Kelp Forest Community Biomass Time Series Methods

Overview: These data are part of a larger collection of datasets associated with a long-term experiment designed to examine trajectories of change in the structure and ecological function of kelp forest communities in response to changes in the frequency and severity of disturbance to giant kelp. The experiment was motivated by previous findings demonstrating the important foundational role of giant kelp in structuring subtidal reefs and its high susceptibility to being removed by winter wave disturbance, which has been predicted to increase in frequency and severity due to ongoing anthropogenic climate change. The disturbance manipulations in this experiment included: (1) removing giant kelp from permanent plots once annually in winter to simulate increases in the frequency and severity of winter wave disturbance, and (2) removing giant kelp 1-2 times per season in permanent plots to examine the ecological consequences of the continuous loss of giant kelp from this system. The experiment was replicated at five reef sites in the Santa Barbara Channel and data for a variety of biological and physical variables associated with the experiment were collected from 2008-2023.

Study Sites: Time series data of reef biota (i.e., algae, invertebrates and fish), detrital accumulation, substrate type and topography, and surface and seafloor irradiance were collected at five reefs as part of a long-term experiment designed to evaluate the effects of disturbance to giant kelp (*Macrocystis pyrifera*) on the structure and productivity of the kelp forest community of algae, invertebrates and fishes. The five reefs (Arroyo Quemado 34^{0} 28.048'N, 120^{0} 07.031'W; Carpinteria 34^{0} 23.474'N, 119^{0} 32.510'W; Isla Vista 34^{0} 23.275'N, 119^{0} 32.792'W; Mohawk 34^{0} 23.649'N, 119^{0} 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 the structure and productivity of subtidal reef communities in the region. A ubiquitous (but not always persistent) feature on these reefs was the presence of giant kelp, which forms a dense canopy at the sea surface that alters the biomass, diversity and temporal stability of reef biota (Castorani et al. 2018, Miller et al. 2018, Lamy et al. 2020).

Beginning in 2008, giant kelp was removed once per year in winter from a 40 m x 50 m plot at three reefs (Arroyo Quemado, Carpinteria, and Naples) and a 30 m x 50 m plot at one reef (Mohawk) to simulate the effects of winter storm disturbance (referred to as "annual removal" treatment). An adjacent unmanipulated 40 m x 50 m plot at each site served as a control. Beginning in winter 2010, giant kelp was removed 1 to 2 times each season in a 10 m x 50 m area within (or in the case of Mohawk adjacent to) each of the annual removal plots to create a "continual removal" treatment. In fall 2011, a fifth site was established at Isla Vista with paired 40 m x 50 m annual removal and control plots (a 50 m x 10 m continual removal treatment was not established at this site). The reef community of algae (including giant kelp), invertebrates and fish were surveyed in annual removal and continual removal plots prior to each experimental removal of giant kelp. Thus, data collected on the date following the first kelp removal represents the first sampling period of the annual and continual removal treatments. The last experimental removals of giant kelp occurred in winter 2016 or winter 2017, depending on the site. The last sampling of reef communities under experimental conditions for annual and continual kelp removal treatments occurred ~12 months following the last kelp removal.

Control, annual removal, and continuous removal plots continued to be sampled seasonally through spring 2023 to document the recovery of the reef community in the absence of experimental kelp removal. Dates of the initiation and cessation of kelp removal in the experimental plots are provided in Table 1.

Table 1: Dates (format yyyy/mm/dd) of the first and last experimental kelp removal for the annual and continual giant kelp removal treatments at the five reef sites.

Reef	Treatment	Date of First Removal	Date of Last Removal
Arroyo Quemado	Annual	2008/01/30	2017/03/02
	Continual	2010/02/04	2017/03/02
Carpinteria	Annual	2008/02/12	2017/02/15
	Continual	2010/01/29	2017/02/15
Isla Vista	Annual	2011/10/26	2016/02/18
Mohawk	Annual	2008/01/17	2017/02/13
	Continual	2010/05/05	2017/02/13
Naples	Annual	2008/01/10	2016/02/09
	Continual	2010/01/28	2016/02/09

Abundance

Species specific estimates of biomass of benthic macroalgae, sessile and mobile macro invertebrates and fish were derived from abundance data on size-specific density or percent cover collected by divers within permanent 40 m x 2 m plots (hereafter referred to as transects) at each site. The abundance data and a description of the methods used to collect them can be found at:

1.cover of algae and sessile invertebrates:
https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=28 ;

2.size specific density of algae and invertebrates:
https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=34 ;

3.giant kelp:
https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=29 ;

4. fish:
https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=30

The surveys were conducted 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. Occasionally data were lost or not collected for a particular taxon. In these cases, all metrics of abundance and biomass were assigned a value = -99999.

