Using Historical Data to Estimate Changes in Floating Kelp (Nereocystis luetkeana and Macrocystis integrifolia) in Puget Sound, Washington

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Abstract
Floating kelp beds *(Nereocystis luetkeana and Macrocystis integrifolia)* are important nearshore habitats that support commercial and sport fish, invertebrates, marine mammals and marine birds. Research has shown that floating kelp is affected by multiple anthropogenic and natural factors, but little is known about how floating kelp abundance in Washington State has changed over time. To investigate long-term temporal trends in floating kelp, we tested for changes over time in kelp canopy area along the Strait of Juan de Fuca and the outer coast using canopy area estimates that were derived from annual low-tide aerial photographs. Regression analysis was used to test for significant trends at three spatial scales: the study area, 3 regions, and 66 shoreline sections. We found that kelp canopy area increased significantly since 1989 over the study area as a whole, and in two of three regions ($p<.01$). At the shoreline section scale, kelp canopy area increased significantly in 18 sections, decreased significantly in 1 section and did not change in 47 sections. Multiple factors could have contributed to observed changes in kelp canopy area, including sea otter population growth and range expansion, sea urchin harvest, uncertainty in monitoring data, changes in habitat characteristics, algal community shifts, and climate change.

Introduction
Bull kelp *(Nereocystis luetkeana)* and giant kelp*(Macrocystis integrifolia)* form extensive canopies along the coast of the northern and western Olympic peninsula of Washington State. Kelp beds are important nearshore habitats that support commercial and sport fish, invertebrates, marine mammals and marine birds. Many factors, both natural and anthropogenic, are known to affect the extent and composition of kelp beds.

Scientists with the Nearshore Habitat Program in Department of Natural Resources have inventoried canopy-forming kelp beds using aerial photography annually since 1989, with the exception of 1993. This long-term data set provides insight into how the extent of kelp canopies changes over time. Previous change analysis of the data set between 1989-1999 found large yearly fluctuations, no trend in the study area as a whole, and local losses around Protection Island (Berry 2001). The purpose of this analysis is to more fully evaluate the longer time series for long-term trends over multiple spatial scales. Due to the synoptic nature of the data set, it is possible to discern scale-dependent patterns by testing for trends at multiple, nested spatial scales.

Methods

We investigated long-term temporal trends in floating kelp canopy area along the Strait of Juan de Fuca and the outer coast using canopy area estimates that were derived from annual low-tide aerial photographs. Since 1989, color-infrared photographs have been collected annually in the late summer, the season of maximum canopy extent. Kelp canopies were photo-interpreted onto USGS 7.5 minute base maps, then scanned and converted into spatial data sets (Van Wagenen 1996).

Regression analysis was used to test for significant trends in the data at three spatial scales: the study area, regions, and shoreline sections. The study area as a whole encompassed approximately 360 km of shoreline (figure 1). Three regions were defined based on broad-scale habitat characteristics, including wave energy, current energy, salinity, and temperature. Regions were of similar size, containing an average of 120 km of shoreline each.

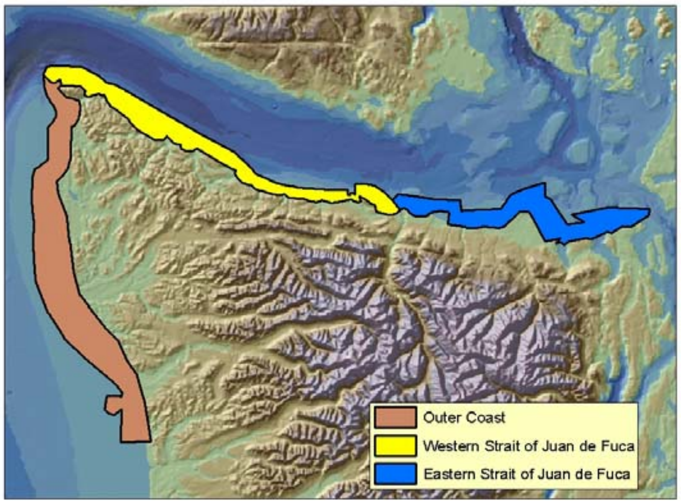

Figure 1. Study area, showing three regions used for trends analysis.

A total of 66 shoreline sections were defined to track canopy area over smaller areas. Sections contained 5- 15 km of shoreline (figure 2). Section boundaries were based on geomorphic characteristics, such as headlands, to the greatest extent practical (Van Wagenen 1996). In many of the program's monitoring documents and digital data sets, sections are referred to 'kelp sub-beds' or 'kelp IDs'.

