INTERNATIONAL PACIFIC HALIBUT COMMISSION

ESTABLISHED BY A CONVENTION BETWEEN
CANADA AND THE UNITED STATES OF AMERICA

Scientific Report No. 76

Mark-Recapture Methods for Pacific Halibut Assessment: A Feasibility Study Conducted off the Central Coast of Oregon

by

Patrick J. Sullivan, Tracee O. Geernaert,
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SEATTLE, WASHINGTON
1993

The International Pacific Halibut Commission has three publications: Annual Reports (U.S. ISSN 0074-7238), Scientific Reports, and Technical Reports (U.S. ISSN 0579-3920). Until 1969, only one series was published (U.S. ISSN 0074-7246). The numbering of the original series has been continued with the Scientific Reports.

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ABSTRACT

Pacific halibut abundance is assessed annually by the staff of the International Pacific Halibut Commission. For this assessment, the staff uses catch-at-age and catch-per-unit-effort data collected and standardized over a fifteen to twenty year time horizon. The resulting exploitable biomass estimates form the basis for catch limit recommendations. It is necessary, at times, to test the assumptions made in this analysis, and hence it is useful to have information collected from other independent sources. The feasibility of using mark-recapture methods for Pacific halibut assessment was examined in an experiment conducted off the central coast of Oregon. Experiment results indicate that halibut abundance estimates derived from mark-recapture methods are likely to be biased due to assumption violations, as one might expect for a migratory marine species. In spite of these problems, insights were gained on local halibut movement and fishing activity. Recommendations are provided for future research addressing questions regarding halibut biology and fleet behavior.

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INTRODUCTION

In 1989, the International Pacific Halibut Commission (IPHC) conducted a Pacific halibut (*Hippoglossus stenolepis*) tagging experiment off the central coast of Oregon between 44° and 45°N latitude. This experiment had two objectives: (1) determine the feasibility of using mark-recapture techniques for assessing halibut population size; and (2) examine the dynamics of the fishery and the behavior of the halibut population to gain insight on how these factors influence interpretations of stock dynamics. This report documents this study and forms the basis for future research in this and other regulatory areas.

The IPHC specifies regulatory areas off the west coast of North America to control the distribution of fishing effort and mortality on the halibut stock (Figure 1). IPHC Area 2A, the Washington and Oregon coasts, yields approximately one percent of the total coastwide annual harvest and includes less than one percent of the coastwide exploitable biomass of Pacific halibut. In 1989, 789,000 pounds of halibut were

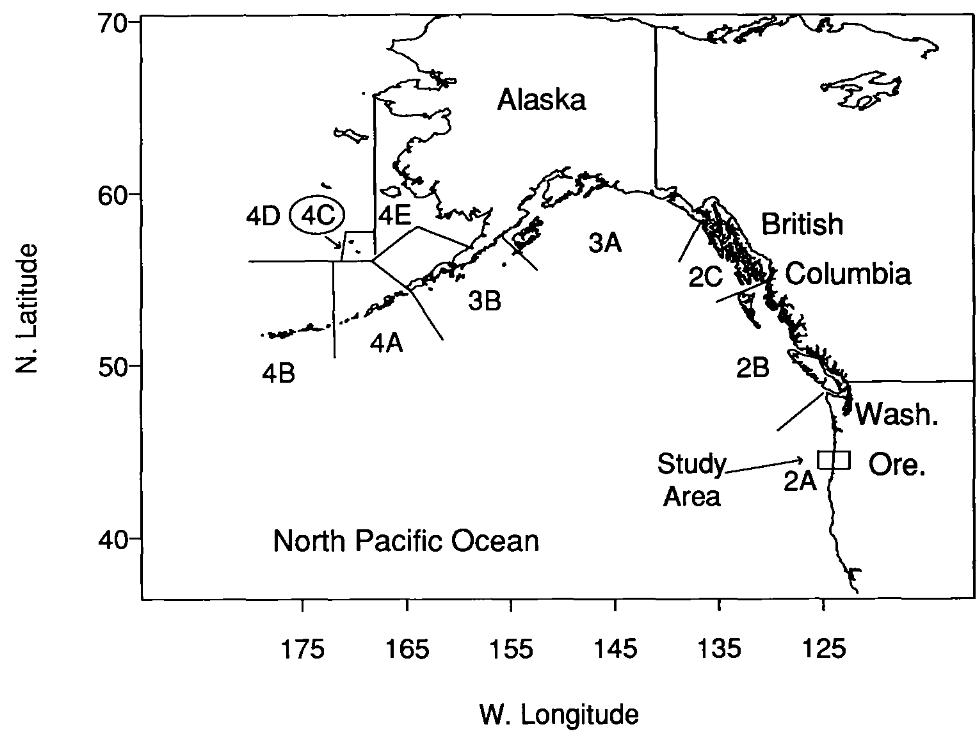

Figure 1. Regulatory areas of the International Pacific Halibut Commission.

removed in Washington and Oregon while 66.95 million pounds were landed coastwide. Catch-at-age analyses indicate that in 1989 there was 1.5 - 2.0 million pounds of exploitable biomass in Area 2A and between 230 and 320 million pounds of exploitable biomass coastwide. Despite the relatively small yield obtained from this IPHC area, which occupies the southern-most region of the population's range, a significant contribution to the economy and social structure of these two states is made by this fishery. In particular, this yield is important to the commercial, sport, and tribal user groups, who split the allowable yield on an annual basis. The approach currently used by the IPHC to assess Pacific halibut abundance is the catch-at-age analysis procedure CAGEAN (Deriso et al. 1985). This approach is applied on an area by area basis. In Area 2A, the assessment of halibut stock abundance is arrived at by applying the CAGEAN procedure to catch and effort data pooled from Areas 2A and 2B (British Columbia). Allowable yield is partitioned between the two areas on the basis of CPUE and habitat area (Quinn et al. 1983).

The CAGEAN procedure is based on the principle of repeatedly measuring the strength of a cohort, or year class, from the time it first enters the fishery to the present. The catch at age, estimated from the Commission's annual port sampling program, provides this measure of cohort abundance. If there were no sources of mortality on a cohort other than that due to fishing, then the sum of the number of fish caught from that cohort over its lifetime would equal the total number present upon first entering the fishery, thus providing an enumeration of that cohort's abundance. Since other sources of mortality do exist (e.g. predation, disease, bycatch in non-directed fisheries) and there are multiple cohorts in the fishery, the analysis is often more complicated than this and subject to several assumptions.

Catch-at-age analyses generally provide good estimates of fish abundance. However, questions regarding the assumptions or the complexity of this type of analysis often lead one to seek out simpler alternative measures of abundance. As we shall see, this is not always a straightforward proposition.

The experiment discussed in this report examines the feasibility of improving the assessment in two ways: (1) the utility of mark-recapture techniques for determining an independent estimate of population size; and (2) the data are examined for information on behavior of the fish and the fishery that could lead to refinements in the catch-at-age method of assessment.

It seemed, from the outset, that the probability of arriving at a viable assessment of stock abundance, independent of the catch-at-age analysis, using a mark and recapture technique was low. First, the lack of success in using the technique for freshwater fish has been clearly documented (Beukema and DeVos 1974, Cone et al. 1988). Problems associated with violations in model assumptions become exacerbated when the approach is applied to marine species (Kelly and Barker 1963); and halibut is no exception (Myhre 1963). Furthermore, the information present in a single recapture experiment is small when compared with the data used in the catch-at-age analysis. In 1989, for example, a fifteen year period of fishery data are used in the catch-at-age analysis, encompassing a total catch of 637 million pounds (IPHC 1990). In addition, 208,000 individual fish measurements from commercial landings, thousands of log book tallies of effort information, and annual surveys and biological investigations designed to address assumptions made in the analysis, were also employed.

However, we hoped that the experiment might be controlled to prevent assumptions from being violated, and that repeated application of the approach might provide a time series of observations similar to that obtained from catch sample data. Such an approach was successfully undertaken for herring (Dragesund and Jakobsson 1963). Given this rationale, and the prospect that insights on the biology and the behavior of the fishery might also be forthcoming, we initiated the study described here.

In the sections to follow we review the experimental design and methodology, present the basic data, and derive an abundance estimate based on this data. We evaluate the reliability of the estimate and explore other features of the data in order to suggest future research.

EXPERIMENTAL DESIGN

There are many ways to estimate animal abundance and Seber (1982, 1986) provides a good introduction to this material. Several of these methods consist of marking a portion of the population with tags and then using subsequent samples of the population to make inferences about total abundance. Tagging experiments can be used to gather other types of information, such as estimates of mortality and migration rates (Paloheimo 1958, Gulland 1963a, Paulik 1963, Chapman 1965, Youngs 1972, Youngs and Robson 1975, Pollock and Mann 1983), and in other situations model assumptions can be verified (Beukema and DeVos 1974, Cone et al. 1988). Emery and Wydoski (1987) provide a recent compilation of references in the tagging literature, and developments in the technology of fish-marking may be found in Parker et al. (1990).

We used a Petersen model, assuming that a population assessment would be based on a single marking event with one or more recapture events. The model assumes that tagged fish are as likely to be captured in a sample as untagged fish. Therefore, the proportion of tagged fish in the total population equals the expected proportion of tagged fish in the total sample:

$$\frac{M}{N} = \frac{M_c}{N_c}$$

where M is the number of fish marked initially, N is the total number in the population, M_c is the number of marked fish recovered in the catch sample, and N_c is the total number in the catch sample. Since the number of tagged fish released and caught, and the total number of fish caught are known, the total abundance estimate is:

$$N = M \frac{N_c}{M_c}$$

Chapman (1951) discusses an unbiased estimator of N based on a hypergeometric model:

$$N = \frac{(M+1)\,(N_c+1)}{(M_c+1)} - 1$$

and an approximately unbiased estimate of the variance is given by Seber (1970) and Wittes (1972):

$$V(N) = \frac{(M+1)\,(N_c+1)\,(M-M_c)\,(N_c-M_c)}{(M_c+1)^2\,(M_c+2)}$$

These estimators may be used in assessing population abundance, when certain assumptions are satisfied.

The following assumptions must hold for the procedure to provide reasonable estimates (Seber 1982):

(1) The population must be closed, that is there must be no immigration or emigration of fish from the study area;

(2) Each fish in the population must have an equal probability of being marked, or alternatively;
(3) The samples taken subsequent to marking must be simple random samples of the population;
(4) Neither the tag, nor the tagging operation, can affect fish viability, availability, or vulnerability;
(5) No tags are lost by the fish;
(6) All tags are reported on recovery.

The validity of these assumptions will be addressed in our analysis.

The confidence interval of the estimate, as measured by the variance (equation 4), is a function of the number of fish marked initially, the number of marked fish recovered, and the total number of fish examined for marks. In order to constrain the confidence interval to a range that would allow reasonable inferences, control is exercised over these three factors. The number of marks released and the total number of fish examined for marks can be specified by design, but the number of marked fish recovered depends on the ratio of marked fish to total population abundance. Because total abundance is what we are trying to estimate, it appears we are at an impasse. We get around this by establishing a reasonable range of population sizes, based on a preliminary estimate of population abundance, and examine how the confidence level is likely to change with changes in the factors we control, namely, the number of marks released and the number of fish examined for marks. Robson and Regier (1964) provide a method for determining the confidence level based on the number released, the number captured, and the population abundance using a hypergeometric distribution. All that remains is to find a preliminary estimate of population abundance, which we do here using an assumed exploitation rate and the catch taken in the study area in a previous year.

