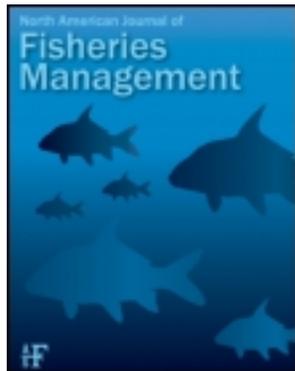


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Spatial Changes in Trawl Fishing Effort in Response to Footrope Diameter Restrictions in the U.S. West Coast Bottom Trawl Fishery

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Abstract.—Changes in the spatial distribution of U.S. west coast bottom-trawl effort in relation to areas of prime habitat for rockfish *Sebastes* spp. were evaluated between 1992 and 2001. Prime trawlable rockfish habitat (PTRH) was defined based on the spatial distribution of high rockfish catches from logbook data for 1992–1995. Bottom-trawl effort was sharply reduced within PTRH after the establishment of maximum trawl footrope diameter restrictions in 2000. However, reductions in rockfish catch limits prior to 2000 had already reduced trawl activity within these areas, confounding the effects of reduced trip limits and footrope diameter restrictions. Fishing inside PTRH rebounded in 2001, when retention limits for yellowtail rockfish *Sebastes flavidus* as flatfish bycatch were raised, suggesting that limits may be as important as gear restrictions in determining the spatial distribution of trawl effort in this fishery. The untrawled area of PTRH between 43°N and 48°N in 2000–2001 was estimated at about 186,000 ha.

Beginning in 2000, the National Marine Fisheries Service sharply reduced the allowable harvest of several rockfish *Sebastes* spp. on the U.S. west coast continental shelf, including canary rockfish *Sebastes pinniger*, which has been declared “overfished” (PFMC 2000). The decline in shelf rockfish stocks was most likely a result of a harvest policy that was too aggressive for such relatively unproductive fishes (Ralston 2002). Part of the strategy to rebuild shelf rockfish stocks included gear restrictions on the maximum diameter of footrope rollers and on the use of chafing gear (PFMC 2000). The intent was to make it more difficult for bottom trawlers to fish in high-relief, rocky areas, where canary rockfish and other shelf rockfish species are most abundant. The footrope and chafing gear restrictions were added, at least in part, to address concerns that simply reducing catch limits would only result in more discard, not in a reduced total take of shelf rockfish.

The regulations enacted were actually a combination of rules linking the use of large roller gear (>20.3 cm in diameter) to restricted limits on shelf rockfish species (PFMC 2000). For continental slope species such as Dover sole *Microstomus pacificus*, sablefish *Anoplopoma fimbria*, and thornyheads *Sebastolobus* spp., higher limits were allowed with large roller gear. Higher trawl limits were also allowed for some other rockfish, such as yellowtail rockfish *Sebastes flavidus* and widow

rockfish *Sebastes entomelas*, taken with midwater trawls. So in a practical sense, though large roller gear was not banned throughout the continental shelf, all financial incentives for using such gear in areas with abundant rockfish were eliminated.

The suite of new regulations was intended to both reduce the landings of shelf rockfish and to shift bottom-trawl effort away from the areas in which shelf rockfish are most abundant. If the anticipated reduction in bottom trawling in rocky areas is realized, this set of regulations might represent a first step towards setting aside marine protected areas in a manner compatible with large-scale commercial fisheries. It could also represent a starting point for protecting high-relief benthic habitat from the physical impacts of trawl gear (e.g., Van Dolah et al. 1987; Jones 1992; Collie 1998; Kaiser et al. 1998; Rogers et al. 1998; Hansson et al. 2000).

Most management measures, such as quotas or size limits, are directed at limiting the amount or qualitative composition of fishery catch. Evaluation of such measures is a matter of monitoring total catch or evaluating catch composition via biological samples. The management measures evaluated in this study were aimed at producing a spatial shift in trawl fishing effort with respect to prime rockfish habitat. Accordingly, a spatial evaluation of the effectiveness of the management measures was needed. In this study, I examined vessel logbook data to conduct a quantitative analysis of the changes in the spatial distribution of trawl fishing effort that resulted from the new management approach enacted in 2000.

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TABLE 1.—Monthly maximum rockfish catch limits for bottom trawlers on January 1 of each year (1992–2001), for waters off the coast of northern Oregon and Washington.

Year	Monthly limit (kg)	
	Widow rockfish	Other rockfish
1992	13,607 ^a	45,359 ^{ab}
1993	13,607 ^a	45,359 ^{ab}
1994	13,607	36,287 ^b
1995	13,607	15,876 ^b
1996	15,876	15,876 ^b
1997	15,876	6,804 ^b
1998	5,670	9,072 ^b
1999	10,584	3,629 ^b
2000	454 ^c	953 ^{bc}
2001	454 ^c	953 ^{bcd}

^a Limit period was 4 weeks.

