Temporal and spatial summer groundfish assemblages in trawlable habitat off the west coast of the USA, 1977 to 2009

Jason M. Cope*, Melissa A. Haltuch

Fishery Resource Analysis and Monitoring Division, Northwest Fisheries Science Center,
NOAA Fisheries, 2725 Montlake Blvd. East, Seattle, Washington 98112-2097, USA

ABSTRACT: Increasingly, multispecies interactions are being considered by US management councils during decision making, which highlights the need for identification of fish assemblages across varying spatial and temporal resolutions. On the US West Coast, previous groundfish assemblage analyses have focused either on particular species groups (i.e. *Sebastes*) or limited time frames and/or geographic regions within the groundfish fishery. The present study expands on previous work to identify groundfish assemblages across the full spatial extent of the West Coast groundfish fishery from 1977–2009, by using 2 fishery-independent trawl surveys. Species assemblages were identified using 2 clustering methods (partitioning analysis and hierarchical analysis) and 2 realizations of the data (presence-absence and log+1 transformed catch-per-unit-effort, CPUE). The analysis using presence-absence data provides information on species that co-occur while the CPUE data provides information on species that occur at similar magnitudes. Temporally and spatially persistent assemblages were detected by both clustering methods through most years. Assemblages identified using CPUE were often subsets of those identified using presence-absence, indicating that the members of an assemblage may occur together, but not necessarily at the same magnitude, a result that should be considered when choosing the clustering metric. Identification of species assemblages is applicable to bycatch models and informative when evaluating the implementation of spatial management measures, and thus germane to current challenges faced by marine resource managers.

KEY WORDS: Cluster analysis · Fisheries management · Multispecies interactions · Catch-per-unit-effort · Marine ecosystems

—Resale or republication not permitted without written consent of the publisher—

INTRODUCTION

The US West Coast groundfish fishery is a complex multispecies fishery with many stocks linked via biological (e.g. shared habitat) and technical (e.g. similar gear catchability) interactions. During the past 3 decades many groundfish stocks (including several rockfishes of the genus *Sebastes*) have experienced major declines in abundance (Ralston 1998, 2002), resulting in the implementation of strict management actions, including significant catch reductions and extensive time and area closures. In order to include

considerations of species interactions into future management decisions, the managing entity, the Pacific Fishery Management Council (PFMC), is moving towards more formal incorporation of ecosystem-based fishery management principles into their decision making process.

Several ecological topics of interest have been identified during the development of an ecosystem-based fishery management plan, including understanding community composition and possible community shifts through time and space, characterizing and maintaining ecosystem resilience, assessing changes

*Email: jason.cope@noaa.gov

in the availability of target stocks and associated non-target species, and examining the ecological interactions influencing managed species (PFMC 2011). Identifying and describing the persistence of species assemblages across space and time is pertinent to many of these topics, and may provide managers information germane to the consideration of incorporating multispecies interactions into management policies (Jennings et al. 2001). Additionally, the implementation of marine reserves and other forms of spatial multispecies management requires knowledge of species assemblages (Jamieson & Levings 2001). A comprehensive analysis of species co-occurrences and assemblages across both temporal and spatial scales is thus warranted (Tyler et al. 1982, Jay 1996) so that multispecies interactions can be more practically incorporated into the decision-making process.

Previous studies have investigated US West Coast groundfish assemblages using fishery-dependent data (Nagtegaal 1983, Lee & Sampson 2000). However, due to fishery discards these data are potentially skewed towards abundant species with high market value, reflecting only a subset of the groundfish community exposed to trawling (Weinberg 1994). Currently, fishery-dependent data collected by observers (Rogers & Pikitch 1992) or standardized fishery-independent surveys provide the best source of information for identifying species complexes. Two major standardized scientific surveys exist for West Coast groundfish, the triennial continental shelf trawl survey (1977–2004) and the annual continental shelf-slope trawl survey (2003–2009).

Several studies have used portions of the triennial continental shelf trawl survey data to define groundfish assemblages. Gabriel & Tyler (1980) used cluster analysis of 1977 triennial data to identify twelve groundfish species assemblages within 4 faunal zones off of Oregon. Weinberg (1994), using aggregate triennial trawl data from 1977–1992, identified 3 rockfish (genus *Sebastes*) assemblages off the coasts of Washington and Oregon using agglomerative hierarchical cluster analysis (HCA). Jay (1996) extended the use of this dataset to include California and, using HCA, identified 23 bottom trawl fish assemblages from a subset of 33 groundfish species. Williams & Ralston (2002) extended the years of analysis (1977–1998) and defined 4 general rockfish assemblages off the northern and central California coast using partitioning analysis and multidimensional scaling (MDS). Zimmermann (2006) used the full spatial extent of the triennial data set for years 1995–2001 and offered yearly species groupings based on several multivariate approaches, including HCA. Finally, Tolimieri &

Levin (2006) combined the 1999–2002 West Coast slope survey data, identifying 5 assemblages on the continental slope relative to environmental factors. The above studies are limited by (1) focusing on specific taxonomic groups (Weinberg 1994, Williams & Ralston 2002), (2) investigating geographically limited segments of the US West Coast (Gabriel & Tyler 1980, Weinberg 1994, Williams & Ralston 2002), (3) spatially clustering trawl sites as opposed to directly investigating species assemblages (e.g. Jay 1996), (4) generally combining data across years (Gabriel & Tyler 1980, Jay 1996, Williams & Ralston 2002, Tolimieri & Levin 2006) and (5) using catch-per-unit-effort (CPUE) as the only clustering metric (all of the above sources except Weinberg 1994). Additionally, the differing subsets of species, data types (presence-absence or CPUE), and time periods used in each analysis make it difficult to compare the results among studies. While the above studies provide insight into aspects of West Coast groundfish species assemblages, none have provided an analysis investigating the full temporal and spatial extent of the data currently available. Furthermore, the annual continental shelf-slope trawl survey is a new, uninvestigated time series.

This work provides an analysis of the available data from these 2 main fishery-independent trawl survey data sets collected on the US West Coast to (1) offer insight into the utility of these datasets in identifying biologically meaningful fish assemblages that persist through time and (2) examine differences between the 2 datasets. Three questions are investigated: (1) Are species assemblages identifiable and persistent over space and time? (2) Which species co-occur and are caught at the same magnitude within definable assemblages? (3) Are similar assemblages identified in the triennial and annual survey datasets? Two clustering methods used in previous US West Coast species assemblage studies are used to provide multiple realization of species assemblages and enable a qualitative comparison among past studies. In addition, the use of both presence-absence and CPUE data as clustering metrics are investigated to determine assemblages that co-occur and that were caught at similar magnitudes, respectively.

