Title
A Dynamic Approach to the Characterization of Marine Habitats

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Final Report

A Dynamic Approach to the Characterization of Marine Habitats

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Introduction.

One of the greatest challenges faced by coastal conservation and management initiatives is the dynamical nature of nearshore ocean waters. Coastal oceans represent the fundamental habitat of a large number of species that are of key importance both for society and the environment. Despite an increasing awareness that these habitats change rapidly in space and time, our capacity to predict where and when these fundamental habitats occur is still very limited. Thus, deepening our understanding of how the coastal ocean changes and influences coastal ecological processes becomes of paramount importance.

As one moves alongshore for more than a few kilometers, changes in ecological and oceanographic patterns take place. These changes consist, for example, of differences in seawater temperature or variation in the abundance and productivity of phytoplankton. The physical and biological features of coastal marine habitats are constantly in flux. Satellite observations of the coastal ocean visibly show the widespread presence of complex and highly dynamic oceanographic structures in the nearshore. A key insight gleaned from these images is that persistent boundaries between oceanographic regimes could be found in coastal waters. More recently, the persistent presence of these different water masses has been associated with ecological differences in shoreline community structure, opening the possibility of casting general ecological predictions based on a set of physical parameters.

Through the funding provided by CEQI to complete my doctoral dissertation, I was able to explore the dynamical nature of marine habitats. More precisely, the results that I present below represent an attempt to characterize and link patterns of variation in different oceanographic variables with underlying ecological processes. In the *Results* section below, I provide a brief description of the main results of my doctoral dissertation. The results of each chapter are detailed in the dissertation manuscript[1], which includeda three different manuscripts plus another manuscript presented as accompanying material for the thesis. All of these have been submitted for publication in major journals of the fields of Marine Ecology, Oceanography and Geophysics (see below).

Results.

The initial portion of the research[2] was aimed at addressing the main question I posed in the proposal: are there different oceanographic climates? If so, can we define regions of the coast subject to these different climates? In collaboration with my advisor S. D. Gaines and Professor P. A. Kyriakidis from the Department of Geography at UCSB, I utilized publicly available coastal time series of chlorophyll-a concentration from remote sensing, to examine the alongshore extent of coastal regions subject to

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[1] Patch Scales in Coastal Ecosystems. Ph.D. Thesis, University of California, Santa Barbara. Author: B. R. Broitman.

[2] In review at Geophysical Research Letters. Patch Scales of Coastal Chlorophyll-a Dynamics. Authors: B. R. Broitman, P. A. Kyriakidis and S. D. Gaines.

similar temporal patterns of oceanographic variability in Western North America (WNA) and North-Central Chile (Chile). These data depict the concentration of microscopic plants in the seawater close to the coast, thus offering a proxy for the temporal variability of planktonic life close to shore. They also indicate the availability of food for benthic organisms that feed on plankton. I found striking interhemispherical differences in the length of coastal sections under similar oceanographic regimes (Figure 1). These regions were notoriously smaller in the Chile region (~60 km) than on the coast of WNA (~140 km). Through a spatial analysis of coastal orientation I suggest that the length of the coastline sections may be traced to the geomorphologic character of the ocean margins. Chile, which is of more recent geologic origin, lacks the large headlands and bights that are so characteristic of the WNA region. In North America, such large coastal features impose regular restrictions on the flow of surface waters along the coast and generate predictable oceanographic regimes that repeat along the coastline.

As part of another manuscript[3], in collaboration with fellow graduate student B. P. Kinlan, I focused more closely on the alongshore distribution of primary production, an estimate of ecosystem productivity. Through long-term means of coastal chlorophyll-a concentration and kelp (*Macrocystis pyrifera*) cover (Figure 2 a and 2 b) we explored their relationship with coastal geomorphology and sea surface temperature (SST). The spatial analyses were utilized to objectively determine the size (length) of coastal sections where large (or small) abundance of chlorophyll-a and kelp are observed. Again, we utilized time series of chlorophyll-a concentration and sea surface temperature derived from publicly available satellite datasets. B.P. Kinlan as part of his doctoral dissertation compiled aerial photographic surveys of kelp abundance over the study region. Spatial

[3] Submitted to Limnology and Oceanography: Spatial scales of primary production in coastal upwelling ecosystems. Authors: B.R. Broitman and B.P. Kinlan

analysis detected a striking match in the length of patches of primary production around 180-250 km. Strong negative correlations at small distances and positive correlations at longer distances suggest that there is little overlap between the locations of patches of kelp and sectors of high concentration of coastal chlorophyll-a. In agreement with findings from the previous chapter, I suggest that the location of the coastal patches of elevated primary production may be traced back to spatial patterns of coastal geomorphology.

