georgia during 1943–54, 73 (21.3%) were recaptured within 1.6 km (1 mile) and 32 (9.3%) were recaptured >8.1 km from the point of release. Of those recaptured >8.1 km, the average time at liberty was 3 years and the net movement was northwesterly within the Strait (Chatwin 1956). Mathews and LaRiviere (1987) reported that of 1692 lingcod tagged during 1976–81 in the eastern Strait of Juan de Fuca and in the vicinity of the San Juan Islands, 74 (49.6%) of 149 fish recovered moved >8.1 km and were judged to be migratory. Most recaptures were south or west of the tagging site; the predominant pattern of movement was south and west through the Strait of Juan de Fuca. Fish tagged in the eastern Strait of Juan de Fuca migrated more than fish tagged in the San Juan Islands. Five recaptures were reported from the Pacific Ocean. The longest movement to the northeast was to Porlier Pass, British Columbia; the longest movement to the southwest was off Newport, Oregon.

Previous offshore tagging studies have reported some movement between the various offshore fishing banks. Reeves (1966) reported that of 437 tagged on La Perouse (Forty Mile) Bank in June of 1960, 284 were recovered of which 74% were captured in the area of release, 21% had uncertain recovery location, and 5% were recaptured away from Forty Mile Bank (as far as Cape Flattery to the south and Ucluelet-Barkley Sound to the north.) The majority of all recaptures (82%) occurred within a 6-week period following the release because of an intensive trawl fishery for lingcod in the vicinity of tagging on Forty Mile Bank. Forrester (1973) reported the release of 2000 tagged lingcod on the Lennard Island trawling grounds in September of 1964; 535 were recovered with known locations of which 92 (17.2%) moved from the tagging site. Most of the fish recovered away from the tagging site were recaptured on Big Bank (southern La Perouse Bank) to the south. Fish were recaptured from as far as Cape Russell to the north and as far as Cape Flattery to the south. Most recaptures occurred in the summer months of the year following tagging (A.J. Cass, Pac. Biol. Stn., Dep. Fish. Oceans, Nanaimo, BC, Canada, pers. commun.). Jack Robinson (Oreg. Dep. Fish. Wildl., Newport, OR, pers. commun.) reported the tagging of 3800 lingcod in offshore waters near Newport, Oregon in July of 1978. Within 17 months, approximately 10% of the tagged fish were recovered of which approximately 9% were recovered away from the area of tagging. Mathews and LaRiviere (1987) reported the results of H. Horton from 522 lingcod tagged off Depot Bay on the central Oregon coast during June 1978–January 1982. Of 19 recaptures reported through 1985, 10 had not moved significantly and 9 (47%) had migrated more than 10 km. Of those that migrated, 2 went a distance of more than 100 km.

Chatwin (1956) reported evidence of homing behavior in Strait of Georgia lingcod. Of 14 lingcod captured at Entrance Island and transported 9.7 km (6 miles) to Departure Bay (Hart 1943), 4 were subsequently recaptured at Entrance Island, and one at Newcastle Island (between Entrance Island and Departure Bay) within 2 years of release. Buckley et al. (1984) reported evidence of homing behavior in Strait of Juan de Fuca lingcod. Of 187 adult lingcod transferred from the eastern Strait of Juan de Fuca to Pulali Point in Hood Canal in 1978, 9 recoveries all were recaptured at distances >8.1 km from the release site. Of the 9, 7 were recaptured northward in the direction of their original capture site.