MATERIALS AND METHODS

Fishery-independent surveys

The US West Coast triennial shelf survey provides a fishery-independent estimation of the distribution and abundance of fishes accessible to bottom trawls

from California to Washington and was conducted by the Resource Assessment and Conservation Engineering (RACE) division of the Alaska Fisheries Science Center (AFSC) from 1977 to 2001 (and hereafter referred to as the 'triennial survey'). The 2004 survey was conducted by the Fishery Resource Analysis and Monitoring (FRAM) Division of the Northwest Fisheries Science Center (NWFSC) following the RACE survey protocol. Sample tows were taken during the summer months (June to September) ranging roughly between latitudes 34°N (Point Conception region) and 50°N (northern Vancouver Island) and from depths of 50 to 500 m (Figs. 1 & 2). Specific sampling design and gear, trawling procedures, and historical changes in yearly survey objectives are documented in Weinberg et al. (2002; Table 1). One notable change was the extension of the survey depth of 367 m to 500 m in 1995 to provide a more thorough coverage of continental slope and shelf rockfishes.

The annual NWFSC shelf-slope survey began operation in 2003 as a transition from the triennial survey with the intent of maintaining a US West Coast

Fig. 2. Depth range (median with 5 and 95% quantiles) and sample sizes for each year (vertical numbers), for each year across all regions (left side of vertical line), and for each region across all years (right side of vertical) for both surveys

Fig. 1. Map of the (a) AFSC triennial (1977–2004) and (b) annual NWFSC shelf-slope (2003–2009) US West Coast trawl survey data considered in this study. Each dot represents a survey tow location. Vertical lines delineate the area sampled during the dates indicated. Regions 1–3: biogeographic regions

groundfish sampling program (hereafter referred to as the 'annual survey'). While the temporal coverage (generally May through October) was similar to the triennial survey, there are distinct differences between the 2 surveys (Table 1). Notable survey changes include the depth coverage, sampling design, trawl gear, and allocation of samples along the coast (Table 1, Fig. 2). Two additional slope surveys (the AFSC slope survey, 1984–2001, and the NWFSC slope survey, 1999–2002) were excluded from this analysis, the former because of limited coastwide spatial coverage across years and the latter because of its extremely limited depth distribution.

This study characterizes groundfish assemblages across 3 spatio-temporal scales for each survey: (1) coastwide by available year and survey, (2) coastwide across all years for each survey and (3) across 3 biogeographic regions for all years for each survey (south of Cape Mendocino, Cape Mendocino to Cape Blanco, north of Cape Blanco) (Fig. 1). These biogeographic regions

Table 1. Differences in the triennial and Northwest Fisheries Science Center (NWFSC) US West Coast groundfish survey design, gear and operations

Specification	Triennial	Annual
Years conducted (Agency)	1980–2001 (AFSC), 2004 (NWFSC)	2003–2009 (NWFSC)
Commercial vessel class (length in m)	Alaska class (20–45)	West Coast groundfish (20–28)
Survey design	Line transect with random trawls on each line	Stratified random survey
Survey start dates	Mid-July (1980–1992) Early June (1995–2004)	Consistent
Depth range	55–366 m, 55–500 m (changed over time)	55–1280 m (stable over time)
Latitudinal ranges	Northern boundary: 48.4° and 49.6° Southern boundary: 34.5° N and 36.8° N	Northern boundary: 48.17° Southern boundary: 32.5°
Trawl net	High opening Nor'Eastern	4 panel Aberdeen
Distance from net to doors (m)	76.2	62.5
Footrope (length in m)	Roller gear (36.9)	Continuous disk footrope (31.7)
Bottom bridles	Bare wire	8' disks partway
V-Door size (m)	0.55 × 0.82	0.46 × 0.64
Mesh size (cm)	12.7	14
Codend mesh size (cm)	22.6	32.3
Codend liner mesh size (cm)	8.1	9.7
Tow duration (min)	30	15
Tow speed (average in knots)	3	2.2
Mud cloud between doors and net	Little to none (no disks in wings)	Yes (disks in wings)
Proximity to rocky areas	Strong avoidance	Tow close to rocky areas
Relative catch rates	Lower	Higher

were defined using published literature suggesting potentially significant faunal changes within these regions (Gabriel 1982, Williams & Ralston 2002, Francis et al. 2009).

Datasets and species selection

Data fields from each survey and trawl tow included the starting and ending latitude and longitude, duration (min), swept area (ha), bottom depth (m), as well as species abundance (n) and weight (kg). CPUE for each species was defined as the number of individuals per swept area (i.e. width of trawled area × length of tow). About 0.15% of all tows recording fish presence in weights were missing the number of fish by tow. Tows lacking the numerical counts of a species were not discarded because the missing values were randomly distributed between tows and species. Missing values by species were subsequently imputed using the species weight for the tow in question and the overall average weight of the species across all tows. Tows where the gear was not fishing on the bottom ('water hauls') were eliminated (Zimmermann et al. 2003).

In order to limit the size of the assemblage analysis to a meaningful subset of the >150 and 350 species

taken in the triennial and annual surveys, respectively, a decision rule was implemented for species selection. Past studies selected species for analysis by relying on either arbitrary thresholds of occurrence, abundance, or CPUE and/or particular subset of species (e.g. *Sebastes*). This study used the Index of Relative Importance (IRI) (Pinkas et al. 1971) as a decision rule for determining which species to include in the analysis. The IRI is calculated by multiplying percent frequency of occurrence (%FO) by the summation of percent abundance (%no.) and percent weight (%wt), with a maximum individual IRI value of 20 000 (if one species accounts for 100% of the abundance and weight, and occurs in every sample). Theoretically, the IRI should reduce biases from each individual component while simultaneously creating a measure using all 3 pieces of information. To simplify the analysis, Cortés's (1997) recommendation of converting IRI values to %IRI was used:

$$\%IRI_i = 100 \times \left(\frac{IRI_i}{\sum_{i=1}^n IRI_i} \right) \quad (1)$$

where i is the individual species and n is the total number of species.

The IRI was used to rank individual species on a cumulative distribution curve to identify the number of species comprising 99% of the total %IRI.

Species co-occurrence and assemblage analysis

Two approaches were taken to evaluate the co-occurrence of groundfish species: (1) HCA and (2) non-hierarchical cluster analysis or partitioning analysis (PA). We considered the use of multiple methods to investigate a common inquiry as a means to increase our analytical power of an inherently subjective evaluation (Mahon et al. 1998).

Each cluster analysis (HCA and PA) used species as the clustering variable and either the presence-absence or log-transformed CPUE data ($\log_{10}(x+1)$) as clustering metrics. Clustering species using presence-absence data indicates species groups that occur together, while clustering using CPUE indicates species groups captured at the same magnitude. Transforming the CPUE reduces the effect of extremely large and small values in a dataset and mitigates the effect of abundant versus rare species.

Both clustering methods required the transformation of the presence-absence or CPUE data into dis(similarity) matrices before species could be formally assigned to clusters. The Bray-Curtis dissimilarity measure (0 = complete similarity; 1 = complete dissimilarity) was used throughout our analyses. The Bray-Curtis measure is commonly used with ecological data because it ignores samples when both species are absent and is therefore robust to zero values (Krebs 1999). The function 'vegdist' in the 'vegan' library R statistical package (R.2.13.1; R Development Core Team) was used to calculate dissimilarity matrices.