^b Separate sublimits applied for some species.

^c Small-diameter footropes (≤ 20.3 -cm rollers) required; no retention of rockfish was allowed with large footropes.

^d Additional catch of yellowtail rockfish was allowed as flatfish bycatch with small-diameter footropes, based on a percentage of flatfish landed, but not to exceed 6,805 kg/month.

Methods

My general approach was to identify locations in which shelf rockfish have been commonly caught and then determine whether bottom-trawl effort in these areas was reduced after the new regulations were implemented. The preferred method would be to use detailed habitat maps to identify hard bottom areas with the proper depth and relief for harboring shelf rockfish and then to examine the distribution of trawl effort relative to habitat type. However, the accurate high-resolution bathymetry or side-scan sonar data required for identifying such areas are mostly unavailable for the west coast continental shelf. Therefore, to identify the trawlable areas where rockfish are generally found in high densities, I used trawl logbook data from earlier years during which substantial trawl effort targeted shelf rockfish species. This portion of the study focused on 1992–1995, when limits for rockfish species targeted with bottom trawls were high (“other rockfish” in Table 1). Throughout this study, I used the tow start location as the best approximation for the location of fishing, because operators presumably begin towing near areas where they expect to obtain a good catch of the target species. Positional data from Washington and California logbooks during 1992–1995 were based on fixed grids or “blocks,” and accordingly were not of sufficient resolution for this type of analysis. Only logbook data from Oregon were used for identifying areas of high rockfish

catch. The dependence on Oregon logbook data for defining high rockfish catch areas also limited the latitudinal range of the study (Figure 1). Since the 1992–1995 Oregon trawl logbook data became sparse below 43°N and above 48°N, this study was limited to that latitudinal range. The studied area approximately corresponds to the International North Pacific Fisheries Commission’s Columbia area. Because this study focused on shelf rockfish, the logbook data used were further limited by the exclusion of hauls with depths greater than 457 m.

Logbook data can be a powerful tool for spatial analysis of commercial fisheries, but they have some significant limitations that must be understood before results can be correctly interpreted. Probably most relevant to this study, certain types of logbook data errors can be difficult or impossible to detect. Logbook data are routinely put through a variety of quality control procedures. For Oregon data, the vessel operator’s estimates of catch, also known as “hails,” are compared with the species composition on the final landing receipt to flag unreasonable catch estimates. Tow duration is also routinely compared with a reasonable maximum tow duration, and each trip is checked to see if the dates within the trip follow in sequential order. However, positional errors, those most critical to a study of this kind, are much more difficult to reliably detect. In this study, the start locations of all tows were mapped, and tows that did not have a “reasonable position” were excluded from the analysis. Unreasonable positions were those located either on land or in areas where bottom depth was greater than 457 m; these represented less than 1% of the logbook data for any year. Although this approach certainly eliminated some positional errors, any incorrect tow start locations in reasonable positions went undetected. As a result, the data sets analyzed contain some positional errors, as is generally the case for logbook data. Accordingly, conclusions based on the analysis of positional data from logbooks are only reliable when they focus on the distribution of large numbers of tows, thereby minimizing the influence of errant position data. This study focused only on large-scale changes in the trawling distribution based on large numbers of hauls.

The specific process used to identify areas of high rockfish catch involved several steps. First, haul locations in 1992–1995 that produced over 227 kg/h of rockfish were identified. These locations were then mapped into a coastwide grid of contiguous, 148.6-ha square “blocks” measuring 1,219 m on a side. Blocks with at least three suc-

