AN ABSTRACT OF THE THESIS OF

Jean Beyer Rogers for the degree of Doctor of Philosophy in Fisheries Science presented on February 23, 1994.

Title: Assemblages of Groundfish Caught Using Commercial Fishing Strategies off the Coasts of Oregon and Washington from 1985 to 1987.

Abstract approved: Redacted for Privacy

Ellen K. Pikitch

The groundfish trawl fishery operating off the coasts of Oregon and Washington 1985-1987 caught six major assemblages of species which could be treated as units in developing mixed-species management plans. Eighty-one percent of the tows observed on commercial vessels were consistently placed in one of the assemblage designations using three multivariate techniques. Two of the assemblages were dominated by a single species, pink shrimp (Pandalus jordani) or widow rockfish (Sebastes entomelas). The other assemblages identified were: a deepwater rockfish assemblage, a deepwater Dover sole assemblage, a nearshore mixed-species assemblage, and a bottom rockfish assemblage. The assemblage designations of the consistently placed tows were predicted with an estimated 85% average accuracy using discriminant functions based on the gear used and bottom depth fished. Fishermen had different targets (intended catch) for each assemblage caught. The mixed-species assemblages had several targets, representing at least some of the dominant species in the assemblage. Targeting and discarding information indicated that fishermen did not always intend to catch the species together; there were unintentional or unavoidable catches of all the major species except for shrimp in the shrimp assemblage. Discarding occurred in all the assemblages, primarily due to

unmarketable species or fish that were too small to market. Monitoring the assemblages over time could be accomplished by using the defined strategies with logbook data, particularly if the large and small rockfish categories were used to consistently separate shelf and deepwater rockfish. The defined strategies could not effectively predict the research cruise assemblages or catches; research data do not accurately describe commercial catches.

Assemblages of Groundfish Caught Using Commercial Fishing Strategies off the Coasts of Oregon and Washington from 1985-1987

by

Jean Beyer Rogers

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed February 23, 1994

Commencement June 1994

APPROVED:

Redacted for Privacy

Professor of Fisheries and Wildlife in charge of major

Redacted for Privacy

Head of department of Fisheries and Wildlife

Redacted for Privacy

Dean of Graduate School

Date thesis is presented February 23, 1994

Typed by researcher for Jean Beyer Rogers

ACKNOWLEDGEMENTS

I am grateful to Dr. Ellen K. Pikitch, my major professor, and to Dr. Susan S. Hanna, Dr. David C. McIntire, and Dr. William J. Liss, members of my doctoral committee, for their guidance and support. I am also grateful to those who provided the funding necessary to complete my thesis. This project was funded by Barry Fisher; NOAA, Office of Sea Grant, Department of Commerce, under Grant Nos. NA85AA-D-SG095 and NA89AA-D-SG095; the National Marine Fisheries Service (Contract NA-85-ABH-00025); the Oregon Department of Fish and Wildlife; and the commercial fishing industry. This thesis would also not have been possible without the fishermen who allowed observers on board and the observers who collected and input the data. Ken Weinberg, Claire Wood, and Jim Golden took the time to provide the triennial research cruise data and logbook data, and many people contributed their efforts in obtaining those data. Helpful comments and reviews of earlier drafts of the thesis were made by Jose A. Perez Comas, David Rogers, Dan Erickson, William Lenarz, Mark Saelens, Ken Weinberg, Dan Nichols, Neil Nikirk, John Wallace, Jim Bence, and Kate Harps. Bill Hopper, Bryan Coleman, and John Chapman provided programs and computer resources. LaVon Mauer helped arrange my thesis defense and provided formating assistance. John Wallace assisted in producing the figures. Finally, I am especially thankful for the support of my present supervisor, Dr. William Lenarz, and the encouragement of my husband, David Rogers.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ASSEMBLAGES OF GROUNDFISH CAUGHT USING COMMERCIAL FISHING STRATEGIES OFF THE COASTS OF OREGON AND WASHINGTON FROM 1985-1987

I. INTRODUCTION

The trawl fishermen operating off the coasts of Oregon and Washington often catch mixed species of groundfish, and it is now recognized that it may be necessary to manage the species as assemblages, rather than individually. Managing species complexes as units can reduce excessive waste of incidental catch or overharvest of the least productive species (Paulik et al. 1967, Pikitch 1991). Based on qualitative knowledge of the trawl fishery operating off the coasts of Washington and Oregon, Pikitch et al. (1988) described five major groundfish strategies which target different assemblages. Catches from two of the strategies, bottom rockfish and deepwater Dover sole, are presently managed as complexes (PFMC 1990). The strategies, targets of the strategies, and assemblage catches have not, however, been quantitatively defined. Assemblages have been previously defined quantitatively using logbook (Tyler et al. 1984; Rickey and Lai 1990) or research cruise data (Gabriel and Tyler 1980; Pearcy et al. 1982; K.L. Weinberg (in press)), but those data bases may not accurately reflect commercial catches.

Quantitative definition of assemblages, strategies, and targeting using data collected by observers on commercial vessels could provide more accurate information for managing species complexes. Management by species complex may be warranted if fishermen cannot intentionally catch (target) the species separately, but can effectively target the complex. Indications that complex management are appropriate are: 1) the species are consistently caught together 2) decisions the fishermen make can be used to predict the assemblage caught, 3) when catching that assemblage, fishermen's targets are specific to that catching that assemblage, fishermen's targets are specific to that assemblage and represent at least one of its major species, 4) the major species are caught unintentionally at times.

Management of complexes, when justified, can be facilitated if readily available data bases can be used to monitor changes in the catches of the assemblages. Data collected on an ongoing basis that contain information on catches of individual tows include fishermen's logbooks and research trawl cruises. The validity of using those data bases to describe commercial catches could be evaluated by comparing them to data collected by observers on commercial vessels. If complexes defined using the observer data and a readily available data base are similar, then changes in the complexes over time can be assessed without the expense of observers. Determining changes in the complexes is simplified if strategy variables can be used to accurately predict the catches. For instance, if the assemblage caught depends upon the gear used, the species composition in logbook-recorded catches could be summarized for each gear type in successive years to monitor for changes in complexes/strategies.

The overall goal of this thesis is to perform a quantitative investigation of the trawl fishery operating off the coasts of Oregon and Washington which provides definition of species assemblage management units, and assesses the validity of using the logbook and research data bases to monitor the catches of those assemblages.

The specific objectives and the chapters in which they are examined are:

1) Define assemblages of fish consistently caught together using data collected by observers on commercial vessels.(Chapter II)

2) Define assemblages using logbook and research cruise data for the same area and years, compare them to the observer-defined assemblages. (Chapter III)

3) Define the fishing strategies used to catch the observer-defined assemblages, assess their accuracy in predicting the assemblage, and use them to predict catches using logbook and research data. (Chapter IV)

4) Examine the how effective fishermen are at employing the fishing strategies, including analysis of targeting and discarding data. (Chapter V)

II. Numerical Definition of Groundfish Assemblages Caught Off the Coasts of Oregon and Washington Using Commercial Fishing Strategies

Jean Beyer Rogers [1] and Ellen K. Pikitch[2]

Department of Fisheries and Wildlife
Oregon State University
Mark O. Hatfield Marine Science Center
Newport, OR 97365, USA

[1]Present Address: National Marine Fisheries Service
3510 Paradise Dr.
Tiburon, CA 96032

[2] Present Address: Fisheries Research Institute
School of Fisheries WH-10
University of Washington
Seattle, WA 98195, USA

Abstract

Numerical definition of species caught together by the groundfish trawl fishery operating off the Oregon and Washington coasts during 1985-1987 indicated six major assemblages of species. Observers on commercial vessels recorded data allowing estimation of the weights of commercially important species caught in each tow. Assemblages were selected based on consistencies in three types of analysis of the species weights: detrended correspondence ordination, two-way-indicator species clustering, and Bray-Curtis group average clustering. Two of the assemblages were dominated by a single species, one consisting largely of pink shrimp (*Pandalus jordani*) and the other primarily of widow rockfish (*Sebastes entomelas*). The other assemblages identified were: a deepwater rockfish assemblage, a deepwater Dover sole assemblage, a nearshore mixed-species assemblage; and a bottom rockfish assemblage. These assemblages of commercially co-occurring species may be treated as units in developing mixed-species management plans. The deepwater rockfish we identify has not been previously described.

Introduction

The trawl fishermen operating off the coasts of Oregon and Washington often catch mixed species of groundfish including rockfishes and thornyheads (Scorpaenidae), Pacific whiting (Merluccius productus), flatfishes (Pleuronectidae and Bothidae), and sablefish (Anoplopoma fimbria). Although in the past these fishes have been managed on an individual species basis, it is now recognized that this can result in excessive waste of incidental catch or overharvest of the least productive species (Paulik et al. 1967, Pikitch 1991). Managers have begun to set trip limits based on species complexes (PFMC 1990), and mixed-species models have been developed to assess the effects of technological interactions (Murawski 1984; Pikitch 1987a). To be effective, these approaches require accurate knowledge of which species are consistently caught together.

Based on qualitative knowledge of the fishery, we would expect five major assemblages of species in the commercial catches. Using information from managers and fishermen, Pikitch et al. (1988) described five major West Coast groundfish strategies which target (intend to catch) different assemblages. Assuming that strategies are accurate and effective, the assemblages caught by the trawl fishery would include: 1) a bottom rockfish assemblage (BRF) consisting of rockfish (Sebastes spp.); 2) a midwater assemblage (MID), including widow rockfish (Sebastes entomelas) and Pacific whiting; 3) a deepwater Dover sole assemblage (DWD), primarily Dover sole (Microstomus pacificus), along with sablefish and thornyheads (Sebastolobus spp.); 4) a nearshore mixed-species assemblage (NSM) consisting of flatfish; and 5) a shrimp assemblage (SHR), primarily pink shrimp (Pandalus jordani).

Quantitative definition of trawl assemblages for the area has been accomplished using research or logbook data, but the resulting assemblages may not accurately represent those caught commercially. Research data analyzed by Alverson (1953), Hitz and Alverson (1963), Day and Pearcy (1968), Pearcy (1978), Gabriel and Tyler (1980), Pearcy et al. (1982), and Weinberg (in press) were generally collected using standardized strategies with one or two gears. The commercial fishery uses six gears and probably operates with variety of strategies (Pikitch et al. 1988). Logbook data, analyzed by Tyler et al. (1984) and Rickey and Lai (1990), do not include discarded fish, have low resolution for rockfish species, and have not been verified for accuracy or consistency. Prior definitions using both types of data are difficult to assess for accuracy since they generally relied on one or two methods of analysis, which varied between studies.

Quantitative definition using unbiased data and consistencies among a variety of methods of analysis could provide managers and modelers with a more accurate description of the commercially caught assemblages and help assess the previously defined commercial strategies. Data collected by observers on commercial vessels would be relatively accurate and unbiased, assuming that fishermen's behavior on boats that allow observers is representative of commercial fishing behavior. Assemblages determined using a combination of ordination and classification techniques would have greater reliability than definition based on any one method alone (Gauch 1980; Gabriel and Murawski 1985). Consistencies between methods could also allow determination of a few assemblages which reflect major sources of variation in the data; without relying on knowledge of external factors, such as correlation with environmental variables.

The specific objectives of this research were to: 1) quantitatively define assemblages of fish caught in the commercial trawl fishery off the coasts of Oregon and Washington using data collected by observers on commercial vessels; 2) assess the accuracy/effectiveness of the strategies described by Pikitch et al. (1988) by comparing tows designated by strategy to tows designated by the defined assemblages; 3) develop a method of using consistencies in three data analysis techniques to select the assemblages.

Materials and Methods

Data Collection

Observers of normal fishing operations on commercial fishing vessels collected the data (1469 tows) during 1985 through 1987 (Pikitch 1987b). The northern and southern boundaries of the study were 48^0 42'and 42^0 60' latitude, respectively, primarily within the INPFC Columbia Management Area. Participation in the study was voluntary, and included vessels using bottom, midwater, and shrimp trawls. The skipper and/or observer visually estimated the total weight of the catch from a single tow. The observer then took a random sample from each catch, or examined the entire catch if the total weight was sufficiently small. The weight of each species retained or discarded in the sample was recorded. Total weights of the various species kept or discarded in the catch were estimated by multiplying the sampled weight of the species by the ratio of the total catch weight to the total sample weight. Based on the gear used, depth fished, and species targeted, observers designated a pre-defined trawling strategy (Pikitch et al. 1988) for each tow. To clarify the distinction between the strategies and the assemblages they are expected to catch, which were described earlier, we added an S in front of the acroynms used by Pikitch et al. (1988) when referring to the strategies. These strategies were: 1) bottom rockfish trawling (SBRF); tows conducted using roller gear on the ocean bottom, with rockfish as the intended catch; 2) midwater trawling (SMID); tows conducted using midwater trawl gear above the bottom, targeting on widow rockfish and Pacific whiting; 3) deepwater Dover trawling (SDWD); bottom tows conducted in areas exceeding 100 fathoms, using mud gear, roller gear, or mud-roller combination gear, with targeting primarily on Dover sole, along with sablefish and thornyheads; 4) nearshore mixed-species trawling (SNSM); tows conducted using mud gear on the bottom in less than 183 m with flatfish as primary targets; and 5) shrimp trawling (SSHR); tows conducted using shrimp gear, targeting on pink shrimp.

Data Preparation

We used a data base consisting of total species weights in each catch, and corrected and reduced the data base by eliminating certain tows and species. Ranges, plots, and charts of the data were examined and outliers that were obvious errors were removed. To fit the available clustering capacity (amount of computer memory) and make the results more interpretable, we used only those species deemed commercially important in defining assemblages. The species selected were those that the fishermen identified as target species or those species that composed at least 1% of the estimated total of all catches sampled. We eliminated tows without any catch, lacking a sample, or missing information on the weight of a species. Tows with missing weights of Pacific halibut (*Hippoglossus stenolepis*) or salmon (*Oncorhynchus* spp.) were not eliminated. Observers usually did not weigh those two species as it was illegal to retain them on board.

Description of Analyses

We analyzed the data using an ordination technique and two opposite types of hierarchical classification techniques. Ordination was used to represent catch and species relationships in a low-dimensional space (Gauch 1980). Hierarchical classification was used to place catches into groups, with relationships among groups demonstrated by a dendrogram (Gauch 1980). We employed two types of hierarchical classification: agglomerative, which starts with individual hauls and progressively combines them; and divisive, which starts with all the hauls and progressively divides them.

For ordination, we selected detrended correspondence analysis (DCA) (Hill 1979a), which is a modification of reciprocal averaging and iteratively maximizes the correspondence between the species and catch ordinations. DCA derives a series of ordination axes. Each axis consists of a set of species scores and a corresponding set of catch scores, which are weighted averages of the species scores (Hill and Gauch 1980). Each axis has an eigenvalue which represents the amount of correspondence between species and catch scores on that axis. The axes are scaled so that on a species axis, a species may be expected to appear, rise to its mode of abundance, and disappear in about 4 units, and on a catch axis, a full turnover in species composition occurs over 4 units (Hill and Gauch 1980). DCA is preferable to other ordination techniques in that it does not require a linear relationship between species and catches, eliminates any systematic relationship between the series of ordination axes, and scales the axes so that the dispersion of species scores within samples is constant.

The hierarchical agglomerative technique used to classify the hauls was based on the Bray-Curtis dissimilarity index (Bray and Curtis 1957) with group average fusion criteria (Sneath and Sokal 1973). The Bray-Curtis index has been used extensively in marine ecology (Boesch 1977) and tends to be good at reflecting abiotic aspects (Clifford and Stephenson 1975). Group average fusion is the most widely used clustering method in aquatic ecology and introduces relatively little distortion to the relationships expressed in the matrix (Boesch 1977). The hierarchical divisive clustering technique used was Two-way Indicator Species Analysis (TWINSPAN)(Hill 1979b). TWINSPAN was selected because it uses information on all the species (it is polythetic rather than monothetic), it provides an objective method of splitting ordinations, and it has minimal computer space and time requirements (Gauch 1980). TWINSPAN operates by dividing ordinations in half. It constructs three ordinations: a "primary" ordination using reciprocal averaging, a "refined" ordination using as a basis the species preferential to one side or the other of the primary ordination, and an "indicator" ordination based on only the most highly preferential species. The refined ordination generally determines the division, while the indicator ordination describes it. To account for differences in abundance, we designated cut-off values so that each species could be treated as four separate "species", based on abundance in the haul. Since cut-off values had to be the same for all species, we computed the means of target species abundances and designated cut-off values as absence of catch, the minimum of the target species means, the mean of target species means, and the maximum mean.

Assemblage Determination

To look for consistent assemblage patterns in the three methods of data analysis, we first determined the maximum number of clusters to consider for each clustering method. We utilized dendrograms, illustrating the way groups hierarchically combined or divided, with the number of clusters increasing with decreasing levels on the dendrograms. We began by selecting a level of agglomeration or division which resulted in two groups of catches and used those cluster designations on plots of the DCA catch scores. We plotted the DCA catch scores for two axes at a time (x and y), with each catch designated by cluster. This was done for both the Bray-Curtis and TWINSPAN cluster designations. The levels were then changed to increase the number of groups until the cluster designated for catches with scores near one end of each DCA axis was different than the cluster designated for the catches with scores near the other end of the axis. If the groups did not separate similarly to the axis scores at any level of clustering, the axis was not used. At each level of clustering, we only considered catch groups that contained more than 1% of the catches. Clusters with less than 1% of the catches were not split off in the TWINSPAN clustering, and were eliminated from the Bray-Curtis clustering.

After the maximum number of clusters to consider was determined, clusters were combined or recombined to higher levels on the dendrograms to achieve consistency in catch placement on the DCA axes between the two methods of clustering. This was done given that different clusters were still associated with opposite extremes of the selected DCA axes. For instance, at the minimum levels on the dendrograms, the Bray-Curtis clustering might have determined one cluster for a given area on a DCA axes plot and TWINSPAN determined two clusters in the same area. If those two clusters recombined to one cluster at a higher level on the TWINSPAN dendrogram, that level was selected. If consistency could not be achieved while maintaining different cluster designations for catches with scores near opposite ends of the axes, a cluster was considered an inconsistent assemblage.

We then compared the species associated with the selected DCA axes and the selected catch clusters for each clustering method. The species associations with the catch clusters were emphasized rather than species clusters themselves, since we desired species to be allowed to associate with more than one group. Plots of DCA species scores on the selected DCA axes were examined and species associated with the clusters were outlined on the plots. For the Bray-Curtis catch clusters, we examined two measures of species association. One measure expressed which species were caught in the greatest abundance (percentage of total weight in the cluster). The second measure indicated additional species, which, though in low abundance in all clusters, were caught selectively in certain clusters (average weight in a cluster divided by the average weight caught in all the clusters) (Boesch 1977). For TWINSPAN, we looked at the indicator species for each cluster.

The defined assemblages were then assigned names based on their similarity to assemblages expected from the strategy definitions. A table was derived showing the number of tows for each combination of strategy and assemblage designation. An assemblage was given the name and acronym of the expected assemblage if most of the tows placed in that assemblage were designated as that strategy, and the species associated with the assemblage were similar to the species expected given that strategy. If there was not a strong agreement between an assemblage and any one strategy, the assemblage was given a name based on the species associated with it.

Results

Preliminary Analysis

The species abundance data matrix on which we based the analyses contained information on 1351 of the 1469 tows and 26 of the 178 species found in the catches. Five species were not identified as target species, but had total catches greater than 15,323 kg, which was one percent of all the weight sampled. Those species were longnose skate (Raja rhina), spiny dogfish (Squalus acanthias), Pacific whiting, sharpchin rockfish (Sebastes zacentrus), and yellowmouth rockfish (Sebastes reedi). Six species were identified as targets by the fishermen, but did not constitute at least one percent of the total catches sampled: sanddab (Citharichthys spp.), starry flounder (Platichthys stellatus), sand sole (Psettichthys melanostictus), Pacific cod (Gadus macrocephalus), bocaccio (Sebastes paucispinis), and yelloweye rockfish (Sebastes ruberrimus). The remaining fifteen species were targeted and constituted >1% of the catch. These comprised arrowtooth flounder (Atheresthes stomias), petrale sole (Eopsetta jordani), English sole (Parophyrs vetulus), Dover sole, rex sole (Glyptocephalus zachirus), sablefish, lingcod (Ophiodon elongatus), shortspine thornyhead (Sebastolobus alascanus), Pacific ocean perch (Sebastes alutus), darkblotched rockfish (Sebastes crameri), splitnose rockfish (Sebastes diploproa), widow rockfish, yellowtail rockfish (Sebastes flavidus), canary rockfish (Sebastes pinniger), and pink shrimp.

We eliminated a total of 118 tows from the species abundance matrix: three tows had uncorrectable errors, there was no sample in 29 tows, no catch in 59 of the tows, and 27 tows had missing information on the weight of a non-prohibited species. We included an additional 390 tows with missing weights for salmon and Pacific halibut. These catches may have slightly overestimated weights for the selected species because the catch weights included the prohibited species but the sample weights did not.

Assemblage Definition

We derived six consistent assemblages based on the three methods of analysis (Figures 1 and 2). Two of the assemblages were dominated by single species, the shrimp assemblage (SHR) and the widow rockfish assemblage (WID) (Figure II2). The nearshore mixed-species assemblage (NSM) contained sanddab, English sole, sand sole, starry flounder, and petrale sole (Figure II2). The bottom rockfish assemblage (BRF) contained yellowtail rockfish, canary rockfish, yelloweye rockfish, lingcod, bocaccio, and sharpchin rockfish. The deepwater Dover sole assemblage (DWD) was primarily Dover sole and sablefish. The deepwater rockfish assemblage (DWR) contained darkblotched rockfish, Pacific ocean perch, splitnose rockfish, and yellowmouth rockfish. Other species considered were associated with the assemblages, but to a lesser degree (Figure II2).

We found there was strong agreement between many of the strategy designations and the assemblage designations, but there were also some differences (Table II1). The tows placed in the SHR, NSM, and BRF assemblages were almost entirely designated the respectively named strategies, and the species associated with the assemblages were similar to the targeted species of those strategies. The DWD tows were mainly designated as SDWD, with associated species similar to the DWD targeted species, but also had a number of SNSM designations (Table II1). Two of the consistent assemblages were not in strong agreement with a strategy. WID was associated with widow rockfish and contained most of the tows designated SMID, but also had a substantial number of SBRF tows. DWR was associated with rockfish species found in relatively deep water and contained tows designated as mainly SBRF or SDWD.

The six consistent assemblages designated were the result of 82% agreement between the Bray-Curtis clusters and the TWINSPAN clusters (Table II1) and had varying degrees of overlap on the DCA axes (Figures II1 and II2). The DCA program derived four axes in order of decreasing correspondence between the catch and species scores (Table II2). The first axis appeared to represent a general separation of catches containing rockfish species from those containing flatfish species, but also separated the rockfish catches into the WID, BRF, and DWR assemblages (Figures 1 and 2). The second axis separated SHR from the other assemblages, particularly from DWR, NSM, and DWD. The third axis served to separate NSM from DWR, and, to a lesser extent, DWD from NSM and DWR. The fourth axis was not used since it represented a separation of rockfish species inconsistent with the TWINSPAN separation of species. The Bray-Curtis clustering tended to provide better separations on the DCA axes, particularly in separating DWD from NSM (Figure II1).

Nine Bray-Curtis clusters were required to derive different groups at opposite ends of DCA axes 1-3 (Figure II3). To achieve consistency with the clustering species associations, three Bray-Curtis clusters were combined to form BRF (Figure II3). These clusters were associated with yellowtail rockfish, canary rockfish, or sharpchin rockfish. There was one inconsistent assemblage, named DOG since it was associated with spiny dogfish. It was primarily part of the TWINSPAN DWD, but could not be included in the Bray-Curtis DWD without first combining DWR with DWD, and DWR was associated with an extreme of DCA axis 3 (Figures 1 and 2). The species associations with the consistent Bray-Curtis assemblages, which were the basis of the outlines in Figure II2, are shown in Table II3.

TWINSPAN showed different clusters at opposite ends of the first three DCA axes after four divisions, resulting in 15 groups (Figure II4). WID was not divided in the first division since it included less than 1% of the catches. Many of the clusters were recombined to be consistent with the other methods of analysis (Figure II4). One of the four clusters combined to form NSM could be considered a transition cluster. It was intermediate in the separation of NSM and DWD on DCA axis 3, was placed primarily in the Bray-Curtis DWD, and was associated with sablefish, arrowtooth flounder, and Dover sole, along with petrale sole and sanddab. The species associations with the consistent TWINSPAN assemblages, which were outlined in Figure II2, are shown in detail in Table II4.

Discussion

Our results suggest that widow rockfish and pink shrimp may be managed as separate species, but the other species could be managed as part of assemblages. As of October 1990, trip limit restrictions were in effect for two multi-species assemblages: a Sebastes complex (all rockfish except widow rockfish, Pacific ocean perch, thornyheads and shortbelly rockfish (Sebastes jordani); and a deepwater complex, including sablefish, Dover sole and thornyheads (PFMC 1990). Sablefish was additionally limited to 25% of the Deepwater complex, yellowtail to 20-30% of the Sebastes complex, and POP to 20% of all fish on board within a given range of weights. Our findings agreed with use of the deepwater complex; Dover sole and sablefish were highly associated with our DWD assemblage, and thornyheads had the next closest association (Figure II2, Table II3). In addition, sablefish averaged close to 25% by weight in the DWD catches (Table II3). We determined that the Sebastes complex could be divided into two assemblages, DWR and BRF, with POP approximately 20 % of DWR and yellowtail rockfish about 50% of BRF (Table II3). The possibility of setting separate trip limits for BRF and DWR could allow managers more flexibility in managing rockfish in the future.

