

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

Jean Beyer Rogers<sup>1</sup> and Ellen K. Pikitch<sup>2</sup>

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

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Numerical definition of species caught together by the groundfish trawl fishery operating off the Oregon and Washington coasts during 1985–87 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 smooth 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 cooccurring species may be treated as units in developing mixed-species management plans. The deepwater rockfish assemblage we identify has not been previously described.

La définition numérique des espèces capturées par les chalutiers qui pêchaient le poisson de fond au large des côtes des États de l'Oregon et de Washington au cours de la période 1985–1987 a indiqué six assemblages d'espèces principaux. Des observateurs se trouvant sur des navires commerciaux ont relevé des données permettant l'estimation des poids des espèces commercialement importantes capturées dans chaque trait. Les assemblages ont été choisis en fonction de la conformité dans trois types d'analyse des poids des espèces : ordination de correspondance à tendance temporelle éliminée, groupement des espèces à indicateur double et groupement de moyenne de groupe de Bray–Curtis. Deux des assemblages étaient dominés par une seule espèce, un consistant largement en crevettes océaniques (*Pandalus jordani*) et l'autre principalement en veuves (*Sebastes entomelas*). Les autres assemblages identifiés étaient : un assemblage de sébaste d'eau profonde, un assemblage de sole de Douvres d'eau profonde, un assemblage d'espèces mélangées situé près du rivage et un assemblage de sébaste de fond. Ces assemblages d'espèces présentes commercialement présentes simultanément peuvent être traités comme des unités dans l'élaboration de plans de gestion d'espèces mélangées. L'assemblage de sébaste d'eau profonde que nous avons identifié n'avait pas été décrit précédemment.

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The trawl fishermen operating off the coasts of Oregon and Washington often catch mixed species of groundfish including rockfishes and thornyheads (Scorpaenidae), Pacific whiting (Pacific hake) (*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.

<sup>1</sup>Present address: National Marine Fisheries Service, 3150 Paradise Dr., Tiburon, CA 94920, USA.

<sup>2</sup>Present address: Fisheries Research Institute, School of Fisheries WH-10, University of Washington, Seattle, WA 98195, USA.

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 smooth 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 K. L. Weinberg (AFSC NMFS, NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115-0070, unpubl. data) were generally collected using standardized strategies with one or two gears. The commercial fishery uses six gears and probably operates with a 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 with tows designated by the defined assemblages and, (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 1985–87 (Pikitch 1987b). The northern and southern boundaries of the study were 48°42' and 42°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 predefined 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 acronyms 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 183 m, 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 Pacific salmon (*Oncorhynchus* spp.) were not eliminated. Observers usually did not weigh those two species, as it was illegal to retain them onboard.

### 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).<sup>3</sup> 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), provides an objective method of splitting ordinations, and 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 cutoff values so that each species could be treated as four separate "species", based on abundance in the haul. Since cutoff values had to be the same for all species, we computed the means of target species abundances and designated cutoff 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 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, although 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 1% 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 1% 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 15 species were targeted and constituted >1% of the catch. These comprised arrowtooth flounder (*Atheresthes stomias*), petrale sole (*Eopsetta jordani*), English sole (*Pleuronectes vetulus*, previously *Parophrys vetulus*), Dover sole, rex sole (*Errex zachirus*, previously *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 smooth 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 and no catch in 59 tows, and 27 tows had missing

<sup>3</sup>A FORTRAN program to form the matrix and a SAS Institute, Inc. (1988) program to compute the group averages are available upon request.

information on the weight of a nonprohibited species. We included an additional 390 tows with missing weights for Pacific 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 (Fig. 1 and 2). Two of the assemblages were dominated by single species, SHR and the widow rockfish assemblage (WID) (Fig. 2). The NSM assemblage contained sanddab, English sole, sand sole, starry flounder, and petrale sole (Fig. 2). The BRF assemblage contained yellowtail rockfish, canary rockfish, yelloweye rockfish, lingcod, bocaccio, and sharpchin rockfish. The DWD assemblage was primarily Dover sole and sablefish. The deepwater rockfish assemblage (DWR) contained darkblotched rockfish, Pacific ocean perch, splitnose rockfish, yellowmouth rockfish, and sharpchin rockfish. Other species considered were associated with the assemblages, but to a lesser degree (Fig. 2).

