# Biomass Coefficients for Kelp Forest Species

**Overview:** The inability to quantitatively compare different measures of species abundance (e.g., density and percent cover) or different metrics of species biomass (e.g., wet mass and dry mass) hampers studies of community dynamics, biodiversity, trophic interactions, and energy flow. This has been especially problematic for the dynamic and highly productive communities inhabiting shallow reefs in temperate seas where varied metrics are commonly used to characterize the abundance and biomass of different suites of species. To facilitate analyses of different types of abundance data we developed quantitative relationships between mass and length or mass and percent cover, and conversion factors for transforming wet mass into dry mass, decalcified dry mass and ash-free dry mass for 103 taxa of benthic macroalgae and macroinvertebrates common to giant kelp (*Marocystis pyrifera*) forests in southern California. We also compiled literature-based relationships between mass and total length for 52 species of reef fish common to giant kelp forests in southern California.

**Study Sites:** Relationships for estimating the mass of species of macroalgae and invertebrates were derived from measurements and tissue samples collected from 4 to 12 m depth at 11 reefs in the Santa Barbara Channel studied by the Santa Barbara Coastal LTER. Nine of the 11 reefs occur along the mainland coast of the Channel (Arroyo Burro 340 24.007' N 1190 44.663' W; Arroyo Hondo 340 28.312' N, 1200 08.663' W; Arroyo Quemado 340 28.127' N, 1200 07.285' W; Bulito 340 27.533' N, 1200 20.006' W; Carpinteria 340 23.545' N, 1190 32.628' W; Goleta Bay 340 24.827' N, 1190 49.344' W; Isla Vista 340 24.170' N 1190 51.472' W; Naples 340 25.340' N 1190 57.176' W; Mohawk 340 23.660' N, 1190 43.800' W) and two occur on the northern coast of Santa Cruz Island (Diablo 340 03.518' N, 1190 45.458' W; Twin Harbors West 340 02.664' N, 1190 42.908' W). Relationships for the invasive fucoid, *Sargassum horneri*, were derived using measurements and tissue samples collected at Catalina Island, CA.

**Algal Biomass Relationships:** We related either percent cover or size to biomass for macroalgae of different sizes and morphologies. Percent cover is used by the SBC LTER as a measure of abundance for taxa that are difficult to count as individuals, which include crustose algae, low lying turfs and small branching and foliose species. Relationships between percent cover and biomass were derived for the following species of macroalgae: *Bossiella orbigniana*, *Callophyllis flabellulata*, *Chondracanthus corymbiferus*, *Corallina chilensis*, large *Stephanocystis osmundacea* (defined as individuals > 10 cm in horizontal dimension), *Desmarestia ligulata*, *Laurencia spectabalis*, *Polyneura latissima*, *Rhodymenia californica*, *Dictyota* spp., family Ectocarpaceae, *Polysiphonia* spp., *Pterosiphonia* spp., *Halymenia* spp., and crustose coralline algae consisting primarily of *Pseudolithophyllum neofarlowii*.

Taxon-specific relationships between percent cover and dry mass were established using data collected from within 20 to 30 replicate 100 $cm^2$ quadrats strategically placed on the bottom by divers over the course of a year at the study sites. Percent cover was estimated as a proportion of 20 uniformly spaced points within the 100 $cm^2$ quadrat that contacted any foliage of the target taxon. Once points were recorded, all tissue of the targeted taxon within the quadrat was carefully collected, placed in a labeled plastic bag and returned to the laboratory for determination of biomass in units of dry mass (g). In the laboratory, each sample was weighed damp, dried at 60 $^oC$ for three days and then re- weighed. *C. chilensis*, *B. orbigniana* and species

of crustose coralline algae were de-calcified using a 10% HCL bath prior to drying to obtain measurements of de-calcified dry mass. Wet mass, de-calcified dry mass, ash free dry mass, percent carbon and percent nitrogen of the tissue sample were also measured for a subset of species.

Relationships between size and biomass were derived for the understory kelps *Laminaria farlowii*, *Pterygophora californica*, *Ecklonia arborea* and *Egregia menziesii*, the fucoids *Sargassum horneri*, *Sargassum muticum* and small individuals (10 cm or less in horizontal dimension) of *Stephanocystis osmundacea*. These relationships enable field measurements of individual size to be coupled with measurements of abundance (i.e., density) to non-destructively estimate the standing biomass of each species. The metrics of size used in these relationships to estimate biomass were: (1) total blade length (*L. farlowii*), (2) total number of blades > 30 cm in length (*P. californica* and *E. arborea*), (3) total number of fronds > 1 m in length (*E. menziesii*), and (4) total frond length (*S. horneri* and *S. muticum*). Measurements of biomass used in the relationships for large individuals of these species (e.g., *L. farlowii* with a blade width > 15 cm, *P. californica* with a stipe length > 20 cm and a stipe diameter > 7 mm, *E. arborea* with a stipe length > 5 cm, *S. horneri* and *S. muticum* (with a frond length > 5 cm, and *E. menziesii* with at least 1 frond > 1 m) were derived from individuals collected in the field and measured and weighed in the laboratory. Smaller individuals of these six species and *Stephanocystis osmundacea* can be extremely abundant and mean size calculated from a subsample of individuals was used to estimate their biomass.

Relationships between biomass and percent cover or biomass and size were derived for 23 taxa that accounted for more than 95% of the standing biomass or understory macroalgae averaged across all sampling locations from 2008 to 2018.

