



Analysis of Benthic Communities on Weathervane Scallop Beds in Shelikof Strait

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Preface

This work was largely motivated by a University of Alaska Coastal Marine Institute (CMI) 2012 research priority to conduct scientific research for a richer understanding of habitats and ecosystem processes that may be affected by oil and gas extraction or renewable energy development in Cook Inlet. Shelikof Strait, in the northern Gulf of Alaska, contains high densities of weathervane scallops and supports a high proportion of the total commercial scallop landings in Alaska. Scallops are harvested from beds between Cape Douglas and Hallo Bay, as well as extending into Cook Inlet.

We conducted this analysis of scallop beds in Shelikof Strait within the broader geographic context of the Gulf of Alaska, Bering Sea, and Aleutian Islands. Full results are included in this report and further explored in the related University of Alaska Fairbanks master's thesis by Jennifer Glass, completed under the supervision of Dr. Gordon Kruse. Additional funding was provided by the National Science Foundation Marine Ecosystem Sustainability in the Arctic and Subarctic Program, the National Science Foundation Graduate Research Fellowship Program, the Northern Gulf of Alaska Applied Research Award, the H. Richard Carlson Fellowship, and the North Pacific Research Board.

Abstract

We conducted an analysis of benthic communities in areas targeted by a commercial weathervane scallop (*Patinopecten caurinus*) fishery on the continental shelf off Alaska, USA. Some bycatch species taken in this fishery are commercially valuable, including Tanner crab (*Chionoecetes bairdi*). Using bycatch data collected by onboard observers during 1996–2012, we analyzed spatial patterns in community composition on weathervane scallop beds, as well as changes in community composition over time. We also explored whether spatiotemporal differences in benthic communities could be related to environmental variables (sediment type, depth, bottom temperature, and freshwater discharge) and anthropogenic variables (trawling and dredging effort). Using non-parametric statistics, statistically significant ($P < 0.05$) differences in community structure were observed at the scale of state fishery registration districts, as well as among individual scallop beds. Certain species displayed a longitudinal gradient across the continental shelf. Spatial differences were most strongly correlated with sediment, depth and dredging effort. Changes over time were also detected, with significant differences between 1996–1999 and 2000–2012. However, these changes could be due to changes in the observer program after start-up years or altered fishing behavior associated with the formation of a fishery cooperative. Subtle changes during 2000–2012 were also present. Temporal changes were weakly yet significantly correlated with freshwater discharge and dredging effort. Results from this study provide a quantitative baseline of benthic community composition on weathervane scallop beds against which future changes can be assessed. Findings also contribute to our understanding of essential fish habitat for weathervane scallops and associated species.

Introduction

Benthic community ecology is gaining interest worldwide with increasing appreciation for benthic species' roles in marine ecosystem function and health (Gili & Coma 1998, Orejas et al. 2000, Austen et al. 2002), and as indicators of ecosystem change, including climate change (Kennedy & Jacoby 1999, Lenihan et al. 2003, Piepenburg et al. 2011). In Alaska, benthic community structure has been studied in the context of oil and gas development (Atlas et al. 1978, Blanchard et al. 2003), effects of commercial fishing (McConnaughey et al. 2000, Brown et al. 2005a, Stone et al. 2005, Rooper et al. 2011), and coastal development (Feder & Jewett 1986, Jewett et al. 2009). Over the past two decades, research focus has shifted towards ecosystem-scale properties, including habitat characteristics, multispecies interactions, and long-term environmental change (Hare & Mantua 2000, Mueter & Megrey 2005). These efforts have paralleled regional and national efforts to implement ecosystem-based management of marine resources (Witherell et al. 2000, Latour et al. 2003). For example, the U.S. Sustainable Fisheries Act of 1996 mandated identification of habitats essential to federally managed species, as well as measures to conserve and enhance these habitats.

The Sustainable Fisheries Act defined essential fish habitat (EFH) as, “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” Sparse information on benthic communities and habitats was originally available to define EFH for federally managed fisheries in Alaska for groundfish, crabs, scallops and salmon. As a default, EFH was primarily described based on the distribution of commercial catches. Benthic epifauna are among the most poorly studied species in Alaskan marine ecosystems. Bottom trawl surveys conducted in the Gulf of Alaska and Bering Sea are designed to assess the abundance and distribution of commercially important groundfish, king crab (*Lithodes* sp., *Paralithodes* sp.), Tanner crab (*Chionoecetes bairdi*), and snow crab (*C. opilio*). Although the focus of benthic invertebrate research on crab stems from their commercial importance, some investigations in Alaska have characterized marine benthic fauna more generally (Feder & Jewett 1986, Feder et al. 2005, Piepenburg et al. 2011).

The weathervane scallop (*Patinopecten caurinus*) is another invertebrate that has been the focus of some research owing to its commercial importance, however, the fishery for this species remains data-limited (Kruse et al. 2005). Prominent scallop beds are located off Yakutat, Kayak Island (southeast of Prince William Sound), Kodiak Island, in lower Cook Inlet, along the Alaska Peninsula and Aleutian Islands, and in the southeastern Bering Sea (Figure 1). Beds consist of a variety of substrates, including clayey silt, sand, and gravely sand sediments (Turk 2001), and tend to be spatially aligned with bottom currents and bathymetry (Masuda & Stone 2003, Kruse et al. 2005). Weathervane scallops are found at depths < 300 m, with commercial harvests generally between 38–182 m (Turk 2001).

The commercial weathervane scallop fishery in Alaska began in 1967, and the current season runs from July 1st–February 15th for most registration districts. Vessels typically tow two New Bedford-style dredges, 4.57 m wide, although smaller versions are also used in some fishing operations. This gear is fairly efficient at catching weathervane scallops, which comprised 73.8–86.1% of the catch during the 2010–2011 season (Rosenkranz & Spafard 2013). Bycatch species include other benthic invertebrates, such as sea stars, clams, anemones, and fishes (e.g., skates, roundfish, and flatfishes, Table 1). Since 1993, all vessels are required to carry observers except those fishing the Cook Inlet registration district; however, data from 1993–1995 were not available for our analyses. Aside from simple summary statistics, bycatch

data in the scallop observer dataset have not been analyzed to date, with the exception of crab bycatch (Rosenkranz 2002).

Our aim was to explore the benthic species composition associated with weathervane scallop beds and to investigate the spatiotemporal variability of benthic communities across scallop beds on the continental shelf off Alaska. Specific objectives were to: (1) quantify the spatial distribution and species composition of benthic communities, (2) quantify changes in species composition of benthic communities over 1996–2012, and (3) relate variability in community composition to environmental (sediment type, depth, freshwater input) and anthropogenic variables (commercial trawl and dredge fishing effort). Spatial and temporal differences in many fish and invertebrate taxa are related to sediments, climate, oceanography, and fishing in the Gulf of Alaska and Bering Sea (Feder & Jewett 1986, McConnaughey et al. 2000, Hare & Mantua 2000, Turk 2001). Understanding benthic community structure and environmental- or anthropogenic-related changes over time is critical to an ecosystem-based approach. Scallop observer data provide a unique opportunity to examine benthic communities over a 17 year time frame.

Methods

Bycatch data

Observer data were obtained from scallop fishing vessels during 1996–2012 (R. Burt, ADF&G, Kodiak, AK, pers. comm.). Detailed observer sampling protocols are described by Rosenkranz and Spafard (2013). In summary, tows are randomly selected for sampling prior to retrieval. Complete haul composition is determined for one dredge per day. Dredge contents are sorted by species (or lowest possible taxon level) into baskets and weighed. Small quantities are weighed entirely, whereas large contents are subsampled. Vessel operators also maintain a logbook provided by the Alaska Department of Fish and Game (ADF&G). For each tow, the operator records the combined width of towed dredges, gear performance, set date, haul number, set position (latitude/longitude), tow duration, average depth, average speed, estimated retained weight of whole scallops, estimated discarded scallop catch, and ADF&G Statistical Area.

Environmental data

Haul depths were extracted from vessel logbook data. Contoured surficial sediment maps of regions in the Gulf of Alaska were obtained directly from the U.S. Geological Survey (J. Reid, USGS Pacific Coastal & Marine Science Center, Santa Cruz, CA, pers. comm.). Data collection methods are described in Evans et al. (2000). Sediment data in the eastern Bering Sea and Aleutian Islands were obtained from the National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center (R. McConnaughey, AFSC, Seattle, WA, pers. comm.; <http://www.afsc.noaa.gov/RACE/groundfish/bathymetry/>). Sediment collection methods in the eastern Bering Sea and Aleutian Islands are described in Smith & McConnaughey (1999) and Zimmermann et al. (2013), respectively. Based on the sediment classification methods for each dataset, we constructed numerical classifications (1–8) to reflect the sediment type, ranging from the largest grain size (bedrock) to the smallest (silty clay/mud). Sediment values were spatially overlaid with scallop haul points using the QGIS software (Quantum GIS Development Team 2014), and a sediment value was assigned to each overlapping haul. Sediment data were not available for many fishery management districts in the Gulf of Alaska (Figure 1), including Kodiak Semidi Islands, Kodiak Southwest, Alaska Peninsula, and the entire Kodiak Shelikof

district except the largest bed, KSH 1 (Table 2). Bottom-layer (75–250 m) temperature data from 1996–2011 were extracted from the GAK1 monitoring station in the northern Gulf of Alaska, maintained by the University of Alaska Fairbanks, and from NMFS summer bottom trawl surveys. Data from annual bottom trawl surveys on the continental shelf of the eastern Bering Sea were obtained from NMFS (<http://www.afsc.noaa.gov/RACE/groundfish/ebs.htm>). The GAK1 data were averaged over summer months (May–July) to be consistent with bottom trawl surveys. Model estimates of freshwater discharge (m^3/s) were obtained from the GAK1 database (<http://www.ims.uaf.edu/gak1/>) and used to index flow of the Alaska Coastal Current in the Gulf of Alaska during 1996–2011 (Royer 1982). Lacking similar regional discharge estimates, beds located in the Bering Sea, Aleutian Islands and Alaska Peninsula management districts were excluded from this portion of the analysis. Temperature and freshwater discharge were excluded from the spatial analyses due to a lack of bed-specific data, and depth was excluded from the temporal analyses because fishing depths were relatively constant within a district over time.

Fishing effort data

Tow data for non-pelagic trawls, as well as tows of pelagic trawls that made contact with the seafloor (indicated by the presence of crab sampled by fishery observers) on vessels ≥ 18.3 m (60 ft.) length overall, were obtained from the NMFS Catch in Areas database (S. Lewis, NMFS, Juneau, AK, pers. comm.) and compiled into a time series of fishing disturbance (proportion of each bed disturbed) for scallop beds that had been fished consistently during 2000–2012. Data were not available over 1996–1999 due to the lack of vessel monitoring systems on commercial trawlers during those years. An index of fishing disturbance was estimated by dividing the total area swept (km^2) by the total area (km^2) of the bed, which was calculated in QGIS using scallop bed polygons obtained from ADF&G (G. Rosenkranz, ADF&G, pers. comm.). To determine the area swept by trawls, we used trawl width estimates from NMFS (2005a). The fishing disturbance index did not consider the extent to which individual trawl tows overlap one another on a particular bed. A similar time series of scallop dredging effort was compiled using area swept data from scallop vessel logbooks. We considered short-term effects of trawling and dredging effort on benthic species composition by lagging values by one year.

Data organization

We compiled two matrices using haul composition and logbook data. The first, a fish log matrix, included information for each haul, including vessel identification, statistical area (management district), bed code, set date, set position (latitude/longitude,) depth, total area swept by the dredge(s), and whether the haul composition was sampled by an observer. The second, a haul composition matrix, contained much of the same information as the fish log matrix including haul ID, set date, haul set position, and area swept, but only for hauls in which the entire composition was sampled by observers. This matrix also included the weight (kg) of each taxon sampled. Haul ID numbers were unique and served as sampling units within the dataset. Area swept (km^2) by the dredge was used to calculate catch per unit effort (CPUE, kg/m^2), which adjusts for differences in observed species densities, as well as variances in dredging effort due to differences in tow duration and dredge widths. To address changes in observer sampling procedures over time, namely a trend toward more detailed classifications of certain taxa during later years of sampling, the CPUE of each taxon was aggregated into taxonomic groups ranging from families to phyla, with most groups classified to family. An initial assumption was that those taxa classified at higher taxonomic resolution (e.g., family) were different than those

included in broader taxonomic groups. Separate categories existed for “roundfish,” “skate egg cases” and “gastropod eggs,” which were frequently recorded by observers. Finally, we constructed a third matrix that contained environmental and anthropogenic (fishing effort) data corresponding to each haul ID.