In 1987, a catch of 592,000 pounds was recorded in Area 2A, approximately a third of which was landed in Newport (roughly 200,000 pounds). Assuming an exploitation rate of 35 percent, the exploitable biomass in this subarea would be 572,000 pounds and the total biomass would be about 1.75 - 2.00 times this figure, or about 1,000,000 to 1,144,000 pounds. The average weight of a fish in this area was assumed to be 20 pounds, so that the preliminary estimate of total abundance was between 50,000 and 60,000 fish. Table 1 gives the sample size required to achieve a 95 percent confidence level that is within plus or minus 10, 25, or 50 percent of the estimated stock size. Assuming that the population in the central Oregon area is 50,000 fish and that port samplers would be able to examine between 1,500 and 3,000 fish for marks, then, 1,100 to 2,200 fish would need to be marked in order to achieve a 95 percent confidence interval that is within plus or minus 25 percent of the estimated stock size. This is equivalent to obtaining an estimate with a coefficient of variation of 12.5 percent.

$$\frac{\delta}{X} = \frac{.25}{2}$$

The number of fish present per unit area varies significantly over the study area. Certain locations, with recognizable bathymetric features, are known to be good halibut fishing grounds. These grounds were divided into two strata representing greater and lesser fish densities. The majority of tags were placed on grounds with the greatest fish densities; however, some effort was allocated to grounds of lesser density so that, if it was shown to be necessary, a stratified analysis could be applied. The fish

Table 1. **Sample size requirements with 95% confidence levels.**

Confidence Level	Number of fish tagged for population size: 50,000	100,000	Number of fish to be examined for tags
1) $A = 0.10$	10,100	20,500	1,500
	5,400	11,200	3,000
2) $A = 0.25$	2,200	4,400	1,500
	1,100	2,300	3,000
3) $A = 0.50$	800	1,600	1,500
	400	800	3,000

$$P[-A < \frac{\hat{N} - N}{N} < +A] \geq 0.95$$

used in the experiment were double tagged with an external wire spaghetti tag inserted on the opercular bone of the dark side of the fish, and an internal coded wire tag inserted in the upper edge of the cheek. The internal tag was visible only to a metal detector. The tags were recovered by two teams operating independently on the docks during the commercial landing period. One team collected the external tags as part of the Commission's ongoing port sampling activity, while the other team examined heads that had been removed from landed halibut by plant workers. The dual tagging procedure is designed to assess the recovery probability of each tag type by the time of the second sample assuming that losses occur only through tag loss or lack of reporting and that the recovery of one tag does not influence the recovery of the second.

METHODS

A commercial longline vessel, the forty-six foot *Donna,* was chartered between May 7 and June 7, 1989 for 22 days of fishing off central Oregon. The experiment covered fishing grounds between Cascade Head (Figure 2, Zone 1) and Heceta Head (Figure 2, southwest of Zone 6). In total, 32,469 pounds of legal-sized halibut were caught by setting and retrieving four hundred and twenty three 1,800 foot skates of snap longline gear with 36-foot hook spacing. The highest catch rate occurred on the first day of the cruise with 2,357 pounds retrieved on one 5-skate set and the lowest rate occurred near the end of the trip with only 3 sublegal fish being caught on 6 skates. There were 1,556 legal-sized ($\geq$ 82 cm) and 562 sublegal-sized halibut tagged and released. The number of tagged halibut released and their release locations are shown in Figure 2. Appendix I provides more detailed information. Legal-sized halibut were tagged on their dark side with both a wire spaghetti tag twisted into the opercular bone and an internal coded wire tag that was injected into the cheek. The double legend spaghetti tags have a unique number printed on the side, whereas the coded wire tags, because they are only two millimeters long and more difficult to handle separately, are numbered with a batch bar code that is read on recovery by microscope. Sublegals were tagged only with external tags. Coded wire tags were injected into 1,541 of the

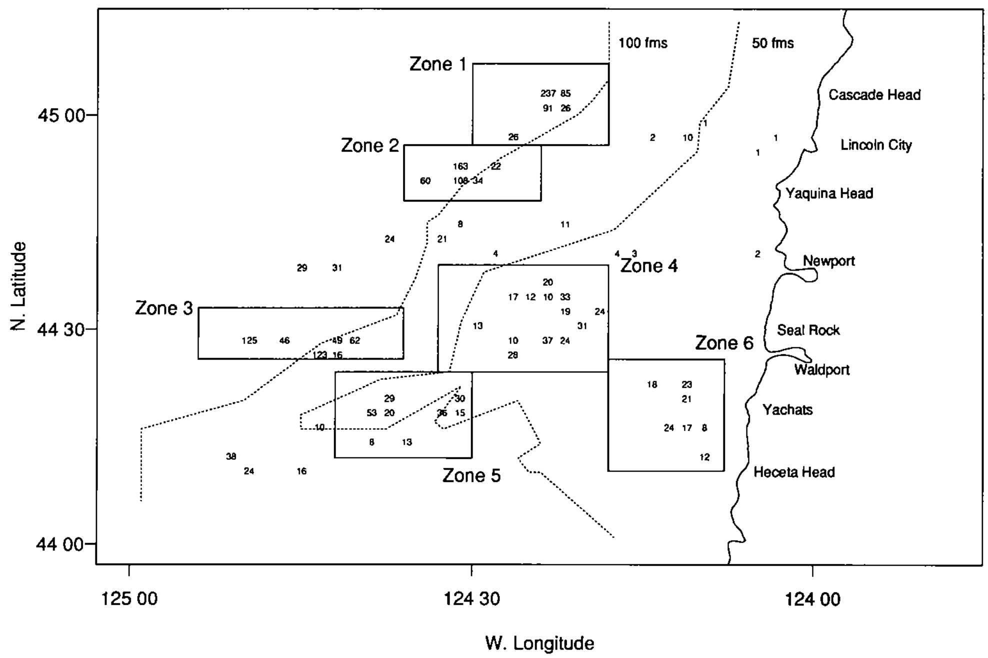

Figure 2. Number of tags released by location and geographical zones.

1,556 legal-sized fish. Coded wire batch numbers corresponding to the spaghetti tag number are listed in Appendix II.

A two to three person internal tag collection team from the IPHC and from the Washington Department of Fisheries (WDF) scanned totes of fish heads for internal coded wire tags in Newport during the June 27-29 fishing period in 1989 and the July 10 fishing period in 1990. The sampling team set up a metal detector and passed halibut heads one at a time through the scanner. A sound was emitted from the detector when an internal tag was present, and the cheek flesh was cut out to isolate the tag. The sample was labelled, frozen, and later the tag was retrieved and the number read at the WDF lab in Olympia. Of the vessels that landed their catch in Newport, the internal tag sampling team collected data only from those for which the entire catch was available for sampling. All halibut heads were examined and counted from each trip sampled. Some landings were not available for sampling as the fish, with the head on, were shipped to customers.

Information about the tagging operation, including posters describing the tags and the rewards, was sent to federal and state agencies, Newport sport charter companies, and posted on the docks, floats, and boat harbors in Newport. A two person IPHC port sampling team was present taking logbooks and collecting external tags during commercial landings. The internal tag collection team operated independently of the port sampling team so that the two types of tag data could be treated separately. External tags were also collected from sport and non-directed commercial fisheries throughout the year by an existing IPHC tag recovery reward program. This program includes an extensive port sampling and mail-in process that operates in British Columbia, Alaska, Washington, and Oregon and rewards a fisherman with a baseball cap or $5.00 if they land a tagged halibut. Tags were also collected and forwarded by state and federal agencies from the directed and non-directed commercial fisheries. Legal-sized ($\geq$82 cm) halibut may be landed commercially only in the longline directed fishery and only during an official halibut season opening.

However, tagged halibut of any size may be landed by any fishery at any time, and, during this study, there was no size limit on sport caught halibut. It therefore becomes important to distinguish tags recovered by fishery and size. Recovery of the internal coded wire tags from the sport and non-directed catch was not possible due to the lack of personnel and equipment needed to detect them.

RESULTS

Almost 180,000 pounds of halibut were landed in Newport during the 1989 and 1990 directed halibut commercial fisheries (Table 2). During the 1989 landing period 18 external tags on legal-sized fish were collected from 116,000 pounds of halibut (dressed weight with heads removed). Three additional tags were found on sublegal-sized fish. Over half (69,000 pounds) was examined for internal tags. Eight internal tags were recovered after examining 3,163 halibut heads. In 1990, the commercial longline catch landed in Newport was approximately 63,000 pounds of halibut. The port sampling team recovered 11 external tags from legal size fish and 2 additional tags from sublegal sized fish. The internal tag sampling team examined 1,742 halibut heads representing over half of the commercial catch or almost 35,000 pounds. Six internal tags were found. In the sport fishery, only the external tags were collected. In Oregon, a total of 100 tagged halibut were landed by the sport fishery; 66 tags were collected from approximately 135,000 pounds of halibut in 1989 and 34 tags were recovered from approximately 73,000 pounds of halibut caught in 1990. Non-directed fisheries (troll and trawl) netted 137 tags, 78 in 1989 and 59 in 1990. The majority of these tags are from the shrimp trawl fishery. Tag recovery information was categorized by year, gear, and size category (Table 3). Approximately 14 percent of the fish tagged in the experiment were recovered in 1989 and 1990. Of the 295 tag recoveries, 182 were from legal-sized fish. This represents a 12 percent recovery rate of the 1,556 legal-sized fish that were tagged. Legal-sized recoveries were split almost evenly among the longline, sport, and trawl fisheries for recovery rates of 3, 4, and 5 percent, respectively. Sublegal fish that were tagged in the experiment totalled 562 and 113 of these were recovered for

Table 2. Newport halibut port sampling summary.

	1989	1990
Commercial catch lbs	115,573	63,480
Legal sized external tags (>82 cm)	18	11
Sublegal sized external tags (<82 cm)	3	2
Number of fish examined	3,163	1,742
Number of internal tags	8	6
Weight of fish examined for internal tags (number x aver.wgt)	63,260	34,840
Percent fish landed and examined for internal tags	55	55

Table 3. **Halibut tag recoveries and recovery rates by gear type and size category for 1989 and 1990.**

All sizes combined

	1989	1990	Total	Recovery Rate (2,118 released)
All gear types	177	118	295	14.0

Legal sized (> 82 cm)

Gear	1989	1990	Total	Recovery Rate (1,556 released)
Longline	26	20	46	3.0
Troll	5	1	6	0.4
Trawl	39	34	73	4.7
Sport	35	22	57	3.6
Total	105	77	182	11.7

Sub-legal sized (< 82 cm)

Gear	1989	1990	Total	Recovery Rate (562 released)
Longline	7	5	12	2.1
Troll	3	3	6	1.1
Trawl	31	21	52	9.2
Sport	31	12	43	7.7
Total	72	41	113	20.1

a recovery rate of 20 percent. The trawl and sport fishery categories represented most of the recoveries in the sublegal size class, with a combined recovery rate of 17 percent. The longline fishery had only 12 sublegal tagged fish recovered, a recovery rate of 2 percent. The troll fishery recovered only 6 tagged fish each from the two size classes.

POPULATION ASSESSMENT

The IPHC's standard stock assessment analysis (IPHC 1990) estimated that there were 1.5 million pounds of exploitable biomass in Area 2A in 1989, although more recent estimates indicate that it may have been closer to 2 million pounds (IPHC 1992). A third of this biomass is believed to reside in the study area off central Oregon. Total biomass is roughly 175 to 200 percent of the exploitable biomass, and since the average net weight of a fish in the catch in this area is 20 pounds, the biomass off central Oregon represents approximately 43,000-67,000 legal-sized fish. If 1,556 of those fish are tagged, then a sampling of approximately 116,000 pounds (5,800 fish) in the commercial catch should have produced 130-210 tagged legal-sized fish. Only 18 tags from legal-sized fish were recovered from the directed Area 2A longline fishery in 1989 (Table 2). The additional eight longline recoveries (Table 3) were from other longline fisheries, such as the blackcod fishery and from directed halibut fisheries in other areas. Similarly, of 3,163 fish examined for internal tags (Table 2), we would expect to find 104 tags and yet only 8 were recovered. Moreover, approximately 135,000 pounds of fish were sport caught and we would expect to find 150 - 240 tags, yet only 35 tagged legal-sized fish were recovered from that fishery in 1989. Thus, under the simple assumptions stated above, the recovery rate of tags from each of these sampling components was much lower than expected. The modified Petersen estimator (equations 2 and 3) is applied to estimate the population size under these assumptions. Let M=1556, N_c=5800, and M_c=18, then total abundance is estimated to be 475,000 fish plus or minus 200,000. This estimate is nearly ten times the number arrived at using the standard stock assessment approach. The result indicates either the abundance of fish off central Oregon is much higher than we expect, given our standard age-based stock assessment analysis, or one or more of the assumptions made in the Petersen estimator are invalid, thus giving a biased estimate of abundance. We now examine whether critical assumptions have been violated.

