

FRI-UW-9508  
November 1995

FISHERIES RESEARCH INSTITUTE  
SCHOOL OF FISHERIES  
UNIVERSITY OF WASHINGTON  
BOX 357980  
SEATTLE, WA 98195

**INCIDENTAL CATCH OF PACIFIC HALIBUT  
(*HIPPOGLOSSUS STENOLEPIS*) IN THE US WEST  
COAST TRAWL FISHERY, 1985-1990**

ELLEN K. PIKITCH,<sup>1</sup> JOHN R. WALLACE,<sup>1</sup> DANIEL L. ERICKSON<sup>1</sup>

and

MARK SAELENS<sup>2</sup>

Approved

Submitted

11-15-95



Director

<sup>1</sup>Fisheries Research Institute, University of Washington School of Fisheries, Box 357980, Seattle, WA 98195.

<sup>2</sup>Oregon Department of Fish and Wildlife, 2040 SE Marine Science Drive, Newport, OR 97365-5294



# CONTENTS

	Page
LIST OF FIGURES .....	iv
LIST OF TABLES .....	iv
INTRODUCTION .....	1
METHODS .....	1
FIELD COLLECTIONS.....	1
1985–1987 Fieldwork.....	2
1988–1990 Fieldwork.....	3
FLEET EFFORT DATA.....	3
DATA ANALYSIS.....	4
DATA INCLUDED IN STATISTICAL ANALYSES .....	5
RESULTS .....	5
1985–1987 STUDY RESULTS .....	5
Shrimp Strategy .....	6
Bottom Rockfish Strategy.....	6
Nearshore Mixed Strategy .....	7
DWD Strategy .....	7
1988–1990 STUDY .....	8
DISCUSSION.....	8
REFERENCES.....	10

## LIST OF FIGURES

Figure	Page
1. Pacific States Marine Fisheries Commission areas along the US West Coast.....	13
2. Non-parametrically smoothed CPUE indicator by depth and trawling strategy for 1985–1987 and 1988–1990 databases .....	14
3. Non-parametrically smoothed CPUE indicator by month and trawling strategy for 1985–1987 and 1988–1990 databases .....	15
4. Tow frequency distribution of Pacific halibut bycatch for each trawling strategy for the 1985–1987 database.....	16

## LIST OF TABLES

Table	Page
1. Boundaries of combined Pacific States Marine Fisheries Commission areas.....	19
2. Sampling effort by calendar period, PSMFC area, and depth category during the 1985-1987 field study for BRF, DWD, NSM, and SHR trawling strategies .....	19
3. Number and percent of tows containing halibut for all trawling strategies, PSMFC areas, and depths combined during the 1985-1987 field study. ....	20
4. Results of analysis of variance to test effects of trawling strategy, depth, calendar period, and PSMFC area on Pacific halibut log transformed catch rates for 1985-1987.....	20
5. Depth and duration of BRF, DWD, NSM, and SHR strategy tows conducted during the 1985-1987 field study.....	21
6. Estimated bottom trawl catches of Pacific halibut in PSMFC areas 2B-3C.....	22
7. Sampling effort by calendar period, PSMFC area, and depth category during 1988-1990 for BRF, DWD, and NSM trawling strategies .....	23
8. Estimated bottom trawl catches of Pacific halibut in PSMFC areas 1B-2A.....	23

## **ACKNOWLEDGMENTS**

Support for the preparation of this report was provided by the National Marine Fisheries Service (NMFS) and the Washington Sea Grant College Program. Direct and in-kind support for the collection of data analyzed in this report was provided by a large number of sources, including NMFS, Washington Sea Grant, the Saltonstall-Kennedy Grant Program, Oregon Department of Fish and Wildlife, Nor'Eastern Trawl Systems, Inc., Seattle Marine Fishing Supply Inc., Fishermen's Marketing Association, the Oregon Trawl Commission, and numerous individuals involved in the commercial fishing industry. Fleet effort data were provided by Mark Saelens and Robert Hannah (Oregon Dep. Fish & Wildlife), Martha Rickey and Claire Wood (Washington State Department of Fisheries) and Brenda Erwin (California Department of Fish and Game). We thank Gary Stauffer and Gregg Williams for their assistance with this report. We are grateful to the many organizations and individuals who made this effort possible, particularly the trawl vessel owners, operators, and crew who voluntarily participated in the research studies, and the staff and students who assisted in data collection and data entry.

## **KEY WORDS**

bycatch, Pacific halibut, trawl fishery, US West Coast



## INTRODUCTION

It is generally known that Pacific halibut (*Hippoglossus stenolepis*) are incidentally captured by bottom trawls operating off the US West Coast; however, the distribution and magnitude of the catch in this fishery has not been well documented. Previous reports have provided bycatch estimates either directly using data collected from commercial trawl vessels operating off the US west coast (e.g., Hannah and Saelens 1993) or indirectly using data from surveys, tagging, and similar fisheries in other areas (e.g., Williams 1993). Annual halibut trawl-bycatch has been estimated using 1991 fleet effort data coupled with catch-rate data obtained from various sources (Hannah and Saelens 1993; Williams 1993). Williams (1993) reported all bycatch estimates in net weight, whereas Hannah and Saelens (1993) estimated halibut bycatch in net weight for the bottom groundfish trawl fishery and round weight for the shrimp trawl fishery. For consistency with our results (shown in round weight), we converted Williams (1993) and Hannah and Saelens (1993) bycatch estimates to round weight using a conversion factor of 1.33 (Hannah and Saelens 1993). In addition, their bycatch estimates (reported in pounds) were converted to kilograms using a factor of 2.2046. Using these conversions, we estimated halibut bycatch (round weight) for the 1991 US West Coast groundfish bottom trawl fishery to be 598,638 kg (Williams 1993) and 369,719 to 765,802 kg (Hannah and Saelens 1993). The 1991 halibut bycatch estimates (round weight) for the shrimp fishery were 252,767 kg (Williams 1993) and 11,099 to 149,521 kg (Hannah and Saelens 1993).

In this report, we re-examine halibut bycatch rates in the trawl fisheries off the US west coast using data collected from two research studies, which together were conducted over a time span of 6 years (1985–1990). These studies provide the most comprehensive direct observations of halibut bycatch in the West Coast domestic trawl fishery obtained to date. Coastwide halibut bycatch (kg) is estimated using 1987 trawling effort data derived from logbooks in conjunction with estimated catch rates obtained from the two research projects.

## METHODS

### FIELD COLLECTIONS

Data were collected during two studies: (1) an observer study conducted off the coasts of Oregon and Washington during 1985–1987, and (2) a codend mesh size study conducted off the Washington, Oregon, and California coasts during 1988–1990. These studies are described in a number of publications, including Pikitch et al. (1988, 1990), Pikitch (1991, 1992), Rogers and Pikitch (1992), Erickson and Pikitch (1994) (also, D. Erickson, E. Pikitch, and J. Wallace, Univ. Washington School of Fisheries, Fish. Res. Inst., Seattle, unpubl. ms.). Although incidental catch of Pacific halibut was recorded during both studies, estimation of Pacific halibut bycatch rates was not a primary objective of either study. Hence, it is pertinent to discuss similarities and differences in data collection methods for these studies.

