

Resident and Dispersal Behavior of Adult Sablefish (*Anaplopoma fimbria*) in the Slope Waters off Canada's West Coast

R. J. Beamish and G. A. McFarlane

Department of Fisheries and Oceans, Fisheries Research Branch, Pacific Biological Station, Nanaimo, B.C. V9R 5K6

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A total of 72 735 adult sablefish (*Anaplopoma fimbria*) were tagged and released off the west coast of Canada from 1977 to 1982. As of December 31, 1985, 11 212 (15%) have been recaptured or 16 539 (23%) when recaptures were standardized for differences in recovery effort and unreported recaptures. Off Vancouver Island, relatively few sablefish moved more than 200 km. More movement occurred in Queen Charlotte Sound and off the Queen Charlotte Islands. Thirteen percent of recaptures were made in the United States zone and 96% of these were made in waters off Alaska. Movement was not related to length, age, or sex of adult fish. There was also no relationship between time at liberty and distance travelled; however, there was a trend to move out of the release area with time at liberty. In general, most adults remained within the release area. This resident behavior could result in overfishing because recruitment is dependent on occasional strong year-classes rather than movement from other areas.

De 1977 à 1982, on a étiqueté et relâché 72 735 morues charbonnières (*Anaplopoma fimbria*) adultes au large de la côte ouest du Canada. Le 31 décembre 1985, on en avait recapturé 11 212 (15 %), ou 16 539 (23 %) quand les recaptures sont normalisées afin de tenir compte des différences de récupération et des recaptures non signalées. Très peu de morues charbonnières ont parcouru plus de 200 km au large de l'île de Vancouver. De plus grands déplacements ont eu lieu dans le bassin de la Reine-Charlotte et dans les eaux au large des îles de la Reine-Charlotte. Du 13 % des recaptures provenant des eaux américaines, 96 % ont été effectuées dans les eaux au large de l'Alaska. Les déplacements ne sont pas liés à la longueur, l'âge ou le sexe des poissons adultes. De plus, il n'existe aucune relation entre le moment du lâcher et la distance parcourue; toutefois, il existe une tendance de sortie de la zone de lâcher en fonction du moment de lâcher. En général, la plupart des adultes sont demeurés à l'intérieur de la zone de lâcher. Ce comportement sédentaire peut mener à une surpêche car le recrutement dépend d'importantes classes annuelles fortuites au lieu de migrations d'autres régions.

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Sablefish (*Anaplopoma fimbria*) are a long-lived fish (Beamish and Chilton 1982; McFarlane and Beamish 1983b) that occur along the continental slope from California to Alaska. In the Canadian fishery they are captured using baited traps that are set on bottom at average depths of 500-1500 m. The landed value of sablefish increased from less than 1 million Canadian dollars in 1977 to approximately 14 million Canadian dollars in 1985 and currently is the second most important groundfish fishery on Canada's west coast.

In anticipation of increased fishing effort, a tagging study was initiated in 1977 to determine if adult sablefish should be managed as one stock within the Canadian zone and if there was significant movement between Canadian and United States fishing zones. Although tagged fish are still being recovered, the current number of recoveries is relatively small compared with recaptures in previous years. Accordingly, it is appropriate to report the results of the tagging study for adults (55 cm and greater) at this time. Juveniles were tagged later in the study and are still being recovered in large numbers. Thus, the results

of the juvenile tagging studies will be reported later. Preliminary information on the movement of juvenile sablefish indicates that they do not behave in a manner similar to adults (Beamish and McFarlane 1983).

Adult sablefish that were recovered within 200 km of the release area were considered resident and those that move beyond 200 km were considered dispersing. Although recoveries have been made for up to 9 yr, it might be argued that the length of the study is not sufficient to indicate long-term movements when the age of sablefish can exceed 50 yr. We show, however, that over a 9-yr period, fishing and natural mortality remove about 90% of all adult fish in a cohort. Thus, relative to the known longevity, our study may not describe long-term movements, but relative to the exploited population, we have studied the movements of most fish throughout their normal life span.

Materials and Methods

Fishing Methods

Most fish were captured using collapsible rectangular traps

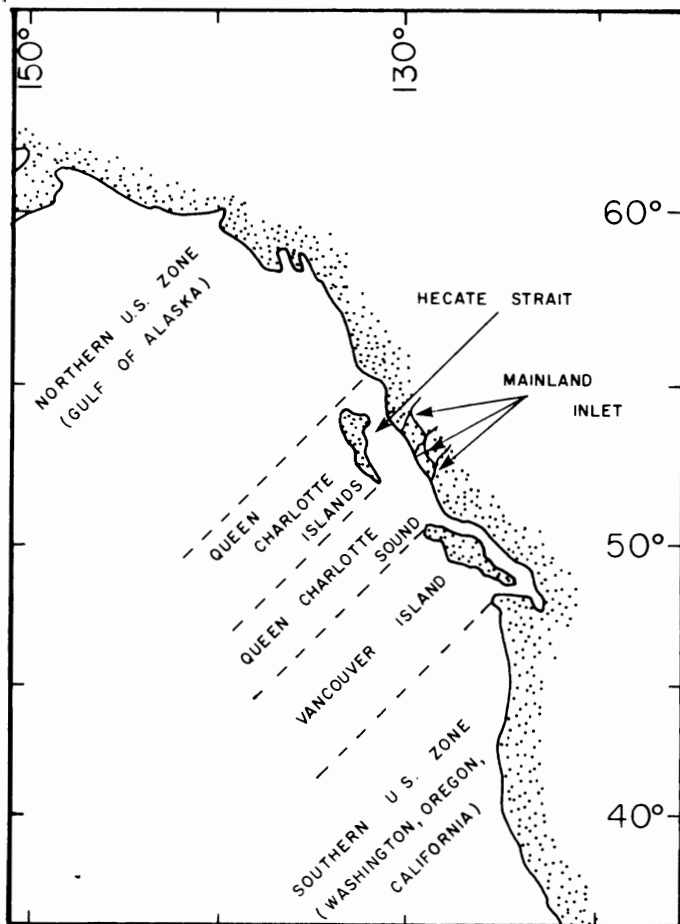


FIG. 1. Major areas used to describe movements of tagged sablefish.

(approximately $85 \times 85 \times 2.4$ m) that were equipped with two tunnels and baited with 5 kg of frozen Pacific herring (*Clupea harengus pallasii*). Korean-style, circular traps with one tunnel were also used. Traps were set on bottom in strings of 15–30 traps at average depths ranging from 300 to 700 m. They were fished for approximately 24 h according to the procedures described by Low et al. (1976) and Webb and Lockner (1973).

Tagging and Recapture

A Floy FD-68 anchor tag was applied according to procedures described in Beamish et al. (1978, 1979). Approximately 10% of the fish received a second "suture" tag (White and Beamish 1972). On the fishing vessel, fish were transferred directly into holding tanks that had a continuous supply of seawater. Most fish were measured for fork length, tagged, and released immediately. Initially, fish were anaesthetized using MS 222 (ethyl aminobenzoate methane sulfonate), but its use was discontinued after several cruises when it was found that fish could be easily handled without anaesthetic.

As part of the recovery procedure, letters describing the tagging experiment and offering a reward were sent to Canadian and foreign fishermen. Fishermen were asked to return the whole fish and were compensated for all reasonable expenses. Recovered tagged sablefish were measured for fork length, examined for sex and maturity, and sampled for otoliths.

Comparisons of Recaptures Among Areas and Years

Tag recaptures were recorded for the five major areas in Fig. 1 in the following categories: less than or equal to 50 km, less

TABLE 1. Catch per unit effort in the Canadian zone (kg/trap).

Year	Vancouver Island	Queen Charlotte Sound	Queen Charlotte Island
1978	25.2	11.6	20.1
1979	14.1	14.0	20.9
1980	15.0	18.5	13.5
1981	10.3	17.9	18.5
1982	11.8	16.6	24.8
1983	13.7	17.0	17.9
1984	11.7	15.0	12.7
1985	15.2	20.3	19.6

than or equal to 200 km, and more than 200 km from the release area. In the three recovery areas in the Canadian zone, we standardized the number of recaptures using estimates of catch per unit of effort (Table 1). Catch per unit effort was used instead of effort because catches will not always be directly proportional to effort. For example, if two areas of different population size receive equal fishing effort, it is probable that catch rates will be higher in the area with more fish. If the rate of movement into these areas from a release area is equal, the higher catch per unit effort in the one area will capture more tagged fish, and if only effort is used to standardize recaptures, it will be assumed erroneously that the rate of movement into this area is greater. All catch per unit effort values were standardized to the 1978 Queen Charlotte Sound values, so that the correction factors in the Canadian zones equalled CPUE in year i divided by CPUE in Queen Charlotte Sound in 1978.

