Macroalgal production rates

We determined size-specific growth and loss rates using an approach modified from Rassweiler et al. (2008, 2018). We use the term "size" broadly here, as we utilize either frond density (*M. pyrifera*) or blade length (understory species) to estimate sporophyte size as a proxy for sporophyte biomass. Because we use single conversion factor to calculate each species' sporophyte biomass from its size, size-specific and mass-specific growth rates are equivalent. Thus, hereafter we refer to them simply as "specific" rates. We calculated the specific frond loss or blade erosion rate (f_i; d^{-1}) of each plant during a survey period using the equation:

$$f_i = \frac{1}{T} ln(\frac{F_T}{F_0})$$

where T is the number of days between surveys, F_0 is the frond density (*M. pyrifera*) or the maximum blade length (*N. fimbriatum, H. nigripes*) at the start of the survey period (time *0*), and F_T is the number of fronds > 1 m that had zip ties at time 0 that remain at time T (*M. pyrifera*) or the maximum blade length at time *0* plus the difference between the total blade increase (maximum blade length at time T minus maximum blade length at time *0*) and the linear blade growth (*N. fimbriatum, H. nigripes*).

We calculated the specific growth rate (g_i; d^{-1}) of each plant during a survey period using the equation:

$$g_i = \frac{1}{T} ln(\frac{B_T}{B_0}) + f_i$$

where T is the number of days between surveys, B_0 is the frond density (*M. pyrifera*) or the maximum blade length (*N. fimbriatum, H. nigripes*) at the start of the survey period (time *0*), and B_T is the total frond density or the maximum blade length at time T.

We calculated the per capita plant loss rate (p; d^{-1}) for each species during a survey period using the equation:

$$p = \frac{1}{T} ln(\frac{P_T}{P_0})$$

where T is the number of days between surveys, P_0 is the total number of individual plants of a species at the start of the survey period (time 0), and P_T is the number of plants at time 0 that remain at time T.

To determine a net rate of change (n; d^{-1}) for all individuals of a species during a survey period, we calculated the difference between each individual's specific growth rate and the sum of the individual and species' loss rates: $n_i = g_i - (f_i + p)$. We then averaged n_i among all individuals to get n. Similarly, we averaged g_i among individuals of each species during each survey period to calculate a mean specific growth rate (g).

Growth and loss equations were not defined in cases when all fronds were lost (*M. pyrifera*), or when the punched hole from time 0 was not re-sighted at time T (*N. fimbriatum, H. nigripes*). In the case of *M. pyrifera*, we substituted a value of ½ frond to enable an approximation of growth and loss rates as they approached zero (per Rassweiler et al. 2018). We did not observe any *M. pyrifera* plant to recover from a complete loss of fronds, and thus these individuals were accounted for in plant loss rates during a later survey period. When a punched hole was not re-sighted on a tagged understory kelp species, we did not include the individual in our analyses for that survey period. Following our observations of multi-year declines in *M. pyrifera* populations at two of our sites, we used regression analysis (R Core Team, 2021) to test if the number of elapsed days in the study period was a significant predictor of *M. pyrifera* net growth rates at Harris and Breast Islands.

We estimated macroalgal production rates in terms of dry mass, carbon mass and nitrogen mass produced per square meter per day using a similar approach to Rassweiler et al. (2008, 2018). Calculations of giant kelp bed productivity in southern California were found to be

robust to the type of growth model employed (Rassweiler et al. 2018). We chose to use an exponential growth model, which assumes that any new growth or erosion of a kelp sporophyte during a survey period occur in constant proportion to its starting size. For each survey period where we could estimate the starting dry mass FSC (S_0; g $\cdot$ m^{-2}) of a species at a site, we used the specific growth rate (g) and the specific net rate of change (n) to estimate the daily average dry mass production (P; g $\cdot$ m^{-2} $\cdot$ d^{-1}) that occurred during this sampling interval:

$$P = \frac{g \cdot S_0}{n}(e^n - 1)$$

We used the equation to calculate P in terms of carbon mass (i.e., primary production) and nitrogen mass, except we first defined S_0 in units of carbon or nitrogen mass by multiplying by the average carbon and nitrogen content of each species during that time period: $S_{0(C\ or\ N)} = S_0$ $\cdot$ (%C or %N). We recognize the significant variation in C and N content that can exist within kelp thalli (Gevaert et al. 2001) and have confirmed inter-thallus variability in elemental content for our monitored kelps in Sitka Sound that differs by species and season (authors' pers. obs.). Incorporation of this level of macroalgal elemental content variation into our productivity estimates was beyond the scope of this paper. We chose to use the average C and N content of the 'newest' blade tissue (sampled closest to the intercalary meristem) as the sole conversion factor for each species in each time period. To calculate the error around our estimates of macroalgal production rates for each species at a site in a survey period, we used Monte Carlo methods to propagate uncertainty from measured variability in the actual data (Harmon et al. 2007). We generated 1,000 randomly simulated normal distributions for each variable used in each calculation of P (as dry mass, C mass, and N mass) to create a normally distributed range of 1,000 estimates of P. We then used the standard deviation of these values as the standard error in each of our estimates of P.