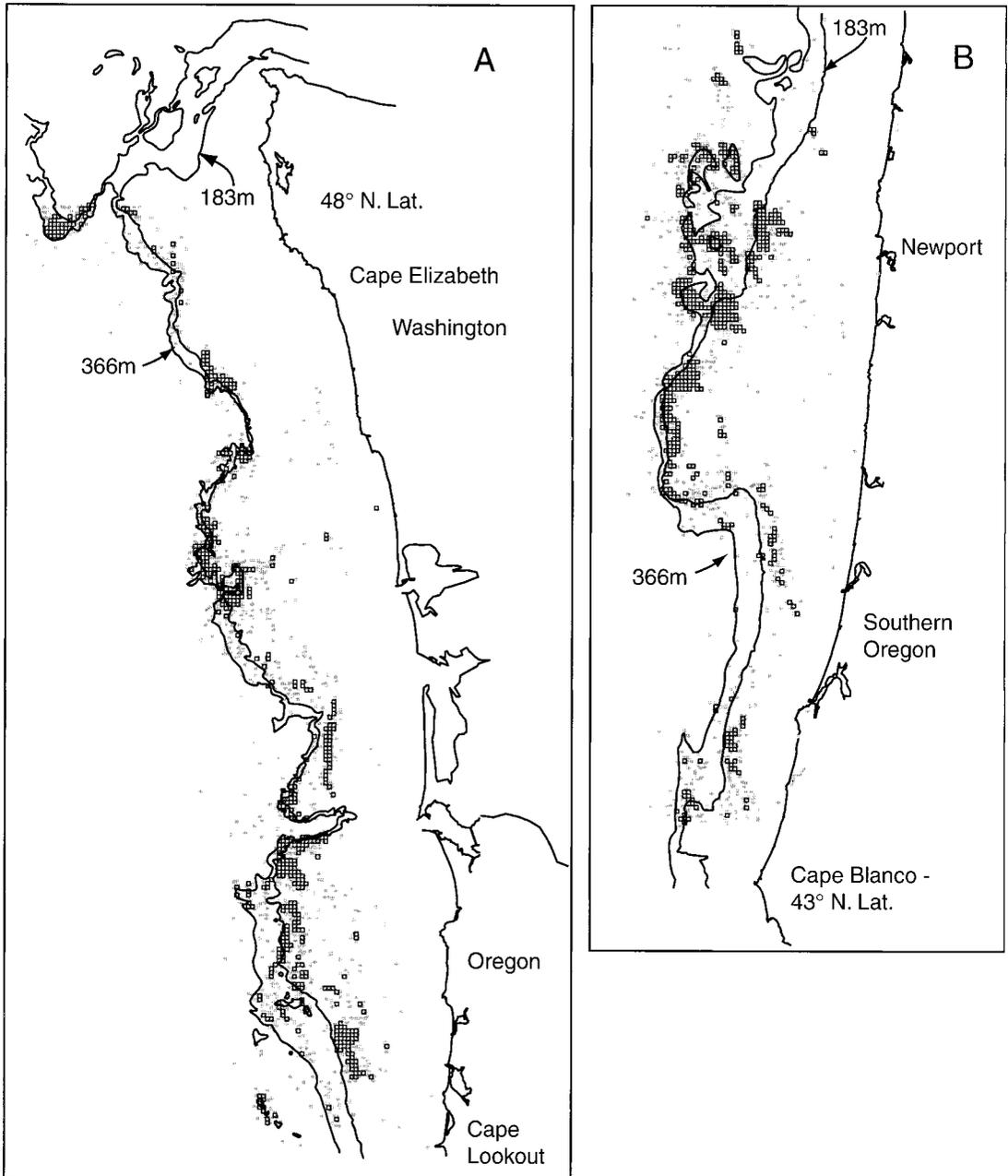


FIGURE 1.—Spatial distribution of prime trawlable rockfish habitat (squares; see text) and bottom-trawl tow start locations from Oregon logbook data, 1992–1995, for fishing (A) north and (B) south of Cape Lookout, Oregon. Only hauls that produced catches greater than 227 kg/h of rockfish inside of 457 m depth (shaded circles) are shown.

cessful hauls during 1992–1995 were identified. These blocks were assumed to represent prime trawlable rockfish habitat (PTRH). The choice of this approach was arbitrary. Nevertheless, a catch threshold of 227 kg/h approximates the 75th per-

centile of rockfish catch per unit effort (CPUE) for all bottom-trawl hauls within the study area for 1992–1995, suggesting that this threshold correctly identifies high catches of rockfish. The choice of block size was evaluated by use of a

sensitivity analysis. The threshold of three hauls in any given block simply requires that the selected areas harbor rockfish routinely, thereby preventing an isolated incident of good rockfish catch from indicating prime rockfish habitat. Though these are reasonable thresholds, a choice of different values could certainly change the results of this analysis.

Next, the time series of the percentage of bottom hauls originating inside PTRH was examined for 1992–2001. The full time series was examined to see how both the footrope regulation enacted in 2000 and the declining rockfish limits prior to 2000 (Table 1) influenced the choice of fishing location. Data from both Oregon and Washington were used; however, only the data for 1997–2001 were used from Washington, due to problems with Washington's positional data prior to 1997, as mentioned above.

Whenever points on a spatial grid are mapped into blocks, the block size used can influence the amount of area identified. In this case, the arbitrary choice of 148.6-ha blocks to identify PTRH begs the question of how block size might influence both the amount of habitat identified as PTRH and the resulting time series of the percentage of trawl effort originating inside PTRH. To test how block size influenced the results in this study, the percentage of Oregon bottom-trawl effort located inside PTRH for 1992–2001 was compared among block sizes of 83.6, 148.6, and 232.2 ha.