In the United States zone, it was not possible to obtain effort or catch per unit effort values for all years. Instead, we used the relationship of average catch per biomass in the United States zone compared with average catch per biomass in the Canadian zone for the combined years 1979 to 1982 as follows:

$$\frac{\text{Catch}_{\text{Can}}}{\text{Biomass}_{\text{Can}}} \times \frac{\text{Biomass}_{\text{US}}}{\text{Catch}_{\text{US}}} = \text{correction factor.}$$

We used the average biomass off the states of Washington and Oregon from 1980 to 1982 (Francis 1985) to represent the average biomass from 1979 to 1982. Dividing the average biomass and catch off the Canadian zone by the average biomass and catch off the United States zone produces a constant correction factor of 0.83.

In the Gulf of Alaska, most recoveries were made in the central and southern areas. The biomass from these areas was obtained from Fujioka (1985) and excluded the estimates in waters shallower than 200 m because the biomass estimates at these depths were considered unreliable (Fujioka 1985). Furthermore, in the Canadian zone, almost no fishing occurs at depths shallower than 200 m (McFarlane and Beamish 1983b), indicating that few adult fish occur here. Dividing the average biomass and catch off the Canadian zone by the average biomass and catch in the Gulf of Alaska produced a correction factor of 1.67.

The number of tag recaptures was also standardized for unreported recaptures. In the Gulf of Alaska we used the nonreporting rates developed by Bracken (1983) and Sasaki (1985). In the central and western portions it appeared from these studies that approximately half of the recaptures were reported. Accordingly, recaptures were standardized by a factor of 2. In the Canadian zone and the southeastern portion of the Gulf of Alaska, reporting of recaptured fish was high (Beamish and

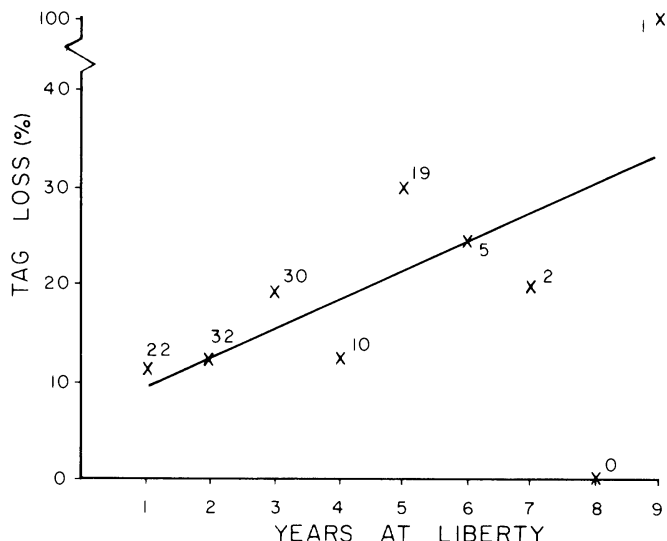


FIG. 2. Percentage of fish recaptured annually with one tag missing. Numbers of fish recaptured with lost tags are indicated for each year at liberty. Line fitted by eye.

McFarlane 1983; Bracken 1983) and required no standardization.

The accuracy of the standardization procedure was assessed by comparing the standardized recapture numbers with the expected number of returns. The expected number of returns was estimated for 2 yr in two of the three release areas using an estimated average annual exploitation rate of 0.1, a natural mortality rate of 0.1 (McFarlane et al. 1985; Funk and Bracken 1983), the rate of tag loss observed in this study, and an estimate of tagging mortality that was guessed to be 0.05. Fish receiving injections of oxytetracycline were not used.

Once the recapture numbers were standardized the percentage movement in and out of the major areas were determined. Each point is a composite number made up of data from a number of release years but the same number of years at liberty. Consequently, the nature of the error structure around each line does not lend itself to statistical hypothesis testing. Therefore, to determine rates of movement, straight lines were fitted by eye.

Results

A total of 72 735 adult sablefish were tagged and released off the west coast of Canada from 1977 to 1982. As of December 31, 1985, 11 212 (15%) of these fish were recaptured (Table 2). Some of these tagged fish were injected with oxytetracycline to mark the otolith as part of a study to validate a method of age determination (Beamish et al. 1983). Injections of 100 and 75 mg/kg produced a high percentage of mortalities (Beamish et al. 1983; McFarlane and Beamish 1987) reducing the overall recovery percentage for the study. If all fish receiving injections of 100 and 75 mg/kg were excluded, a total of 54 916 adult fish were released of which 10 152 (18.5%) were recovered as of December 31, 1985. When all recaptures were standardized (includes oxytetracycline injected fish), a total of 16 539 (23%) were considered recovered.

A total of 5076 fish received two tags. As of December 31, 1985, 822 such fish (16.2%) were recaptured. There was no significant difference in tag loss between the two tag types (*t*-test, $p \geq 0.01$), indicating that the loss of either tag can be

considered as a lost tag for an individual fish. This assumes that the rate of loss of either tag is not a result of interaction between the two tags. Using the fitted line in Fig. 2, tag loss in the first year was approximately 10% and after that approximately 2% per year.

Evaluation of Standardization Procedure

One release each year off Vancouver Island in 1979 and in 1980 and one each year off the Queen Charlotte Islands in 1977 and in 1980 were used to compare expected and standardized number of returns. The total number of released fish was 23 060 and the expected number of returns was 6972 (Table 3). The standardized number of returns was 5576 or 20% fewer than expected. If only the release that had been at liberty the longest was used from each area, the expected return was 4510 fish and the standardized number was 4041 or 10% fewer than expected. This close agreement confirms the reliability of the standardization procedure. Consequently, all subsequent analyses use standardized recapture numbers.

Reporting Rates

To assess whether reporting rates changed throughout the study, we compared the annual rate of movement beyond 200 km within the Canadian zone with the annual rate of movement beyond 200 km for the combined Canadian and United States zones. The annual rate of movement greater than 200 km for all years within the Canadian zone was less than the rate for the combined zones (Fig. 3). However, when rates of movement more than 200 km were compared by release years, it was found that for releases from 1977 and 1979 the rates for the Canadian zone and the combined zones (Fig. 4) were similar. Because Canadian fishermen cooperated in this study, we assumed that most fish recaptured in the Canadian zone were reported to us, resulting in a constant reporting rate for the Canadian zone. The assumption of constant reporting in the Canadian zone and similarity of the rates of movement beyond 200 km for 1977 and 1979 releases between the Canadian zone and the combined Canadian and United States zones indicates that the reporting rates within the United States zone for these years did not change.

Standardized Recoveries from Releases off Vancouver Island

From 1977 to 1982, a total of 26 443 fish (including fish injected with oxytetracycline) were tagged and released off Vancouver Island (Table 2). As of December 31, 1985, the recaptures, when standardized for catch per unit effort and corrected for unreported recaptures, were 4258 or 16.1% of the releases (Table 4). Most recaptures (74.5%) were made within 50 km of the release area (Table 4). The annual percentage of recaptures within 50 km of the release area declined at a rate of less than 1% per year (Fig. 5).

A total of 3707 (87%) sablefish were recaptured less than 200 km from the release area (Table 4), and a total of 555 (13%) were recaptured at distances more than 200 km. Fish recaptured at distances more than 200 km within the first year at liberty represented 10% of all recaptures. This percentage increased linearly throughout the study at the rate of 2.2% per year to 28% of all recaptures in the ninth year (Fig. 5).