In both studies, data were collected onboard commercial trawl vessels that operated under production fishing conditions. Trawler participation was voluntary. Observers recorded trip and tow information, and sampled most tows during each trip. Tow information included date, location, start and finish time, depth, and total catch weight (estimated visually by skippers or samplers).

Fishing strategies were created (post-hoc) for each tow based on gear type (i.e., shrimp, bottom, or midwater trawl), depth, and species composition of the catch. Strategies were categorized as follows:

1. midwater trawling (MID)—tows conducted using midwater gear above the ocean bottom; the primary target species was widow rockfish (*Sebastes entomelas*);
2. shrimp trawling (SHR)—tows conducted using single or twin shrimp trawls; pink shrimp (*Pandalas jordani*) was the principal target species;
3. bottom rockfish trawling (BRF)—tows conducted using bottom trawl gear; greater than 50% of the utilized catch consisted of rockfish (*Sebastes* spp.) species and lingcod (*Ophiodon elongatus*);
4. nearshore mixed trawling (NSM)—tows conducted using bottom trawl gear at depths less than or equal to 163 m (89 fm) that were not categorized as MID, SHR, or BRF; and
5. deep-water Dover (DWD)—tows conducted using bottom trawl gear at depths greater than 163 m (89 fm) that were not categorized as MID, SHR, or BRF.

#### *1985–1987 Fieldwork*

The principal objective of the study conducted during the years 1985–1987 was to evaluate the effectiveness of management-imposed trip limits on the West Coast trawl fishery (Pikitch et al. 1988, Pikitch 1991). Midwater, shrimp, bottom rockfish, nearshore mixed, and deep-water Dover trawling strategies were examined. Trips were sampled during most months, beginning June 1985 and ending December 1987. Bottom rockfish, deep-water Dover, and nearshore mixed strategies were sampled year-round; most NSM trips took place during July through October. The SHR strategy was sampled during May through October, corresponding with the timing of the shrimp season. All trips originated from Oregon ports; however, tows were conducted off both the Oregon and Washington coasts. A total of 139 trawl fishing trips was sampled during this study.

Vessels that participated in the 1985–1987 fieldwork were constrained by management regulations that varied during the course of the study. Participating vessels used their customary fishing gear for all tows conducted.

Four or five random basket samples (~160 kg) were collected from catches >454 kg (1,000 lb). Samples were sorted by species, weighed, and enumerated. In most cases, whole haul sampling was conducted for individual species that were relatively rare in the catch (e.g., Pacific halibut) or when the total catch of all species combined was <454 kg. Total catch weights of each species in each tow were estimated by multiplying the weight of each species in the sub-sample by the ratio of total tow weight (less the weight of whole-haul sampled species) to total sample weight. That is,

$$\text{Total catch weight of species A} = (\text{Sample weight of species A}) \times \frac{(\text{Total tow weight})}{(\text{Total sample weight of all species})}$$

For each species, total numbers caught were estimated by applying average weights to the total catch weight. Specifically,

$$\text{Total number of species A} = \frac{\text{Total catch weight of species A}}{\text{Average weight of species A}}$$

Catches of both single- and double-rig shrimp trawls were sampled during this field work. Shrimp trawling effort (hours) was standardized to single-rig equivalent by multiplying double-rig effort by 1.6 (Robert Hannah, Oregon Dep. Fish and Wildlife, Newport, pers. comm.).

### *1988–1990 Fieldwork*

The primary objective of the 1988–1990 experiment was to assess short- and long-term biological and economic impacts of potential changes in codend mesh size and shape on the West Coast trawl fishery. Trips were sampled during July–December of 1988 and 1989, and July–November of 1990. A total of 102 trawl fishing trips were sampled off the Washington, Oregon, and California coasts. Only the BRF, NSM, and DWD trawl strategies were included in this study. BRF and DWD strategies were sampled July–December, whereas NSM tows were sampled only during July through October.

Vessels that participated in the 1988–1990 fieldwork operated under an experimental fishing permit that allowed participating vessels to use detachable codends of various mesh sizes and to exceed trip poundage limits. Participating vessels towed experimental codends that were attached to the intermediate section of the vessel's trawl net. Experimental codends were towed following a predetermined randomized block design (Bergh et al. 1990). Three or four experimental codends were alternately towed during each trip. Hence, gear used and allowable amount of fish landed during experimental trips differed from that practiced during normal commercial trawling operations. Sampling of the catch was generally performed as described for the 1985–1987 study with the exception that only sample weights (and not numbers of individuals) were recorded.

### FLEET EFFORT DATA

West Coast bottom groundfish trawling effort (towing hours and number of tows) for 1987 was estimated using trawl logbook data obtained from Oregon, Washington, and California. Estimates of trawling effort were tabulated by trawling strategy (as defined above), depth category (0–163 m, 163–320 m, and 320–640 m), calendar period (November–June and July–October) and Pacific States Marine Fisheries Commission (PSMFC) areas (Fig. 1).

## DATA ANALYSIS

For each database, statistical analyses were performed after pooling data over 3 years because sample sizes were insufficient for annual comparisons. Scatter plot smoothing was used to evaluate trends in bycatch among fishing depths and months (Friedman 1984). Statistical analyses performed were similar to those previously applied to data on chinook salmon bycatch (Erickson and Pikitch 1994). Analysis of variance (ANOVA) was used to determine whether the incidental catch of Pacific halibut varied among codend mesh sizes, fishing strategies, seasons, depths, and geographic regions. Geographic regions were based on PSMFC area boundaries (Table 1). The effect of codend mesh size was analyzed only for the 1988–1990 data set using a randomized complete block design. The remaining variables were considered for both 1985–1987 and 1988–1990 data sets following procedures for an unbalanced design. Pacific halibut catches in number and weight for the 1985–1987 and 1988–1990 studies, respectively, were standardized by dividing each observation by tows duration (hours). These CPUE data were then transformed to obtain homogeneity of variances (i.e., “transformed catch rates” were derived as  $\log_e(\text{CPUE}+a)$ , where  $a$  = one half the minimum non-zero value). Towing depth was used as a factor with three levels in the initial ANOVA’s.

A ratio estimator technique (Cochran 1977) was used to estimate coastwide Pacific halibut catch in trawls. Estimates of the population ratio of Pacific halibut number (1985–1987 data) or weight (kg; 1988–1990 data) per trawling hour,  $R_{ijk}$ , were calculated for each data set by strategy, calendar period, and depth category and pooled across years as

$$R_{ijk} = y_{ijk} / x_{ijk}$$

where  $y_{ijk}$  = number (or weight) of halibut sampled,  
 $x_{ijk}$  = number of tows hours sampled = effort,  
 $i$  = trawl strategy,  
 $j$  = calendar period, and  
 $k$  = depth category.