Statistical analyses

Multivariate statistical analyses were conducted using the software package PRIMER (Clarke 1993, Clarke & Gorley 2006). Environmental and anthropogenic data were standardized to mean zero and standard deviation one to account for large differences in measurement units. Taxa contributing to at least 5% of the total biomass of the dataset were selected, and a 4th-root transformation was applied to the CPUE data to down weight the effects of the most abundant species (Clarke 1993). The biomass of each taxon was then standardized relative to its maximum for the overall dataset, so that each taxon contributed equally (Clarke & Warwick 2001). From that data matrix, we computed pairwise similarities between samples based on the Bray-Curtis similarity coefficient (Bray & Curtis 1957).

Using various groupings (e.g., district, bed, year), non-metric multidimensional scaling (NMDS) was conducted to visualize similarities in CPUE (used as a metric of haul composition) between groups. To test whether haul composition differed significantly among regions at varying spatial scales and across time, analyses of similarity (ANOSIMs) were conducted using the Bray-Curtis resemblance matrices. ANOSIM is a permutation test that is most applicable to multispecies data that do not meet standard assumptions required by multivariate analysis of variance. As differences between species compositions become larger, the test statistic, Clarke’s *R*, approaches one. When significant differences were detected in the ANOSIM ($P < 0.05$), a similarity percentages analysis (SIMPER) was conducted to examine the taxa that contributed most to the differences. To identify environmental and anthropogenic variables that best explained variations in species compositions, a bio-environmental analysis (Bio-Env; Clarke & Ainsworth 1993, Clarke 1993) was conducted. Bio-Env calculates the Spearman rank correlation between the species similarity matrix and corresponding environmental similarities. The rank correlation coefficient (ρ) indicates the significance of agreement in the multivariate pattern when comparing two similarity matrices.

For some analyses, data were averaged by bed code and year before calculating the similarity matrix to eliminate the risk of pseudo-replication (Hurlbert 1984). For district-scale spatial analyses, hauls were averaged by bed. Scallop beds off Yakutat and in adjacent District 16 (D16) were combined for these analyses, because the latter was represented by a single bed and is contiguous with Yakutat beds. Analyses were performed separately for two early years (1997 and 2000) and one late year (2010) to investigate spatial differences independently from potentially confounding temporal changes. These three years were selected because they span nearly the entire 1996–2012 time series and contain high levels of sampling effort across the ten management districts that had observers. We chose 2010 because of reduced observations in 2011 and 2012 owing to fishery closures of some management districts. Both 1997 and 2000 were selected for comparison because preliminary analyses suggested a split in haul composition during 1996–1999 and 2000–2012, and we wanted to include “early” samples from both of those groups. We chose 1997 instead of 1996, because the latter was a poorly sampled year.

Bed-scale analyses were limited to districts with large numbers of beds that were consistently sampled. These included the Kodiak Shelikof, Kodiak Northeast, Yakutat, D16, and Prince William Sound districts. Yakutat, D16, and Prince William Sound were analyzed together

due to their close proximity. Hauls were averaged by bed and year for NMDS ordinations to facilitate visual examination of patterns but were not aggregated for ANOSIM and SIMPER analyses. Bed-scale analyses were conducted in 1997, 2000, and 2010. For temporal analyses, hauls in a given district or bed were limited to those that were continuously sampled over 1996–2012 to account for confounding changes due to differing fishing locations across time. These included Kodiak Shelikof, Kodiak Northeast, Yakutat/D16/Prince William Sound, and the Bering Sea. In Kodiak Shelikof, only the KSH 1 bed was sampled consistently, and was the only bed analyzed for temporal differences. Bed Yak B in the Yakutat district was excluded, because it was only sampled in 2009–2012. Due to preliminary splits in haul composition between 1996–1999 and 2000–2012 observed through CLUSTER analyses in PRIMER, temporal analyses were performed spanning both 1996–2012 and 2000–2012. In the CLUSTER analyses, we tested for the significance of observed splits using a SIMPROF (similarity profile) permutation test, which gives a test statistic (π) indicating whether group structure is significantly different from random. We also looked for patterns of seriation (continual change over time), using the RELATE procedure, which generates a Spearman coefficient (ρ) to indicate presences of serial structure across years.

Results

Descriptive statistics

A total of 4,420 hauls and 79 taxa (Table 1) from ten registration districts and 42 individual scallop beds were included in the final data matrix. Most taxa were resolved to the family level (48), followed by class (12), order (10), phylum (4), N/A (3), subclass (1) and infraorder (1). Observations included 94 taxa before exclusion of those that contributed < 5% to overall biomass. Hauls were sampled in habitats ranging from bedrock to silty clay/mud (Table 2) at depths of 46 to 172 m (Table 3). The combined proportion of scallop beds swept by both pelagic and non-pelagic trawl gear ranged from 0–0.224, depending on the bed and year, with the highest proportion in the Bering Sea. Dredging effort averaged 0.068 overall during 1996–2012 (Table 4) and, on average, was the highest on the KSH 1 bed in the Kodiak Shelikof Strait district, ranging from 0.02–0.41 during 1996–2012.

Registration district spatial analyses

The ANOSIM test revealed statistically significant differences in CPUE between registration districts in 1997, 2000 and 2010 (Clarke's $R = 0.533, 0.646, 0.682, P = 0.001, 0.003, 0.001$, respectively). A longitudinal gradient in haul composition was apparent, with significant differences between Yakutat/D16 and all districts to the southwest except the Bering Sea (Table 5). However, a small sample size (single bed) hampered significance testing of any comparisons involving the Bering Sea. The adjacent districts of Kodiak Shelikof and Kodiak Northeast were significantly different from one another in 1997 and 2010 (Clarke's $R = 0.443, 0.438, P = 0.026, 0.029$, respectively). Among the years examined, separation by district was most clearly visualized via NMDS ordination in 2010 (Figure 2).

Three to four taxa contributed most to similarities across all districts. These included Pectinidae, Pleuronectiformes, Rajidae, and Asteroidea. The remaining taxa tended to differ by district. Spearman rank correlation with environmental variables was significant in 2010 ($\rho = 0.533, P = 0.002$) compared to 1997 ($\rho = 0.149, P = 0.270$) and 2000 ($\rho = 0.409, P = 0.056$).

Sediment, depth and dredging effort were most highly correlated with district-scale spatial patterns in species composition in 2010.

Large dissimilarities in species composition existed between Yakutat and the Aleutian Islands in both 1997 and 2010; the Aleutian Islands were not sampled in 2000. The SIMPER analysis revealed the basis for differences in community composition in these districts. In 1997 and 2010, Yakutat had higher CPUEs of Rajidae, Cirriedia and skate egg cases, whereas the Aleutian Islands beds contained more Echinoida, gastropod eggs, and Oregoniidae (Table 6). Yakutat beds consisted mainly of sand, silty clay/mud, and sandy silt sediments, whereas the Aleutian Islands beds contained sand or gravelly sand (Table 2). The Aleutian Islands beds generally exhibited a narrower depth range than the Yakutat/Prince William Sound/D16 beds; the deepest sampled haul in the Aleutian Islands was 26 m shallower than in Yakutat (Table 3).

Compared to other districts, the Bering Sea had higher relative abundances of Oregoniidae, Paguridae, Ranellidae, Buccinidae, Polynoidae, and Gastropoda (Appendix 1). However, Kodiak Shelikof had higher abundances of gastropod eggs than the Bering Sea (and all of the other districts). Yakutat had higher relative abundances of skate egg cases, Crangonidae, Hirudinea, Veneridae, Luidiidae, Cirripedia, and Aphroditidae. However, a shift in Cirripedia and Aphroditidae prevalence occurred, with Kodiak Shelikof having higher abundances than Yakutat (and all the other beds) in 1997 and 2000, respectively. Kodiak Shelikof had high relative abundances of Cancridae, Ascidiacea, Brachiopoda, and Nereidae. Relative to Kodiak Northeast and Yakutat, Kodiak Shelikof had a larger representation of Gastropoda, except when compared to the Bering Sea. Kodiak Northeast had higher relative abundances of Lithodidae, Solasteridae, Brachiopoda, Goniasteridae, and Pennatulacea. However, there was a shift in higher CPUE of Pennatulacea to the Bering Sea in 2010.

Bed-scale spatial analyses

Kodiak Shelikof. Significant differences in haul composition were revealed by the ANOSIM test between Kodiak Shelikof beds in 1997 (Clarke's $R = 0.336$, $P = 0.001$) and 2010 (Clarke's $R = 0.629$, $P = 0.001$). Only bed KSH 1 was fished in 2000. Beds within the Kodiak Shelikof district were distinguishable by variable CPUE among taxa rather than differences in presence or absence. We observed large differences between bed KSH 1, the northwestern-most bed in Shelikof Strait, and KSH 6, located in southeast Shelikof Strait. Dissimilarity between these two beds was characterized by higher CPUEs of most taxa in KSH 6, some of which are displayed in Table 7. Across all years, bed KSH 1 was characterized mainly by Pectinidae, Rajidae, and Pleuronectiformes. In the Kodiak Shelikof district, dredging effort was significantly correlated with biological differences in both 1997 ($\rho = 0.247$, $P = 0.001$) and 2010 ($\rho = 0.289$, $P = 0.001$). Dredging effort was nominally higher in KSH 1 than KSH 6, averaging 0.247 compared to 0.046 over 1996–2012. Potential association of benthic communities with sediment type was not possible due to lack of sediment data for all beds in the Kodiak Shelikof district except KSH 1. Due to the lack of bed-specific environmental data in this district, environmental mechanisms behind the lower CPUEs in KSH 1 could not be investigated.

Kodiak Northeast. The ANOSIM revealed significant differences in CPUE between beds in the Kodiak Northeast District in 1997 (Clarke's $R = 0.427$, $P = 0.001$), 2000 (Clarke's $R = 0.224$, $P = 0.001$), and 2010 (Clarke's $R = 0.567$, $P = 0.001$). These differences were significantly correlated with depth and dredging effort in 1997 ($\rho = 0.295$, $P = 0.001$), depth and sediment in 2000 ($\rho = 0.308$, $P = 0.001$), and depth in 2010 ($\rho = 0.589$, $P = 0.001$). Beds KNE 3

and KNE 6 had the most distinct sediment types and depth profiles within this district, with KNE being fairly shallow (68–88 m) and containing a mix of sand and gravel, and KNE 6 being deeper (80–117 m) and consisting of silty sand. Bed KNE 3 had higher CPUE of Actiniaria, Brachiopoda, Buccinidae, as well as most echinoderms (Table 8). Bed KNE 6 had higher densities of crustaceans and Pennatulacea.