HCA is a commonly applied method to investigate potential variable groupings. HCA makes no *a priori* assumptions regarding variable relationships and therefore is a useful descriptive tool (McGarigal et al. 2000). We chose an agglomerative average linkage method that uses the minimized average distance between neighbors to construct branching cluster diagrams (Venables & Ripley 2002). Two approaches were considered when defining significant HCA groupings: (1) groups <0.4 (dis)similarity level (consistent with Weinberg 1994) and (2) introducing 'fake' species with random presence-absence across all tows into the cluster. The concept is to identify the dissimilarity point at which the fake species are grouped. Species groups at levels more dissimilar than the fake species are considered no better than

random groupings. The consistency of the significance level with the applied number of fake species was also investigated, from 1 fake species to the number of fake species equivalent to the total number of 'real' species.

Unlike HCA, non-hierarchical PA requires a pre-specified number of groups to allocate variables into, producing a single solution to group clustering by minimizing the dissimilarity within clusters (Timm 2002, Williams & Ralston 2002, Venables & Ripley 2002). We chose the k-medians method because the use of medians rather than means produces results less sensitive to outliers (Kauffman & Rousseeuw 1990). We evaluated the optimal number of groups (clusters) using 2 cluster validity diagnostics: (1) average silhouette coefficient (SC) (Kauffman & Rousseeuw, 1990) and (2) Hubert's Γ (Hg). The 2 diagnostics have a tendency to lump (SC) and split (Hg), respectively (Cope & Punt 2009), so results from both were considered. Cluster validity diagnostics were examined for 2 through $N - 1$ groups, with N being the total number of species clustered. The number of groups indicated by both the overall highest average SC and highest Hg were considered best supported by the data. Significant species groupings from the PA were then determined by choosing groups with average SCs ≥ 0.25 (Kauffman & Rousseeuw 1990). All cluster analyses were performed using the `hclust()`, `cluster.stats()` and `pam()` functions in R.2.13.1 (R Development Core Team 2010). For each assemblage, 'core' species were defined as species groups supported by both methods and/or the most strongly supported (i.e. above the significance thresholds) groupings. 'Additional' species were usually only supported by one of the methods or only weakly supported (i.e. at or near the significance thresholds).

RESULTS

Survey descriptive summaries

The number of tows conducted yearly differed between the triennial and annual survey, with the annual survey generally providing greater spatial coverage and more samples (Fig. 2). The spatial extent covered by the triennial survey varied from year to year. Tows conducted during 1977 and from 1989 through 2001 covered the complete survey range, whereas tows during 1980, 1983, and 1986 were skewed north of 36.7° N latitude. When aggregating the data for all years nearly two-thirds of the

triennial survey tows covered Region 1 (Fig. 2). Region 2 is spatially smaller and had the lowest number of triennial tows (Fig. 2). Median depths were generally held between 120 and 150 m (with the one exception being 1977), though depth distributions shifted to deeper waters in 1995 (Fig. 2). Median depths in the triennial survey were similar among regions compared to all regions and years.

The spatial coverage of the annual survey was more stable, with median depths twice that of the triennial survey. Annual survey tows in regions 1 and 3 had similar sample allocation, whereas the smaller Region 2 had proportionally smaller samples. Median depths among regions in the annual survey were notably different from each other and the yearly medians, with Region 1 having the shallowest median depths, and Regions 2 and 3 having the deepest median depths.

Species selection

The IRI decision rule produced different sets of species for each survey. Thirty species were selected for the triennial survey (Table 2) and 36 for the annual survey (Table 3), with 22 species in common (bolded species in Tables 2 & 3).

Species occurrences and catch magnitudes varied greatly among the species in each survey (Tables 2 & 3). Pacific hake dominated catch in the triennial survey (48% IRI; Table 2), while it ranked second in IRI in the annual survey for all years and areas (13%; Table 3). Most species demonstrated left skewed CPUE distributions, with long right tails, indicating greatly varying catch magnitudes. Rockfishes as a group had the most skewed distributions, with shortbelly rockfish demonstrating the widest CPUE distribution in both surveys. The annual survey demonstrated consistently higher catch rates.

Relative species occurrences also varied temporally and spatially (Tables 2 & 3). Some species (e.g. Pacific hake, Pacific sandab) maintained similar occurrence levels and rankings among years for both surveys, whereas others (e.g. sharpchin rockfish) were highly variable. Differences in relative species occurrences were also seen regionally compared to all regions combined across years.

Species assemblages

The dissimilarity significance levels were weakly sensitive to the number of fake species included in

the cluster analysis (Fig. 3) and leveled out with increasing number of species. The levels indicating significant assemblages in the triennial and annual surveys were thus determined to be 0.415 and 0.48, respectively, using the value derived when the number of fake species was equivalent to real species.

Nine species assemblages based on the presence-absence data and 9 based on CPUE data were delineated using HCA and PA (Tables 4 & 5) for both surveys, though these groups were not always similar. Two of the assemblages identified using presence-absence data have no analog when using CPUE (Table 4, assemblages G and H), while one assemblage identified using CPUE had no analog when using presence-absence data (Table 5, assemblage 4). The CPUE groups tended to be subsets of the presence-absence data and only 3 of the groups (A, B, and C from Table 4 and 1, 2, and 3 from Table 5) are shared among both surveys for both datasets (Figs. 4 to 7). The annual survey, with its greater depth range (Fig. 2), generally identified more groups than the triennial survey.

Results for the 2 clustering methods were interpreted in 2 ways: (1) by including all assemblages recognized by either method ('Combined results') and (2) by including only assemblages recognized by both methods ('Overlapped results'). The presence-absence data show strong agreement between the 2 clustering methods (Figs. 4 & 5), while the CPUE data shows less agreement between clustering methods (Figs. 6 & 7).

Most species assemblages from both surveys were temporally stable (Fig. 4). Both surveys showed 3 particularly strong and consistent groups for the whole time period: (A) the 'Dover-hake-rex-slender sole' complex, (B) the 'English-sanddab-petrable' complex, and (C) the 'chilipepper-shortbelly' complex. Each of these core assemblages included several species that showed higher assemblage variability across time and surveys and were well supported by both cluster methods. For example, arrowtooth flounder, sablefish, and ratfish were found in assemblage A for every year except 2008. Stripetail rockfish was commonly found in assemblage C for most years in the triennial survey, but rarely associated with that assemblage in the annual survey. Assemblages A and B, although distinct by our above definitions, were often shown to have similarity values just below the threshold value, meaning it was not rare to find both assemblages in the same tows. Additionally, the triennial survey indicated a strongly persistent grouping of shortspine thornyhead and splitnose rockfish with Pacific Ocean perch (assemblage

Table 2. Dominant species of the triennial Alaska Fisheries Science Center (AFSC) shelf-slope surveys from 1977 to 2004 and the percent weight (%wt), numbers (%no.), frequency of occurrence (%FO), index of relative importance (%IRI) with respective coefficients of variation in parentheses. Summary catch per unit effort (CPUE; untransformed) information by quantiles are also given. **Bold:** common between both surveys