Pacific halibut catch estimates for the West Coast trawl fleet during 1987 were then calculated as:

$$Y_{ijk} = R_{ijk} \cdot X_{ijk}$$

where  $Y_{ijk}$  = coastwide estimate of Pacific halibut catch by trawl strategy  $i$  during period  $j$  in depth  $k$ ,  
 $X_{ijk}$  = coastwide tows hours by trawl strategy  $i$  during period  $j$  in depth  $k$ .

For the 1988–1990 data, estimates of numbers of halibut caught per tows hour were obtained by dividing the observed weight of halibut per tows hour by the strategy-specific average weight per fish obtained from the 1985–1987 data.

## DATA INCLUDED IN STATISTICAL ANALYSES

Tows sampled in depths  $\geq 640$  m (350 fm) caught no Pacific halibut during either the 1985–1987 study (111 h of towing) or the 1988–1990 study (697 h of towing for all codend types) and were excluded from further analyses. Similarly, midwater tows were excluded from analysis because none of the 39 midwater tows sampled during the 1985–1987 study contained Pacific halibut. Only eight tows were conducted in PSMFC area 1A (i.e., south of  $36^{\circ}$ N latitude), which represents the southern extreme of Pacific halibut distribution (International Pacific Halibut Commission 1987). No halibut were captured in this extreme southern area. Hence, bycatch estimates reported herein exclude PSMFC area 1A.

Differences in Pacific halibut transformed catch rates among codend mesh sizes were analyzed using a randomized complete block design for the 1988–1990 data set. Significant differences in catch rates were found among codends in some instances; thus, data for codends constructed of mesh sizes and shapes not typically used by the fleet were excluded from further analyses. Data included in subsequent analyses for this database were obtained from tows conducted using codends with either 11.4-cm (4.5-in) or 12.7-cm (5-in) diamond meshes; no significant difference in halibut catch rate was observed for this codend pair ( $p > 0.05$ ).

Smoothed fits of the CPUE indicator against depth and month were used to categorically describe these continuous variables. CPUE varied with trawling depth (Fig. 2); most significant changes in this smoothed CPUE indicator occurred at depths of 163 m and 320 m. Smoothed fits were not similar between databases; trends suggested highest halibut catch rates in the shallowest depths during the 1985–1987 study, whereas highest catch rates were in moderate depths (i.e., 163 to 320 m) during the 1988–1990 field work. The CPUE indicator also varied seasonally (Fig. 3). Highest catch rates were observed from July through October, and lowest catches were observed during the remainder of the year. Data for the months January–June were not collected during the 1988–1990 study. On the basis of these results, analyses were conducted with depth (0–163 m, 163–320 m, 320–600 m) and period (July–October, November–June), which were included in models as categorical variables.

## RESULTS

### 1985–1987 STUDY RESULTS

Sampling effort (number of tows) varied among fishing strategies, PSMFC areas, calendar periods, and depth categories (Table 2). Sampling intensity was greater for PSMFC areas 2B–2C (Oregon) than for areas 3A–3C (Washington) for all strategies and calendar periods. November–June sampling effort exceeded July–October effort for the BRF, DWD, and SHR strategies, whereas the opposite was generally the case for the NSM strategy. Sampling effort was most unbalanced among depth categories: fewer than 10 tows were sampled in certain depth categories within PSMFC areas 3A–3C.

Halibut were caught by trawling during all months off the Oregon and Washington coasts (Table 3). The percentage of tows containing halibut ranged from 18% to 46% mo<sup>-1</sup> (all strategies, depths, and areas combined). Tow frequency distributions of halibut (in numbers) per towsing hour were highly skewed (Fig. 4), with the majority of tows containing no Pacific halibut. When halibut were captured, catch rates were typically <4 halibut per towsing hour. Occasionally, catch rates exceeded 10 halibut per towsing hour. The range of observed halibut catch rates was greatest for NSM and BRF strategies; maximum rates for these strategies were 45 and 25 halibut per towsing hour, respectively. Catch rates in excess of 10 halibut per towsing hour were most frequently observed for the NSM strategy.

The average weight of individual halibut caught per tow ranged from 2 to 32 kg, and varied among fishing strategies. Mean weight observed was lowest for the NSM strategy (3.05 kg fish<sup>-1</sup>), highest for the BRF strategy (8.46 kg fish<sup>-1</sup>), and intermediate for the SHR and DWD strategies (4.82 and 6.78 kg fish<sup>-1</sup>, respectively).

Results of the analysis of variance suggested no difference in Pacific halibut transformed catch rates between PSMFC areas 2B-2C and 3A-3C (Table 4). Differences in transformed catch rates were significantly different among strategies, depth categories, and calendar period. On the basis of these results, data were pooled across PSMFC areas (i.e., 2B through 3C), and estimates of halibut bycatch were calculated by trawling strategy, calendar period, and depth category.

#### *Shrimp Strategy*

Shrimp tows averaged 2.0 h in duration (not converted to single-rig equivalent) and were conducted in depths ranging from 86 to 247 m (Table 5). During the time of this study, shrimp trawling occurred only during the months of May through October. Thus, estimated population ratios and halibut catch for this strategy were provided by depth category across all sampled months. Sampling effort exceeded 100 tows per cell and was nearly balanced between depth categories (Table 2).

Population ratio estimates were 0.09 and 0.14 halibut per trawling hour (single-rig equivalent) for depths <163 m and depths of ≥163–320 m, respectively (Table 6). The highest catch rate observed was 4.38 halibut h<sup>-1</sup>. Ninety-five percent confidence intervals were broadest (0.06 to 0.22 halibut h<sup>-1</sup>) for the deepest depth category. Although highest catch rates were obtained at depths >163 m, most shrimp trawling took place at depths shallower than this category (i.e., 77% of 193,694 single-rig equivalent trawling hours were conducted at depths <163 m); hence, estimated halibut bycatch for this fishery was highest for the shallowest depth category. Estimated halibut catch for this strategy off Oregon and Washington (i.e., PSMFC areas 2B-3C) was 20,536 individuals (95% C.I. = 8,652–32,218 individuals) or 98,983 kg.

#### *Bottom Rockfish Strategy*

Tows identified as employing the BRF strategy were conducted over a wide range of depths (24–604 m); towsing duration for this strategy also varied considerably (i.e., 0.2–8.5 h; Table 5). The estimated average number of halibut caught per towsing hour by calendar period and depth category (Table 6) ranged from 0.14 (95% C.I. = 0.05–0.22) to 1.12 (95% C.I. = 0.58–1.65). The

maximum catch rate observed for an individual tow was 25.4 halibut per towing hour during July–October at depths of 163–320 m. Sampling effort exceeded 48 tows for each calendar period and depth category in five of six cells; however, only 16 BRF tows were sampled during July–October at depths of 320–640 m. Estimated halibut bycatch was lowest for the deepest depth category examined (320–640 m), primarily because trawling effort for this strategy was lowest at these depths. Estimated halibut catch for the BRF strategy in PSMFC areas 2B-3C was 5,834 individuals (95% C.I. = 2,809–8,810 individuals) or 49,359 kg. Eliminating the “extreme” value from the July–October period at 163–320 m depths (i.e., 25.4 halibut per towing hour) would reduce the bycatch estimate by only 234 halibut.