To be useful to managers and modelers, the assemblages we defined should be persistent over time. The assemblages could change if the species mixes available to the fishermen change or the fishermen change the strategies they use to catch the species. The species available could change as a result of environmental changes or harvesting pressures. Strategies employed may change based on market prices, regulations, or new technology.

Although monitoring the fishery over time using our same methodology would be desirable to examine persistence of the assemblages, comparison of our study with other trawl studies conducted in the same area does indicate some persistence which is independent of methodology. Assemblages were defined previously with various method of data analysis; using data collected with a variety of strategies; from time periods before, during, and after our data base. In spite of this, some consistencies were evident between our assemblages and those defined by other authors. A species association similar to our NSM was designated by Alverson (1953), Day and Pearcy (1968), Pearcy (1978), Gabriel and Tyler (1980), and Tyler et al. (1984). Prior studies determined a deepwater assemblage, though the DWR and DWD assemblages were often combined and a separate DWR was never distinguished. Alverson (1953), Hitz and Alverson (1963), and Gabriel and Tyler (1980) and Weinberg (in press) defined species associations and assemblages using a combination of DWD and DWR species. Pearcy et al. (1982) determined a sablefish, Dover sole, and thornyhead cluster when investigating deepwater areas. Rickey and Lai (1990) analyzed only four species in defining a deepwater complex, but determined that Dover sole and sablefish had the strongest association, followed by thornyheads, and then arrowtooth flounder. One study defined an assemblage similar to BRF. Weinberg (in press) analyzed Scorpaenidae only and described an assemblage which was associated with yellowtail and canary rockfishes.

Differences which did exist between the assemblages we defined and those defined previously were primarily a result of different placement of the boundaries separating the assemblages. Not only were DWD and DWR often combined, but some studies determined additional assemblages which could be considered intermediate between our assemblages. An assemblage intermediate between NSM and DWD was described by (Hitz and Alverson 1963, Day and Pearcy 1968, Pearcy 1978, Tyler et al. 1984), between DWR and BRF by Gabriel and Tyler (1980). The one major difference between our assemblages and those defined earlier which could not be attributed to differences in boundary placement was Gabriel and Tyler's (1980) definition of an assemblage which included Dover sole and Pacific whiting with canary rockfish. We did not find that those three species had any close association.

Differences among the assemblages definitions could result from many factors. It is possible that the location of the boundaries between assemblages depended upon the method of data analysis employed. The previous studies generally used one or two types of analysis and stressed selection of assemblages with hauls made in the same depth range or area. For instance, we could have selected levels in the clustering that combined DWR and DWD, and may have done so if we had not considered the DCA axes separation of the two assemblages. Differences could also result from variations in the data. As stated previously, logbook and research data may not accurately reflect the commercial catch. The targeting and strategies used by commercial fishermen may have resulted in distinctions between assemblages which were not present in research catches. The research cruises were conducted using more restrictive time periods, bottom depths, and gear types than used by the commercial fishery. The studies that combined DWR and DWD were all based on research cruise data. The inclusion of discarded fish in the observer data versus the logbook data could also have affected the boundaries between assemblages. It is also possible that observer coverage of the commercial fleet was not representative of the total commercial effort. Another factor which may have caused the differences could be changes in the relative amounts of the species within assemblages over time. Most of other studies used data collected prior to our data base. Further study is needed to determine the actual reasons for dissimilarities noted between our assemblage definitions and those defined previously.

Some of the strategies defined by Pikitch et al. (1988); based on gear, water depth, and targeted species appeared accurate and effective, allowing prediction of the assemblages caught, but some modifications appeared necessary (Table II1). Comparison of strategy and assemblage designations indicated that the use of shrimp gear was adequate to predict the catch of SHR, and fishermen using midwater gear nearly always caught WID. NSM was caught with mud gear in less than 183 m, but some DWD was also caught in the shallower water. Mud gear used in water greater than 100 fm caught DWR as well as DWD. BRF was caught primarily with roller gear, but that gear was also used to catch WID and DWR. The strategies need modification because either targeting was ineffective or samplers, constrained to the five defined strategies, designated strategies based more on the gear and depth than on targeted species. The similarities that were present between the designated strategies and the assemblages implies that targeting was effective on certain assemblages, particularly SHR and WID, and that the strategies generally remained stable over time.

Comparing the results of the three methods of analysis not only led to assemblages relatively independent of method used, but also allowed us to determine the hierarchical levels to select in the clusterings. A common problem in using hierarchical clustering is determining the level (levels) on the dendrogram at which to select the clusters (Boesch 1977). The DCA ordination axes pointed out the major sources of variation in the data which should be included in the selected clusters. By combining or dividing clusters until the groups included the DCA axis separations and were consistent between the two types of clustering, we utilized the strengths in the different clustering methods. Consistent groups formed by the two clustering methods balanced the disadvantages and advantages of each method. TWINSPAN started with the data base as a whole and therefore used the maximum amount of information in determining the major breaks in the data, making it a more robust technique than group-average fusion (Gauch and Whittaker 1981). It also used the original data rather than a secondary dissimilarity matrix and integrated the classifications of both catches and species (Gauch 1980). A disadvantage is that it was biased towards forming subdivisions of nearly equal size during each division (Boesch 1977). It also had the disadvantage that each split was not treated totally hierarchically since each cluster split at each level of the dendrogram. Further analysis to determine average ordination distances between clusters would have been required to achieve a fully hierarchical dendrogram (Gauch and Whittaker 1981). Defining species based on abundance levels in TWINSPAN allowed consideration of both scarce and dominant species, but had the disadvantage that different abundances of a species were treated as separate species, with arbitrary cutoff values. The Bray-Curtis index with group-average fusion clustering utilized the range of abundances of the species, but placed emphasis on dominant species and large hauls (Clifford and Stephenson 1975). Comparing the clusters formed by the two different methods allowed us to better determine the hierarchy of the TWINSPAN splittings, and balanced the influence of dominant and scarce species.

Conclusions and Recommendations

Six major assemblages of species could be used by managers and modelers to develop management plans for the trawl fishery operating off the Oregon and Washington coasts. Two of the assemblages were dominated by single species, widow rockfish or pink shrimp. The other four included a deepwater Dover assemblage, a deepwater rockfish assemblage, a bottom rockfish assemblage, and a nearshore mixed-species assemblage. The separation of the deepwater rockfish assemblage from the bottom rockfish assemblage has not been previously used in setting trip limits, and the separation of a deepwater rockfish assemblage from deepwater Dover was not previously designated quantitatively.

Although we could not unambiguously determine year-to-year persistence of the assemblages based on the limited number of years in our data base, comparison with past studies did indicate there may be some persistence. There were overall similarities between our findings and assemblages defined previously based on logbook or research data collected in other periods. It is possible that the assemblages caught were based on relatively stable biological associations of the species, which limited the possible technological interactions.

Our results indicated that the strategies defined by Pikitch et al. (1988) need some modification to accurately predict the assemblages caught. These modifications may include designating a separate deepwater rockfish strategy, a widow strategy using roller gear as well as midwater gear, and reducing the depth criteria separating the nearshore mixed-species and deepwater Dover sole strategies.

The method we used to determine the assemblages using consistencies from three methods of analysis could be applied to other data bases. An advantage of our method is that it allows relatively objective determination of assemblages based solely on species abundances in samples. Our method allows definition of groups which reflect the major sources of variation in the data, without requiring knowledge of the factors that cause the variation.

Future studies could include further assessment of the similarities and differences between logbook, research, and observer data. We found general consistencies in assemblages defined from the different types of data, but there was variation in the placement of the boundaries between assemblages. Differences may be more evident or conclusive if comparisons are based on data collected in the same years and analyzed using the same methodology.

Comparison of targeted species to species caught and assessment of the species discarded could be useful. It would help determine if the modifications in the strategies described by Pikitch et al. (1988) are required because targeting was ineffective, or because the strategies did not accurately define the behavior of the fishermen during the study.

It would be valuable to define strategies quantitatively for each of the assemblages, based solely on the operational decisions the fishermen make, and without relying on knowledge of the targeted species. It could provide necessary modifications to the strategies as well as aid managers and fishermen in determining how to control the catch of the six assemblages defined in this paper.

Table III. Number of tows in strategies designated by observers and in assemblages determined by a) Bray-Curtis catch clusters b) TWINSPAN catch clusters, and c) both, designated as catching the same assemblage by both methods of clustering (tows which were inconsistent were not included).

	Designated Strategy					
	SNSM	SDWD	SSHR	SBRF	SMID	Total
<u>a) BRAY-CURTIS</u>						
NSM	101	1	0	5	0	107
DWD	148	439	0	29	2	618
DWR	0	33	2	77	0	112
SHR	0	0	217	0	0	217
BRF	4	4	2	172	2	184
WID	0	0	0	25	24	49
DOG	8	13	1	17	0	39
<u>b) TWINSPAN</u>						
NSM	192	4	6	8	0	210
DWD	73	455	3	44	0	575
DWR	0	33	1	98	0	132
SHR	0	0	211	4	7	222
BRF	1	0	2	162	2	167
WID	0	0	0	19	26	45
<u>c) BOTH</u>						
NSM	100	1	0	4	0	105
DWD	63	428	1	17	0	509
DWR	0	25	0	72	0	97
SHR	0	0	209	0	0	209
BRF	0	0	1	140	2	143
WID	0	0	0	15	24	39

Table II2. Detrended Correspondence Analysis species scores on axes 1-4, where scores are 100 times the units and closely related species have similar scores. Eigenvalues (EIG.) represent the amount of correspondence between the species scores and the sample scores for that axis. DCA axes are plotted in Figure II2.

DCA1 EIG.= 0.901		DCA2 EIG.=0.718		DCA3 EIG.=0.525		DCA4 EIG.=0.358	
Widow	551	Pink Shrimp	392	Sand S.	572	Canary	344
Yellowtail	460	Pac. Whit.	339	Sanddab	559	Bocaccio	314
Canary	446	Yellowtail	310	Starry F.	483	Yelloweye	306
Yelloweye	441	Widow	271	English S.	475	Darkblotch.	277
Bocaccio	427	Sablefish	232	Sp. Dogfish	417	Pink Shrimp	273
Sharpchin	400	S.S.Thorny.	215	Petrale S.	385	Sand S.	272
Lingcod	370	Dover S.	212	Canary	351	Splitnose	265
Yellowmth.	343	Canary	190	Rex S.	344	Starry F.	261
Pac. Whit.	336	Yelloweye	180	Pac. Whit.	340	P.O.P.	232
P.O.P.	323	Bocaccio	175	Lingcod	340	Yellowmouth	225
Sp.Dogfish	282	Sand Sole	171	L.N. Skate	334	Sablefish	197
Splitnose	272	Arrowt. F.	162	Pac. Cod	315	S.S.Thorny.	187
Darkblotch.	230	Lingcod	155	Yelloweye	302	Arrowt. F.	180
Pac. Cod	229	Rex S.	155	Bocaccio	280	Widow	161
Petrale S.	218	L.N. Skate	134	Dover S.	270	Lingcod	147
Pink Shrimp	207	Starry F.	125	Widow	249	Sanddab	135
English S.	196	Pacific Cod	121	Yellowtail	228	English S.	131
L.N. Skate	195	Sharpchin	115	Pink Shrimp	192	Pac. Whit.	91
Rex S.	193	Sanddab	88	Arrowt. F.	182	Dover S.	91
Sanddab	164	P.O.P.	70	Sablefish	166	Sp. Dogfish	78
Arrowt. F.	147	English S.	55	S.S. Thorny.	154	L.N. Skate	73
Dover S.	104	Yellowmouth	43	Sharpchin	137	Rex S.	59
Sablefish	81	Splitnose	40	P.O.P.	70	Petrale S.	59
S.S.Thorny.	70	Sp. Dogfish	7	Splitnose	40	Pac. Cod	54
Starry F.	5	Darkblotch.	4	Darkblotch.	31	Sharpchin	25
Sand S.	-1	Petrale S.	-23	Yellowmouth	-12	Yellowtail	0

Table II3. Species associations with Bray-Curtis catch clusters designated by assemblage name. Two indices of species associations are shown: [%], average percent by weight in the hauls and [x], ratio of average weight in the assemblage catches to average weight caught for that species overall (where 4=greater than or equal to 4 times the average, 3=2-4 times the average, 2=average-2 times, 1=0-below average, and 0=none).

ASSEMBLAGE	DWD		DWR		DOG		NSM		SHR		BRF		WID	
SPECIES	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$	%	$\bar{x}$
Dover S.	27	2	3	1	7	1	2	1	<1	1	<1	1	<1	1
Sablefish	21	2	5	1	3	1	<1	1	1	1	<1	1	<1	1
S.S. Thorny.	7	3	2	1	1	1	0	0	<1	1	<1	1	<1	1
Arrowtooth Fl.	11	2	2	1	5	2	<1	1	1	1	<1	1	0	0
P.O.P.	3	1	21	4	1	1	<1	1	<1	1	1	1	<1	2
Darkblotched R.F.	3	1	31	4	2	1	0	0	<1	1	<1	1	<1	1
Yellowmouth R.F.	<1	1	14	4	<1	1	0	0	<1	1	1	1	<1	1
Splitnose R.F.	1	1	9	4	<1	2	0	0	<1	1	<1	1	0	0
Dogfish S.	2	1	<1	1	62	4	<1	1	<1	1	<1	1	<1	1
Petrale S.	5	2	<1	1	4	3	10	2	<1	1	<1	1	<1	1
Sanddab	<1	1	0	0	<1	1	25	4	<1	1	<1	1	0	0
English S.	1	2	<1	1	<1	2	22	4	<1	1	<1	1	0	0
Sand S.	<1	1	0	0	0	0	18	4	0	0	0	0	0	0
Starry Fl.	<1	1	0	0	0	0	2	4	0	0	0	0	0	0
L.N. Skate	3	2	<1	1	1	2	6	2	<1	1	<1	1	<1	1
Rex S.	4	2	<1	1	2	2	6	2	1	1	<1	1	<1	1
Pac. Whiting	7	1	3	1	2	1	6	1	12	1	1	1	2	1
Pink Shrimp	<1	1	0	0	0	0	0	0	78	4	<1	1	0	0
Pac. Cod	1	2	<1	1	<1	1	<1	1	<1	1	<1	1	<1	1
Lingcod	1	1	<1	1	2	3	1	1	<1	1	7	4	<1	1
Yellowtail R.F.	<1	1	<1	1	2	1	<1	1	2	1	49	4	2	2
Canary R.F.	<1	1	<1	1	<1	1	<1	1	<1	1	18	4	1	3
Sharpchin R.F.	<1	1	4	3	2	3	<1	1	<1	1	9	4	<1	2
Bocaccio	<1	1	<1	1	<1	1	<1	1	<1	1	3	4	<1	3
Yelloweye R.F.	<1	1	<1	1	<1	1	<1	1	0	0	2	4	<1	2
Widow R.F.	<1	1	3	1	<1	1	0	0	<1	1	1	1	92	4

Table II4. Species associations with TWINSPAN haul clusters designated by assemblage name. Species associations shown are the inclusive weight categories (kg per haul) of the indicator species as determined by TWINSPAN.

SPECIES	ASSEMBLAGE					
	DWD	DWR	NSM	SHR	BRF	WID
Dover S.	15-933					
P.O.P.		15-126				
Yellowmouth R.F.		>0-126				
Splitnose R.F.		>0-15				
Petrale S.			>0-15			
Sanddab			15-126			
English S.			>0-126			
Pink Shrimp				15-126		
Lingcod					>0-15	
Canary R.F.					>0-126	
Widow R.F.						>15

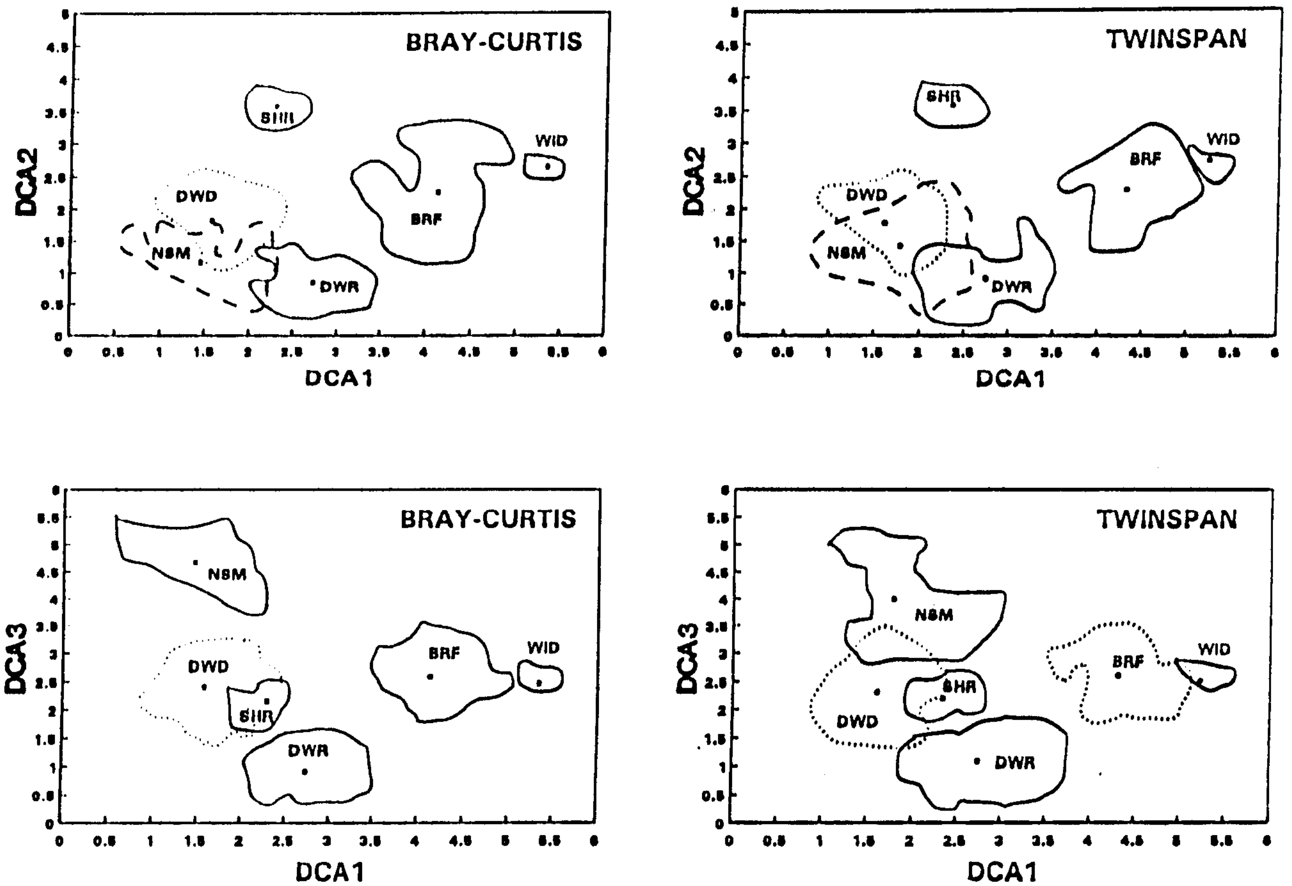


Figure II1. Consistency of catch separations as demonstrated by the concentration of DCA catch scores for the Bray-Curtis clusters and TWINSPAN clusters. The mean catch scores for the clusters are designated by a dot, while the outlines enclose 75 % of the hauls in the cluster closest to the mean. The means are labelled to show the assemblage names assigned the respective clusters.

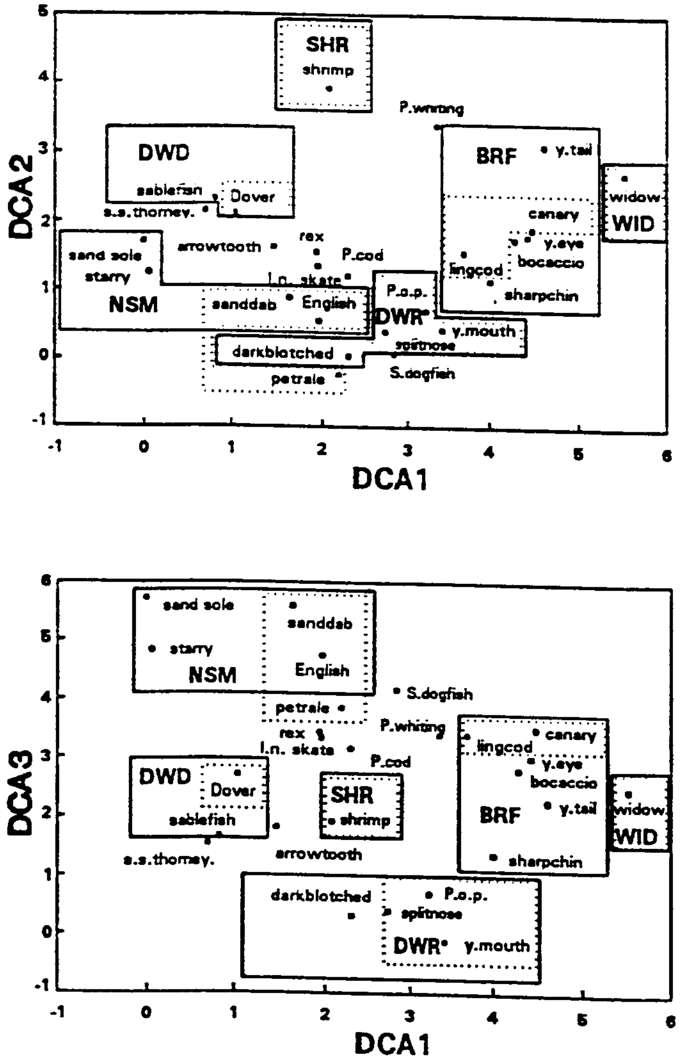
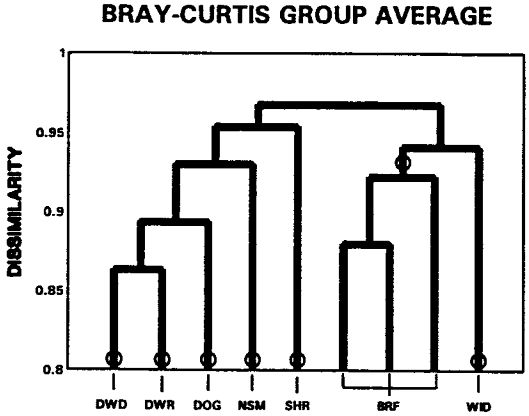


Figure II2. Consistency in species associated with the catch clusters labeled by assemblage name. Species scores are designated by dots and labeled with species names. Boxes (...) enclose the indicator species of the TWINSPAN clusters and (___) enclose the species associated with the Bray-Curtis clusters. Species selected for Bray-Curtis were species averaging > 20 % by weight in the catches and/or > 4 times the average weight.



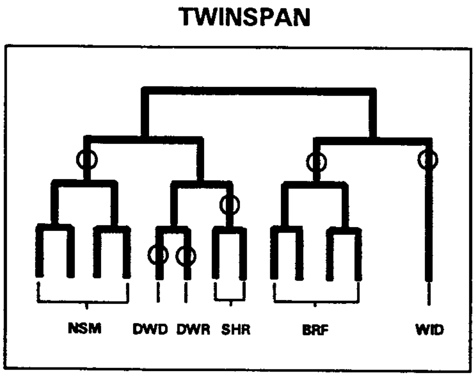


Figure II3. Dendrograms depicting progressive separations (TWINSPAN) or combinations (Bray-Curtis) of the clusters. Level selected in determining labeled assemblages is indicated by an O.

The Validity of Using Logbook and Research Cruise Trawl Data to Determine and Monitor Groundfish Management Assemblages

Jean Beyer Rogers[1] and Ellen K. Pikitch[2]

Department of Fisheries and Wildlife
Oregon State University
Mark O. Hatfield Marine Science Center
Newport, OR 97365, USA

[1] Present Address: National Marine Fisheries Service
3150 Paradise Dr.
Tiburon, CA 94920

[2] Present Address: Fisheries Research Institute
School of Fisheries WH-10
University of Washington
Seattle, WA 98195, USA

Abstract

Groundfish assemblages caught by the trawl fishery off the coasts of Oregon and Washington were defined using ongoing data bases and compared to the assemblages defined earlier using data collected by observers on commercial vessels 1985-1987. The data selected from the ongoing data bases were trawl fishermen's 1987 logbooks and 1986 NOAA research cruise records. The logbook data assemblages were similar to assemblages defined using observer data, except that the logbook data indicated that there were was an intermediate rockfish (Sebastes) assemblage between the bottom rockfish and the deepwater rockfish assemblages. The logbook data may differ because many rockfish species were designated only as large or small rockfish. Comparison of the frequency distributions of the proportions of species in the hauls indicated that fishermen tend to under-report some catches and report medium proportions as either large or small in the logbooks. The research cruise data did not contain the range of assemblages present in the observer data. A separate widow rockfish (*Sebastes entomelas*) assemblage was not defined, and another research assemblage contained species from both the observer-data deepwater rockfish and deepwater Dover sole assemblages. The research assemblages were more dominated by commercially undesireable species than were the observer-defined assemblages.

Introduction

Fisheries managers largely depend upon two data sources to provide information on a haul-by-haul basis regarding the trawl fishery operating off the coasts of Oregon and Washington. These data bases are the logbooks completed by the commercial fishermen, and the data collected on research cruises, conducted primarily by National Oceanographic and Aeronautics Administration (NOAA). These data bases may not accurately represent either what is caught or what is available to the commercial fishermen. The accuracy of the logbook data base has not been verified, and much of the rockfish (Sebastes spp.) catch is categorized as large or small, without information on individual species. Research data have been collected primarily in the summer months, while the fishery is year-round, and may not be adequately sampling the highly aggregated rockfish species.