Common name	Scientific name	%wt	%no.	%FO	%IRI				Positive CPUE (no. m ⁻²)		
					All regions	Region 1	Region 2	Region 3	5%	50%	95%
American shad	<i>Alosa sapidissima</i>	0.46 (60)	0.31 (60)	19.89 (12)	0.16 (55)	0.14 (79)	0.06 (64)	0.24 (86)	0.02	0.08	2.44
Arrowtooth flounder	<i>Atheresthes stomias</i>	3.27 (49)	1.16 (38)	55.49 (13)	2.21 (57)	0.79 (194)	1.49 (44)	7.07 (47)	0.03	0.31	4.38
Bocaccio	<i>Sebastes paucispinis</i>	1.2 (97)	0.39 (193)	15.15 (20)	0.23 (104)	0.22 (153)	0.07 (214)	0.26 (135)	0.02	0.06	1.33
Canary rockfish	<i>Sebastes pinniger</i>	1.66 (75)	0.32 (68)	20.08 (11)	0.39 (82)	0.16 (66)	0.39 (84)	1.01 (119)	0.02	0.06	2.78
Chilepepper	<i>Sebastes goodei</i>	2.38 (80)	2.43 (70)	11.36 (34)	0.7 (113)	1.16 (101)	0.01 (206)	0.17 (316)	0.03	0.38	34.24
Darkblotched rockfish	<i>Sebastes crameri</i>	0.84 (37)	0.71 (20)	34.47 (8)	0.52 (32)	0.41 (35)	0.78 (52)	0.66 (63)	0.03	0.20	3.47
Dover sole	<i>Microstomus pacificus</i>	5.81 (33)	5.71 (28)	84.09 (5)	9.3 (31)	7.72 (29)	13.78 (46)	10.72 (31)	0.03	0.98	13.41
English sole	<i>Parophrys vetulus</i>	1.57 (44)	2.52 (32)	53.6 (9)	2.2 (39)	2.26 (37)	2.06 (93)	1.72 (41)	0.03	0.58	8.51
Eulachon	<i>Thaleichthys pacificus</i>	0.19 (93)	1.86 (77)	24.62 (13)	0.44 (79)	0.14 (46)	0.39 (99)	1.47 (111)	0.03	0.43	12.47
Greenstriped rockfish	<i>Sebastes elongatus</i>	0.57 (28)	0.74 (27)	34.66 (6)	0.46 (32)	0.4 (41)	0.41 (47)	0.58 (53)	0.03	0.24	4.31
Jack mackerel	<i>Trachurus symmetricus</i>	1.89 (67)	0.9 (86)	9.09 (29)	0.23 (70)	0.4 (65)	0.13 (249)	0 (171)	0.03	0.11	17.03
Lingcod	<i>Ophiodon elongatus</i>	1.36 (46)	0.14 (25)	37.88 (8)	0.57 (49)	0.37 (82)	0.27 (50)	1.12 (73)	0.02	0.06	0.55
Pacific hake	<i>Merluccius productus</i>	36.31 (11)	27.09 (13)	79.73 (6)	48.16 (14)	54.94 (14)	50.77 (32)	26.88 (30)	0.05	1.98	76.73
Pacific herring	<i>Clupea harengus</i>	1.59 (53)	5.35 (55)	25.76 (15)	1.7 (64)	1.44 (64)	0.93 (147)	2.54 (92)	0.03	0.42	46.20
Pacific Ocean perch	<i>Sebastes alutus</i>	1.44 (70)	0.64 (66)	21.21 (23)	0.38 (85)	0.06 (123)	0.43 (93)	1.88 (77)	0.02	0.19	7.34
Pacific sanddab	<i>Citharichthys sordidus</i>	2.95 (26)	8.08 (22)	40.91 (12)	4.64 (24)	6.45 (23)	1.79 (66)	1.65 (116)	0.03	2.41	34.43
Petrale sole	<i>Eopsetta jordani</i>	0.4 (34)	0.28 (32)	48.48 (10)	0.32 (40)	0.28 (32)	0.33 (94)	0.34 (33)	0.02	0.12	0.94
Redstripe rockfish	<i>Sebastes proriger</i>	1.11 (69)	0.96 (64)	10.23 (41)	0.16 (101)	0.01 (79)	0.16 (261)	1.09 (75)	0.02	0.22	31.06
Rex sole	<i>Glyptocephalus zachirus</i>	2.84 (35)	7.03 (26)	85.42 (4)	8.17 (26)	7.48 (25)	12.76 (53)	7.06 (28)	0.05	1.48	14.76
Sablefish	<i>Anoplopoma fimbria</i>	6.3 (20)	2.03 (38)	65.53 (6)	5.32 (21)	4.41 (39)	3.96 (63)	7.34 (31)	0.03	0.24	3.48
Sharpchin rockfish	<i>Sebastes zacentrus</i>	1 (48)	1.25 (49)	15.72 (17)	0.32 (58)	0.06 (65)	1.25 (136)	1.16 (74)	0.02	0.19	17.54
Shortbelly rockfish	<i>Sebastes jordani</i>	2.09 (81)	7.77 (83)	11.36 (21)	1.27 (76)	2.09 (97)	0.01 (178)	0.21 (287)	0.03	0.27	96.09
Shortspine thornyhead	<i>Sebastolobus alascanus</i>	0.63 (18)	1.24 (14)	35.04 (8)	0.58 (20)	0.41 (50)	1.56 (114)	0.72 (62)	0.03	0.56	7.56
Slender sole	<i>Lyopsetta exilis</i>	0.24 (46)	1.24 (36)	49.62 (14)	0.82 (50)	0.7 (102)	0.96 (44)	0.94 (50)	0.03	0.29	4.29
Spiny dogfish	<i>Squalus acanthias</i>	7.61 (38)	2.12 (44)	53.41 (7)	5.06 (40)	2.4 (51)	0.61 (61)	13.77 (45)	0.02	0.15	6.34
Spitnose rockfish	<i>Sebastes diploproa</i>	2.94 (67)	5.66 (68)	25 (10)	2.16 (69)	1.8 (54)	2.23 (80)	2.73 (203)	0.03	1.06	38.01
Spotted Ratfish	<i>Hydrolagus collei</i>	0.53 (37)	0.4 (39)	48.3 (14)	0.41 (46)	0.28 (64)	0.23 (73)	0.83 (43)	0.02	0.08	1.15
Stripetail rockfish	<i>Sebastes saxicola</i>	1.63 (41)	4.56 (34)	18.18 (18)	1.35 (48)	1.86 (53)	0.91 (164)	0.38 (272)	0.03	0.44	49.48
Walleye pollock	<i>Theragra chalcogramma</i>	0.55 (115)	1.03 (194)	7.39 (49)	0.11 (157)	0 (83)	0 (160)	1.26 (152)	0.02	0.13	10.78
Yellowtail rockfish	<i>Sebastes flavidus</i>	2.51 (31)	0.64 (36)	21.59 (13)	0.59 (46)	0.23 (60)	0.26 (90)	1.89 (61)	0.02	0.12	9.05