We found strong agreement between many of the strategy designations and the assemblage designations, but there were also some differences (Table 1). 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 1). 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 1) and had varying degrees of overlap on the DCA axes (Fig. 1 and 2). The DCA program derived four axes in order of decreasing correspondence between the catch and species scores (Table 2). 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 (Fig. 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

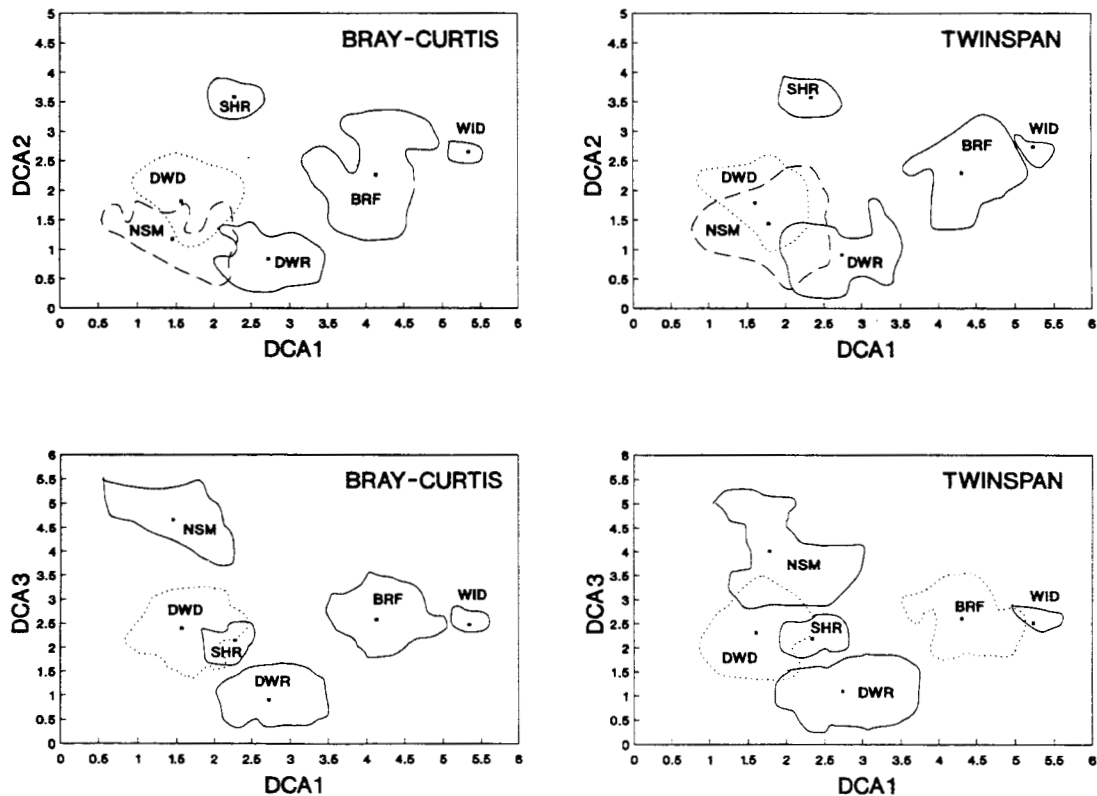


FIG. 1. Consistency of catch separations as demonstrated by the concentration of DCA catch scores for the Bray-Curtis clusters and TWINSpan clusters. The mean catch scores for the clusters are designated by a dot, while the outlines enclose 75% of the hauls in the cluster closest to the mean. The means are labeled to show the assemblage names assigned the respective clusters.