Yakutat, D16, Prince William Sound. Significant differences in CPUE were revealed by ANOSIM among scallop beds within the Yakutat, D16 and Prince William Sound districts in 1997 (Clarke's $R = 0.290$, $P = 0.001$), 2000 (Clarke's $R = 0.241$, $P = 0.001$), and 2010 (Clarke's $R = 0.303$, $P = 0.001$). Biological differences were significantly, although weakly, correlated with depth in 2000 ($\rho = 0.118$, $P = 0.001$) and dredging effort in 2010 ($\rho = 0.114$, $P = 0.008$). No anthropogenic or environmental variables were correlated with biological patterns in 1997. Although no latitudinal or longitudinal gradient was evident, beds Yak 2 and Yak 3, as well as Yak 4 and Yak 5, tended to cluster together with similar species compositions. Apart from these groupings, we did not observe any beds that were consistently or largely different from one another across the sampling period. Beds in the Yakutat, D16 and Prince William Sound districts span a multitude of sediment types, and were generally fished at a wide depth range (49–117 m, Table 3). Beds Yak 1–3, Yak B, Western Kayak Island (WKI), and Eastern Kayak Island (EKI) are predominantly composed of silty clay/mud and sandy silt sediment types, although EKI also contains bedrock. Beds Yak 4 and Yak 5 are predominantly sand, whereas Yak 6 is a mix of sand and silty clay/mud. The bathymetry of this region features underwater canyons and banks that shape the formation of the beds. For example, Yakutat Bay physically separates beds Yak 4 and Yak 5, which span the Yakutat and Alsek canyons, from beds Yak 2 and Yak 3.

Temporal analyses

Kodiak Shelikof. Haul composition varied significantly on KSH 1 over 1996–2012 (Clarke's $R = 0.257$, $P = 0.001$) and 2000–2012 (Clarke's $R = 0.158$, $P = 0.001$), with the most significant differences occurring between early and late years of sampling (Table 9). A NMDS diagram of hauls averaged by year (Figure 3) revealed a time trajectory, particularly a split between 1996–1999 and subsequent years. The SIMPROF test within the CLUSTER analysis indicated this split to be statistically significant ($\pi = 3.25$, $P = 0.001$). Effects of seriation were present, implying that changes in community composition occurred sequentially across years, but were more apparent during 1996–2012 ($\rho = 0.236$, $P = 0.001$) than 2000–2012 ($\rho = 0.063$, $P = 0.001$). A SIMPER comparison indicated a higher prevalence of Ranellidae, Aphroditidae, Nereidae, Buccinidae, and Rajidae during 2010–2012 than 1996–1999. During 1996–1999 there was a higher prevalence of Polychaeta, Bivalvia, Cirripedia, Hirudinea, and Gastropoda in the haul samples. Similar patterns were observed when comparing 2000 with 2012. A time series comparing CPUE of select taxa during 1996–2012 suggests little interannual variability (Figure 4). Dredging effort was significantly, although weakly, correlated with temporal changes on bed KSH 1 ($\rho = 0.190$, $P = 0.001$). Dredging effort fluctuated from year to year, ranging from a low of 0.02 in 2008 to a high of 0.41 in 1997.

Kodiak Northeast. Temporal differences in haul composition samples in the Kodiak Northeast District were statistically significant over 1996–2012 (Clarke's $R = 0.22$, $P = 0.001$) and 2000–2012 (Clarke's $R = 0.129$, $P = 0.001$). The years with the greatest differences were 2010 and 1996 (Clarke's $R = 0.674$, $P = 0.001$). Similar to Kodiak Shelikof, 1996–1999 grouped

separately from later years on the NMDS ordination (Figure 3), as well as significantly in CLUSTER analysis ($\pi = 3.28$, $P = 0.001$). Significant seriation occurred from 1996–2012 ($\rho = 0.116$, $P = 0.001$) and 2000–2012 ($\rho = 0.077$, $P = 0.001$). Annual changes in species composition may play a large role in determining the similarity of haul samples between years. For example, a pairwise comparison between 2010 and 1997 revealed a Clarke's R of only 0.234 ($P = 0.001$), indicating relatively high similarity; however, R increased to 0.671 when comparing 2010 and 1998 ($P = 0.001$), indicating much greater differences in CPUE in just one year. Interannual variability in CPUE was observed in Ophiuridae, Rajidae and skate egg cases, Aphroditidae, and Polychaeta, among others (Figure 4). Similar to KSH 1, a SIMPER analysis revealed a comparatively high overlap in haul composition throughout the sampling period, with dissimilarities between years attributed to varying CPUEs of certain taxa. For example, 2010 had higher densities of Rajidae, Roundfish, Ranellidae, Demospongiae, Oregoniidae, Lithodidae, Pleuronectiformes, and Brachiopoda than 1996–1998. In 1998, higher CPUEs of Asteroidea and Clypeastroida were observed than in 2010, whereas 1997 had higher densities of those taxa, as well as Polychaeta and Polynoidae. The Bio-Env analysis revealed a very small but significant correlation between patterns observed in species composition and dredging effort ($\rho = 0.085$, $P = 0.02$). Dredging effort in this district ranged from 0.01 in 2007 to 0.07 in 2008.

Yakutat, D16, Prince William Sound. The ANOSIM revealed a significant difference in CPUE trends in the Yakutat, D16 and Prince William Sound districts over 1996–2012 (Clarke's R = 0.273, $P = 0.001$) and 2000–2012 (Clarke's R = 0.154, $P = 0.001$). Clustering of 1996–1999 from 2000–2012, as observed through NMDS (Figure 3), was statistically significant ($\pi = 3.36$, $P = 0.001$). Seriation was detected from 1996–2012 ($\rho = 0.251$, $P = 0.001$) and 2000–2012 ($\rho = 0.159$, $P = 0.001$). A comparison of early and late years suggests an increase of Aphroditidae, Pandalidae, and Crangonidae over time, and a slight decrease of Pleuronectiformes, roundfish, Cirripedia, Polychaeta, and Actiniaria. This is illustrated by a comparison of the years 2000 and 2012 (Table 10). Large interannual variability in CPUE over 1996–2012 of select taxa, including Ophiuridae, Pennatulacea, Rajidae and skate egg cases, Aphroditidae, and Polychaeta was apparent (Figure 4). Freshwater discharge was significantly, although weakly, correlated with temporal changes ($\rho = 0.107$, $P = 0.001$). Freshwater discharge in these three districts displayed interannual variability. The average annual discharge during 1996–2011 was 15,015 m³/s, with a maximum value of 21,717 m³/s in 1999 and a minimum of 11,776 m³/s in 1998.

Bering Sea. The ANOSIM revealed that the Bering Sea, consisting of just one bed, exhibited the greatest differences over time of all districts analyzed over 1996–2012 (Clarke's R = 0.485, $P = 0.001$) and 2000–2012 (Clarke's R = 0.349, $P = 0.001$). As in other areas, the largest differences occurred between early and late years, with a split visualized on an NMDS ordination diagram (Figure 3) and through CLUSTER analysis. A significant split was evident between 1996–1999, but also including 2005, and the remaining sampling years ($\pi = 2.15$, $P = 0.001$). This difference may be due, in part, to a serial trend in haul composition over time, which was more prominent over 1996–2012 ($\rho = 0.327$, $P = 0.001$) than 2000–2012 ($\rho = 0.285$, $P = 0.001$). Throughout all years, Oregoniidae, Pectinidae, and Pleuronectiformes were dominant in haul composition samples, with Pennatulacea and Polychaeta becoming more prominent in later years (Figure 4). Rajidae were also highly abundant during 2003–2005. Major distinctions between early and late years, illustrated by comparing 2000 and 2012 (Table 11), included increases over time in Polychaeta, Porifera, Pennatulacea, Cirripedia, Buccinidae, Nereidae, and

Gastropod eggs, although the CPUE of gastropod eggs exhibited large interannual variability (Figure 4). Scyphozoa and roundfish were more abundant in early years. Dredging effort was the most significant correlate with temporal differences in species composition, as indicated by the Bio-Env analysis ($\rho = 0.172$, $P = 0.001$). Dredging effort, which averaged 0.019 in the Bering Sea over 1996–2012, increased after 1996 (0.027), and reached a peak in 2000 (0.040) before dropping to about 0.01 in 2006 and remaining relatively constant thereafter.

Discussion

Spatial differences

In general, during 1996–2012 commercial dredge hauls on weathervane scallop beds in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea were dominated by Pectinidae, Pleuronectiformes, Rajidae and Asteroidea. However, the remaining taxa differed across registration districts, with the strongest differences between the eastern-most (Yakutat/D16) and western-most districts (Aleutian Islands and Bering Sea). These differences were observed in all three years selected for detailed examination (1997, 2000 and 2012). Within districts, spatial differences in community composition at the smaller scale of individual scallop beds (< 50 km) were observed. Spatial differences were most often correlated with dredging effort, sediment and depth. Our results are in accord with past characterizations of benthic communities across Alaska (Feder & Jewett 1986, Yeung & McConnaughey 2006), as well as previous findings of important linkages between benthic community structure, depth and substrate (Grebmeier et al. 1989, McConnaughey & Smith 2000).

Previous studies identified scallop beds predominantly on sandy and sandy silt substrates in the Gulf of Alaska (Turk 2001); indeed, other sediment types were less represented in our study. In some cases, such as between the Yakutat and Aleutian Islands districts, clear correlations between depth and sediment type were reflected in differing species compositions. For example, higher gravel content on Aleutian Islands beds may have contributed to higher abundances of taxa that require structure, such as Echinoida and Porifera. Yakutat contained more skate egg cases than the Aleutian Islands, consistent with previous findings of skate nurseries in relatively deep environments with sandy and muddy substrates in the Bering Sea (Hoff 2010).

Temporal changes

Temporal changes in taxon CPUEs were observed in beds that were routinely sampled, but no taxa exhibited consistent changes across all districts over time. Temporal changes were generally weaker than spatial differences and exhibited lower correlations with environmental variables. Serial changes over time were evident in all districts analyzed; trajectories in similarity were less pronounced but still statistically significant when 1996–1999 were excluded. We hypothesize three potential reasons for the split between 1996–1999 and subsequent years: (1) changes in observer protocols, namely that onboard observers classified taxa more finely over time, (2) changes in fishing fleet behavior after formation of a fishing cooperative in 2000, or (3) changes associated with other environmental or anthropogenic variables, occurring either before or at the beginning of the sampling period. We sought to eliminate the first possibility by aggregating taxa to higher taxonomic levels. However, we cannot fully rule out that some taxa were initially classified more crudely. For example, in recent years in Kodiak Shelikof, it is possible that observers increasingly classified worms to the family Nereidae (Class: Polychaeta)

as opposed to the broader class Polychaeta. Polychaeta were more abundant in 1997, whereas Nereidae were more abundant during 2000–2012. It is not possible to determine how often worms in the family Nereidae were classified as Polychaeta, particularly in the early years.

The only environmental variable significantly correlated with temporal changes was freshwater discharge in Yakutat, D16 and Prince William Sound, although the correlation was weak. Specific changes in haul composition are difficult to attribute to patterns of freshwater discharge, given that it may not be a good indicator of bottom currents. Nevertheless, we decided to include this variable, given a regime shift in the North Pacific in the late 1990s. The highest variability in freshwater discharge in Yakutat, D16 and Prince William Sound occurred within 1996–1999, with the overall lowest value occurring in 1998 and the highest value in 1999. In 1997, anomalous weather conditions occurred in the North Pacific, influenced by El Niño and other, decadal-scale atmospheric processes (Napp & Hunt 2001, Overland et al. 2001). This was followed by a shift from a warm to cold regime in 1998 (Peterson 2003), resulting in cooler sea surface temperatures, anticyclonic winds, and shifts in zooplankton and some pelagic fish abundances. No stark differences were evident in scallop haul compositions between 1998 and 1999 that could be distinguished from natural interannual variability, but large differences are not expected for multi-aged taxa. Weathervane scallops, for example, live to 29 years (Hennick 1973) and red king crab (*Paralithodes camtschaticus*) live >20 years (Matsuura & Takeshita 1990). Nevertheless, these fluctuations may have contributed to the observed splits between the late 1990s and remaining years. When freshwater discharge was excluded from the Bio-Env analyses, there were no significant correlations between biological patterns and any other environmental variables in the Yakutat/D16/Prince William Sound districts. Better estimates of bottom flow from current meters are needed to more fully evaluate this potential relationship.

Interestingly, we found no significant correlations between temporal changes in species composition and bottom temperature. While other studies in Alaska have indicated strong effects of temperature on marine species compositions (Grebmeier et al. 1989, Anderson & Piatt 1999, Mueter & Litzow 2008, Siddon et al. 2011), the haul composition samples in this study contain many sessile taxa that are unlikely to show short-term shifts in distribution. Benthic communities in other Alaskan regions demonstrate long-term stability (Dunton et al. 2005, Renaud et al. 2007), which suggests identifying changes in community composition may require longer, multi-decadal examinations.