#### *Nearshore Mixed Strategy*

Depths of NSM tows ranged from 11 m to 163 m, and towing duration ranged from 0.3 h to 8.5 h (Table 5). Depth of towing was generally shallower during July–October (mean = 86 m) than during November–June (mean = 126 m). Results with respect to seasonal variation were weak because the number of tows observed during November–June was small in comparison with that observed during the other calendar period (Table 2).

Halibut catch rates were higher during July–October (1.46 halibut per towing hour; 95% C.I. = 0.95–1.97) than during November–June (0.81 halibut per towing hour; 95% C.I. = 0.09–1.54; Table 6). Higher catch rates during July–October, coupled with substantially higher NSM trawling effort during this calendar period (relative to November–June), produced quite different halibut bycatch estimates for the seasons (in total number; Table 6). The halibut bycatch estimate for this strategy was 41,850 individuals (95% C.I. = 20,557–63,233) or 127,640 kg. The most extreme value in the database occurred for this strategy during July–October (i.e., 45.4 halibut per trawling hour). Excluding this extreme value decreased the population ratio estimate for this cell from 1.46 to 1.38 halibut per towing hour (95% C.I. = 0.93–1.83) and decreased the estimated annual bycatch for PSMFC areas 2B–3C to 40,259 individuals (95% C.I. = 20,153–60,405).

#### *DWD Strategy*

The DWD strategy was conducted over a broad range of depths (165–635 m) and averaged 299 m during July–October and 393 m for November–June (Table 5). Mean towing duration for this strategy exceeded that of other strategies examined.

For July–October, halibut catch rate was much higher in shallow water (1.38 halibut h<sup>-1</sup> at depths of ≥163–320 m) than at greater depths (0.50 halibut/hour; Table 6). Catch rates were more consistent across depths for November–June (0.37 vs. 0.43 halibut h<sup>-1</sup> for shallow versus deep water, respectively). The estimated halibut bycatch for this strategy was 20,259 individuals (95% C.I. = 12,175 to 28,401), or 137,353 kg. The estimated bycatch weight exceeds that reported for the NSM strategy because average halibut size is larger for the DWD strategy (6.78 kg fish<sup>-1</sup>) than the NSM strategy (3.05 kg fish<sup>-1</sup>).

The DWD strategy did not have an extreme value. The halibut per hour for the top five tows was 16.0, 12.6, 12.6, 12.0, and 9.1.

## 1988–1990 STUDY

Although the geographic extent of sampling was greater for the 1988–1990 study than for the 1985–1987 study, sampling intensity for a given cell (i.e., strategy, calendar period, and depth) was generally lower (Table 7). Small samples and empty cells are prevalent in this database because of the wide geographic distribution of sampling effort, and because only two of six codend types used during this experiment were included in these analyses (i.e., 11.4- and 12.7-cm [4.5- and 5-inch]) diamond mesh codends; see preceding text). In addition, since most sampling occurred only during the second half of the year, the period November through June is poorly represented in this database. Hence, bycatch estimates were calculated by strategy, and data were pooled across PSMFC areas 1B through 2A, calendar period, and depth. Even after pooling across these various categories, sample sizes for this southern area remained small (i.e., 8, 28, and 29 tows for NSM, BRF, and DWD strategies, respectively).

Population ratio estimates (Table 8) were lowest for the BRF strategy (0.07 kg/h; 95% C.I. = 0.00–0.16 kg h<sup>-1</sup>), and highest for the DWD strategy (3.00 kg h<sup>-1</sup>; 95% C.I. = 0.00–7.32 kg h<sup>-1</sup>). The population ratio estimate for the NSM strategy was 0.38 kg h<sup>-1</sup> (95% C.I. = 0.00–1.26 kg h<sup>-1</sup>). Pacific Halibut were caught in only 1 of the 8 tows for the NSM strategy (in area 1C) and 1 of 28 tows for the BRF strategy (area 1B). For the DWD strategy, 4 of 14 tows captured Pacific halibut in area 2A, and 2 of 7 tows caught Pacific halibut in area 1C. Of the six DWD tows conducted in area 1B, none contained halibut.

Estimated halibut bycatch was highest for the DWD strategy, because fleet effort and the population ratio estimate were highest for this strategy (Table 8). Total estimated halibut bycatch for all strategies combined in PSMFC areas 1B–2A was 135,940 kg (95% C.I. = 0 to 351,142 kg), or 20,718 individuals (approximate 95% C.I. = 0 to 57,355 individuals).

Of special note are two BRF tows containing a large number of halibut. Both tows were conducted north of area 1B–2A and, hence, are not part of the results provided above. These large catches were 2,041 kg (4,500 lb) in area 3A–3C and 1,814 kg (4,000 lb) in area 2B–2C.

## DISCUSSION

The incidental catch of halibut in bottom trawl tows varied significantly among fishing strategies, depth categories, and calendar periods. Log transformed catch rates did not differ significantly among PSMFC areas, which may have resulted from insufficient sample sizes across areas. Hence, most bycatch estimates were calculated by fishing strategy, depth category, and calendar period.

The estimated coastwide Pacific halibut catch in 1987 derived in this report must be applied with caution for several reasons. The distribution of halibut catches among tows was skewed (Fig. 4), with most tows containing no halibut and some tows consisting of relatively large quantities of halibut. These skewed catch distributions, along with small sample sizes, were responsible for the wide confidence intervals around the bycatch estimates (Tables 6 and 8). The problem of small sample sizes was most pronounced for PSMFC areas 1B–2A (i.e., 8 to 29 tows were sampled per

cell). Hence, a much greater level of sampling effort, or the implementation of an observer program, is needed if more precise bycatch estimates are desired.

Population ratio estimates were typically lowest for the BRF and SHR trawling strategies. One might expect relatively low BRF bycatch rates (compared with NSM and DWD strategies) because many BRF tows are made over hard, rocky bottom. Shrimp trawls are typically smaller than other groundfish trawls and are towed at slower speeds (Erickson and Pikitch 1994); hence, once halibut encounter trawl gear (i.e., doors, wings, etc.), they have a better chance of escaping shrimp trawls than other types of bottom trawls.

Highest population ratios were estimated for DWD (inside 640 m) and NSM strategies. A variety of flatfish species are targeted by these strategies (Rogers and Pikitch 1992), which generally tow over soft bottom (i.e., sand or mud). Population ratio estimates also were generally highest during July-October, when Pacific halibut are concentrated at depths of 27 to 274 m (15 to 150 fathoms; International Pacific Halibut Commission 1987).

Bycatch estimates were higher for PSMFC areas 2B-3C (413,335 kg) than areas 1B-2A (135,940 kg). Higher bycatch in this northern area is due to higher bycatch rates (ANOVA;  $p < 0.05$ ) and more trawling effort (273,678 h versus 81,397 h). Halibut bycatch by the bottom trawl groundfish fishery (i.e., excluding SHR) in the northern areas was 314,352 kg, even though trawling effort (79,984 h) was slightly less than trawling effort in PSMFC areas 1B-2A during 1987. Comparisons of bycatch between these areas are tenuous because samples in PSMFC areas 1B-2A were small, and were collected only during July through December.