So far, most of the analyses presented dealt with patterns in space of static variables, such as long-term means in the abundance of primary production or coastline orientation. Although the first[1] section examined correlations in temporal variability, time series analysis of physical and ecological processes has provided with major insights into the functioning of ecological processes. In the final manuscript I examine ecological implications of temporal variations in oceanography on spatial and temporal patterns of larval arrival at Santa Cruz Island [4]. This study utilized time series of sea surface temperature from satellite imagery (figure 3) and long-term datasets of recruitment of planktonic larvae of intertidal organisms from PISCO[5]. In this study I showed that intertidal study sites experiencing low larval recruitment rates were dominated by strong temporal variability in sea surface temperature. These sites, located in the western end of the island (figure 3), experienced the coldest oceans' temperature detected during the study. Cold water suggests the presence of deep water that has been recently brought up to the surface by wind mixing (upwelling), thus containing low number of larvae which inhabit surface waters. Larval supply, along with patterns of community organization

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[4] In review at Limnology and Oceanography. Recruitment of intertidal invertebrates and oceanographic variability at Santa Cruz Island, California, USA. Authors: B.R. Broitman, C.A. Blanchette and S.D. Gaines

[5] The Partnership for Interdisciplinary Studies of Coastal Oceans: a long-term consortium funded by the David and Lucille Packard Foundation.

presented an accompanying manuscript[6], indicated that very strong upwelling might curb the size of populations of intertidal invertebrates through the limited delivery lack of young to replenish the population. However, upwelling delivers large quantities of nutrients from the deep, thus enhancing the growth of algae and surfgrass in the "cold" sites through increased nutrient delivery and limited consumption and competition by intertidal invertebrates (figure 4).

[6] In review at Marine Ecology Progress Series. Oceanographic forcing of intertidal community structure around Santa Cruz Island, California, USA. Authors: C.A. Blanchette, : B.R. Broitman and S.D. Gaines.

Conclusions.

The results accomplished over the 2-year CEQI funding for the completion of the Ph.D. represent important contributions to the characterization of the dynamic nature of marine habitats. Firstly, I established the presence of different ocean climates along the entire coast of Western North America and Chile and objectively defined the extent of these regions. Secondly, I showed that the length of these regions is not only tightly matched by important ecological patterns such as the abundance of kelp and concentration of food for marine organism, but also showed that the location of these regions is fixed in space by the orientation of the coastline. Lastly, I statistically characterized contrasting ocean climates and showed that their presence largely determines the type of ecological community that will occur and that these different ecological communities may actually develop surprisingly close to each other. These results bear extremely important implications for coastal management initiatives, because they provide a strong indication that identifiable sections of the coast share a common ocean climate. One of the first implications that spring to mind is the fact that marine reserves and fisheries may be located optimally along the coast based on the presence of predefined ocean conditions. That approach could, for example, minimize redundancy in the size of protected areas.

Figures.