If the rate of movement beyond 200 km from the release area is constant, then the recapture percentage beyond 200 km for fish at liberty for the same number of years but released in different years should also be constant. To examine this, we compared recaptures from releases from different years (Fig. 6)

TABLE 2. Releases (to 1982) and recaptures (to 1985) of tagged adult sablefish released off the west coast of Canada. A, fish with no injection of oxytetracycline (OTC); B, fish receiving an injection of less than or equal to 50 mg OTC/kg fish; C, fish receiving an injection of 75 or 100 mg OTC/kg fish.

Year	Releases			Recaptures (%)		
	A	B	C	A	B	C
<i>Vancouver Island</i>						
1977	227		5 278	3 (1.3)		206 (3.9)
1978	1		4 110	0 (0)		375 (9.1)
1979	9 111			1655 (18.2)		
1980	4 703			857 (18.2)		
1982	3 013			501 (16.6)		
Total	17 055		9 389	3016 (17.7)		581 (6.2)
<i>Queen Charlotte Islands</i>						
1977	5 158			1340 (26.0)		
1978	978		4 427	340 (34.8)		264 (6.0)
1979	6 621			1702 (25.7)		
1980	4 088			399 (9.8)		
1981	3 602	4276	2 552	512 (14.2)	437 (10.2)	90 (3.5)
1982	3 008			474 (15.8)		
Total	23 455	4276	6 979	4767 (20.3)	437 (10.2)	354 (5.1)
<i>Queen Charlotte Sound</i>						
1978	2		1 452	0 (0)		125 (8.6)
1980	3 110			598 (19.2)		
Total	3 112		1 452	598 (19.2)		125 (8.6)
<i>Mainland Inlet</i>						
1980	7 019			1334 (19.0)		
Total all areas	50 640	4276	17 819	9715 (19.2)	437 (10.2)	1060 (6.0)

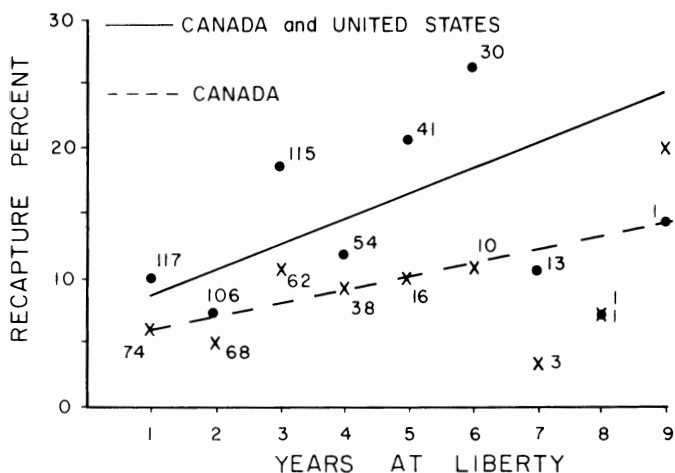


FIG. 3. Percentages of annual recaptures at distances greater than 200 km in the Canadian zone and greater than 200 km in the Canadian and United States zones combined. Numbers of recaptures are indicated for each year at liberty. Lines fitted by eye.

TABLE 3. Expected and standardized number of recaptured sablefish from the earliest releases off the west coast of Queen Charlotte Islands and Vancouver Island.

Year	Number released	Expected number of recaptures as of Dec. 31, 1985	Standardized number of recaptures as of Dec. 31, 1985
<i>Queen Charlotte Islands</i>			
1977	5 158	1746	2084
1980	4 088	1117	556
<i>Vancouver Island</i>			
1979	9 111	2764	1957
1980	4 703	1345	979
Total	23 060	6972	5576

but recaptured after the same number of years at liberty. The recapture percentage was constant or increased slightly for fish at liberty for 1, 2, 4 and 5 yr. For fish at liberty for 3 and 6 yr the recapture percentage increased for fish released later in the

study. Percentage recaptures for 3 yr at liberty was strongly influenced by the unusually large number of recaptures in 1985. If the 1985 recaptures are excluded, the relationship is similar to the other years. Percentage recaptures of fish at liberty for

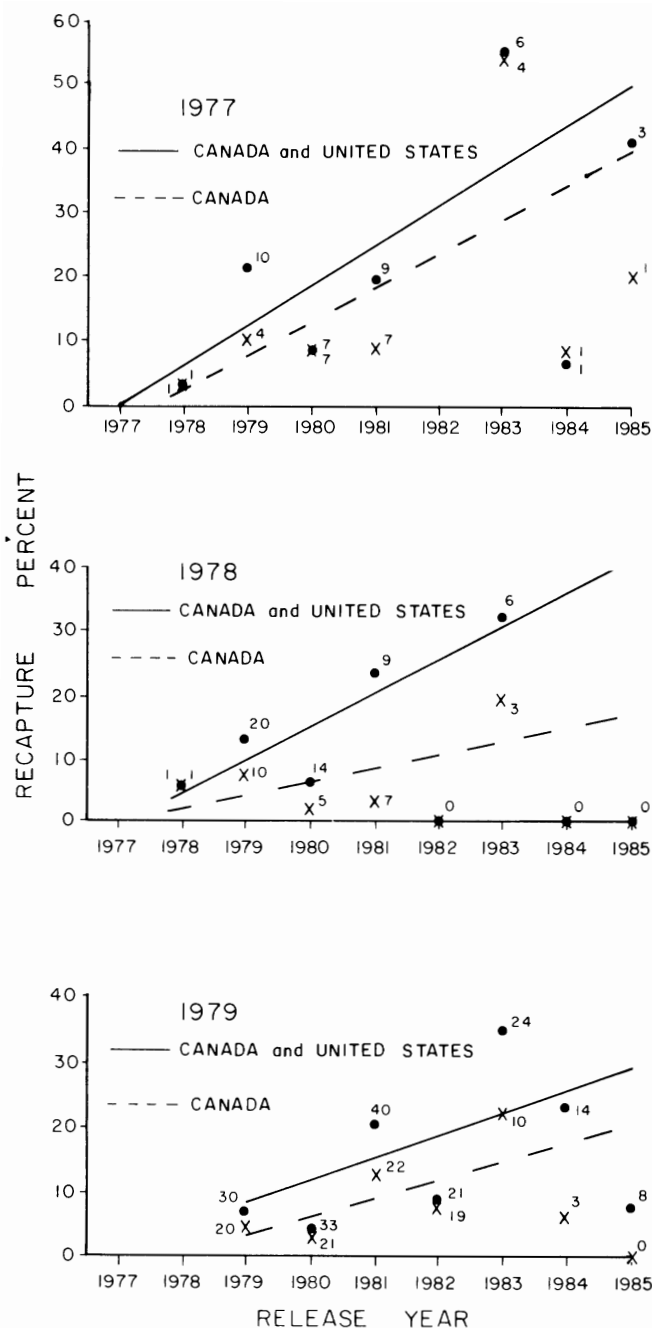


FIG. 4. Percentages of annual recaptures at distances greater than 200 km in the Canadian zone and greater than 200 km in the Canadian and United States zones combined for 1977, 1978, and 1979. Numbers of recaptures are indicated for each recovery year. Lines fitted by eye.

6 yr increased over the release period. This percentage was strongly influenced by the absence of any recaptures of the 1977 releases in 1982.

Standardized Recoveries from Releases in Queen Charlotte Sound and a Mainland Inlet

In 1978 and in 1980, 1454 and 3110 tagged fish, respectively, were released in Queen Charlotte Sound. In 1980, 7019 tagged fish were released in a mainland inlet (Table 2). As of December 31, 1985, the recaptures when standardized were 1094 (24%) from the Queen Charlotte Sound releases and 2015 (28.7%) from the mainland inlet release (Tables 5 and 6).