Fishing effects

No changes in species composition, either spatial or temporal, were correlated with bottom trawling effort. In contrast, bottom trawling was previously found to significantly reduce macrofauna abundance and diversity relative to unfished areas in the southeastern Bering Sea (McConnaughey et al. 2000). These divergent results are likely due to differences in fishing intensity. An intensive yellowfin sole (*Limanda asper*) fishery occurs in the southeastern Bering Sea, whereas commercial trawl fisheries occurred on only a few scallop beds, and in those cases the spatial overlap was quite small.

Scallop dredging effort was significantly correlated with spatial changes in haul composition in the district- and bed-scale analyses, as well as with temporal changes in the Kodiak Shelikof, Kodiak Northeast and Bering Sea districts. The most apparent dredging effects were observed as much lower CPUEs for most taxa on bed 1 versus bed 6 in the Kodiak Shelikof district. During 1990–1994, before our sampling period, dredging effort was significantly higher across the state, with a statewide harvest of 795 mt in 1992, four times higher than the average

harvest during the past decade. In the Bering Sea, 227 mt of shucked meats were harvested in 1994, but dredging effort in this district has decreased since 2000. Though not statistically significant, commercial trawling effort in the Bering Sea also decreased from 0.22 in 2000 to 0.04 in 2012, likely due in part to a reduction in pelagic trawling over this period (Zador 2013), but perhaps also due to geographical shifts in trawling effort outside the scallop bed. In the Bering Sea, increases in relative abundance of certain organisms over this time period, including sessile taxa such as Porifera, Pennatulacea and Gastropod eggs, might be indicative of a recovering system. The Bering Sea bed is composed of sand, which is more naturally dynamic and tolerant of disturbance than mud or silt (Kaiser et al. 2006). On this bed, we observed increases in the carnivorous Polychaete family Nereidae, but decreases in the carnivorous family Polynoidae from 2000–2012, both of which were classified separately from Polychaeta. Research in the northwest Atlantic identified higher abundances of Polychaeta in undisturbed sites (Collie et al. 1997). However, in the Bering Sea, errant polychaetes may benefit from sediment disruption caused by trawling, implying that polychaete reactions to disturbance are taxon-specific (Yeung et al. 2010). The CPUE of Aphroditidae, a family composed of carnivores and detritivores, was higher in later years in three (Kodiak Shelikof, Kodiak Northeast, and Yakutat/D16/Prince William Sound) out of the four districts analyzed temporally, which may be an indicator of repeated dredging disturbance (Yeung et al. 2010). Dredging effort in these districts fluctuated over time and exhibited no consistent trend during our sampling period. Aphroditidae CPUE was also higher on the heavily fished bed, KSH 1, compared to KSH 6 in the Kodiak Shelikof district.

Given the relatively weak correlation with dredging effort and lack of correlation with trawling effort, it is difficult to conclude whether observed temporal changes in haul composition in the Bering Sea are indicative of a recovering system, a result of differences in sampling protocols, or due to other environmental variables not included in this study. Relative abundances of many taxa fluctuated from year to year, undoubtedly in part due to observational error, but more detailed analyses of individual taxa were beyond the scope of our community analysis. Finer-scale analyses of the most heavily fished portions of some beds might shed more light on potential changes due to dredging, but State of Alaska confidentiality limitations restricted our analysis to the bed level. Moreover, separation of dredging effects from natural disturbances is difficult without a controlled experimental design, such as contrasting trawl survey catches in areas open to heavy fishing versus long-term (1959–present) no-fishing closure areas in the eastern Bering Sea (McConnaughey et al. 2000). Using a similar approach, submersible transects identified lower species richness and abundances of low-mobility and prey epifaunal species off Kodiak Island in areas open to fishing compared to two areas that were closed to scallop dredging and bottom trawling for 11–12 years (Stone et al. 2005). Interestingly, weathervane scallop density was not significantly lower in open than closed areas (Masuda & Stone 2003). Elsewhere in Alaska, a model of the effects of bottom trawling on deep-sea corals and sponges along the Aleutian Islands demonstrated two to threethree3 decades of recovery subsequent to cessation of disturbance (Rooper et al. 2011), and subtle but significant differences in several grain size and organic matter parameters were detected in shallow (<26 m), sandy habitats among fished versus unfished areas in the southeastern Bering Sea (Brown et al. 2005b). Likewise, placer gold mining with bucket-line dredges in depths of 9–20 m in Norton Sound, northeastern Bering Sea, led to significantly reduced total abundance, biomass, and diversity of benthic macrofaunal communities at mined stations composed of sand and cobble substrates (Jewett et al. 1999). Globally, intense bottom trawling and dredging have had severely

detrimental effects on benthic communities, such as decreased species abundance, biomass, richness and diversity, as well as altered ecosystem structure (Thrush & Dayton 2002, Brown et al. 2005a).

Research caveats, implications, and recommendations

Our data have spatial and temporal limitations. First, observations are confined to commercial scallop beds fished during July through February, so seasonal variability in abundance and distribution cannot be addressed. Second, dredge haul composition depends on gear selectivity, which is relatively high for scallops, but unknown for other taxa. Third, differences in observer skills may have affected recorded taxa, and taxon identification requirements have evolved since 1996. Fourth, differences in spatial scales of environmental and biological data may have adversely affected our ability to detect associations. For example, availability of set positions of trawl and dredge tows did not allow us to distinguish between spatially overlapping versus unique tow paths, prohibiting an evaluation of variability of fishing intensity within a bed. Similarly, estimates of the proportion of the bed trawled or dredged annually depend upon bed area delineations provided by ADF&G, which reflect judgments based on past fishing effort. Lastly, as with all such observational studies, we are limited to describing correlations between haul composition and environmental variables, which do not necessarily reflect causation. Despite these limitations and given the long-term stability in scallop dredge gear, we feel that observed differences in haul composition at the regional and bed-scale on the continental shelf off Alaska are meaningful.

Our study provides a quantitative baseline of benthic community composition on weathervane scallop beds against which future changes, such as the effects of climate change and ocean acidification, can be assessed. Much baseline research has been conducted recently in the Arctic (Piepenburg et al. 2011), but some of the most comprehensive benthic characterizations across the Gulf of Alaska were collected over three decades ago (Feder & Jewett 1986). Effects of ocean acidification on weathervane scallops and associated taxa is unknown given species-specific responses to changing ocean conditions (Ries et al. 2009), but recent die-offs of farmed weathervane-Japanese scallop hybrids in British Columbia have been attributed to declining pH levels (Shore 2014). Climate change brings threats to ocean circulation, food supplies, and larval development, with potential detrimental economic impacts (Byrne 2011, Narita et al. 2012). Gathering benthic baseline data in Alaska is also critical in light of oil and natural gas exploration. After the Exxon Valdez oil spill in 1989, for example, a significant amount of overlap was observed between weathervane scallop beds in Shelikof Strait and sites where oil drifted with the currents, but no scallop observer data were being collected at that time (G. Rosenkranz, ADF&G, pers. comm.). A lack of pre-spill baseline data in the northern Gulf of Alaska severely hampered analyses of oil effects associated with this spill (Rice et al. 2007).

In addition, our results can improve weathervane scallop EFH designations, which do not associate scallop geographic distribution with habitat characteristics at present (NMFS 2005b). We found associations between benthic community composition and depth and sediment characteristics throughout the Gulf of Alaska, Aleutian Islands, and Bering Sea. Given these relationships, advancements in habitat mapping can improve EFH definitions for scallops and associated benthic organisms, specifically related to habitat requirements and connectivity. Whereas our research quantified broad associations at the bed level based on contents of dredges hauled over long distances, fine-scale spatial analyses of submersible observations have provided evidence of associations between adult weathervane scallops and both anemones and large sea

whips, and negative associations with sunflower sea stars (*Pycnopodia helianthoides*, Masuda & Stone 2003). Collection of bed- or haul-specific environmental information, such as temperature, salinity, pH and dissolved oxygen could contribute to more detailed understanding scallop habitat requirements. Collectively, such information could lead to development of simple habitat suitability index models (e.g., Brown et al. 2000), which would further improve EFH definitions for weathervane scallops. Identifying links between benthic communities, physical variables and pelagic fish communities are important steps towards a true implementation of ecosystem-based management (Peterson et al. 2000, Fluharty 2000).

To deepen understanding of spatiotemporal variability of benthic communities and effects of anthropogenic and environmental factors, several other additional future research needs were identified. Studies of scallop physiology and ecology, such as larval advection and metapopulation dynamics, would inform habitat connectivity. Food habits studies would shed further light on trophic interactions that may shape benthic community structure on scallop beds. All sampling gears are selective and studies of scallop dredge selectivity would clarify the size spectra of species that are reliably indexed by haul contents. Additional research needs concerning potential effects of fishing on benthic communities on weathervane scallop beds were identified during a 2000 workshop sponsored by the Alaska Department of Fish and Game, Division of Commercial Fisheries and can be found in the related workshop publication (ADF&G and UAF 2000).

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Table 1. Taxa included in the analysis after excluding the rarest 5%.

Taxonomic Level	Name	Taxonomic Level	Name
Family	Myxinidae (Hagfishes)	Class	Bivalvia (Bivalve molluscs)
Family	Petromyzontidae (Lampreys)	Family	Mytilidae (Mussels)
Subclass	Elasmobranchii (Sharks)	Family	Pectinidae (Scallops)
Family	Rajidae (Skates)	Family	Hiatellidae (Rock borer clams)
N/A	skate egg cases	Family	Nuculanidae (Clams)
Family	Chimaeridae (Chimeras)	Family	Thyasiridae (Clams)
Order	Pleuronectiformes (Flatfishes)	Family	Cardiidae (Cockles)
N/A	Roundfish	Family	Veneridae (Venus clams)
Class	Hydrozoa (Hydrozoans)	Family	Mactridae (Surf clams)
Class	Scyphozoa (Jellyfish)	Family	Tellinidae (Tellin clams)
Order	Alcyonacea (Soft corals)	Family	Solenidae (Razor clams)
Order	Pennatulacea (Sea pens)	Family	Myidae (Softshell clams)
Order	Actiniaria (Sea anemones)	Family	Pandoridae (Clams)
Class	Polychaeta (Annelid worms)	Family	Anomiidae (Jingle shell clams)
Family	Aphroditidae (Sea mice)	Family	Octopodidae (Octopus)
Family	Nereidae (Polychaete worms)	Order	Teuthoidea (Squids)
Family	Polynoidae (Scale worms)	Family	Sepiolidae (Bobtail squids)
Class	Hirudinea (Leeches)	Class	Asteroidea (Sea stars)
Order	Amphipoda (Amphipods)	Family	Echinasteridae (Sea stars)
Order	Isopoda (Isopods)	Family	Goniasteridae (Sea stars)
Class	Cirripedia (Barnacles)	Family	Luidiidae (Sea stars)
Order	Decapoda (Decapods)	Family	Poraniidae (Sea stars)
Family	Pandalidae (Pandalid shrimp)	Family	Solasteridae (Sea stars)
Family	Hippolytidae (Cleaner shrimp)	Family	Pterasteridae (Sea stars)
Family	Crangonidae (Crangon shrimp)	Family	Porcellanasteridae (Sea stars)
Infraorder	Brachyura (True crabs)	Family	Goniopectinidae (Mud stars)
Family	Canceridae (Rock crabs)	Family	Astropectinidae (Sea stars)
Family	Oregoniidae (Tanner/snow crabs)	Family	Benthopectinidae (Sea stars)
Family	Paguridae (Hermit crabs)	Order	Echinoidea (Sea urchins)
Family	Lithodidae (King crabs)	Order	Clypeasteroidea (Sand dollars)
Family	Cheiragonidae (Helmet crabs)	Class	Ophiuroidea (Brittle stars)
N/A	Gastropod eggs	Family	Gorgonocephalidae (Basket stars)
Family	Onchidoridae (Sea slugs)	Family	Ophiuridae (Brittle stars)
Family	Tritoniidae (Nudibranchs)	Class	Holothuroidea (Sea cucumbers)
Class	Gastropoda (Snails and slugs)	Phylum	Porifera (Sponges)
Family	Naticidae (Moon snails)	Class	Demospongiae (Demosponges)
Family	Buccinidae (Whelks)	Phylum	Platyhelminthes (Flatworms)
Family	Capulidae (Sea snails)	Phylum	Bryozoa (Bryozoans)
Family	Ranellidae (Tritons)	Phylum	Brachiopoda (Brachiopods)
		Class	Ascidiacea (Sea squirts)

Table 2. Surface sediment types assigned to each registration district based on overlap of surficial sediment observations with commercial scallop hauls. Sediment data were sourced from Evans et al. (2000)¹, Smith & McConnaughey (1999)², and Zimmerman et al. (2013)³.