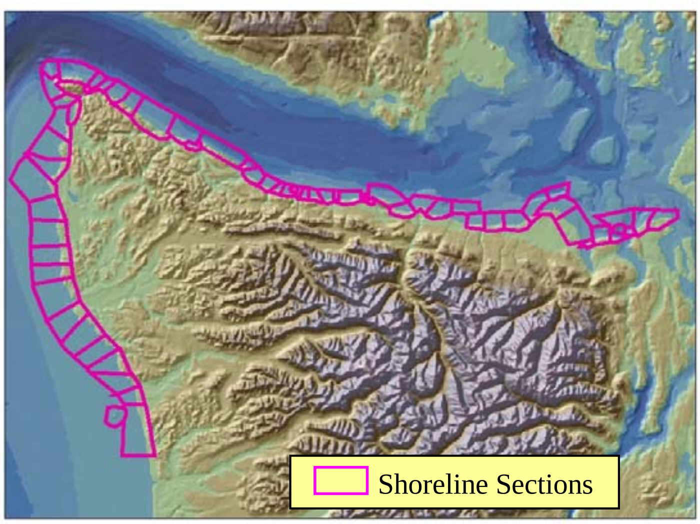

Figure 2. Shoreline sections used for trends analysis.

Results

Kelp canopy area showed high year-to-year variation, ranging from 722 hectares in 1997 to 2,575 hectares in 2000 (table 1). *M. integrifolia* canopy area was more stable over time than *N. luetkeana* canopy area.

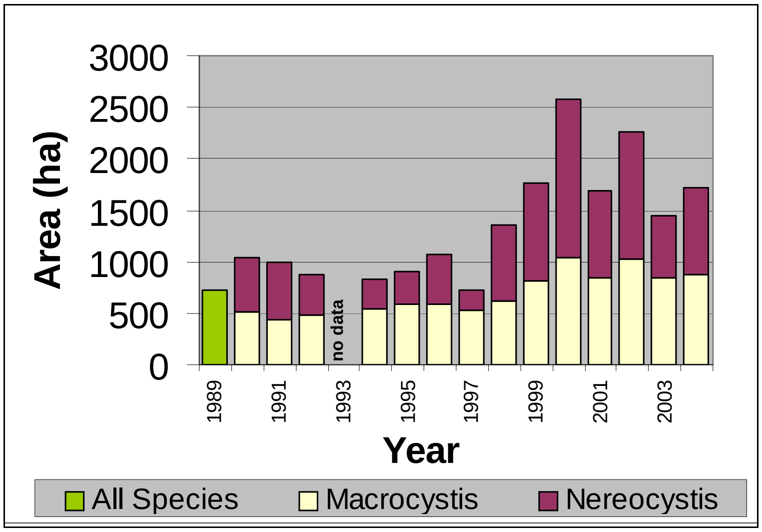

Table 1. Floating Kelp Canopy Area on Washington's outer coast and the Strait of Juan de Fuca, 1989-2004.

Floating kelp canopy area increased significantly ($p<.01$) over the study area as a whole. However, increases were not distributed evenly throughout the study area, as shown by higher resolution trends analysis at the regional and shoreline section scales. Kelp canopy area increased in two of three regions, the Outer Coast Region and the Western Straits of Juan de Fuca (figure 3).

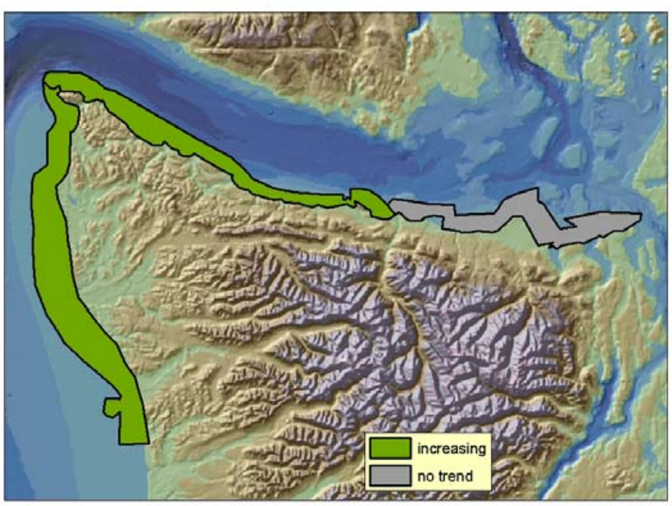

Figure 3. Regions with significant trends in kelp canopy area ($p<.01$), based on annual surveys between 1989 and 2004.

At the shoreline section scale, kelp area increased significantly in 18 sections, decreased significantly in 1 section, and did not change significantly in 47 sections (figure 4). In many areas, significant increases occurred in two adjacent sections, suggesting that patterns of change might be occurring over larger areas than shoreline sections. All increases occurred in the Outer Coast and Western Strait of Juan de Fuca regions, this finding is consistent with observed trends at the regional scale.