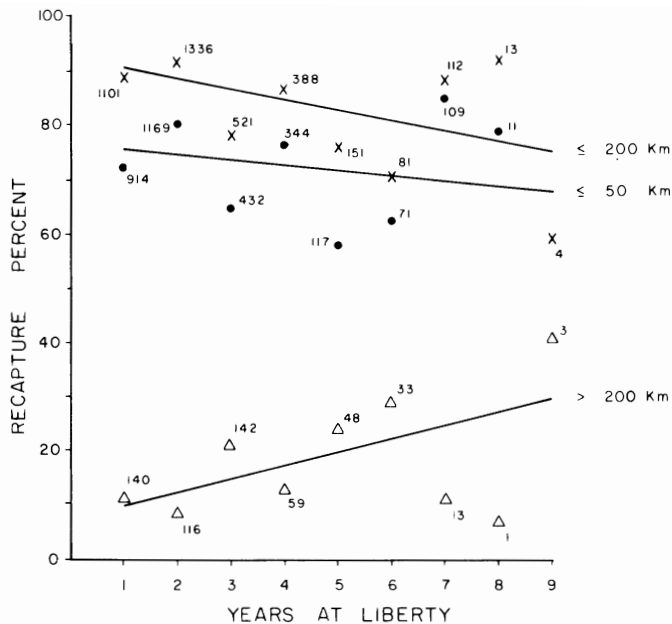


FIG. 5. Percentages of annual recaptures for each distance travelled category for fish released off the west coast of Vancouver Island. Numbers of recaptures are indicated for each distance travelled category and for each year at liberty. Lines fitted by eye.

In Queen Charlotte Sound, most fish (80%) were recaptured within 50 km of the release area. The annual percentage recaptured within 50 km declined from 89 to 69% over the 8-yr recapture period at a rate of 3.1% per year (Fig. 7). A total of 963 (88%) were recaptured less than 200 km from the release area (Table 5), and 131 (12%) were recaptured at distances more than 200 km. The rate at which fish moved out of the release area and farther than 200 km increased at 5% per year from approximately 4 to 40% (Table 5; Fig. 7).

Most recaptures from the mainland inlet release (77%) were within 50 km of the release area (Table 6). A total of 1654 (82%) were recaptured less than 200 km from the release area and 361 (18%) were recaptured at distances more than 200 km. The annual percentage of fish that were recaptured less than 200 km and less than 50 km from the release area declined sharply (Fig. 8). The rate of decline, however, was strongly influenced by the first year recaptures. If these recaptures are omitted, because the fisherman participating in this study returned the same year to fish this unexploited stock, then the annual percentage that were recaptured less than 200 km and less than 50 km from the release area is almost constant (Fig. 8).

Standardized Recoveries from Releases off the Queen Charlotte Islands

A total of 34 710 fish were tagged and released off the Queen Charlotte Islands from 1977 to 1982 (Table 2). As of December 31, 1985, recaptures, when standardized, were 9098 or 26.6% of the releases (Table 7). The percentage of fish recaptured within 50 km declined from 63 to 32% (Fig. 9) over 9 yr. A total of 7177 (79%) fish were recaptured less than 200 km from the release area (Table 7), and a total of 1921 (21%) were recaptured at distances greater than 200 km from the release area. The annual percentage of fish recaptured beyond 200 km, increased from approximately 20% to 40% at a rate of 2.5% per year (Table 7; Fig. 9).

TABLE 4. Recoveries of tagged sablefish released off the west coast of Vancouver Island by years at liberty and distance travelled.

Years at liberty	No. recaptured (%)							
	Total		>200 km		≤200 km		≤50 km	
	Actual	Standardized	Actual	Standardized	Actual	Standardized	Actual	Standardized
1	973	1241	87 (8.9)	140 (11.3)	886 (91.1)	1101 (88.7)	799 (82.1)	914 (73.7)
2	1211	1452	81 (6.7)	116 (8.0)	1130 (93.3)	1336 (92.0)	998 (82.4)	1169 (80.5)
3	585	663	98 (16.8)	142 (21.4)	487 (83.2)	521 (78.6)	404 (69.1)	432 (65.0)
4	410	447	41 (10)	59 (13.2)	369 (90)	388 (86.8)	325 (79.3)	344 (77.0)
5	175	200	32 (18.3)	48 (24.2)	143 (81.7)	151 (75.8)	116 (66.3)	117 (58.4)
6	103	114	23 (22.3)	33 (29)	80 (77.7)	81 (71.0)	70 (68)	71 (62.6)
7	120	120	10 (8.3)	13 (10.6)	110 (91.7)	112 (89.4)	108 (90)	109 (86.1)
8	14	14	1 (7.1)	1 (7.1)	13 (92.9)	13 (92.9)	11 (78.6)	11 (78.6)
9	6	7	2 (40.8)	3 (40.8)	4 (66.6)	4 (59.2)	4 (66.6)	4 (59.2)

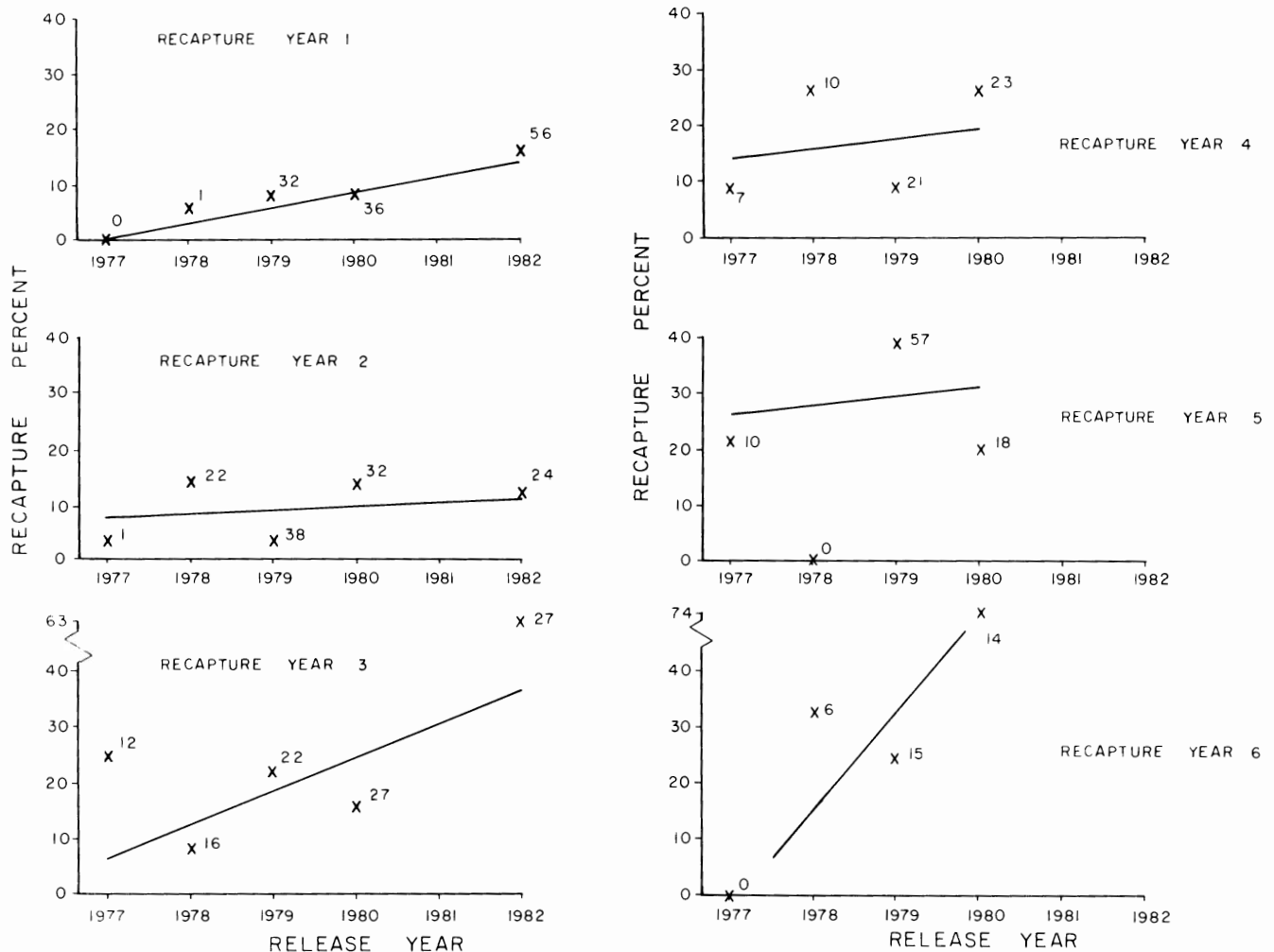


FIG. 6. Percentages of annual recaptures for releases from different years but recaptured greater than 200 km after the same number of years at liberty for fish released off the west coast of Vancouver Island. Numbers of recaptures are indicated for each release year. Lines fitted by eye.