Biomass of Macroalgae

Time series data of the abundance of all understory species including small *Macrocystis 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 de-calcified dry mass for less common taxa was done by proxy using the relationship generated for a morphologically similar species (Table 2). Biomass for the seagrasses *Phyllospadix torreyi* and Zostera marina were converted from de-calcified dry to wet using the relationship of Wickham et al. 2018 and from de-calcified dry to carbon, nitrogen, and ash-free dry using the relationships of Van Lent et al. 1991.

Biomass was converted from de-calcified dry mass to units of wet mass and ash free dry mass using ratios developed from tissue samples collected for common taxa. Wet mass and ash free dry mass of less common taxa were calculated using conversions for proxy taxa, when necessary. Decalcified dry to wet mass, decalcified dry to ash free dry mass, decalcified dry to carbon mass, and decalcified dry to nitrogen mass conversions are provided in: https://portal.edirepository.org/nis/mapbrowse?scope=knb-lter-sbc&identifier=127. Proxy species for these measures are presented in Table 2.

Table 2: SBC algal species list and the species code of the taxa used to: (1) estimate de-calcified dry mass (BMASS_PROXY) from size specific density or percent cover, and (2) convert de-calcified dry mass to wet mass, C mass or N mass (WET_C_N_PROXY) and ash free dry mass (AFD_PROXY).

SP_CODE	GENUS	SPECIES	BMASS_PROXY	WET_CN_PROXY	AFD_PROXY
AMZO	*Amphiroa*	*zonata*	BO	BO	CF
ANPA	*Anisocladella*	*pacifica*	R	R	R
AU	*Acrosorium*	*uncinatum*	CF	BF	BF
BF	*Cryptopleura*	*farlowianum*	BF	BF	BF
BLD	Unidentified juvenile kelp	spp.	MPJ	PTCA	PTCA
BO	*Bossiella*	*orbigniana*	BO	BO	CF
BPSE	*Botryocladia*	*pseudodichotoma*	POLA	R	R

SP_CODE	GENUS	SPECIES	BMASS_PROXY	WET_CN_PROXY	AFD_PROXY
BR	Blady red	spp.	BR	CC	POLA
BRA	Branching Red Algae	spp.	R	R	R
CAL	*Calliarthron*	*cheilosporioid*	BO	CO	CF
CC	*Chondracanthus*	spp.	CC	CC	BF
CF	*Callophyllis*	*flabellulata*	CF	CF	CF
CG	*Cladophora*	*graminea*	RAT	RAT	RAT
CO	*Corallina*	*officinalis*	CO	CO	RAT
COF	*Codium*	*fragile*	GS	GS	GS
CP	*Colpomenia*	spp.	POLA	POLA	POLA
CRYP	*Cryptopleura*	spp.	BF	BF	BF
CYJ	*Stephanocystis*	*osmundaceae* - juvenile	CYJ	CYOS	CYOS
CYOS	*Stephanocystis*	*osmundaceae* - adult	CYOS	CYOS	CYOS
CYOS_R	*Stephanocystis*	*osmundaceae* - reproductive frond	CYOS_R	CYOS	CYOS
CZ	*Chondracanthus*	*spinosa*	CC	CC	GS
DIAT	Diatom	Mat	EC	FB	FB
DL	*Desmarestia*	*ligulata*	DL	DL	DL
DP	*Dictyota*	spp.	DP	DP	DP
DU	*Dictyopteris*	*undulata*	DP	DP	DP
EA	*Eisenia*	*arborea* - adult	EA	PTCA	PTCA
EAJ	*Eisenia*	*arborea* - juvenile	EAJ	PTCA	PTCA
EC	Encrusting	*coralline*	EC	CO	CF
EGJ	*Egregia*	*menziesii* - juvenile	MPJ33	PTCA	PTCA
EGME	*Egregia*	*menziesii* - adult	EGME	PTCA	PTCA
ER	Encrusting	red	EC	CO	CF
FASP	*Fauchea*	spp.	R	R	R
FB	Filamentous brown	spp.	FB	DL	FB
FG	Filamentous green	spp.	FR	DL	FB
FR	Filamentous red	spp.	FR	RAT	RAT
FTHR	*Neoptilota Ptilota Rhodoptilum*	spp.	CF	RAT	RAT

