

## Kelp Forest Community Biomass Time Series Methods

*Overview.* Little information exists on the biomass dynamics of taxonomically complex communities of marine plants and animals inhabiting shallow reefs. To address this lack of information we estimated the biomass of benthic species of macroalgae, sessile and mobile macro invertebrates and fish in permanent plots on subtidal reefs off Santa Barbara, California by combining time series data of size-specific density or percent cover with taxon-specific relationships between biomass and size for solitary taxa and between biomass and percent cover for taxa that are difficult to distinguish as individuals.

*Study Sites.* The biomass of > 200 species of macroalgae, invertebrates and fish was estimated at five reefs as part of a long-term experiment designed to evaluate the effects of disturbance to giant kelp on the structure and productivity of the benthic community. The five reefs (Arroyo Quemado 34° 28.048'N, 120° 07.031'W; Carpinteria 34° 23.474'N, 119° 32.510'W; Isla Vista 34° 23.275'N, 119° 32.792'W; Mohawk 34° 23.649'N, 119° 43.762'W; and Naples 34° 25.342'N, 119° 57.102'W) ranged in depth from 5.8 m to 8.9 m (MLLW) and were chosen to represent a range of physical and biological characteristics known to influence subtidal macroalgal assemblages in the region. A common (but not always persistent) feature on these reefs was the presence of the giant kelp, which forms a dense canopy at the sea surface that suppresses recruitment and growth of understory algae below it.

Beginning in 2008, *M. pyrifera* was removed from a 2000 m<sup>2</sup> plot once per year in early winter at four reefs (Arroyo Quemado, Carpinteria, Mohawk and Naples) to simulate the effects of winter storm disturbance. An adjacent unmanipulated 2000 m<sup>2</sup> plot served as a control. Beginning in winter 2010, *M. pyrifera* was removed 1 to 2 times per season in a 600 m<sup>2</sup> area at each of these reefs to create a “continuous kelp removal” plot. In fall 2010 we established a fifth reef site at Isla Vista with 2000 m<sup>2</sup> annual kelp removal and kelp control plots (a 600 m<sup>2</sup> continuous kelp removal plot was not established at this site). The experimental removal of kelp ceased in winter 2016 or winter 2017 depending on the site (see Table 1). Data collection in all plots is ongoing.

Table 1: Establishment date and manipulation schedule at the five study reefs from 2008 - present.

Reef	Manipulation	First Sampling Date	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18 - present
Arroyo Quemado	Control	January 2008	Not manipulated										
	Annual removal in winter	January 2008	1 x per year in winter									Not manipulated	
	Seasonal removal within annual removal plot	May 2010	1 x per year in winter	2 x per season starting May 2010		1 x per season				Not manipulated			
Carpinteria	Control	January 2008	Not manipulated										

	Annual removal in winter	January 2008	1 x per year in winter			Not manipulated
	Seasonal removal within annual removal plot	May 2010	1 x per year in winter	2 x per season starting May 2010	1 x per season	Not manipulated
Isla Vista	Control	October 2011	Not Manipulated			
	Annual removal in winter	October 2011	Not manipulated	1 x per year in winter	Not manipulated	
Mohawk	Control	January 2008	Not manipulated			
	Annual removal in winter	January 2008	1 x per year in winter			Not manipulated
	Seasonal removal adjacent to annual removal plot	May 2010	Not manipulated	2 x per season starting May 2010	1 x per season	Not manipulated
Naples	Control	January 2008	Not manipulated			
	Annual removal in winter	January 2008	1 x per year in winter			Not manipulated
	Seasonal removal within annual removal plot	May 2010	1 x per year in winter	2 x per season starting May 2010	1 x per season	Not manipulated

*Abundance.* Divers surveyed the size-specific density or percent cover of benthic macroalgae, sessile and mobile macro invertebrates and fish (cover: <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=28> ; Quad and Swath: <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=34> ; kelp: <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=29> ; fish: <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=30> ) within permanent 40 m x 2 m sampling areas (hereafter referred to as transects) located in the center of each plot twice per season (approximately every six weeks) from January 2008 through December 2012 and once per season (approximately every 12 weeks) beginning in the winter of 2013.

#### *Biomass of Macroalgae.*

Time series data of the abundance of all understory species including small *M. pyrifera* (< 1 m in height) were converted to dry mass using -taxon-specific relationships with size-specific density or percent cover developed 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 (algae

biomass relationship data table in <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=127> ). The conversion of abundance to mass for less common taxa was done by proxy using the relationship generated for a morphologically similar species (Table 2).

Table 2. List of uncommon taxa of macroalgae recorded in permanent plots and the proxy species used to convert their abundance to biomass.