District	Sediment types
Alaska Peninsula	N/A
Aleutian Islands ³	gravelly sand
Bering Sea ²	sand sand/mud
Kodiak Northeast ¹	bedrock gravelly sand muddy to sandy gravel sand sandy silt silty clay/mud
Kodiak Shelikof (Bed KSH 1) ¹	muddy to sandy gravel gravelly mud sandy silt silty clay/mud
Kodiak Southwest	N/A
Prince William Sound ¹	bedrock sand sandy silt silty clay/mud
Kodiak Semidi Islands	N/A
Yakutat ¹	gravelly sand muddy to sandy gravel gravelly mud sand sandy silt silty clay/mud
District 16 ¹	gravelly sand sand silty clay/mud

Table 3. Depth ranges (m), sample sizes (N, number of tows sampled for complete haul composition), and years sampled for each state registration district and individual scallop beds off Alaska. Note that fishing still occurred during some years on certain beds that were not sampled for complete haul composition by observers, and that some hauls in a district did not fall within a delineated bed.

District/Bed	Depth range	N	Years sampled	District/Bed	Depth range	N	Years sampled
Alaska Peninsula	69–137	165	'96-'00, '06, '08	Kodiak Shelikof	46–172	1339	'96-'12
C 1	69–130	16	'98, '99	KSH 1	46–172	1262	'96-'12
C 2	101–102	2	'98, '99	KSH 2	64–119	31	'96-'99, '01, '03, '12
C 3	90–137	12	'97-'99, '06	KSH 3	64–84	17	'96, '01, '02, '11, '12
C 4	93–113	87	'96-'00, '06	KSH 4	51–106	12	'97, '03, '04, '10
WC 1	99–124	3	'97, '98	KSH 5	57–106	8	'96, '97, '03, '10
WC 2	99–128	10	'97-'99, '08	KSH 6	62–68	5	'97, '02, '10
WC 3	88–102	3	'97, '99	KSH 7	64–69	3	'97
UB 1	106	1	'12	Kodiak Southwest	69–82	31	'09–12
UB 2	88–102	13	'12	KSW 1	73	1	'09
UB 3	108–113	6	'12	KSW 2	69–82	29	'09, '11, '12
UB 4	88–101	2	'12	Prince William Sound	57–101	164	'98-'00, '02-'11
UB 5	101–108	2	'12	EKI	60–97	79	'98, '99, '00, '02, '04-'11
Aleutian Islands	55–91	49	'97-'99, '08-'12	WKI	57–101	85	'98, '99, '00, '02-'09
O 1	64–71	7	'09-'11	Kodiak Semidi Islands	46–124	38	'96-'99
O 2	55–64	7	'99	KSEM 1	80–88	2	'96, '97
O 3	59–91	5	'97-'99, '08	KSEM 2	73–110	6	'96-'98
O 4	75–90	23	'10-'12	KSEM 3	91	3	'96
Bering Sea			'96-'12	KSEM 4	95–124	5	'97, '98
Q 1	90–115	563	'96-'12	KSEM 5	46–97	18	'96-'99
Kodiak Northeast	68–155	547	'96-'12	KSEM 6	93–119	4	'96
KNE 1	88–126	27	'96, '97, '03-'06, '08, '12	Yakutat	49–117	1517	'96-'12
KNE 2	88–15	98	'96-'98, '03-'06, '08-'12	Yak B	82–106	23	'09, '11, '12
KNE 3	68–88	280	'97-'11	Yak 1	69–108	95	'98-'02, '05-'10, '12
KNE 4	77–82	18	'96, '98, '01, '03, '07-'10	Yak 2	49–84	291	'96-'12
KNE 5	73–95	54	'96-'00, '02, '04-'06, '08, '09, '12	Yak 3	55–102	252	'96-'02, '04-'12
KNE 6	80–117	67	'97, '98, '00-'06, '08-'12	Yak 4	55–110	395	'96-'12
				Yak 5	55–117	264	'96-'12
				District 16	55–101	196	'96-'06, '08-'12
				Yak 6	55–101	196	'96-'06, '08-'12

Table 4. Average scallop dredging effort (proportion of beds dredged) by year on all beds that were actively fished for weathervane scallops. Dredging effort for a given year was calculated by dividing the total area swept by dredges on a bed (km²) by the area of that bed (km²).

Year	Proportion Dredged
1996	0.0537
1997	0.0865
1998	0.0647
1999	0.0639
2000	0.0602
2001	0.0852
2002	0.1042
2003	0.0549
2004	0.0594
2005	0.0683
2006	0.0449
2007	0.0505
2008	0.0980
2009	0.0731
2010	0.0639
2011	0.0566
2012	0.0691
Total:	0.0681

Table 5. Clarke's R values indicating strength of pairwise spatial differences in haul composition samples among Alaska scallop registration districts in (a) 1997, (b) 2000, and (c) 2010. Significant values ($P < 0.05$) are indicated by an asterisk (*).

a) 1997						
	Yakutat/D16	Kodiak Shelikof	Kodiak Northeast	Semidi Islands	Alaska Peninsula	Aleutian Islands
Kodiak Shelikof	0.805*					
Kodiak Northeast	0.744*	0.443*				
Semidi Islands	0.831*	0.635*	0.600*			
Alaska Peninsula	0.616*	0.411*	0.164*	0.469*		
Aleutian Islands	1.000*	0.833*	0.600*	0.179	0.055	
Bering Sea	0.760	0.622	0.360	-0.167	-0.080	1.000

b) 2000					
	Yakutat/D16	Kodiak Shelikof	Kodiak Northeast	Prince William Sound	Alaska Peninsula
Kodiak Shelikof	0.622				
Kodiak Northeast	0.741*	-0.333			
Prince William Sound	0.438	-1.000	0.333		
Alaska Peninsula	1.000	undef	-0.333	1.000	
Bering Sea	1.000	undef	-0.111	1.000	undef

c) 2010					
	Yakutat/D16	Kodiak Shelikof	Kodiak Northeast	Prince William Sound	Aleutian Islands
Kodiak Shelikof	0.798*				
Kodiak Northeast	0.905*	0.438*			
Prince William Sound	0.000	0.333	1.000		
Aleutian Islands	0.875*	0.321	0.536	-1.000	
Bering Sea	1.000	0.333	0.667	undef	0.000

Table 6. Comparison of relative contributions of each taxon to 90% of the cumulative dissimilarities between Yakutat and Aleutian Islands districts in (a) 1997 and (b) 2010. The average CPUEs for each taxon in each district are shown, along with the percentage that each taxon contributes to the total (Contrib. %) and the cumulative percentage contribution (Cum. %).

a) 1997: Average dissimilarity = 57.21				
Taxa	Yakutat Avg. CPUE	Aleutian Islands Avg. CPUE	Contrib. %	Cum. %
Pennatulacea	0.00	41.75	8.64	8.64
Gastropoda	3.03	39.56	7.32	15.96
Cardiidae	1.91	36.43	7.06	23.02
Roundfish	16.01	49.46	6.94	29.96
Decapoda	8.41	31.87	6.02	35.99
skate egg cases	29.10	0.00	5.96	41.95
Gastropod eggs	11.51	37.44	5.49	47.44
Echinoida	0.00	28.21	5.20	52.64
Rajidae	38.50	26.46	5.15	57.79
Pleuronectiformes	26.46	52.32	5.09	62.88
Porifera	0.00	23.78	4.86	67.74
Paguridae	14.72	33.66	3.89	71.62
Oregoniidae	7.30	19.32	3.70	75.32
Pectinidae	49.74	33.65	3.48	78.80
Hirudinea	15.55	0.00	3.06	81.86
Actiniaria	14.15	11.33	2.59	84.45
Ophiuroidea	12.88	0.00	2.58	87.03
Cirripedia	13.16	8.85	2.33	89.36
Bivalvia	9.95	0.00	1.97	91.33

Table 6. Continued.

b) 2010: Average dissimilarity = 56.89				
Taxa	Yakutat Avg. CPUE	Aleutian Islands Avg. CPUE	Contrib. %	Cum. %
Bryozoa	0.00	50.00	9.66	9.66
Rajidae	42.11	0.00	7.30	16.96
Aphroditidae	40.25	0.00	6.93	23.89
Cirripedia	29.64	0.00	5.22	29.10
Veneridae	27.47	0.00	4.56	33.66
Echinoidea	0.00	26.13	4.02	37.68
Asteroidea	37.42	46.15	3.59	41.28
skate egg cases	30.18	10.78	3.21	44.49
Paguridae	23.15	17.81	3.18	47.67
Luidiidae	39.01	19.17	3.18	50.85
Buccinidae	13.06	14.19	2.95	53.80
Ranellidae	1.54	18.54	2.88	56.68
Gastropod eggs	0.96	18.56	2.87	59.55
Oregoniidae	11.45	16.62	2.76	62.31
Naticidae	20.88	8.12	2.74	65.06
Actiniaria	20.52	13.56	2.73	67.79
Pennatulacea	18.23	8.62	2.68	70.47
Roundfish	16.81	7.42	2.37	72.84
Decapoda	13.26	0.00	2.24	75.08
Goniasteridae	6.22	13.45	2.21	77.30
Cheiragonidae	0.00	13.72	2.11	79.41
Octopodidae	7.27	8.35	2.10	81.51
Goniopectinidae	7.97	9.43	2.04	83.55
Pleuronectiformes	38.25	47.09	1.77	85.32
Demospongiae	2.90	10.44	1.67	86.99
Cardiidae	9.10	9.03	1.62	88.61
Pectinidae	49.75	43.03	1.41	90.02

Table 7. Comparison of relative contributions of each taxon to 50% of the cumulative dissimilarities between beds KSH 1 and KSH 6 in the Kodiak Shelikof district in (a) 1997 and (b) 2010. The average CPUEs for each taxon in each district are shown, along with the percentage that each taxon contributes to the total (Contrib. %) and the cumulative percentage contribution (Cum. %).

a) 1997: Average dissimilarity = 61.37

Taxa	KSH 1	KSH 6	Contrib. %	Cum. %
	Avg. CPUE	Avg. CPUE		
Brachiopoda	2.51	81.98	9.10	9.10
Cancridae	2.86	50.75	5.50	14.60
Polychaeta	12.83	47.98	5.14	19.74
Ascidiacea	0.85	39.03	4.34	24.08
Holothuroidea	4.84	39.00	4.16	28.24
Gorgonocephalidae	1.70	35.34	3.84	32.08
Rajidae	46.39	48.29	3.80	35.89
Demospongiae	1.91	34.24	3.73	39.62
Gastropoda	20.15	52.24	3.48	43.11
Onchidoridae	0.00	31.47	3.48	46.58
Echinoida	14.05	34.17	3.42	50.00

b) 2010: Average dissimilarity = 51.99

Taxa	KSH 1	KSH 6	Contrib. %	Cum. %
	Avg. CPUE	Avg. CPUE		
Cancridae	1.74	72.87	10.34	10.34
Nereidae	31.73	76.38	7.02	17.36
Holothuroidea	6.11	51.35	6.64	24.00
Aphroditidae	43.58	0.00	6.09	30.09
Gastropod eggs	13.83	47.85	4.96	35.05
Ascidiacea	1.81	35.38	4.90	39.95
Goniasteridae	1.85	34.65	4.77	44.72
Paguridae	33.43	0.00	4.71	49.44