The time series of bottom-trawl effort inside PTRH should show how fishing effort has changed in response to the new footrope diameter restrictions and reduced catch limits. Moreover, this analysis might reveal how much area that was heavily trawled in 1992–1995 is now untrawled. However, an accurate estimate of the area involved may be difficult to generate for several reasons. First, although the time series of variation in trawl effort inside PTRH is likely robust to the choice of block size used for mapping, it is anticipated that the area enclosed will be somewhat dependent on block size. Accordingly, the area enclosed in PTRH will be inflated or reduced by the block size chosen. Also, as this analysis is based completely on trawl start locations, it is impossible to know for sure that any area received zero trawl effort because no information is available on the actual path trawled. Also, some limited areas in which groundfish trawling no longer takes place may still receive a small amount of trawl effort from the fishery for spot shrimp *Pandalus platyceros*. Despite these problems, even a very crude estimate of the area without trawling, or with substantially

TABLE 2.—Total number of tows and hours fished for usable bottom-trawl tows (Oregon data only) and number of tows, percentage, and hours fished within prime trawlable rockfish habitat (PTRH) between 43°N and 48°N by year, 1992–2001. Usable bottom-trawl tows were those with depths less than 457 m and reasonable positions.

Year	Usable bottom-trawl tows			Usable fishing effort (h)	
	Total	Number inside PTRH	Percent inside PTRH	Total	Inside PTRH
1992	13,381	4,292	32.1	39,250	9,007
1993	17,316	5,510	31.8	54,187	12,721
1994	11,689	3,964	33.9	36,645	9,781
1995	9,513	2,932	30.8	30,487	7,385
1996	9,796	2,912	29.7	31,679	7,857
1997	9,203	2,051	22.3	30,641	5,581
1998	8,604	2,003	23.3	28,469	5,144
1999	7,015	1,350	19.2	24,542	3,964
2000	5,185	391	7.5	20,119	1,641
2001	5,814	616	10.6	21,659	2,275

reduced trawl effort, could be useful. To generate such an estimate, a simple graphical approach was used. The tow start locations were represented graphically by circles with a radius of 610 m. The start locations of high rockfish catch tows from 1992 to 1995 were then overlaid with Oregon and Washington bottom-trawl locations for 2000–2001. Polygons were then drawn around areas that had high rockfish catch tows from 1992 to 1995 but no bottom-trawl tows from 2000 to 2001. These polygons were considered to represent an approximate estimate of the area untrawled since the new footrope restrictions were implemented in January 2000.

Results

Analysis of the 1992–1995 commercial logbook data identified 1,048 blocks (148.6 ha each) as PTRH (Figure 1). Prime trawlable rockfish habitat was clustered along the 183-m contour, with more habitat present off the coasts of Washington and northern and central Oregon than off southern Oregon. During 1992–1995, substantial trawl effort (31–34% of total Oregon effort in the study area) was concentrated in these relatively small areas (Table 2).

The time series of the number and percentage of hauls inside PTRH shows that the limitation on footrope size in 2000, in combination with the reduced catch limits, substantially reduced bottom-trawl effort inside PTRH (Tables 2, 3). In 1999, 1,578 tows, or 19.0% of all bottom-trawl tows in the study area, began inside PTRH (Table 3). By 2000, only 428 tows, or 7.2% of the total, began

TABLE 3.—Total number of usable bottom-trawl tows (Washington data [WA] and Washington and Oregon data combined [WA/OR]) and number and percentage of tows located within prime trawlable rockfish habitat (PTRH) between 43°N and 48°N by year, 1997–2001. Usable bottom-trawl tows were those with depths less than 457 m and reasonable start locations.

Year	Usable bottom-trawl tows (Washington)			Usable bottom-trawl tows (Washington/Oregon)		
	Total	Number inside PTRH	Percent inside PTRH	Total	Number inside PTRH	Percent inside PTRH
1997	1,185	218	18.4	10,388	2,269	21.8
1998	1,252	202	16.1	9,856	2,205	22.4
1999	1,282	228	17.8	8,297	1,578	19.0
2000	749	37	4.9	5,934	428	7.2
2001	517	50	9.7	6,331	666	10.5

inside PTRH, which translates to a 62% reduction in total effort inside PTRH (Table 3). Effort inside PTRH rebounded in 2001 (10.5% of tows), but remained well below pre-2000 levels. Although effort was reduced inside PTRH, some effort was clearly concentrated near the edges just outside of PTRH (Figure 2). It should be noted that the large reduction in the number of hauls inside PTRH overstates the actual reduction in fishing effort, because average tow duration inside PTRH increased from 2.7 h in 1998–1999 to 3.9 h in 2000–2001. The increase in tow duration in 2000–2001 is probably due to the severe reduction in targeted fishing for rockfish, in which tow duration is usually shorter than tows targeting other species.