SP_CODE	GENUS	SPECIES	PROXY SP_CODE	Proxy GENUS	PROXY SPECIES
AMZO	<i>Amphiroa</i>	<i>zonata</i>	BO	<i>Bossiella</i>	<i>orbigniana</i>
ANPA	<i>Anisocladella</i>	<i>pacifica</i>	R	<i>Rhodymenia</i>	<i>californica</i>
AU	<i>Acrosorium</i>	<i>uncinatum</i>	CF	<i>Callophyllis</i>	<i>flabellulata</i>
BLD	Unidentified brown blade	spp.	MPJ	<i>Macrocystis</i>	<i>pyrifera</i> - < 1m in height
BRA	Branching Red Algae	spp.	R	<i>Rhodymenia</i>	<i>californica</i>
CAL	<i>Calliarthron</i>	<i>cheilosporioid</i>	BO	<i>Bossiella</i>	<i>orbigniana</i>
CG	<i>Cladophora</i>	<i>graminea</i>	RAT	Red Algal Turf	spp.
COF	Codium	<i>fragile</i>	GS	<i>Gracilaria</i>	spp.
CP	<i>Colpomenia</i>	spp.	POLA	<i>Polyneura</i>	<i>latissima</i>
CRYP	<i>Cryptopleura</i>	spp.	BF	<i>Cryptopleura</i>	<i>farlowianum</i>
CZ	<i>Chondracanthus</i>	<i>spinosa</i>	CC	<i>Chondracanthus</i>	spp.
DIAT	Diatom	Mat	EC	Encrusting	coralline
DU	<i>Dictyopteris</i>	<i>undulata</i>	DP	<i>Dictyota</i>	spp.
EC	Encrusting	coralline	EC	Encrusting	coralline
EGJ	<i>Egregia</i>	<i>menziesii</i>	MPJ	<i>Macrocystis</i>	<i>pyrifera</i> - < 1m in height
ER	Encrusting	red	EC	Encrusting	coralline
FASP	<i>Fauchea</i>	spp.	R	<i>Rhodymenia</i>	<i>californica</i>
FG	Filamentous green	spp.	FR	Filamentous red	spp.
FTHR	<i>Neoptilota Ptilota Rhodoptilum</i>	spp.	CF	<i>Callophyllis</i>	<i>flabellulata</i>
GEL	<i>Gelidium</i>	spp.	GS	<i>Gracilaria</i>	spp.
GR	<i>Gelidium</i>	<i>robustum</i>	GS	<i>Gracilaria</i>	spp.
GYSP	<i>Gymnogongrus</i>	spp.	R	<i>Rhodymenia</i>	<i>californica</i>
HAGL	<i>Halosaccion</i>	<i>glandiforme</i>	POLA	<i>Polyneura</i>	<i>latissima</i>
IR	<i>Iridaea</i>	spp.	CC	<i>Chondracanthus</i>	spp.
LI	<i>Lithothrix</i>	spp.	CO	<i>Corallina</i>	<i>officinalis</i>
LX	<i>Osmundea</i>	<i>spectabilis</i>	LS	<i>Laurencia</i>	spp.
NA	<i>Nienburgia</i>	<i>andersoniana</i>	CF	<i>Callophyllis</i>	<i>flabellulata</i>
NEO	<i>Neoagardhiella</i>	<i>baileyi</i>	GS	<i>Gracilaria</i>	spp.
PHSE	<i>Phycodrys</i>	<i>setchellii</i>	R	<i>Rhodymenia</i>	<i>californica</i>
PHTO	<i>Phyllospadix</i>	<i>torreyi</i>	DL	<i>Desmarestia</i>	<i>ligulata</i>
PL	<i>Prionitis</i>	<i>lanceolata</i>	CC	<i>Chondracanthus</i>	spp.
PRSP	<i>Prionitis</i>	spp.	CC	<i>Chondracanthus</i>	spp.
SAFU	<i>Sarcodiotheca</i>	<i>furcata</i>	CF	<i>Callophyllis</i>	<i>flabellulata</i>

SCCA	<i>Scinaia</i>	<i>confusa</i>	GS	<i>Gracilaria</i>	spp.
SELO	<i>Scytosiphon</i>	<i>lomentaria</i>	DP	<i>Dictyota</i>	spp.
STIN	<i>Stenogramme</i>	<i>interrupta</i>	R	<i>Rhodymenia</i>	<i>californica</i>
TALE	<i>Taonia</i>	<i>lennebackerae</i>	DP	<i>Dictyota</i>	spp.
UBB	Unidentified brown blade	spp.	BR	Blady red	spp.
UEC	Unidentified erect coralline	spp.	CO	<i>Corallina</i>	<i>officinalis</i>
UV	<i>Ulva</i>	spp.	DP	<i>Dictyota</i>	spp.
ZOMA	<i>Zostera</i>	<i>marina</i>	DL	<i>Desmarestia</i>	<i>ligulata</i>

Biomass was converted from de-calcified dry mass to units of wet mass and ash free dry mass for all taxa, using proxy taxa when necessary. Dry to wet mass and dry to ash free dry mass conversions are provided. These ratios did not highly vary among measured taxa and thus those proxy species are not presented here.

