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# Small proportions of silt linked to distinct and predictable differences in marine macrofaunal assemblages on the continental shelf of the Pacific Northwest

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ABSTRACT

Increasing interest in offshore development has motivated intensified efforts to map the seafloor for marine spatial planning. However, surficial geologic maps do not accurately represent habitats for various species groups of concern. This study used a bottom-up approach to integrate macrofaunal densities and benthic conditions on the Pacific Northwest shelf to identify macrofaunal assemblages and associated habitat features. Benthic cores and water-column profiles were collected from 137 stations from 50 to 110 m depth. Analyses grouping stations based on both similar species abundances and benthic conditions resulted in six broad habitats. Within the sampled depth and latitudinal range, sediment characteristics were the primary structuring variable. A major break in assemblages was detected between sediment that had less than 1% silt/clay and those containing more than 1% silt/clay. Assemblages differed primarily in the bivalve species present and secondarily in polychaete species. Within the greater than and less than 1% silt/clay habitats, further discretization of assemblages was based mostly on differing abundances of characteristic bivalves and polychaetes associated with differing median grain sizes, which did not correspond to traditional definitions of fine or medium sand. These data show that a bottom-up methodology is necessary to discern habitats for macrofauna and that site-specific physical sampling is necessary to predict macrofaunal assemblage composition. However, if detailed sediment characteristics are known, macrofaunal assemblages may be predicted without time-intensive biological sampling and processing. These results also indicate that seemingly small sedimentary changes due to offshore installations may have measureable effects on the relative abundances and even the species composition of macrofauna.

## 1. Introduction

Sedimentary (soft bottom) seafloor is the predominant habitat on the continental shelf and thus is increasingly targeted for emerging offshore uses such as renewable energy and aquaculture. Siting offshore renewable energy facilities, offshore aquaculture, dredged material disposal, and marine reserves all require an understanding of species distributions and habitat associations to evaluate effects of such space use changes. With increasing interest in using environmental variables as surrogates to describe and predict spatial patterns in benthic diversity and distributions (e.g. McArthur et al., 2010), determining current species- and assemblage-habitat associations provides a tool for researchers and managers to make predictions and assess impacts of changing ocean conditions both from environmental drivers and offshore development.

Macrofauna (fauna retained on a 1 mm screen; Mare, 1942) long have been used as indicators of various environmental characteristics or 'quality' as well as ecosystem function (see review in Barrio Froján et al., 2012) and are a group of organisms likely to respond to changes in seafloor use. Effects of offshore developments arise from introducing structure to sedimentary seafloor habitats and are expected to change local hydraulics and sediment distributions as well as introduce hard substrate for colonization and fish attraction (Cada et al., 2007). The intensity and extent of such effects on seafloor assemblages by renewable energy and/or aquaculture installations are as yet uncharacterized but may be hypothesized from studies of artificial reefs and oil platforms. Studies of offshore platforms in the Mediterranean observed that benthic macrofaunal assemblages varied with distance from a platform and that the spatial extents of the differences varied with depth of the platform (Terlizzi et al., 2008) and over time (Manoukian,

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2010 ); see also reviews in Boehlert and Gill (2010) and Henkel et al., (2013, 2014b). It is less certain how the installation of multiple aquaculture or renewable energy structures could extend the impact footprint or how the effects of energy removal associated with wave or tidal energy devices may interact with effects due to structure alone.

The spatial distribution patterns of benthic invertebrates found on or in seafloor sediments result from interactions with a host of environmental variables. Multiple studies have found significant associations between macrofaunal composition and sediment characteristics (percent silt-clay, organic carbon, grain size; Weston, 1988; van Hoey et al., 2004; Jayaraj et al., 2008; Labrune et al., 2008), particular water temperatures and/or dissolved oxygen levels (Cerame-Vivas and Gray, 1966; Cimberg et al., 1993; Carroll and Ambrose, 2012), or differences related mostly to depth (Hyland et al., 1991; Oug, 1998; Bergen et al., 2001). In southern California, depth was considered to be the primary variable structuring macrofaunal invertebrate species distributions with other factors such as dissolved oxygen, grain size, and total organic carbon being secondary (SAIC, 1986; Lissner, 1989; Hyland et al., 1991, Bergen, 2001, Allen et al., 2007). The macrofaunal community of the Pacific Northwest continental shelf, however, has been relatively understudied in comparison to other continental shelves. Areas further south in the California Current systems have been repeatedly evaluated by SAIC (1986), Kanter et al. (1989), Lissner (1989), Hyland et al. (1991), Bergen et al. (2001), Allen et al. (2007) and Oliver et al. (2011) while surveys in Washington are rarer, mostly focused on Puget Sound (Lie, 1968; Lie and Kelly, 1970; and Lie and Kisker, 1970). Thus a description of macrofaunal assemblages and an understanding of the habitat features that structure them on the Pacific Northwest shelf are needed.