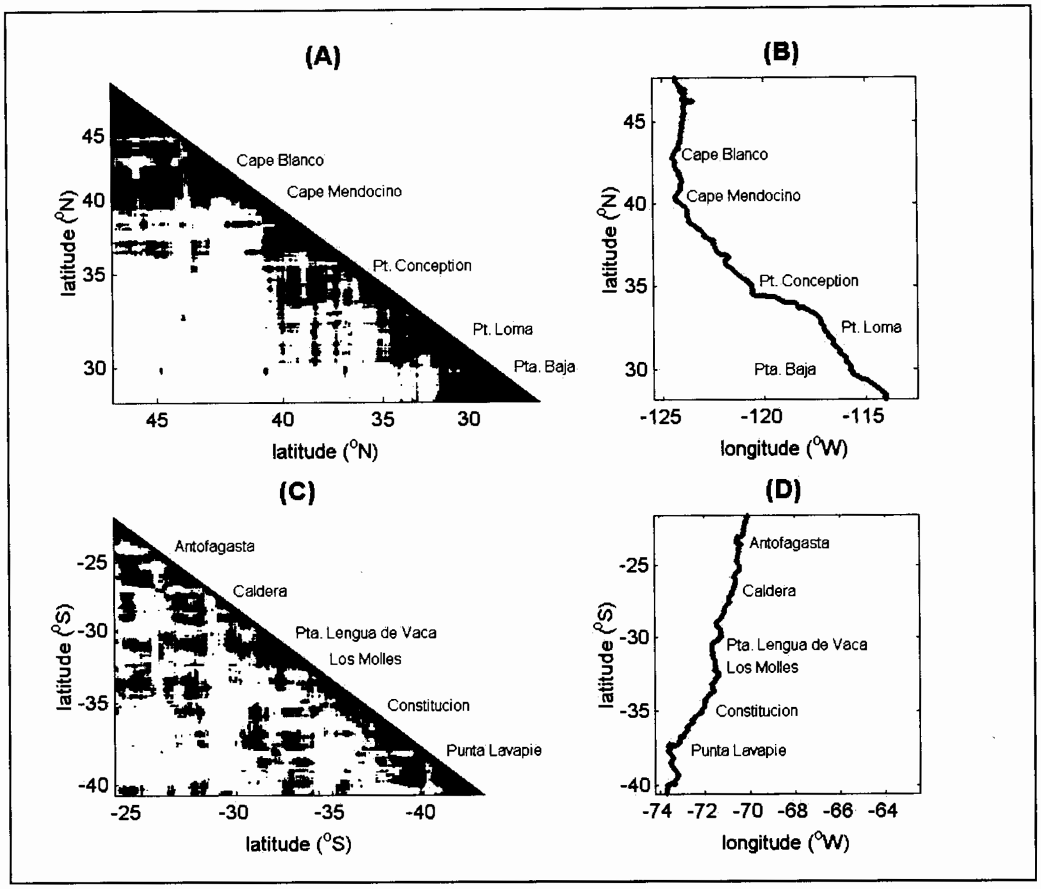

Figure 1

(a) Geographic pattern of significant correlations between chlorophyll-a concentration time series along the coast of Western North America shown in (b), $r = 0.28621$, $df = 1165$. (c) Same as (a) along the coast of Chile show in (d), $r = 0.28214$, $df = 916$. Significant correlations were Bonferroni-adjusted with _ = 0.05. It is notorious the presence of large "islands" of correlation in WNA, evidenced by the larger shaded regions when compared to Chile. These regions represent portions of the coast sharing a pattern of variation of chlorophyll-a concentration over time.