Commercially caught fish assemblages have recently been described based on data collected year-round by observers during 1985-1987 (Rogers and Pikitch 1992). Assuming that the fishermen participating in the study were representative of the fleet and did not change their methods of fishing due to the presence of observers, this data base provided accurate records of commercial catches obtained by fishing practices that target aggregations of groundfish. Small boats may have been under-represented in the study because they had limited space for an observer, but those boats fished mainly inshore and caught the near-shore mixed species assemblage (Rogers and Pikitch 1994b). Because the purpose of the study was to determine if trip limits caused discarding, if there was a bias in the data, it was likely that fishermen increased their catch of limited species after a trip limit was reached.

Comparison of assemblages defined using the observer data base to those defined using research and logbook data bases, for the same years and similar methodology, is needed to assess the validity of using the latter data bases to describe and predict commercial catches. Rogers and Pikitch (1992), for instance, described a separate deepwater rockfish assemblage which had not been determined in previous investigations using research data (eg. Gabriel and Tyler 1980), but this may have been due to differences in data analysis methods or year-to-year changes in abundance and distribution. The specific objectives of this paper are to: 1) use the methodology of Rogers and Pikitch (1992) to describe catch assemblages in the 1985-1987 logbook and research data bases and 2) compare them to 1985-1987 catch assemblages using observer data.

Materials and Methods

We conducted analyses using three different data bases: data collected by observers on commercial vessels from 1985-1987 (Rogers and Pikitch 1992), NOAA research cruise data for 1986, and Oregon Department of Fish and Wildlife logbook data for 1987. These were the only computer records available from the logbook and survey data bases during the observed time period. The geographic region examined was the same for all three sources, with northern and southern boundaries, 48^0 42′, and 42^0 60′, respectively.

The observer study was conducted year-round over bottom depths from 11-998 m; we used information on 1142 of the observed hauls. Participation in the study by vessel skippers/owners was voluntary, and participating vessels used a variety of gear types including bottom, midwater, and shrimp trawls. For these comparisons, we did not use the information on shrimp trawls or pink shrimp (*Pandalus jordani*) because logbook and research data for shrimp gear were not available and pink shrimp were caught almost entirely with that gear (Rogers and Pikitch 1992). We considered the 25 other species used by Rogers and Pikitch (1992). Those species had the potential of being commercially important in that they comprised greater than 1 % of the total catch sampled or they were indentified as a target by the fishermen)(Table III1). The observers collected data on the weights of species caught and kept in each tow (Rogers and Pikitch 1992).

Research survey data were collected during the summer months (July to September) between the bottom depths of 55 and 366 m (30-200 fm) and consisted of 409 tows (Coleman 1988). Data were collected aboard commercial bottom trawlers equipped with roller gear. The distribution of sampling effort among areas was proportional to the expected abundance of species of major interest, yellowtail and canary rockfishes across areas. Sampling was concentrated in the 92 to 219 m depth stratum north of 42°35'N latitude (Coleman 1988). For each tow conducted, the weight of the total catch was recorded. Catches greater than 1,200 kg were subsampled for species composition, and the total weight caught for each species was estimated via extrapolation (Weinberg et al. 1984). For smaller catches, weights of each species were measured directly. We included data on the same 25 groundfish species, as defined above for the observer data base. Using the 1% cutoff in the research data would have led to the exclusion of several of the selected species (Table III1) and to the inclusion of Pacific halibut (Hippoglossus stenolepis). Redstripe rockfish (Sebastes proriger) and walleye pollack (Theragra chalcogramma) were just under 1%, but would have met the criterion by rounding the values. We applied the log transformation to the research cruise data before calculating the Bray-Curtis indices (see below). This was done to reduce the sensitivity of the results to large hauls, and the resulting clusters were more consistent with those derived from other methods.

The 1987 logbook data base contained information recorded by commercial fishermen on the estimated weight of species or groups of species caught in 12,847 hauls. There were two types of logbook data available, the raw data as recorded by the fishermen, and that data adjusted to be consistent with the processor landing receipts ("pink tickets") for the trip. The landing receipts were separated into either bottom or midwater gear. Bottom gear included both roller and mud gear. When the weight of a species landed did not match the total logbook recorded landings for all tows on that trip, adjustments were made to each tow's landings proprotional to the logbook recorded catch of that species. If landings of a species were present in the pink tickets but no landings were reported in the logbook for that trip, the catch was divided proprotional to tow duration for the tows made using that gear (Mark Saelens, Oregon Dept. Fish and Wildl., Marine Science Drive, Building 3, Newport, Oregon 97365, USA, unpubl. data) We analyzed both the adjusted and unadjusted data and selected the type which defined assemblages which were most consistent with the observer data. From each data base, we randomly selected 1500 hauls for our analyses (tows selected without catches of the species of interest were not used). That number of tows was at the upper limit of our clustering program's capacity and was comparable to the number of tows in the observer data base. Species-specific information was available for 16 of the 25 species included in the research and observer analyses, and on two species categories (small rockfish and large rockfish). All the species and categories included were identified as targets in the logbook data and most met the criteria of representing at least 1% of the total catch (Table III1).

Species placed in each rockfish category likely varied among logbooks, but generally small rockfish included darkblotched rockfish, splitnose rockfish, sharpchin rockfish , and yellowmouth rockfish; while large rockfish included bocaccio, canary rockfish, and yelloweye rockfish (Jim Golden, Oregon Dept. Fish and Wildl., Marine Science Drive, Building 3, Newport, Oregon 97365, USA, unpubl. data). Other species which we did not select for analysis may also be placed in those categories. The Oregon Department of Fish and Wildlife has listed 15 species to be placed in the small rockfish category and 13 species for the large rockfish category (Elaine M. Stewart, Oregon Dept. Fish and Wildl., Marine Science Drive, Building 3, Newport, Oregon 97365, USA, unpubl. data). Information was not present in the logbook data base on spiny dogfish or longnose skate (although there was a general skate category). It is likely, however, that those species were caught and discarded.

To define assemblages using the research and logbook data bases, we grouped tows based on their similarity in species abundances. We used an ordination technique and two types of classification methods and looked for consistent assemblage patterns using the weights of the species in the catches. The methodology was that used by Rogers and Pikitch (1992) to group the tows in the observer data base. For ordination, we used detrended correspondence analysis (DCA) (Hill 1979a). To classify the hauls and species, we used both agglomerative (combines the data) and divisive (divides the data) techniques. The agglomerative technique used the Bray-Curtis dissimilarity index (Bray and Curtis 1957) with group average fusion criteria (Sneath and Sokal 1973). The divisive technique used was Two-way Indicator Species Analysis (TWINSPAN)(Hill 1979b). The pseudospecies cutoffs considered in the TWINSPAN analysis were those values used for the observer data base, as well as the minimum, average, and maximum means of the species catches in the logbook and research survey data bases. The final cutoffs selected were those which yielded results most consistent with the other methods of analysis.

We determined that an assemblage was consistent if the groups formed by TWINSPAN and Bray-Curtis clustering were placed similarly on the DCA axes and the species highly associated with the groups were similar. To achieve this, we allowed selection of groups at different levels of similarity on the cluster dendrograms (Rogers and Pikitch 1992). This was done given that different groups were still associated with opposite extremes of the selected DCA axes. If the groups did not separate similarly to a DCA axis at any level, the axis was not used.

Criteria used to determine species that were highly associated with an assemblage differed for each of the clustering methods (Rogers and Pikitch 1992). For the Bray-Curtis group average clustering, we derived two measures of species association. One measure expressed which species were caught in the greatest abundance, as represented by the average percentage by weight in that assemblage's hauls. The second measure indicated which species were caught primarily in one assemblage, even if they were not abundant in any of the assemblages. The latter measure was a ratio of the average weight of the species caught in the assemblage to the average weight of that species caught overall. Species were considered to be highly associated with an assemblage if they averaged greater than 20% by weight in the catches, or if the average weight in the assemblage was greater than 4 times the average weight in all assemblages combined. Due to the limited number of assemblages present in the research data, however, the cutoff for high concentration was modified to include species either 2 times the overall average and/or caught only in that assemblage. Species highly associated with the TWINSPAN clusters were the indicator species supplied in the output of the program.

The assemblages were named based on their highly associated species. When possible, the assemblage names were consistent with those determined by Rogers and Pikitch (1992). They defined a deepwater rockfish assemblage (DWR), highly associated with darkblotched, splitnose, yellowmouth, and Pacific ocean perch rockfishes; a deepwater Dover assemblage (DWD), with Dover sole and sablefish; a nearshore mixed-species assemblage (NSM), with English sole, sand sole, starry flounder, petrale sole, and sanddab; a bottom rockfish assemblage (BRF), with lingcod and yellowtail, canary, yelloweye, bocaccio, and sharpchin rockfishes; and a widow assemblage (WID), highly associated with widow rockfish.

Comparison with the Observer Data

Comparisons were conducted between the logbook and observer data bases and between the research and observer data bases. Some modifications were made to the observer data base to improve comparability between the data bases. For analyses which compared the observer and logbook data bases, we used only the species weights kept (rather than caught). We also excluded observer tows made using shrimp gear and species weight information on longnose skate, spiny dogfish, and pink shrimp. We created large and small rockfish categories in the observer data, comparing the effect of including only the species selected as having commercial potential versus including all the species listed by the Oregon Department of Fish and Wildlife. For comparison with the research data base, we used only those tows which were made in the summer, with roller gear, in the depth range 55-366 m. The modified data bases were analyzed using the methodology described above to determine assemblages and species associations with the assemblages, and the species meeting the criteria for high association were compared to those derived using the observer data.

We also conducted further analyses to test the differences among the data bases. Conclusions regarding the assemblages based only on the highly associated species may be misleading because our cutoff values were arbitrary; the overall average weight caught varied depending upon the number and type of assemblages; and we used only the mean values, without consideration of the variation within and among assemblages.

To include information on the variation in the proportions, for each assemblage we conducted nonparametric tests to compare the ranks (Mann-Whitney U test, Zar 1984) and distributions (Kolmogorov-Smirnow two sample test, Conover 1980) of the proportion of the total haul weight for each of the highly associated species between data bases. Parametric tests for comparing the means were not used because for many species, the proportion of among hauls was not normally distributed. Many tows had zero catches (particularly in the logbook and research data bases). Application of the arcsin, log, square root, or inverse transformations did not achieve even approximate normality in most cases.

As a final comparison, we determined the accuracy with which we could predict the type of data given the species weights in the hauls. This was done using linear discriminant function analysis, with cross-validation error rates (see Rogers and Pikitch 1994b). The linear function was chosen because a precise prediction function was not required, and that type of function is simple to determine and present. Although the data did not appear to be multivariate normal with equal covariances, the linear function can provide good discrimination even if that assumption is not met (Krzanowski 1988, Rogers and Pikitch 1994b).

Results

Research Data Base

The research data base yielded three consistent assemblages: nearshore mixed species (NSM), bottom rockfish (BRF), and an assemblage which could be considered intermediate to the deepwater Dover sole and deepwater rockfish assemblages (DWR-DWD)(Figure III1). Seventy-six percent of the hauls were consistently designated to an assemblage using all three methods. The first two ordination axes were used, DCA1 and DCA2, with eigenvalues 0.739 and 0.533, respectively. The first axis separated BRF from NSM and DWR-DWD, and the second axis separated DWR-DWD from NSM (Figure III1). To achieve consistency, hauls were split using the TWINSPAN clustering method into four groups and two groups were then recombined to form DWR-DWD. Using the Bray-Curtis index with group averaging clustering method, hauls were combined to various levels of dissimilarity (Figure III2). There were two inconsistent clusters formed using the Bray-Curtis clustering method. A cluster with a high average percentage of English sole (ENG), was considered part of NSM by TWINSPAN and close to NSM on the DCA axes. A cluster associated with Pacific whiting (PHW) was placed near the end of the first DCA axis, but was considered part of NSM by TWINSPAN. The Bray-Curtis clustering also had 8 clusters (15 tows total) which were not considered part of an assemblage since they contained less than 1% of the hauls at the selected level of separation. These hauls often were primarily a single species of rockfish (including much of the catch of yellowtail rockfish and Pacific ocean perch).

Comparison with Observer Study

One obvious difference between the research-defined assemblages and the assemblages defined by Rogers and Pikitch (1992) was that there were only three assemblages, rather than six. The research data did not produce a separate DWD assemblage, nor assemblages dominated by widow rockfish (WID) or pink shrimp (SHR). Our results using the modified observer data base (53 tows made in the summer with roller gear in the research depth range), indicated that the restricted research strategy led to the reduced range of assemblages caught. The modified observer data base, however, produced an even a smaller range of assemblages, with more predominance of rockfish than in the research data. There were only two assemblages in the modified data, deepwater rockfish (DWR) and bottom rockfish (BRF), and only one ordination axis was consistent with the clusterings (Figure III3). DWR was highly associated with shortspine thornyhead, a species close to association with DWD in the full observer analyses, but was not named DWD-DWR because that species did not meet the criteria for high DWD association (Rogers and Pikitch 1992). The three methods of analysis resulted in 95% consistency in tow placement.

Placement of the observer tows in an assemblage was little affected by restricting the data base. The assemblage designations were the same for 94% of the tows. The only difference was that in the full data observer analyses, five tows were designated to DWD, while using the modified data those tows were either placed in BRF or were inconsistently placed.

Comparing the relative percents of the species highly associated with the assemblages indicated that comparable observer and research assemblages differed, and that restricting the observer data in terms of gear used, depth, and season did not make them more similar. For the purposes of comparison, the research DWD-DWR assemblage was considered to be the DWR assemblage. In the research assemblages, the species whose average weight exceeded the greater than 20% of the total haul weight were arrowtooth flounder in DWR (DWR-DWD), Pacific Whiting in NSM, and spiny dogfish and canary rockfish in BRF (Table III3). Of those, only canary rockfish met the criteria for high association for all data types (Table III3). Ranks and frequencies were often more similar between the research and entire observer data base than between the research and modified data base (Table III4). One difference which did not appear significant among data bases was that shortspine thornyhead met the criterion for high association with DWR using the research and modified observer data, but did not meet it using the full observer data base (Table III4). The BRF assemblage appeared to be more similar between data bases than the other assemblages. BRF species comparisons were often found to be not significantly different (P>0.0001).

Discriminant function analysis using species weights also indicated that for a similar assemblage designation, the research data was distinctive, even when comparing the observer data with similar gear, season, and depth range. In fact the smallest percent of errors (implying the data types were the most different) occurred between the research data and the modified observer data (Table III2). The errors indicated that the two observer data bases were more alike than either one compared to the research data.

Logbook Data

There were six consistent logbook data assemblages: including nearshore mixed species (NSM), deepwater Dover sole (DWD), deepwater rockfish (DWR), and widow rockfish (WID), as well as two other assemblages which contained relatively high percents/concentration of rockfish species (Figure III4). One of those two assemblages consisted primarily of yellowtail rockfish, and was designated the YT assemblage. The other assemblage was called bottom rockfish (BRF) because of it's association with large rockfish, but may be considered intermediate between bottom rockfish and deepwater rockfish. A deepwater rockfish species, Pacific ocean perch, was a TWINSPAN indicator species for the assemblage (Figure III4). Fifty-eight percent of the tows were placed in the consistent assemblages. Thirty percent of the inconsistent tows were the result of a TWINSPAN cluster which was considered intermediate to NSM and DWD, and was designated NSM-DWD (Figure III5). The Bray-Curtis clustering placed 60% of those tows in DWD and 19% in NSM. Four percent of the NSM-DWD tows were placed in a Bray-Curtis cluster which was highly associated with petrale sole (PET) (Figure III5). NSM-DWD and PET were not considered a combined consistent assemblage because of the small percent overlap in the NSM-DWD, and because they did not form a separate assemblage on the DCA axes.

Only the first and fourth DCA axes were selected (eigenvalues 0.945 and 0.541 respectively); the other axes were inconsistent with the clustering methods. The first axis separated the flatfish assemblages (DWD and NSM) from the rockfish assemblages (Figure III4). It also separated the rockfish assemblages, making WID and YT distinctive. The fourth axis separated DWR from BRF (Figure III4).

The assemblages presented were based on the adjusted logbook data. The raw logbook data assemblages were similar except that they did not include a separate DWR assemblage, there was no separate PET cluster in the Bray-Curtis index analyses, and the inconsistent TWINSPAN DWD-NSM cluster comprised only 18% of the tows, rather than 30%. Other differences included less of a separation of the WID and YT assemblages on the DCA axes, and that shortspine thornyhead met the criteria for association with DWD and lingcod was considered associated with BRF.

Logbook-Observer Assemblage Comparison

The logbook presence of a distinct separation of the YT and BRF assemblages and association of Pacific ocean perch with BRF was not replicated in the observer data analyses. Assemblages derived using the observer data modified to use only retained catches without shrimp gear, longnose skate or spiny dogfish, and with placement of the appropriate selected species into large and small rockfish categories were similar to those using the full observer data. There was a single BRF assemblage, highly associated with yellowtail and large rockfish and not associated with Pacific ocean perch (Figure III6). That assemblage took the place of the logbook YT assemblage in the dendrograms, with close association to the WID assemblage and wide separation from DWD. Analyses done using the total weights of all the rockfish species considered by the Oregon Department of Fish and Wildlife to be in the large and small categories were very similar to those done using only the selected species.

The other noted distinction in the logbook data analyses, the NSM-DWD separation in the TWINSPAN clustering, was present in the analyses done using the modified observer data. That NSM-DWD assemblage was not as dominant as in the logbook analyses, however, causing only 16% of the total inconsistencies (29%). As with the logbook data, DWD and NSM were closely associated on the axes (Figure III6). The Bray-Curtis clustering of the modified data did not designate an assemblage similar to the logbook PET assemblage.

A comparison of the placement of the observer tows using the full and modified data bases verified that the only substantial difference was the separate TWINSPAN NSM-DWD assemblage produced by the modification of the data. In the Bray-Curtis clustering, ninety percent of the tows were given the same designation, while the TWINSPAN clustering was only 83% consistent, due to the NSM-DWD cluster derived using the modified data. Tows consistently placed in an assemblage using all three methods were given the same designation using the full and modified data bases 97% of the time.

Species meeting the criteria for high association with the assemblages in all three data bases were most different for the NSM and BRF assemblages (Table III5). Comparisons of the ranks and frequency distributions of the percent weight of the species, using the tows consistently placed in an assemblage, however, indicated significant ($p<0.0001$) differences for all the species-assemblage combinations considered except widow rockfish in WID ($p>0.05$). Test results were similar between the logbook and observer data were similar, regardless of whether or not the observer data was modified. Visual examination of the frequency distributions indicated that often the logbook data had more small and large catches of a species, with fewer intermediate values than in either of the observer data bases.

Discriminant function analysis indicated that the modifications made to the observer data were effective in making the data more similar to the logbook data (Table III2). There was more confusion (greater percent of the errors) in predicting logbook data and modified observer data than between logbook and the full observer data for all assemblages (Table III2). For the WID and NSM assemblages, the errors indicated that the modified observer and logbook data were more similar than the two observer data bases (Table III2).

Discussion

Logbook Data

Our findings indicate that the logbook data could be used to determine the general assemblages caught, but may not accurately reflect catches of individual species. The major difference between the observer and logbook assemblages was in the separation of the rockfish species. Species in the large rockfish category may have been more distinct from yellowtail rockfish and more closely related to deepwater species in the logbook data because the categories were not used consistently. Placement in the categories may have been done at times based on size of the fish rather than species, particularly when processing plants were paying less for physically small fish (Mark Saelens unpubl. data). In addition, sharpchin rockfish were placed in the small rockfish category and were also small in size. Rogers and Pikitch (1992) found that this species was associated with both of the rockfish assemblages. When considering only the hauls consistently placed in an assemblage using the three methods of analysis, however, sharpchin rockfish met the criteria for high association only with the bottom rockfish assemblage. If reporting on individual rockfish species is not practical, the logbook data would be most useful if the categorization of species was consistent and based on deepwater versus bottom rockfish assemblage associated species. This could be facilitated by changing the names of the categories to "shelf" and "slope" rockfish, with both categories specified on the logbook and processing-plant forms. Sub-categories of "large" and "small" for each of the two categories could further improve the accuracy of species placement. This may cause more consistency between the adjusted and unadjusted logbooks. The separate deepwater rockfish assemblage formed using the adjusted data may have resulted from a greater tendency of the processors to separate large and small fish because of the price diferential for the two categories (Rogers and Pikitch 1994c).

Logbook reporting practices may be responsible for the intermediate nearshore mixed species-deepwater Dover sole cluster (NSM-DWD) produced by TWINSPAN clustering, but it was also determined in past studies, most of which used research data. Hitz and Alverson (1963), Day and Pearcy (1968), Pearcy (1978), and Tyler et al. (1984) all found a NSM-DWD assemblage, and only the latter used logbook data. The border between NSM and DWD was not always distinct even using the full observer data base (Rogers and Pikitch 1992). It is likely, however, that the logbook reporting practices increased the confusion. To achieve consistency between methods and the most accurate results in deriving assemblages using logbook data, it may be best to eliminate the use of TWINSPAN. In order to incorporate abundance information, that program requires that a single species be treated as several species based on the size of the catch. TWINSPAN is therefore likely sensitive to estimating catches as either small or large, as indicated in the logbooks. The overlap between DWD and NSM was probably also increased by a lack of logbook information on the species weights discarded. Using data on only the retained catches, the observer-defined NSM and WID assemblages were more similar to the comparable logbook assemblages. Discarding in the NSM assemblage was substantial (Rogers and Pikitch 1994c), particularly for sanddab, a species highly associated with the assemblage (Rogers and Pikitch 1992).

Research Data

Our results indicated that the unique separation of deepwater rockfish and deepwater Dover sole assemblages defined by Rogers and

Pikitch (1992) was not merely an artifact of their method of analysis, but instead may be related to their use of data collected by observers on commercial vessels. Prior to that study, rockfish analyses were conducted using research cruise data because logbook data contained information on only a few separate species. Triennial research cruise data apparently led to a combined deepwater rockfish and deepwater Dover sole assemblage (DWR-DWD) because the data was collected only in the summer season with a shallower depth range, and that the research use of roller gear was less selective for rockfish than commercial use of the gear. Gabriel and Tyler (1980) used triennial cruise data and determined a deep/slope assemblage of Pacific ocean perch, Dover sole, sablefish, and darkblotched rockfish. K.L. Weinberg (in press) analyzed triennial data using only rockfish and thornyhead species, and derived a deep water rockfish assemblage very similar to the one we determined using only the observer tows made with roller gear in the summer in the research depth range. Those assemblages included shortspine thornyhead, as well as deepwater rockfish. Our results indicated that shortspine thornyhead met the criteria for high concentration in DWR in the restricted observer data base because a separate DWD assemblage was not defined.

Research data collected with otter trawls in a deeper depth range also indicated a DWR-DWD assemblage, although qualified with some depth separation (Alverson 1953, Hitz and Alverson 1963). The data was collected in the spring and summer only. Dover sole and sablefish have been found to migrate to deeper water in the winter (Alverson 1960, Westrheim 1992), so a separation between DWR and DWD may be more evident in hauls conducted in the winter season. Those studies do indicate a movement of Dover sole into shallower water in the summer, with more overlap with Pacific ocean perch. Alverson (1953) analyzed data collected in the summer and determined that there was overlap between Dover sole, Pacific ocean perch, and sablefish, but sablefish were also found much deeper. Hitz and Alverson (1963) collected data in the spring and also found an overlap, but that Pacific ocean perch was concentrated in shallower water than Dover sole, and sablefish had the widest depth range.

It is also possible that the combination of DWD and DWR in the reseach studies was influenced by the size of the fish caught. Triennial research cruises use a 1.25-in (32 mm) web liner in the codend (Coleman 1988), while the commercially-used roller gear had no liner and a codend mesh averaging greater than 3 inches (77 mm) (Rogers and Pikitch 1994b). Sablefish do tend to migrate into deeper water as they age (Methot 1992).

Although the research assemblages we identified were similar to those previously determined for comparable NOAA research cruises in terms of a combined DWR-DWD assemblage, the prior studies determined a separation in the BRF assemblage, and did not define a NSM assemblage (Weinberg in press; Gabriel and Tyler 1980). Splitting BRF into two assemblages may have been a result of analysis methodology. Only cluster analysis was used in the two prior studies, and they likely selected a lower level of dissimilarity (more clusters with hauls in the same cluster more similar). They also included more species of rockfish in their analyses. Weinberg (in press) determined that the rockfish species we used separated into two groups; with sharpchin, bocaccio, and widow rockfish in one group and yellowtail and canary in the other group. He found that the strongest association in the first group, however, was among sharpchin and species which we did not consider: redstripe rockfish (Sebastes proriger) and rosethorn rockfish (Sebastes helvomaculatus). The yellowtail and canary group was also associated with greenstiped rockfish (Sebastes elongatus). Gabriel and Tyler (1980) also found two BRF related groups, but they defined an association between canary and yellowtail rockfishes, and an association between canary, Pacific ocean perch, and sharpchin. The absence of a NSM assemblage in the prior studies is explainable because Weinberg (in press) considered only rockfish and the cruise examined by Gabriel and Tyler (1980) did not sample in less than 90 m. None of the research analyses derived a WID assemblage. Although large catches of widow rockfish can be made with roller gear, it is thought that fishermen may intentionally drive the species to the bottom, representing a specialized strategy (Wilkins 1987). The one assemblage which Gabriel and Tyler (1980) found (a combination of Dover sole, Pacific whiting, and canary rockfish) which was different from any assemblage noted by Rogers and Pikitch (1992) was also absent in our assemblages defined from research data.