The data suggest that the new regulations had the desired effect on the spatial distribution of trawl effort, shifting it outside of prime rockfish habitat. However, the decline in effort within PTRH prior to 2000 also indicates that catch limits may have had an equal or greater effect than gear restrictions on the spatial distribution of effort. Fishing effort inside PTRH clearly responded to reduced limits in the absence of gear restrictions prior to 2000 (Table 2). A comparison of Oregon effort in 1992–1995 to effort in 1999 suggests that the number of tows by Oregon vessels inside PTRH had already declined from 3,000–6,000 tows (30.8–33.9% of the total) to less than 1,400 tows (19.2% of the total). This shows the effect that reduced limits alone (Table 1) had on the amount of bottom-trawl effort inside PTRH. The rebound in effort inside PTRH in 2001 further supports the importance of limits in determining the spatial distribution of effort. The most significant change in the retention limits for rockfish in 2001 was the increase in the limits for yellowtail rockfish taken as bycatch during flatfish trawling (see Table 1, footnote d). In 2000, only 953 kg of rockfish catch was allowed. In 2001, the total was in-

creased to include up to 6,805 kg of yellowtail rockfish, if taken with the proper mix of flatfish, while the gear restrictions were maintained. The increase in trawling inside PTRH shows that even with footrope and chafing gear restrictions, increased catch limits led to more fishing in rockfish habitat. However, given that effort inside PTRH in 2001 did not reach 1999 levels, it appears that linking rockfish limits to flatfish catch also helped distribute trawl effort outside of PTRH.

Sensitivity analysis showed that the choice of block size affected the amount of area identified as PTRH as well as the mean percentage of hauls inside PTRH (Figure 3). However, the general shape of the time trend in the percentage of hauls inside PTRH was insensitive to the choice of block size. Accordingly, the reduction in trawl tows inside PTRH shown in Tables 2 and 3 can be considered a reliable but approximate estimate of the change in fishing effort inside PTRH, offset by the increase in tow duration. The surprising conclusion is that although PTRH cannot be precisely quantified with logbook data, the shift in fishing effort away from PTRH is consistent enough that the approximate magnitude of the decline in fishing effort inside PTRH can be determined.

Although difficult to precisely measure, the spatial shift in trawl effort is evident in the map showing areas with no groundfish bottom hauls in 2000–2001 (Figure 4, gray areas). Many of these large polygons correspond closely with clusters of PTRH blocks identified in Figure 1 and indicate the size of the area in which bottom trawling has recently been eliminated, or at least severely reduced. In particular, four clusters of closely associated polygons represent large areas with little or no bottom-trawl activity. The most northerly of these areas is a large group of about 14 polygons off Gray's Harbor, Washington (Figure 4A, area A). The largest polygons in this group represent