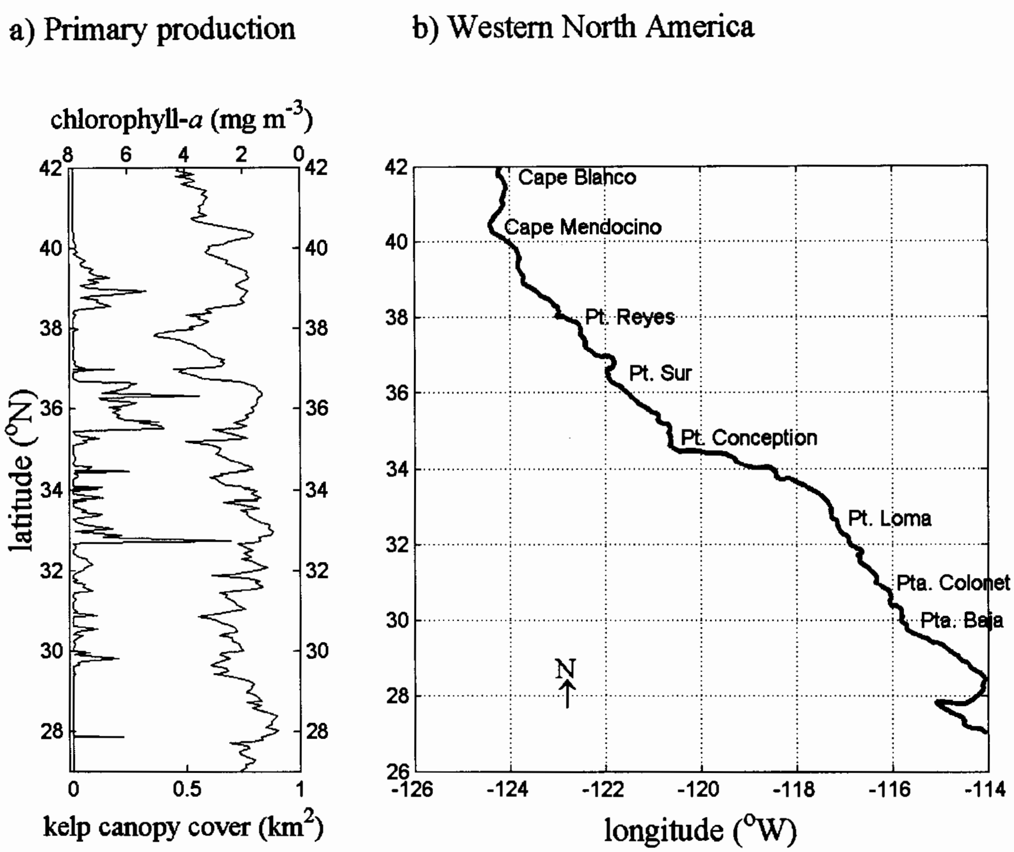

Figure 2

(a) Bottom label: Multi-survey composite of kelp surface canopy cover (km^2) measured from aerial infrared photography (California; 1989, 1999, 2002) and Landsat-7 imagery (Mexico; 2000, 2001). Top label: Long-term mean of SeaWiFS coastal chlorophyll-a concentration (mg m^{-3}). It can be seen that peaks in chlorophyll-a concentration and kelp abundance are offset in space and extend over similar distances (b) Coastline of continental western North America between 27°N and 42°N (note that offshore islands have been removed).

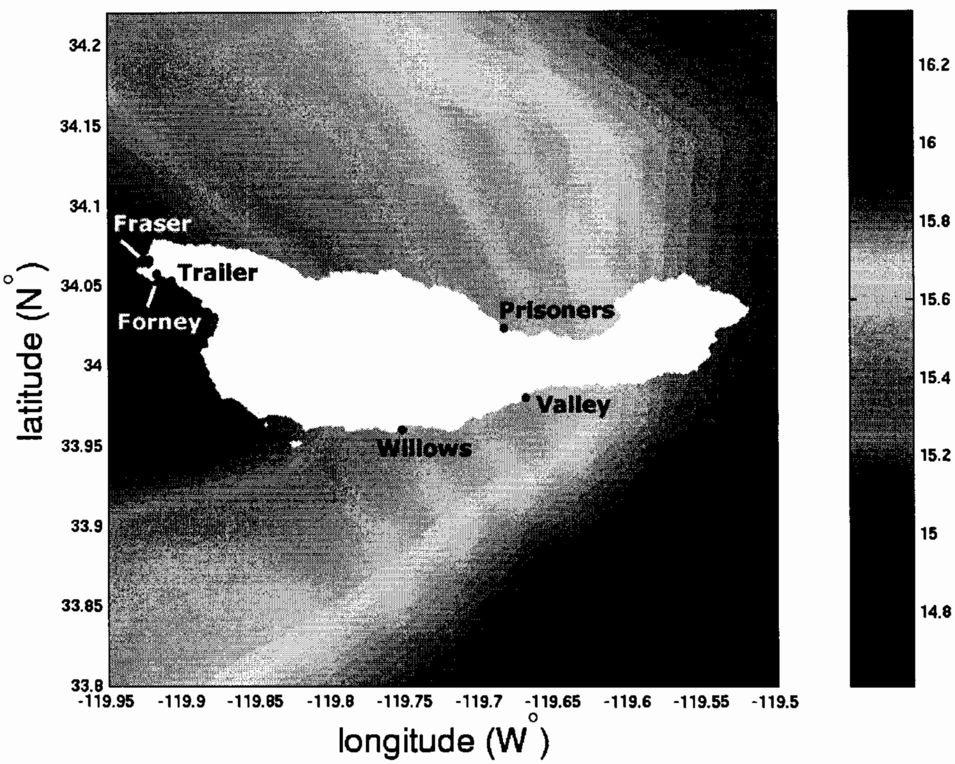

Figure 3

Location of study sites and long-term mean of sea surface temperature derived from 1-km resolution AVHRR satellite imagery between 1996 and 2002. Note the large temperature gradient between sites located less than 20 km apart. Sea surface temperature time series were compiled from the pixels closer to the location of the sites.