Table 8. Comparison of relative contributions of each taxon to 50% of the cumulative dissimilarities between beds KNE 3 and KNE 6 in the Kodiak Northeast district in (a) 1997 and (b) 2010. The average CPUEs for each taxon in each district are shown, along with the percentage that each taxon contributes to the total (Contrib. %) and the cumulative percentage contribution (Cum. %).

a) 1997: Average dissimilarity = 49.83

Taxa	KNE 3	KNE 6	Contrib. %	Cum. %
	Avg. CPUE	Avg. CPUE		
Clypeastroida	37.45	0.00	8.21	8.21
Actiniaria	33.83	0.00	7.34	15.55
Rajidae	25.93	34.50	6.21	21.76
Polynoidae	7.58	26.78	5.81	27.57
Asciacea	0.00	25.16	4.94	32.51
Pennatulacea	35.77	56.76	4.33	36.84
Gastropoda	14.44	23.24	4.17	41.01
Onchidoridae	12.61	14.17	3.71	44.72
Roundfish	15.82	9.64	3.46	48.18
Asteroidea	56.05	44.37	3.36	51.53

b) 2010: Average dissimilarity = 47.17

Taxa	KNE 3	KNE 6	Contrib. %	Cum. %
	Avg. CPUE	Avg. CPUE		
Lithodidae	0.00	51.44	7.16	7.16
Actiniaria	48.84	6.82	5.84	13.00
Brachiopoda	39.04	21.49	5.30	18.30
Buccinidae	39.00	6.00	4.78	23.08
Rajidae	31.48	45.79	4.16	27.24
Roundfish	29.93	31.14	3.82	31.06
Ophiuridae	26.12	0.00	3.61	34.68
Luidiidae	26.85	0.00	3.57	38.24
Pennatulacea	27.63	54.16	3.57	41.81
Solasteridae	28.73	3.53	3.53	45.34
Clypeastroida	24.76	3.84	3.21	48.55
Gorgonocephalidae	4.02	23.62	2.79	51.33

Table 9. Clarke's R values indicating strength of pairwise spatial differences in haul composition samples between years (1996– 2012) on bed KSH 1 in the Kodiak Shelikof district. Non-significant values ($P \geq 0.05$) have been removed.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1996																	
1997	0.199																
1998	0.204	0.056															
1999	0.423	0.111	0.131														
2000	0.588	0.154	0.276	0.131													
2001	0.561	0.155	0.305	0.197	0.072												
2002	0.670	0.285	0.401	0.283	0.172	0.202											
2003	0.548	0.331	0.472	0.325	0.183	0.145	0.070										
2004	0.570	0.220	0.357	0.208	0.098	0.109	0.103	0.078									
2005	0.656	0.260	0.431	0.306	0.163	0.185	0.173	0.089	0.084								
2006	0.775	0.232	0.525	0.288	0.210	0.277	0.283	0.041	0.087	0.131							
2007	0.826	0.419	0.686	0.480	0.363	0.410	0.409	0.198	0.279	0.222	0.115						
2008	0.664	0.146	0.304	0.234		0.202	0.188				0.360	0.379					
2009	0.692	0.389	0.582	0.401	0.261	0.214	0.234	0.149	0.134	0.099	0.054	0.222					
2010	0.724	0.336	0.547	0.303	0.229	0.225	0.242	0.133	0.171	0.154	0.010	0.122		0.175			
2011	0.671	0.163	0.318	0.173	0.088	0.139	0.181	0.143	0.066	0.148	0.155	0.339		0.161	0.132		
2012	0.710	0.171	0.418	0.208	0.139	0.201	0.209		0.061	0.120		0.161	0.361	0.068			0.081

Table 10. Comparison of relative contributions of each taxon to 50% of the cumulative dissimilarities between 2000 and 2012 in the combined Yakutat (D16) and Prince William Sound districts. The average CPUEs for each taxon in each year are shown, along with the percentage that each taxon contributes to the total (Contrib. %) and the cumulative percentage contribution (Cum. %).

Average dissimilarity = 57.74				
Taxa	2000 Avg. CPUE	2012 Avg. CPUE	Contrib. %	Cum. %
Aphroditidae	22.79	38.60	5.51	5.51
Pandalidae	11.51	31.88	5.27	10.78
Rajidae	28.04	33.75	4.88	15.66
Crangonidae	19.30	22.22	4.50	20.16
Luidiidae	0.00	25.21	4.36	24.51
Pleuronectiformes	31.75	28.57	3.97	28.48
Roundfish	21.12	20.27	3.78	32.26
Cirripedia	23.50	7.11	3.56	35.82
Polychaeta	24.88	0.70	3.38	39.20
Echinasteridae	25.18	0.00	3.19	42.39
Paguridae	23.93	23.57	3.09	45.48
Nereidae	15.47	11.61	3.02	48.50
Actiniaria	22.17	16.66	2.83	51.33

Table 11. Comparison of relative contributions of each taxon to 50% of the cumulative dissimilarities between 2000 and 2012 in the Bering Sea district. The average CPUEs for each taxon in each year are shown, along with the percentage that each taxon contributes to the total (Contrib. %) and the cumulative percentage contribution (Cum. %).

Average dissimilarity = 51.17				
Taxa	2000 Avg. CPUE	2012 Avg. CPUE	Contrib. %	Cum. %
Polychaeta	1.62	59.19	9.00	9.00
Porifera	1.35	50.23	7.57	16.57
Pennatulacea	0.00	43.48	6.77	23.34
Cirripedia	12.15	41.55	5.53	28.87
Buccinidae	29.97	45.51	5.15	34.03
Gastropod eggs	5.15	35.42	4.97	39.00
Nereidae	0.00	28.90	4.26	43.26
Scyphozoa	20.43	9.42	3.58	46.84
Roundfish	24.44	17.01	3.44	50.27

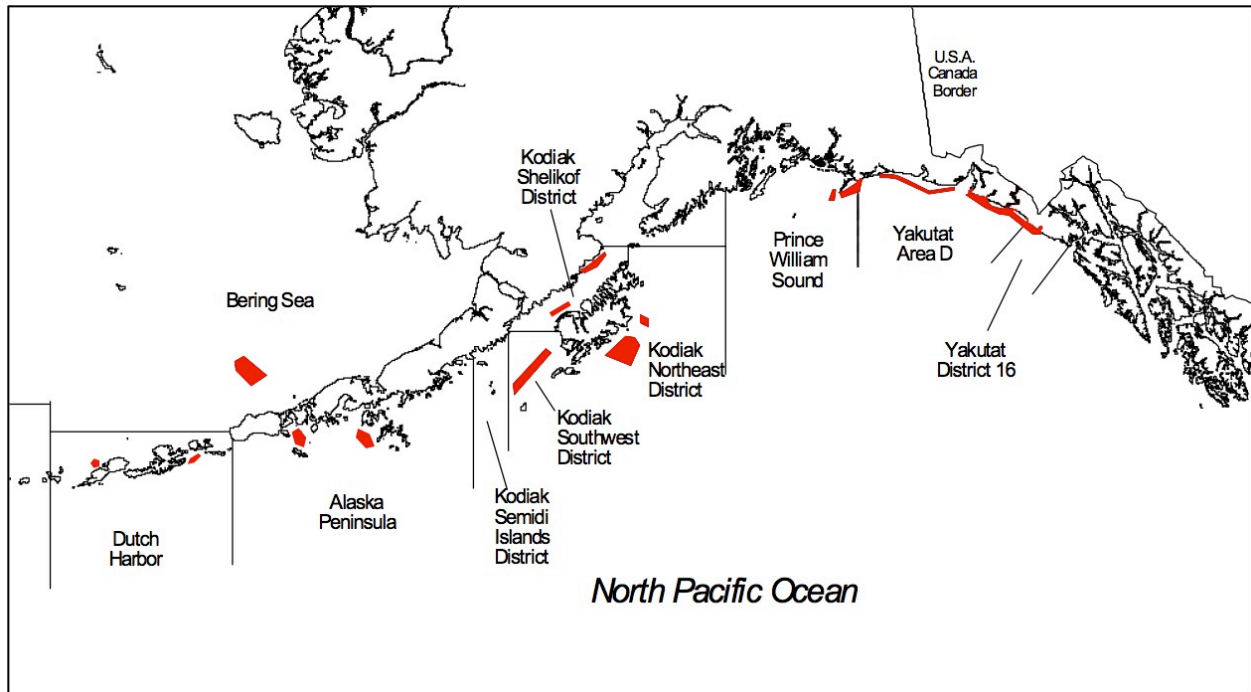


Figure 1. Map of State of Alaska registration areas (labels) for the weathervane scallop fishery and general areas of commercial effort (red polygons). Figure modified from Rosenkranz and Spafard (2013). The Cook Inlet registration area (north of Kodiak) is not included because onboard observers are not required for this area.

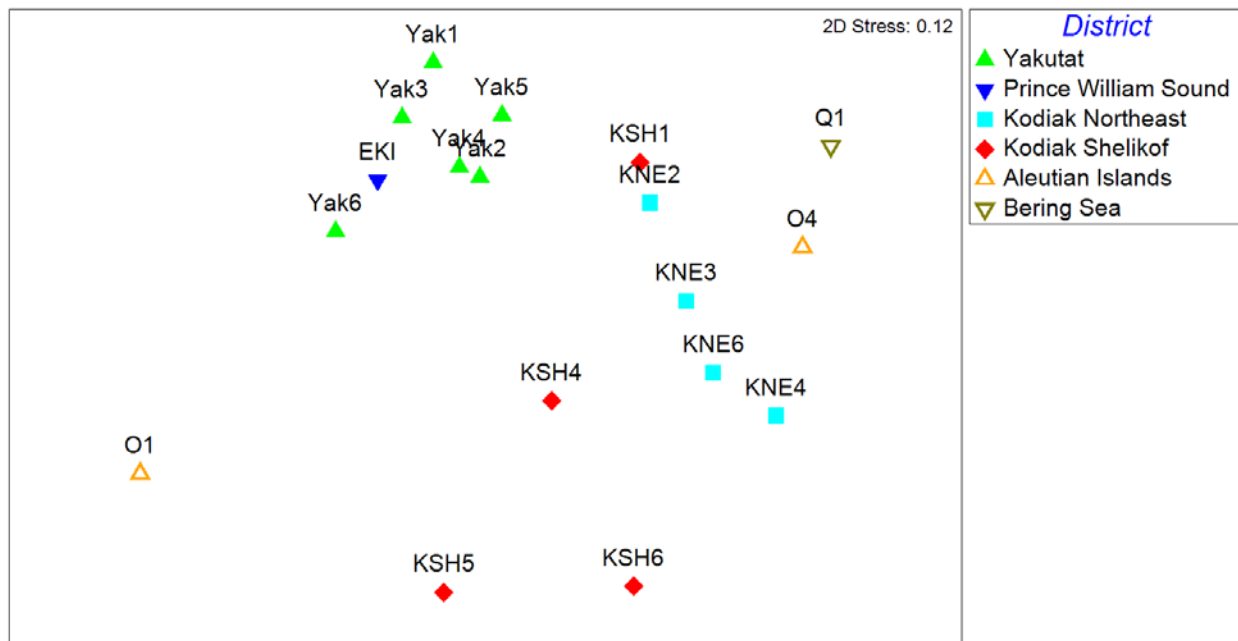


Figure 2. Non-metric multidimensional scaling ordination for Alaska scallop registration districts in 2010. Data are aggregated by individual beds and points are labeled with bed codes listed in Table 3.