Movements were compared for recaptured sablefish which moved more than 200 km from releases from different years (Fig. 10), but recaptured after the same number of years at liberty, as was done for the Vancouver Island releases. Off the Queen Charlotte Islands the percentage recaptures increased for all years. In most cases a larger percentage of fish that moved beyond 200 km were recaptured from releases made in 1980, 1981, and 1982. This was particularly evident for fish recaptured after 1 and 5 yr where a dramatic increase in recapture

percentage occurred from 1980 releases.

Movements of recaptured sablefish from one release off the west coast of Queen Charlotte Islands in 1977 were compared with the exact location of capture and release. A total of 5158 sablefish were released and 2084 (40%) recaptured (Table 3). The average recapture rate within 20 km of the release area decreased from 74 to 25% at a rate of 6% per year. After 9 yr, 45% of these recaptures were still being recaptured within 50 km of the immediate release area.

TABLE 5. Recoveries of tagged sablefish released off Queen Charlotte Sound by years at liberty and distance travelled.

Years at liberty	No. recaptured (%)							
	Total		>200 km		≤200 km		≤50 km	
	Actual	Standardized	Actual	Standardized	Actual	Standardized	Actual	Standardized
1	165	258	7(4.2)	17(6.6)	158(95.8)	241(93.4)	150(91)	229(88.8)
2	265	395	21(7.9)	39(9.8)	244(92.1)	356(90.2)	215(81)	326(82.5)
3	145	228	13(10)	32(14.0)	132(90)	196(86.0)	117(81)	169(74.1)
4	82	123	6(7.3)	15(12.2)	76(92.7)	108(87.8)	65(79)	97(78.9)
5	41	54	7(17)	10(18.5)	34(83)	44(81.5)	29(71)	42(77.8)
6	14	23	7(50)	14(60.8)	7(50)	9(40.2)	7(50)	9(39.1)
7	8	10	3(38)	4(40)	5(62)	6(60)	4(50)	5(50)
8	3	3	0(0)	0(0)	3(100)	3(100)	3(100)	3(100)

TABLE 6. Recoveries of tagged sablefish released in a mainland inlet by years at liberty and distance travelled.

Years at liberty	No. recaptured (%)							
	Total		>200 km		≤200 km		≤50 km	
	Actual	Standardized	Actual	Standardized	Actual	Standardized	Actual	Standardized
1	472	745	2(0.4)	2(0.3)	470(99.6)	743(99.7)	465(98.5)	734(98.5)
2	271	424	65(24)	109(25.7)	206(76)	315(74.3)	187(69)	286(67.5)
3	236	366	59(25)	113(33.6)	177(75)	253(66.4)	157(66.5)	223(60.9)
4	143	217	35(24.5)	61(28.1)	108(75.5)	156(71.9)	94(65.7)	136(62.7)
5	169	221	41(24.3)	58(26.2)	128(75.7)	163(73.8)	120(71)	154(69.7)
6	30	42	11(36.7)	18(42.9)	19(63.3)	24(57.1)	14(46.7)	18(42.9)

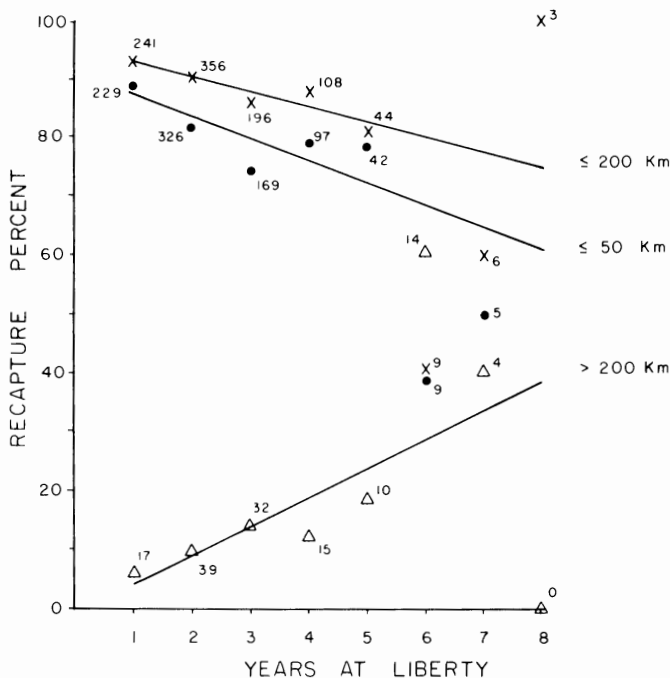


FIG. 7. Percentages of annual recaptures for each distance travelled category for fish released in Queen Charlotte Sound. Numbers of recaptures are indicated for each distance travelled category and for each year at liberty. Lines fitted by eye.

Distance Travelled in Relation to Sex, Size, Age, and Time at Liberty

Sex of tagged and released fish could not be determined without killing the fish. Therefore, comparisons of movements of males and females were made by examining sex ratios of recaptured fish. The female to male ratio for fish recaptured within 50 km of the release area was 1.8:1 and for fish recaptured more than 200 km was 2:1.

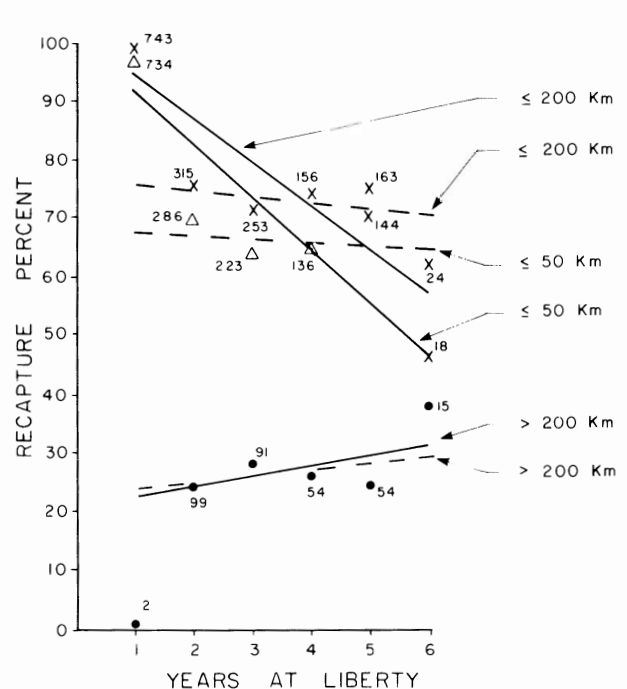


FIG. 8. Percentages of annual recaptures for each distance travelled category for fish released in a mainland inlet. Numbers of recaptures are indicated for each distance travelled category and for each year at liberty. Broken lines identify the relationship if the first year recaptures are excluded. Lines fitted by eye.

The movements of males and females were examined separately because mature males grow much less than mature females (Beamish and Chilton 1982; McFarlane and Beamish 1983b). A total of 7992 sablefish that were not tagged were examined for sex during tagging cruises from 1977 to 1980. There were 4790 females of which 40% were less than 70 cm and 60% were greater than or equal to 70 cm. If these per-

TABLE 7. Recoveries of tagged sablefish released off the west coast of the Queen Charlotte Islands by years at liberty and distance travelled.