Divers also counted the density of *M. pyrifera* fronds  $\geq 1$  m in height in the 40 m x 2 m transects. The density of *M. pyrifera* fronds  $\geq 1$  m in height was converted to the biomass of giant kelp by applying month-specific relationships between frond density (no. m<sup>-2</sup>) and dry mass density (dry kg m<sup>-2</sup>) developed by Rassweiler et al. (2018). These relationships allowed us to use our measurements of frond density to estimate total standing biomass of giant kelp in any given month, as well as the individual components of *M. pyrifera* standing biomass, namely: (1) the mass of the surface canopy, (2) the mass of the water column portion of fronds that form a surface canopy, and (3) the mass of young subsurface fronds that have not yet reached the sea surface. The latter is important because the standing biomass *M. pyrifera* consisted entirely of subsurface fronds for at least three months following its removal from our experimental plots. Thus, during the three months following experimental kelp removal we used month-specific relationships between frond density and the mass of subsurface fronds to convert *M. pyrifera* frond density to standing biomass in our experimental kelp removal plots. In all other cases, we assumed a natural distribution of frond sizes in our plots and we estimated *M. pyrifera* biomass using month specific relationships between frond density and total standing biomass.

#### *Biomass of Invertebrates.*

Time series data of the abundance of macroinvertebrate species were converted to shell free or decalcified dry mass using taxon-specific relationships with size-specific density or percent cover developed for the 78 most common taxon (invertebrate biomass relationship data table in <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=127> ). The conversion of abundance to mass for less common invertebrate taxa was done by proxy using the relationship generated for a morphologically similar species Table 3.

Table 3. List of uncommon taxa of benthic invertebrates recorded in permanent plots and the proxy species used to convert their abundance to biomass.

SP_CODE	GENUS	SPECIES	PROXY SP_CODE	PROXY GENUS	PROXY SPECIES
ANSP	<i>Anthopleura</i>	spp.	URLO	<i>Urticina</i>	<i>lofotensis</i>
APVA	<i>Aplysia</i>	<i>vaccaria</i>	APCA	<i>Aplysia</i>	<i>californica</i>

ARUD	<i>Discophyton</i>	<i>rudyi</i>	PLUM	<i>Plumularia</i>	sp.
BOW	<i>Amathia</i>	<i>gracilis</i>	TC	<i>Thalamoporella</i>	<i>californica</i>
BRSP	<i>Barentsia</i>	sp.	TC	<i>Thalamoporella</i>	<i>californica</i>
CECO	<i>Centrostephanus</i>	<i>coronatus</i>	SFL	<i>Sebastes</i>	<i>flavidus</i>
COST	<i>Celleporina</i>	<i>robertsoniae</i>	DC	<i>Diaperoforma</i>	<i>californica</i>
CROC	<i>Crisia</i>	<i>occidentalis</i>	TC	<i>Thalamoporella</i>	<i>californica</i>
CUPI	<i>Cucumaria</i>	<i>piperata</i>	LINU	<i>Lissothuria</i>	<i>nutriens</i>
ECB	<i>Bryozoa</i>	spp.	CESP	<i>Cellaria</i>	sp.
HACO	<i>Haliotis</i>	<i>corrugata</i>	HARU	<i>Haliotis</i>	<i>rufescens</i>
HACR	<i>Haliotis</i>	<i>cracherodii</i>	HARU	<i>Haliotis</i>	<i>rufescens</i>
HADE	<i>Halcampa</i>	<i>decemtentaculata</i>	HARU	<i>Haliotis</i>	<i>rufescens</i>
HAKA	<i>Haliotis</i>	<i>kamtschatkana</i>	HARU	<i>Haliotis</i>	<i>rufescens</i>
HC	<i>Acanthancora</i>	<i>cyanocrypta</i>	ES	<i>Demospongiae</i>	spp.
HIP	<i>Primavelans</i>	<i>mexicana</i>	DC	<i>Diaperoforma</i>	<i>californica</i>
HPAC	<i>Heteropora</i>	<i>pacifica</i>	DC	<i>Diaperoforma</i>	<i>californica</i>
LIGS	<i>Lithopoma</i>	spp.	LIGL	<i>Lithopoma</i>	spp.
MISE	<i>Metridium</i>	<i>dianthus</i>	CY	<i>Corynactis</i>	<i>californica</i>
MT	<i>Jellyella</i>	<i>tuberculata</i>	CESP	<i>Cellaria</i>	sp.
MUFR	<i>Muricea</i>	<i>fruticosa</i>	MUCA	<i>Muricea</i>	<i>californica</i>
OBSP	<i>Obelia</i>	sp.	PLUM	<i>Plumularia</i>	sp.
OKL	<i>Orthasterias</i>	<i>koehleri</i>	PGL	<i>Pisaster</i>	<i>giganteus</i>
PHOR	<i>Phoronida</i>	spp.	SABW	<i>Sabellidae</i>	spp.
PHSP	<i>Phyllactis</i>	spp.	CY	<i>Corynactis</i>	<i>californica</i>
PIEL	<i>Pista</i>	<i>elongata</i>	SABW	<i>Sabellidae</i>	spp.
PLAB	<i>Phidolopora</i>	<i>labiata</i>	DC	<i>Diaperoforma</i>	<i>californica</i>
SC	<i>Sphaciospongia</i>	<i>confoederata</i>	ES	<i>Demospongiae</i>	spp.
UAB	<i>Bryozoa</i>	spp.	TC	<i>Thalamoporella</i>	<i>californica</i>
UM	<i>Arthropoda</i>	spp.	ATM	<i>Amphipoda</i>	spp.
URPI	<i>Urticina</i>	<i>piscivora</i>	URLO	<i>Urticina</i>	<i>lofotensis</i>
WASP	<i>Phidolopora</i>	<i>labiata</i>	DC	<i>Diaperoforma</i>	<i>californica</i>