**Invertebrate Biomass Relationships**: As done for macroalgae we related either percent cover or size to the biomass of macroinvertebrates depending on their morphologies. Specimens of common taxa were collected throughout the year over a four-year period (April 2010 – May 2014) to account for seasonal and inter annual variation in body weight and composition; specimens of uncommon taxa were collected opportunistically. Taxa displaying large intra annual variation in biomass due to seasonal gonadal development (e.g., sea urchins, crustaceans) were collected during non-spawning periods.

Specimens were collected by divers, transported to the laboratory in insulated coolers, and placed in tanks supplied with running filtered seawater for 1-2 days before processing. This procedure allowed organisms to clear their digestive tract minimizing the contribution of gut contents to biomass. Taxa that could not be easily maintained in seawater tanks (e.g. sponges, hydroids) were processed immediately upon their arrival to the laboratory.

Percent cover is used by the SBC LTER as a measure of abundance for colonial taxa (e.g., bryozoans, sponges, and compound tunicates). As done for macroalgae, data on percent cover used to generate relationships with biomass were obtained by divers using a uniform grid of 20 points placed within 10 cm x 10 cm quadrats. After percent cover was recorded, all tissue of the targeted taxa within the quadrat was collected by carefully removing it from the bottom or by collecting the substrate to which the taxa were attached and removing the tissue in the laboratory. Replicate quadrats (n = 9 - 40 quadrats per taxa) containing varying amounts of

percent cover were sampled to generate sufficient data for determining the relationship between percent cover and biomass.

Data on individual size used to generate relationships with biomass for solitary taxa whose abundance is measured as density were based on morphological traits specific for a given taxa. Because our objective was to develop non-destructive methods for estimating standing biomass from abundance data collected in situ, only traits that were easily measured by divers without damaging the organism were used (e.g., total length, arm diameter, test diameter). Individuals of varying sizes were collected to generate relationships between length and wet mass (n = 6 - 207 individuals per taxa).

Biomass is often reported using a variety of metrics. To facilitate interconversion among these various metrics we estimated body mass as wet mass, dry mass, decalcified dry mass and ash free dry mass. To minimize effects of water adhesion on wet mass measurements, specimens were removed from holding tanks and blotted dry with a clean paper towel or exposed in air at room temperature and allowed to drip dry for 1-2 minutes prior to being weighed (Dermott and Paterson 1974). Estimates of dry mass were obtained by placing specimens of known wet mass in a drying oven at 60°C for several days until their mass remained constant. Water content was estimated as [1 – (dry mass/ wet mass)] x 100.

After being measured and weighed wet, the calcareous shells of molluscs and the chitonous exoskeletons of crustaceans were separated from the soft tissue, and dried and weighed separately to obtain estimates of dry mass (i.e. dried soft tissue + shell) and decalcified dry mass (i.e. dried soft tissue without the shell). The separation of soft tissue from chitonous exoskeletons of crustaceans was facilitated by microwaving the specimen for 1-2 minutes. Taxa with calcified structures such as bryozoans, gorgonians and echinoderms were dried whole to measure dry mass, and then treated with a 5% HCl solution for 3-4 hours to dissolve the calcified structures. Treatment with acid was repeated as necessary to remove all calcification. After full decalcification the remaining soft tissue was carefully separated from the acidic solution, rinsed in deionized water and placed back into the drying oven until the mass remained constant. The dried soft tissue was then reweighed to obtain a measure of decalcified dry mass. Dry mass samples of taxa without hard external structures, and shell-free decalcified dry mass samples of taxa with hard structures were processed to obtain estimates of ash free dry mass. Samples of known mass were placed in aluminum trays and burned in a muffle furnace at 500°C for 4 hours to volatize all organic material (Holme and McIntyre 1984). The weight of the remaining ash was subtracted from the shell free decalcified dry mass to obtain a value for the ash-free dry mass of the sample.

The relationship between length and wet mass was best explained by the power function $M = aL^b$ where M is wet mass in grams and L is length of the taxa-specific morphological trait used to estimate size in mm (Reed et al. 2016). Linear regression was performed on log transformed values of length and mass to estimate the slope (b) and intercept (a) for each taxon. The antilog of the intercept was calculated for use in the power function. Smearing estimates (Duan 1983) were calculated to correct for bias caused by back-transformation of logged parameters, which can result in an underestimate of the response variable (Smith 1993). Residuals from the log-log regression between length and mass for each taxon were tested for homoscedasticity using

White's General Test (SAS 9.4 Cary, NC, USA). A simple linear regression of the form M = bC was used to describe the relationship between percent cover (C) and wet mass (M). Examination of residuals and graphical inspection showed that percent cover data met the assumptions of linear regression for all taxa examined.

The relationship between percent cover and mass or individual size and mass were determined for 80 taxa of benthic invertebrates found at the 11 study sites (Reed et al. 2016).

**Fish Biomass Relationships:** We compiled literature-based relationships of the form $M = aL^b$ (Quast 1968b, DeMartini et al. 1987, Love et al. 1990, Love and Johnson 1999, Fishbase.org.) to convert total length (L) of kelp forest reef fishes to wet mass (M) for 52 fish species observed at the 11 SBC LTER study sites. In some cases, relationships were derived using an independent variable other than total length (e.g., standard length, disc diameter). In these cases, we documented the author's suggested conversion from total length to the appropriate independent variable.

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