Years at liberty	No. recaptured (%)							
	Total		>200 km		≤200 km		≤50 km	
	Actual	Standardized	Actual	Standardized	Actual	Standardized	Actual	Standardized
1	1475	2556	150(10)	338(13.2)	1325(90)	2218(86.8)	1120(76)	1900(74.1)
2	2065	3426	264(13)	544(15.8)	1801(87)	2882(84.2)	1415(69)	1534(44.5)
3	1009	1557	219(22)	479(30.8)	790(78)	1078(69.2)	583(58)	915(58.8)
4	463	711	116(25)	240(33.7)	347(75)	471(66.3)	234(51)	334(47.0)
5	268	406	73(27)	150(37.0)	195(73)	256(63.0)	129(48)	190(46.8)
6	155	253	40(26)	92(36.4)	115(74)	161(63.6)	89(57)	133(52.6)
7	73	117	18(25)	38(32.5)	55(75)	79(67.5)	43(59)	68(58.1)
8	30	40	11(37)	19(47.5)	19(63)	21(52.5)	13(43)	16(41.3)
9	20	32	9(45)	21(65.6)	11(55)	11(34.4)	8(40)	9(28.1)

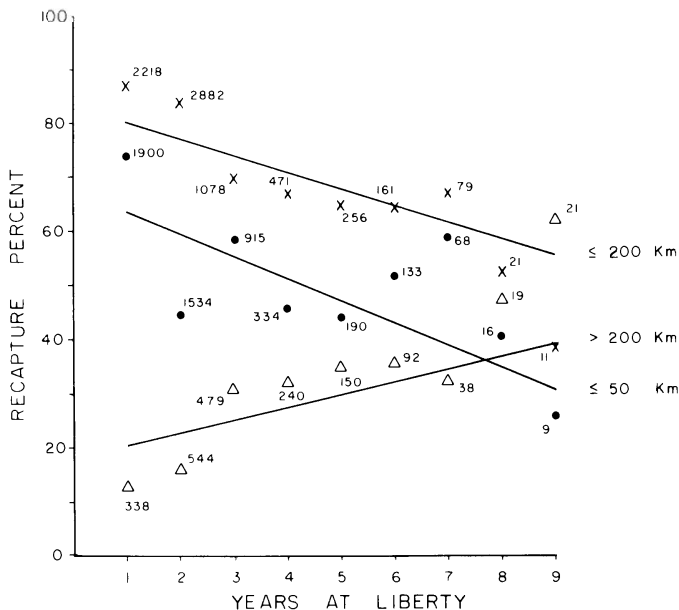


FIG. 9. Percentages of annual recaptures for each distance travelled category for fish released off the west coast of the Queen Charlotte Islands. Number of recaptures are indicated for each distance travelled category and for each year at liberty. Lines fitted by eye.

centages were representative for all areas and all years and if larger females moved farther than smaller females, the percentage larger than 70 cm and recaptured more than 200 km would increase. Because all fish will grow, there will be a tendency to recapture larger fish; however, adult female sablefish grow less than 1 cm/yr, and by restricting the recapture period to 3 yr, we minimize the effect of growth on the analysis. For females that moved more than 200 km, 42% were less than 70 cm and 58% were greater than or equal to 70 cm.

Because adult males grow very slowly and few grow to sizes larger than 65 cm, it is difficult to examine movement in relation to size. There was no difference in the mean size of males that moved greater than 200 km (61.3 cm) and those recovered within 50 km (61.1 cm) of the release area.

There was no significant difference (t -test, $p > 0.05$) in the mean age of male or female fish that moved more than 200 km from the release area and fish recaptured within 200 km of the release area in the Canadian zone. The mean age of male sablefish recaptured within 200 km of the release area was 16 yr, compared with 14 yr for fish recaptured more than 200 km from the release area. Females recaptured within 200 km of the

release area had a mean age of 17 yr, compared with 18 yr for those recaptured more than 200 km from the release area.

No relationship was found between distance travelled and time at liberty for all recoveries (Fig. 11).

Movement into United States Zone

A total of 2156 (13.0%) of all standardized recoveries were made in United States waters. Of these, 2070 (96%) were recovered in the Gulf of Alaska. Releases off Vancouver Island accounted for 254 of the recaptures in United States waters, of which 216 (85%) were recovered in the Gulf of Alaska. This, however, represents only 6% of the total recaptures of the total Vancouver Island releases. In contrast, 15.8% of total recaptures from releases off the Queen Charlotte Islands were made in the United States zone. For fish recaptured in United States waters from releases from Queen Charlotte Sound (451) and Queen Charlotte Island (1451), 96 and 98%, respectively, of recaptures were made in the Gulf of Alaska.

Throughout the study the annual percentage of fish that were recaptured in the Gulf of Alaska increased from 9 to 18%. In contrast, the percentage movement from the Canadian zone to waters off the southern United States increased from 0.2 to 2%.

Discussion

Sablefish tagging studies before 1966 (Alaska Department of Fish and Game 1953, 1954; Phillips et al. 1954; Edson 1954; Holmberg and Jones 1954; Pruter 1959; Pasquale 1964) were of limited value because there was no commercial fishery throughout the range of the species. The limited ability to recapture sablefish precluded estimates being made of rates and direction of movement out of the release area.

Although tagging continued after 1966 (Phillips 1969; Pattie 1970; Sasaki 1979, 1980, 1985; Beamish et al. 1980; Beamish and McFarlane 1983; Bracken 1982, 1983; Weststad et al. 1978), recapture rates remained low except in studies by Beamish et al. (1980) and Beamish and McFarlane (1983). Beamish and McFarlane (1983) and Bracken (1983) were the only ones to standardize recaptures for variation in catch and effort among areas; these authors and Sasaki (1985) also considered unreported recaptures.

In our study, the recapture rate as of December 31, 1985, was 23% including fish receiving oxytetracycline injections. This is considerably higher than previously reported recaptures which ranged from less than 1 to 6.4% (Holmberg and Jones 1954; Novikov 1968; Sasaki 1979, 1980; Weststad 1983;

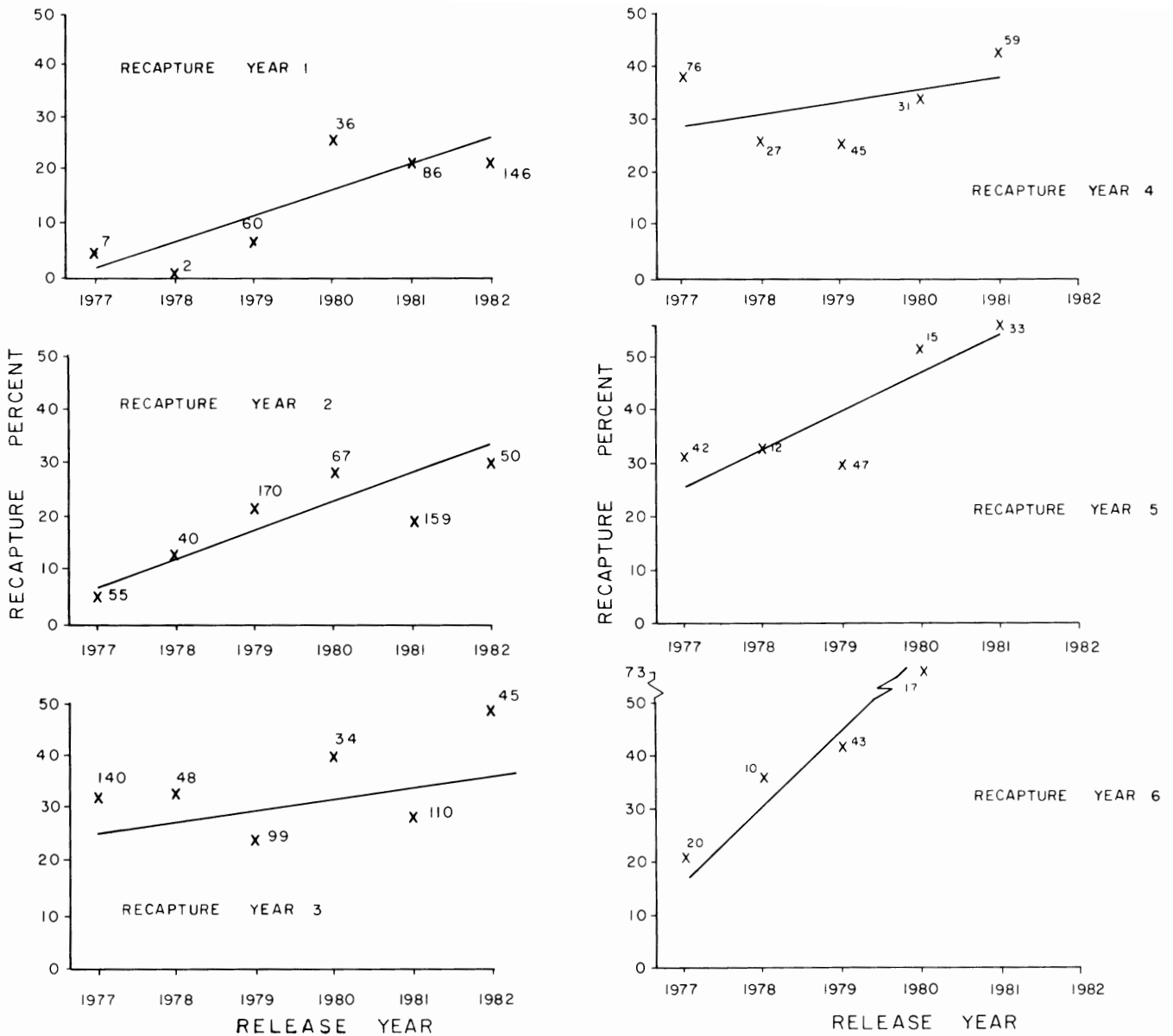


FIG. 10. Percentages of annual recaptures for releases from different years but recaptured greater than 200 km after the same number of years at liberty for fish released off the west coast of the Queen Charlotte Islands. Numbers of recaptures are indicated for each release year. Lines fitted by eye.