The first three assumptions specify that the population remains closed to immigration and emigration, and uniform in its accessibility to sampling. Random, small-scale movement of fish within the study area should not affect the results under these assumptions, but significant movement into and out of the study area can bias the estimate. To address this issue, movement patterns derived from tag release and recovery location information are used. Figures 3 and 4 show the movement of fish by type of recovery fishery (longline, sport, trawl , and troll) and year. The arrows track the movement of fish from release to recovery. Release locations are known precisely (Figure 2) whereas recovery locations correspond to landing information gathered from the different fisheries when the tags were returned. Each arrow indicates the distance and direction traveled by a recovered fish. The solid arrows shown in Figure 3 indicate recoveries made prior to and during the directed longline opening. The dashed arrows indicate recoveries made after the 1989 season closure.

Three things can be noted from these figures. The first concerns movement of halibut out of the study area. While there are no recorded recoveries of tagged fish outside of the study area prior to or during the directed longline opening, (see Table 4 for fishery details) fish did move out of the study area within the first year. Approximately 7 percent of the fish recovered in 1989 and 10 percent of those recovered in 1990 were found outside of the release area (Table 5). Much of this movement may be related to the northerly and north westerly migration of adults to spawn, (St-Pierre 1984) but it might also indicate a unidirectional drift of adults north.

Figure 5 provides the length composition at release of longline caught halibut within (south) and north of the study area. These data indicate the degree to which length specific movement may affect the distribution of halibut once seasonal migration has ceased. Since halibut were longline caught only in the spring and summer months during this study, a period when migration to the spawning grounds is minimal, the recovery of larger halibut in the north may indicate a preference by these fish for the more northern grounds. However, it might also reflect a difference in targeting or gear selectivity between fisheries in these two areas. Further studies are needed to deduce the degree and timing of northward drift.

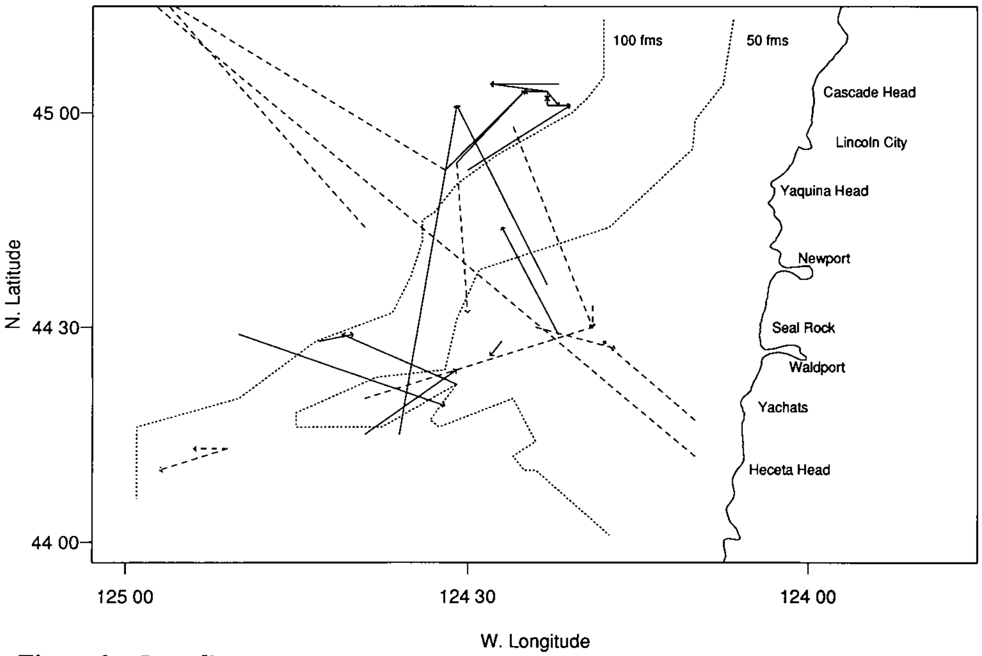

Figure 3a. Longline

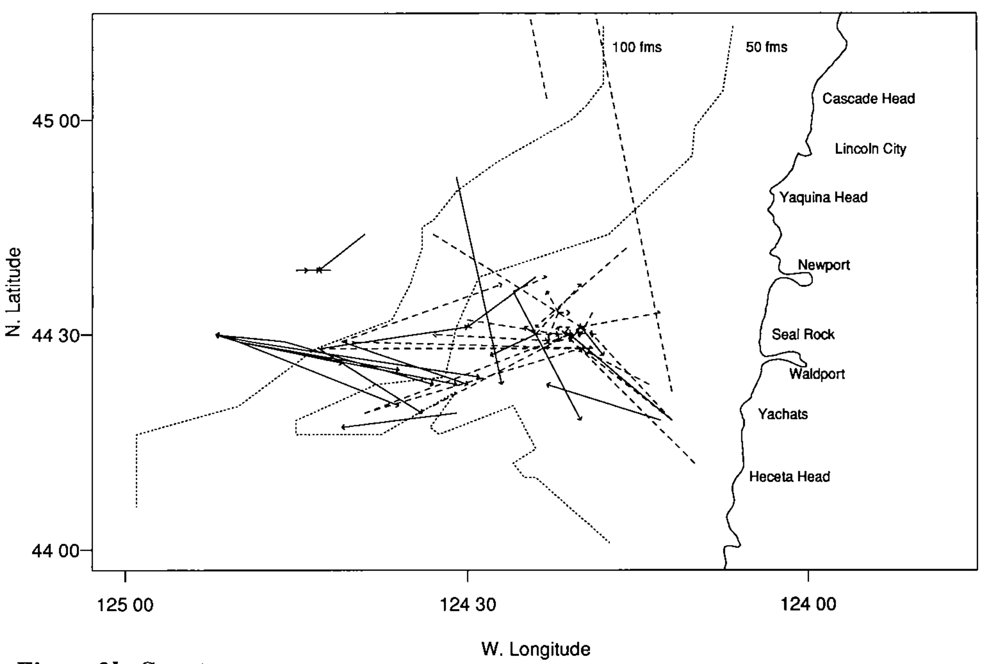

Figure 3b. Sport

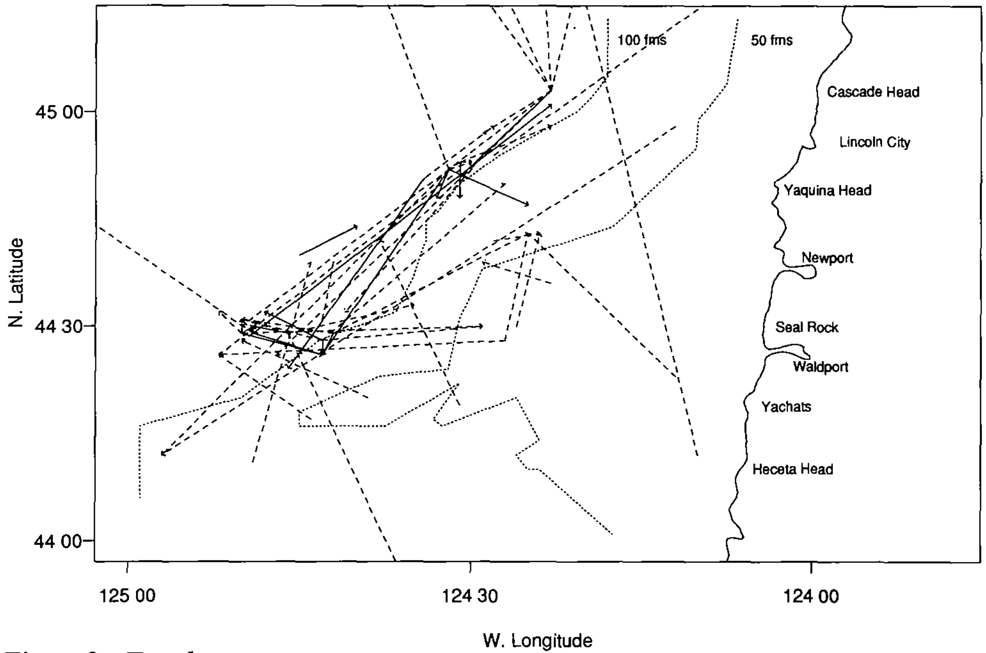

Figure 3c. Trawl

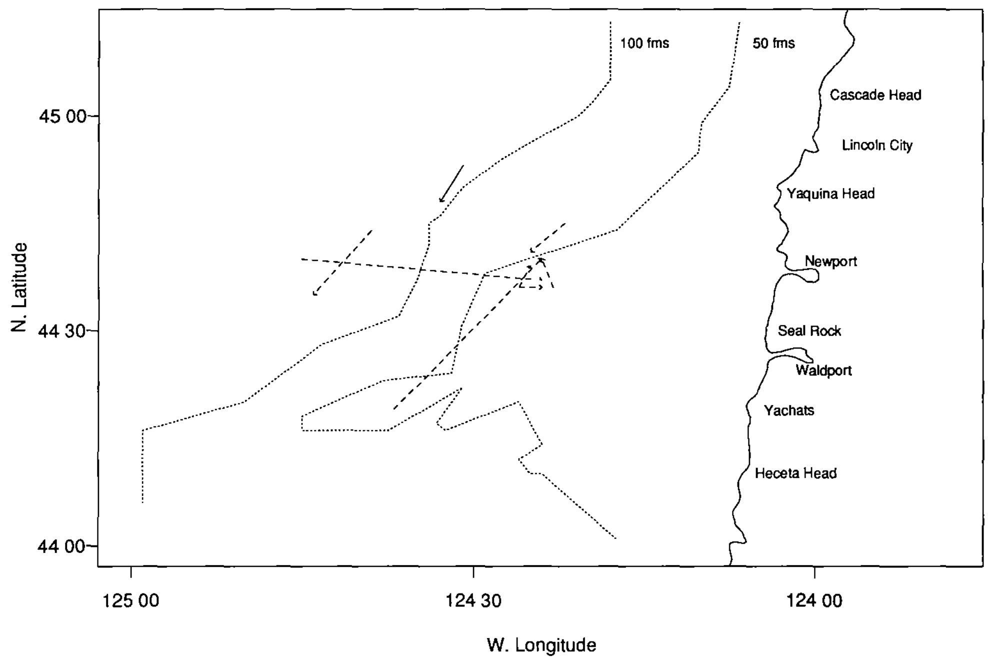

Figure 3d. Troll

Figure 3a-d. Longline, sport, trawl, and troll release-recovery vectors for recoveries made in 1989.