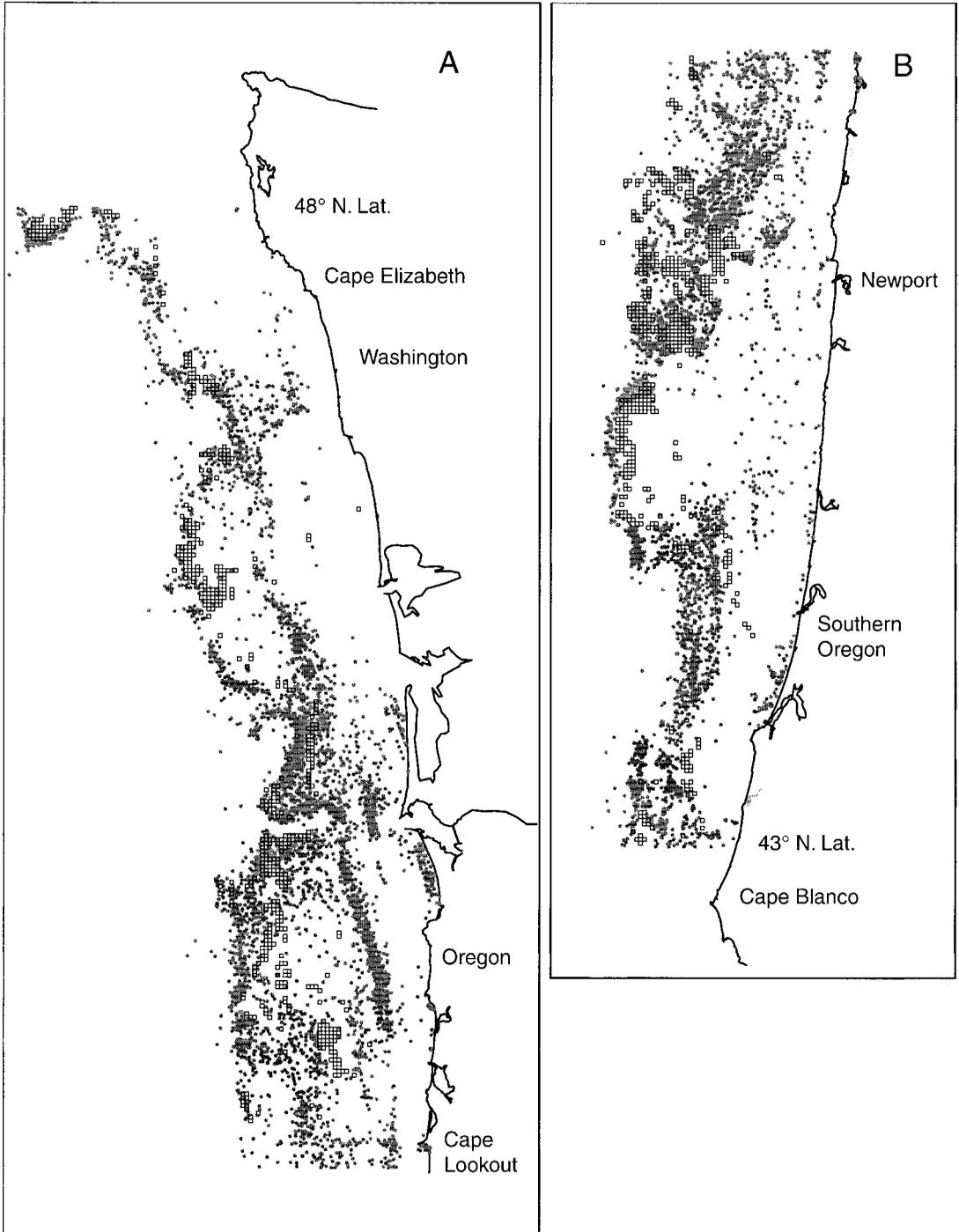


FIGURE 2.—Spatial distribution of prime trawlable rockfish habitat (squares; see text) and trawl start locations for all Oregon bottom-trawl tows (A) north and (B) south of Cape Lookout, Oregon, 2000–2001, inside a depth of 457 m (shaded circles).

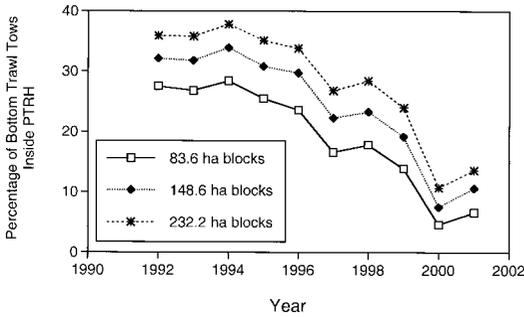


FIGURE 3.—Percentage of Oregon bottom-trawl tows started inside prime trawlable rockfish habitat (PTRH), by year, based on three different block sizes used to grid the logbook start locations.

about 5,000–6,000 ha. A larger area off Tillamook Bay, Oregon (Figure 4A, area B), is composed of about 18 polygons, the largest of which represents over 10,000 ha. Farther south, another large group of polygons denotes an area located off the coast of Newport, Oregon (Figure 4B, area C). The largest polygons in this group represent areas of about 6,000–8,000 ha. Seaward of Heceta Bank (Figure 4B, area D), the final cluster includes only nine polygons of various sizes. Nevertheless, this is the largest contiguous area in which no trawl start locations occurred, measuring over 24,000 ha. The total area of all polygons with little or no trawl activity combined represents 186,000 ha, with a mean polygon size of about 1,000 ha.

Discussion

The data presented here show a correspondence between the percentage of bottom hauls started inside PTRH (Figure 3) and the rockfish catch limits allowed off the northern U.S. west coast (Table 1). During 1992–1995, a large percentage of the bottom-trawl effort was concentrated inside PTRH, which contains a modest portion of the available continental shelf within the study area (Figure 1). This concentration of effort into relatively small areas of prime habitat (Figure 1) is consistent with the findings of Rijnsdorp et al. (1998) on the microdistribution of beam-trawl effort in the North Sea, and is an expected result of fishers applying their knowledge of fish distribution to the problem of catching the available limits of fish. However, it is also a result of fishery managers choosing a harvest policy that was ultimately too aggressive for the productivity of the stocks (Ralston 2002). Generous rockfish catch limits prior to 1995 (Table 1) encouraged fishing in these areas, ultimately contributing to serious declines

in shelf rockfish and concerns about high discard rates and physical impacts to high-relief rocky habitat. Given present concerns regarding the need for marine reserves and for the protection of habitat from damage by fishing gear, it is noteworthy that the spatial distribution of fishing effort resulting from any particular set of catch limits was historically not explicitly considered in the management process. More explicit consideration of how regulations influence the spatial distribution of trawling would be a logical first step in addressing marine reserve issues and protecting benthic habitats from physical damage.