Comparing assemblages derived using different data bases is statistically problematical. As in our data, the distributions of the percents of the different species in hauls may differ between data bases. In addition, the percents are interrelated for all species in the same haul. By using non-parametric statistics and choosing a very strict criterion for significant differences ($p<0.0001$), we hope to provide meaningful results. Discriminant function analysis gave further insight into the differences and all species could be considered simultaneously. Another possible method of comparing the data would be to define assemblages using the combined data and determine the percent of each type of data in each assemblage. We did not utilize that method because the observer data is not a random sample, and so may be under-represented in certain assemblages.

Conclusions and Recommendations

Our findings indicated that the logbook data may be accurate enough to determine the general assemblages caught, allowing monitoring of the fishery over time. This would be especially true if the large and small rockfish categories were used consistently and were based on BRF-associated species versus DWR species. Results would be more comparable to observer data if only DECORANA and the Bray-Curtis index with group average clustering are used, eliminating the use of TWINSPAN.

Assemblages determined using the research cruise data appeared to reflect substantial differences in the methods of fishing. The research cruise did not effectively sample canary and (in particular) yellowtail rockfish, when compared to results seen for catches made by commercial fishermen. Research assemblages were dominated by species which were not commercial targets, and more non-rockfish species were caught than by commercial fishermen using the same gear, season, and water depths. Restrictions on the cruise in terms of mesh size, locations fished, length of tow, and tow speed may have been responsible for the differences.

Our findings substantiated that the separation of DWD and DWR determined by Rogers and Pikitch (1992) was not merely a methodological effect. Combining data from the slope research surveys, which are conducted in the fall, in deeper water with modified mud gear, with triennial cruise data may give the full complement of assemblages found in the observer data.

Table III1. Comparison of the percent of the total weight in the data bases for each species considered. O= 1985-1987 observer data, L= 1987 logbook data adjusted using "pink ticket" data, and R= 1986 triennial research cruise data. The large and small rockfish categories for O and R include some of the species already listed as well as species not listed individually.

Species				
Common Name	Latin Name	O	L	R
widow rockfish	Sebastes entomelas	15	21	<1
Dover sole	Microstomus pacificus	12	26	4
sablefish	Anoplopoma fimbria	10	10	4
Pacific whiting	Merluccius productus	8	<1	34
yellowtail rockfish	Sebastes flavidus	6	5	4
arrowtooth flounder	Atheresthes stomias	5	2	5
spiny dogfish	Squalus acanthias	4	-	17
darkblotched rockfish	Sebastes crameri	3	-	1
shortspine thornyhead	Sebastolobus alascanus	3	2	<1
Pacific ocean perch	Sebastes alutus	3	1	1
canary rockfish	Sebastes pinniger	2	-	6
petrale sole	Eopsetta jordani	2	4	<1
rex sole	Glyptocephalus zachirus	2	1	2
longnose skate	Raja rhina	2	-	<1
sharpchin rockfish	Sebastes zacentrus	1	-	<1
lingcod	Ophiodon elongatus	1	2	2
yellowmouth rockfish	Sebastes reedi	1	-	<1
splitnose rockfish	Sebastes diploproa	1	-	<1
English sole	Parophyrs vetulus	1	3	2
sanddab	Citharichthys sp.	1	1	2
sand sole	Psettichthys melanostictus	<1	1	<1
starry flounder	Platichthys stellatus	<1	<1	0
Pacific cod	Gadus macrocephalus	<1	3	1
bocaccio	Sebastes paucispinis	<1	-	<1
yelloweye rockfish	Sebastes ruberrimus	<1	-	<1
Large rockfish	Sebastes sp.	4	11	8
Small rockfish	Sebastes sp.	10	3	4

Table III2. Comparison of discriminant function analysis cross-validation errors in predicting data type by assemblage based on species weights in tows. Errors were classified as deriving from confusion of : OR-RES= research and research-observer modified data bases, OA-RES= all observer and research data, OR-OA= research modified observer and all observer, OL-LOG= logbook modified observer and logbook, OA-LOG= all observer and logbook, OL-OA=logbook observer modified and all observer.

Total % Errors		% of Errors		
Research		OR-RES	OA-RES	OR-OA
BRF	31	5	17	78
DWR	25	6	45	49
NSM	12	NA	100	NA
Logbook		OL-LOG	OA-LOG	OL-OA
BRF	42	25	3	72
DWR	41	20	9	72
NSM	34	40	32	29
DWD	43	35	13	52
WID	55	59	14	27

Table III3. Average percent of highly associated species in hauls consistently placed in an assemblage using three methods, compared among the observer data (O), observer data collected with roller gear in the summer in depths 55-366 fm (RR), and research cruise data (R). *= species considered highly associated with the assemblage.

ASSEMBLAGE	BRF			DWR			NSM	
SPECIES	O	R	RR	O	R	RR	O	R
n	143	26	40	97	121	13	105	143
Yellowtail R.F.	49**	<1	16*					
Lingcod	7*	20*	16					
Canary R.F.	18*	23*	22*					
Sharpchin R.F.	9*	<1	17					
Bocaccio	3*	2*	5					
Yelloweye R.F.	4*	<1	8*					
S. Dogfish	2	40*	<1*					
Petrale Sole	<1	2	1*					
Sanddab	<1	<1	<1*					
P.O.P				24*	2*	40*		
Darkblotched R.F.				26*	5*	13*		
Yellowmouth R.F.				16*	<1	9		
Splitnose R.F.				9*	3*	2*		
Sablefish				5	15*	3		
S.S. Thornyhead				3	3*	2*		
Sharpchin				3*	<1	6		
Arrowtooth F.L.				2	23*	3		
English Sole							22*	9*
Starry Flounder							4*	0
Sand Sole							27*	<1*
Sanddab							15*	13*
Petrale Sole							9	2
Pac. Whiting							5	39*
Rex Sole							6	6*

Table III4. Comparison of significance in difference in ranks and frequencies for species highly associated with assemblages derived using research (R), full observer (OA), or research-observer modified data (OR).

Assemblage	OA versus R		OR versus R	
Species	Rank	Freq	Rank	Freq
BRF				
yellowtail r.f.	<0.0001	<0.0001	<0.0001	0.0017
lingcod	0.0012	0.0211	0.8647	0.6818
canary	0.6027	0.2200	0.2176	0.1503
sharpchin r.f.	0.0192	0.2058	<0.0001	<0.0001
bocaccio r.f.	0.2779	0.9314	0.0049	0.0198
yelloweye r.f.	0.0026	0.0374	<0.0001	<0.0001
spiny dogfish	<0.0001	<0.0001	<0.0001	<0.0001
petrale sole	0.0003	0.0310	0.0314	0.1503
DWR				
Pac. ocean perch	<0.0001	<0.0001	<0.0001	<0.0001
darkblotched r.f	<0.0001	<0.0001	0.0002	0.0010
yellowmouth r.f.	<0.0001	<0.0001	<0.0001	<0.0001
splitnose r.f.	<0.0001	<0.0001	<0.0001	<0.0001
s.s. thornyhead	0.3998	0.0044	0.2567	0.0521
sharpchin r.f.	<0.0001	<0.0001	<0.0001	<0.0001
sablefish	<0.0001	<0.0001	<0.0001	<0.0001
arrowtooth fl.	<0.0001	<0.0001	<0.0001	<0.0001
NSM				
English sole	<0.0001	<0.0001		
starry fl.	<0.0001	<0.0001		
sand sole	<0.0001	<0.0001		
sanddab	0.3504	0.4822		
petrale sole	<0.0001	<0.0001		
Pacific whiting	<0.0001	<0.0001		
Rex sole	0.2023	0.0018		

Table III5. Percent weight in an average tow of highly associated species compared among the observer data (O), the observer data for fish retained (OK), and the logbook data (L), using the tows consistently placed in an assemblage by three methods. * signifies that the species met the criteria (see text) for high association with the assemblage.

ASSEMBLAGE	DWD			DWR			NSM			BRF			WID			YT
SPECIES	O	OK	L	O	OK	L	O	OK	L	O	OK	L	O	OK	L	L
n	509		473	97		21	105		180	143		75	391		86	41
Dover Sole	27*	38*	48*													
Sablefish	25*	31*	23*													
S.S. Thornyhead	9	12*	5													
Small R.F.				54*	45*	86*										
P.O.P.				24*	38*	8*										
English Sole							22*	26*	18*							
Starry Fl.							4*	4*	15*							
Sand Sole							27*	30*	49*							
Petrale Sole							9*	23*	2							
Sanddab							15*	<1	9							
Large R.F.										24*	29*	86*				
Yellowtail R.F.										50*	52*	8				77*
Lingcod										7*	10	4				
P.O.P.											<1	11*				
Widow R.F.													96*	96*	97*	

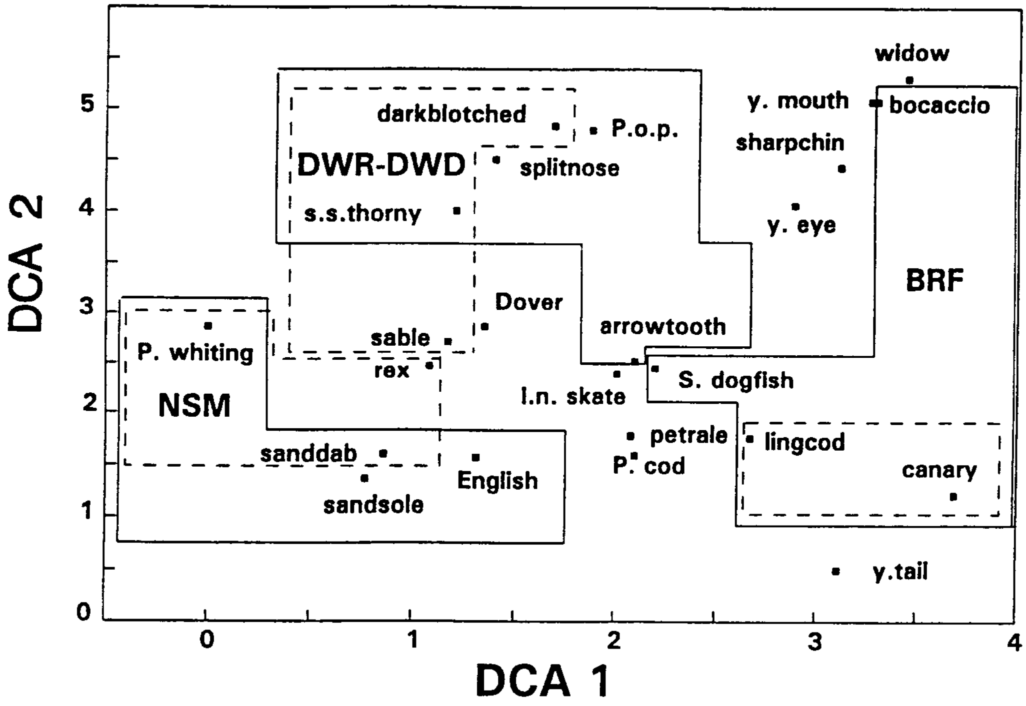


Figure III1. Consistency in species associated with the research catch clusters, labeled by assemblage name. Species scores on the DCA axes are designated by squares and labeled with the species names. Boxes enclose species associated with the haul clusters. --- = TWINSPAN indicator species,--- =species in the Bray-Curtis clusters which averaged > 20 % by weight in the assemblage catches and/or > 4 times the average weight of the species in all hauls.

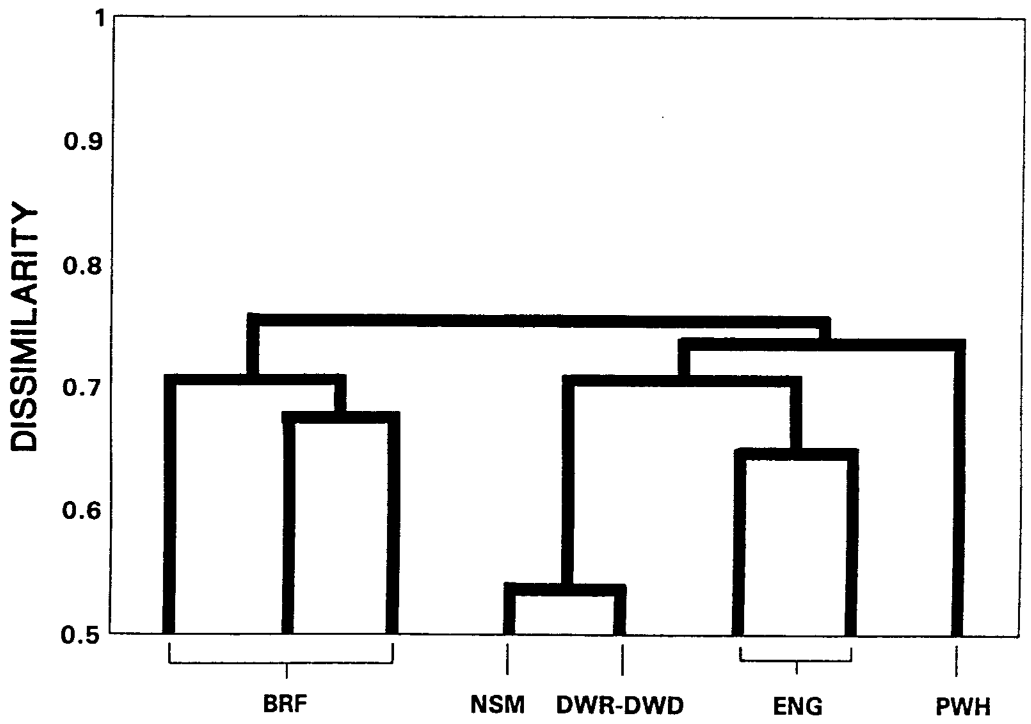


Figure III2. Dendrogram of Bray-Curtis research cluster combinations at increasing levels of dissimilarity. The assemblage labels indicate the level selected to achieve consistency with TWINSPAN and DCA.

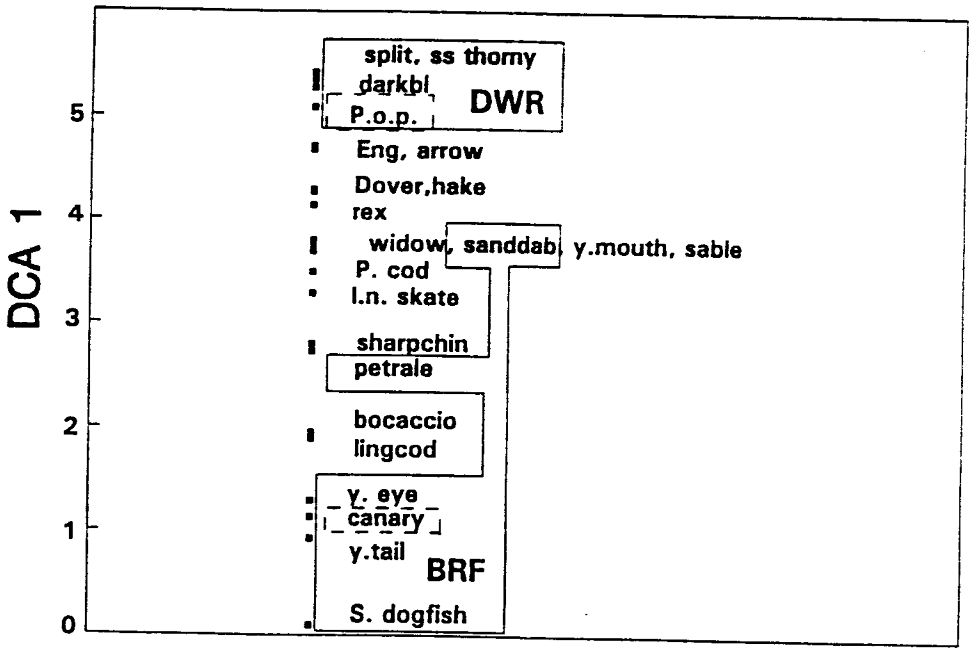


Figure III3. Consistency in species associated with modified observer data (roller gear, summer, research depths) labeled by assemblage name. (see figure 1 label for complete explanation).

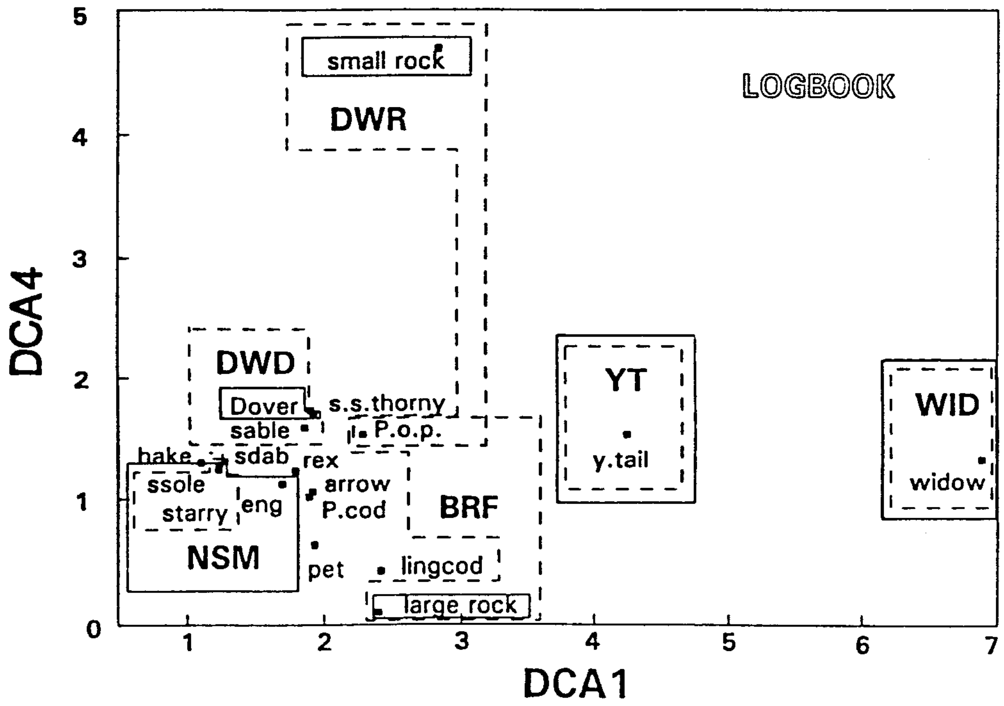


Figure III4. Consistency in species associated with logbook cruise data labeled by assemblage name. (see figure 1 for explanation).

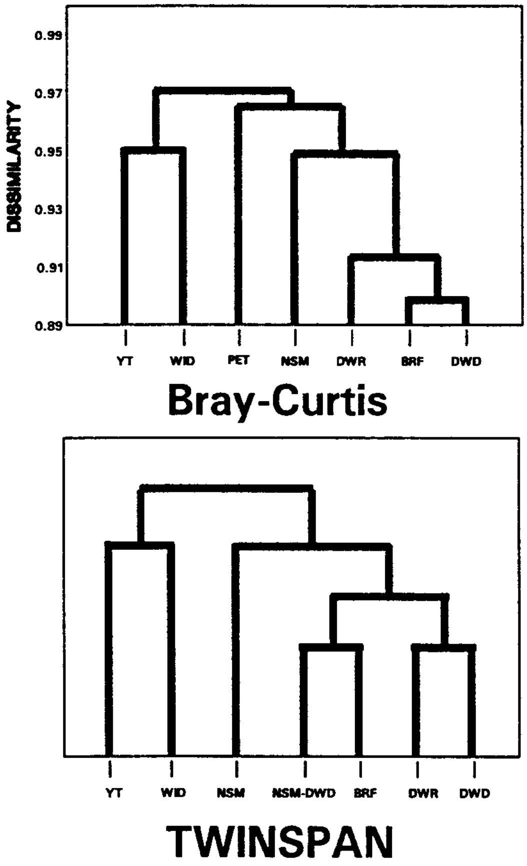


Figure III5. Dendrograms depicting progressive separations (TWINSPAN) or combinations (Bray-Curtis) of the logbook clusters. The dendrograms end at the level selected for the labeled assemblages.

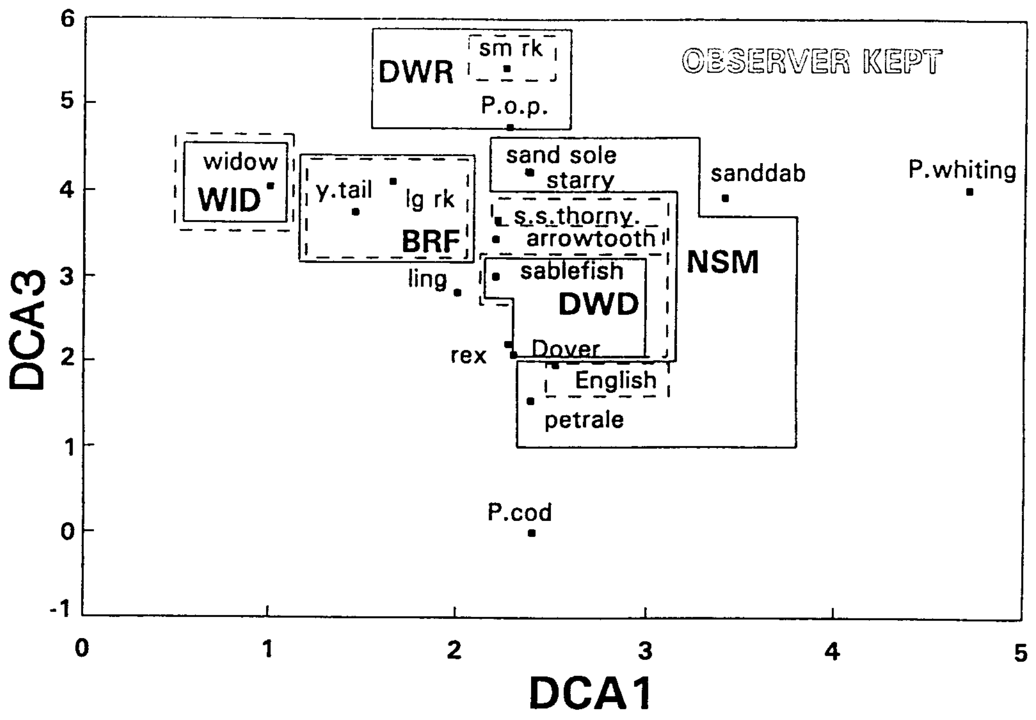


Figure III6. Consistency in species associated with modified observer data (weight kept and no shrimp gear) catch clusters, labeled by assemblage name. (see figure 1 label for complete explanation).

Fishing Strategies Used by Commercial Groundfish Fishermen Off the Coasts of Oregon and Washington

Jean Beyer Rogers[1] and Ellen K. Pikitch[2]

Department of Fisheries and Wildlife
Oregon State University
Mark O. Hatfield Marine Science Center
Newport, OR 97365, USA

[1] Present Address: National Marine Fisheries Service
3510 Paradise Dr.
Tiburon, CA 94920

[2] Present Address: Fisheries Research Institute
School of Fisheries WH-10
University of Washington
Seattle, WA 98195, USA

Abstract

Identification of fishing strategies used by the trawl fishery operating off the Oregon and Washington coasts can aid both managers and researchers in understanding how to control the composition of the catch. We defined fishing strategies used to catch six commonly-occurring assemblages (groups) of species. Strategies were derived using discriminant function analysis applied to data on 46 decision variables collected by observers on commercial vessels during 1985-1987. The most accurate two variable model which defined strategies based on gear type used and bottom-depth fished, had 66-85 percent accuracy in predicting the catch assemblage. Adding information on season (winter, spring, or summer-fall), latitude, longitude, and tow duration increased the accuracy of prediction to 75-92 percent. Mapping the distribution of the assemblage catches indicated "hot spots" where assemblages were concentrated. Discriminant function analysis was used to further describe the gear types observed. The function derived was able to predict the type of gear with an average of 95% accuracy, based primarily on mesh sizes in the net, the dimensions of the trawl doors, vessel length, vertical opening of the net, and tow speed. We applied the depth and gear functions to three types of data: observer, logbook, and research cruise data. The predicted assemblage groups indicated that the logbook data was similar to observer data, but that the logbook large and small rockfish categories had overlapping species. The research data was less dominated by rockfish than predicted based on commercial gear usage.

Introduction

Knowledge of commercial trawl-fishing strategies used to catch major groundfish assemblages of cooccurring species is important to both researchers and managers. For the purposes of this paper, we define fishing strategies as the operational decisions that fishermen make which can be used to predict the assemblage caught. In this sense, fishing strategies are equivalent to "metiers", the term used by Anon (1987a) and Laurec et al. (1991) to describe types of fishing activities.

Researchers can use knowledge of different strategies in modelling, data analysis, and study design. Laurec et al. (1991), for instance, modelled technical interactions by assuming a constant multispecies fishing pattern within each metier. Pikitch (1988) separated data by strategy definition before assessing discard patterns and designed a mesh size study to focus on two strategies (Pikitch 1991). Changes in the composition of a catch assemblage over time could be monitored by using strategy definitions to separate readily available data, such as contained in fishermen's logbooks, and comparing the catches to those predicted for the strategies.

Another potential use of strategy definitions is to determine the type and amount of control that fishermen have over the assemblage caught. If strategies can be described which accurately predict assemblages caught, it could be inferred that fishermen are able to control the catch (i.e. management by assemblage would be effective). The most accurate predictor variables may suggest ways to achieve assemblage-specific catch restrictions. For example, if bottom depth fished and gear used were found to be highly predictive of species composition caught, this would indicate that area-gear closures may be effective management options.