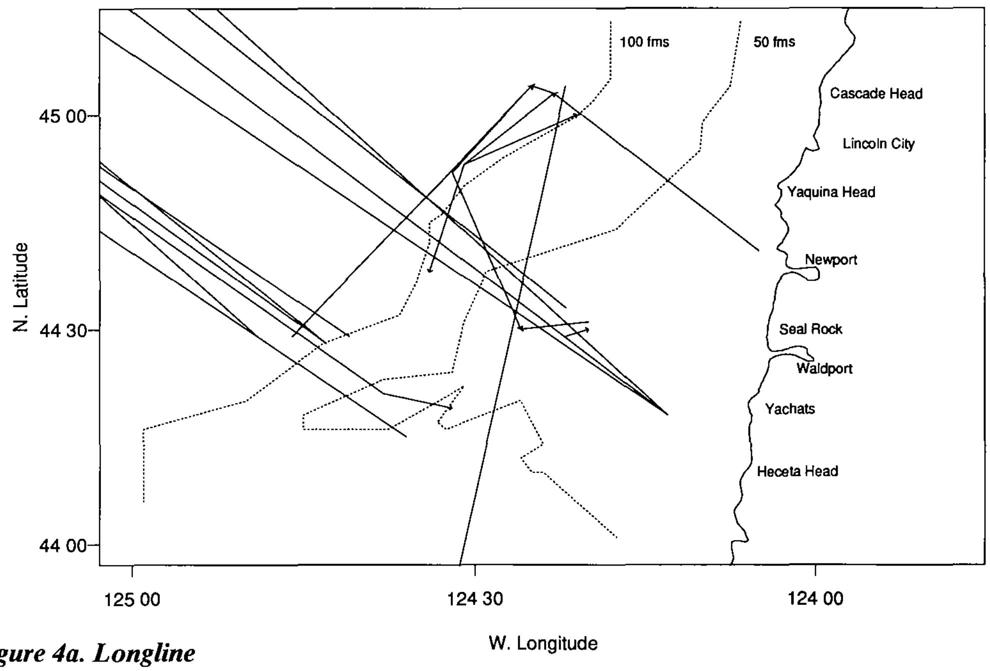

Figure 4a. Longline

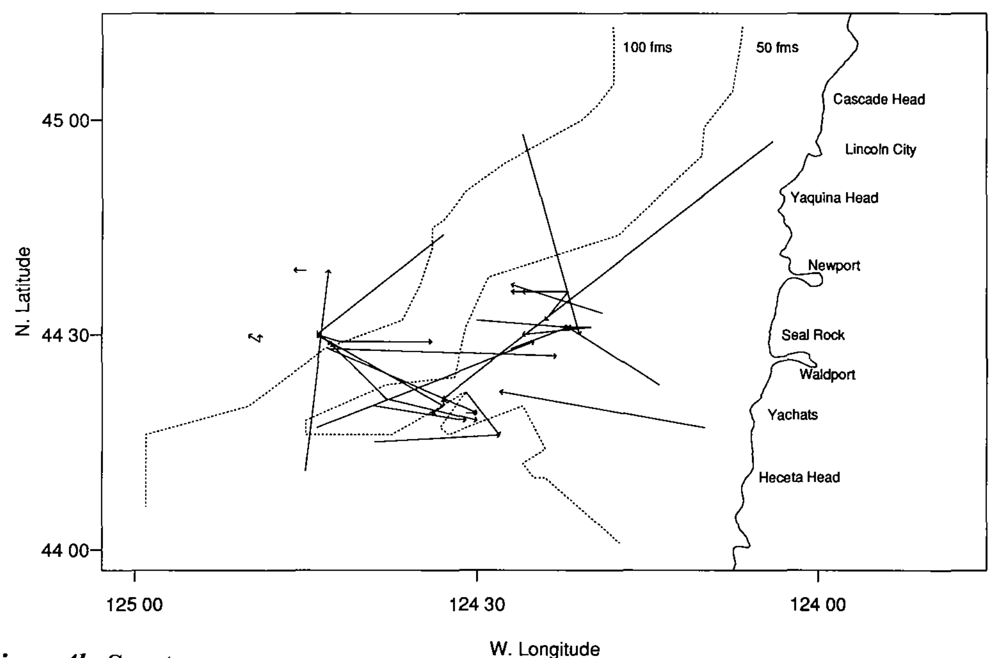

Figure 4b. Sport

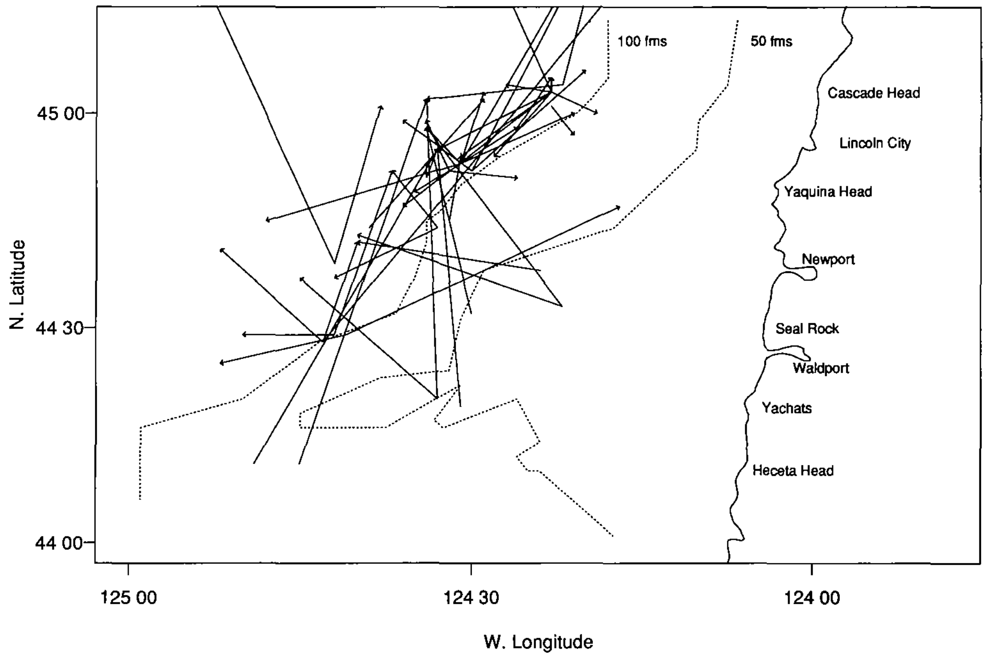

Figure 4c. Trawl

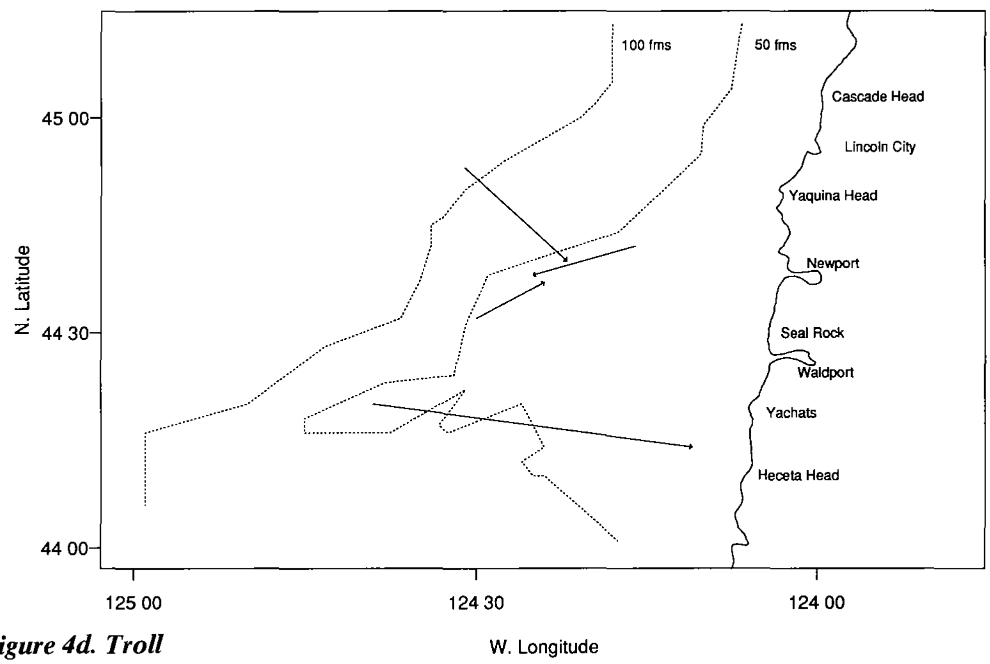

Figure 4d. Troll

Figure 4a-d. Longline, sport, trawl, and troll release-recovery vectors for recoveries made in 1990.

Table 4. Summary of the 1989 and 1990 commercial fishery in IPHC Area 2.

Area	Seasons	Catch (000's lbs)
1989		
2A	Jun 27 - 29	330
	Mar 1 - Oct 13[1]	142
		472
2B	Apr 25 - May 3	7,187
	Sep 9 - 12	3,244
		10,431
2C	May 16 - 16	3,457
	Jun 12 - 13	4,570
	Sep 7 - 8	1,505
		9,532
1990		
2A	Jul 10	174
	Jul 30	7
	Aug 27	14
	Sep 11	8
	Mar 1 - 27[1]	122
		325
2B	Apr 16 - 20	2,552
	Jun 14 -18	3,049
	Sep 13 - 15	2,973
		8,574
2C	May 1 - 2	4,026
	Jun 5 - 6	5,675
	May 20 - Jun 3[2]	33
		9,734

[1]Treaty Indian Fishery
[2]Metlakatla Indian Fishery (four 2-day fishing periods)

Table 5. **Halibut tag recoveries from the central Oregon tagging experiment by year and statistical area.**

Geographic Area	Statistical Area	1989	1990	Total
Cape Spencer	185	1	1	2
Frederick Sound	162	0	1	1
Dixon Entrance	132	0	1	1
Whaleback Grounds	131	1	3	4
Moresby Island	120	0	1	1
Goose Island Bank	102	1	1	2
Queen Charlotte Sd.	100	0	2	2
Vancouver Island	70	1	0	1
N. Washington Coast	50	1	2	3
S. Washington Coast	40	1	0	1
N. Oregon Coast	30	6	1	7
Stonewall Bank	20	106	82	188
Hecata Bank	10	59	21	80
Unknown		0	2	2
	Total	177	118	295

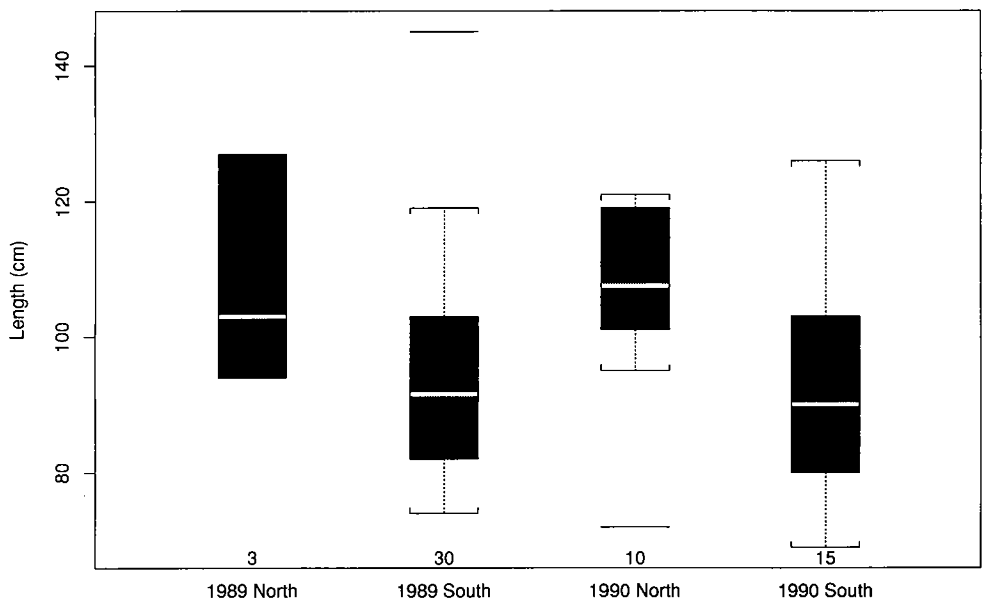

Figure 5. **Distribution of release lengths of longline caught halibut by year and area (north and south of 45° 06′ latitude). Boxplots show median (mid-point of data) with shaded range from 25th to 75th quartile (the middle half of the data). Whiskers indicate range of remaining points and floating lines indicate outlying points. Numbers at bottom of each plot show sample size.**

Movement of halibut northward and out of the study area violates the assumption of a closed population if it occurs prior to taking the recovery sample. The information presented thus far indicates that this most likely occurred. If emigration alone occurred, the Petersen estimate would remain unbiased provided we can assume that marked and unmarked fish behaved in the same manner. Although unbiased, the estimate would reflect a loss in efficiency since the variance would increase as M_c would most likely decrease. Immigration, on the other hand, will bias the estimate upward. Although this experiment was not designed to test the level of immigration, our recoveries of halibut tagged in areas outside of the central Oregon study area indicate an influx of fish from regions to the north (Table 6). Six of those seven recoveries were of sublegal-size on release, so the immigration seen here is consistent with the south and east migration pattern of sublegals tracked in other areas. The 1983 release was a legal-sized halibut (84 cm on release, 131 cm on recovery).