The gear restrictions enacted for the U.S. west coast bottom-trawl fishery in 2000 changed the spatial distribution of effort, which was an expressed management goal. This analysis shows that the management strategy was a qualified success. Bottom trawling activity was substantially redistributed to areas outside of PTRH by the new regulations. The area that no longer receives bottom-trawl effort is substantial in size (186,000 ha) and persistent in location. Though it is unclear how the extremely low catch limits and gear restrictions individually contributed to the spatial shift, the data suggest that catch limits for rockfish may be as important as, if not more important than, gear restrictions in determining where vessels trawl. As depressed rockfish stocks recover, modest increases in limits along with continued restrictions on maximum footrope diameter could help managers better discern the relative importance of each management measure for maintaining some untrawled rockfish habitat.

This spatial shift in trawl effort (Figures 1, 2) represents a dramatic change in effort distribution in just a few short years. Similarly, but over a longer time frame (1981–1982 and 1994–1996), Macomber (2000) demonstrated an offshore shift in Oregon's bottom-trawl fishery that accompanied the development of the continental slope fishery for Dover sole, sablefish, and thornyheads. With at least two substantial shifts in the spatial distribution of trawl effort occurring within the last 20 years, it is easy to see why, despite major efforts (Fox and Starr 1996), CPUE data derived from logbooks have not been used as a primary index of abundance for most west coast groundfish. Attempts to use logbook CPUE as an index of abundance (e.g., Ralston 1999) have more recently employed linearized additive models to account for changes in measurable factors such as depth fished, season, vessel size, and latitude (Hilborn and Walters 1992). This approach could be effective per-