Strategies for the trawl fishery operating off the coasts of Oregon and Washington were initially defined by Pikitch et al.(1988), based on discussions with fishermen and managers. They identified five strategies based on gear type used, bottom-depth fished, and species desired (targeted). Rogers and Pikitch (1992), who derived fish assemblages based on species catch weight, determined that those strategy definitions needed modification to adequately predict the groundfish assemblages caught by the fishery. The modifications suggested included designating a new strategy aimed primarily at deepwater rockfish (Sebastes spp.), and changing the strategy aimed at widow rockfish (Sebastes entomelas) to reflect the use of roller gear as well as midwater gear. A reduction in the depth boundary used to separate the strategy aimed at a nearshore flatfish (Pleuronectidae and Bothidae) assemblage from the strategy aimed at a deepwater assemblage consisting mainly of Dover sole (Microstomus pacificus), sablefish (Anoplopoma fimbria), and shortspine thornyhead (Sebastolobus alascanus) was also indicated. Rogers and Pikitch (1992) proposed defining the revised strategies based only on the operational decisions of the fishermen, eliminating the need to know the target species.

Quantitative definition of trawl-fishing strategies could provide the necessary modifications to the previously-defined strategies, and also verify or expand the knowledge presently held by fishermen and managers. To be of value, the quantitative definitions should accurately predict the catch of each assemblage; be based on as few variables as possible, preferably those which are easily measured and/or controlled; and be easily described and used. If gear type is selected as a predictor variable, a description of gear usage would aid evaluation of potential changes in the strategies over time.

The overall objective of this study was to examine, and modify if necessary, the strategies described by Pikitch et al. (1988). The specific objectives were to: 1) determine if choice of gear type and bottom depth fished were the operational decisions which most accurately predicted the assemblages described by Rogers and Pikitch (1992), 2) evaluate increases in accuracy obtained from the use of more than two predictor variables, 3) if gear type was selected as a predictor variable, use variables not selected to describe its usage in the study, 4) evaluate the ability of the selected variables to predict assemblages described for logbook and research triennial cruise data.

Materials and Methods

Data

Data on operational characteristics of tows were collected by observers of normal fishing operations on commercial trawlers between 1985-1987 in the area between 48^0 42′ and 42^0 60′ N latitude, (primarily the INPFC Columbia Management Area off the coasts of Oregon and Washington). Tow attributes were recorded when possible. Data specific to each tow included the date, time of day (start and finish), bottom depth (start and finish), position (start and finish), towing speed, length of the tow cable wire, and gear type. Gear types designated included roller gear (RG), mud gear (MG), a combination of mud and roller gears (CB), midwater gear (MW), shrimp trawls with one net (S1), and shrimp trawls with two nets (S2). Gear attributes were usually recorded for each gear used by the boat. These included the lengths of the headrope and footrope, the age of the gear, the number and size of primary and secondary floats, the length of the bridle, the vertical opening of the net, the dimensions and weight of the trawl doors, and mesh sizes in different parts of the net. Other data were specific to the boat, but updated when changes were made. This included vessel length, maximum horsepower of the engine, cable diameter, and cable length available.

Each tow was previously assigned to an assemblage based on the species composition of the catch (Rogers and Pikitch 1992). Only tows that were consistently assigned to the same assemblage by two types of cluster analysis and an ordination technique (Rogers and Pikitch 1992) were used in the analyses to develop strategy designations (1100 of the 1469 tows observed). The other tows were either inconsistently assigned an assemblage designation (251 tows), or there was insufficient information on species weights to conduct the assemblage analyses (118 tows). Rogers and Pikitch (1992) identified six consistent assemblages from the trawl catches: a bottom rockfish assemblage (BRF), which included catches of primarily yellowtail rockfish (Sebastes flavidus), canary rockfish (Sebastes pinniger), lingcod (Ophiodon elongatus), yelloweye rockfish (Sebastes ruberrimus), bocaccio (Sebastes paucispinis), and sharpchin rockfish (Sebastes zacentrus); a widow rockfish assemblage (WID), consisting primarily of widow rockfish; a deepwater Dover assemblage (DWD), dominated by Dover sole and sablefish; a nearshore mixed-species assemblage (NSM), including English sole (Parophyrs vetulus), sanddab (Citharichthys spp.), sand sole (Psettichthys melanostictus), starry flounder (Platichthys stellatus), and petrale sole (Eopsetta jordani); a shrimp assemblage (SHR), containing mostly pink shrimp (Pandalus borealis); and a deepwater rockfish assemblage (DWR), which included darkblotched rockfish (Sebastes crameri), Pacific ocean perch (Sebastes alutus), splitnose rockfish (Sebastes diploproa), yellowmouth rockfish (Sebastes reedi), and sharpchin rockfish (Sebastes zacentrus).

Data preparation

Additional variables were developed as functions of observed variables or from independent data sets. Duration of tow was calculated as the difference between the time the net began being towed at depth and the initial time of retrieval. Minimum change in location (MCL) was calculated as the spherical distance (Dunlap and Shufeldt 1970) between the latitude and longitude (from Loran; Star and Saelens 1988) at the start of the tow and the latitude and longitude at the end of the tow.

Tows were categorized by season, as defined from water temperature patterns. Monthly water temperatures at the surface and 100 m depth intervals, observed between 1985-1987 (National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, Washington, D.C. 20233) were plotted over time for 2^0 latitude by 1^0 longitude areas off the coasts of Oregon and southern Washington. Seasons were defined as consistent groups of months with similar temperature trends: increasing, decreasing, stable, or variable. Changes in trends were identified visually.

Tows were categorized by time of day into one of four periods based on changes in light levels: morning, a four hour period bracketing sunrise; day, two hours after sunrise to two hours before sunset; evening, a four hour period bracketing sunset; and night, two hours after sunset to two hours before sunrise. Sunrise and sunset times were specific for the date and latitude of the tow (NOAA 1986; NOAA 1987: NOAA 1988). The time of day relative to sunrise and sunset was standardized to a 12l:12d photoperiod.

All the categories (gear type, season, time of day) were converted into dummy variables (Zar 1984), so that they could be analyzed with the continuous variables. This resulted in four gear variables, three season variables, and three time of day variables.

There were missing values for most of the variables and the variables were measured with different frequencies (trip, gear, or haul). Because of this, we evaluated whether there was sufficient variability in fishing within a trip or with a gear type to require analysis on a haul-by-haul basis. This was done by determining the percent of trips and trip/gear combinations which caught more than one designated assemblage.

Derivation of Strategy Definitions

Discriminant function analysis was used to derive functions based on the operational strategy variables which could be used to classify tows into the different assemblage designations. We could not assume that the data were normally distributed because they contained dummy variables having a value of one or zero. We therefore derived our initial functions using non-parametric normal kernal discriminant functions, an option available with SAS (1989) statistical programs. A smoothing factor of 0.5 was selected because initial runs indicated it would produce functions which were accurate, but not so variable that they would tend to reproduce noise in the data and be difficult to describe or explain.

Since our data were not a random sample of the fishery, and the relative proportions of the assemblages caught are likely to change over time based on factors such as regulations and market conditions; we assumed that observations were equally likely to be obtained from any assemblage. When probabilities are considered unequal, the discriminant function places borderline tows (tows close to the division between assemblages) in the assemblage which is expected most often.

Performance of alternative discriminant function models was evaluated in terms of accuracy of prediction. The accuracy of prediction was estimated using a cross-validation error rate. This rate was an approximation of the rate of future misclassifications when using the discriminant function. The rate was determined by removing one tow from the data set, calculating the function without it, then using the function to classify the tow and recording whether the classification was correct (Hora and Wilcox 1982). This was repeated for all tows. Cross-validation rates are unbiased, whether or not the data is multivariate normal, and give a good estimate of the total error rate, although there can be high variance in determining individual assemblage error rates (Hora and Wilcox 1982; Krzanowski 1988). We considered the total error rate (the mean rate across assemblages since prior probabilities were equal) to be our primary measure of accuracy, but for completeness we also considered several other measures. To determine if the function was consistently accurate for all the assemblages, we calculated the standard deviation of the average rate. We also considered the total number of misclassifications, which reduced the effect of the errors in assemblages with small sample sizes. A final criterion used assessed how well the function could estimate the relative proportions of the assemblages, even if the placement of individual hauls was inaccurate. This was based on the posterior probabilites and was defined as "C" by M.H. Prager, unpubl. data, SE Fisheries Science Center, US NMFS, 75 Virginia Beach Drive, Miami, FL 33149.

Selection of Variables

To determine if gear type and bottom depth fished (the variables in the strategies described by Pikitch (1991)), were in fact the best predictors of the assemblage caught, we compared the accuracy of discriminant functions based on each individual variable. Selection of the variables was made without including the shrimp gear types or the SHR assemblage to avoid biasing the results with the highly predictive relationship between gear and that assemblage (Rogers and Pikitch 1992), Because the accuracy could depend upon the hauls used, we then compared functions for the most accurate predictor to functions for the other variables using only the hauls on which we had information for both predictors. The most accurate variable in those comparisons was considered to be the first variable in the discriminant function. The second variable was found by adding each variable to the first, selecting the most accurate two variable model, and comparing it to the other two variable models using only hauls with information for both variables.

To determine the benefit of deriving strategies based on more than two predictor variables, we then added other variables recorded in logbooks by commercial fishermen. Those variables included location (latitude and longitude), year, season, time of day, and duration of tow, in addition to gear type and bottom depth fished. We selected those variables because information regarding them is easily available, regulations are often based on spatial and temporal limits, and those variables potentially change with each haul. To allow comparisons among all the variables, we used only the hauls with information on each of those variables. We compared the accuracy of the two variable model to each three variable model, as well as models adding both location variables, the three temporal variables, and all the variables together.

Because presentation of the non-parametric function is very complex for more than one continuous variable, to help explain the functions, we presented the means of each variable in each assemblage designation. The actual functions may be obtained by contacting the authors.

Sensitivity analysis

We tested the sensitivity of our findings to our method of selecting variables, the type of discriminant function, and our determination of equal probabilities. To further examine our selection of the best predictors of the assemblage, we used stepwise analysis (SAS 1988) performed using stepwise selection. Stepwise analysis was not used initially because it can be sensitive to violations of the assumptions of multivariate normality and equal covariances (Manly 1986) and so may not select the best variables from our data base. We attempted to meet the assumption of multivariate normality as closely as possible by transforming the continuous variables when necessary based on normal probability plots. Stepwise analysis also cannot be performed with missing information on a variable, and so we were not able to use all the variables measured (there were no hauls with complete information). For our initial selection, we used only the variables on which we had information for at least one-half of the hauls, unless the variable was found important in our earlier analyses. We then progressively eliminated the variables not selected and re-ran the stepwise selection until the variables selected did not change. During the stepwise selection, variables were entered if they significantly ($p<0.0001$) added to the discriminatory power, but were later removed if, after adding other variables, they not longer met the criterion.

We compared the accuracy of prediction using the non-parametric discriminant functions we derived above to linear and quadratic functions using those same variables (SAS 1988). The linear function is consistent with an assumption that the variables in each assemblage are normally distributed with equal covariances, while the quadratic function only "requires" normal distributions. Krzanowski (1988), however, determined that the function selected should be based on comparisons of the estimated error rates of prediction rather than on the distribution of the data. Prager (unpubl. data) also found that the usefulness (in terms of accuracy of prediction) of the linear and quadratics functions not dependent upon the distribution of the data.

Finally, we tested the sensitivity of our functions to the assumption of equal prior probabilities. Prager (unpubl. data) determined that the assumptions made about the probability of drawing a new observation from each assemblage were important. We subsequently assumed that observations were likely to be obtained from an assemblage proportional to that assemblage's occurrence in the logbook data base, as estimated by Rogers and Pikitch (1994b).

Those probabilitites were: BRF=.14, DWR=.02, NSM=.21, DWD=.54, and WID=.10 (where the BRF category was BRF and YT combined).

Description of gear usage

If gear type was selected as one of the best predictors of the assemblage caught, one of our objectives was to describe gear usage in the fishery for the period (1985-1987) during which trips were observed. To simplify the analyses and presentation of results, we selected the variables using stepwise analysis and derived linear functions. Although this may not be optimal for prediction due to a lack of multivariate normality, the functions were derived for descriptive purposes only. We used only the variables (transformed when necessary) which were not specific to a particular gear and on which we had information for at least one-half of the hauls.

Predictions using Three Types of Data

To evaluate the practical application of the selected function given available data bases for the area observed, we separated 1987 logbook data (12,847 tows), 1986 triennial research cruise data (409 tows), and all the 1985-1987 observer data (1351 tows-including those inconsistently designated to an assemblage) into predicted assemblage groups. The logbook data were available either as raw data or adjusted to be compatible with the trip landings data recorded on the processing plant pink tickets. We tried predictions using both sets of data and presented the results that were most compatible with the observer data. We then compared the species meeting the criterion for high association with the assemblage. The criterion was that the percent of a species in an average haul was either greater than 20% or greater than 2 times the average in all assemblages combined.

Results

The non-parametric analyses demonstrated that bottom depth fished and gear type used provided the most accurate two variable predictor model. That function predicted that mud gear fished over bottom depths less than 163 m (89 fm) would catch NSM, and DWD would be caught at greater depths. Roller gear fished over bottom depths of less than 245 m (134 fm) was predicted to catch BRF. If that gear was fished over bottoms 245-518 m (134-282 fm), DWR would be predicted, and DWD would be caught if roller gear was fished over even deeper bottoms. Midwater gear was predicted to catch WID, while combination gear would catch DWD. The function using bottom depth at the start of the tow (start depth) was the most accurate single variable model, with an average error rate of 36% (Table IV1). The two variables with the next highest average error rates, bottom depth at the end of the tow and the length of the wire let out, were highly correlated with start depth ($p>0.90$). Start depth was also more accurate than finish depth and wireout in terms of the SD of the error rate among assemblages and better than finish depth in predicting the relative proportions of the assemblages (C). The addition of gear type to starting depth decreased the average error rate to 18 % (Table IV1), and that model was the most accurate two variable model based on all criteria except the standard deviation. If shrimp gear was considered, the average rate was reduced to 15% and the total error rate was 13%. A function based on depth and minimum distance travelled had a lower standard deviation (0.11 versus 0.137), but the average error rate increased to 27%.

Adding most of the additional variables recorded in fishermen's logbooks decreased the average error rate (Table IV1). The addition of season decreased the error rate to the lowest level (12%). That function predicted that roller gear catches in the winter in less than 150 fm were WID, which correctly placed an additional nine WID hauls from 3 trips (making the error rate for WID = 0). The gain in accuracy was, however, partially offset by the incorrect placement of 10 BRF hauls meeting those criteria. The next lowest average error rate (14%) was for the time of day categories (diurn). That three variable function designated roller gear catches at night as WID, which correctly placed 5 WID hauls (but only one trip), without causing incorrect predictions of BRF. In considering functions with more than three variables, we found that the error rates were not decreased further by using the position variables, the temporal variables, or all the variables recorded in logbooks (Table IV1).

Sensitivity analysis

Stepwise selection verified our selection of depth and gear as the best predictors of the assemblage caught. Gear and depth related variables were selected first by stepwise selection. Four of the variables did not have data in more than one-half of the hauls (Table IV2), so they were not used in the stepwise analyses. Stepwise selection using only the variables available in the logbooks led to derivation of functions with lower average error rates (9%) than we determined without stepwise selection (Table IV3). The average rate was further reduced to 8% (6% total errors) when shrimp gear was considered. Winter, spring, latitude, longitude, and tow duration were selected in addition to gear and depth. Means of those variables indicated that WID was caught mainly in the winter and DWR in the spring, DWD more northerly and BRF more southerly, and that BRF tows were short and DWD tows long in duration (Table IV2). Adding those variables to gear and depth improved the errors rates for DWD, DWR, and WID (Table IV4). Since season was a part of the function, as mentioned earlier, WID was improved at a cost to BRF

(Table IV4). Selection using all the variables on which we had sufficient data first selected two gear categories (RG and MW) and wire let out (a variable highly correlated with bottom depth). The next variables which met the criteria for selection were the season spring, cable length, and minimum distance travelled (Table IV3). The means of the variables by assemblage indicated that boats fishing NSM carried less cable, that boats catching DWD travelled longer distances, and BRF travelled shorter distances (Table IV2).

Other forms of the discriminant function using gear type and bottom depth fished resulted in higher average error rates than the non-parametric function (Table IV3). The linear function using only depth and gear was, however, very close to the nonparametric function in accuracy, with an average error rate of 19% rather than 18%. The quadratic form had substantially higher average error rates than either of the other two forms, for both the depth and gear function and the selected logbook function (Table IV3).

Setting the prior probabilities of assemblage occurrence proportional to their estimated occurrence in the 1987 logbook data instead of equal probabilities resulted in higher average error rates and poorer ratings on the other criteria (Table IV3). As would be expected, lower error rates were estimated for the most predominant assemblage (DWD) and higher rates for the lest abundant assemblage (DWR). The mud gear depth cutoff between NSM and DWD increased from 163 m to 172 m, and the roller gear depth cutoffs increased from 245 m to 253 m between BRF and DWR and from 518 m to 536 m between DWR and DWD.

Gear Usage

Examination of the possible unit of observation to use in the analyses indicated that data on an individual tow basis were necessary to distinguish among assemblages catches. Information was collected from 39 boats; 80% of the boats caught more than one assemblage. There were data on multiple trips for 82% of the boats; fishermen caught more than one assemblage during 43% of the 132 trips observed. The fishermen switched gear types in 24% of the trips, and 23% of the 168 trip/gear combinations caught more than one assemblage. Only the shrimp gears types were consistently used alone on a trip, and only midwater gear and shrimp gear with one net consistently caught one assemblage on a trip. Shrimp with two nets caught an assemblage other than shrimp only once. Although individual hauls were used to derive the functions, we considered the number of trips represented in assessing the validity of our conclusions.

Some missing values were present on the boat and gear level. All vessel and gear information was missing for one boat (two trips, 14 hauls). All gear specifications were missing for a gear type on five trips; four of those trips used only that gear.

Linear discriminant function analysis derived a function using the strategy variables which was able to predict gear type with a cross-validated estimated error rate of 5%, averaged across gears. S1, S2, and MW were predicted without error. The selection of variables and their weightings indicated that mesh size was an important factor in discriminating among gears. Of the top six variables selected, four were measures of mesh and tended to separate the S1, S2, and MW gears. MW gear had the largest mesh size (the largest coefficients) for three of the four measures (not codend), while the S1 and S2 coefficients tended to be smallest. The second variable selected, door dimension, tended to separate S2 from S1,as well as MW. The weightings implied that S2 had the largest doors and MW the smallest.

Linear functions derived using only the three gears which were the most similar (CB, RG, MG) had estimated error rates of 13%, averaged across gear types. The greatest confusion was between CB and the other two gear types, accounting for 90% of the errors. An examination of the order of selection and coefficients of the variables indicated the most important distinguishing factors were that MG was generally used on smaller vessels than RG, RG was towed with faster speed, and MG had a much smaller vertical opening (transformed with 1/x) than roller gear (Table IV5).

Spatial investigation of the gear-depth relationship

Since gear and depth were selected as the best predictors of assemblage catch, we mapped the locations of the catches designated by gear and assemblage to investigate the possibility of using area closures to regulate assemblage catches (Figures IV1 and IV2). Most of the tows were made off the coast of Oregon, whereas few of the tows sampled were made off of Washington. There was no apparent separation among assemblages based on latitude, but there was an indication of "hot spots" where the catches of some assemblages were concentrated. DWR was caught almost entirely with roller gear at depths exceeding 200 m, primarily between 44.5 and 45.5 0 latitude and off Cape Blanco (Figures IV1 and IV2). BRF was caught primarily with roller gear in less than or slightly over 200 m, with most of the catches in three locations: off Cape Blanco, off Hecata Banks, and somewhat south of the Columbia River (Figure IV2). WID was caught close to the 200 m contour, with midwater and (occasionally) roller gear. SHR was caught in less than 200 m in three concentrations: north of Cape Blanco, south of the Columbia River, and off Cape Flattery. NSM was caught mainly with MG close to shore south of Newport, Oregon (Figure IV1). DWD catches appeared to be the most widely distributed considering gear, depth and areas. Most of the catches were made, however, with mud gear and combination gear, in depths greater than 200 m, in the area south of Newport, Oregon (Figure IV1).

Prediction using Three Types of Data

Differences among species associations were apparent for the three data types. The 1987 logbook hauls were divided into BRF (14%), DWD (37% hauls), DWR (7%), NSM (38%), and WID (4%). DWR in the assemblages predicted from logbook data was associated with both large and small rockfish (Table IV6), although large rockfish are thought to be primarily BRF species. The adjusted logbook data was more similar to the observer data in species associations. The logbook data as written by the fishermen indicated an association of widow rockfish with BRF. In both logbook data bases, Dover sole averaged just slightly over the 20% cutoff criterion for association with the NSM and DWR assemblages. The research cruise data was predicted to be 96% BRF and 4% DWR. Species associations were quite different than the other two data bases for BRF, with the only rockfish association a DWR species, and DWR was associated with both DWR and DWD species (Table IV6).

Discussion

Our strategies provide quantitative verification and extension of strategies which in the past were only described qualitatively (Pikitch et al. 1988). They provide a more refined depth cutoff for the separation of the NSM and DWD catches using mud gear, and provide previously undefined depth cutoffs between catches of BRF, DWR, and DWD using roller gear.

The strategies can help managers and researchers monitor the fisheries, restrict catches, design studies, and analyze data bases. They are simple, easy to apply, and fairly accurate at predicting the assemblages caught. Information on gear and depth fished is readily available, recorded in both the logbook and research cruise data bases. Dividing data based on gear and cutoff depths is also computationally simple.

Managers can use the information on depth and gear recorded in logbooks to help monitor fisheries and strategies. Monitoring the catch of many rockfish species is difficult because their catches are recorded only in species categories in the logbooks and processing plant receipts. These categories and the species assigned to them can vary depending upon the fisherman, processor, or area. Our results confirm the findings of Rogers and Pikitch (1994a) that the large and small rockfish categories do not cleanly separate BRF from DWR species. Port sampling of the mixed rockfish landings is generally sparse, and can only provide estimates of the species composition on a trip rather than tow basis. Using our strategies, managers can predict the species assemblage caught, providing estimates of the species mixture in the recorded categories. Enforcing depth and gear usage, which would be necessary if the strategies were to be used by managers as a means of restricting catches of certain assemblages, may be feasible but not necessarily easy or efficient. Restricting catches of an assemblage by closing certain geographic areas to certain gear types appears possible, especially for mud gear usage. Closed areas can, however, be difficult and expensive to enforce. This could be facilitated by requiring boats to have a location monitoring device, but monitoring of the gears on board would still be necessary if boats could legally be in the area using other gears.

Researchers could also utilize the strategies we defined. In designing studies, gear usage and bottom depth fished are used as a means of controlling the assemblage caught. Data can also be easily divided by gear and depth and analyzed by strategy. Researchers could use the information we provided on variables other than gear and depth to try to become more effective in catching rockfish, although many variables, such as those involved in searching for a school were not measured.

Regardless of whether the strategies are used to estimate the species composition in a tow, restrict the catches of an assemblage, or design and analyze data, their effectiveness depends upon their ability to predict over time. Fishermen may change their strategies to become more efficient, catch a different mix of species, or in response to regulations. Application of our strategies to logbook data could provide some information on possible changes in the strategies over time, at least for individually specified species, A change in strategy would be indicated if the strategy predictions are grossly different than the logbook records of catch composition.
The similarity of the depth and gear strategies we defined to those defined earlier by Pikitch et al.(1988), based on general knowledge of the fishery, however, indicates that there is some ongoing stability in the strategies. We would also expect the gear and depth associations with the assemblage catches to be fairly consistent over time.

Some of the gears are specialized to catch certain assemblages, which is not likely to change substantially. Only the shrimp gears, for instance, have small enough mesh to retain the shrimp assemblage. Midwater gear is especially effective at catching the large aggregations of widow rockfish which occur in midwater. Mud gear is designed to be used over mud bottoms and retain flatfish. Roller gear was used to catch a wide variety of assemblages and, though designed to be used over rocky surfaces, is able to be used over mud bottoms as well. It has also been used to catch midwater aggregations of the WID assemblage by first driving the species to the bottom (Wilkins 1987). Combination gear, which uses both rollers and mud flaps, was associated in this study primarily with the catch of DWD, but seems likely to have the potential to efficiently catch other assemblages. Although specialized gear usage will likely continue, the potential for fishermen to use any of the gears in new ways should be considered when applying the strategies we defined.

The accuracy of bottom-depth as a predictor of assemblages appears to be based on species distributions, which are fairly consistent from year to year. Hydroacoustic studies off Oregon (Dark et al. 1980) and rockfish distributions viewed from a submersible off British Columbia (Richards 1986) determined that groundfish distribute by depth. Research trawl cruises off Oregon have indicated that species composition of bottom and midwater catches obtained using standardized strategies also varies with bottom depth (Hitz and Alverson 1963; Day and Pearcy 1978; Gabriel and Tyler 1980; Gunderson and Sample 1980; Dark et al. 1980; Weinberg et al. 1984; Coleman 1986; K.L. Weinberg, AFSC NMFS NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115-0070, unpubl. data). Gabriel and Tyler (1980) and K.L. Weinberg (unpubl. data) compared depth distributions between years and found them to be generally consistent. This biological basis and year-to-year consistency indicate that the separation of assemblages based on choice of bottom depth will be a stable part of the strategies.