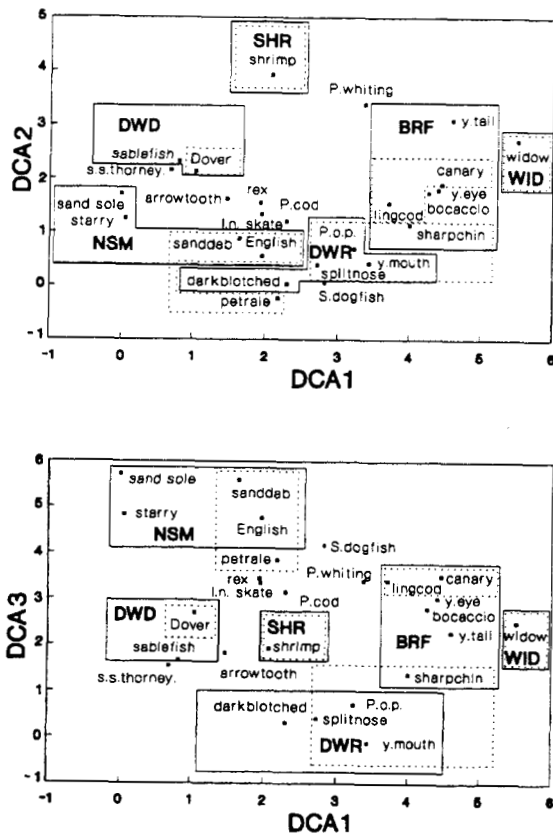


FIG. 2. Consistency in species associated with the catch clusters labeled by assemblage name. Species scores are designated by dots and labeled with species names. Dotted boxes enclose the indicator species of the TWINSpan clusters and solid boxes enclose the species associated with the Bray-Curtis clusters. Species selected for Bray-Curtis were those averaging >20% by weight in the catches and/or >4 times the average weight.

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 (Fig. 1).

Nine Bray-Curtis clusters were required to derive different groups at opposite ends of DCA axes 1-3 (Fig. 3). To achieve consistency with the clustering species associations, three Bray-Curtis clusters were combined to form BRF (Fig. 3). These clusters were associated with yellowtail rockfish, canary rockfish, or sharpchin rockfish. There was one inconsistent assemblage, named DOG because 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 (Fig. 1 and 2). The species associations with the consistent Bray-Curtis assemblages, which were the basis of the outlines in Fig. 2, are shown in Table 3.

TWINSpan showed different clusters at opposite ends of the first three DCA axes after four divisions, resulting in 15 groups (Fig. 4). 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 (Fig. 4). 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 Fig. 2, are shown in detail in Table 4.

## Discussion

Our results suggest that widow rockfish and smooth 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 multispecies 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 Pacific ocean perch to 20% of all fish onboard 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 (Fig. 2; Table 3). In addition, sablefish averaged close to 25% by weight in the DWD catches (Table 3). We determined that the *Sebastes* complex could be divided into two assemblages, DWR and BRF, with Pacific ocean perch approximately 20% of DWR and yellowtail rockfish about 50% of BRF (Table 3). 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 methods 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 Percy (1968), Percy (1978), Gabriel and Tyler (1980), and Tyler et al. (1984). Prior studies determined a deepwater assemblage, although the DWR and DWD assemblages were often combined and a separate DWR was never distinguished. Alverson (1953), Hitz and Alverson (1963), Gabriel and Tyler (1980), and K. L. Weinberg (unpubl. data) defined species associations and assemblages using a combination of DWD and DWR species. Percy 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

TABLE 1. Number of tows in strategies designated by observers and in assemblages determined by Bray-Curtis catch clusters, TWINSpan catch clusters, and both, designated as catching the same assemblage by both methods of clustering (tows that were inconsistent were not included).

|             | Designated strategy |      |      |      |      | Total |
|-------------|---------------------|------|------|------|------|-------|
|             | SNSM                | SDWD | SSHR | SBRF | SMDI |       |
| Bray-Curtis |                     |      |      |      |      |       |
| 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    |
| TWINSpan    |                     |      |      |      |      |       |
| 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    |
| Both        |                     |      |      |      |      |       |
| 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 2. DCA 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 species axes are plotted in Fig. 2.