Table 6. Immigrant tags to the study area by area and year of release.

	Area of release				
Year of Release	Bering Sea	Kodiak Area	Cook Inlet	Dixon Entr.	Year recovered
1979		1			1990
1981			1		1990
1983				1	1989
1984	1				1989
1985		2			1989, 1990
1986		1			1990
Total	1	4	1	1	Total recovered in study area = 7

The release-recovery data may also be used to show how halibut move within the study area. Figures 3 and 4 suggest that the fish are recovered in patterns that depend on the fishery and the time fished. However, small scale patterns may be detected when the data are pooled by season. Figure 6 presents seasonally averaged patterns of release-recovery location information for the spring and summer of 1989. Spring is defined as the period from the March equinox to the June solstice, and summer as the June solstice to the September equinox. The patterns represent the average distance and direction of all release-recovery vectors passing through circles of radius 0.1 degree located at equispaced grid points within the study area. This averaging is demonstrated for an example grid point and its circle of influence in the top two diagrams shown in Figure 6. The bottom two diagrams show the resulting averages for the spring and summer season.

A counter-clockwise pattern of release to recovery is apparent in the figure. This indicates that halibut on the grounds during placement of the tags may have moved off those grounds prior to the onset of directed fishing. Fishing effort was concentrated in Zones 1, 3, and 5 (Figure 2) during the longline fishery in 1989, and the release-recovery pattern (Figure 6) appears to show that tagged fish, on average, moved out of those areas. While these patterns may be influenced by size-specific movement interacting with the targeting and gear selectivity exhibited by recovery vessels, movement of halibut counter to that shown and into Zones 1, 3, and 5 certainly should have been

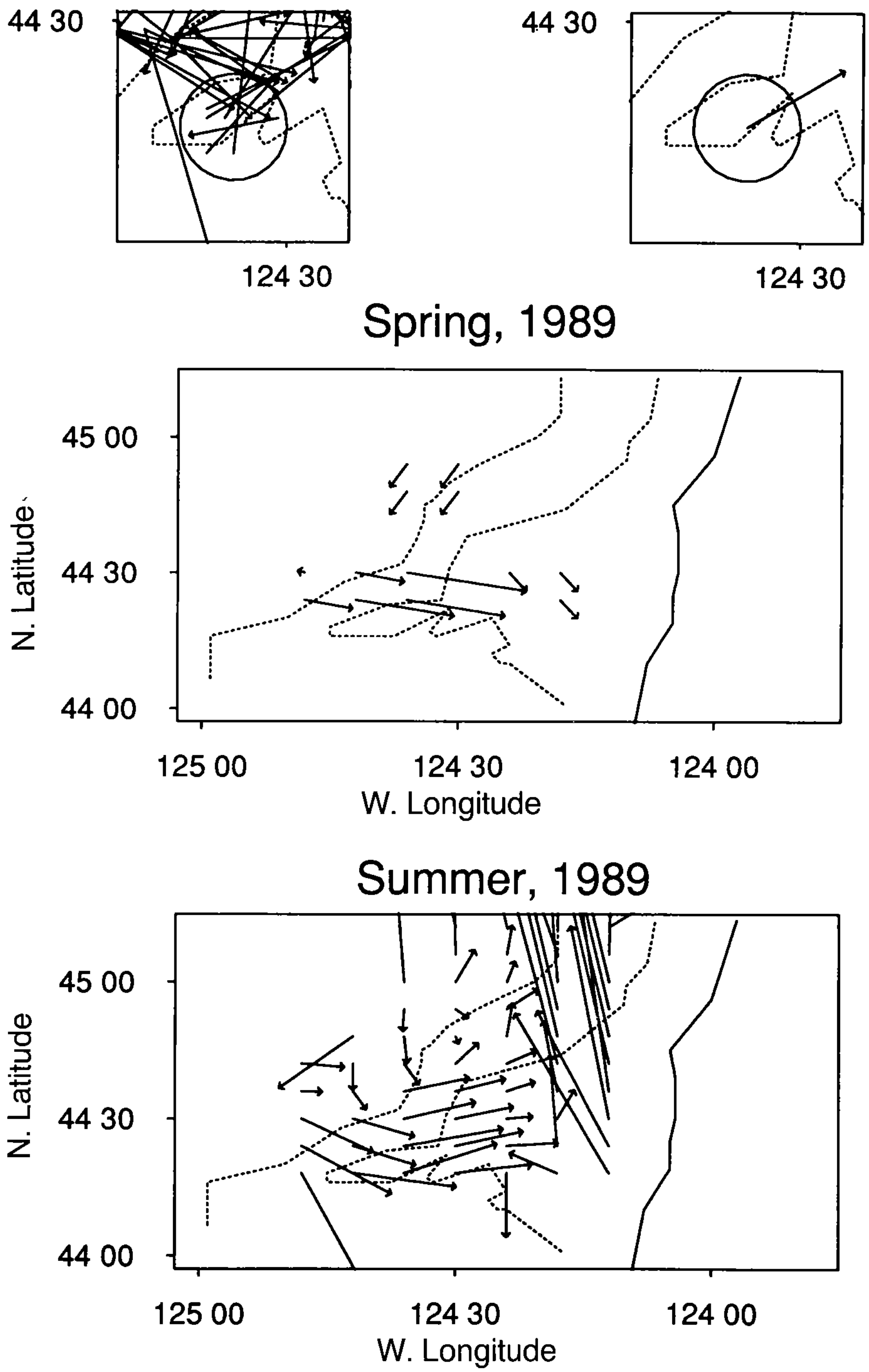

Figure 6. Average distance and direction between release and recovery points from data gathered in the spring and summer of 1989. The top two diagrams demonstrate, at a single grid point, how the averages are taken. The average (shown on the right) was computed by averaging the latitudinal and longitudinal components of all release-recovery vectors passing through the circle (shown on the left). The second set of diagrams presents the average for the spring and summer recoveries on the full 7 by 11 grid.

greater than that detected by the directed longline fleet. What influence tidal currents and feeding behavior have on these patterns is unknown. Further research on oceanographic and behavioral influences on halibut movement is needed. When the areas of concentrated directed longline fishing are compared with the movement patterns shown in Figure 6, it appears as though halibut are moving out of, or quickly passing through, these areas. We know little of the seasonal movement of halibut on to and off of grounds in this area but it seems likely, given these observations, that not all halibut present on the grounds during the directed fishery openings were equally likely to have marks, thus violating the second stated assumption.

Figures 3 and 4 also indicate where the different fisheries operate. The directed longline fishery concentrated its effort in localized regions at the northern end of the study area, with some effort applied to grounds south of Newport, where the depth is less than 50 fathoms, or at locations where the depth is greater than 100 fathoms. The trawl fishery, on the other hand, concentrated its effort broadly along the 100 fathom contour (Figures 3c and 4c), while the sport fishery appeared to have fished almost exclusively in the southern, shallower regions (Figures 3b and 4b). This information, coupled with the previous observations on fish movement, addresses the third assumption, namely whether the fish in the population are randomly sampled. The fisheries are operating on specific grounds, while the fish are moving nonrandomly between grounds or out of the area. All of this together suggests an uncertain sampling frame.

Size-specific features of the data complicate the analysis. Figure 7 shows histograms of the length-class specific recoveries made by each of the four fisheries. Not only are the different fisheries fishing different grounds, they are selecting different fish. The fish themselves, however (based on fish lengths gathered during the tag-and-release operation), do not appear to stratify themselves over the grounds by length (Figure 8), for the six zones shown in Figure 2. Thus the length-class specific recovery relationships found by fishery and shown in Figure 7 are not likely to be due to changes in the size composition of fish over the area.

The final three assumptions that are necessary for a valid Petersen estimate of stock abundance relate to the tags and their influence on the interpretation of results. These assumptions specify that the tagging process must not affect the fish marked for the experiment and that a tag must be recovered for each of these fish landed. A double tagging procedure (Gulland 1963b, Russell 1980) was carried out to address the issue of tag loss.

Of the 1,556 legal-sized fish tagged with an external spaghetti tag, 1,541 also received an internal coded wire tag. The coded wire tags were assigned numbers in batches at the start of the experiment. A single batch number corresponded to 20-25 uniquely numbered external tags (Appendix II). To determine tag loss, the appearance of one tag type versus the other on legal-sized halibut in the sample is examined. The probability that a tag of type A is lost is given by

$$\pi_A = \frac{m_B}{m_B + m_{AB}}$$

where m_B is the number of tagged fish in the second sample with only tag B, and m_{AB} is the number of tagged fish in the second sample carrying both tags (Seber 1982). Since the coded wire tags were numbered in batches and the two tag types were sampled independently, there is not necessarily a one-to-one correspondence in code number for each tag type released. However, we can determine the association between tag types using length-at-release information, since the number of tags per batch is small. What we will show is that the correspondence between tag types in the sample does appear to be one-to-one.