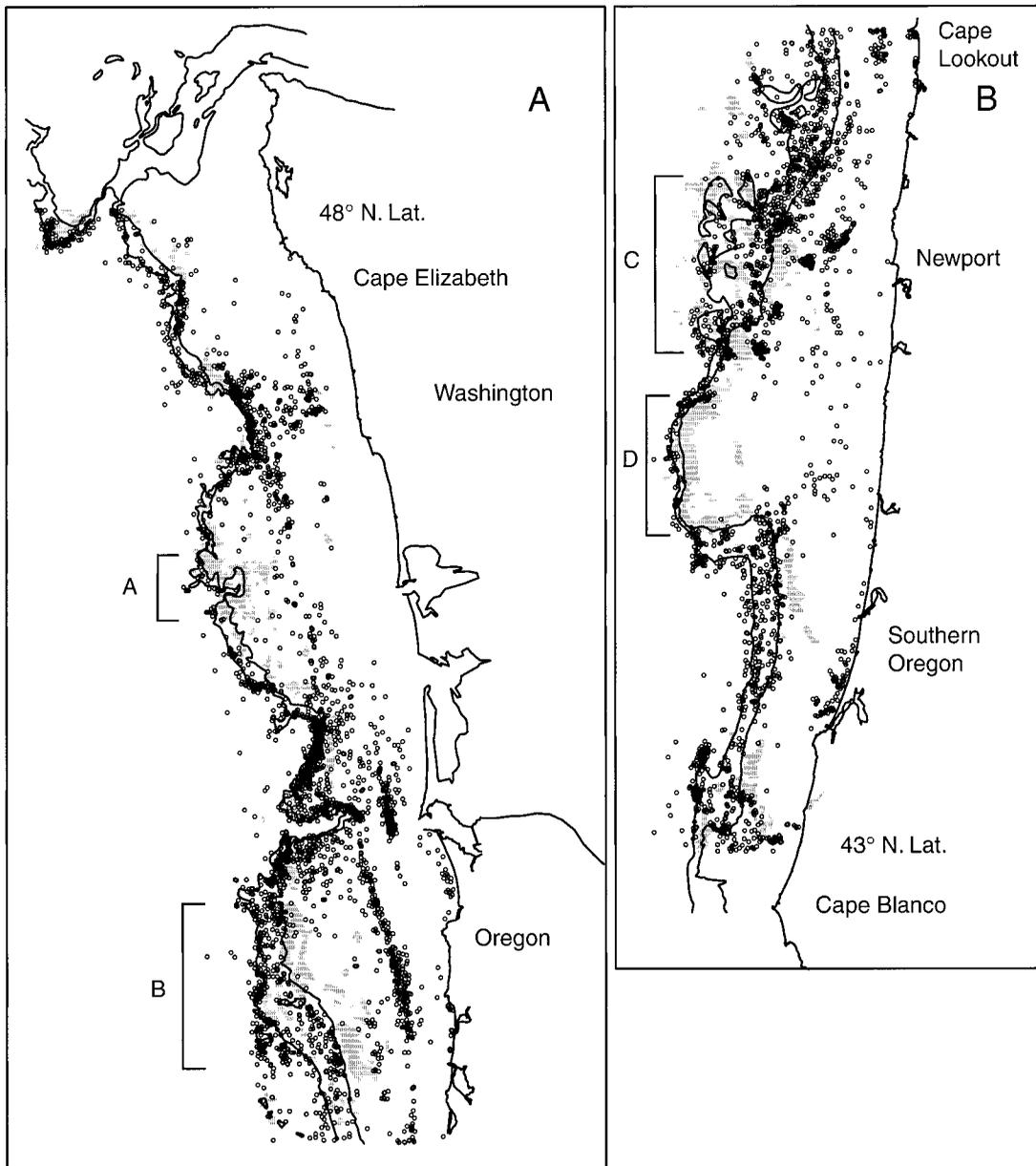


FIGURE 4.—Spatial distribution of areas with no bottom-trawl start locations in 2000 or 2001 (shaded polygons; based on Oregon and Washington logbook data) and Oregon and Washington bottom-trawl start locations (A) north and (B) south of Cape Lookout, Oregon, 2001 (circles). Letters A–D with brackets denote large complexes of polygons discussed in the text.

haps in correcting for the change in depth of trawling noted by Macomber (2000). However, the type of shift in fishing effort shown in this study is less amenable to such an approach, because vessels now fish different types of habitat, not necessarily in relation to systematic changes in a measurable scalar such as depth or latitude. The data presented

here suggest a habitat-based approach might be better for deriving a reliable CPUE index from logbook data for rockfish, perhaps by use of tow location (inside or outside of PTRH) as an additional factor.

Does this shift in bottom-trawl effort to the outside of PTRH represent potential progress towards

establishing marine reserves and protecting essential fish habitat on the U.S. west coast in a manner that is compatible with large-scale commercial fisheries? Some west coast trawl fishers have asserted that, with the new footrope restrictions evaluated in this study, most hard-bottom marine habitats on the shelf are now protected from trawl gear and further work on marine reserves is unnecessary. The data presented here suggest that fishers are only partially correct, in that some large areas are now untrawled. However, in the areas identified as having no bottom-trawl effort in 2000–2001, some spot shrimp trawling and commercial fixed-gear and recreational fishing still occur, as do midwater trawling and trolling for pelagic fish. So, these areas are clearly not marine reserves or no-take areas; however, some of the areas could form the basis of reserves to be established in the future by additional restrictions on fishing with other gears.

It is difficult to evaluate what progress these findings represent on the issues of marine reserves and the protection of benthic habitat from physical damage by fishing gear. The 1996 amendments to the Magnuson–Stevens Fishery Conservation and Management Act require managers to “describe and identify essential fish habitat for the fishery, . . . minimize to the extent practicable adverse effects on such habitat caused by fishing, and identify other actions to encourage the conservation and enhancement of such habitat” (Kurland 1998). This requirement relates to the debate on the use of marine reserves and to concerns about physical impacts on benthic habitat from trawling. However, the definitions that have been adopted to guide actions on these two issues reference adverse impacts at the population level and in fisheries (Kurland 1998). Given the complexity of estimating population-level impacts from changes in habitat, it may be decades before fishery scientists can make quantitative inferences about population-level impacts originating from management measures designed to protect habitat. The spatial shift in trawl effort demonstrated in this study may represent a reasonable starting point for an interim strategy that lessens habitat impacts while the science and policy develop further. One benefit of this approach is that some areas of excellent fish habitat will have time to recover from the impacts of trawling. They might then be useful as control areas for future studies of gear impacts on fish habitat or for studies aimed at determining how habitat damage from fishing may influence stock population dynamics.

If the current trawl gear restrictions on the U.S. west coast are maintained as an interim habitat protection strategy, the general relationship between catch limits and effort inside PTRH suggests caution in responding to significant improvements in stock status of shelf rockfish. If catch limits are increased, trawling activity inside PTRH will increase, even if the gear restrictions are maintained. However, it is unlikely that all of the habitat classified as PTRH in this study can be fished with small-diameter footropes. If higher catch limits lead to increased trawling inside PTRH, there probably will be some benefit to continuing the gear restrictions. One likely benefit is the continued protection of at least some rocky habitat from the physical impacts of trawls.

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