Depth criteria used for defining assemblages in prior research studies were similar to our criteria, except that prior findings indicated BRF and DWR depth distributions overlapped. Studies which determined assemblages similar to our NSM associated them with maximum depths of: 73 m (Day and Pearcy 1968), 92 m (Gabriel and Tyler 1980), 103 m (Pearcy 1968), and 183 m (Alverson 1953). These depth designations span a range which includes our 163 m maximum depth cutoff for NSM. The two studies which designated assemblages similar to our BRF found they were associated with depths less than 275 m (K.L. Weinberg unpubl. data) or less than 146 m (Gabriel and Tyler 1980), bracketing our 245 m cutoff for the assemblage. Several studies determined assemblages which were combinations of DWD and DWR, with associated minimum depths of: 110 m (K.L. Weinberg unpubl. data), 165 m (Hitz and Alverson 1963), 183 m (Alverson 1953), or 220 m (Gabriel and Tyler 1980). These depth criteria were somewhat shallower than our 245 m minimum cutoff for DWR and tended to overlap the BRF criteria mentioned earlier. The difference between the research studies and our study may be related to changes in distribution over time, but it may also reflect a difference in strategies, or the result of differences in data analysis methodologies. The only study which defined a separate DWD assemblage and associated it with depth, did so with a greater than 512 m cutoff, similar to our 518 m minimum depth criteria (Pearcy et al. 1982). Our predictions of the research assemblages indicated that our depth cutoff did separate most of the deepwater species into DWR. Yellowmouth rockfish, an expected DWR species was, however, considered highly associated with BRF. Similarities which did exist between our designations and those in prior research studies further emphasize the biological basis of depth associations and indicate stability of the criteria over time.

Selection of the best function to use in a particular application may differ from the function we selected for discussion. In selecting a function, the probabilities of assemblage occurrence should be considered, as well as the costs of misclassification of an assemblage. For instance, if it is determined that there is a high proportion of the NSM assemblage caught with roller gear in the data base, or it is important that NSM caught with roller gear be correctly predicted, it may be best to select a function which provides that ability.

Our results demonstrated that stepwise selection of variables can be valuable even if the data cannot be assumed to be multivariate normal. We did determine, however, that non-parametric discriminant function analysis can be an improvement over linear or quadratic functions, at least when the data are not multivariate normal. The quadratic function, which has been noted by past researchers as unstable, performed poorly.

Conclusions and Recommendations

Our strategies provide a quantitatively-verified tool which can be used to research and manage the groundfish fishery off the coasts of Oregon and Washington. They improve upon the previously available qualitatively defined strategies in that they give more accurate average predictions of the assemblages caught and do not require knowledge of the targeted species. The strategies we defined are simple, easily applied and explained, and easily controlled by fishermen, though perhaps not easily regulated by managers.

Using information on season, latitude, longitude, and tow duration could improve the accuracy of prediction, but further investigation is needed regarding the stability of the relationship between those variables and the catch. For instance, the DWR may have been caught more in the spring due to market conditions or regulations, which could change from year to year.

Table IV1. Comparison of error rates for non-parametric discriminant functions, where position=latitude and longitude, temporal=season, diurnal, and year, and step= winter, spring, position, and tow duration.

VARIABLE	n	AVE	STD	%COR	C	BRF	DWD	NSM	DWR	WID
stdepth	884	0.36	0.34	48.3	0.39	0.14	0.77	0.08	0.12	0.68
+ gear	884	0.18	0.14	83.9	0.15	0.07	0.17	0.04	0.27	0.37
+ gear	678	0.20	0.22	84.2	0.14	0.06	0.19	0.01	0.18	0.56
+ lat.	678	0.17	0.09	84.8	0.10	0.22	0.16	0.01	0.21	0.25
+ long.	678	0.16	0.08	84.7	0.10	0.19	0.17	0.03	0.17	0.25
+ timeday	678	0.14	0.10	84.2	0.11	0.06	0.20	0.01	0.18	0.25
+ dur.	678	0.20	0.12	83.9	0.12	0.05	0.19	0.02	0.20	0.56
+ season	678	0.12	0.12	84.1	0.10	0.27	0.18	0.01	0.15	0.00
+ year	678	0.15	0.15	82.0	0.13	0.36	0.19	0.01	0.21	0.00
+position	678	0.16	0.09	87.5	0.05	0.25	0.12	0.03	0.14	0.25
+temporal	678	0.12	0.07	85.4	0.05	0.10	0.16	0.04	0.24	0.06
+all	678	0.15	0.07	88.2	0.16	0.15	0.09	0.12	0.26	0.13

Table IV2. Means of strategy variables, continuous and dummy, for hauls separated by assemblage designation (Rogers and Pikitch 1992).

			Assemblage					
Variable	Units	# Hauls	NSM	DWD	DWR	BRF	WID	SHR
Towspeed	knots	929	2.3	2.2	2.5	2.6	2.9	1.7
Starting depth	fm	1093	31	192	182	86	91	88
Finish depth	fm	993	30	197	181	83	98	88
Wire Out	fm	1088	124	441	393	207	193	203
Gear depth	fm	45	10	111	.	71	79	.
Starting latitude	deg	968	44.69	44.98	44.71	44.24	44.83	44.97
Starting longitude	deg	968	124.23	124.72	124.81	124.69	124.75	124.61
Finish latitude	deg	938	44.70	44.96	44.69	44.23	44.83	44.97
Finish longitude	deg	938	124.24	124.73	124.80	124.68	124.74	124.61
Minimum Distance	nm	938	5.	7.5	4.4	3.6	3.3	3.2
Year	yrs(AD)	1102	1986	1986	1986	1986	1986	1986
Body mesh,bottom	in	933	4.9	4.9	5.7	5.8	7.3	1.5
Body mesh,side	in	933	4.9	5.2	5.8	5.8	7.3	1.5
Body mesh,top	in	933	4.9	5.3	5.8	6.5	7.3	1.5
Intermed. mesh size	in	921	4.8	4.7	4.3	4.7	4.2	1.5
Codend mesh size	in	929	4.6	4.6	4.4	3.5	3.6	1.4
Headrope	ft	892	57	67	64	76	128	70
Footrope	ft	983	69	85	93	94	129	70
Gearage	yr	988	1	2	2	2	3	4
Primary floats	#	946	19	28	41	39	44	16
Primary float size	in	927	9	9	9	9	8	10
Secondary floats	#	153	.	17	14	21	28	.
Secondary float size	in	202	7	12	14	20	.	.
Bridle	fm	1014	14	18	19	22	26	37
Vertical opening	fm	832	1.98	2.36	2.57	3.97	8.92	3.50
Mud gear length	fm	660	60	54	46	.	.	.
Mud gear diameter	in	510	4.09	2.62	2.74	.	.	.
Door dimensions	ft sq	953	30	46	37	38	33	62

Table IV2.(continued)

Door weight	lb	949	860	1196	1190	1093	1024	1355
Vessel length	ft	1034	53	69	71	75	76	68
Horsepower	hp	1052	235	404	460	502	573	368
Cable diameter	in	1033	0.47	0.60	0.59	0.63	0.64	0.56
Cable length	fm	1033	482	706	707	750	780	548
Tow Duration	hr	1016	3.0	4.0	3.1	1.5	2.3	2.1
Mud	binary	1102	0.96	0.58	0.08	0	0	0
Combination	binary	1102	0	0.32	0.12	0.03	0	0
Roller	binary	1102	0.04	0.09	0.79	0.95	0.39	0
Midwater	binary	1102	0	0	0	0.01	0.62	0
Shrimp(1 net)	binary	1102	0	0	0	0	0	0.09
Shrimp(2 nets)	binary	1102	0	0	0	0	0	0.91
Summer	binary	1102	0.90	0.34	0.25	0.25	0.10	0.48
Fall	binary	1102	0.04	0.33	0.21	0.39	0	0.04
Winter	binary	1102	0.06	0.15	0.03	0.22	0.68	0
Spring	binary	1102	0.01	0.18	0.52	0.13	0.23	0.48
Morning	binary	965	0.20	0.17	0.24	0.32	0.19	0.16
Day	binary	965	0.54	0.37	0.57	0.53	0.19	0.70
Evening	binary	965	0.16	0.22	0.10	0.12	0.26	0.15
Night	binary	965	0.10	0.25	0.09	0.02	0.37	0

Table IV3. Comparison of error rates between non-parametric discriminant functions with variables selected by stepwise selection versus our method (see text), between non-parametric, linear, and quadratic functions, and between prior probabilities assumed equal versus probabilities in logbook data (Rogers and Pikitch 1994b). Position=latitude and longitude, temporal=season, diurnal, and year, and logstep= winter, spring, position, and tow duration; and allstep= wire let out, cable length, minimum distance travelled, and spring. Comparisons are made using only the tows which have information on all the variables in both functions.

VARIABLE	n	AVE	STD	%COR	C	BRF	DWD	NSM	DWR	WID
Variable Selection										
depth+ gear	678	0.20	0.22	84.2	0.14	0.06	0.19	0.01	0.18	0.56
+temporal	678	0.12	0.07	85.4	0.05	0.10	0.16	0.04	0.24	0.06
+logstep	678	0.09	0.07	91.0	0.03	0.18	0.08	0.06	0.14	0.00
Gear										
+depth	698	0.16	0.13	84.7	0.14	0.08	0.19	0.01	0.19	0.35
+allstep	698	0.10	0.05	88.5	0.06	0.07	0.14	0.05	0.16	0.12
+allstep	619	0.10	0.08	88.4	0.05	0.19	0.12	0.04	0.16	0.00
+logstep	619	0.08	0.06	91.6	0.03	0.16	0.08	0.06	0.11	0.00
Type of Function										
depth+gear npar	884	0.18	0.14	83.9	0.15	0.07	0.17	0.04	0.27	0.37
lin	884	0.19	0.14	83.4	0.02	0.07	0.19	0.04	0.26	0.37
quad	884	0.31	0.40	61.9	0.38	1.00	0.33	0.04	0.27	0.00
depth+logstep										
lin	678	0.24	0.23	81.1	0.23	0.07	0.21	0.06	0.27	0.56
quad	678	0.32	0.33	72.4	0.33	0.06	0.29	0.02	0.71	0.50
Prior Probability Assumptions (BRF=0.14,DWR=0.02,NSM=0.21,DWD=0.54,WID=0.10)										

Table IV4. Comparison of cross-validation misclassifications (hauls in error) using the a depth-gear function to those from a function using the stepwise-selected logbook variables (gear, depth, winter, spring, geographic position (lat/long), and tow duration.

Variables	Correct Assemblage	To Assemblage					Total	Errors	Percent Errors
		NSM	DWD	DWR	BRF	WID			
Depth, gear	NSM	94	0	0	1	0	95	1	1
	DWD	45	353	24	12	0	434	81	19
	DWR	0	8	54	4	0	66	12	18
	BRF	0	0	4	63	0	67	4	6
	WID	0	0	0	9	7	16	9	56
	Total	89	361	139	82	7	678	134	ave 20
Logbook Sel.	NSM	89	5	0	0	1	95	6	6
	DWD	11	400	21	2	0	434	34	8
	DWR	0	6	57	3	0	66	9	14
	BRF	1	0	1	55	10	67	12	18
	WID	0	0	0	0	16	16	0	0
	Total	101	411	79	60	27	678	61	ave 9

Table IV5. Coefficients of linear discriminant function analpredict mud gear (MG), roller gear (RG), or combination gear (CB) given strategy variables. Variables are listed in the order they were selected using stepwise analysis.

	MG	RG	CB
Constant	-651.54663	-691.00380	-646.07384
Vessel Length	1.85999	2.22514	2.16716
log(Tow speed)	30.58513	40.74051	27.13871
1/(Vertical Opening)	18.38221	1.61012	8.17513
Spring	-30.97891	-26.56677	-25.33252
Finish depth	0.01698	0.00703	0.02941
Primary float size	-1.17983	-2.26327	-1.57772
Body mesh, bottom	18.54546	20.92466	20.13533
log(Horse power)	153.61512	154.90376	147.54061
Fall	-28.61845	-27.99741	-23.68491
1/(Door weight)	136739	136268	126864
Cable length	-0.00783	-0.00225	0.01398
1/(Door dimension)	2953	3240	3386
Body mesh, side	1.01718	1.44596	-1.13713
Body mesh, top	-8.66940	-10.16429	-8.17330
Summer	9.81127	6.33974	10.17858

Table IV6. Species highly associated with the assemblages predicted using depth and gear with observer (O), logbook adjusted to pink tickets (L), and research (R) data.*=species assumed to be in logbook rockfish category(s) selected.

Species	Assemblages				
	BRF	DWR	NSM	WID	DWD
yellowtail r.f.	O L -	- - -	- -	O -	- -
bocaccio r.f.	O * -	- * -	- -	- -	- -
canary r.f.	O * -	- * -	- -	- -	- -
yelloweye r.f.	O * -	- * -	- -	- -	- -
lingcod	O L -	- - -	- -	- -	- -
sharpchin r.f.	O - -	O * -	- -	- -	- -
large r.f.	- L -	- L -	- -	- -	- -
widow r.f.	- - -	- - -	- -	O L	- -
Pacific whiting	- - R	- - -	- -	- L	- -
yellowmouth r.f.	- - R	O * -	- -	- -	- -
sanddab	- - R	- - -	O L	- -	- -
sand sole	- - R	- - -	O L	- -	- -
darkblotched r.f.	- - -	O * R	- -	- -	- -
splitnose r.f.	- - -	O * R	- -	- -	- -
P.o.p.	- - -	O L R	- -	- -	- -
small r.f.	- - -	- L -	- -	- -	- -
Dover sole	- - -	- L R	- L	- -	O L
sablefish	- - -	- - R	- -	- -	O -
s.s. thornyhead	- - -	- - R	- -	- -	O L
starry flounder	- - -	- - -	O L	- -	- -
Pacific cod	- - -	- - -	O -	- -	- -
petrale sole	- - -	- - -	O -	- -	- -
English sole	- - -	- - -	- L	- -	- -
arrowtooth fl.	- - -	- - -	- -	- -	O -

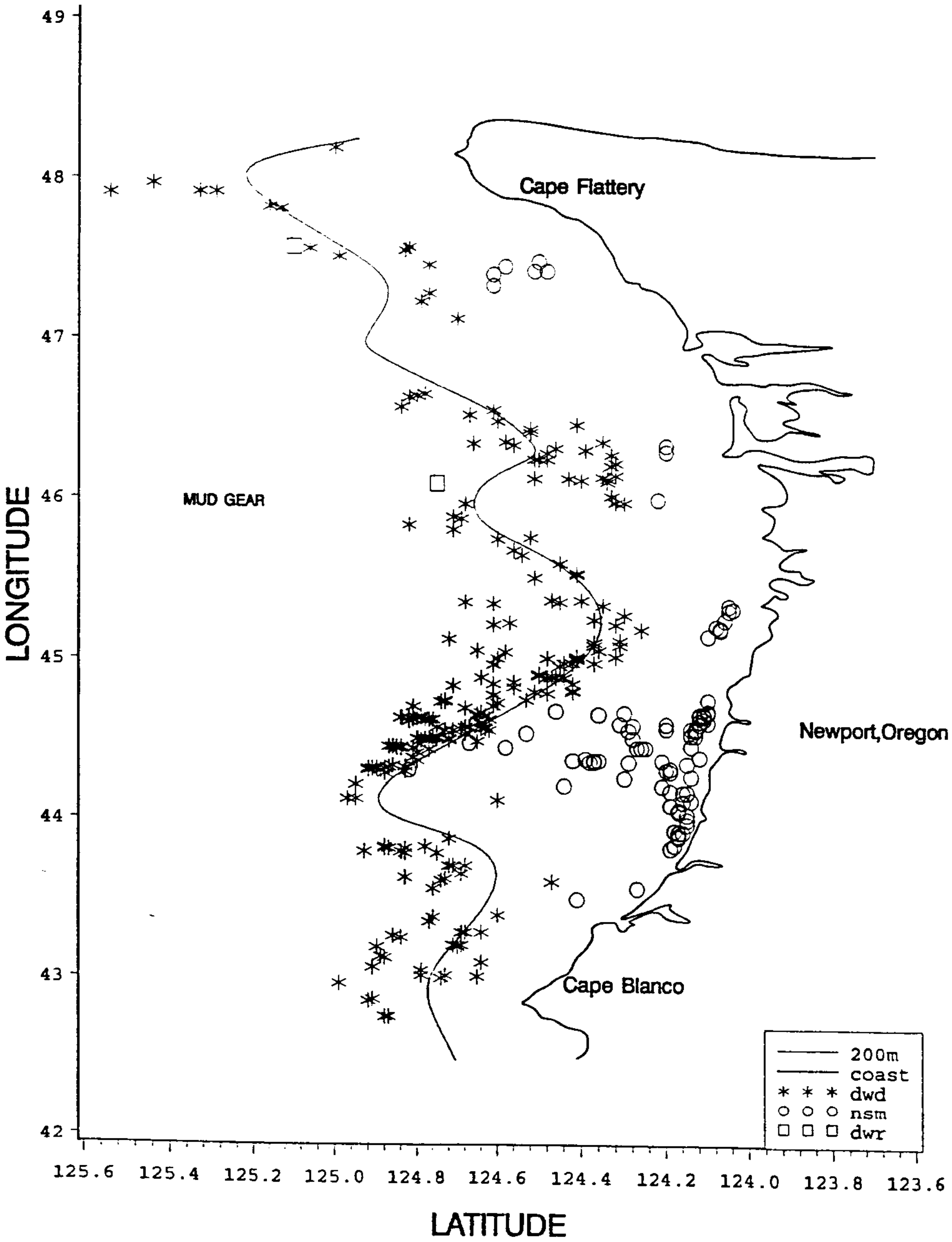


Figure IV1. A map of the starting locations of the tows made with mud gear, designated by assemblage. *=DWD, o=NSM, and =DWR. The solid line represents the shoreline.

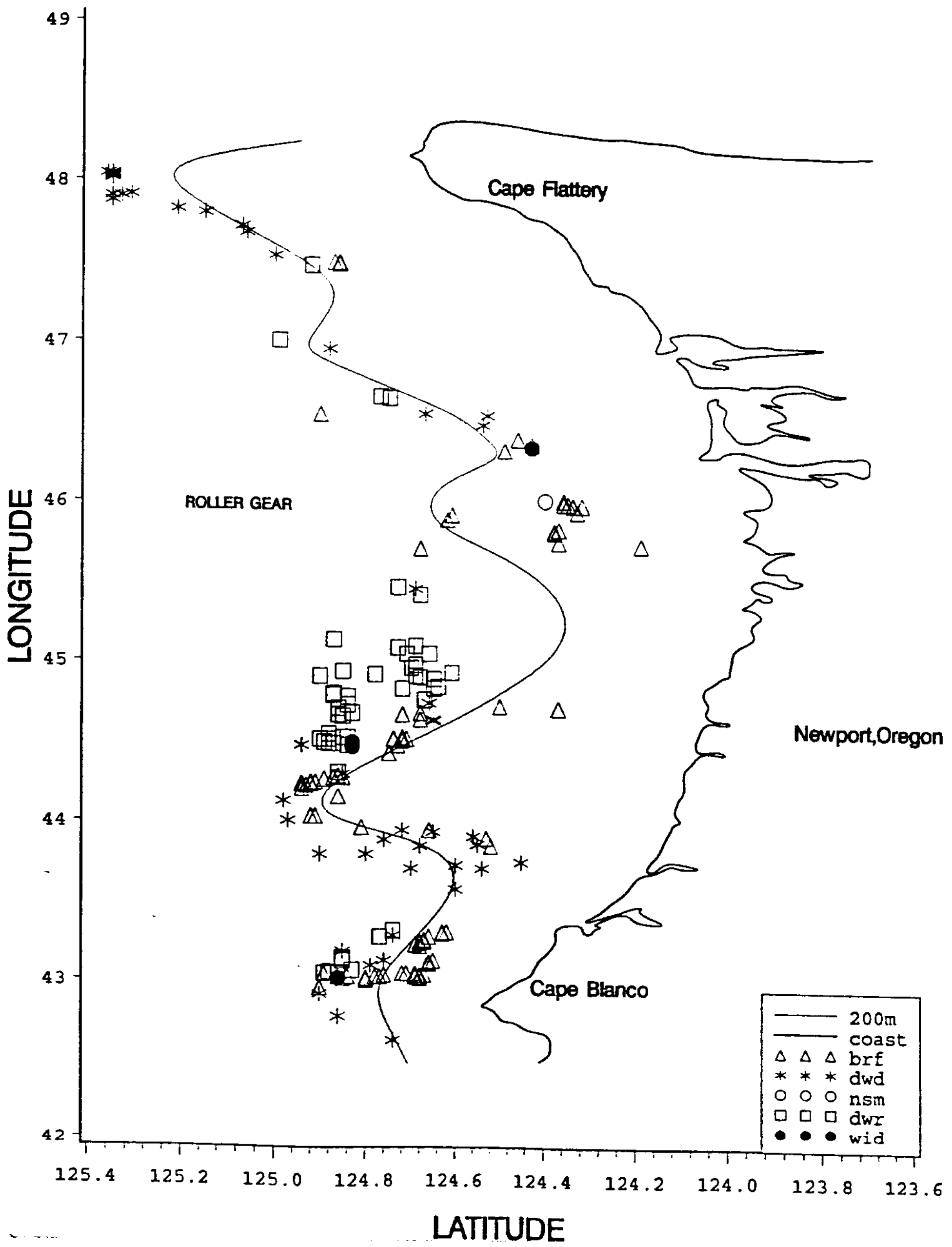


Figure IV2. A map of the starting locations of the tows made with roller gear, designated by assemblage: *=DWD, o=NSM, =DWR, =BRF,

Effectiveness of Fishing Strategies Used by Commercial Groundfish Fishermen off the Coasts of Oregon and Washington.

Jean Beyer Rogers[1] and Ellen K. Pikitch[2]

Department of Fisheries and Wildlife
Oregon State University
Mark O. Hatfield Marine Science Center
Newport, OR 97365, USA

[1] Present Address: National Marine Fisheries Service
3510 Paradise Dr.
Tiburon, CA 94920

[2] Present Address: Fisheries Research Institute
School of Fisheries WH-10
University of Washington
Seattle, WA 98195, USA

Abstract

The effectiveness of fishing strategies employed by the trawl fleet operating off the coasts of Oregon and Washington was investigated using data collected by observers on commercial vessels during 1986-1987. We examined targeting and discarding patterns occurring when fishermen caught different assemblages (groups of species). Fishermen targeted (intended to catch) different species when they caught the different assemblages, indicating that they could effectively target an assemblage. Fishermen often did not, however, intend to catch all the species within the assemblages, nor the sizes or amounts of the species that they caught. The average percent of the catch weight which was intentional (mentioned as a target species and kept) varied between greater than 80%, of the widow rockfish (Sebastes entomelas) assemblage, to less than 20% of the nearshore-mixed species assemblage catches. For each of the commercially important species, except widow rockfish and pink shrimp (Pandalus jordani), at least 15% of the average catch was unintentional (not mentioned as a target species). The average percent of the catch weight which contained unavoidable species and sizes (non-targeted and discarded) ranged from 1% for the widow assemblage to 65% for the nearshore mixed-species assemblage. When fishermen targeted widow rockfish they caught primarily the desired species in marketable sizes, but apparently had difficulty controlling the amount of catch in a tow (13% average targeted and discarded). This resulted in substantial amounts of regulation-induced discards of widow rockfish in an average haul.

Introduction

Knowledge of the effectiveness of fishing strategies used by the trawl fishery operating off the coasts of Oregon and Washington is necessary for developing management plans. Two measures of effectiveness are the correspondence between targets (intended catch) and the actual catch, and the amount of discarding occurring.

Recent work by Rogers and Pikitch (1992,1994a,1994b) suggested that management of groundfish off the coasts of Oregon and Washington could be based on six major assemblages (groups) of species which were consistently caught together. Management of the separate complexes, however, depends upon the assemblages having different targets, implying that fishermen can intentionally catch or avoid the assemblage. In addition, to justify managing the species as complexes rather than individual species, the fishermen should not be able to target the species separately. For instance, management is presently based on a deepwater Dover complex (DWD) and a bottom rockfish complex (<u>Sebastes</u> spp.) (BRF). Rogers and Pikitch (1992) determined an intermediate assemblage, the deepwater rockfish complex (DWR). That assemblage was closely related to DWD, but considered part of BRF for management purposes. From the information presently available, it appears the fishermen intended to catch either rockfish in general or the DWD complex when catching DWR (Rogers and Pikitch 1992a). This was based, however, on the assignment of a preselected set of targets, which did not include a deepwater rockfish option. The target of BRF was also primarily rockfish in general. Other analyses indicated that the catch of DWR could be predicted given information on the decisions which fishermen make (Rogers and Pikitch 1994b), but that there was some confusion between DWR and DWD. Further investigation of the targeting occurring in that assemblage, as well as in the other assemblages, could help determine the validity of managing based on those complexes.

Knowledge of discarding in the assemblage catches is also vital in assessing management options, as well as conducting stock assessments. Discarding of all the major species in an assemblage indicates that the catch of the complex was not intentional and management of that complex may not be possible. Discarding of only some of the major species indicates that management of the assemblage is not only possible but necessary. In addition, it is important to have estimates of discarding when using landing information to produce stock assessments, or for determining trip limits. Prior analyses of the data base used to define the assemblages have determined that discarding was occurring during the study, but estimates were made only for species regulated by trip limits (Pikitch et al. 1988), or in a general way between assemblages (Rogers and Pikitch 1994b). The specific objective of this paper is to the determine the targeting and discarding patterns for each assemblage identified for the West Coast ground trawl fishery.

Materials and Methods

Observers of normal fishing operations on commercial fishing vessels collected the data during study conducted in 1985-1987 (Pikitch 1987b, Pikitch et al. 1988). The northern and southern boundaries of the study were 48^0 42′ and 42^0 60′, respectively, primarily the Columbia management area. Participation in the study was voluntary, and included vessels using bottom, midwater, and shrimp trawls.