This report provides a rough estimate of the incidental catch of halibut in the West Coast trawl fishery for a single year (1987). Catches likely vary over time in concert with changes in halibut abundance; the geographical, seasonal and depth distribution of trawling effort; trawling strategies and techniques employed; and other factors. The extent of interannual variability in total catch and catch rates may also be considerable. These factors, as well as the wide confidence intervals around our estimates, indicate that an extensive and ongoing sampling program is needed to precisely monitor halibut bycatch over time.

## REFERENCES

- Bergh, M. O., E. K. Pikitch, J. R. Skalski, and J. R. Wallace. 1990. The statistical design of comparative fishing experiments. *Fish. Res.* 9:143-160.
- Cochran, W. G. 1977. *Sampling Techniques*. Pages 150-157. John Wiley and Sons, New York.
- Erickson, D. L., and E. K. Pikitch. 1994. Incidental catch of chinook salmon in commercial bottom trawls off the U.S. west coast. *N. Am. J. Fish. Mgmt.* 14:550-563.
- Friedman, J.H. 1984. A variable span smoother. Technical Report No. 5, Laboratory for Computational Statistics, Department of Statistics, Stanford University, California.
- Hannah, R. W. and M. Saelens. 1993. Oregon Department of Fish and Wildlife review of March 31, 1993 IPHC halibut bycatch memo. Oregon Dep. Fish Wildlife, Newport, OR. 19 p.
- International Pacific Halibut Commission. 1987. The Pacific halibut: biology, fishery, and management. *Int. Pac. Halibut Comm. Tech. Rep. No. 22.* 59 p.
- Pikitch, E. K. 1991. Technological interactions in the U.S. west coast groundfish trawl fishery and their implications for management. *ICES Mar. Sci. Symp.* 193:253-263.
- Pikitch, E. K. 1992. Potential for gear solutions to bycatch problems. Pages 128-138 *in* R.W. Schoning, R.W. Jacobsen, D.L. Gentle and J. Auyong (eds.), *Proceedings of the National Industry Bycatch Workshop*. Natural Resources Consultants, Seattle.
- Pikitch, E. K., D. L. Erickson, and J. R. Wallace. 1988. An evaluation of the effectiveness of trip limits as a management tool. NOAA, NMFS, Northwest and Alaska Fisheries Center Processed Report 88-27.
- Pikitch, E. K., M. O. Bergh, D. L. Erickson, J.R. Wallace, and J. R. Skalski. 1990. Final report on the results of the 1988 West Coast groundfish mesh size study. Univ. Washington, School of Fisheries, Fish. Res. Inst. FRI-UW-9019. Seattle, WA.
- Rogers, J. B., and E. K. Pikitch. 1992. Numerical definition of groundfish assemblages caught off the coasts of Oregon and Washington using commercial fishing strategies. *Can. J. Fish. Aquat. Sci.* 49(12):2648-2656.
- Williams, G. H. 1993. Estimates of Pacific halibut bycatch mortality in U.S. domestic fisheries in IPHC area 2A. Report by the Int. Pac. Halibut Comm., Seattle, WA. 19 p.

## **FIGURES**



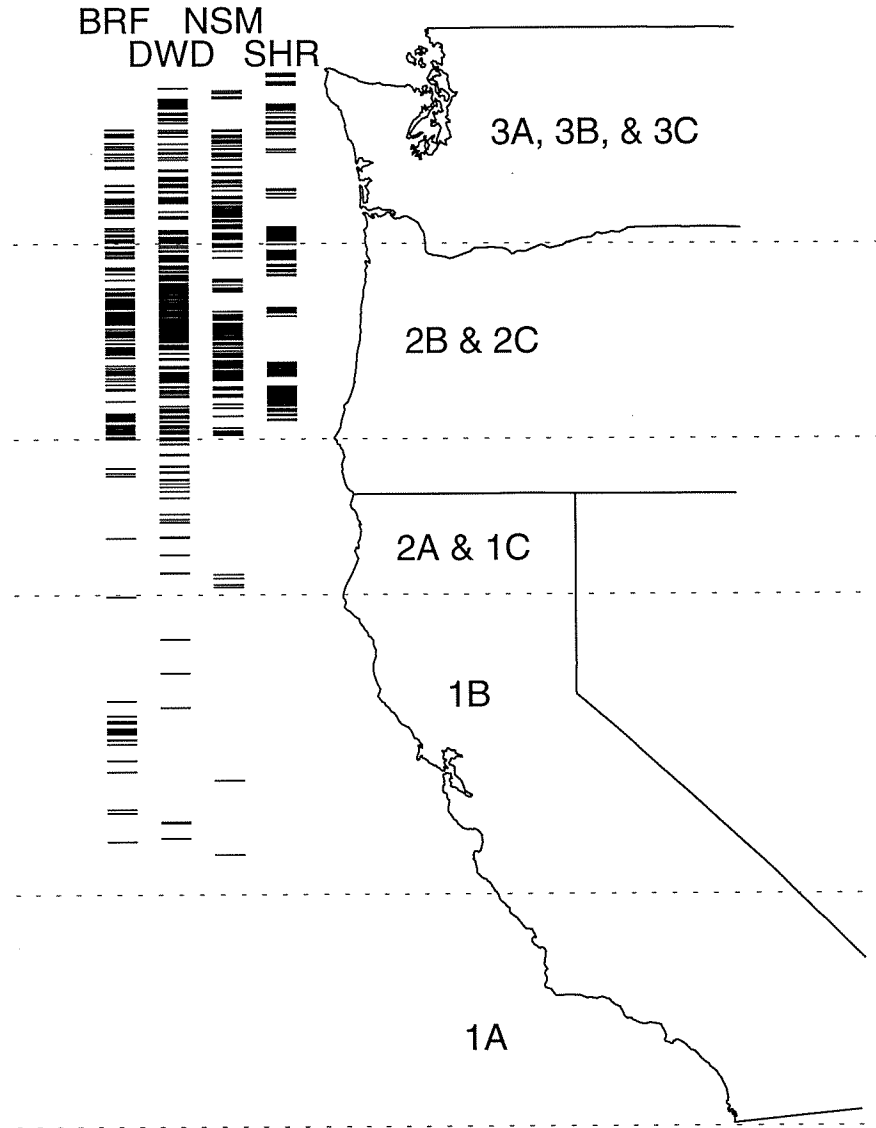
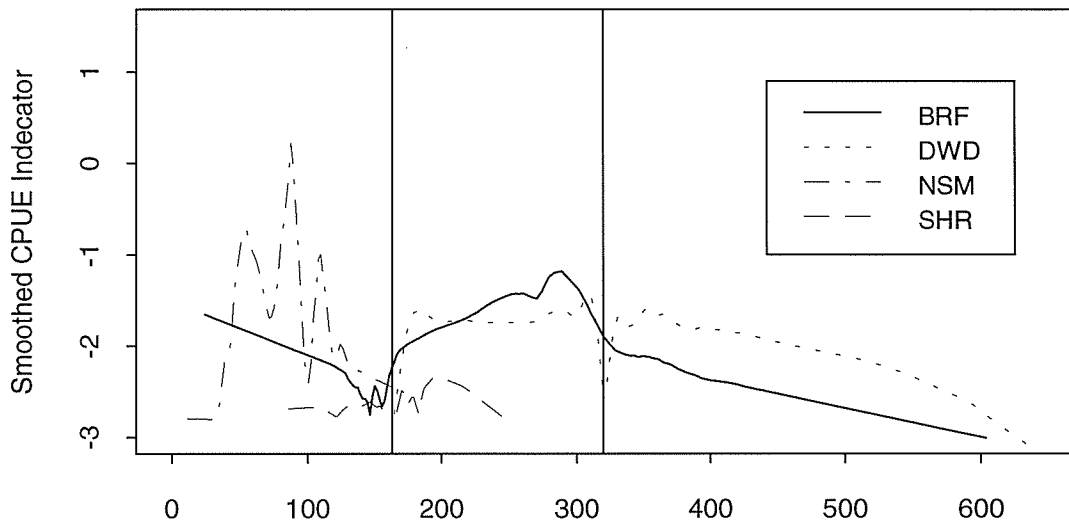