Shaw 1986). Our high recapture percentage provided sufficiently large numbers for studying patterns of movement.

All recovery percentages must be directly comparable before rates and direction of movement are determined and compared. For example, an increase or decrease in reporting rate could give the appearance of increased or decreased movement. Because reporting within the Canadian zone was known to be high and probably constant, the rate of movement beyond 200 km within the Canadian zone provides a basis for assessing changes in reporting rate within the United States zone. The annual rate of movement of fish more than 200 km within the Canadian zone was less than movement more than 200 km for the Canadian and United States zones combined. This indicates that either there were gradual increases in number of fish that moved into the United States zone or that there was an increase in the reporting rate in the United States zone. Because the annual rate of movement of fish beyond 200 km was similar for the Canadian zone and the combined Canadian and United

States zones for 1977 and 1979 releases, it is unlikely that a change in reporting occurred. Thus, there must have been increased movement into the United States zone. The difference in behavior that occurred for the 1978 releases cannot be explained but cannot be a result of reporting changes because fishermen would not be able to selectively report recaptures of only the 1978 releases.

The accuracy of our standardization procedures was assessed by comparing standardized number of recaptures with the expected number of recaptures. The standardized estimate was 20% less than expected or 10% less than expected for releases that were out the longest. The differences between the standardized and expected numbers are quite small considering that the expected number of recaptures was based on exploitation and natural mortality rates that were assumed to be constant among years and areas and the error associated with these rates was unknown. This close agreement indicates that the standardization procedures were reliable and that the movements

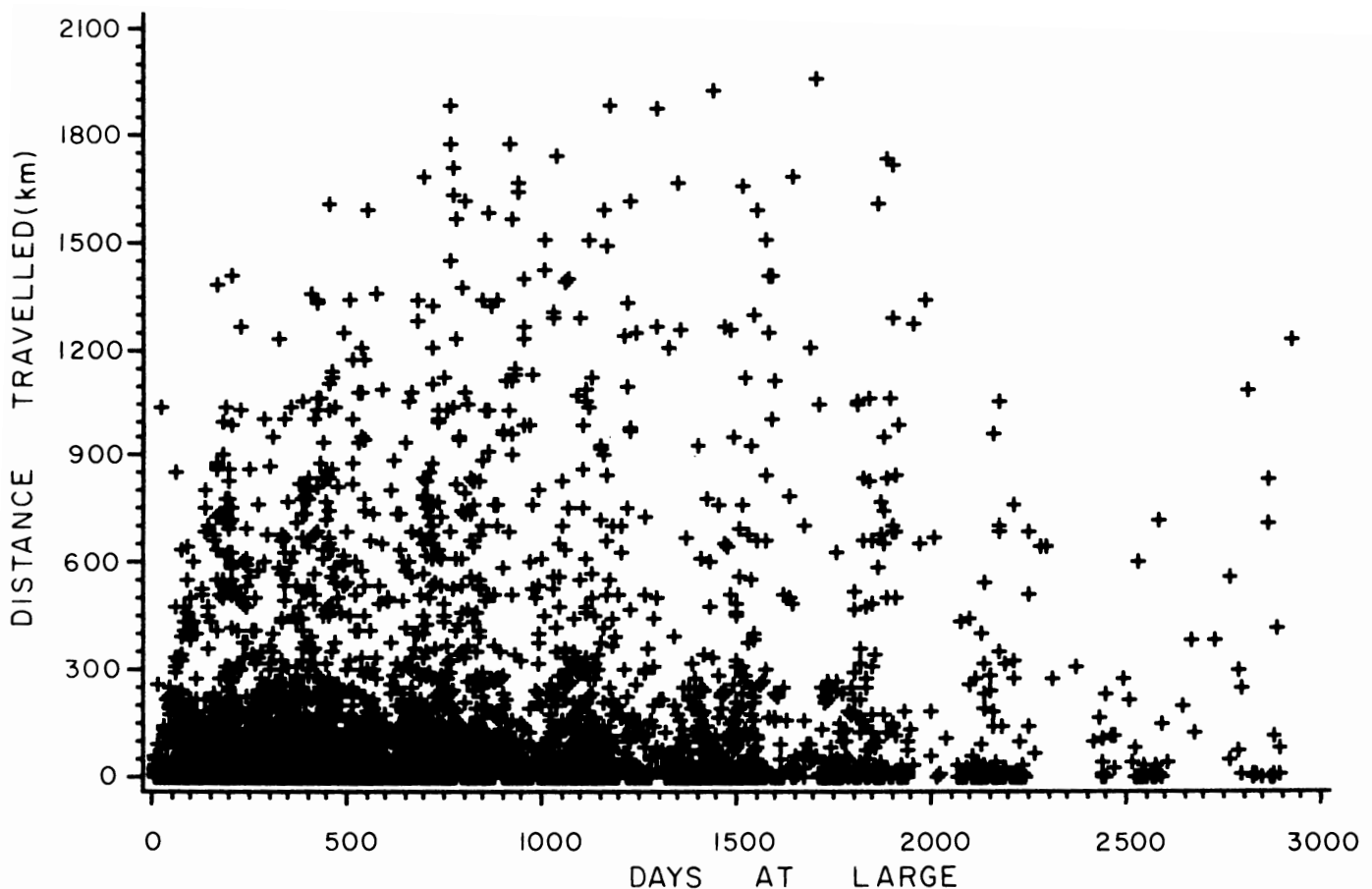


FIG. 11. Comparison of distance travelled and time at liberty for all recaptured sablefish.

described in this study were real and not the result of differences in fishing effort or in the reporting of tag recaptures.

Tag loss and total mortality reduced the number of marked fish in the population. After approximately 9 yr the number of recaptures was small and contributed more to the variance associated with the trends in movement than an improved understanding of these trends (Fig. 5, 9). Accordingly, fish were at liberty for a sufficient time to identify resident and dispersal behavior within the population.

Movements from Release Areas

Off Vancouver Island, there was a slight decline in the annual percentage of fish recovered within 50 km of the release area over the 9-yr period. The percentage of fish that were recaptured more than 200 km from the release area increased at an annual rate of approximately 2%, indicating that there was a small and relatively constant percentage of fish that moved beyond 200 km annually. This behavior was confirmed by examining fish from different release years that were recaptured after the same number of years at liberty. The percentages of fish recaptured at distances more than 200 km after 1, 2, 4, and 5 yr at liberty were almost constant and increased with time at liberty for each of these years. Although there were differences in behavior for fish recaptured after 3 and 6 yr at liberty, the trends for 1, 2, 4, and 5 yr at liberty were quite strong and believed to indicate the true behavior of the population. In general, off Vancouver Island, the percentage of sablefish that moved more than 200 km was small and increased slightly throughout the study.

In contrast, off the Queen Charlotte Islands there was more movement and the rate of movement out of the release area was not always constant. The average annual percentage of fish that were recaptured within 50 km of the release area declined approximately 35% over the study. This compares with a 9% decline observed off Vancouver Island. At the same time, annual percent recaptures of fish beyond 200 km from the release area increased from approximately 20 to approximately 40%. Comparisons of fish from different release years but recaptured after the same number of years at liberty also showed increasing rates of recapture percentage. The difference in behavior cannot be explained but could be partly related to sablefish density. The area of the continental slope (100–1000 m) off the Queen Charlotte Islands is approximately one-half of the area off Vancouver Island, and it is possible that the increasing abundance of sablefish in the Canadian zone (McFarlane et al. 1985) affected the behavior of resident sablefish off the Queen Charlotte Islands more than off Vancouver Island. The limited area of the continental slope off the Queen Charlotte Islands and the recruitment of the large 1977 year-class (McFarlane and Beamish 1983a; McFarlane et al. 1985) may have contributed to the increasing rate of movement.