My results at Neah Bay show more lingcod migratory behavior than most of the previous studies, but less than that reported in the eastern Strait of Juan de Fuca (Mathews and LaRiviere 1987). I found 70 of 363 recaptures (19%) to be migratory. Of the 70 that migrated, 24 (34%) moved in excess of 50 km. Mathews and LaRiviere (1987) reported 74 of 149 recaptures (50%) to be migratory, of which 13 (18%) moved over 50 km. The difference in percent migratory could be due to differences in exploitation rates. The Neah Bay tagging was conducted in March and April, and most tags were recaptured in the spring and summer months immediately following tagging. Most of the tags came from the intense sportfishery operating in the vicinity of Neah Bay, which may have removed potential migrants. Most of those that moved over 50 km escaped the sportfisheries and were recaptured on trawl grounds offshore. In the eastern Strait of Juan de Fuca, tagging was conducted through May and most of the recaptures occurred the year following tagging by Canadian trawlers on Constance Bank (Mathews and LaRiviere 1987). These fish were probably not subject to the same recreational fishing pressure in the vicinity of tagging, and have had a greater opportunity to migrate. The difference in the relative proportion of fish moving >50 km could be due to the distances from release sites to trawling sites; Constance bank is 18 km west of Middle Bank, where much of the eastern Juan de Fuca tagging occurred, while most of the coastal trawling occurs over 50 km from the Neah Bay study area.

The predominance of male fish tagged at Neah Bay can be explained by the different bathymetric distribution of the two sexes. Others have reported that lingcod are distributed by depth according to sex and size; larger fish (mainly females) inhabit deep banks or reefs, while smaller fish (typically males) inhabit the shallower reefs nearshore (Chatwin 1956, Forrester 1973, Miller and Geibel 1973, Cass et al. 1984). Mathews and LaRiviere (1987) noted a similarly skewed sex ratio for fish tagged nearshore in the eastern Strait of Juan de Fuca.

While the results of this and previous nearshore tagging studies give evidence of nearshore to offshore movement, a coherent pattern is not evident and a reliable working model of coastal lingcod migration is not yet available. Migratory recaptures from the present study were typically larger at the time of release than nonmigratory fish, suggesting a size threshold for movement; however, Mathews and LaRiviere (1987) failed to show a relationship between size at release and migratory tendency, and Hart (1943) concluded that large lingcod move less than small lingcod and that "some but not more than 5% of lingcod are more or less migratory during each year." Since the tagging at Neah Bay occurred nearshore in a narrow depth range (15–25 m) where the relative abundance of females is low, the effect of sex and size on lingcod movement reported here is likely biased with reference to the population as a whole. This depth-related bias may explain the discrepancies between this and other studies with regard to lingcod movement.

Some level of female movement from offshore to nearshore areas for spawning is implied by the high relative abundance of females at depth, though the nature and extent of such spawning migrations is poorly understood. It is unclear, for instance, whether females spawning nearshore reside nearby at depth and make vertical seasonal migrations to spawn, or whether female lingcod migrate seasonally from the deep offshore trawling grounds to spawn nearshore. Such movements have been widely accepted as fact, though tagging experiments to date have failed to confirm a seasonal mass spawning migration (Miller and Geibel 1973).

An appropriate tagging study design to model coastal lingcod movement will require tagging in both nearshore and offshore areas and the estimation of both the probability of survival as well as the probability of capture across the time-area strata. To separate movement from survival, a minimum of three samples is needed. Iwao (1963) and Arnason (1972) gave models under this scenario, but only for the case with multiple recaptures. These approaches are not applicable to most fisheries tagging studies in which individuals are recaptured once by a commercial or recreational fishery and recovered dead. Potentially more applicable to fisheries tagging studies, Schwarz (1988) and Schwarz and Arnason (1990) have extended the traditional exploitation-based models of Brownie et al. (1985) to include tag recoveries over both time and space, and Hilborn (1990) recently provided a general framework for analysis of movement and mortality which incorporates a population dynamics and movement model using a maximum-likelihood minimization approach.

In conclusion, this study gives evidence that a component of the lingcod population at Neah Bay is exposed to fishing mortality from the offshore trawling fleet. Research is needed to yield quantitative estimates of lingcod mixing rates, stratified by sex and size, between the nearshore and offshore fishing grounds. These mixing rates will be essential to establish mortality rates by sex and age for the population as a whole, to clarify the collective impact of the nearshore and offshore fisheries on the coastal lingcod population.

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