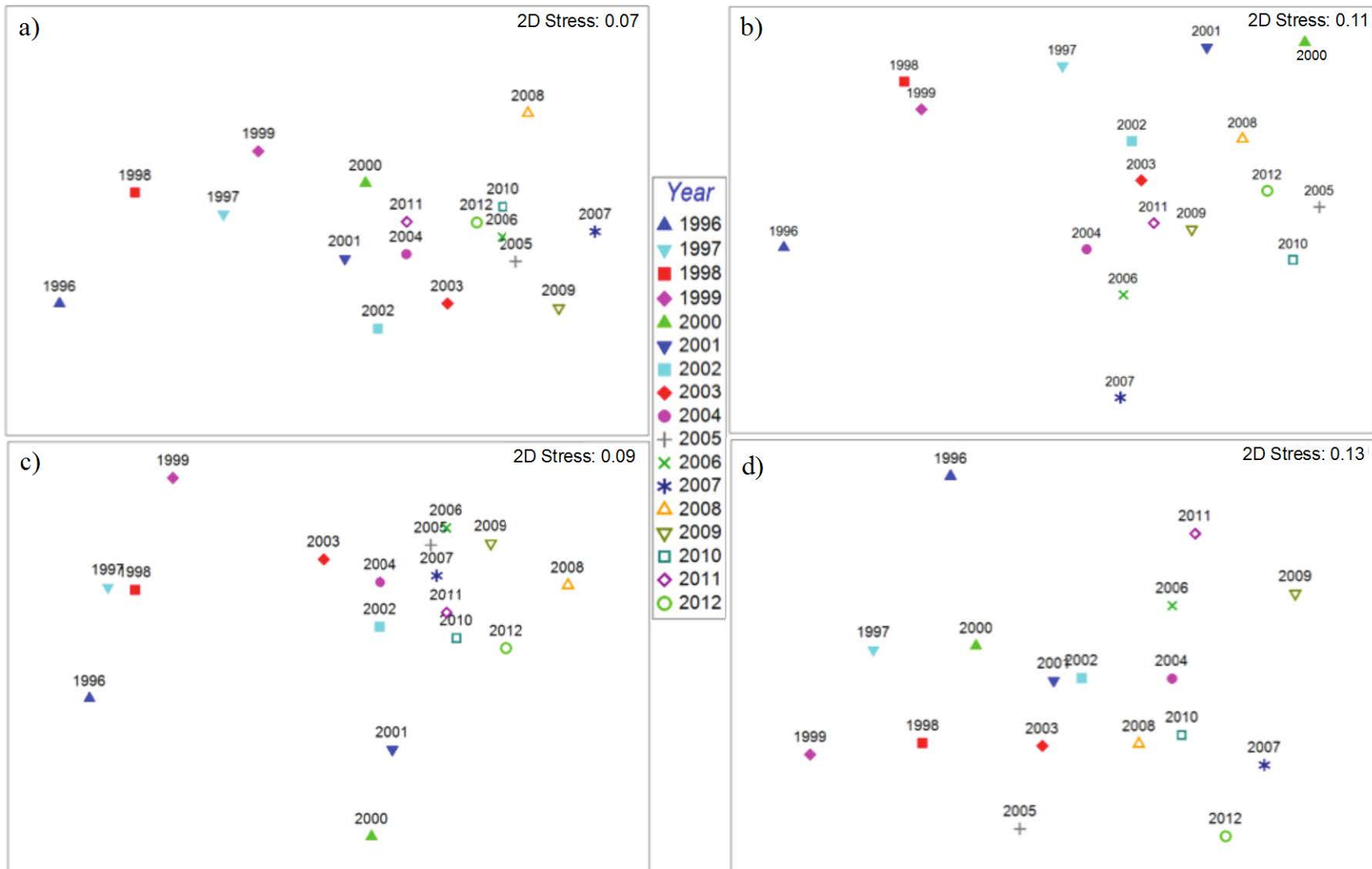


Figure 3. Non-metric multidimensional scaling ordination of haul composition samples aggregated by year (1996–2012) in the (a) Kodiak Shelikof, (b) Kodiak Northeast, (c) Yakutat/D16/Prince William Sound, and (d) Bering Sea districts.

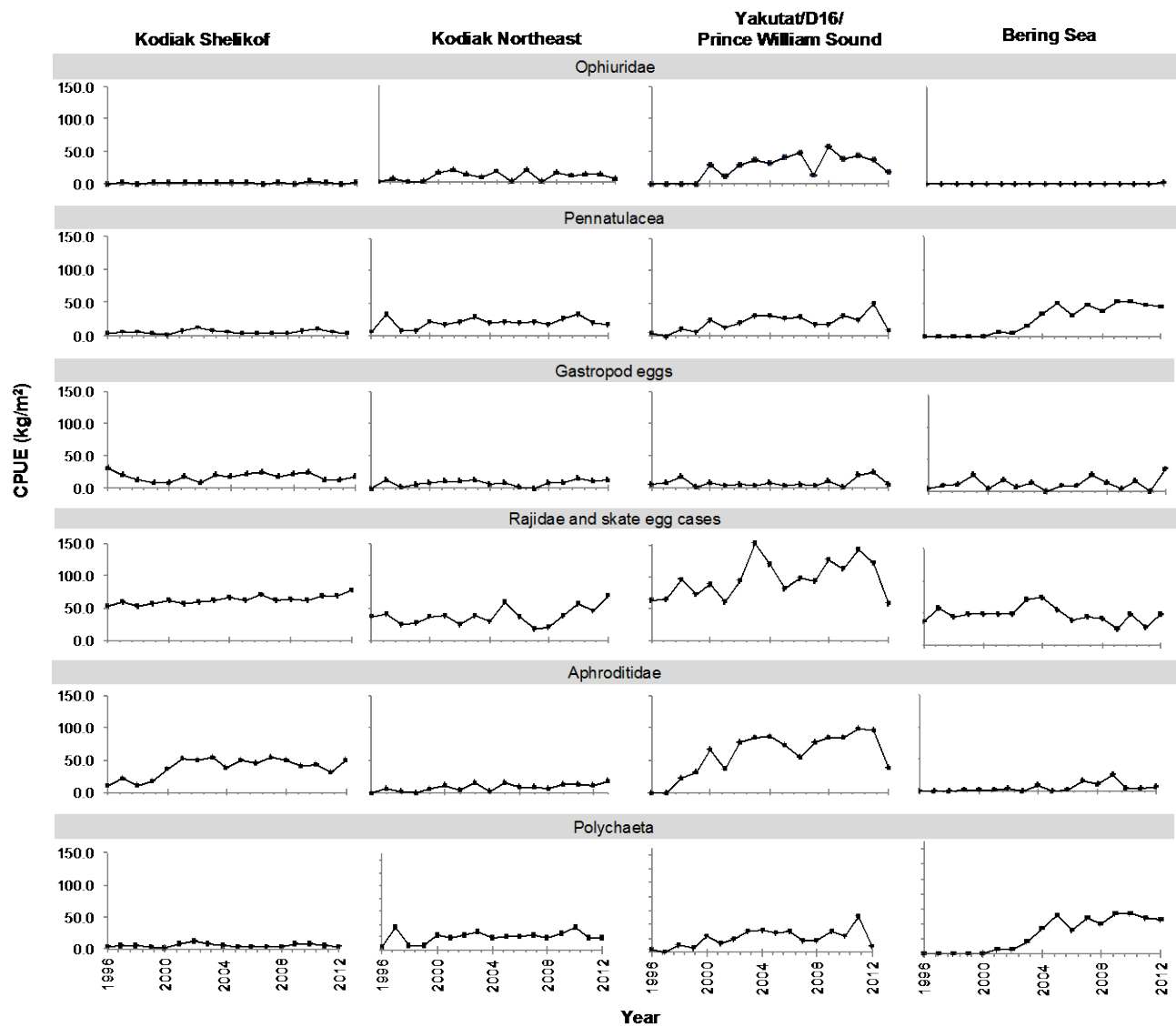


Figure 4. Average catch per unit effort (CPUE, kg/m²) of taxa exhibiting temporal changes over 1996 to 2012 across four registration districts. Yakutat/D16/Prince William Sound incorporates the sum of CPUE values in these three districts.

Appendix

A1. Results of similarity percentages (SIMPER) analyses from (a) 1997, (b) 2000, and (c) 2010 for the Kodiak Shelikof, Kodiak Northeast, Yakutat/District 16, and Bering Sea districts. Shown are the average CPUEs for each taxon contributing to ~50% of the dissimilarities between two districts, along with the percentage that each taxon contributes to the total (Contrib. %) and the cumulative percentage contribution (Cum. %).

a) 1997

Yakutat & Kodiak Shelikof
Average dissimilarity = 50.12

Taxa	Yakutat Avg. CPUE	Kodiak Shelikof Avg. CPUE	Contrib. %	Cum. %
Polychaeta	0.00	52.55	9.86	9.86
Gastropoda	3.03	32.53	5.43	15.29
Cancridae	2.17	30.20	5.07	20.36
Ascidacea	0.00	25.06	4.44	24.80
Brachiopoda	0.00	25.53	4.38	29.18
Pleuronectiformes	26.46	45.98	4.13	33.31
Cirripedia	13.16	26.39	4.07	37.38
Gastropod eggs	11.51	29.28	3.95	41.33
Echinoida	0.00	21.41	3.85	45.19
Demospongiae	0.00	20.14	3.61	48.79

Kodiak Shelikof & Kodiak Northeast
Average dissimilarity = 46.08

Taxa	Kodiak Shelikof Avg. CPUE	Kodiak Northeast Avg. CPUE	Contrib. %	Cum. %
Polychaeta	52.55	28.02	5.44	5.44
Pennatulacea	2.73	31.75	5.29	10.73
Cancridae	30.20	0.96	4.82	15.54
Cirripedia	26.39	7.71	4.36	19.90
Ascidacea	25.06	5.03	3.86	23.76
Brachiopoda	25.53	9.22	3.71	27.48
Hirudinea	21.86	3.47	3.26	30.74
Gastropoda	32.53	14.81	3.23	33.97
Rajidae	47.41	34.09	3.16	37.13
Gastropod eggs	29.28	11.55	3.14	40.27
Polynoidae	0.78	18.72	3.14	43.40
Demospongiae	20.14	7.45	2.97	46.38
Echinoida	21.41	5.71	2.94	49.32
Actiniaria	19.22	18.40	2.63	51.96

Kodiak Shelikof & Bering Sea

Average dissimilarity = 46.85

Taxa	Kodiak Shelikof Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Polychaeta	52.55	1.45	9.53	9.53
Oregoniidae	22.79	63.44	7.79	17.33
Cancridae	30.20	0.00	5.28	22.61
Cirripedia	26.39	0.00	4.96	27.57
Ascidacea	25.06	0.00	4.44	32.00
Brachiopoda	25.53	0.00	4.38	36.39
Gastropod eggs	29.28	7.66	4.10	40.49
Asteroidea	38.62	18.27	3.84	44.32
Scyphozoa	0.05	19.37	3.71	48.03
Demospongiae	20.14	0.00	3.60	51.63

Kodiak Northeast & Bering Sea

Average dissimilarity = 44.83

Taxa	Kodiak Northeast Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Oregoniidae	20.21	63.44	10.45	10.45
Asteroidea	52.00	18.27	7.96	18.40
Pennatulacea	31.75	0.00	7.59	26.00
Polychaeta	28.02	1.45	6.39	32.39
Gastropoda	14.81	39.44	5.77	38.16
Rajidae	34.09	50.91	4.80	42.96
Actiniaria	18.40	23.66	3.83	46.79
Polynoidae	18.72	4.86	3.69	50.48

Yakutat & Aleutian Islands

Average dissimilarity = 57.21

Taxa	Yakutat Avg. CPUE	Aleutian Islands Avg. CPUE	Contrib. %	Cum. %
Pennatulacea	0.00	41.75	8.64	8.64
Gastropoda	3.03	39.56	7.32	15.96
Cardiidae	1.91	36.43	7.06	23.02
Roundfish	16.01	49.46	6.94	29.96
Decapoda	8.41	31.87	6.02	35.99
skate egg cases	29.10	0.00	5.96	41.95
Gastropod eggs	11.51	37.44	5.49	47.44
Echinoida	0.00	28.21	5.20	52.64