SP_CODE	GENUS	SPECIES	BMASS_PROXY	WET_CN_PROXY	AFD_PROXY
GEL	*Gelidium*	spp.	GS	GS	R
GR	*Gelidium*	*robustum*	GS	GS	GS
GS	*Gracilaria*	spp.	GS	GS	GS
GYSP	*Gymnogongrus*	spp.	R	GYSP	GS
HAGL	*Halosaccion*	*glandiforme*	POLA	R	R
IR	*Iridaea*	spp.	CC	CC	BF
LAFA	*Laminaria*	*farlowii* - adult	LAFA	LAFA	LAFA
LFJ	*Laminaria*	*farlowii* - juvenile	LFJ	LAFA	LAFA
LI	*Lithothrix*	spp.	CO	CO	CF
LS	*Laurencia*	spp.	LS	RAT	LS
LX	*Osmundea*	*spectabilis*	LS	RAT	LS
MAPY	*Macrocystis*	*pyrifera* - adult	MAPY	MAPY	MAPY
MPJ	*Macrocystis*	*pyrifera* - juvenile	MAPY	MAPY	MAPY
NA	*Nienburgia*	*andersoniana*	CF	BF	BF
NEO	*Neoagardhiella*	*baileyi*	GS	GS	GS
PHSE	*Phycodrys*	*setchellii*	R	BF	BF
PHTO	*Phyllospadix*	*torreyi*	DL	ZOMA	ZOMA
PL	*Prionitis*	*lanceolata*	CC	GYSP	R
POLA	*Polyneura*	*latissima*	POLA	POLA	POLA
PRSP	*Prionitis*	spp.	CC	GYSP	R
PTCA	*Pterygophora*	*californica*	PTCA	PTCA	PTCA
PTJ	*Pterygophora*	*californica* - juvenile	PTJ	PTCA	PTCA
PTL	*Pterygophora*	*californica* - subadult	PTL	PTCA	PTCA
R	*Rhodymenia*	*californica*	R	R	R
RAT	Red Algal Turf	spp.	RAT	RAT	RAT
SAFU	*Sarcodiotheca*	*furcata*	CF	CF	CF
SAGA	*Sarcodiotheca*	*gauchaudii*	SAGA	SAGA	GS
SAHO	*Sargassum*	*hornerii - adult*	SHJ	SHJ	CYOS
SAMU	*Sargassum*	*muticum*	SAMU	PTCA	CYOS
SCCA	*Scinaia*	*confusa*	GS	GS	GS
SELO	*Scytosiphon*	*lomentaria*	DP	DL	DL
SHJ	*Sargassum*	*horneri* -juvenile	SHJ	PTCA	CYOS
SMJ	*Sargassum*	*muticum*	SMJ	PTCA	CYOS
STIN	*Stenogramme*	*interrupta*	R	R	R
TALE	*Taonia*	*lennebackerae*	DP	DL	DP
UBB	Unidentified brown blade	spp.	BR	CYOS	CYOS

SP_CODE	GENUS	SPECIES	BMASS_PROXY	WET_CN_PROXY	AFD_PROXY
UEC	Unidentified erect coralline	spp.	CO	CO	CF
UV	*Ulva*	spp.	DP	DL	DL
ZOMA	*Zostera*	*marina*	DL	ZOMA	ZOMA

Divers also counted the density of *M. pyrifera* fronds ≥ 1 m in height in the 40 m x 2 m transects. The density of *M. pyrifera* fronds ≥ 1 m in height was converted to the biomass of giant kelp by applying month-specific relationships between frond density (no. m^{-2}) and dry mass density (dry kg m^{-2}) 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	*Anthopleura*	spp.	URLO	*Urticina*	*lofotensis*
APVA	*Aplysia*	*vaccaria*	APCA	*Aplysia*	californica
ARUD	*Discophyton*	*rudyi*	PLUM	*Plumularia*	sp.
BOW	*Amathia*	*gracilis*	TC	*Thalamoporella*	*californica*
BRSP	*Barentsia*	sp.	TC	*Thalamoporella*	*californica*

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

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). *Note, the accuracy of sampling fish may vary with water clarity and data collected during sampling events when horizontal visibility was < 2 m should be used with caution*.

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

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