|                       | DCA1<br>(EIG = 0.901) | DCA2<br>(EIG = 0.718) | DCA3<br>(EIG = 0.525) | DCA4<br>(EIG = 0.358) |     |                       |     |
|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----|-----------------------|-----|
| Widow rockfish        | 551                   | Smooth pink shrimp    | 392                   | Sand sole             | 572 | Canary rockfish       | 344 |
| Yellowtail rockfish   | 460                   | Pacific whiting       | 339                   | Sanddab               | 559 | Bocaccio              | 314 |
| Canary rockfish       | 446                   | Yellowtail rockfish   | 310                   | Starry flounder       | 483 | Yelloweye rockfish    | 306 |
| Yelloweye rockfish    | 441                   | Widow rockfish        | 271                   | English sole          | 475 | Darkblotched rockfish | 277 |
| Bocaccio              | 427                   | Sablefish             | 232                   | Spiny dogfish         | 417 | Smooth pink shrimp    | 273 |
| Sharpchin rockfish    | 400                   | Shortspine thornyhead | 215                   | Petrable sole         | 385 | Sand sole             | 272 |
| Lingcod               | 370                   | Dover sole            | 212                   | Canary rockfish       | 351 | Splitnose rockfish    | 265 |
| Yellowmouth rockfish  | 343                   | Canary rockfish       | 190                   | Rex sole              | 344 | Starry flounder       | 261 |
| Pacific whiting       | 336                   | Yelloweye rockfish    | 180                   | Pacific whiting       | 340 | Pacific ocean perch   | 232 |
| Pacific ocean perch   | 323                   | Bocaccio              | 175                   | Lingcod               | 340 | Yellowmouth rockfish  | 225 |
| Spiny dogfish         | 282                   | Sand sole             | 171                   | Longnose skate        | 334 | Sablefish             | 197 |
| Splitnose rockfish    | 272                   | Arrowtooth flounder   | 162                   | Pacific cod           | 315 | Shortspine thornyhead | 187 |
| Darkblotched rockfish | 230                   | Lingcod               | 155                   | Yelloweye rockfish    | 302 | Arrowtooth flounder   | 180 |
| Pacific cod           | 229                   | Rex sole              | 155                   | Bocaccio              | 280 | Widow rockfish        | 161 |
| Petrable sole         | 218                   | Longnose skate        | 134                   | Dover sole            | 270 | Lingcod               | 147 |
| Smooth pink shrimp    | 207                   | Starry flounder       | 125                   | Widow rockfish        | 249 | Sanddab               | 135 |
| English sole          | 196                   | Pacific cod           | 121                   | Yellowtail rockfish   | 228 | English sole          | 131 |
| Longnose skate        | 195                   | Sharpchin rockfish    | 115                   | Smooth pink shrimp    | 192 | Pacific whiting       | 91  |
| Rex sole              | 193                   | Sanddab               | 88                    | Arrowtooth flounder   | 182 | Dover sole            | 91  |
| Sanddab               | 164                   | Pacific ocean perch   | 70                    | Sablefish             | 166 | Spiny dogfish         | 78  |
| Arrowtooth flounder   | 147                   | English sole          | 55                    | Shortspine thornyhead | 154 | Longnose skate        | 73  |
| Dover sole            | 104                   | Yellowmouth rockfish  | 43                    | Sharpchin rockfish    | 137 | Rex sole              | 59  |
| Sablefish             | 81                    | Splitnose rockfish    | 40                    | Pacific ocean perch   | 70  | Petrable sole         | 59  |
| Shortspine thornyhead | 70                    | Spiny dogfish         | 7                     | Splitnose rockfish    | 40  | Pacific cod           | 54  |
| Starry flounder       | 5                     | Darkblotched rockfish | 4                     | Darkblotched rockfish | 31  | Sharpchin rockfish    | 25  |
| Sand sole             | -1                    | Petrable sole         | -23                   | Yellowmouth rockfish  | -12 | Yellowtail rockfish   | 0   |

sablefish had the strongest association, followed by thornyheads and then arrowtooth flounder. One study defined an assemblage similar to BRF. K. L. Weinberg (unpubl. data) analyzed Scorpaenidae only and described an assemblage which

was associated with yellowtail and canary rockfishes.