Observers recorded information on catch and discarding for each species in each tow. The data included weights and numbers of species kept and discarded (Rogers and Pikitch 1992). Total lengths of fish (to the nearest cm) were measured for a subsample of hauls. Reasons given by the fishermen for the discarding a species in a tow were classified by the observers as either regulations (trip limit for species previously reached); high grade (fish have lesser value per unit weight than other individuals, but are marketable); size (fish are below the minimum acceptable market size); market problems (fish are not marketable for reasons other than size); or other (other reasons for discard).

Before each tow, the fishermen stated their target species. Observers recorded up to five targets, in order of decreasing importance. Targeting information was available on only 376 of the 1482 tows; that information was not sought before September 1986.

We summarized the targeting and discarding information for the tows catching each assemblage, as designated by Rogers and Pikitch (1992a). The designations included a shrimp assemblage (SHR) mostly pink shrimp; a widow rockfish assemblage (WID), primarily widow rockfish; a bottom rockfish assemblage (BRF), which included catches of primarily yellowtail rockfish (<u>Sebastes</u> <u>flavidus</u>), canary rockfish (<u>Sebastes</u> <u>pinniger</u>), lingcod (<u>Ophiodon</u> <u>elongatus</u>), yelloweye rockfish

(Sebastes ruberrimus), bocaccio (Sebastes paucispinis), and sharpchin rockfish (Sebastes zacentrus); a deepwater Dover sole assemblage (DWD), dominated by Dover sole (Microstomus pacificus) and sablefish (Anoplopoma fimbria); a nearshore mixed-species assemblage (NSM), including English sole (Parophyrs vetulus), sanddab (Citharichthys spp.), sand sole (Psettichthys melanostictus), starry flounder (Platichthys stellatus), and petrale sole (Eopsetta jordani); and a deepwater rockfish assemblage (DWR), including darkblotched rockfish (Sebastes crameri), Pacific ocean perch (P.O.P.) (Sebastes alutus), splitnose rockfish (Sebastes diploproa), yellowmouth rockfish (Sebastes reedi), and sharpchin rockfish (Sebastes zacentrus).

To determine which species the fishermen were targeting when they caught each assemblage, we summed the number of times each species was recorded as a target for the tows in an assemblage designation. This was done for the primary targets, as well as for the lesser targets if any were indicated.

When targeting information was available, we divided the entire catch (vertebrates and invertebrates) in each tow into four categories: targeted and kept, targeted and discarded, non-targeted and kept, and non-targeted and discarded. If the stated target of a tow was a group of species, such as rockfish (Sebastes spp.) or flatfish (Pleuronectidae and Bothidae), the tow was not used in the analyses because it could not be determined exactly which species the fisherman had in mind. The percent of the total weight caught in each of the four categories was calculated for each tow. For an overall comparison among assemblages, the percents in each category were then averaged using the tows in each assemblage designation. By averaging in this way, each tow was given equal weight regardless of the size of the catch, indicating the control that fishermen had over an average catch.

The reasons for discarding were examined for each type of discard (targeted and non-targeted) in each assemblage. The percent weight of fish discarded for each reason in each type of discard was calculated for each tow. The percents were then averaged by assemblage designation.

We also performed the same targeting and discarding analyses described above for each of the species used to define the assemblages (Rogers and Pikitch 1992). Those selected species were determined to have potential commercial importance because they were identified as targets in the study or their catch was at least 1% of the total weight sampled in the study. For each species, the average percent weight in the various categories, using only the tows that caught that species, was calculated for each assemblage designation. In interpreting the results for each assemblage, we concentrated upon the species which were highly associated with the assemblages. Those species, mentioned earlier in the assemblage definitions, either had a high average percent weight in the hauls or they were selectively caught in that assemblage (Rogers and Pikitch 1992).

To assess the significance of the discards, the actual amount of discarding, in terms of both weight and numbers, was determined for the potentially commercial species in each assemblage designation. The weight and numbers in each category (targeted and non-targeted discards for each reason) were summed for all the selected species in each haul. The totals were then averaged for each assemblage designation. The targeted and non-targeted weights and numbers discarded were also summed for each species in each haul that caught that species, and then averaged for each assemblage.

Since there was targeting information only for the latter part of the study, we also performed analyses to estimate discarding patterns using all the data. The percent weight discarded in each tow, using all the species or only the selected species, was averaged for all the tows in each assemblage designation. To aid in comparing the significance of the discards in the two data bases, we also calculated the average weight of the catch, using all the species or only the selected species.

Other analyses were performed to provide supplemental information on the market conditions present during our study. Since the amount of discarding because of market factors could be expected to be related to the price for the fish offered by the processors, we compared price per pound paid for the selected species. The prices were obtained from processing plant receipts ("pink tickets") collected by the Oregon Department of Fish and Wildlife for the trips observed during the study. The categories specified were those determined by the processors, including the rockfish and red-rockfish categories. We determined the range of prices per pound paid for each species/category. Price information was based on 104 of the 139 trips observed, and included trips made with no targeting information. Although the minimum sizes of fish accepted by the markets were not recorded during our study, we investigated this by examining the sizes of the fish in the discarded catch. Using the entire data base, we calculated the range and mean of the total lengths of the selected species discarded when the stated reason for the discard was size.

To account for possible bias from fishermen changing their targets to match species already caught in the same area, we compared the average percent of targeted fish caught in new locations versus the average caught in subsequent catches in the same locations. We compared the means using t tests, having determined the variances were equal using F tests.

Results

The target species/categories for the tows catching the different assemblages varied among assemblages, and were consistent with the species highly associated with the assemblages. Targets indicated for the SHR and WID assemblages were always pink shrimp and widow rockfish respectively. The main targets for tows catching the other assemblages were: Dover sole and sablefish for DWD; rockfish in general for DWR; sand, petrale, and English soles for NSM; and yellowtail and canary rockfish for BRF (Table V1). All the often targeted species met the criteria stated earlier for high association with their respective assemblages, but some of the species which were highly associated with NSM, BRF, and DWR were rarely mentioned as targets (Table V1). Tows catching DWD had the greatest average number of targets identified (2.1) for a given tow, followed by NSM, which averaged 1.8 targets, and then BRF and DWR, both averaging 1.2 targets.

The analyses with all species combined indicated substantial differences among assemblages in the amount of control that fishermen had over their catches. Targeting success, or intentional catch, as evaluated by the average percent of the target species caught and kept, varied greatly among assemblage designations (Figure V1). More than 80% of the average catch in the WID assemblage hauls was intentional, while less than 20% of the average NSM catch was intentional. Except when catching the NSM and SHR assemblages, fishermen kept a substantial percent of the non-targeted fish they caught (Figure V1). The NSM assemblage had a much higher average percent of the catch discarded than did catches of the other assemblages (Figures V1 and V2). Discards of targeted species averaged a small percentage of the catch, except for widow rockfish in WID (Figures V2 and V3).

The reasons given for discarding were similar among assemblages for the non-targeted discards, but varied for the targeted discards (Figure V2). For the non-targeted discards, market problems was the stated reason for the highest percent of the discard. Size was generally the next most important reason. For the targeted discards, all the discards in WID were attributed to regulations and most of the discards in NSM were caused by size (Figure V2).

When comparing the species highly associated with the assemblages, it was apparent that not all the catches of those species were intentional. This was true even for the species which were mentioned most often as targets. Except for pink shrimp in SHR and widow rockfish in WID, at least 15% of the average catch of every highly associated species in every assemblage was unintentional (Table V2). The only species where greater than 50% of the average catch occurred when the species was targeted were: yellowtail and canary in BRF, Dover sole in DWD, Sand Sole in NSM, pink shrimp in SHR, and widow rockfish in WID. Other assemblage-associated species had greater than 50% of the average catch kept but caught unintentionally: lingcod, bocaccio, and yelloweye in BRF, starry flounder in NSM, and sharpchin in DWR (Table V2). Some of the associated species were never discarded: bocaccio, yelloweye, and canary in BRF catches, darkblotched rockfish in DWR, and pink shrimp in SHR. Other associated species were often discarded and apparently could not be avoided. Those species, whose average catch was over 50% non-targeted and discarded, included sharpchin in BRF, sanddab in NSM, and splitnose in DWR.

The reasons given for discarding the highly associated species varied (Table V3). Regulations caused the targeted discards of widow rockfish in the WID assemblage and some of the DWD assemblage targeted sablefish discards. Regulations were also stated as the reason for some of the non-targeted discards of yellowtail in BRF assemblage catches and sablefish in DWD. Only sablefish had any discard due to high grading. Size was responsible for the all the discards of lingcod and sharpchin in BRF, Dover sole in DWD, starry flounder and petrale, English, and sand soles in NSM, and P.O.P., darkblotched, and yellowmouth rockfishes in DWR. Sanddab was discarded due to market problems and size.

Four of the six potentially commercial species which were not highly associated with any assemblage had substantial discards due to market problems. Spiny dogfish (Squalus acanthias) and Pacific hake (Merluccius productus) were always discarded, almost all longnose skate (Raja rhina) catches were discarded, and greater than 60% of the catches of arrowtooth flounder (Atheresthes stomias) were discarded (Table V2). Those discards were primarily a result of market problems (Table V3).

The analyses which compared discarding of the potentially commercial species in the assemblages in terms of weight and numbers, demonstrated the importance of the WID discards. The average WID weight discarded was substantially greater than the discards in the other assemblages (Figure V3). The average number of fish discarded in WID was closer to that discarded for the other assemblages, but was still about two times higher than the next highest average (NSM) (Figure V4). As would be expected, discards due to size gained relative importance when comparing numbers rather than weight (Figures V3 and V4).

Comparing the numbers and weights discarded for the individual species showed their relative contributions to the total discards. Again the average weight discarded for widow rockfish was substantially greater than the weights for the other species (Table V4). The next highest average weights discarded were for Pacific whiting in WID and sanddab in NSM. Pacific whiting had noticeably high average weights discarded in all assemblages. In considering the average number discarded versus the weight discarded, the discards of widow rockfish, yellowtail rockfish, spiny dogfish, and longnose skate generally lost importance (Tables V4 and V5). The average number of widow rockfish discarded in WID was still much higher than the other discards, but the discards of sanddab and English sole in NSM and the discards of Pacific whiting in WID, DWD, and SHR were substantial (Table V5).

Discarding in all the tows made during the 1985-1987 study was similar to discarding in the tows with target information (Table V6). The average percent discarded and weight caught for WID in the targeted hauls was, however, about twice that in all the hauls. This reflected the influence of one large haul which was 63% discarded, the last WID haul made in the study. Using the entire data base, the WID assemblage hauls were still substantially larger than the hauls in the other assemblages, resulting in greater amounts of discard (Table V6).

Comparison of the data bases using all the species versus those using only the potentially commercial species showed substantial differences only for NSM. The NSM catches of 0.41 MT increased by 0.36 MT, and the corresponding increase in the percents discarded indicated that it was all discarded. Most of the additional NSM catch consisted of big skate (Raja binoculata), with some butter sole (Isopsetta isolepis), spotted ratfish ((Hydrolagus colliei), and jellyfish (Scyphozoa). The catches in the other assemblages increased slightly with the added species, but increases in percent discarded indicated the additional catch was also primarily discarded.

The price-per-pound ranges of the landed fish were not always directly related to the amount of discard due to market problems and high grade (Table V5). Pacific hake and arrowtooth flounder did have the lowest prices. Spiny dogfish was never landed, and so did not have any price range. Skate (Raja sp.) however, had relatively high prices, as did sanddab. It is possible that the high prices were paid for other species of skate or sanddabs than the ones discarded due to market problems. Although six of the species/categories had price gradations based on size (Table V5), only sablefish was high graded. The prices for rockfish and red rockfish generally increased over the time of the study. When both small and large rockfish (or red rockfish) were specified for a trip, with one exception the price for small fish was two cents less per pound than for large fish. The category which was considered "large" was specified only as "rockfish" on the pink tickets. The additional categories "red", "small", or "small red" were written in.

The length analyses demonstrated that for most species, only fish under approximately 35 cm total length were discarded due to size (Table V8). This was somewhat higher for sablefish, indicating perhaps that size was stated as the reason when actually the reason was high-grading. The maximum size of shortspine thornyhead discarded was also larger than average, but only 1% of the fish were above 35 cm. P.O.P. discards due to size averaged much smaller than for the other species, but only three fish were measured. Fishermen bias from adjusting the stated target to a prior catch in the same area was not apparent, except in the DWR assemblage catches. Differences in the average percent of the catch which was targeted in the first catches in an area to the average in subsequent catches were not significant ($p<0.05$) for the other assemblages. The DWR assemblage catches had a mean of 39% targeted in the first catches, versus 62% targeted in the subsequent catches, which was significant, though based on small sample sizes (five first catches versus three later catches).

Discussion

Our results indicated that management of the separate assemblages is feasible, but that fishermen had the most difficulty targeting NSM versus DWD and DWR versus DWD. This result was similar to the difficulties encountered in correctly predicting those assemblages based on the decisions the fishermen made (Rogers and Pikitch 1994b). When targeting did fail, usually DWR species were intended or NSM species were intended, but DWD was caught. These failed tows were also a small percentage of the total DWD tows. Based on that information, the unsuccessful tows would not hinder management by assemblages. The estimated errors for Rogers and Pikitch's (1994b) selected strategy predictions substantiated that NSM failures were DWD and DWD failures were not NSM, but strategies which predicted DWD were DWR as often as DWR was predicted and DWD caught (Rogers and Pikitch 1994b). It is possible that fishermen had a strategy for catching DWD instead of DWR which was based on decisions not measured in the study. Fishermen apparently were able to target DWR versus BRF. Although the target for DWR was usually rockfish in general, when fishermen caught BRF, they were specifically targeting yellowtail rockfish or canary rockfish. Few of the errors in predicting the assemblages given gear and depth were a result of confusing DWR and BRF. The feasibility of managing DWR separate from the rest of the Sebastes complex was verified.

Management by assemblage not only appears possible, but seems necessary. There was substantial amount of discarding, even for some of the major species which were often mentioned as targets. For instance, DWD showed some evidence of multiple targets: Dover sole, sablefish, and shortspine thornyhead. In spite of that, 21 % of the average catch of sablefish and 24% of the catch of shortspine thornyhead was not-targeted and discarded. The amount of discarding occurring in NSM is disturbing, as well as the high percents of English sole and petrale sole which were unintentional. Regulating those species may not be possible without also restricting sand sole. There was some evidence that regulation-induced discard did occur, and species which were regulated were caught unintentionally. Our results were similar to those in Pikitch et al. (1988), except that we did not report discards of P.o.p. due to regulations. All the regulation-induced discard of that species occurred in one haul, which was not included in the present analyses.

Regulation-induced discard also occurred because fishermen caught too many widow rockfish in a single haul. Those discards were substantial in both numbers and weight. Limiting that type of discard does not involve assemblage management, but could require changes such as yearly quotas per boat, rather than trip limits. Mesh size increases could help limit the size of the catch.

Although regulations based on assemblages rather than individual species may prevent some discarding, most of the discarding occurred because of market problems and size. Assemblage management may require encouraging utilization of some species, as well as preventing over-utilization of other species. This could not only prevent waste, but also provide the necessary catch information to determine if the stock needs protection. Pacific whiting, for example, was commonly caught with all the assemblages and always discarded, primarily due to market problems. With the proper handling, however, the species is desirable and it is currently regulated in other fisheries (Dorn and Methot 1991). Other species, such as arrowtooth flounder and sanddab could have potential markets. The estimated value of the arrowtooth flounder landings in Oregon did show a steady increase from 1986 to 1989 (Lukas and Carter 1991), indicating a market is developing for that species. Long-term fisheries for spiny dogfish and longnose skate may not be feasible since those species produce very few eggs per year (Hart 1973). In addition, those species may survive since they are large and often discarded soon after catching (Saila 1983).

Assuming that the discarded fish die, the percent discard we estimated could be used to adjust landings when estimates of the actual catch are needed. This information could change over time, based on a variety of factors, but our estimates are the only discarding information available for many of the species. Using the data we presented on the price of the species and the lengths discarded during the study, as well as information on trip limits, year class strengths, and strategy changes, the percent discarded could be adjusted as conditions change. Changes in the market (acceptable size and desirability of the species) may not be reflected in the prices paid for landed fish, so discussions with processing plant managers may be necessary.

Conclusions and Recommendations

Although fishermen did appear to intentionally catch the different assemblages, they did not always intentionally catch the species in the assemblages. This verifies that when attempting to regulate a single species within the multi-species assemblages, managers should consider that fishermen may continue to catch and discard that species while targeting on other species in the assemblage. Methods of conducting stock assessments and setting limits on an assemblage level need to be further explored. For instance, the Sebastes complex presently has a joint trip limit, but this is not based on accurate stock assessments for the individual species or the group considered together.

Management by assemblage needs to involve encouraging markets for underutilized species, as well as regulating the assemblage as a whole. Market development for sanddab and arrowtooth flounder appeared to have particular potential. Our study supplies estimates of discard rates for many species. These rates, modified if necessary based on changing conditions, can be used to derive more accurate estimates of the catch of those species. The catch rates are important both in stock assessments and determining regulation levels, such as trip limits.

Table V1. The number of times a species was mentioned as the target of a haul in each assemblage. The stated primary target of a haul was designated T1, followed by increasingly less important targets.

	ASSEMBLAGE (# of tows)																		
	DWD (231)					DWR (37)				NSM (42)				SHR (96)	BRF (68)				WID (9)
	T1	T2	T3	T4	T5	T1	T2	T3	T4	T1	T2	T3	T4	T1	T1	T2	T3	T4	T1
Dogfish	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LN Skate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sanddab	0	0	0	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0
Arrow. Fl.	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petrale S.	8	16	6	4	1	0	0	0	0	13	6	1	1	0	0	0	0	0	0
English S.	1	3	1	1	0	0	0	0	1	5	11	5	0	0	0	0	0	0	0
Dover S.	145	26	6	0	0	1	3	0	0	1	1	0	0	0	0	0	0	0	0
Rex Sole	0	2	3	2	1	0	0	0	0	0	2	1	0	0	0	0	0	0	0
Starry Fl.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sand S.	0	0	0	0	0	0	0	0	0	16	1	3	0	0	0	0	0	0	0
Flatfish	6	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Sablefish	34	61	16	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Pac. Cod	2	4	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lingcod	2	5	2	1	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0
Pac. Whiting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S.S.Thorny.	5	10	28	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rockfish	14	17	7	1	0	24	2	0	0	0	0	0	0	0	6	2	1	0	0
P.O.P.	2	2	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
Darkbl. R.	3	1	0	1	0	2	2	0	0	0	0	0	0	0	0	1	0	0	0
Splitn. R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Widow R.	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	9
Y.tail R.	1	0	0	0	1	0	0	0	0	3	0	0	0	0	38	2	1	1	0
Bocaccio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Canary R.	0	0	0	1	0	0	0	0	0	0	0	0	0	0	14	11	0	0	0
Yelloweye R.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sharpchin R.	5	1	1	4	0	3	0	0	0	0	0	0	0	0	6	7	0	0	0
Yellowmouth	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
P. Shrimp	0	0	0	0	0	0	0	0	0	0	0	0	0	96	1	0	0	0	0

Table V2. Average percent by weight of selected species caught in targeted hauls, where TK = targeted and kept, TD= targeted and discarded, NK=not-targeted and kept, and ND=not-targeted and discarded. * = 100 percent.

Species	Assemblage																							
	BRF				DWD				NSM				DWR				SHR				WID			
	TK	TD	NK	ND	TK	TD	NK	ND	TK	TD	NK	ND	TK	TD	NK	ND	TK	TD	NK	ND	TK	TD	NK	ND
Dogfish	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*
LN Skate	0	0	0	*	0	0	7	93	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*
Sanddab	0	0	0	*	0	0	39	61	4	4	6	86	0	0	0	0	0	0	0	*	0	0	0	*
Arrow. Fl.	0	0	0	*	7	<1	33	60	0	0	16	84	0	0	0	*	0	0	20	80	0	0	0	0
Petrale S.	0	0	86	14	37	<1	61	3	44	10	40	6	0	0	*	0	0	0	40	60	0	0	0	0
English S.	0	0	43	57	10	<1	80	9	38	15	29	19	0	0	*	0	0	0	50	50	0	0	0	0
Dover S.	0	0	64	36	84	<1	15	<1	5	2	80	13	29	0	71	0	0	0	14	86	0	0	0	0
Rex Sole	0	0	17	83	4	1	78	17	7	1	53	39	0	0	82	18	0	0	<1	99	0	0	0	0
Starry Fl.	0	0	0	0	0	0	0	0	0	5	95	<1	0	0	0	0	0	0	0	0	0	0	0	0
Sand S.	0	0	0	0	0	0	50	50	76	6	17	<1	0	0	0	0	0	0	0	0	0	0	0	0
Sablefish	0	0	40	60	48	3	28	21	0	0	0	*	0	0	58	42	0	0	28	72	0	0	0	0
Pac. Cod	0	0	91	9	16	<1	81	2	0	0	86	14	0	0	*	0	0	0	61	39	0	0	0	*
Lingcod	8	0	78	13	5	0	95	0	0	0	89	11	0	0	*	0	0	0	50	50	0	0	*	0
Pac. Whiting	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*	0	0	0	*
S.S.Thorny.	0	0	0	*	21	4	51	24	0	0	0	0	0	0	50	50	0	0	14	87	0	0	0	0
P.O.P.	0	0	53	47	2	2	92	5	0	0	0	0	50	<1	50	0	0	0	19	81	0	0	*	0
Darkbl. R.	0	0	0	*	6	0	77	17	0	0	0	0	50	0	50	0	0	0	20	80	0	0	0	0
Splitn. R.	0	0	0	0	0	0	53	48	0	0	0	0	0	0	39	61	0	0	0	*	0	0	0	0
Widow R.	0	0	69	31	0	0	*	0	0	0	0	0	*	0	0	0	0	0	*	0	88	12	0	0
Y.tail R.	83	3	10	5	12	0	88	0	50	0	50	0	0	0	0	0	0	0	*	0	0	0	0	0
Bocaccio	8	0	92	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	*	0
Canary R.	67	0	33	0	0	0	*	0	0	0	80	20	0	0	0	0	0	0	*	0	0	0	*	0
Yelloweye R.	0	0	*	0	0	0	*	0	0	0	*	0	0	0	0	0	0	0	0	0	0	0	0	0
Sharpchin R.	0	0	2	98	0	0	52	48	0	0	0	0	0	0	67	33	0	0	14	86	0	0	0	0
Yellowmouth	0	0	0	*	0	0	*	0	0	0	0	0	0	0	*	<1	0	0	0	0	0	0	0	0
P. Shrimp	*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0	0	0	0	0	0

Table V3. Reasons for discarding stated by fishermen for selected species, which were targeted and discarded (TD) or not-targeted and discarded (ND). Codes for the reasons are: 1= size, 2=market problems, 3=high-grading, 4=regulations, and 5=other. A * means that the reason is responsible for discards of greater than 50% of the catch in an average haul.

Species	Assemblage											
	BRF		DWD		NSM		DWR		SHR		WID	
	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND
Dogfish	0	2*	0	1,2*	0	2*	0	2*	0	2*	0	0
LN Skate	0	2*	0	1,2*	0	2*	0	2*	0	2*	0	0
Sanddab	0	2*,5	0	1,2	1,2	1,2*	0	0	0	1,2*	0	0
Arrow. Fl.	0	2*	1	1,2*,5	0	1,2*	0	1,2*	0	1,2*	0	0
Petrale S.	0	1,5	1	1	1	1	0	0	0	5*	0	0
English S.	0	1,5	1	1	1	1	0	0	0	1	0	0
Dover S.	0	1,5	1	1	1	1	0	0	0	1*,5	0	0
Rex Sole	0	1*,5	1	1	1	1	0	1	0	1*,2,5	0	0
Starry Fl.	0	0	0	0	1	1	0	0	0	0	0	0
Sand S.	0	0	0	2	1	1	0	0	0	0	0	0
Sablefish	0	1*	1,3,4	1,3,4,5	0	1*,2	0	1,3	0	1*,2,5	0	0
Pac. Cod	0	0	1	5	0	1,5	0	0	0	2,5	0	5*
Lingcod	0	1	0	0	0	1	0	0	0	1	0	0
Pac. Whiting	0	2*	0	1,2*	0	2*	0	2*	0	2*	0	2*
S.S.Thorny.	0	1*	1	1,2	0	0	0	1*	0	1*,2	0	0
P.O.P.	0	1	1	1	0	0	1	0	0	1*	0	0
Darkbl. R.	0	1*	0	1	0	0	0	0	0	1*	0	0
Splitn. R.	0	0	0	1	0	0	0	1*	0	1*,2	0	0
Widow R.	0	1,3	0	0	0	0	0	0	0	0	3	0
Y.tail R.	5	3,5	0	0	0	0	0	0	0	0	0	0
Bocaccio	0	0	0	0	0	0	0	0	0	0	0	0
Canary R.	0	0	0	0	0	1	0	0	0	0	0	0
Yelloweye R.	0	0	0	0	0	0	0	0	0	0	0	0
Sharpchin R.	0	1*	0	1	0	0	0	1	0	1*	0	0
Yellowmth. R.	0	1*	0	0	0	0	0	1	0	0	0	0
P. Shrimp	0	0	0	0	0	0	0	0	0	0	0	0

Table V4. Kilograms discarded in an average haul for each assemblage designation, where TD is the discards occurring when the species was targeted and ND is the discards when the species is not targeted.