It was possible to study the behavior of sablefish off the Queen Charlotte Islands in detail in one particular area. Over the period 1977–85 the percentage of fish recovered within 20 km of the exact release area declined in the same manner as observed for all other recaptures, corroborating the observation that a greater rate of movement occurred.

Because there were fewer releases in Queen Charlotte Sound than in other areas, the interpretation of movements was more

difficult. In general it appeared that movements were similar to movements off the Queen Charlotte Islands.

Only one release was made in a mainland inlet. Recapture of these fish at distances greater than 200 km indicated a slight increase in recovery percentages with time, which was similar to the behavior in other areas. As mentioned, the release in this inlet was heavily exploited in the first year when approximately one half of the total recaptures were made. Unfortunately, it was not possible to standardize the recaptures between this localized intensive fishery and catches beyond 200 km. However, if the first-year recaptures were ignored, the annual rate of recapture of fish within 50 km declined slightly, similar to the recaptures within 50 km off Vancouver Island. These observations indicate that most sablefish remained in the inlet.

The inability to demonstrate a relationship between time at liberty and distance travelled was consistent with most other studies (Bracken 1983; Dark 1983). Only Weststad (1983) reported a slight but significant increase in distance travelled with days at large. We conclude that sablefish will move out of an area with time but there was no relationship between time and distance travelled.

Movement into Waters off the United States

The tendency for adult sablefish to move north was reported earlier (Beamish and McFarlane 1983; Dark 1983). Because recapture data were not standardized in other studies, we cannot compare our estimates of rates of movement in and out of the Canadian zone. It is known, however, that movement of adults into the Canadian zone occurs from the north and the south. For example, in our study we recaptured 48 fish that were released in United States waters to the south of Canada from 1977 to 1983. Shaw (1986) indicated that these amounted to 4% of the total recaptures of fish tagged and released in the United States zone. There also is some indication that adult sablefish at the northern end of their distribution move south. Bracken (1982) reported the recovery of 164 adult sablefish (>60 cm) from releases in the Gulf of Alaska. He reported that 43% moved south and 7% moved north; however, relatively few fish were recovered and his data were not standardized by area. In the area immediately north of the Canadian zone (between 137°W and 54°30'N), Bracken found that most fish (86%) did not move and of those that did, an equal number moved north and south. In contrast, in the northwest Gulf of Alaska (between 147 and 170°W), most adult fish (53 fish; 72%) moved out of the release area, with 51 (96%) moving south and 26 (51%) moving into the Canadian zone (Bracken 1982). Therefore, Bracken's study shows that sablefish at their extreme northern distribution moved into the Canadian zone although those immediately north of the Canadian zone moved very little. It was not possible to determine if sablefish movement resulted in net losses or net gains to the Canadian zone. However, 13% of all recaptures of Canadian releases were made in the United States zone and 96% of these were recaptured in the Gulf of Alaska. Because the biomass of adult sablefish is thought to be four to five times greater in the Gulf of Alaska than in the Canadian zone (Fujioka 1985; McFarlane et al. 1985), a small percentage of movement into the Canadian zone could compensate for the disproportionate northward movement out of the zone.

Movement by Sex, Size, and Age

The sex ratios of recaptured fish recovered within 50 km and those recaptured more than 200 km were almost identical indicating that there was no trend for either sex to move out of the

release area at a greater rate. In an earlier study (Mason et al. 1983), we showed that there was no spawning migration; therefore, there does not appear to be short-term or long-term differences in the movement of either sex.

In the Gulf of Alaska, the direction of movement was related to fish length (Bracken 1982). Smaller fish moved north and west; larger fish moved southeast. Although the recapture percentages were not standardized and the sample size was small (164 fish), the data appear convincing. In our releases of tagged juveniles in the Canadian zone, we reported a strong tendency for juveniles to move north (Beamish and McFarlane 1983). More recent observations have confirmed this behavior (McFarlane and Beamish, unpubl. data). For adult fish, we did not observe any relationship between movement and length. The absence of a relationship between fish length and direction of movement was also reported by Shaw (1986) and Weststad (1983). Dark (1983) demonstrated a relationship between distance travelled and size in some areas; however, he used only two size categories which would not separate adult and juvenile fish. If the observations of Bracken (1982) are real, then the southward movement probably is a result of adults at the northern limits of their distribution moving south.

Movement beyond 200 km in relation to age was difficult to estimate because otoliths (Beamish and Chilton 1982) were difficult to obtain from fish recaptured by foreign fishermen. Thus, most samples came from the Canadian zone. A comparison of the age distribution of adult fish that moved more than 200 km in the Canadian zone with fish recaptured within 200 km of the release area indicated no tendency for older or younger adult fish to move out of the release area at a greater rate.

Resident and Dispersal Behavior

The observation that rate of movement out of some areas increased at a constant rate suggested that there could be a general pattern to the resident and dispersal behavior of sablefish. Our studies and others (Bracken 1982, 1983; Dark 1983; Weststad 1983; Shaw 1986) all demonstrated that a majority of sablefish are resident. Some fish, however, moved considerable distances, which would ensure that genetic exchange occurs throughout the range and that sablefish are one population. Tsuyuki et al. (1965) were unable to detect genetic differences that would indicate distinct populations. Gharrett et al. (1983), in a preliminary analysis, felt that some stocks could be separated genetically; however, a more extensive comparison (G. Winans and G. Stauffer, NW and Alaska Fisheries Center, Seattle, WA, pers. comm.) has recently concluded that, in general, sablefish stocks are one population.

Our study indicates that throughout their range, the movements of adults will contribute little recruitment to established fisheries. The annual rate of movement varies among areas; however, the biomass of fish that move, relative to the biomass that is fished, is small. The main source of recruitment to any particular area is from juveniles. In particular, occasional strong year-classes are the major source of recruitment. For example, large numbers of sablefish occurred in the eastern Bering Sea in the early 1960s and in the early 1980s (Typanogov and Kodolov 1983). We believe that these sablefish were from strong year-classes produced in the late 1950s and in 1977 (McFarlane and Beamish 1983b). During such periods of strong year-classes, the population expands and areas such as the eastern Bering Sea or inshore waters such as Puget Sound and the Strait of Georgia would be colonized. If conditions are suitable for survival and growth, larval sablefish in these newly colonized

areas will establish new stocks. If conditions for the survival of larvae are not suitable for these stocks and in the absence of successive recruitment from strong year-classes, such stocks are usually overfished.

The tendency for juveniles to move northward has been clearly demonstrated (Beamish and McFarlane 1983; unpubl. data; Dark 1983; Bracken 1982). Bracken (1982) proposed that the northward movement of juveniles was compensated by a southward movement of adults. We conclude that a southward movement of adults could compensate for a northward movement of adults, but not for the movement of juveniles out of the Canadian zone. If there was a compensating movement of adults back into and through the Canadian zone, we should have observed a greater amount of southward movement within the Canadian zone. Because large numbers of juveniles move north, there must be an accumulation of these younger sablefish in northern areas. Because the largest biomass of sablefish appears to be in the southern and central Gulf of Alaska (54°30'N by 154°W), we propose that many of the juveniles that migrate north from the Canadian zone become resident in the southern and central Gulf of Alaska. It also follows that in some location, movements north and south would be equal and that fish in this area would have the lowest dispersal rate. We propose that this area is the southern Gulf of Alaska.

We believe that sablefish constitute one population throughout the range, and within this range most adults are resident. Recruitment is maintained primarily from juveniles and adult dispersal is not a major contributor to the biomass of established fisheries, but does serve to maintain genetic exchange. Recruitment throughout the population and particularly at the extremes of the range is heavily dependent on periodic strong year-classes. Because recruitment is irregular and most adults are resident, localized overfishing can occur even if exploitation rates are relatively low.

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