### *Biomass of Reef Fish.*

Time series data of the abundance and size of reef fish (i.e., those observed within 2m of the benthos) was converted to wet mass (g) using species-specific relationships obtained from the literature (fish biomass relationship data table in <https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=127> ). For some species, relationships were derived for standard length to mass. In these cases, we used information provided from the author to convert measurements of total length to standard length prior to estimating wet mass. The wet mass of bony fishes was converted to de-boned dry mass (g) and ash free dry mass (g) using the average of conversion ratios for all reef fish provided in Taylor (1997). Wet mass of cartilaginous fishes was converted to dry biomass (g) using the conversion factor of Thorson 1976. No information was found to convert wet mass to ash free dry mass for cartilaginous fishes. Published relationships were not available for every fish

species encountered on SBC LTER reefs. Therefore we estimated the biomass of these species by proxy using the relationship published for a morphologically similar species (Table 4).

Table 4. List of reef fish recorded in permanent plots lack a published relationship between size and mass and the proxy species used to convert their abundance to biomass

SP_CODE	GENUS	SPECIES	PROXY SP_CODE	PROXY GENUS	PROXY SPECIES
AHOL	<i>Alloclinus</i>	<i>holderi</i>	CLIN	<i>Gibbonsia</i>	sp.
BOTH	<i>Bothid</i>	spp.	PCAL	<i>Paralichthys</i>	<i>californicus</i>
CAGG	<i>Cymatogaster</i>	<i>aggregata</i>	EJAC	<i>Embiotoca</i>	<i>jacksoni</i>
COTT	<i>Cottidae</i>	spp.	CNIC	<i>Rhinogobiops</i>	<i>nicholsii</i>
CSTI	<i>Citharichthys</i>	<i>stigmaeus</i>	PCAL	<i>Paralichthys</i>	<i>californicus</i>
CVEN	<i>Cephaloscyllium</i>	<i>ventriosum</i>	HEFR	<i>Heterodontus</i>	<i>francisci</i>
ELAT	<i>Embiotoca</i>	<i>lateralis</i>	EJAC	<i>Embiotoca</i>	<i>jacksoni</i>
EMBI	<i>Embiotoca</i>	spp.	EJAC	<i>Embiotoca</i>	<i>jacksoni</i>
HARG	<i>Hyperprosopon</i>	<i>argenteum</i>	EJAC	<i>Embiotoca</i>	<i>jacksoni</i>
LHIR	<i>Leiocottus</i>	<i>hirundo</i>	OPIC	<i>Oxylebius</i>	<i>pictus</i>
NBLA	<i>Neoclinus</i>	<i>blanchardi</i>	CNIC	<i>Rhinogobiops</i>	<i>nicholsii</i>
SCAL	<i>Squatina</i>	<i>californica</i>	RPRO	<i>Pseudobatos</i>	<i>productus</i>
SCHR	<i>Sebastes</i>	<i>chrysomelas</i>	SAUR	<i>Sebastes</i>	<i>auriculatus</i>
SCSP	<i>Sebastes</i>	spp.	SCAR	<i>Sebastes</i>	<i>carnatus</i>
STRE	<i>Sebastes</i>	<i>serriceps</i>	SCAR	<i>Sebastes</i>	<i>carnatus</i>
XCAL	<i>Haemulon</i>	<i>californiensis</i>	DVAC	<i>Rhacochilus</i>	<i>vacca</i>

## References

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