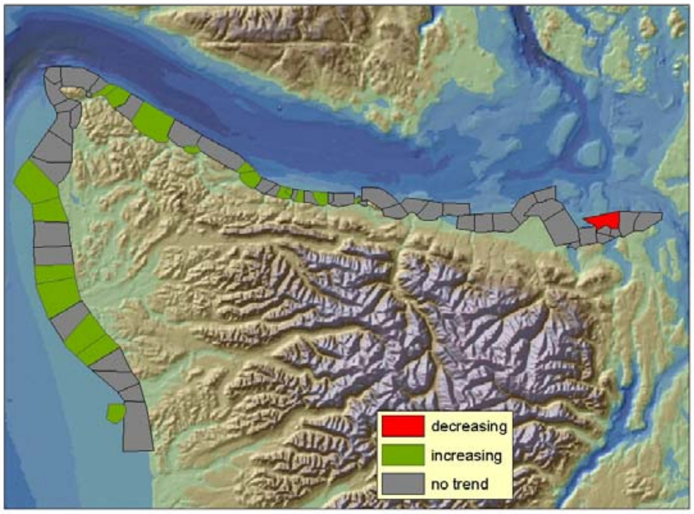

Figure 4. Shoreline sections with significant trends in kelp canopy area (p<.01), based on annual surveys between 1989 and 2004.

The only significant decrease occurred in the waters adjacent to Protection Island, where canopy area declined gradually from more than 10 hectares in 1989 and 1990 to less than 1 hectare annually since 1994. Interestingly, substantial kelp bed losses were noted at this location during two consecutive historical surveys in 1911 and 1912 (Rigg 1915).

Discussion

Multiple factors could be contributing to observed trends in kelp canopy area, including sea otter population growth and range expansion, sea urchin harvest, other habitat-related or climate-related factors, and uncertainty in the monitoring data.

Sea otter population growth and range expansion could have indirectly increased kelp communities through depleting the sea urchin populations that feed on kelp. Sea otters were re-introduced to Washington State in 1969 and 1970 after being extirpated in the early 1900's by hunting (Lance 2004). The sea otter population, which was initially limited to the outer coast around Destruction Island, gradually expanded along the outer coast and into the western Strait of Juan de Fuca in 1995, with populations reported as far east as Pillar Point. Studies of sea otter foraging behavior found that urchins made up a majority of the sea otter diet (60%) in newly established areas, while evidence of urchin predation was negligible (1%) in the established range (Laidre et al, in review). As compared to the kelp data, the observed sea otter range falls within the two regions with significant kelp increases, although the time periods and boundaries differ slightly. At the shoreline section scale, some individual shoreline sections with significant increases are located in sea otter concentration areas.

Human harvest of sea urchins could have indirectly affected kelp canopy area by decreasing sea urchin populations. Sea urchins are harvested along the Strait of Juan de Fuca portion of the floating kelp study area, but not the outer coast (M. Ullrich, pers. comm.) Peak landings occurred between 1998 and 1992. Harvest levels have decreased since then, with closures due to depleted stocks in portions of the Strait of Juan de Fuca. In comparison to the kelp trend data set, sea urchin harvest data coincides with kelp increases along the western Strait of Juan de Fuca, where some of the largest sea urchin landings have occurred. In the eastern Strait of Juan de Fuca, harvest continues in areas were no changes in kelp canopy area were observed.

Many other factors that are associated with changes in kelp abundance and distribution could also have caused the observed trends in kelp canopy area. For example, climate changes associated with El Nino are known to cause short term losses, while the Pacific Decadal Oscillation could be driving changes over longer time periods. Substrate movement influences the amount of available habitat for attachment. Competitive interactions among algal species can lead to a community shift from medium disturbance species such as *N. luetkeana* and *M. integrifolia*.

Finally, it is important to consider whether observed trends are an artifact of monitoring data uncertainty or bias. We are confident that aerial photography collection and interpretation methods have not introduced substantial differences in results among years because a single individual has collected and analyzed the data using the same methods since 1989. Environmental factors, primarily tidal height or current speed, could introduce apparent differences in the data because these factors change the amount of kelp that is floating on the surface. Limited work has been completed on the effect of tides and currents: 1) Van Wagenen (1996, 2004) hypothesized that the impact of tidal variation on the monitoring data has been confined to isolated portions of the study area during several years, this hypothesis was based on extrapolation of field measurements from northern California; 2) Britton-Simmons et al (2005) found that changes in tidal currents have substantial effects on kelp bed size along San Juan Island as measured using oblique color photography collected from the adjacent shoreline.

Priorities for future research include: 1) compare observed changes in kelp to spatial data describing trends in potential contributing factors; 2) further evaluate the potential impact of environmental factors on monitoring results; and 3) explore longer term trends in kelp abundance and distribution through comparing kelp monitoring data to historical kelp maps from 1911 and 1912 (Rigg 1915).

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