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Micronekton community structure in the epipelagic zone of the northern California Current upwelling system

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ABSTRACT

Spatial and temporal variability in the micronekton community and in oceanographic conditions were evaluated from nighttime midwater trawl samples collected between Heceta Head, Oregon (44.0°N) and Willapa Bay, Washington (46.6°N). Collections from 13 cruises (176 trawls) from 2004 to 2006 yielded over 17,000,000 micronekton individuals (350,000 excluding euphausiids), representing 76 taxa and 43 families. The community was numerically dominated by euphausiids, followed in decreasing order by midwater shrimp (*Sergestes similis*), lanternfishes (Myctophidae), late larval/juvenile rockfishes (*Sebastes* spp.), age-0 Pacific hake (*Merluccius productus*), and pelagic squid (*Abraliopsis felis*). We used cluster analysis, ordinations, multi-response permutation procedures (MRPP), and indicator species analysis (ISA) to examine community structure of the 28 dominant taxa. Ordination and cluster results indicated that distance from shore and sea-floor depth best characterized habitats used by different assemblages of the micronekton community. Temperature and salinity at various depths influenced community structure to a lesser extent, along with Ekman transport. MRPP and ISA results indicated that nearly all dominant taxa were associated with cross-shelf gradients. Based upon a comparison between historical samples collected in 1976 and 1981 and comparable trawls from this survey, distinct decadal differences among micronektonic fish assemblages were observed, including more juvenile flatfishes and rockfishes but a lower diversity of mesopelagic fishes, which may be related to interdecadal environmental changes between the two time periods. This study represents the first examination of the relationships between both vertebrate and invertebrate members of the epipelagic nekton community.

1. Introduction

The California Current, which forms the eastern limb of the North Pacific subtropical gyre, is one of the major eastern boundary currents in the world. It supports highly productive pelagic ecosystems via upwelling-related enrichment (Wooster and Reid, 1963; Barber and Smith, 1981; Bakun, 1993). The pelagic ecosystem of the northern California Current (NCC) is subject to significant seasonal and decadal variability (Peterson and Schwing, 2003; Brodeur et al., 2005a; Legaard and Thomas, 2006) and is heavily influenced by oceanic and terrestrial effects (Hickey and Banas, 2003). Similar to other upwelling regions, the NCC is characterized by high biomasses of pelagic fish stocks such as sardine, anchovy, hake, and mackerel (Brodeur et al., 2003, 2005b).

Similar to many other areas of the ocean, a substantial part of pelagic biomass in the NCC is concentrated in what is known as micronekton: a diverse community of small but actively moving fishes, cephalopods, and crustaceans, all ranging in length from 2 to 10 cm (Blackburn, 1968; Brodeur and Yamamura, 2005; Brodeur et al., 2005b; Pereyra et al., 1969). This diverse assemblage is known to have significant influence on vertical transport of organic material from the surface to deeper waters through daily vertical migrations. Such transport constitutes a significant food source for larger nektonic organisms (Hidaka et al., 2001; Yamamura and Inada, 2001). The importance of small pelagic fishes in transferring energy to top predators is well-recognized in marine ecosystems (Pearcy, 1972b; Pereyra et al., 1969; Cury et al., 2000; Cartes et al., in press). However, the role of lanternfishes and other components of the micronekton assemblages in upwelling systems remains enigmatic.

Micronektonic fishes in the NCC have been extensively studied in terms of species composition (Pearcy, 1964; Willis, 1984), cross-shelf and vertical distribution (Pearcy and Laurs, 1966; Pearcy, 1976, 1983; Pearcy et al., 1977; Willis and Pearcy, 1982), acoustic patchiness and structure (Greenlaw and Pearcy, 1985; Kalish et al., 1986), distribution in relation to large-scale physical and chemical

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variables (Aron, 1962), population structure (Willis and Pearcy, 1980), feeding habits (Tyler and Pearcy, 1975; Pearcy et al., 1979; Fisher and Pearcy, 1983), and growth and reproduction (Smoker and Pearcy, 1970).

Among the micronekton, crustaceans have been studied less than fishes, but studies have been made of their vertical and geographical distribution (Pearcy and Forss, 1966, 1969; Pearcy, 1970, 1972a; Krygier and Pearcy, 1981) and diets (Renfro and Pearcy, 1966; Nishida et al., 1988). Similarly, relatively little is known of micronektonic cephalopods, with the exception of studies on composition and distribution (Pearcy, 1965; Jefferts, 1982) and acoustic assessment (Jefferts et al., 1987). Much of the present knowledge on micronekton for the North Pacific is summarized by Brodeur and Yamaura (2005).

Other than a limited study of micronekton collected during a single cruise in Astoria Canyon (Bosley et al., 2004), there has been no comprehensive examination of micronekton community structure. In addition to the potential advantage of the community-oriented approach to understanding the general functioning, persistence, and variability of micronekton, changes in assemblages of these communities over time can be useful proxies for documenting environmental variability or major regime shifts (Watanabe and Kawaguchi, 2003).

The objectives of the present study were to assess spatial and temporal variations in composition, concentration, and other characteristics of the near-surface micronekton community off the coast of Oregon and Washington, and relate them to environmental conditions in the region during the main upwelling season (April to September) from 2004 to 2006. We also compare these recent results to observations made several decades earlier during highly different environmental conditions.