Figure 1. Pacific States Marine Fisheries Commission (PSMFC) areas along the US West Coast. The 'bar-coding' shows the latitude of each tow by the newly defined strategies. The data in areas 2A & 1C and 1B are from the 1988–90 database, the data in the other areas are only from the 1985–87 database.

## 1985-1987 Data



## 1988-1990 Data

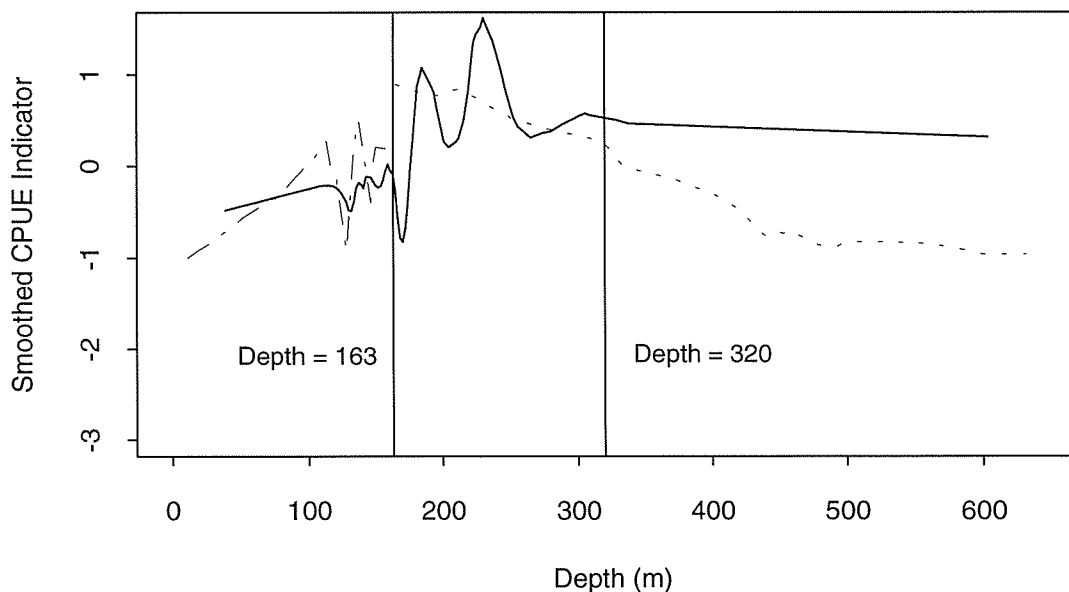
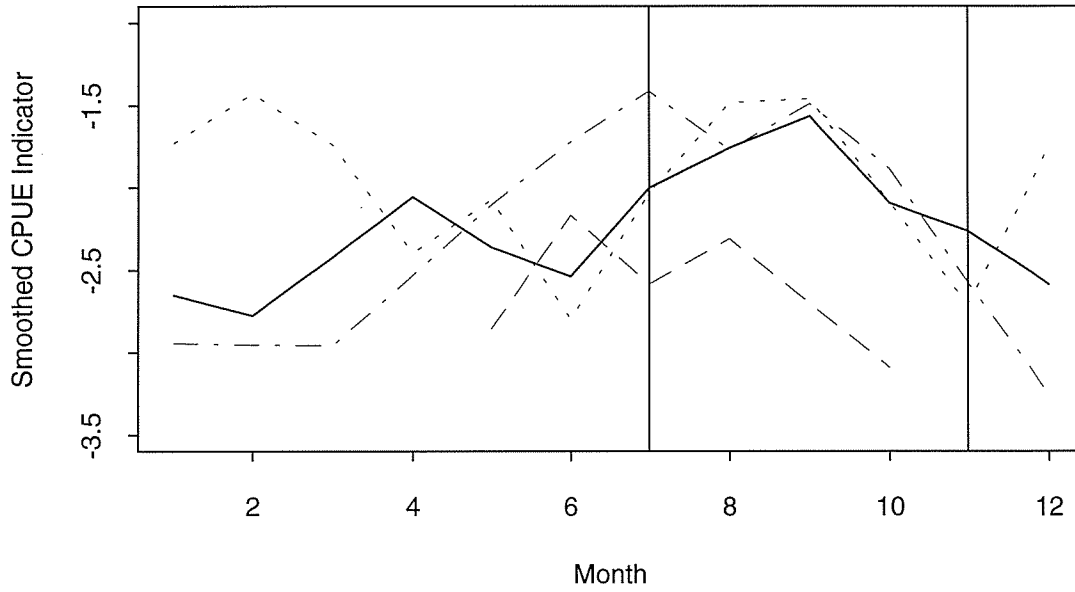


Figure 2. Non-parametrically smoothed CPUE indicator by depth (m) and trawling strategy (BRF, DWD, NSM, and DWD) for 1985–1987 and 1988–1990 databases. Vertical lines represent depth categories (<163 m, 163 to <320 m, and 320 to 640 m).