Yakutat & Kodiak Northeast
Average dissimilarity = 50.33

Taxa	Yakutat Avg. CPUE	Kodiak Northeast Avg. CPUE	Contrib. %	Cum. %
Pennatulacea	0.00	31.75	7.39	7.39
Polychaeta	0.00	28.02	6.40	13.80
skate egg cases	29.10	8.31	4.96	18.76
Pleuronectiformes	26.46	46.70	4.76	23.52
Polynoidae	0.00	18.72	4.23	27.75
Cirripedia	13.16	7.71	3.66	31.41
Oregoniidae	7.30	20.21	3.63	35.03
Paguridae	14.72	29.86	3.55	38.59
Actiniaria	14.15	18.40	3.40	41.98
Lithodidae	1.72	15.03	3.23	45.22
Rajidae	38.50	34.09	3.18	48.39
Hirudinea	15.55	3.47	3.17	51.57

Yakutat & Bering Sea
Average dissimilarity = 46.19

Taxa	Yakutat Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Oregoniidae	7.30	63.44	16.44	16.44
Gastropoda	3.03	39.44	10.69	27.13
Pleuronectiformes	26.46	51.76	7.36	34.49
Asteroidea	41.89	18.27	6.92	41.42
skate egg cases	29.10	6.30	6.78	48.20
Scyphozoa	0.00	19.37	5.69	53.88

b) 2000

Yakutat & Kodiak Shelikof
Average dissimilarity = 38.61

Taxa	Yakutat Avg. CPUE	Kodiak Shelikof Avg. CPUE	Contrib. %	Cum. %
Ranellidae	3.38	36.10	7.40	7.40
Echinasteridae	25.63	0.48	5.36	12.76
Rajidae	32.40	51.74	4.37	17.13
Cirripedia	22.37	4.16	3.95	21.09
Aphroditidae	20.64	35.64	3.88	24.97
Polychaeta	24.54	6.63	3.87	28.84
skate egg cases	26.10	10.45	3.46	32.29

2000 Yakutat & Kodiak Shelikof Continued:

Crangonidae	20.19	7.05	3.43	35.72
Buccinidae	15.95	18.13	3.17	38.90
Echinoida	0.47	14.39	3.12	42.02
Ophiuridae	14.91	1.05	3.09	45.11
Hirudinea	16.49	3.20	2.98	48.09
Pleuronectiformes	30.93	42.91	2.75	50.84

Yakutat & Kodiak Northeast
Average dissimilarity = 50.41

Taxa	Yakutat Avg. CPUE	Kodiak Northeast Avg. CPUE	Contrib. %	Cum. %
Lithodidae	2.76	43.36	7.18	7.18
Solasteridae	0.00	39.76	6.49	13.67
Ranellidae	3.38	29.50	4.19	17.86
skate egg cases	26.10	5.14	3.39	21.25
Polychaeta	24.54	10.78	3.26	24.51
Oregoniidae	16.54	36.25	3.25	27.77
Echinasteridae	25.63	6.70	3.24	31.01
Cirripedia	22.37	10.76	3.00	34.02
Crangonidae	20.19	11.06	2.97	36.99
Aphroditidae	20.64	12.03	2.81	39.80
Hirudinea	16.49	0.00	2.59	42.39
Pennatulacea	13.37	26.98	2.57	44.96
Decapoda	7.27	18.12	2.54	47.50
Pleuronectiformes	30.93	45.09	2.51	50.00

Kodiak Northeast & Kodiak Shelikof
Average dissimilarity = 42.41

Taxa	Kodiak Northeast Avg. CPUE	Kodiak Shelikof Avg. CPUE	Contrib. %	Cum. %
Lithodidae	43.36	0.00	9.51	9.51
Solasteridae	39.76	4.75	7.37	16.88
Pennatulacea	26.98	2.03	5.17	22.05
Aphroditidae	12.03	35.64	4.63	26.68
Actiniaria	34.67	14.93	3.85	30.53
Rajidae	32.40	51.74	3.64	34.17
Decapoda	18.12	7.45	3.24	37.41
Buccinidae	8.37	18.13	3.04	40.44
Crangonidae	11.06	7.05	2.48	42.92
Oregoniidae	36.25	25.46	2.47	45.39
Polychaeta	10.78	6.63	2.39	47.78
Pandalidae	1.99	13.39	2.37	50.15

Yakutat & Bering Sea
Average dissimilarity = 51.61

Taxa	Yakutat Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Ranellidae	3.38	55.30	8.69	8.69
Oregoniidae	16.54	56.91	6.72	15.41
Asteroidea	38.46	11.57	4.62	20.03
Echinasteridae	25.63	0.00	4.06	24.09
Paguridae	25.67	47.55	3.76	27.85
Buccinidae	15.95	30.35	3.74	31.59
Polychaeta	24.54	1.65	3.70	35.29
Pleuronectiformes	30.93	52.27	3.60	38.90
Crangonidae	20.19	0.00	3.27	42.16
Scyphozoa	1.83	20.69	3.18	45.34
Aphroditidae	20.64	1.94	2.98	48.32
skate egg cases	26.10	9.25	2.77	51.09

Kodiak Northeast & Bering Sea
Average dissimilarity = 48.78

Taxa	Kodiak Northeast Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Lithodidae	43.36	0.00	8.20	8.20
Solasteridae	39.76	0.00	7.19	15.39
Pennatulacea	26.98	0.00	4.81	20.20
Ranellidae	29.50	55.30	4.43	24.63
Buccinidae	8.37	30.35	4.08	28.71
Actiniaria	34.67	11.27	3.96	32.67
Gastropoda	0.00	20.14	3.50	36.17
Oregoniidae	36.25	56.91	3.41	39.57
Scyphozoa	1.80	20.69	3.34	42.91
Polynoidae	0.00	19.17	3.33	46.25
Asteroidea	31.88	11.57	3.28	49.53
Decapoda	18.12	5.02	2.90	52.43

Kodiak Shelikof & Bering Sea
Average dissimilarity = 36.70

Taxa	Kodiak Shelikof Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Aphroditidae	35.64	1.94	8.55	8.55
Oregoniidae	25.46	56.91	7.98	16.54
Ranellidae	36.10	55.30	4.87	21.41

2000 Kodiak Shelikof & Bering Sea Continued:

Polynoidae	0.00	19.17	4.87	26.28
Asteroidea	30.39	11.57	4.78	31.06
Gastropoda	1.64	20.14	4.70	35.75
Paguridae	29.26	47.55	4.64	40.39
Scyphozoa	3.37	20.69	4.40	44.79
Asciacea	0.00	16.34	4.15	48.94
Echinoida	14.39	0.49	3.53	52.47

c) 2010

Yakutat & Kodiak Shelikof
Average dissimilarity = 53.09

Species	Yakutat Avg. CPUE	Kodiak Shelikof Avg. CPUE	Contrib. %	Cum. %
Cancridae	1.41	36.94	5.83	5.83
Ranellidae	1.54	37.50	5.82	11.65
Cirripedia	29.64	0.28	4.81	16.46
Aphroditidae	40.25	17.72	4.30	20.76
Luidiidae	39.01	11.63	4.26	25.03
Veneridae	27.47	1.86	4.19	29.21
Nereidae	2.23	27.03	4.09	33.30
Gastropod eggs	0.96	24.63	3.76	37.06
Goniasteridae	6.22	25.08	3.64	40.70
Rajidae	42.11	39.86	3.35	44.05
Naticidae	20.88	1.98	3.15	47.20
Ophiuridae	19.80	0.25	3.14	50.33

Yakutat & Kodiak Northeast
Average dissimilarity = 50.64

Species	Yakutat Avg. CPUE	Kodiak Northeast Avg. CPUE	Contrib. %	Cum. %
Aphroditidae	40.25	9.66	4.45	4.45
Cirripedia	29.64	0.00	4.38	8.83
Ranellidae	1.54	29.36	4.01	12.84
Veneridae	27.47	0.00	3.88	16.72
Brachiopoda	1.14	28.09	3.86	20.59
Demospongiae	2.90	28.98	3.78	24.37
Lithodidae	1.55	26.23	3.75	28.12
Oregoniidae	11.45	36.62	3.71	31.83
Luidiidae	39.01	16.39	3.45	35.28
Buccinidae	13.06	26.58	3.17	38.45

2010 Yakutat & Kodiak Northeast Continued:

Actiniaria	20.52	33.32	3.04	41.49
Goniasteridae	6.22	23.67	2.97	44.46
Pennatulacea	18.23	33.27	2.70	47.16
Astropectinidae	0.00	19.83	2.69	49.85
Pleuronectiformes	38.25	56.08	2.64	52.49

Kodiak Shelikof & Kodiak Northeast
Average dissimilarity = 47.96

Species	Kodiak Shelikof Avg. CPUE	Kodiak Northeast Avg. CPUE	Contrib. %	Cum. %
Cancridae	36.94	1.67	5.45	5.45
Roundfish	5.95	33.54	4.19	9.64
Lithodidae	0.00	26.23	4.00	13.64
Brachiopoda	1.78	28.09	3.97	17.61
Nereidae	27.03	7.70	3.93	21.53
Oregoniidae	13.33	36.62	3.62	25.16
Buccinidae	6.32	26.58	3.53	28.68
Demospongiae	9.73	28.98	3.50	32.18
Paguridae	12.18	34.11	3.44	35.63
Rajidae	39.86	39.12	3.38	39.01
Pennatulacea	15.01	33.27	3.31	42.32
Gastropod eggs	24.63	10.95	3.02	45.34
Astropectinidae	0.16	19.83	2.80	48.13
Echinasteridae	11.59	11.76	2.67	50.80

Yakutat & Bering Sea
Average dissimilarity = 57.00

Species	Yakutat Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Oregoniidae	11.45	52.73	6.18	6.18
Luidiidae	39.01	0.00	5.78	11.96
Asteroidea	37.42	0.00	5.49	17.46
Polynoidae	0.29	35.54	5.23	22.68
Aphroditidae	40.25	5.17	5.16	27.84
Pennatulacea	18.23	52.65	5.12	32.96
Ranellidae	1.54	33.87	4.80	37.76
Buccinidae	13.06	43.93	4.78	42.54
Cirripedia	29.64	0.00	4.45	46.99
Porifera	0.00	27.73	4.11	51.10

Kodiak Shelikof & Bering Sea
Average dissimilarity = 54.32

Species	Kodiak Shelikof Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Asteroidea	44.48	0.00	6.80	6.80
Oregoniidae	13.33	52.73	6.13	12.93
Pennatulacea	15.01	52.65	5.84	18.77
Buccinidae	6.32	43.93	5.79	24.56
Cancridae	36.94	2.30	5.35	29.91
Polynoidae	4.17	35.54	4.82	34.73
Polychaeta	1.29	29.22	4.27	39.00
Porifera	0.28	27.73	4.19	43.18
Goniasteridae	25.08	0.00	3.93	47.11
Nereidae	27.03	0.00	3.85	50.96

Kodiak Northeast & Bering Sea
Average dissimilarity = 42.24

Species	Kodiak Northeast Avg. CPUE	Bering Sea Avg. CPUE	Contrib. %	Cum. %
Asteroidea	46.15	0.00	7.82	7.82
Polynoidae	7.21	35.54	4.79	12.61
Polychaeta	1.78	29.22	4.64	17.25
Brachiopoda	28.09	0.00	4.59	21.84
Porifera	1.78	27.73	4.40	26.25
Lithodidae	26.23	1.52	4.35	30.60
Goniasteridae	23.67	0.00	3.94	34.54
Pennatulacea	33.27	52.65	3.35	37.89
Astropectinidae	19.83	14.04	3.27	41.16
Buccinidae	26.58	43.93	3.24	44.40
Roundfish	33.54	15.85	2.96	47.37
Solasteridae	17.57	0.00	2.93	50.30



The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the sound use of our land and water resources, protecting our fish, wildlife and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island communities.



The Bureau of Ocean Energy Management

The Bureau of Ocean Energy Management (BOEM) works to manage the exploration and development of the nation's offshore resources in a way that appropriately balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.