Supporting Online Material for

Strong Top-down Control in Southern California Kelp Forest Ecosystems

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Published 26 May 2006, *Science* **312**, 1230 (2006)
DOI: 10.1126/science.1128613

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Supporting Online Material

Methods

Datasets

The U.S. National Park Service has been conducting annual surveys of algal, invertebrate, and fish abundances at 16 different kelp forest sites around the five islands in the Channel Islands National Park since 1982 as part of the Kelp Forest Monitoring Program (KFMP; (S1)). Here we focused on data from the KFMP for only four years, 1999-2002 (for our purposes, a year runs from July the previous year to June of the current year), as these were the only years for which oceanographic data were available (see below), and only for the 4 northern Channel Islands (Fig. 1). Abundance data were available for 49 species, with trophic classifications of these species as elsewhere (S2). Three detritivorous invertebrate species were excluded from analyses. Full details on how these data were processed prior to analyses are provided elsewhere (S3).

Spatial, temporal, and environmental data were also used in analyses, as described elsewhere (S3). The KFMP recorded hourly temperature at each site (environmental variable), latitude and longitude of each sites was used to calculate spatial variables, and 4 potential temporal patterns were modeled using Principal Components of Neighboring Matrices (PCNM) techniques (S4) to represent temporal variables.

We estimated primary production around the KFMP monitoring sites from satellite-based observations of chlorophyll-a biomass (mg m^{-3}) from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) between September 1997 and October 2002. The quality of SeaWiFS observations in coastal waters off California has been extensively validated ((S5), see also (S6)), and primary production around the islands has been shown to be negatively correlated with SST (S7), which in turn is strongly and negatively

correlated with nutrient levels (S8). Thus primary production is a strong, albeit indirect, metric for local nutrient levels. The satellite observations used in the present analyses were collected at a nominal resolution of 1.1 km, such that each of the KFMP sites was assigned to ~1km^2 pixels, and averaged to monthly means. From the satellite composite we then calculated the long-term annual (July to June) and winter (January to March) means and standard deviations for each site.

We did not include data on fishing effort (ultimate top-down control) as high-resolution fishing data for the Channel Islands (species and location-specific catch rates) do not exist. Furthermore, recreational and commercial fishermen target species in all trophic levels (e.g., giant kelp, urchins, rockfishes and kelp bass) and only heavily target one species (lobster) from those identified in the forward selection procedure, and so humans act as herbivores and primary, secondary and tertiary predators in this system. In theory, although fishing could mask bottom-up regulation of the kelp forest communities by harvesting any changes in biomass distribution among trophic levels that resulted from differences in primary production, this is not likely the case around the Channel Islands. Recreational fishing around the islands is heterogeneously distributed in a similar pattern to primary production, since the warmer-water islands (Anacapa and Santa Cruz Islands) are also much closer to mainland harbors, and commercial fishing primarily targets market squid and sea urchins. If anything, fishing pressure should accentuate differences in biomass distribution among trophic levels between low and high-productivity systems if productivity were the main driver of those differences.

Statistical Analyses

Variation decomposition analysis (VDA) is a statistical technique that partitions the amount of variation explained by each variable (S9). The technique produces an F-statistic that is an asymptotically pivotal reference statistic and compares the amount of explained variation with the residual error (scaled for the appropriate degrees of freedom). The significance of the F-statistic is obtained through permutations of the data, and the degrees of freedom are not used directly for the computation of the p-values associated with the F-statistics (as is common practice with RDA results; (S9). To investigate the unique amounts of variation of a particular trophic level explained by top-down versus bottom-up processes, we restricted our dependent species matrix to contain only the species abundances of that particular trophic level. We also included data on and accounted for the location (longitude and latitude were transformed into third-degree spatial polynomials, creating 9 spatial variables), temporal patterns in the data (12 Principal Coordinates of Neighboring Matrices variables; (S4), and a variety of environmental variables (regional wave height, ENSO index values, local temperature; see (S3) for additional descriptions of all three types of variable). Our aim in including these latter variables was to remove their influence on species abundances and isolate true top-down and bottom-up effects.

Methods References

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Table S1. List of all species included in analyses. Species are grouped by trophic levels.

Algae

Eisenia arborea, Pterygophora californica, Laminaria farlowii, Macrocystis pyrifera

Herbivorous Invertebrates

Strongylocentrotus purpuratus, Strongylocentrotus franciscanus, Lytechinus anamesus, Haliotis corrugata, Haliotis refescens, Haliotis fulgens, Lithopoma undosum, Megathura crenulata, Aplysia californica

Herbivorous Fishes

Girella nigricans

Planktivorous Invertebrates

Crassedoma giganteum, Stylaster californica, Urticina lofotensis, Corynactis californica, Balanophyllia elegans, Serpulorbis squamigerus, Astrangia lajollaensis, Lophogorgio chilensis, Muricea fruticosa, Tethya aurantia, Diaperoecia californica, Phragmatopoma californica, Dioptra ornata, Styela montereyensis

Planktivorous Fishes

Chromis punctipinnis, Sebastes mystinus

Predatory Invertebrates

Pisaster giganteus, Pycnopodia helianthoides, Kelletia kelletti, Panulirus interruptus

Predatory Fishes

Sebastes atrovirens, Embiotoca jacksoni, Embiotoca lateralis, Oxyjulis californica, Damalichthys vacca, Hypsypops rubicundus, Alloclinus holderi, Rhinogobiops nicholsii, Lythrypnus dalli, Semicossyphus pulcher

Secondary Predators

Sebastes serranoides, Paralabrax clathratus

Table S2. Results from variation decomposition analyses for the relative strength of top-down versus bottom-up forces in controlling different trophic levels. Results indicate percentage of variance explained for each variable when controlling for all other potential variables. Degrees of freedom, F-statistics, and p-values are derived from VDA tests, as described in the Methods.

	All predators			Primary predators only			Secondary predators only		
	% explained	F	p-value	% explained	F	p-value	% explained	F	p-value
Plants									
Bottom-up	0.020	0.05	0.77	0.020	0.05	0.78	0.022	0.05	0.84
Top-down	0.201	0.43	0.01	0.195	0.55	0.002	0.010	0.03	0.87
Other variables	0.076	0.16	0.09	0.095	0.21	0.03	0.261	0.41	<0.001
Herbivores									
Bottom-up	0.018	0.19	0.76	0.025	0.28	0.32	0.018	0.17	0.80
Top-down	0.128	0.75	<0.001	0.103	0.56	0.003	0.050	0.69	0.003
Other variables	0.358	1.41	<0.001	0.362	1.33	<0.001	0.507	1.53	<0.001
Planktivores									
Bottom-up	0.017	0.58	0.29	0.019	0.60	0.24	0.017	0.41	0.63
Top-down	0.114	1.06	0.002	0.102	0.95	0.01	0.022	0.75	0.04
Other variables	0.268	2.60	<0.001	0.307	2.66	<0.001	0.601	3.49	<0.001
Herbivores + Planktivores									
Bottom-up	0.017	0.69	0.69	0.022	0.83	0.34	0.018	0.57	0.76
Top-down	0.145	1.72	<0.001	0.124	1.54	0.002	0.034	1.56	0.01
Other variables	0.291	3.75	<0.001	0.322	3.58	<0.001	0.561	4.26	<0.001