## Halibut; 1985-87 Data



## Halibut; 1988-90 Data

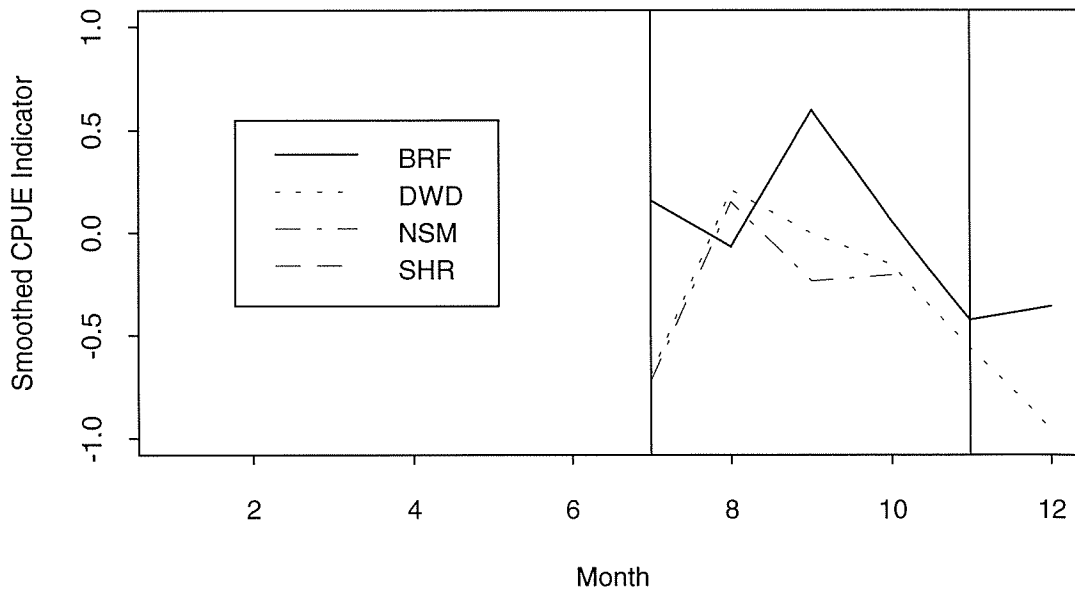


Figure 3. Non-parametrically smoothed CPUE indicator by month and trawling strategy (BRF, DWD, NSM, and DWD) for 1985–1987 and 1988–1990 databases. Vertical lines represent calendar periods July–October and December–June.

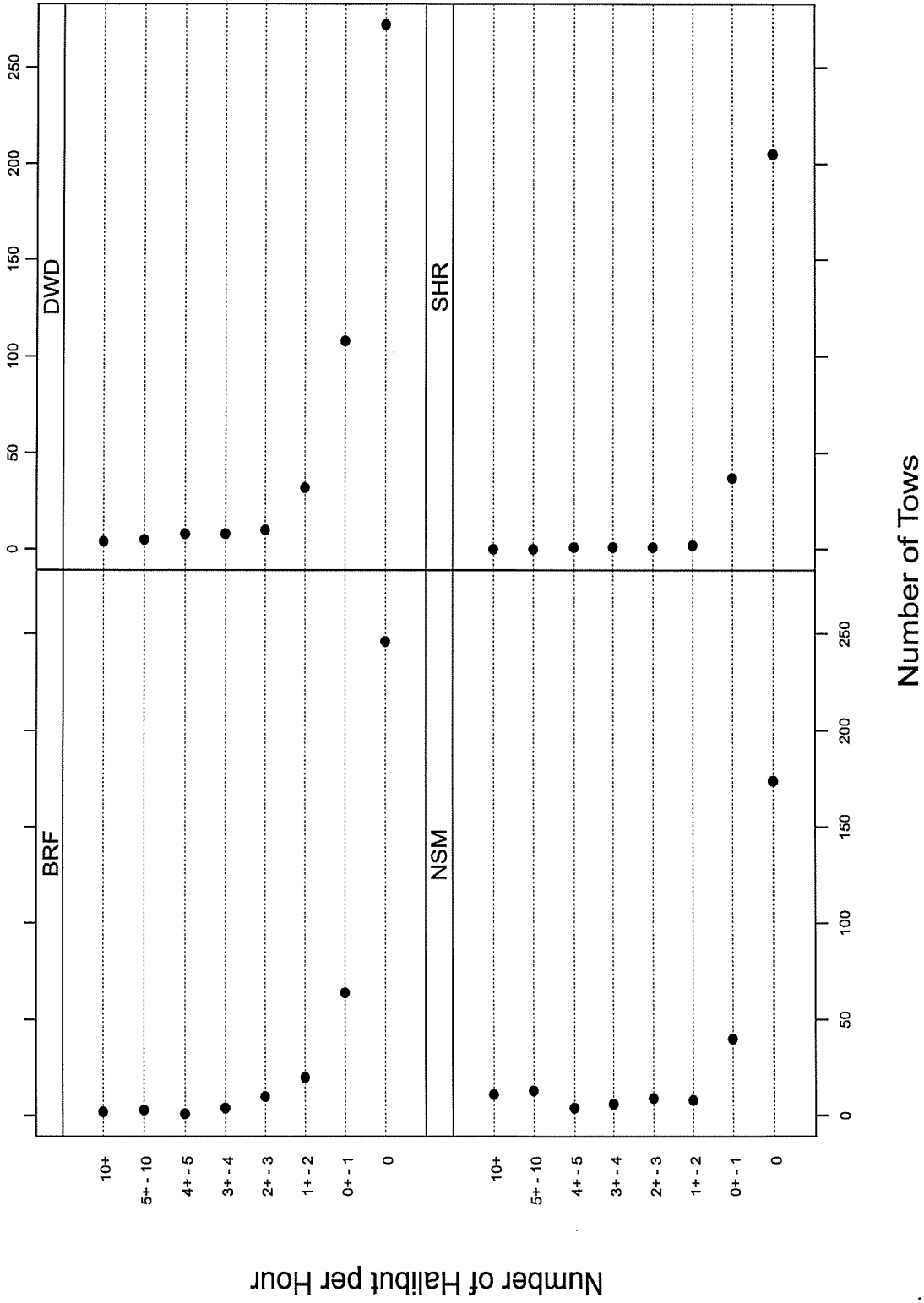


Figure 4. Tow frequency distribution of Pacific halibut bycatch (number of halibut per tow) for each trawling strategy (i.e., BRF, DWD, NSM, and SHR) for the 1985-1987 database.

# **TABLES**



Table 1. Boundaries of combined Pacific States Marine Fisheries Commission (PSMFC) areas.

Combined PSMFC areas	Latitude (N)
3A-3C	45°46' to Canada
2B-2C	42°50' to 45°46'
1B-2A	36°00' to 42°50'

Table 2. Sampling effort (number of tows) by calendar period, PSMFC area, and depth category (m) during the 1985-1987 field study for BRF, DWD, NSM, and SHR trawling strategies.

Strategy	Depth (m)	Calendar period and PSMFC area						Grand total
		Nov-Jun			Jul-Oct			
		2B-2C	3A-3C	Total	2B-2C	3A-3C	Total	
BRF	< 163	69	40	109	34	17	51	160
	163 - < 320	46	3	49	49	17	66	115
	320 - 640	55	4	59	15	1	16	75
	Total	170	47	217	98	35	133	350
DWD	163 - < 320	47	14	61	90	23	113	174
	320 - 640	153	49	202	63	8	71	273
Total		200	63	263	153	31	184	447
NSM	< 163	16	15	31	124	110	234	265
SHR	< 163	23	52	75	40	13	53	128
	163 - < 320	48	4	52	48	19	67	119
	320 - 640	0	0	0	0	0	0	0
Total		71	56	127	88	32	120	247
Grand total		457	181	638	463	208	671	1309

Table 3. Number and percent of tows containing halibut for all trawling strategies, PSMFC areas, and depths combined during the 1985-1987 field study.