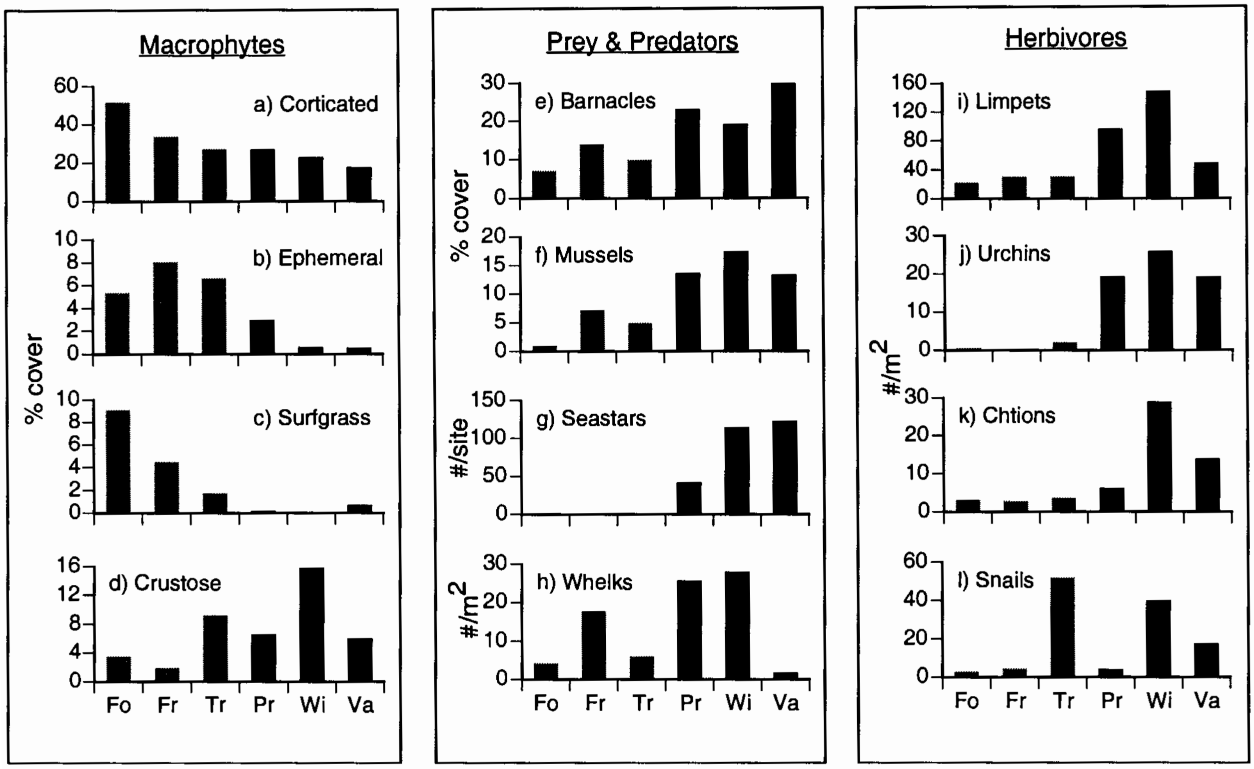

Figure 4

Patterns of space occupancy and densities of mobile taxa for the dominant functional groups. Sites are arranged in order of increasing long-term SST from coldest to warmest. Bars for the three western sites are shaded gray and bars for the 3 eastern sites are black; Fo=Forney, Fr=Fraser, Tr=Trailer, Pr=Prisoners, Wi=Willows, Va=Valley.

a-d) Percent cover of macrophytes (corticated, ephemeral and crustose algae and surfgrass).

e-f) Percent cover of filter-feeders (barnacles and mussels)

g) Numbers of seastars (*Pisaster ochraceus*) per site based on seastar swath counts

h) Mean density of whelks (*Nucella* sp., *Acanthina* sp. and *Ocenebra* sp.)

i-l) Mean densities of herbivores (limpets, urchins, chitons, snails)