Species	Assemblage											
	BRF		DWD		NSM		DWR		SHR		WID	
	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND
Dogfish S.	0	2	0	23	0	4	0	1	0	1	0	0
LN Skate	0	1	0	28	0	25	0	2	0	1	0	0
Sanddab	0	<1	0	<1	1	135	0	0	0	2	0	0
Arrow. Fl	0	<1	<1	62	0	<1	0	33	0	1	0	0
Petrale S	0	<1	<1	<1	7	2	0	0	0	<1	0	0
English S	0	<1	<1	<1	20	26	0	0	0	<1	0	0
Dover S.	0	1	4	<1	1	<1	0	0	0	5	0	0
Rex Sole	0	9	3	5	<1	13	0	2	0	4	0	0
Starry Fl	0	0	0	0	<1	<1	0	0	0	0	0	0
Sand S.	0	0	0	<1	7	<1	0	0	0	0	0	0
Sablefish	0	<1	22	34	0	<1	0	4	0	7	0	0
Lingcod	0	<1	0	0	0	<1	0	0	0	<1	0	0
Pac. Whiting	0	<1	0	64	0	50	0	24	0	60	0	135
S.S.Thorny	0	<1	5	14	0	0	0	8	0	1	0	0
P.O.P.	0	<1	<1	<1	0	0	<1	0	0	<1	0	0
Darkbl. R.	0	<1	0	<1	0	0	0	0	0	2	0	0
Splitn. R.	0	0	0	3	0	0	0	19	0	2	0	0
Widow R.	0	5	0	0	0	0	0	0	0	0	2954	0
Y.tail R.	<1	9	0	0	0	0	0	0	0	0	0	0
Bocaccio	0	0	0	0	0	0	0	0	0	0	0	0
Canary R.	0	0	0	0	0	<1	0	0	0	0	0	0
Yelloweye	0	0	0	0	0	0	0	0	0	0	0	0
Sharpchin	0	2	0	<1	0	0	0	2	0	<1	0	0
Yellowmouth	0	<1	0	0	0	0	0	<1	0	0	0	0
P. Shrimp	0	0	0	0	0	0	0	0	0	0	0	0

Table V5. Number discarded in an average haul for each assemblage designation, where TD is the discards occurring when the species was targeted and ND is the discards when the species is not targeted.

Species	Assemblage											
	BRF		DWD		NSM		DWR		SHR		WID	
	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND	TD	ND
Dogfish S.	0	2	0	13	0	3	0	1	0	1	0	0
LN Skate	0	1	0	11	0	18	0	1	0	1	0	0
Sanddab	0	1	0	2	7	806	0	0	0	13	0	0
Arrow. Fl	0	1	1	85	0	2	0	31	0	4	0	0
Petrale S	0	1	1	1	38	14	0	0	0	1	0	0
English S	0	3	2	1	160	240	0	0	0	1	0	0
Dover S.	0	6	16	1	7	3	0	0	0	24	0	0
Rex Sole	0	70	21	38	3	88	0	11	0	58	0	0
Starry Fl	0	0	0	0	1	1	0	0	0	0	0	0
Sand S.	0	0	0	1	43	1	0	0	0	0	0	0
Sablefish	0	1	25	34	0	1	0	3	0	16	0	0
Lingcod	0	1	0	0	0	1	0	0	0	1	0	0
Pac. Whiting	0	1	0	125	0	63	0	40	0	145	0	409
S.S.Thorny	0	1	40	83	0	0	0	49	0	9	0	0
P.O.P.	0	1	1	1	0	0	2	0	0	2	0	0
Darkbl. R.	0	1	0	2	0	0	0	0	0	15	0	0
Splitn. R.	0	1	0	19	0	0	0	98	0	51	0	0
Widow R.	0	3	0	0	0	0	0	0	0	0	2741	0
Y.tail R.	1	8	0	0	0	0	0	0	0	0	0	0
Bocaccio	0	0	0	0	0	0	0	0	0	0	0	0
Canary R.	0	0	0	0	0	1	0	0	0	0	0	0
Yelloweye	0	0	0	0	0	0	0	0	0	0	0	0
Sharpchin	0	18	0	2	0	0	0	4	0	1	0	0
Yellowmouth	0	4	0	0	0	0	0	1	0	0	0	0
P. Shrimp	0	0	0	0	0	0	0	0	0	0	0	0

Table V6. Comparison of the average percent discarded and metric tons caught in hauls for each assemblage designation, using four different selections of the observer data. The data compared included all the hauls used to define the assemblages and all the species caught, all the hauls and the potentially commercial species, the hauls with targeting information and all the species, and the hauls with targeting information and the potentially commercial species.

Assemblage	All Hauls					Hauls with Targeting Data				
	n	All Sp.		Comm. Sp.		n	All Sp.		Comm. Sp.	
		%	MT	%	MT		%	MT	%	Mt
BRF	143	**22**	1.41	**16**	1.21	46	**14**	0.94	**11**	0.94
DWD	509	**29**	1.32	**25**	1.21	176	**25**	1.42	**21**	1.30
NSM	209	**65**	0.77	**38**	0.41	41	**65**	0.98	**47**	0.57
DWR	39	**13**	1.04	**13**	0.97	8	**18**	0.83	**17**	0.82
SHR	105	**26**	0.60	**19**	0.55	96	**31**	0.54	**23**	0.49
WID	97	**7**	6.42	**6**	6.40	9	**13**	13.08	**13**	13.08

Table V7. Range of prices paid in dollars for species landed from the sampled trips. Species are arranged in order of increasing minimum price paid.

Species	Minimum Dollars per kg (lb)	Maximum Dollars per kg (lb)
Pac. Whiting	0.02 (0.05)	0.05 (0.10)
arrowtooth Fl.	0.05 (0.10)	0.13 (0.29)
S.S. Thorny.	0.05 (0.10)(small)	0.15 (0.34)(large)
Sablefish	0.08 (0.18)(small)	0.36 (0.80)(large)
Lingcod	0.08 (0.18)(small)	0.18 (0.40)
Rockfish	0.11 (0.23)(small)	0.15 (0.33)(large)
Dover Sole	0.11 (0.25)	0.15 (0.33)
P.O.P.	0.11 (0.25)	0.15 (0.33)
Widow R.F.	0.11 (0.25)	0.15 (0.33)
Red Rockfish	0.11 (0.25)	0.15 (0.33)(large)
Skate	0.11 (0.25)	0.14 (0.30)
Rex Sole	0.11 (0.25)	0.18 (0.40)
Pac. Cod	0.12 (0.26)	0.15 (0.33)
Yellowtail R.F.	0.13 (0.28)	0.15 (0.33)
Starry Fl.	0.13 (0.28)	0.21 (0.45)
Sanddab	0.15 (0.33)	0.17 (0.37)
English Sole	0.15 (0.33)	0.19 (0.41)
Petrale Sole	0.15 (0.33)(small)	0.39 (0.85)
Sand Sole	0.29 (0.63)	0.39 (0.85)

Table V8. Total length (cm) ranges and means for fish discarded due to size.

Species	n	Minimum	Maximum	Mean
Sanddab	93	15	30	22
Arrow. Fl	23	23	33	28
Petrale S	25	20	30	26
English S	108	16	32	24
Dover S.	225	17	36	29
Rex Sole	218	6	33	24
Sand S.	33	21	30	25
Sablefish	74	27	53	41
S.S.Thorny.	268	9	48	22
P.O.P.	3	10	12	11
Darkbl. R.	25	9	30	20
Splitn. R.	21	13	26	21
Widow R.	10	26	32	28
Sharpchin R.	113	14	30	24
Yellowmouth	3	21	25	23

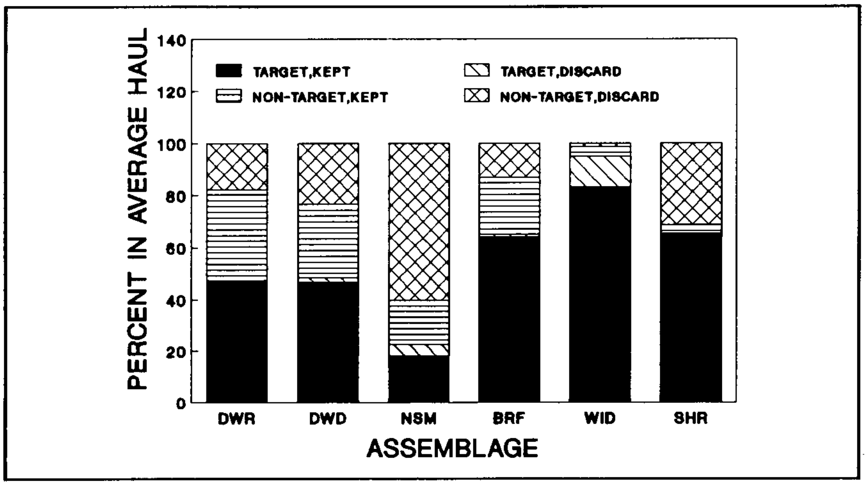


Figure V1. The average percent weight of the hauls in each assemblage which was targeted and kept, targeted and discarded, non-targeted and kept and non-targeted and discarded.

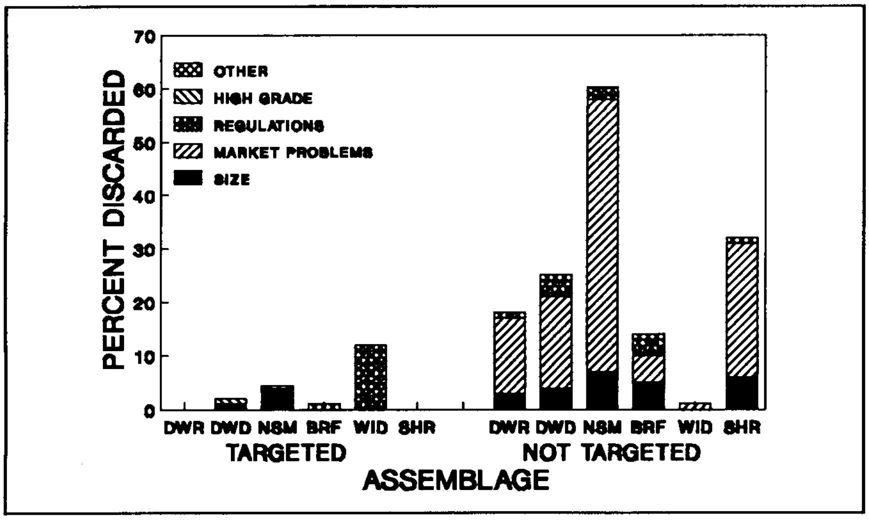


Figure V2. The average percent weight discarded in hauls in each assemblage, designated by reason given for the discard.

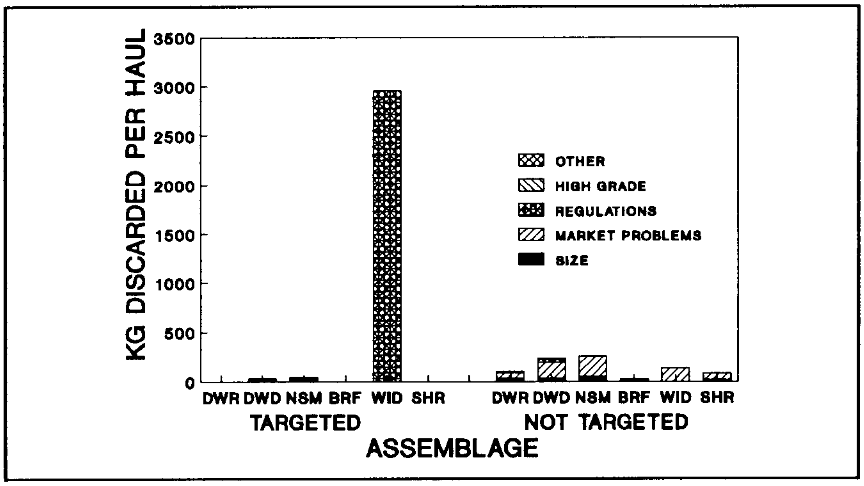


Figure V3. The kg of potentially commercial fish discarded in an average haul in each assemblage, designated by reason given for the discard.

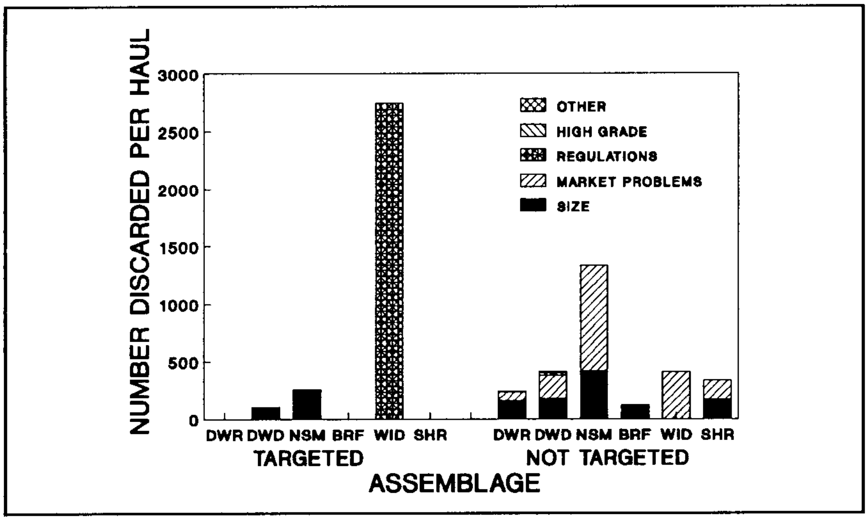


Figure V4. The number of potentially commercial fish discarded in an average haul in each assemblage, designated by reason given for the discard.

CONCLUSIONS AND RECOMMENDATIONS

The trawl fishermen operating off the coasts of Oregon and Washington in 1985-1987 caught six major assemblages of species which could be used as units in developing mixed-species management plans. The definition of the assemblages was based on multivariate analysis of data collected by observers on commercial vessels. Two of the assemblages were dominated by a single species, pink shrimp or widow rockfish. The other assemblages identified were: deepwater rockfish (DWR), deepwater Dover sole (DWD), bottom rockfish (BRF), and nearshore mixed-species (NSM).

Those assemblages could be considered management units because our findings indicated that fishermen could determine which assemblage they would catch, but could not intentionally catch individual species within the complexes. The species were consistently caught together, the decisions the fishermen made could be used to predict the assemblages with 60-91% accuracy, fishermen's targets were generally specific to the assemblage caught and represented at least one of its major species, and all the major species in each assemblage (except the assemblage dominated by pink shrimp) were at times caught unintentionally or unavoidably.

The DWR assemblage was not previously defined as a separate assemblage, either qualitatively or quantitatively. Although DWR and DWD were closely related, we determined that DWR was distinct from DWD based on consistencies in three methods of grouping the haul catches. The strategies that we selected were able to distinguish DWD from DWR with DWD predicted as DWR an estimate 5% of the time and DWR as DWD 9-22% of the time. The errors were primarily the catches of DWR made with mud and combination gears that were predicted as DWD. Targeting information indicated that most of the DWR catches were intentional, but often when DWR was desired DWD was caught.

Since those hauls were a small percent of the DWD catches, this may not preclude managing the complexes separately. The separation between DWR and BRF was more distinct and predictable. Those two assemblages presently have a joint trip limit, but separate trip limits seem feasible.

The strategies derived to predict the assemblages suggested that managers could limit the catch of an assemblage by restricting gear usage in specified areas which were based on bottom depth. This option would provide an alternative means of limiting catches of the assemblages than the current trip limit regime, and would prevent regulation-induced discarding. The fishery would have to be monitored, however, since fishermen could derive new ways of using gears to catch assemblages.

Monitoring the fishery could be accomplished by using the strategies we derived to group logbook data into assemblages. If the species composition of the assemblages changed substantially over time, this would indicate a shift in strategies, discarding practices, or in the relative abundance of the species. This monitoring could be improved if the large and small rockfish categories were used to consistently separate DWR and BRF species. Research cruise data was sufficiently different from the observer data to prohibit its use in making references about the species composition of commercial catches.

While conducting our research to determine species complexes, we found that attention should not be limited to the prevention of over-utilization of species, but must also consider developing markets for under-utilized species in the assemblages. The near-shore mixed species assemblage, which was not associated with any of the regulated species, had the greatest average waste of incidental catch. Sixty-five percent of the weight of the average catch was discarded, with approximately 40% of the weight of potentially marketable fish species discarded. Much of the discarded catch in all the assemblages except the widow assemblage consisted of unmarketable species or fish too small for the processing plants to accept. Development of markets for arrowtooth flounder or sanddab, in particular, could potentially reduce discards to minimal limits.

BIBLIOGRAPHY

Alverson,D.L. 1953. Deep-water trawling survey off the Oregon and Washington coasts (August 27-October 19,1951). Commer. Fish. Rev. 15(10):5-15.

Alverson, D.L. 1960. A study of annual and seasonal bathymetric catch patterns for commercially important groundfishes of the Pacific Northwest coast of North America. Pacific Marine Fisheries Commission Bulletin 4: 6-66.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA-600/3-77-033. Environ. Res. Lab., Corvallis, OR. 115 p.

Bray, J.R. and J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27: 325-349.

Clifford, H.T., and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York, NY. 229 p.

Coleman, B.A. 1986. The 1980 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, length and age composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-100. 181 p.

Coleman, B.A. 1988. The 1986 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, length and age composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-152. 136 p.

Conover, W.J. 1980. Practical nonparametric statistics, 2nd Edition. John Wiley & Sons, Inc., New York, NY. 493 p.

Dark, T.A., M.O. Nelson, J.J. Traynor, and E.P. Nunnallee. 1980. The distribution, abundance, and biological characteristics of Pacific whiting (Merluccius productus), in the California-British Columbia region during July-September 1977. U.S. Dep. Commer. Mar. Fish. Rev. 42(3-4):17-30.

Day, D.S. and W.G.Pearcy. 1968. Species associations of benthic fishes on the continental shelf and slope off Oregon. J. Fish. Res. Board Can. 25(12):2665-2675.

Dorn, M.W. and R.D. Methot. 1991. Status of the coastal Pacific whiting resource in 1991. Appendix A in Status of the Pacific coast groundfish fishery through 1991 and recommended acceptable biological catches for 1992. PFMC, 2000 SW First Ave., Portland, OR. 44 p.

Dunlap, G.D. and H.H. Shufeldt. 1970. Dutton's navigation and piloting. United States Naval Institute, Annapolis, MD.

Gabriel, W.L. and S.A. Murawski. 1985. The use of cluster analysis in identification and description of multispecies systems. p. 112-117. In R. Mahon [ed.] Towards the inclusion of fishery interactions in management advice. Can. Tech. Rep. Fish. Aquat. Sci. No. 1347.

Gabriel W.L. and A.V. Tyler. 1980. Preliminary analysis of Pacific coast demersal fish assemblages. U. S. Nat. Mar. Fish. Serv., Mar. Fish. Rev. 42(3-4):83-88.

Gauch, H.G. 1980. Multivariate analysis in community ecology. Cambridge University Press, Cambridge, New York. 289 p.

Gauch, H.G. and R.H. Whittaker. 1981. Hierarchical classification of community data. J. Ecol. 69:537-557.

Gunderson, D.R., and T.M. Sample. 1980. Distribution and abundance of rockfish off Washington, Oregon, and California during 1977. U.S. Nat. Mar. Fish Serv. Mar. Fish. Rev. 42(3-4):2-16.

Hart, J.L. 1973. Pacific fishes of Canada. Fish. Res. Bd. Can. Bull. 180. Ottawa, Canada. 740 p.

Hill, M.O. 1979a. DECORANA - A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ecology and Systematics, Cornell University, Ithaca, NY 14850. 52 p.

Hill, M.O. 1979b. TWINSPAN - A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Ecology and Systematics, Cornell University, Ithaca, NY 14850. 31 p.

Hill, M.O. and H.G. Gauch, Jr. 1980. Detrended correspondence analysis: and improved ordination technique. Vegetatio 42:47-58.

Hitz, C.R. and D.L. Alverson. 1963. Bottom fish survey off the Oregon coast, April-June 1961. Commer. Fish. Rev. 25(6):1-7.

Hora, S.C. and J.B. Wilcox. 1982. Estimation of error rates in several-population discriminant analysis. J. Market. Res. 9:57-61.

Krzanowski, W.J. 1988. Principles of multivariate analysis. A user's perspective. Oxford University Press, New York, NY. 533 p.

Laurec, A., A. Biseau and A. Charau. 1991. Modelling technical interactions. ICES mar. Sci. Symp. 193:225-236.

Lukas, J. and C. Carter. 1991. 1989 pounds and value of commercially caught fish and shellfish landed in Oregon. OR Dept. Fish and Wild., P.O. Box 59, Portland, OR. 116 p.

Manly, B.F.J. 1986. Multivariate statistical methods. A primer. Chapman and Hall, Bristol, U.K. 159 p.

Methot, R. 1992. Assessment of the west coast sablefish stock in 1992. Appendix D in Status of the Pacific coast groundfish fishery through 1992 and recommended assceptable biological catches for 1993. PFMC, 2000 SW First Ave., Portland, OR. 96 p.

Murawski, S.A. 1984. Mixed-species yield per recruitment analyses accounting for technological interactions. Can. J. Fish. Aquat. Sci. 41:897-916.

NOAA. 1986. Tide Tables 1985, West Coast of North and South America. U.S. Dep. Commer., Wash. D.C. 234 p.

NOAA. 1987. Tide Tables 1986, West Coast of North and South America. U.S. Dep. Commer., Wash. D.C. 234 p.

NOAA. 1988. Tide Tables 1987, West Coast of North and South America. U.S. Dep. Commer., Wash. D.C. 234 p.

Paulik, G.J., A.S. Hourston, and P.A. Larkin. 1967. Exploitation of multiple stocks by a common fishery. J. Fish. Res. Board Can. 24:2527-2537.

Pearcy, W.G. 1978. Distribution and abundance of small flatfishes and other demersal fishes in a region of diverse sediments and bathymetry off Oregon. U.S. Nat. Mar. Fish. Serv. Fish. Bull. 76(3):629-640.

Pearcy, W.G., D.L.Stein, and R.S.Carney. 1982. The deep-sea benthic fish fauna of the northeastern pacific ocean on cascadia and tufts abyssal plains and adjoining continental slopes. Biol. Oceanogr. 1(4):375-427.

PFMC (Pacific Fishery Management Council). 1990. Status of the Pacific coast groundfish fishery through 1990 and recommended acceptable biological catches for 1991: stock assessment and fishery evaluation. Pacific Fishery Management Council, Metro Center, Suite 420, 2000 S.W. First Avenue, Portland, Oregon 97201. 58 p.

Pikitch, E.K. 1987a. Use of a mixed species yield-per-recruit model to explore the consequences of various management policies for the Oregon flatfish fishery. Can. J. Fish. Aquat. Sci. 4(Sup.2):349-359.

Pikitch, E.K. 1987b. Impacts of management regulations on the catch and utilization of rockfish in Oregon. p. 369-381. In Proceedings of the International Rockfish Symposium, October 20-22, 1986. Lowell Wakefield Fisheries Symposia Series. University of Alaska Sea Grant Press, Fairbanks, Alaska.

Pikitch, E.K. 1991. Technological interactions in the US West Coast groundfish trawl fishery and their implications for management. ICES mar. Sci. Symp.:253-263.

Pikitch, E.K., D.L. Erickson, and John R. Wallace. 1988. An evaluation of the effectiveness of trip limits as a management tool. U.S. Dep. Commer., NWAFC Proc. Rep. 88-27.

Richards, L.J. 1986. Depth and habitat distributions of three species of rockfish (Sebastes) in British Columbia: observations from the submersible PISCES IV. Environ. Biol. Fishes 17(1):13-21.

Rickey, M.H. and H-L. Lai. 1990. The deep water complex species mix in the Washington and Oregon trawl fishery. Wash. Dep. Fish. Tech. Rep. no. 111. 40 p.

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. 49:2648-2656 (Also Chapter II in this document).

Rogers, J.B. and E.K. Pikitch. 1994a. The validity of using logbook and research cruise trawl data to determine and monitor groundfish management assemblages. Chapter III in this document.

Rogers, J.B. and E.K. Pikitch. 1994b. Fishing strategies used by commercial groundfish fishermen off the coasts of Oregon and Washington. Chapter IV in this document.

Rogers, J.B. and E.K. Pikitch. 1994c. Effectiveness of fishing strategies used by commercial groundfish fishermen off the coasts of Oregon and Washington. Chapter V in this document.

Saila, S.B. 1983. Importance and assessment of discards in commercial fisheries. FAO Fish.Circ., (765). 62 p.

SAS,Institute, Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. Cary, NC:SAS Institute Inc. 1028 p.

Sneath, P.H.A. and R.R. Sokal. 1973. Numerical taxonomy. The principles and practice of numerical classification. Freeman, San Francisco. 573 p.

Starr, R.M. and M.R. Saelens. 1988. Marine fishery catch mapping. Oreg. Dep. Fish Wildl., Mar. Reg., Inform. Rep. Ser., April 1988. 35 p.

Tyler, A.V. , E.L.Beals, and C.L.Smith. 1984. Analysis of logbooks for recurrent multi-species effort strategies. Int. North Pac. Fish. Comm. Bull. 42:39-46

Weinberg, K.L. in press. Rockfish assemblages of the middle shelf upper slope off Oregon and Washington. Fish. Bull. 20 p.

Weinberg, K.L., M.E. Wilkins, and T.A. Dark. 1984. The 1983 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, age, and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-70. 376 p.

Westrheim, S.J., W.H. Barss, E.K. Pikitch, and L.F. Quirollo. 1992. Stock delineation of Dover sole in the California-British Columbia Region, based on tagging studies conducted during 1948-1979. N. Am. Journ. Fish. Manag. 12:172-181.

Wilkins, M.E. 1987. Results of an investigation of widow rockfish Sebastes entomelas behavior. p. 43-47. In Lenarz, W.H. and D.R. Gunderson (eds.), Widow rockfish, proceedings of a workshop, Tiburon, Calif., Dec. 11-12, 1980. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 48.

Zar, J.H. 1984. Biostatistical analysis, 2nd edition. Prentice-Hall Inc., Englewood Cliffs, N.J. 718 p.