Table 3. Dominant species of the annual Northwest Fisheries Science Center (NWFS) shelf-slope surveys from 2003 to 2009 and the percent weight (%wt), numbers (%no.), frequency of occurrence (%FO), index of relative importance (%IRI) with respective coefficients of variation in parentheses. Summary catch per unit effort (CPUE; untransformed) information by quantiles are also given. Swept area is measured in hectares. **Bold:** common between both surveys

Common name	Scientific name	%wt	%no.	%FO	%IRI			Positive CPUE (no. ha ⁻¹)		
					All regions	Region 1	Region 2	Region 3	5 %	95 %
Arrowtooth flounder	<i>Atheresthes stomias</i>	3.00 (25)	0.85 (32)	27.78 (9)	1.62 (10)	4.57 (18)	3.66 (20)	0.50 (164)	0.57	5.80
Aurora rockfish	<i>Sebastes aurora</i>	0.28 (29)	0.24 (26)	11.56 (7)	0.09 (7)	0.79 (102)	0.98 (46)	1.66 (43)	0.54	4.36
Big skate	<i>Raja binoculata</i>	0.60 (37)	0.03 (27)	10.59 (12)	0.1 (12)	1.45 (33)	1.34 (23)	0.53 (90)	0.49	1.05
Bigfin eelpout	<i>Lycodes cortezianus</i>	0.28 (25)	0.46 (30)	24.09 (6)	0.27 (6)	2.25 (58)	2.53 (23)	3.27 (34)	0.54	5.10
Black eelpout	<i>Lycodes diapterus</i>	0.11 (30)	0.44 (34)	15.20 (7)	0.13 (7)	1.61 (38)	2.11 (35)	1.30 (81)	0.54	4.75
Brown cat shark	<i>Apristurus brunneus</i>	0.41 (23)	0.44 (15)	29.15 (6)	0.37 (7)	2.32 (25)	4.24 (32)	3.26 (49)	0.47	3.77
California slickhead	<i>Alepocephalus tenebrosus</i>	0.63 (29)	0.54 (22)	18.24 (8)	0.33 (10)	1.18 (48)	2.55 (38)	3.05 (74)	0.53	7.20
Canary rockfish	<i>Sebastes pinniger</i>	1.21 (128)	0.18 (106)	5.92 (14)	0.12 (14)	0.77 (48)	0.83 (38)	0.31 (93)	0.48	1.15
Chilipepper	<i>Sebastes goodie</i>	5.09 (39)	2.36 (44)	11.07 (10)	1.25 (10)	0.14 (141)	0.96 (76)	1.74 (44)	0.52	6.58
Darkblotched rockfish	<i>Sebastes crameri</i>	0.88 (44)	0.45 (25)	15.25 (9)	0.31 (8)	2.55 (37)	1.97 (29)	0.80 (132)	0.53	3.13
Deepsea sole	<i>Embranchichthys bathybius</i>	0.38 (25)	0.19 (23)	18.87 (10)	0.16 (10)	1.67 (49)	3.52 (31)	1.80 (64)	0.45	3.07
Dover Sole	<i>Microstomus pacificus</i>	16.46 (23)	9.84 (22)	70.13 (2)	27.92 (3)	7.42 (7)	7.79 (7)	6.16 (27)	0.68	32.97
English Sole	<i>Parophrys vetulus</i>	1.81 (39)	2.04 (28)	33.47 (4)	1.95 (5)	3.44 (30)	2.69 (30)	2.86 (56)	0.60	13.47
Giant grenadier	<i>Albatrossia pectoralis</i>	1.23 (21)	0.23 (24)	14.57 (12)	0.32 (11)	1.46 (49)	1.98 (30)	1.18 (69)	0.43	2.41
Greenstriped rockfish	<i>Sebastes elongatus</i>	1.04 (33)	1.15 (33)	21.64 (8)	0.72 (6)	2.69 (23)	1.91 (32)	1.82 (57)	0.55	5.08
Halfbanded rockfish	<i>Sebastes semicinctus</i>	0.70 (73)	5.48 (76)	6.70 (8)	0.63 (8)	0.03 (215)	NA	2.02 (81)	0.59	12.34
Lingcod	<i>Ophiodon elongatus</i>	1.91 (36)	0.22 (25)	25.33 (5)	0.82 (6)	2.85 (27)	3.01 (30)	2.34 (82)	0.52	1.53
Longnose skate	<i>Raja rhina</i>	3.48 (26)	0.5 (23)	49.26 (3)	2.97 (3)	4.93 (12)	5.70 (24)	4.91 (56)	0.54	2.96
Longspine thornyhead	<i>Sebastolobus altivelis</i>	6.17 (29.1)	15.27 (22)	30.61 (7)	9.94 (6)	2.50 (34)	3.93 (25)	3.30 (59)	4.36	152.47
Pacific butterflyfish	<i>Peprilus simillimus</i>	0.14 (78)	1.11 (81)	5.11 (21)	0.1 (21)	0.02 (70)	NA	1.39 (67)	0.59	13.78
Pacific flatnose	<i>Antimora microlepis</i>	0.19 (39)	0.23 (36)	16.89 (8)	0.11 (7)	1.34 (44)	2.02 (27)	1.57 (71)	0.47	3.34
Pacific grenadier	<i>Coryphaenoides acrolepis</i>	2.06 (30)	1.14 (30)	16.94 (9)	0.82 (10)	1.71 (50)	2.50 (34)	1.53 (76)	0.51	8.46
Pacific hake	<i>Merluccius productus</i>	9.79 (28)	7.83 (32)	50.25 (5)	13.4 (4)	5.17 (17)	4.47 (8)	4.90 (16)	0.58	11.06
Pacific sanddab	<i>Citharichthys sordidus</i>	3.68 (32)	7.52 (31)	26.02 (4)	4.41 (3)	2.46 (36)	1.84 (29)	4.31 (44)	1.11	57.39
Petrale sole	<i>Eopsetta jordani</i>	1.20 (28)	0.63 (14)	33.56 (4)	0.93 (5)	4.01 (17)	2.69 (26)	2.92 (70)	0.56	4.92
Pink seaperch	<i>Zalemmbius rosaceus</i>	0.12 (34)	1.11 (34)	10.75 (9)	0.2 (11)	NA	NA	2.06 (58)	0.76	20.33
Rex sole	<i>Glyptocephalus zachirus</i>	5.83 (11)	0.88 (14)	52.7 (5)	7.49 (6)	6.21 (14)	5.56 (25)	4.58 (64)	0.85	28.24
Sablefish	<i>Anoplopoma fimbria</i>	2.27 (15)	3.16 (19)	55.8 (2)	5.67 (3)	5.42 (13)	6.16 (9)	6.99 (36)	0.55	3.64
Sandpaper skate	<i>Bathyraja interrupta</i>	0.43 (28)	0.15 (25)	27.71 (7)	0.25 (9)	3.68 (22)	2.79 (40)	1.65 (44)	0.49	1.42
Sharpchin rockfish	<i>Sebastes zacentrus</i>	1.90 (135)	5.46 (166)	5.11 (23)	0.42 (27)	0.79 (38)	0.60 (70)	0.21 (128)	0.51	3.83
Shortbelly rockfish	<i>Sebastes jordani</i>	2.22 (90)	1.86 (58)	7.13 (9)	0.79 (11)	0.04 (122)	0.21 (158)	1.36 (41)	0.53	7.63
Shortspine thornyhead	<i>Sebastolobus alascanus</i>	0.53 (24)	2.16 (26)	43.3 (4)	2.68 (5)	4.27 (23)	4.46 (21)	3.68 (44)	0.59	7.05
Slender sole	<i>Lyopsetta exilis</i>	6.96 (17)	2.03 (17)	42.44 (7)	1.72 (5)	5.27 (9)	4.00 (12)	3.51 (38)	0.62	11.15
Spiny dogfish	<i>Squalus acanthias</i>	2.73 (83)	4.92 (73)	30.3 (5)	4.12 (5)	3.32 (43)	2.55 (37)	2.71 (51)	0.52	2.80
Spitnose rockfish	<i>Sebastes diploproa</i>	1.80 (63)	1.27 (40)	18.58 (10)	2.15 (10)	1.66 (44)	1.63 (33)	2.91 (31)	0.58	23.13
Spotted Ratfish	<i>Hydrolagus collei</i>	3.53 (29)	5.86 (30)	43.07 (4)	2 (5)	4.59 (20)	3.27 (45)	4.53 (48)	0.55	3.51
Stripetail rockfish	<i>Sebastes saxicola</i>	1.49 (31)	4.01 (24)	17.75 (8)	1.48 (9)	0.82 (39)	1.74 (44)	2.95 (50)	0.54	10.08
White croaker	<i>Genyonemas lineatus</i>	0.39 (40)	0.78 (43)	5.78 (19)	0.1 (18)	NA	0.03 (172)	1.38 (75)	0.71	13.82
Yellowtail rockfish	<i>Sebastes flavidus</i>	1.34 (43)	0.26 (45)	5.15 (17)	0.13 (17)	0.98 (83)	0.30 (83)	0.14 (92)	0.52	1.94

