

Density of algae and invertebrates

Overview: One potential manifestation of climate change is an increase in the frequency of severe storms. Such changes are likely to have profound effects on giant kelp forest ecosystems because storms are a major source of disturbance that removes kelp and other biota. An increase in the frequency of severe storms would likely result in large losses of giant kelp every winter. Giant kelp is the foundation species of the ecosystem and our long-term monitoring shows that the dynamics of the benthic community of understory algae and sessile invertebrates are directly linked to the dynamics of giant kelp (Arkema et al. 2009. Ecology 90: 3126–3137).

Study Sites: Time series data of reef biota (i.e., algae, invertebrates and fish) and 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 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 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 from a 2000 m² plot once per year in winter at four reefs (Arroyo Quemado, Carpinteria, Mohawk and Naples) to simulate the effects of winter storm disturbance (referred to as “annual removal” treatment). An adjacent unmanipulated 2000 m² plot served as a control. Beginning in winter 2010, giant kelp was removed 1 to 2 times per season within a 600 m² 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 2000 m² annual removal and control plots (a 600 m² 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 continue to be sampled seasonally 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, in the format yyyy/mm/dd, of the first and last 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

Methods: The abundance and size of a specified number of common species of invertebrates, algae are sampled by divers in 1 m² quadrats positioned at each of the six permanent bolts along each transect (Figure 1). The list of species and size categorizes sampled in the quadrats is shown in Table 1. Sampling entails thoroughly searching the area within each quadrat for the targeted species without disrupting the bottom substrate or displacing organisms.

The abundance and average size of a select group of larger common algae and mobile invertebrates that are not easily counted in a 1 m² quadrats are counted in four contiguous 20 m x 1m swaths that run parallel and adjacent to the 40 m transect (Figure 2). The average size of each targeted species encountered is estimated for each 20 m x 1 m swath. The list of species and size categorizes sampled in the swaths is shown in Table 2. Sampling entails thoroughly searching the area within each swath for the targeted species without disrupting the bottom substrate or displacing organisms.

Figure 1. Schematic diagram showing the positioning of the 1 m² quadrats along the 40 m transect. Quadrats at 0 m, 16 m, and 32 m are positioned on the offshore side of the transect and quadrats at 8 m, 24 m and 40 m are positioned on the onshore side of the transect