Differences that did exist between the assemblages we defined and those defined previously were primarily a result of different placement of the boundaries separating the assem-

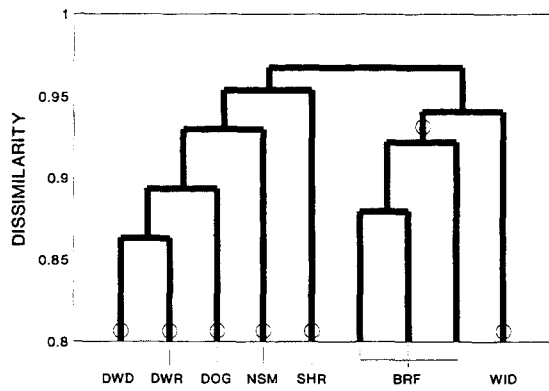


FIG. 3. Dendrogram of Bray-Curtis cluster combinations at increasing levels of dissimilarity. Level of dissimilarity selected in determining labeled assemblages is indicated by a circle.

blages. 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), and Tyler et al. (1984), between DWR and BRF by Gabriel and Tyler (1980), and between BRF and WID by K. L. Weinberg (unpubl. data). 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 assemblage definitions could result from many factors. It is possible that the location of the boundaries between assemblages depended on 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 that may have caused the differences could be changes in the relative

TABLE 3. 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;  $\bar{x}$  = 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 to 2 times, 1 = 0 to below average, and 0 = none).

| Species               | Assemblage |           |     |           |     |           |     |           |     |           |     |           |     |           |
|-----------------------|------------|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|-----|-----------|
|                       | DWD        |           | DWR |           | DOG |           | NSM |           | SHR |           | BRF |           | WID |           |
|                       | %          | $\bar{x}$ | %   | $\bar{x}$ | %   | $\bar{x}$ | %   | $\bar{x}$ | %   | $\bar{x}$ | %   | $\bar{x}$ | %   | $\bar{x}$ |
| Dover sole            | 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         |
| Shortspine thornyhead | 7          | 3         | 2   | 1         | 1   | 1         | 0   | 0         | <1  | 1         | <1  | 1         | <1  | 1         |
| Arrowtooth flounder   | 11         | 2         | 2   | 1         | 5   | 2         | <1  | 1         | 1   | 1         | <1  | 1         | 0   | 0         |
| Pacific ocean perch   | 3          | 1         | 21  | 4         | 1   | 1         | <1  | 1         | <1  | 1         | 1   | 1         | <1  | 2         |
| Darkblotched rockfish | 3          | 1         | 31  | 4         | 2   | 1         | 0   | 0         | <1  | 1         | <1  | 1         | <1  | 1         |
| Yellowmouth rockfish  | <1         | 1         | 14  | 4         | <1  | 1         | 0   | 0         | <1  | 1         | 1   | 1         | <1  | 1         |
| Splitnose rockfish    | 1          | 1         | 9   | 4         | <1  | 2         | 0   | 0         | <1  | 1         | <1  | 1         | 0   | 0         |
| Spiny dogfish         | 2          | 1         | <1  | 1         | 62  | 4         | <1  | 1         | <1  | 1         | <1  | 1         | <1  | 1         |
| Petrale sole          | 5          | 2         | <1  | 1         | 4   | 3         | 10  | 2         | <1  | 1         | <1  | 1         | <1  | 1         |
| Sanddab               | <1         | 0         | 0   | 0         | <1  | 1         | 25  | 4         | <1  | 1         | <1  | 1         | 0   | 0         |
| English sole          | 1          | 2         | <1  | 1         | <1  | 2         | 22  | 4         | <1  | 1         | <1  | 1         | 0   | 0         |
| Sand sole             | <1         | 1         | 0   | 0         | 0   | 0         | 18  | 4         | 0   | 0         | 0   | 0         | 0   | 0         |
| Starry flounder       | <1         | 1         | 0   | 0         | 0   | 0         | 2   | 4         | 0   | 0         | 0   | 0         | 0   | 0         |
| Longnose skate        | 3          | 2         | <1  | 1         | 1   | 2         | 6   | 2         | <1  | 1         | <1  | 1         | <1  | 1         |
| Rex sole              | 4          | 2         | <1  | 1         | 2   | 2         | 6   | 2         | 1   | 1         | <1  | 1         | <1  | 1         |
| Pacific whiting       | 7          | 1         | 3   | 1         | 2   | 1         | 6   | 1         | 12  | 1         | 1   | 1         | 2   | 1         |
| Smooth pink shrimp    | <1         | 1         | 0   | 0         | 0   | 0         | 0   | 0         | 78  | 4         | <1  | 1         | 0   | 0         |
| Pacific 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 rockfish   | <1         | 1         | <1  | 1         | 2   | 1         | <1  | 1         | 2   | 1         | 49  | 4         | 2   | 2         |
| Canary rockfish       | <1         | 1         | <1  | 1         | <1  | 1         | <1  | 1         | <1  | 1         | 18  | 4         | 1   | 3         |
| Sharpchin rockfish    | <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 rockfish    | <1         | 1         | <1  | 1         | <1  | 1         | <1  | 1         | 0   | 0         | 2   | 4         | <1  | 2         |
| Widow rockfish        | <1         | 1         | 3   | 1         | <1  | 1         | 0   | 0         | <1  | 1         | 1   | 1         | 92  | 4         |