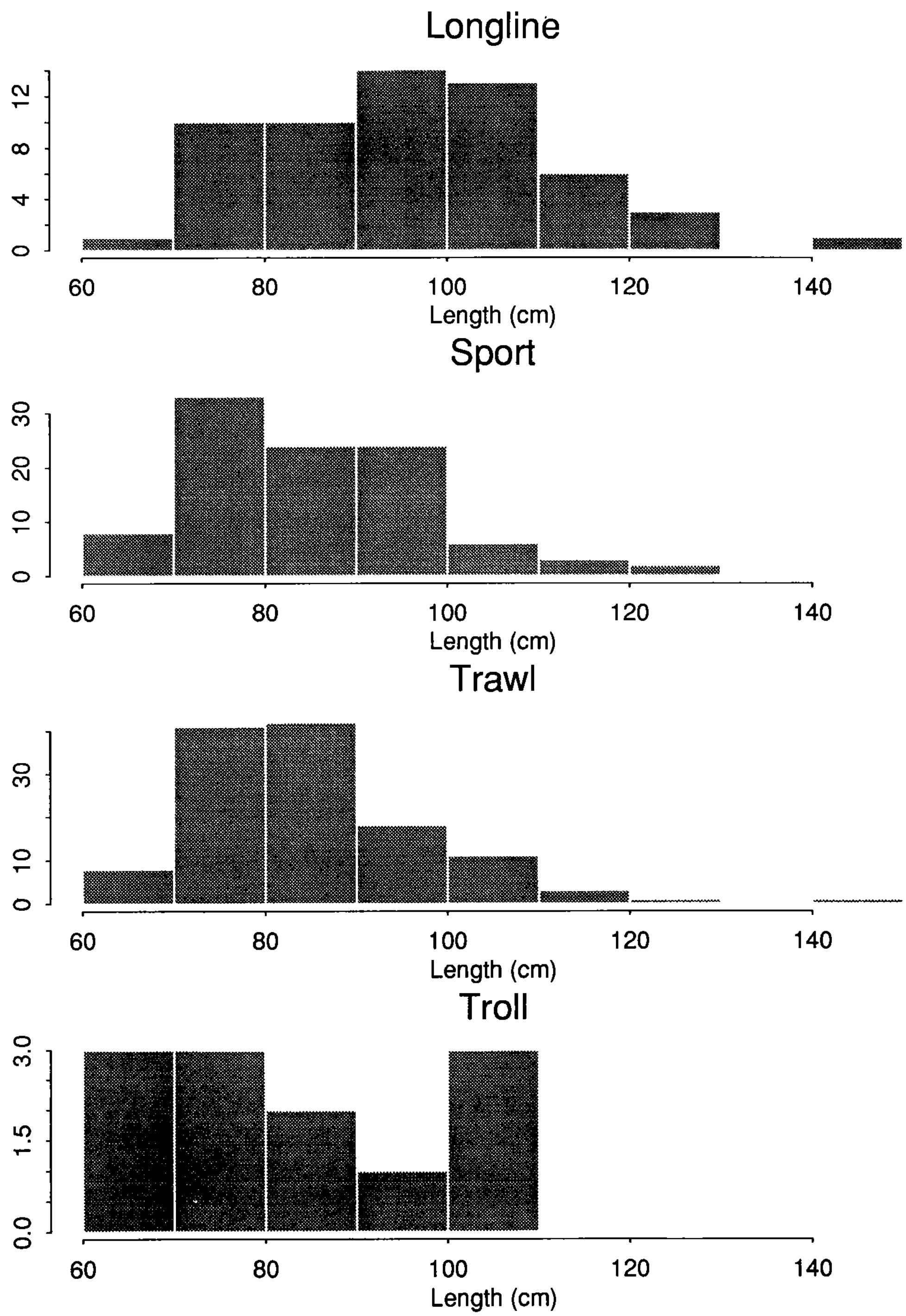

Figure 7. **Histograms of length-at-release for recoveries by the longline, sport, trawl and troll fisheries.**

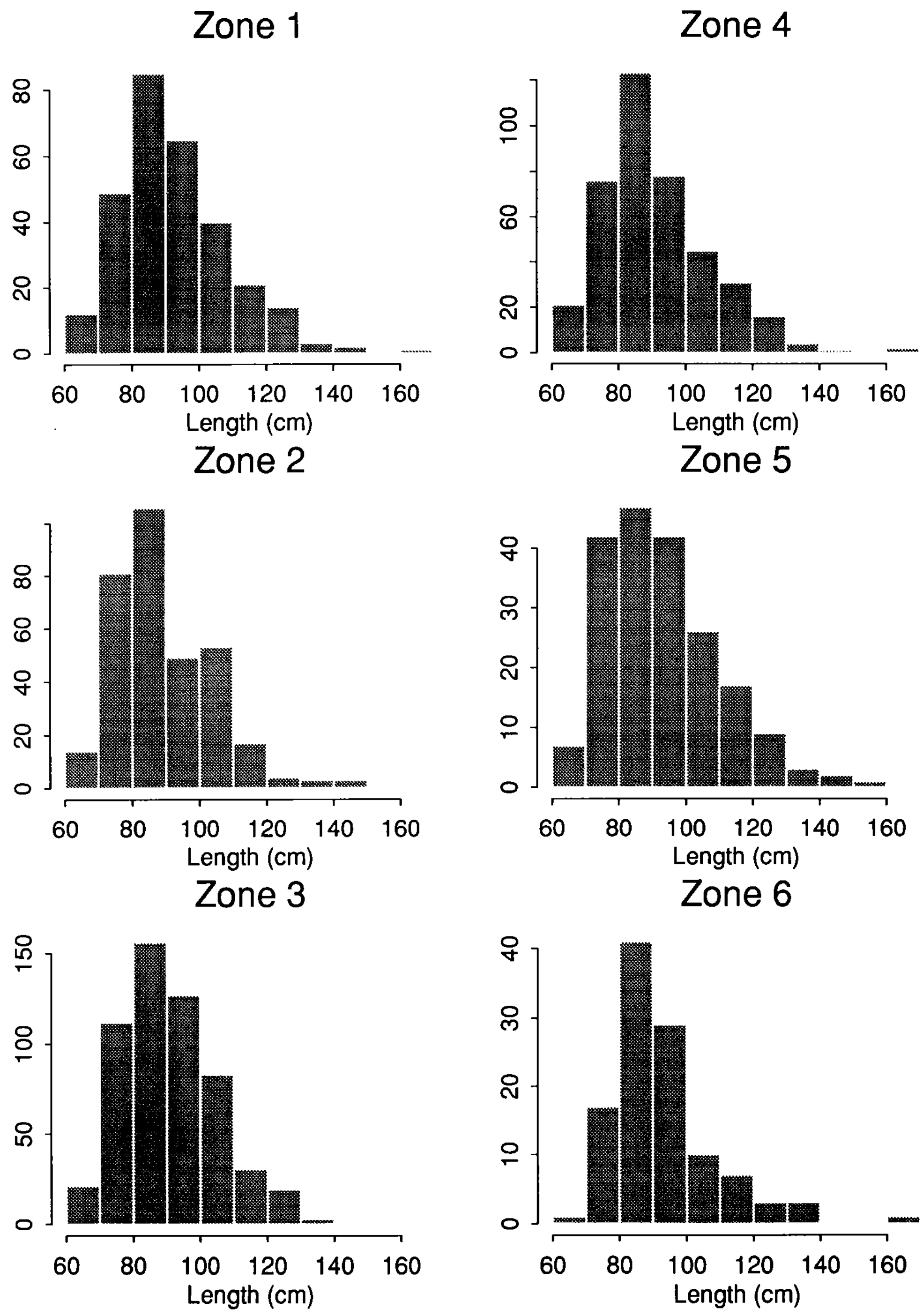

Figure 8. **Histograms of length-at-release for recoveries taken within the six geographic zones shown in Figure 2.**

Over half of the commercial catch was sampled for internal coded wire tags (Table 2). There were 18 external tag recoveries and 8 internal tag recoveries from legal-sized fish taken in the directed halibut fishery in 1989. Of the 8 internal tags recovered, all 8 had unique batch numbers. Of the 18 external tags recovered, 16 had unique corresponding internal tag batch numbers upon release, while 2 had the same batch number. Of the 16 tags with unique batch numbers, 8 matched the batch numbers from the 8 internal tags recovered. Furthermore, the same number of tags of each tag type was recovered from each vessel sampled, and the length-at-release matched between corresponding tag types. Of the 8 internal tags recovered, 4 had a length-at-release that could have corresponded to one other external tag number within the batch. In this instance, the likelihood that a length-at-release should match, but that the tags do not within a batch, is between 1 chance in 20 and 1 chance in 25. The likelihood that this should happen 4 times in a row, especially given that 4 others already matched uniquely, is quite negligible.

A similar pattern is seen among the 1990 recoveries. Over half the commercial catch was sampled. There were 11 external and 6 internal tags recovered. All 6 internal tags had unique numbers. Of the 11 external tags, 9 had unique corresponding batch numbers, while 2 had the same batch number. Of the 9 uniquely numbered external tags, 6 match the batch numbers from the 6 internal tags recovered. The same number of tags of each tag type was recovered from each vessel sampled, and again the length-at-release matched between corresponding tag types. Of the 6 internal tags, 2 had a length-at-release that could have corresponded to one other external tag number within the batch. Thus, recalling again that there are 20-25 tags per batch, there is little likelihood that the match is not unique.

In both instances, a one-to-one correspondence in recovery between tag types is strongly indicated. No internal tag was found for which an external tag could not be associated. No external tag was found, among legal sized fish from vessels sampled for internal tags, for which an internal tag could not be associated. That means that the estimated loss rate for both tag types is zero, as indicated by the equation given above, since both m_A and m_B appear to be zero.

Given the analysis discussed above, it appears that both tag types have a low loss rate (at least over time periods covering this experiment). Unfortunately, the data tell us little else regarding other tag-related violations of assumptions. If external tags were removed and not reported, then internal tags without the corresponding external tag would have been found in the sample. But this was not the case. However, other factors influencing the joint recovery rate, such as tag induced fishing mortality or the discarding of visibly tagged fish, are not detectable under the present design. Tagging fish with one, or the other, of the two tag types alone in conjunction with the double tagging experiment might have provided more information here. Sample size was a concern in estimating tag loss, which is why all fish were tagged with both tags.

BEHAVIOR OF THE FISH AND THE FISHERY

Mark and recapture techniques can also be used to obtain estimates of growth, migration, and survival. In some instances the technique is more reliable for estimating rates than for estimating total abundance because the assumptions applied in estimating rates may be restricted to just the tagged population itself, and not necessarily to the population as a whole. However, the estimation of migration and survival rates for halibut is not without problems (Hilborn et al. Unpub.[1], Pollock et al. Unpub.[2]) These

[1]Hilborn, R., J. Skalski, A. Anganuzzi and A. Hoffman. Unpub. Movements of juvenile halibut in IPHC regulatory Areas 2 and 3.

[2]Pollock, K. H., H. C. Chen, C. Brownie and W. L. Kendall. Unpub. Age dependent tag recovery analyses of Pacific halibut.

authors, respectively, examined recovery information from the release of over 56,000 fish tagged in Areas 2B, 2C, and 3A from 1979 through 1986, and over 40,000 fish tagged in Areas 3A and 3B in 1980 and 1981. Complications in their analyses resulted from differential growth rates by sex and area, and from unknown reporting rates. These factors affect the recovery rate estimates and consequently the overall estimates of migration and survivorship. We have already indicated the limitation in obtaining abundance from the data for this small scale study. It is interesting to note that more sophisticated large-scale tagging studies have limitations as well. However, other interesting aspects of the behavior of the fish and the fishery may be extracted from the central Oregon tagging data. The catch and effort information shown in Appendix I can be used to gather an approximate estimate of spatial distribution of fish on the fishing grounds prior to the opening of the fishery. Figure 9 shows a contour plot of fish density based on a grid of points linearly interpolated from the survey charter catch-per-unit effort data. This pattern should be contrasted with the movement patterns presented in Figure 6 to see how halibut density may have shifted on the grounds during the time period of this study. Seasonal and bathymetric features of the study area appear to play a role in determining movement patterns and, as a consequence, the relative abundance of halibut on the grounds.

The ratio of males to females among longline caught halibut is another biologically important point that has been considered in recent research. This issue has become particularly important with regard to determining the average weight at age of halibut in the commercial catch, since growth rates differ between sexes. Figure 10 indicates the ratio of females to males by length category for all fish tagged and released during the experiment. Females are the more abundant of the two sexes in the survey sample, especially among halibut of legal size. The contribution of females in the commercial catch is amplified when biomass is considered, since biomass has a cubic relationship with length.