Fig. 3. Dissimilarity level of significance based on the inclusion of fake species in the hierarchical cluster analysis. The number of fake species ranged from 1 to the number of real species in the cluster analysis. The solid line is the suggested dissimilarity level (0.4) determining significant assemblages from Weinberg (1994). The broken lines nearest the triennial and annual survey points are the respective dissimilarity levels (0.415 and 0.48) determining significant assemblages as indicated by the inclusion of various fake species (x-axis)

D), an assemblage not detected in the annual survey. Shortspine thornyhead instead is found with longspine thornyhead and other deepwater slope species in assemblage E. Likewise, the annual survey detected 2 deep water assemblages (E and H) along

with 2 more assemblages (F and G) not observed in the triennial data. These differences in results are due to both differences in survey depth coverage and the inclusion of different species in the clustering analysis, altering relative similarities.

Assemblages from the triennial survey were found throughout the survey range when years were combined (Fig. 5). The annual survey results also indicate regional consistency, except for assemblages C, H and I that were associated with southern regions and assemblage G that was associated with the central region.

CPUE-based assemblages 1, 2 and 3 persisted through many years of both surveys, though assemblages 1 and 3

drop out in several years when overlapping cluster method results were considered (Fig. 6). Assemblages 5, 6 and 7 are unique to the annual survey and also demonstrated temporal persistence, though assemblage 7 does not hold up when the overlapped results

Table 4. Species assemblages (denoted by letter and number combinations) based on HCA and PA cluster analyses of presence-absence data. rf: rockfish

Assemblage	Core species	Additional species		
		1	2	3
A	Dover sole Pacific hake Rex sole Slender Sole	Arrowtooth flounder Ratfish Sablefish	Spiny dogfish	Longnose skate Sandpaper skate
B	English Sole Pacific Sanddab	Petrale Sole	Lingcod Spiny dogfish	Ratfish
C	Chillipepper rf Shortbelly rf	Stripetail rf	Bocaccio	Greenstriped rf
D	Shortspine thornyhead Splitnose rf	Pacific Ocean Perch	Darkblotched rf	
E	California slickhead Deepsea sole Giant grenadier Pacific flatnose Pacific grenadier	Brown catshark	Longspine thornyhead Shortspine thornyhead	Sablefish
F	Pink seaperch Pacific butterflyfish White croaker	Halfbanded rf		
G	Greenstriped rf Stripetail rf			
H	Aurora rockfish Blackfin eelpout			
I	Canary rf Yellowtail rf			

Table 5. Species assemblages (denoted by number and letter combinations) based on HCA and PA cluster analyses of transformed catch per unit effort data. Letter designation specifies less persistent components of the major assemblage component. rf: rockfish

Assemblage	Core species	Additional species	
		A	B
1	Dover sole Rex sole	Pacific hake Slender sole	Arrowtooth flounder
2	English Sole Pacific Sanddab	Petrable sole	
3	Chillipepper rf Shortbelly rf	Stripetail rf	
4	Redstripe rf Sharpchin rf		
5	Deepsea sole Flatnose Giant grenadier Pacific grenadier	California slickhead	Longspine Brown catshark
6	Pink seaperch White croaker	Pacific butterfish	Halfbanded rf
7	Sablefish Shortspine thornyhead	Brown catshark	
8	Yellowtail Canary		

are considered. All other assemblages either occurred less consistently or were not identified by both interpretations. Assemblages 1 and 2 for both surveys and 5 and 6 from the annual survey occurred throughout the survey range when both clustering results are combined (Fig. 7). Only assemblages 5 and 6 were identified across all regions when overlapping results are used. The difference seen between the results of the presence-absence and CPUE clusters indicated that members of an assemblage may occur together, but not necessarily at similar magnitudes.

DISCUSSION

This study identifies groundfish species assemblages of the US West Coast with varying degrees of temporal and spatial persistence using cluster analysis of trawl survey presence-absence and CPUE data from the longest available time series. The identified species assemblages provide information regarding community composition and interactions that can guide the implementation of an ecosystem-based fishery management plan for the US West Coast; the application provides general methodological guidance on how fisheries data can be interpreted to determine species assemblages. Defining species assemblages using presence-absence and CPUE data classifies the frequency and magnitude of catch complexes, respectively. Such multi-layered information is particularly germane to evaluating target and bycatch species assemblages in multi-species complexes (Crowder & Murauski 1998) and to fishery bycatch and discard modeling (e.g. Fujita et al. 1998). Species assemblage analysis is also pertinent to broader marine ecology issues such as the study of ecosystem resilience and ecological interactions impacting managed species (Jamieson & Levings 2001).