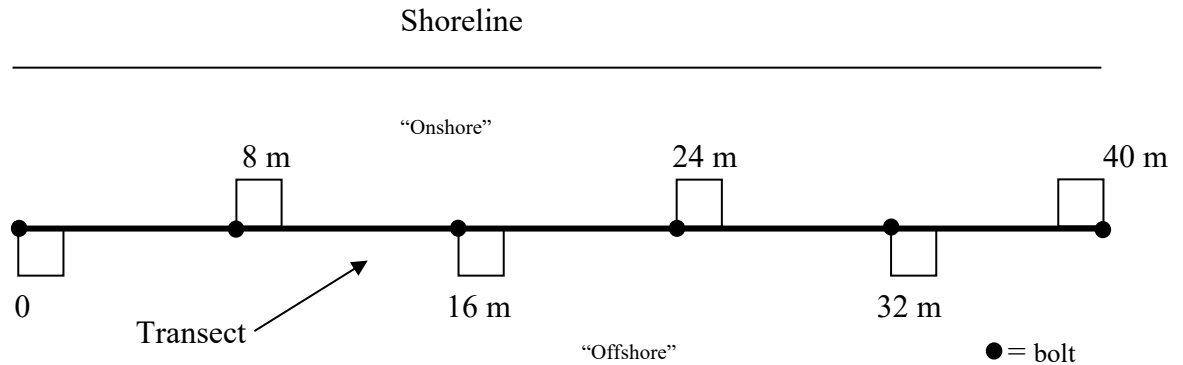


Table 1. List of species sampled in 1 m² quadrats

SP_CODE	GENUS	SPECIES	SIZE MEASUREMENT	COMMON_NAME
AMS	<i>Asterina</i>	<i>miniata</i>		Bat Star (<25mm)
ANSP	<i>Anthopleura</i>	<i>spp.</i>	.	.
BAEL	<i>Balanophyllia</i>	<i>elegans</i>	.	Orange Cup Coral
BLD		.	.	Blade stage of unidentified juvenile kelp
CHOV	<i>Chaceia</i>	<i>ovoidea</i>	.	Wart Necked Piddock
*COCA	<i>Conus</i>	<i>californicus</i>	length	California Cone Snail
CUSA	<i>Cucumaria</i>	<i>salma</i>	.	.
CYJ	<i>Cystoseira</i>	<i>osmundaceae</i>		Bladder chain juvenile (< 5 cm diameter)
*CYSP	<i>Cypraea</i>	<i>spadicea</i>	length	Chestnut cowry
DIOR	<i>Diopatra</i>	<i>ornata</i>	.	Ornate tube worm
DIS	<i>Dermasterias</i>	<i>imbricata</i>		Leather star juvenile(<25mm)
EAJ	<i>Eisenia</i>	<i>arborea</i>		Southern sea palm juvenile (<5 cm stipe length).
EGJ	<i>Egregia</i>	<i>menziesii</i>		Feather boa kelp juvenile (<1m height)
*EUPO	<i>Eudistylia</i>	<i>polymorpha</i>	tube diameter	Feather duster worm
*EUQU	<i>Eupentacta</i>	<i>quinquesemita</i>	length	White sea cucumber
*LA	<i>Lytechinus</i>	<i>anamesus</i>	test diameter	White urchin
LFJ	<i>Laminaria</i>	<i>farlowii</i>		Oar weed juvenile (<15cm blade width).
LIGS	<i>Lithopoma</i>	<i>spp.</i>		Wavy turbin snail juvenile (<9cm diameter)
*MIID	<i>Mitra</i>	<i>idae</i>	length	Ida's mitre
MPJ	<i>Macrocystis</i>	<i>pyrifera</i>	0-33 cm, 34-66 cm,	Giant kelp juvenile (<1m

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Last Modified: 8/24/2020

			or 67-99 cm size categories	height)
*NONO	<i>Norrisia</i>	<i>norrisi</i>	length	Norris's top snail
OKS	<i>Orthasterias</i>	<i>koehleri</i>		Rainbow star juvenile (<25mm)
*OPES	<i>Ophioplocus</i>	<i>esmarki</i>	disc diameter	Smooth brittle star
*OPSP	<i>Ophiothrix</i>	<i>spiculata</i>	arm length (>2.5cm)	Spiny brittle star
PACA	<i>Parapholas</i>	<i>californica</i>	.	Scaleside piddock
*PAFI	<i>Pachycerianthus</i>	<i>fimbratus</i>	diameter	Tube dwelling anemone
PAST	<i>Paracyathus</i>	<i>stearnsi</i>	.	Brown cup coral
PBS	<i>Pisaster</i>	<i>brevispinus</i>		Short spined sea star juvenile (<25mm)
PGS	<i>Pisaster</i>	<i>giganteus</i>		Giant spined sea star juvenile (<25mm)
PHS	<i>Pycnopodia</i>	<i>helianthoides</i>		Sunflower sea star juvenile (<25mm)
*POPL	<i>Polyclinum</i>	<i>planum</i>	length	Elephant ear tunicate
POS	<i>Pisaster</i>	<i>ochraceus</i>		Ochre's sea star juvenile (<25mm)
PRUB	<i>Pachythyone</i>	<i>rubra</i>	.	.
PTJ	<i>Pterygophora</i>	<i>californica</i>		Stalked kelp juvenile (<20 cm stipe length)
*PTTR	<i>Pteropurpura</i>	<i>trialata</i>	length	Three-winged murex
*SFL	<i>Strongylocentrotus</i>	<i>franciscanus</i>		Red urchin adult (>25mm)
SFS	<i>Strongylocentrotus</i>	<i>franciscanus</i>		Red urchin juvenile (<25mm)
SKE	<i>Small Kelletia</i>	.	.	Kellet's welk
*SPL	<i>Strongylocentrotus</i>	<i>purpuratus</i>		Purple urchin adult (>25mm)
SPS	<i>Strongylocentrotus</i>	<i>purpuratus</i>		Purple urchin juvenile (<25mm)
STMO	<i>Stylela</i>	<i>montereyensis</i>	siphon diameter	Stalked tunicate
*TEAU	<i>Tethya</i>	<i>aurantia</i>	diameter	Orange puffball sponge
*TESP	<i>Tegula</i>	<i>spp.</i>	length	Turbin snail
URLO	<i>Urticina</i>	<i>lofotensis</i>	.	White-spotted rose anemone
URPI	<i>Urticina</i>	<i>piscivora</i>	.	Fish eating anemone

*denotes an estimate of mean size is recorded

Figure 2. Schematic diagram showing the position of the four 20 m x 1 m swaths relative to the 40 m transect.