Month	Number of tows	Number of tows containing halibut	Percent of tows containing halibut
Jan	26	5	19
Feb	85	34	40
Mar	49	9	18
Apr	84	24	29
May	110	16	15
Jun	98	30	31
Jul	202	51	25
Aug	203	81	40
Sep	146	67	46
Oct	120	35	29
Nov	83	18	22
Dec	103	42	41
Total	1,309	412	31

Table 4. Results of analysis of variance to test effects of trawling strategy (BRF, DWD, NSM, and SHR), depth (0 to 163 m, 163+ to 320 m, and 320+ to 640 m), calendar period (July-October and November-December), and PSMFC area (combined as shown in Table 1) on Pacific halibut log transformed catch rates (number/hour) for 1985-1987. (A) Area included as a factor. (B) Area excluded in the analysis. \* =  $P < 0.05$ ; \*\* =  $P < 0.01$ .

Source of variation	Pr(F-statistic)	
	A	B
Strategy	<0.01**	<0.01**
Depth	<0.01**	<0.01**
Period	0.01*	0.01*
Area	0.12	
Strategy x Depth	0.03*	0.03*
Strategy x Period	0.09	0.11
Depth x Period	0.03*	0.05
Strategy x Area	0.32	
Depth x Area	0.26	
Period x Area	0.19	
Strategy x Depth x Period	0.01*	0.01*
Strategy x Depth x Area	0.71	
Strategy x Period x Area	0.05	
Depth x Period x Area	0.53	
Strategy x Depth x Period x Area	0.52	

Table 5. Depth and duration of BRF, DWD, NSM, and SHR strategy tows conducted during the 1985-1987 field study. Towing duration for shrimp strategy represents actual tows hours (i.e., double rig effort was not converted to single rig equivalent for these descriptive statistics)

Strategy	Period	N	Depth (m)			Towing Duration (h)		
			Range	Mean	Std dev	Range	Mean	Std dev
BRF	Nov-Jun	217	24-604	225	106.1	0.2-8.5	2.1	1.5
	Jul-Oct	133	101-426	205	78.8	0.2-7.5	2.4	1.4
DWD	Nov-Jun	263	165-635	393	115.1	0.2-11.3	4.2	1.8
	Jul-Oct	184	165-611	299	93.7	0.1-8.5	3.6	1.5
NSM	Nov-Jun	31	73-163	126	25.6	0.3-8.5	2.0	1.6
	Jul-Oct	234	11-163	86	38.5	0.3-4.7	2.6	0.9
SHR	May-Oct	247	86-247	159	32.3	0.3-5.1	2.0	0.8

Table 6. Estimated bottom trawl catches of Pacific halibut in PSMFC areas 2B-3C. Estimates of the population ratio were pooled from data collected by observers during 1985-1987. Fleet effort was calculated from 1987 Washington, Oregon, and California logbook data.

Strategy	Period	Depth (m)	Number of tows	Estimate of the population ratio		Upper limit of 95% C.I.	Estimate of the population ratio (kg h <sup>-1</sup> )	Adjusted effort (hr)	Effort subtotal (hr)	Estimated halibut bycatch		Estimated bycatch subtotal (kg)	
				Estimate of the population ratio (number h <sup>-1</sup> )	Lower limit of 95% C.I.					(number)	(kg)		
BRF	Nov - Jun	<163	109	0.33	0.14	0.51	2.76	3,016	985	985	8,335	8,335	
		163 - <320	49	0.32	0.16	0.47	2.69	3,119	991	991	8,383	8,383	
	Jul - Oct	320 - 640	59	0.18	0.05	0.30	1.49	1,316	231	231	1,957	1,957	
		<163	51	0.14	0.05	0.22	1.15	2,903	395	395	3,338	3,338	
		163 - <320	66	1.12	0.58	1.65	9.45	2,600	2,905	2,905	24,578	24,578	
		320 - 640	16	0.52	0.27	0.77	4.42	626	13,580	327	5,834	2,768	49,359
DWD	Nov - Jun	163 - <320	61	0.37	0.20	0.54	2.51	5,546	2,051	2,051	13,903	13,903	
		320 - 640	202	0.43	0.30	0.57	2.94	13,805	5,983	5,983	40,564	40,564	
	Jul - Oct	163 - <320	113	1.38	0.87	1.89	9.35	7,314	10,081	10,081	68,347	68,347	
		320 - 640	71	0.50	0.13	0.86	3.37	4,318	30,983	2,144	20,259	14,539	137,353
NSM	Nov - Jun	<163	31	0.81	0.09	1.54	2.48	15,224	12,362	12,362	37,703	37,703	
		<163	234	1.46	0.95	1.97	4.45	20,197	35,421	29,488	41,850	89,937	127,640
SHR	May - Oct	<163	128	0.09	0.04	0.15	0.46	148,496	14,103	14,103	67,975	67,975	
		163 - <320	119	0.14	0.06	0.22	0.69	45,198	193,694	6,433	20,536	31,008	98,983

Table 7. Sampling effort (number of tows) by calendar period, PSMFC area, and depth category (m) during 1988-1990 for BRF, DWD, and NSM trawling strategies. Only tows made using 11.4-cm (4.5 inch) and 12.7-cm (5-in) diamond mesh codends are shown.

Strategy	Depth (m)	Calendar period and PSMFC area										Grand total
		Nov - Jun					Jul - Oct					
		1B	1C & 2A	2B & 2C	3A & 3B	Total	1B	1C & 2A	2B & 2C	3A & 3B	Total	
BRF	<163	2	4	10	9	25	1	2	24	68	95	120
	163 - <320	13	0	15	1	29	5	0	12	50	67	96
	320 - 640	1	0	0	0	1	0	0	5	4	9	10
	Total	16	4	25	10	55	6	2	41	122	171	226
DWD	163 - <320	2	0	0	0	2	0	2	18	13	33	35
	320 - 640	1	0	8	1	10	3	21	35	11	72	82
	Total	3	0	8	1	12	3	23	53	24	103	115
NSM	<163	0	0	0	0	0	4	4	12	25	45	45
Grand total		19	4	33	11	67	13	29	106	171	321	386

Table 8. Estimated bottom trawl catches of Pacific halibut in PSMFC areas 1B-2A. Estimates of the population ratio were pooled using data collected by observers during 1988-1990. Fleet effort was calculated from 1987 Washington, Oregon and California logbook data. Note that the “kg h<sup>-1</sup>” and “number h<sup>-1</sup>” columns are switched relative to Table 6.

Strategy	Number of tows	Estimate of the population ratio (kg/h <sup>-1</sup> )	Lower limit of 95% C.I.	Upper limit of 95% C.I.	Estimate of the population ratio (number h <sup>-1</sup> )	Adjusted effort	Estimated halibut bycatch (number)	Estimated halibut bycatch (kg)
BRF	28	0.07	0.00	0.16	0.01	14,595	116	979
DWD	29	3.00	0.00	7.32	0.44	43,715	19,337	131,104
NSM*	8	0.38	0.00	1.26	0.13	23,087	1,265	3,857

\*Pacific Halibut was caught in only one of the eight tows.