Fig. 4. Species assemblages occurring in each sampled year based on species presence-absence for the triennial (1977–2004) and annual (2003–2009) surveys. Gray: core assemblages recognized by either hierarchical agglomerative cluster analysis or partitioning analysis ('combined'). Black: core assemblages recognized by both cluster analyses ('overlapping'). White: no assemblage presence. Numbers within cells: 'additional species' in each assemblage, as defined in Table 4. The 2004 cell is split between the triennial (left) and annual (right) survey findings

Fig. 5. Species assemblages occurring in each region or all regions based on species presence-absence for the entire triennial (1977–2004) and annual (Northwest Fisheries Science Center: 2003–2009) surveys. Gray: core assemblages recognized by either HCA or PA ('combined'). Black: core assemblages recognized by both cluster analyses ('overlapping'). White: no assemblage presence. Numbers within cells: 'additional species' in each assemblage, as defined in Table 4

Fig. 6. Species assemblages occurring in each sampled year based on species catch per unit effort for the triennial (1977–2004) and annual (Northwest Fisheries Science Center: 2003–2009) surveys. Gray: core assemblages recognized by either HCA or PA ('combined'). Black: core assemblages recognized by both cluster analyses ('overlapping'). White: no assemblage presence. Numbers within cells: 'additional species' in each assemblage, as defined in Table 5. The 2004 cell is split between the triennial (left) and annual (right) survey findings

Generally, core assemblages persisted through time and space, indicating useful long-term management units (Williams & Ralston 2002), while minor components tended to vary spatiotemporally, indicating that a number of species caught in the groundfish fishery are loosely coupled. Persistence in species

assemblages as recorded in the survey data may be attributed to a number of factors such as changing survey sampling, environmental variability (e.g. ENSO events), habitat availability, and fisheries removals (Mantua & Hare 2002, Miller et al. 2009). The most persistent assemblages contained some of the most valuable species in terms of groundfish fisheries management (assemblages A–D in Table 4 and Fig. 4; and assemblages 1–3 in Table 5 and Fig. 5). The canary-yellow-tail assemblage (Assemblage I and 8) also contains species important to management, but was rare in occurrence. Given the low stock status of canary rockfish (Stewart 2009) and restrictions of the surveys from entering rockfish conservation zones, the rarity of this assemblage is not surprising. The ubiquitous nature of ratfish, sablefish, and spiny dogfish is demonstrated by their assignments with multiple core species groups and possible interactions across several groundfish fisheries. Some core assemblages were consistently recognized by one survey (e.g. D in the triennial; E & F in the annual

surveys; Fig. 4), reflecting differences in sampling, while other core assemblages were sporadic and rare (e.g. I in Fig. 4). Understanding how species assemblages either persist or change over time can lead to the development of ecosystem structure indicators useful for highlighting assemblages in need of in-

Fig. 7. Species assemblages occurring in each region or all regions based on species catch per unit effort for the entire triennial (1977–2004) and annual (2003–2009) surveys. Gray: core assemblages recognized by either HCA or PA ('combined'). Black: core assemblages recognized by both cluster analyses ('overlapping'). White: no assemblage presence. Letters within cells: 'additional species' in each assemblage, as defined in Table 5

creased management attention (Rochet & Trenkel 2003). Overall, species assemblages presented in this study are generally consistent with those identified in previous investigations (Gabriel & Tyler 1980, Weinberg 1994, Jay 1996, Williams & Ralston 2002, Tolimieri & Levin 2006).

Methods and data choices

Applying multiple methods to investigate the relationships among species (Levins 1966, 1993) proved useful in this study. The consistent identification of groupings by different techniques was encouraging, although the use of multiple methods lacks sufficient sample size (i.e. replicates of alternative methods) to produce robust statistics to formally compare methods (Orzack & Sober 1993). We nevertheless recommend using multiple clustering methods (e.g. HCA and PA) to provide a multi-faceted representation of the ecological relationships described by species assemblage analysis.

Considering multiple data types (presence-absence and CPUE) revealed 2 fundamentally different, though not mutually exclusive, ways of describing species assemblages. Presence-absence data addresses whether species co-occur; no other relationship is inferred. In using transformed or standardized CPUE, one can investigate which co-occurring species have similar catch magnitudes. For example, bocaccio were a common component of assemblage C using the presence-absence data (Figs. 4 & 5), but

were never included in the same assemblage (Assemblage 3) when using CPUE (Figs. 6 & 7) because of low bocaccio catch magnitudes. Additionally, unique species groupings were identified by the presence-absence (Groups G and H in Table 4) and CPUE data (Group 4 in Table 5), underscoring the sensitivity of interpreting species relations given either presence-absence or CPUE data alone. Investigators should ask whether they are interested in co-occurrence or occurrence magnitude before deciding to use presence-absence and/or CPUE data for species assemblage analyses.

Assumptions and limitations of the available data series must be considered when interpreting the results of assemblage analyses. Many species, especially those associated with rocky/high-relief structures (like many rockfishes) are inaccessible to the trawl surveys' designs and are therefore under-represented (Zimmermann et al. 2003). In addition, trawl survey techniques miss many pelagic and nearshore species. Many commercially-important species (particularly several rockfishes) will be under-represented in these survey data sets, thus their absence does not reflect their lack of co-occurrence with others species. This study provides insight specifically into fish assemblages occurring in the trawlable shelf and slope of the US West Coast. Ideally, alternative survey techniques (Tolimieri et al. 2008) are needed to supplement trawl surveys to develop a holistic look at species assemblages. Similarly, many of the species included in this study are either seasonally or ontogenetically transitory (Saun-

ders & McFarlane 1997). The surveys in this study are limited to a 4 to 6 mo period of the year during the summer, so subsequent characterizations of assemblages may only be valid for this timeframe. Due caution is recommended when extending these results beyond the spatial and temporal limitations of the data.

Conclusion

This study offers an improved understanding of groundfish species assemblages accessible to the US West Coast trawl fishery. Assemblage information is an integral piece of the multispecies management puzzle, allowing insight into co-occurring non-target species from targeted species fisheries. Persistence of assemblages through time, even under intense fishing pressure and variable environmental conditions, suggests predictable functional relationships between species. Further research characterizing the interactions among members of an assemblage is needed to determine the efficacy of managing assemblages as opposed to single species (Tyler et al. 1982).

This trawl survey assemblage analysis forms the foundation for several future projects. Survey assemblages can be compared to fishery-dependent data assemblage analysis to investigate the role of discard in the reported and landed catches. Latitudinal changes in species assemblages could be investigated in detail by performing the analysis by region across years. Similar trawls for each survey could be grouped based on the trawl species composition (Jay 1996) to address the spatial distribution of groundfish assemblages through time. Dominant species within each trawl could then be identified using the IRI as applied in this study. Finally, further insight into assemblage ecology, fishery impacts, and management application can be gained by exploring the relationship between the above survey trawl assemblages and environmental (e.g. temperature, depth) and fisheries (e.g. capture fleets, removal periods) variables (Tolimieri & Levin 2006).

Acknowledgements. We are grateful to D. Bryan, J. Field, E. D. Ford, J. Hastie, E. Heery, R. Methot, K. McGourty, A. Punt, M. Zimmermann, and 3 anonymous reviewers for valuable comments and insight as reviewers on earlier versions of this manuscript. We are also appreciative of B. Horne and J. Wallace (NWFSC), and M. Wilkins (AFSC) for providing us with datasets, and all those affiliated with NOAA Fisheries who were involved with collecting and processing survey data.