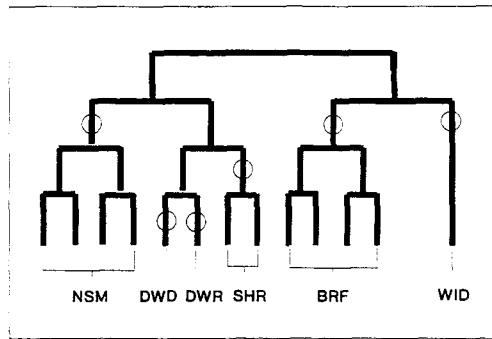


FIG. 4. Dendrogram of TWINSPAN haul cluster divisions at progressive separations. Level of separation selected in determining labeled assemblages is indicated by a circle.

amounts of the species within assemblages over time. Most of the 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 1). 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 183 m 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 imply 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(s) 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 smooth pink shrimp. The other four included a deepwater Dover assemblage, a deepwater rockfish assemblage, a bottom rockfish assemblage, and a nearshore mixed-species assem-

TABLE 4. Species associations with TWINSPAN haul clusters designated by assemblage name. Species associations shown are the inclusive weight categories (kilograms per haul) of the indicator species as determined by TWINSPAN.

| Species              | Assemblage |        |        |        |        |     |
|----------------------|------------|--------|--------|--------|--------|-----|
|                      | DWD        | DWR    | NSM    | SHR    | BRF    | WID |
| Dover sole           | 15-933     |        |        |        |        |     |
| Pacific ocean perch  |            | 15-126 |        |        |        |     |
| Yellowmouth rockfish |            | >0-126 |        |        |        |     |
| Splitnose rockfish   |            | >0-15  |        |        |        |     |
| Sharpchin rockfish   |            | >0-15  |        |        |        |     |
| Petrale sole         |            |        | >0-15  |        |        |     |
| Sanddab              |            |        | 15-126 |        |        |     |
| English sole         |            |        | >0-126 |        |        |     |
| Smooth pink shrimp   |            |        |        | 15-126 |        |     |
| Lingcod              |            |        |        |        | >0-15  |     |
| Canary rockfish      |            |        |        |        | >0-126 |     |
| Widow rockfish       |            |        |        |        |        | >15 |



blage. 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 that 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 with 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.

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