Overview

The inability to quantitatively compare different measures of species abundance (such as density and percent cover) or different metrics of species biomass (such as wet mass and ash-free dry mass) hampers studies of community dynamics, trophic interactions, energy flow and biodiversity. 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 the conversion of abundance data into common metrics of biomass, we developed quantitative relationships between mass and length or mass and percent cover, and conversion factors for transforming wet mass into dry mass, shell free and decalcified dry mass, and ash-free dry mass for 103 taxa of benthic macroalgae and macroinvertebrates common to giant kelp 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 algae and invertebrates were derived using data and samples collected from 11 reefs (4 to 12 m depth) that are long-term study sites for the Santa Barbara Coastal Long-Term Ecological Research program (see http://sbc.lternet.edu/sites/sampling/ for detailed site descriptions) and were chosen to capture the taxonomic diversity in the region. Relationships for the invasive fucoid, *Sargassum hornerii*, were derived using data and tissue samples from Catalina Island, CA.

Algal Biomass Relationships

We related either percent cover or size to biomass for macroalgae of different sizes and morphologies. Relationships between percent cover and biomass were derived for the following crustose forms, low lying turfs and understory foliose algae: *Bossiella orbigniana, Callophyllis flabellulata, Chondracanthus corymbiferus, Corallina chilensis,* large *Cystoseira osmundacea* (defined as individuals of diameter > 10 cm)*, 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 over the course of a year at the study sites. Percent cover was estimated by divers 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. 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 in the tissue sample and percent nitrogen in 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*, *Eisenia arborea* and *Egregia menziesii*, the fucoids *Sargassum horneri* and *Sargassum muticum* and small individuals of the fucoid *Cystoseira osmundacea*. This allows measurements of individual size to be coupled with measures of abundance (e.g., density) to estimate the biomass of these species. For large individuals of *L. farlowii* (defined as having a blade width > 15 cm), *P. californica* (defined as having a stipe length $\geq$ 20 cm and a stipe diameter > 7 mm) and *E. arborea* (defined as having a stipe length $\geq$ 5 cm)*, S. horneri* and *S. muticum* (defined as having a frond length > 5 cm), and *E. menziesii* (defined as having at least 1 frond $\geq$ 1 m), biomass was estimated from allometric relationships developed using individuals collected in the field and measured and weighed in the laboratory. Dry mass of large *L. farlowii* was related to total blade length, dry mass of large *P. californica* and *E. arborea* was related to the total number of blades > 30 cm in length, dry mass of large *E. menziesii* was related to the total number of fronds $\geq$ 1 m in length, and dry mass of large *S. horneri* and *S. muticum* was related to total frond length. Smaller individuals of these species can be extremely abundant and mean size calculated from a subsample of individuals was used to estimate their biomass.

These relationships were derived for 23 taxa that accounted for more than 95% of the standing biomass of understory macroalgae averaged across all sampling locations from 2008 to 2018.

Invertebrate Biomass Relationships

The relationship between individual size and mass or aggregate percent cover and mass were determined for 80 taxa of benthic invertebrates found at study sites. 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 using SCUBA, brought back 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.

Converting data on numerical abundance (i.e. density) to biomass requires information on the relationship between individual size and mass. For solitary taxa, individual size was measured as the length of a morphological trait specific for that 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 for taxa whose abundance is recorded as density by the SBC LTER (n = 6 - 207 individuals per taxa). Percent cover is frequently used as a measure of abundance for many colonial taxa (e.g., hydrozoans, anthozoans, polychaetes). Developing non-destructive methods for estimating standing biomass for these taxa thus requires information on the relationship between percent cover and mass. To obtain this information, divers measured the percent cover of a taxa within 10 cm x 10 cm quadrats using a uniform grid of 20 points. After data on percent cover were 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 containing varying amounts of percent cover were sampled to generate sufficient data for determining the relationship between percent cover and biomass for remaining taxa (n = 9 - 40 quadrats per taxa).

Biomass can be reported using a variety of metrics. To facilitate interconversion among these various metrics we estimated body mass as wet mass, dry mass, shell free and 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 desiccate 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 shell-free dry mass (i.e. dried soft tissue only). 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. Linear regression was performed on log transformed values of length and mass to estimate the slope (b) and intercept (a) for each taxa. The antilog of the intercept was calculated for use in the power function. Smearing estimates (Duan 1983) were calculated to correct for biased 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.

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 of kelp forest reef fishes to wet mass (g) for 52 fish species observed at SBC LTER 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.

References

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