2. Methods

2.1. Sampling procedures

In 2004, the Northwest Fisheries Science Center (NWFSC) Fish Ecology Division initiated a Stock Assessment Improvement Program (SAIP) to survey juvenile fishes off central Oregon and Washington. Juvenile fishes and other micronekton were sampled with midwater trawls from summer to fall 2004–2006. Several stations were sampled along four transects: Heceta Head (HH) (44.00°N), Newport (NH) (44.65°N), and the Columbia River (CR) (46.16°N) off Oregon; and Willapa Bay off Washington (WB) (46.67°N) (Fig. 1). Stations ranged from approximately 20 to 100 km offshore along each transect (Table 1).

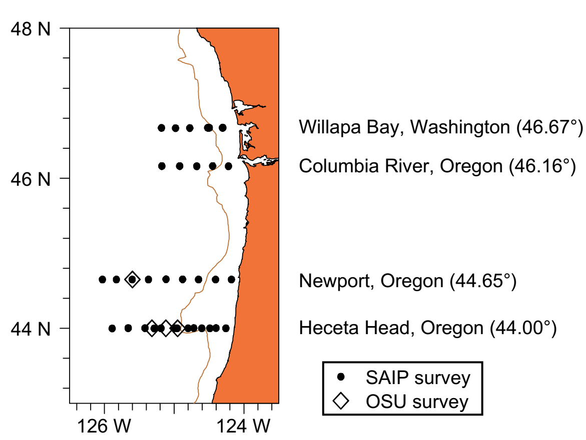

Fig. 1. Location of the sampling stations from the NOAA Fisheries, NWFSC SAIP survey from 2004 to 2006 and Oregon State University experimental midwater trawls from July 1976 and September 1981. The solid line indicates the 200 m isobath.

At each station, a Nordic 264-rope trawl was towed for 15–30 min with the headrope at a target depth of 30 m, with two exceptions. For the first two cruises in 2004, we used a modified Cobb trawl with a mouth opening one-third the size of the Nordic rope trawl (see Phillips et al., 2007). The Nordic 264-rope trawl had an effective fishing mouth 12 m high and 28 m wide (336 m^2) based on net mensuration estimates and variable mesh sizes (162.6 cm at mouth to 8.9 cm at cod end) (Emmett et al., 2004), with a 6.1-m long, 3-mm stretched knotless web liner in the cod end. All trawls were conducted at night except for two day tows identified in Table 1. After removing all fishes and invertebrates >10 cm in length, the catch was subsampled as follows: samples with a remaining volume of unsorted catch $\leqslant 0.25$ m^3 were frozen in their entirety, while samples with a remaining volume of unsorted catch >0.25 m^3 were subsampled in the amount of 0.25 m^3 or 20% of the entire sample (whichever was larger). The retained unsorted catches were frozen at sea and later thawed and sorted in the lab. Species densities were determined by multiplying the distance towed (as determined by a flowmeter) by the mouth opening of the net. For more detailed collection methodology, see Phillips et al. (2007).

Individuals captured were identified to the lowest possible taxonomic level (mostly species). However, due to the large number of individuals collected and ambiguous meristics, some of the taxa were identified to a higher taxonomic level than species (Table 2). Two specific examples are: late-larval/juvenile rockfishes (*Sebastes* spp.) and Euphausiidae (family level only).

At each station, physical data were collected using a Sea-Bird SBE25 CTD cast from the surface to 100 m in depth. Ekman transport vectors were expressed as monthly averages at a 1×1 cell resolution and were obtained from the Pacific Fisheries Environmental Laboratory website (http://www.pfeg.noaa.gov).

2.2. Data analysis

Shannon–Wiener diversity (H′) (MacArthur and MacArthur, 1961) and Pielou's index of evenness (J′) (Pielou, 1969) were calculated from a matrix of (64) micronekton taxa (Table 2) grouped by cruise. Cephalopoda, Oegopsida, Gonatidae, Euphausiids (not quantifiable), Teleostei, Osmeridae, Bathylagidae, Paraplepididae, Myctophidae, Gadiformes, Scorpaenidae, and *Citharichthys* spp. were excluded because they were most likely unidentified individuals of lower taxonomic categories already included. Using 65 micronekton, taxa-area curves were generated to assess adequacy of sample size (McCune and Grace, 2002). These determined 76 taxa for a first-order jackknife estimate, and 80 taxa for a second-order jackknife estimate (±1 SD; Fig. 2). Based on jackknife estimates, which tended to be positively biased with large sample sizes, it appeared that adequate sample sizes for this survey were obtained. Several multivariate analyses were used to investigate the community structure, including (1) Nonmetric multidimensional scaling (NMS) ordinations, (2) one-way and two-way cluster analyses, (3) multi-response permutation procedures (MRPP), and (4) indicator species analysis (ISA). Analyses were conducted using PC-ORD (version 5) software (McCune and Mefford, 1999).

2.3. Nonmetric multidimensional scaling (NMS) analysis

For multivariate analyses, only taxa that occurred in at least 10% of trawls taken over bottom depths of either <200 m or >200 m (total 28 taxa) for all years combined were used (Table 3). NMS was conducted using Bray–Curtis similarity matrices with a grouped-average linkage strategy (see Clarke and Ainsworth, 1993 and McCune and Grace, 2002 for a detailed description of NMS analysis).

The taxon data were fourth-root transformed to deemphasize the dominant taxa. We experimented with several other transformation (e.g., $\log_e$-transformed and presence/absence) and subsets