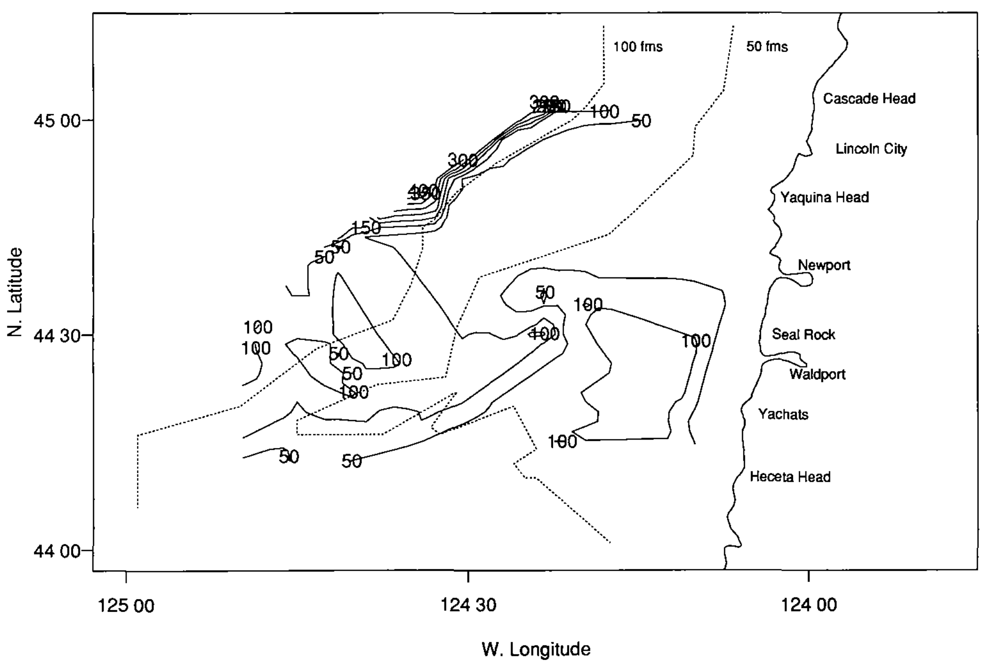

Figure 9. Contour plot of CPUE within the Newport study area. Contour interpolated from catch and effort information gathered during marking survey.

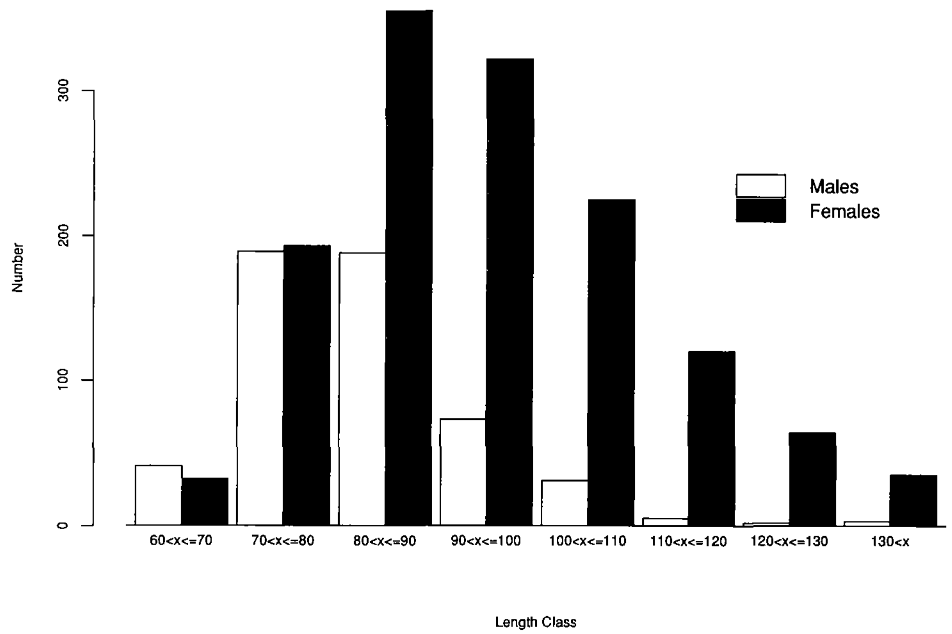

Figure 10. Distribution of release length for male and female halibut. Boxplots show median (midpoint of data) with shaded range from 25th to 75th quartil (the middle half of the data).

An important feature of the recovery information is the recovery rate over time in the different fisheries (Figure 11). Trawl-caught tags (the most abundant recovery group in this study) were recovered throughout the year, suggesting the presence of halibut on the trawl grounds year-round. Length-at-release information collected from the survey charter was used to examine the release-size composition of trawl caught fish recovered in different seasons (Figure 12). The size composition of the fish and the tag recovery rate on the grounds does not appear to change much throughout the year for halibut selected by the trawl fleet. This may indicate that halibut, more specifically smaller-sized immature halibut, remain on the grounds throughout the year.

If the recovery rate by fishery is an indication of the overall harvest rate of halibut by each of these fisheries, then the trawl and the sport fleets may each be encountering twice the number of fish as seen by the directed longline halibut fleet especially given the size distribution of halibut on release (Figure 10). This could be due, in part, to a longer fishing period for the trawl and sport fisheries. However, other complicating factors must be considered. For example, a moderate number (greater than 20, see Figure 11) of trawl caught halibut were reported captured prior to the June opening of the directed longline fishery. If the number of trawl caught tags was under reported or if tagged halibut were taken before they had a chance to mix with the rest of the stock, then the number of tagged halibut on the grounds could be significantly below the number at release, thus biasing upward the abundance estimate. Not enough information is available, however, to tell which, if any, of the above circumstances may be true. The affect that nondirected fishing has on total halibut mortality in the area should be considered as well, but this is beyond the scope of the experiment discussed here.

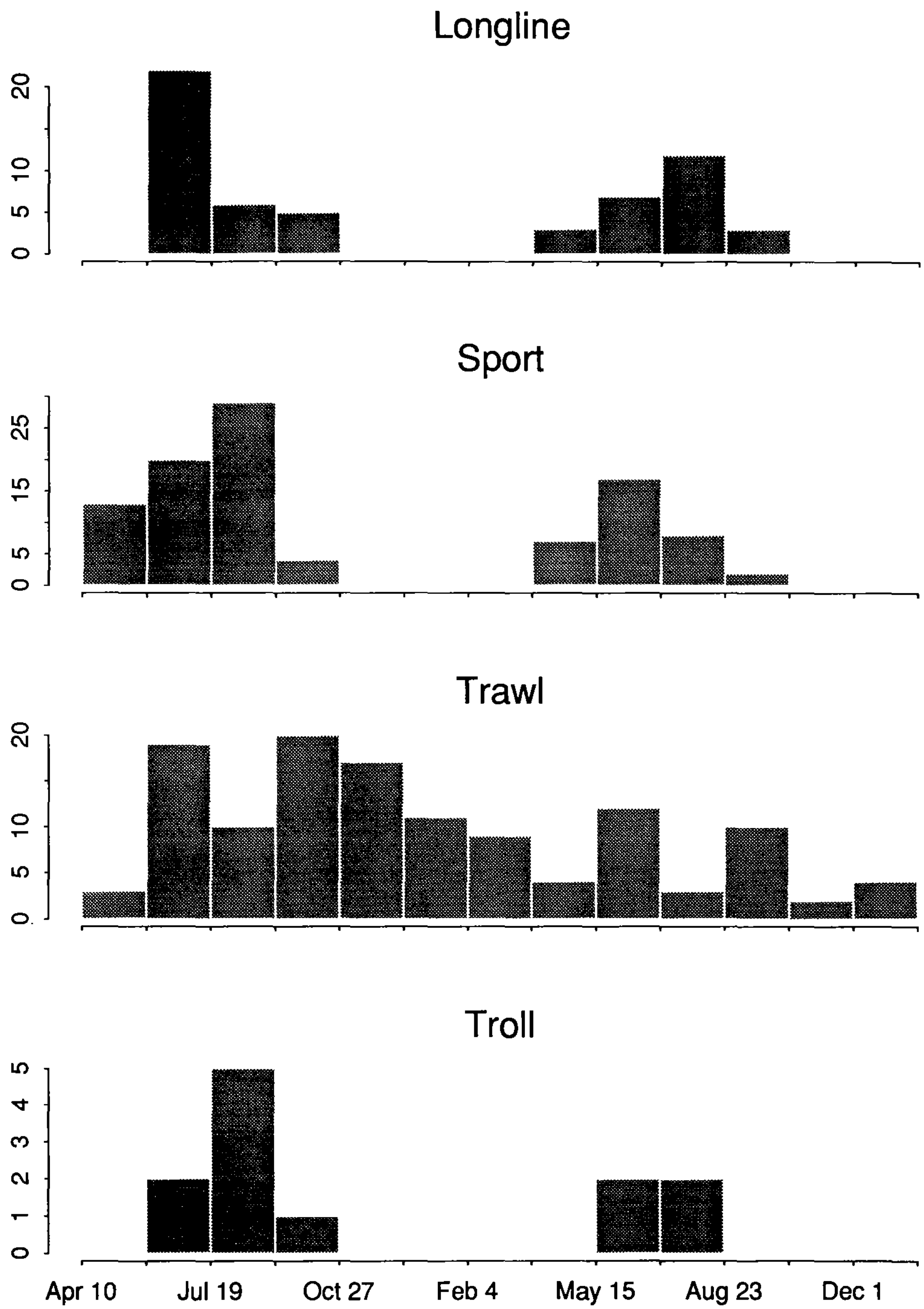

Figure 11. **Halibut tag recovery by date.**

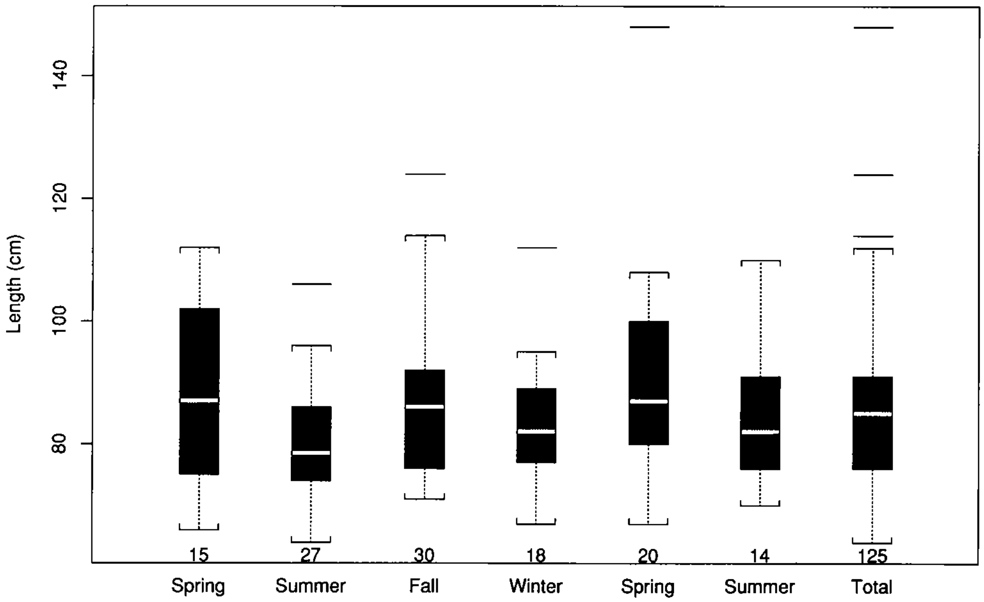

Figure 12. Release length distribution of trawl tagged recoveries by season.