While few recent studies have focused on standard assemblage metrics of marine macrofauna broadly in the region (e.g. Burd et al., 2008; Nelson et al., 2008; Oliver et al., 2011), a description of the structural variability of macrofaunal assemblages is lacking. Because the functional roles of assemblages are based on which species are present, not just how many, an understanding of assemblage-habitat associations and how assemblages might vary in composition (as opposed to simply tracking changes in species richness or diversity) is necessary to fully evaluate the potential effects of ocean space use changes. The first objective of this study was to identify mid- to outer-continental shelf macrofauna assemblages and associated habitat features. The second objective was to define habitat classes using a bottom-up approach (e.g. LaFrance et al., 2014; Shumchenia and King, 2010; Eastwood et al., 2006) that could be broadly applied to the region so that as offshore projects are proposed, resource agencies can understand what macrofaunal communities may be present at a proposed site and how potential habitat changes may alter them. We addressed these objectives by surveying eight offshore sites from northern California to central Washington, USA. We expected to observe differences in macrofaunal assemblages among sites but hypothesized that these would be due to depth or sediment differences at the sites, as previous studies have indicated latitude is not an important factor in structuring assemblages in this region (Bergen et al., 2001).

## 2. Methods

### 2.1. Sampling approach

The initial region for this study included Federal waters from Fort Bragg, California, to Grays Harbor, Washington, as it was funded by the U.S. Bureau of Ocean Energy Management, which only supported sampling in Federal waters (Henkel et al., 2014a). In 2010, we sampled stations at five distinct sites from north to south: Grays Bank, Washington, Nehalem, Newport, and Siltcoos, Oregon, and Eureka, California. These five initial sites were selected primarily to fulfill the objective of the mapping component of the project, which was to fill in gaps in high resolution mapping within the region in order to develop region-wide surficial geologic habitat and predicted rock outcrop maps (Goldfinger et al., 2014). Each site was approximately 10 km across by 14 km alongshore. Because the eastern boundary (the 3 nmi line) of each site had variable depth (a function of the slope of the shelf across latitude), the sites did not span equal depth ranges. Station locations were generated using a Generalized Random Tessellation Stratified (GRTS) survey design, which stratified the sites by 10 m depth bin and randomly assigned stations within each depth bin, proportional to the overall area of that depth bin across sites (Stevens and Olsen, 2004). This stratification was chosen in order to obtain the greatest number of samples from the depth bin that encompassed the most area on the mid-shelf in order to have the most complete assessment of the most common habitat.

The above-described sampling strategy (unequal depth ranges across sites/latitude) and the distances between sites limited our ability to tease apart the relative influence of drivers (e.g. sediment, depth, latitude) of distributional patterns of species. Thus, additional Oregon sites in state waters were added in 2011 (Reedsport and state waters at Siltcoos; Henkel et al.al., 2011b) and in federal waters in 2012 (Cape Perpetua and Bandon-Arago) as funding opportunities arose, reducing the distance between sites in Oregon to an average of 57 km with more distant sites in Washington and California. The same GRTS approach was used to select sampling stations within these additional sites. Because we determined from other studies that a significant break in species assemblages occurs at approximately 50 m on the Oregon shelf (Voorhies, 2015 ), we limited our analysis in this study to stations between 50 m and 110 m to focus on the mid- to outer-continental shelf. Thus, the dataset reported herein consists of a total of 137 stations across eight sites over three years (Fig. 1a; Table 1). All collections were made August to October, and all sampling was conducted during what is considered a La Niña regime in the region. Additionally, sampling conducted at one of the sites repeatedly from June 2010 to June 2015 showed no significant differences across seasons or years at stations 50 m and deeper (Henkel and Hellin, 2016); thus we don't expect significant temporal differences within our time series affecting the outcome of our analysis of physical drivers.

### 2.2. Sample collection and processing

At each station, sediment samples were collected with a modified Gray-O′Hare 0.1 $m^2$ box core. One box core sample was taken at each station. Only samples with a penetration depth of at least 5 cm and no slumping or other evidence of disturbance (i.e. by washing) were accepted for processing. Actual penetration depths averaged 12.5 cm with a median of 10.5 cm for an average total core volume of over 1000 $cm^2$. Approximately 80 mL of sediment were collected from both the undisturbed surface layer and from the mid-core for grain size, total organic carbon (TOC), and total nitrogen (TN) analysis. Any organisms noticed in the sediment subsample were removed and placed in the organism sample at the time of collection (occasionally a specimen was detected when conducting the sediment analysis). The remainder of the collected core was sieved onboard through a 1.0 mm mesh screen, and all collected organisms (both infauna living in the sediment and small epifauna which may have been on the surface – hereafter collectively called macrofauna) were preserved in a mixture of 10% buffered formalin and seawater. At each station vertical water-column profiles of conductivity, temperature, dissolved oxygen, pH, and fluorescence were obtained with a Sea-Bird Electronics CTD (conductivity, temperature, depth) unit equipped with additional sensors. Depth was recorded from the vessels' echosounder at the time the box corer hit the bottom.

Upon return to the laboratory, organisms were transferred to 70% ethanol then sorted into major taxonomic groups by Oregon State University (OSU) staff. Crustaceans, polychaetes, other worm-like creatures, and a portion of the molluscs were sent to contracted