LITERATURE CITED

- Cope JM, Punt AE (2009) Drawing the lines: resolving fishery management units with simple fisheries data. *Can J Fish Aquat Sci* 66:1256–1273
- Cortés E (1997) A critical review of methods of studying fish feeding based on analysis of stomach contents: application to elasmobranch fishes. *Can J Fish Aquat Sci* 54:726–738
- Crowder LB, Murawski SA (1998) Fisheries bycatch: implications for management. *Fisheries* 23:8–17
- Francis RC, Little JE, Bloeser J (2009) Matching spatial scales of ecology, economy, and management for groundfish of the US West Coast marine ecosystem: a state of the science review. Report to the Lenfest Ocean Program at the Pew Charitable Trust
- Fujita RM, Foran T, Zevos I (1998) Innovative approaches for fostering conservation in marine fisheries. *Ecol Appl* 8: S139–S150
- Gabriel WL (1982) Structure and dynamics of northeastern pacific demersal fish assemblages. PhD Dissertation, Oregon State University, Corvallis, OR
- Gabriel WL, Tyler AV (1980) Preliminary analysis of Pacific coast demersal fish assemblages. *Mar Fish Rev* 43: 83–88
- Jamieson GS, Levings CO (2001) Marine protected areas in Canada—implications for both conservation and fisheries management. *Can J Fish Aquat Sci* 58:138–156
- Jay CV (1996) Distribution of bottom-trawl fish assemblages over the continental shelf and upper slope of the US West Coast, 1977–1992. *Can J Fish Aquat Sci* 53:1203–1225
- Jennings S, Kaiser MJ, Reynolds JD (2001) Marine fisheries ecology. Blackwell Science, Oxford
- Kauffman L, Rousseeuw PJ (1990) Finding groups in data: an introduction to cluster analysis. Springer-Verlag, New York, NY
- Krebs CJ (1999) Ecological methodology. Addison-Welsey, Menlo Park, CA
- Lee YW, Sampson DB (2000) Spatial and temporal stability of commercial groundfish assemblages off Oregon and Washington as inferred from Oregon trawl logbooks. *Can J Fish Aquat Sci* 57:2443–2454
- Levins R (1966) The strategy of model building in population biology. *Am Sci* 54:421–431
- Levins R (1993) A response to Orzack and Sober: formal analysis and the fluidity of science. *Q Rev Biol* 68:547–555
- Mahon R, Brown SK, Zwanenburg KCT, Atkinson DB and others (1998) Assemblages and biogeography of demersal fishes of the east coast of North America. *Can J Fish Aquat Sci* 55:1704–1738
- Mantua NJ, Hare SR (2002) The Pacific Decadal Oscillation. *J Oceanogr* 58:35–44
- McGarigal K, Cushman S, Stafford S (2000) Multivariate statistics for wildlife and ecology research. Springer, New York, NY
- Miller SD, Clarke ME, Hastie JD, Hamel OS (2009) Pacific coast groundfish fisheries. In: NMFS (ed) Our living oceans: report on the status of US living marine resources, 6th edn. NOAA Tech Memo NMFS-F/SPO-80. US Department of Commerce, p 211–222
- Nagtegaal DA (1983) Identification and description of assemblages of some commercially important rockfishes (*Sebastes* spp.) off British Columbia. *Can Tech Rep Fish Aquat Sci* 1183, Department of Fisheries and Oceans, Nanaimo

- Orzack SH, Sober E (1993) A critical assessment of Levins's 'The strategy of model building in population biology' (1966). *Q Rev Biol* 68:533–546
- PFMC (Pacific Fishery Management Council) (2011) Pacific coast fishery ecosystem management plan for US portion of the California current large marine ecosystem. Pacific Fishery Management Council, Portland, OR
- Pinkas L, Oliphant S, Iverson ILK (1971) Food habits of albacore, bluefin tuna and bonito in California waters. *Fish Bull* 152:1–105
- R Development Core Team (2010) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. www.R-project.org.
- Ralston S (1998) The status of federally managed rockfish on the US West Coast. In: Yoklavich M (ed) Marine harvest refugia for west coast rockfish: a workshop. NOAA Tech Memo NMFS-SEFSC-255, p 6–16
- Ralston S (2002) West Coast groundfish harvest policy. *N Am J Fish Manag* 22:249–250
- Rochet MJ, Trenkel VM (2003) Which community indicators can measure the impact of fishing? A review and proposals. *Can J Fish Aquat Sci* 60:86–99
- Rogers JB, Pikitch EK (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
- Saunders MW, McFarlane GA (1997) Observation on the spawning distribution and biology of offshore Pacific hake. *CALCOFI Rep* 38:147–160
- Stewart IJ (2009) Status of the US canary rockfish resource in 2009 (update of 2007 assessment model). In: Status of the Pacific coast groundfish fishery through 2009, stock assessment and fishery evaluation: stock assessments, STAR Panel reports, and rebuilding analyses. Pacific Fishery Management Council, Portland, OR (www.pcouncil.org/wp-content/uploads/2009_canary_updated_assessment_SAFE_version.pdf)
- Timm NH (2002) Applied multivariate analysis. Springer-Verlag, New York, NY
- Tolimieri N, Levin PS (2006) Assemblage structure of eastern Pacific groundfishes on the US continental slope in relation to physical and environmental variables. *Trans Am Fish Soc* 135:317–332
- Tolimieri N, Clarke ME, Singh H, Goldfinger C (2008) Evaluating the SeaBED AUV for monitoring groundfish in untrawlable habitat. In: Reynolds JR, Greene HG (eds) Marine habitat mapping technology for Alaska. p 129–141
- Tyler AV, Gabriel WL, Overholtz WJ (1982) Adaptive management based on structure of fish assemblages off northern continental shelves. In: Mercer MC (ed) Multi-species approaches to fisheries management advice. *Can Spec Publ Fish Aquat Sci* 59:149–156
- Venables WN, Ripley BD (2002) Modern applied statistics with S, 4th edn. Springer-Verlag, New York, NY
- Weinberg KL (1994) Rockfish assemblages of the middle shelf and upper slope off Oregon and Washington. *Fish Bull* 92:620–632
- Weinberg KL, Wilkins ME, Shaw FR, Zimmerman M (2002) The 2001 Pacific West Coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length and age composition. NOAA Tech Memo NMFS-AFSC-128
- Williams EH, Ralston S (2002) Distribution and co-occurrence of rockfishes (Family: Sebastidae) over trawlable shelf and slope habitats of California and southern Oregon. *Fish Bull* 100:836–855
- Zimmermann M (2006) Benthic fish and invertebrate assemblages within the National Marine Fisheries Service US West Coast triennial bottom trawl survey. *Cont Shelf Res* 26:1005–1027
- Zimmermann M, Wilkins ME, Weinberg KL, Lauth RB, Shaw FR (2003) Influence of improved performance monitoring on the consistency of a bottom trawl survey. *ICES J Mar Sci* 60:818–826

Editorial responsibility: Konstantinos Stergiou, Thessaloniki, Greece

*Submitted: September 2, 2011; Accepted: January 12, 2012
Proofs received from author(s): March 29, 2012*