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Supplementary material

Appendix 1.

Ecological relationships between predictors and kelp habitat

Hard substrate is critical to provide kelp a strong attachment point. However, unequivocal descriptions of bottom type, particularly near shore, are not broadly available since acoustic bottom-mapping surveys (e.g., Gorman et al. 2013) are time consuming and spatially limited (i.e., suitable acoustic surveys were unavailable across our study area). Instead, we assess the utility of three different predictive models of bottom type. Two were derived from depth according to Haggarty (2015): *RF,* the score of a random forest analysis applied to the bathymetry, and *RMSM, RF* classified to Rock-Mixed-Sand-Mud. The third (bottom patch - *BoP*) classifies bottom type into Hard, Mixed, and Soft using the best available observational data following (Gregr et al. 2013).

Insolation (i.e., sunlight received) is important to all life history stages of kelp (Dayton 1985). Gorman et al. (2013) used mean light levels derived from satellite data, while Bekkby et al. (2009) used a proxy based on slope and aspect of the bottom. We hypothesised that along coasts with high topographic relief like the Northeast Pacific, shading may play an important role and so constructed an insolation model using the Solar Radiation module from ArcGIS 10.2 (ESRI 2015). We estimated monthly potential sunlight for each depth pixel in the study area, and created predictors to represent mean summer (*SumSol*) and winter (*WinSol*) insolation. For comparison, we calculated the proxies *Slope* and *Aspect* proposed by Bekkby et al. (2009) from the bathymetry.

In California, spring growth of giant kelp has been negatively correlated with sea surface temperature (SST). This has been interpreted as a proxy for nutrient availability (Cavanaugh et al. 2010) since cold, upwelled waters are also typically nutrient rich. However, temperature may also be physiologically limiting for canopy kelp, as Springer et al. (2007) reported an upper thermal limit for bull kelp, and Buschmann et al. (2004) reported improved early growth of giant kelp at lower temperatures.

We downloaded satellite-derived SST data using the Marine Geospatial Ecology Tool (version 0.8z40, Roberts et al. 2010) as 3-month averages from the 1-km resolution GLOB-G1SST data set for each quarter for the years 2010 to 2012. We derived three potential predictor variables from these remotely sensed data: *SST* represented the overall mean temperature across all quarters in all years, while *SSTQ2* and *SSTQ3* represented the mean temperature for the second and third quarters of the year (the peak growing period), averaged across the 3 years of sampling. Because many kelp survey points were near shore, some did not fall in a 1 km grid cell. For these points, the closest SST values were used.

Water motion, particularly through wave action, is important because of its ability to dislodge kelp from its substrate (Springer et al. 2007) and was a significant factor in all the studies on kelp distribution we reviewed (e.g., Bekkby et al. 2009, Cavanaugh et al. 2010, Gorman et al. 2013, Pedersen et al. 2012). We used fetch (an index of exposure - Lessard et al. 2007) as a proxy for wave energy. We calculated total fetch (from 120 equally spaced bearings) and directional fetch for the dominant summer (Southeast) and winter (Northwest) wind directions for points spaced 100 m apart across our study area, and interpolated these variables (*FetchTot*, *FetchSE*, *FetchNW*) to the depth grid.

While excessive wave action may be responsible for dislodging plants, we hypothesised that less-disruptive water movement may play a critical role in the circulation of nutrient-rich waters. We therefore considered the role of tidal energy using maximum bottom tidal speed (*MaxTidal*) obtained from Foreman et al. (2008).

Although not well studied, salinity may also affect kelp distribution, as few kelp species can tolerate low salinities (Dayton 1985). This was clearly observed during the kelp survey results, where extensive sampling closer to freshwater inputs (i.e., away from the open ocean) yielded very little kelp. There is also evidence of a positive correlation between giant kelp spore production and salinity (Buschmann et al. 2004). In the absence of contemporaneous salinity data, we defined our salinity predictor (*Salt*) using long-term average summer bottom salinities (Gregr et al. 2016).

Finally, while sedimentation has also been identified as important for kelp habitat (e.g., Springer et al. 2007), we lacked suitable proxies for this factor and thus could not include it in the analysis. However, it is reasonable to assume that sedimentation is correlated with bottom type, meaning that rocky reefs by definition receive little sedimentation. We therefore assumed that sedimentation was sufficiently represented by bottom type in the models.

We used an equidistant projection (BC Albers Conic) to map all predictors to the depth grid. Lower resolution predictors (*BTemp*, *Salt*, *MaxTidal*) were re-sampled to this working resolution.

Interactions

While difficult to quantify, interactions may be critical to understanding habitat suitability and the derivation of more process-based models. We tested a number of possible interactions defined using hypotheses describing how different abiotic variables could combine to improve kelp habitat quality:

1) Slope and aspect. We elaborated on Bekkby et al.'s (2009) use of these two variables as a proxy for sunlight by testing if interaction terms were more effective predictors of kelp.

2) Exposure and temperature. These variables are inversely correlated with distance from shore and also appear to have opposite effects on kelp habitat suitability. Cavanaugh et al. (2010) found the response of giant kelp biomass was dominated by wave disturbance in exposed regions, while a temperature effect was more dominant in sheltered regions. Such regional heterogeneity strongly suggests an interaction between temperature and exposure.

3) Exposure and salinity. In contrast to temperature, salinity is positively correlated with distance from shore, and with exposure. We hypothesised that the importance of elevated salinity would vary with exposure, perhaps playing a more significant role in low exposure areas.

4) Slope and tidal energy. Tidal energy circulates and mixes water quality characteristics; slope can serve as both a proxy for bottom type and a component of insolation. We hypothesised that the role of tidal energy differed in regions with low and high slope.

Table A1. Significance levels (p values: "***"< 0.001; "**" < 0.01; "*" < 0.05; "." < 0.1) for the univariate relationships between linear, quadratic, and cubic polynomial forms of the proposed predictor variables and the presence/absence of kelp canopy and its two component species giant and bull kelp. See text for variable descriptions.

	Canopy			Giant kelp			Bull kelp		
Variable	**Linear**	**2nd order**	**3rd order**	**Linear**	**2nd order**	**3rd order**	**Linear**	**2nd order**	**3rd order**
Depth	***	--	--	***	***	**	--	.	--
Slope	**	***	**	--	--	**	**	.	*
Aspect	--	--	--	**	--	--	*	--	--
RF	***	--	--	.	*	--	***	*	--
RMSM[1]	***	--	--	**	--	--	*	--	--
BoP[1]	***	--	--	*	--	--	.	--	--
Salt	--	--	--	--	***	*	--	*	--
BTemp	--	--	.	*	*	--	**	**	.
SST	--	--	--	*	--	--	**	--	--
SSTQ2	.	--	--	.	--	--	--	--	*
SSTQ3	--	.	--	**	*	--	--	--	--
SumSol	--	--	--	--	--	--	--	--	--
FetchTot	--	*	***	***	***	--	***	--	--
FetchSE	--	--	*	***	*	*	--	***	.
FetchNW	--	--	**	***	--	--	***	--	--
MaxTidal	**	--	--	--	**	--	**	**	--

1. Higher order values not valid for categorical variables.

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