CONCLUSIONS

The objectives of this study were to determine the feasibility of using mark-and-recapture techniques for assessing halibut abundance and examine what other aspects of the fish or the fishery may affect the interpretation of stock dynamics. In terms of the first objective the conclusion must be that the standard Petersen approach to Pacific halibut mark-and-recapture data is not a viable method for halibut stock assessment. Violations in all three assumptions pertinent to population behavior were apparent. Halibut movement off the grounds indicates that the population is not closed to emigration, nor presumably to immigration. Halibut movement on the grounds indicates that all fish did not have the same probability of being marked. And, the tag recovery location by fishery indicates that the harvest was anything but a simple random sample. Analysis of the remaining three assumptions regarding tag related effects indicated that the loss rate of each tag type appears to be low, however, the influence of other factors, specifically tag induced mortality and reporting, remains inconclusive. Modifications to the standard Petersen approach might have been made in order to arrive at a more refined estimate, however, the sheer number of factors and their magnitude of influence (e.g. multiple sources of fishing effort at several locations and times) appear to make the problem intractable. The second objective was addressed by examining other aspects of the release and recovery information. Changes in capture location (reflecting halibut movement) and differences in catch per unit effort (reflecting halibut densities) indicate that the temporal and spatial distribution of halibut on the grounds may affect how we interpret the dynamics of the stock. The relative abundance of females to males by length in the catch was also noteworthy. The influence that this factor may have on interpreting changes observed in the fishery make it an important point worth consideration and future research. Year-round recoveries made by the trawl fishing fleet were insightful in the information they provided concerning the demographics of smaller-sized halibut. Broader conclusions drawn from this experiment in relation to this report's second objective must be made cautiously, however, since the timing and selectivity of the different fisheries can confound interpretation of the effects.

Several proposals may be suggested for further research. First, rather than spend money on expensive tagging programs directed at assessing abundance, Commission field work should focus on gathering information that can provide insight on halibut distribution, behavior, and biology. The small scale movement of halibut on to and off of fishing grounds, the definition of habitat as it relates to the presence or absence of adults and juveniles or of males and females, and the possibility that adults drift north as they mature are all important issues raised by the results of this study. Systemic grid surveys and scientific research surveys directed at specific biological questions can address these issues. The notion of habitat area, for example, needs to be better defined. In the design of this experiment, areas of high and low density were prespecified for stratification of the estimate. Yet, in some situations pockets of high fish density were found on the low density grounds, and later, certain areas which were high in density during the tagging operation were found to have low densities during the period of commercial harvest. Observations such as these influence our interpretation of CPUE as it relates to the distribution of the halibut resource among fisher groups. These issues may be resolved by examining the data collected from scientific surveys and the commercial catch at finer levels of resolution, and by conducting experiments designed to examine the small scale movement and distribution of halibut.

Second, if tags continue to be used, for example to estimate migration and survivorship, more effort must be spent on estimates of recovery rate and tag induced mortality. A double tagging experiment was conducted here to address the problem of tag loss. Internal tags were recovered at the same rate as external tags. The problem is not with the tagging technology. Recovery rates appear to be influenced more by halibut behavior and their survivorship after tagging, and by factors related to the fishery, namely targeting practices and the likelihood of reporting a tag when Commission port samplers are unavailable. Future research in this area should focus on how halibut behavior and survivorship changes by season, age, and sex, and how reporting rates may differ between ports sampled and not sampled.

Mark-and-recapture studies have been widely used, with varying success, for the problem of abundance estimation. It may be more successfully applied as a supplement to the ongoing catch-at-age analyses conducted by the Commission staff than as an independent method of assessment. We know that abundance estimates may be influenced by the biology of the fish and the behavior of the fishery. It is the causes and the consequences of these factors that require additional research now.

ACKNOWLEDGEMENTS

We thank Lee Blankenship and the Washington Department of Fisheries for letting us use their coded-wire tag detector, and for their help in collecting and processing samples. We thank Jerry Butler of the Oregon Department of Fish and Wildlife for coordinating the recovery of the tags landed outside the directed commercial halibut fishery. We also thank Drs. Bruce Leaman of the Department of Fisheries and Oceans, Canada, Loh-Lee Low of the U.S. National Marine Fisheries Service, Han Lin Lai of the Washington Department of Fisheries, and Neal Coenen of the Oregon Department of Fish and Wildlife for the their reviews and comments on earlier versions of this manuscript.

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APPENDICES

APPENDIX I. Tag release location by set number.

APPENDIX II. Internal tag batch number and corresponding range of external tag numbers.

Appendix I. **Tag release location by tag number and date.**

Date	Location	Set #	Depth (fm)	# skates	catch (pounds)	tagged fish		Total	external tag #
						legal	sublegal		
May-07	off Cape Foulweather	1	107/122	5	133	7	11	18	37001-37018
	off Depoe Bay	2	135/138	5	1,738	88	7	95	37019-37113
	(outer edge)	3	147/149	5	2,357	59	1	60	37114-37173
May-08	Cascade Head	4	120/135	5	337	19	10	29	37174-37202
	off Siletz Bay	5	125/144	5	564	27	8	35	37203-37237
	(outer edge)	6	122/141	5	651	35	8	43	37238-37280
		7	132/139	5	239	13	8	21	37281-37301
May-09	Cascade Head	8	121/144	5	298	18	7	25	37302-37326
	(outer edge)	9	122/143	5	132	8	8	16	37327-37342
		10	127/151	5	619	35	16	51	37343-37393
		11	132/137	5	360	19	7	26	37394-37400,37501-37519
May-10	off Cascade Head	12	19/27	6	30	1	0	1	37520
	off Cascade Head	13	23/28	6	26	1	0	1	37521
	off Yaquina Head	14	30/32	6	56	2	0	2	37522-37523
May-11	Stonewall Bank	15	39/46	6	380	16	4	20	37524-37543
	(northern end)	16	24/36	6	501	12	0	12	37544-37555
		17	37/55	6	351	14	3	17	37556-37572
		18	41/47	6	608	23	10	33	37573-37600,37401-37405
		19	34/37	6	180	8	2	10	37406-37415
May-12	Stonewall Bank	20	35/37	6	184	8	11	19	37416-37434
	(inside)	21	34/36	6	573	22	9	31	37435-37464,37631
		22	22/28	6	656	21	3	24	37465-37487,37626
		23	29/37	6	215	10	14	24	37488-37500,37627-37638*
May-14	off Yaquina Head	24	131/136	5	228	14	10	24	37639-37662
	(outer edge)	25	142/146	5	53	2	2	4	37663-37666
		26	137/146	5	136	8	0	8	37667-37674
May-15	off Depoe Bay	27	127/133	5	1,124	64	16	80	37675-37755**
		28	134/143	5	112	61	22	83	37756-37800,41711-41748
		29	125/130	5	284	15	7	22	41749-41770
May-19	off Cape Perpetua	30	46/51	6	467	21	9	30	41771-41800
	(flats above dogleg)	31	47/56	6	223	12	3	15	41801-41815
		32	45/51	6	358	19	17	36	41816-41851
May-20	off Cape Perpetua	33	21/24	6	65	1	0	1	41852
	(nearshore)	34	25/28	6	410	9	2	11	41853-41863
		35	26/33	6	481	16	1	17	41864-41880
		36	25/26	6	191	8	0	8	41881-41888
May-21	Halibut Hill	37	109/132	5	497	29	17	46	41889-41934
		38	105/135	5	492	45	20	65	41935-41999
		39	101/132	5	714	43	17	60	42000,37801-37859
May-22	High Spot	40	46/49	6	242	11	2	13	37860-37872
		41	43/49	6	193	7	1	8	37873-37880
		42	41/51	6	175	9	1	10	37881-37890

Tag Release Locations (Cont'd).

Date	Location	Set #	Depth (fm)	# skates	catch (pounds)	tagged fish legal	tagged fish sublegal	Total	external tag #
May-27	Stonewall Bank (outside south end of rockpile)	43	29/35	6	147	6	4	10	37891-37900
		44	37/41	6	469	18	10	28	37601-37625,37901-37903
		45	46/55	6	228	8	5	13	37904-37916
		46	22/32	6	867	29	8	37	37917-37953
May-26	Fingers	47	68/77	6	747	35	27	62	37954-38015
		48	66/75	6	151	7	9	16	38016-38031
		49	77/85	6	903	71	52	123	38032-38154
		50	62/78	***4	336	22	27	49	38155-38203
May-27	beach north of Cape Perpetua	51	32/35	5	740	19	4	23	38204-38226
		52	30/31	6	738	20	4	24	38227-38250
		53	26/28	6	579	18	3	21	38251-38271
		54	33/34	5	688	18	0	18	38272-38289
May-29	Nelson's Island	55	67/97	4	98	5	6	11	38290-38300
		56	82/109	5	121	8	10	18	38301-38318
		57	77/114	5	521	22	9	31	38319-38349
May-30	Hecata Bank (north end)	58	50/67	6	230	11	4	15	38350-38364
		59	47/64	6	508	20	3	23	38365-38387
		60	38/45	5	421	20	4	24	38388-38411
		61	45/52	6	269	13	3	16	38412-38427
May-31	flats	62	42/48	6	355	17	9	26	38428-38453
		63	47/52	5	481	21	6	27	38454-38480
		64	48/53	6	441	22	7	29	38481-38509
		65	46/49	6	186	10	10	20	38510-38529
Jun-04	off Foulweather (inshore)	66	39/42	6	0	0	3	3	38530-38532
		67	37/49	5	0	0	4	4	38533-38536
		68	53/56	6	0	0	11	11	38537-38547
Jun-05	sand bottom below Cascade Head	69	67/68	6	11	1	1	2	38548-38549
		70	58/59	5	48	3	7	10	38550-38559
		71	45/47	6	13	1	0	1	38560
Jun-06	Cascade Head (outer edge)	72	124/143	5	1,323	68	1	70	38561-38630
		73	122/141	4	1,293	66	1	67	38631-38698**
		74	118/140	5	968	55	1	56	38699-38754
		75	119/133	5	458	26	0	26	38755-38781**
Jun-07	off Depoe Bay	76	131/134	5	296	11	5	16	38782-38798**
		77	141/145	4	116	8	5	13	38799-38811
		78	90/99	5	86	15	6	21	38812-38832
			TOTAL	**423**	**32,469**	**1,556**	**562**	**2,118**	

* 37631 & 37626 missing from set 23, tagged in set 21, 22

** 37730, 38677, 38764 & 38790 missing tags

*** 2 of 6 skates set on set 50 were not retrieved. All skates were 1800 feet groundline with approximately 36 foot hook spacing, 50 hooks per skate.

Appendix II. Internal tag batch number and corresponding range of external tag numbers.*

Internal Tag Batch Number	External Tag Number	Internal Tag Batch Number	External Tag Number	Internal Tag Batch Number	External Tag Number
1	37002-37038	28	37763-37799	96	41993-41998, 37803-37824
2	37039-37067	29	37800, 41712-41738	97	37825-37856
3	37068-37093	30	41740-41770	98	37857-37859
4	37094-37121	31	41773-41804	99	37860-37886
5	37122-37143	32	41805-41846	100	37887-37890
6	37144-37168	33	41847-41851	101	37891-37904
7	37169-37201	34	41852-41875	102	37906-37939
8	37203-37234	35	41876-41888	103	37940-37953
9	37235-37266	36	41892-41923	104	37956-37991
10	37267-37298	37	38468-38498, 38460	105	37992-38032
11	37299-37336	38	38499-38518	106	38033-38076
12	37337-37370	39	38519-38529	107	38079-38114
13	37371-37393	40	38551-38560	108	38115-38154
14	37394-37518	41	38561-38582	109	38157-38203
15	37520-37523	42	38583-38598	110	38204-38226
16	37524-37547	44	38599-38619	111	38227-38254
17	37548-37569	45	38620-38647	112	38255-38279
18	37570-37599	46	38648-38663	113	38280-38289
19	37404-37439	47	38664-38683	115	38290-38324
20	37441-37469	48	38684-38710	116	38325-38349
21	37470-37632	49	38711-38733	117	38352-38376
22	37633-37637	50	38734-38758	118	38377-38404
23	37641-37673	51	38759-38781	119	38405-38427
24	37674	52	38783-38804	120	38429-38459, 38461-38465
25	37675-37703	53	38808-38832		
26	37704-37755	94	41925-41962		
27	37756-37762	95	41963-41992		

*Included in the ranges of external tag numbers are sublegal fish that did not receive an internal tag.