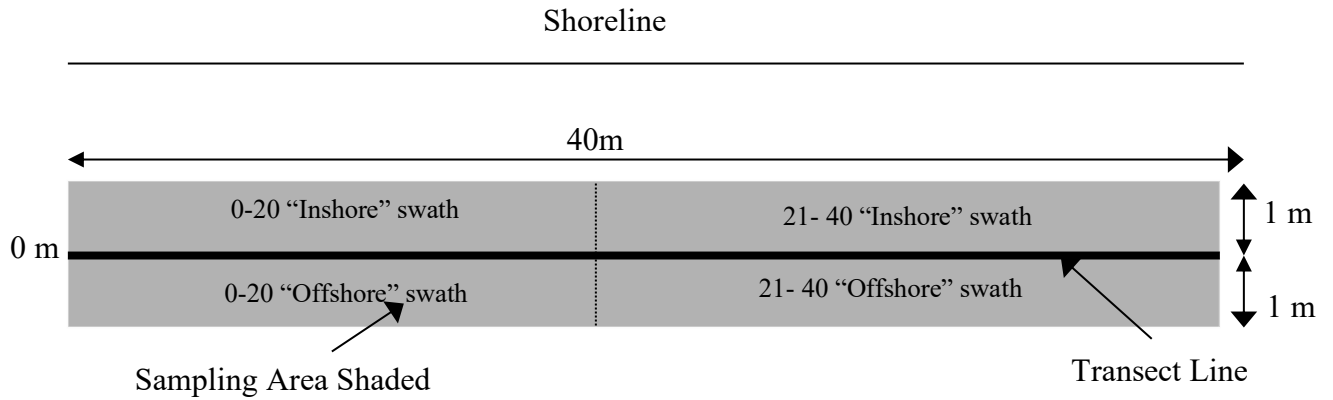


Table 2. List of species sampled in 20m x 1m swaths

SP_CODE	GENUS	SPECIES	SIZE	COMMON_NAME
*AML	<i>Asterina</i>	<i>miniata</i>	diameter	Bat star adult(> 25 mm)
*APCA	<i>Aplysia</i>	<i>californica</i>	agitated length	Sea hare
*APVA	<i>Aplysia</i>	<i>vaccaria</i>	agitated length	Spotted sea hare
*CASP	<i>Cancer</i>	spp.	carapace width	Cancer crab
*CRGI	<i>Crassadoma</i>	<i>gigantea</i>	diameter	Giant scallop
*CUKE	<i>Parastichopus</i>	<i>californicus</i>	agitated length	California cucumber
CYOS	<i>Cystoseira</i>	<i>osmundaceae</i>		Bladder chain adult (> 5 cm height)
*DIL	<i>Dermasterias</i>	<i>imbricata</i>	diameter	Leather star adult (> 25 mm)
*EA	<i>Eisenia</i>	<i>arborea</i>	number of blades >30cm	Southern sea palm adult (>5 cm stipe length)
*EGME	<i>Egregia</i>	<i>menziesii</i>	fronds > 1m tall	Feather boa kelp adult (>1m height)
*HACO	<i>Haliotis</i>	<i>corrugata</i>	length	Pink abalone
*HACR	<i>Haliotis</i>	<i>cracherodii</i>	length	Black abalone
*HAKA	<i>Haliotis</i>	<i>kamtschatkana</i>	length	Pinto abalone
*HARU	<i>Haliotis</i>	<i>rufescens</i>	length	Red abalone
*KEKE	<i>Kelletia</i>	<i>kelletii</i>	length	Kellet's welk
*LAFA	<i>Laminaria</i>	<i>farlowii</i>	length	Oar weed adult (>15cm blade width)
*LIGL	<i>Lithopoma</i>	spp.	diameter	Wavy turbin snail adult (> 25 mm)
*LOCH	<i>Lophogorgia</i>	<i>chilensis</i>	width	Red gorgonian
*LOGR	<i>Loxorhynchus</i>	<i>grandis</i>	carapace width	Sheep crab
*MECR	<i>Megathura</i>	<i>crenulata</i>	length	Giant key hole limpet
*MUCA	<i>Muricea</i>	<i>californica</i>	width	California golden gorgonian
*MUFR	<i>Muricea</i>	<i>fruticosa</i>	width	Brown gorgonian
*OCTO	<i>Octopus</i>	spp.	greatest arm length	Octopus
*OKL	<i>Orthasterias</i>	<i>koehleri</i>	diameter	Rainbow star adult (> 25 mm)
*PAIN	<i>Panulirus</i>	<i>interruptus</i>	carapace length	California spiny lobster
*PAPA	<i>Parastichopus</i>	<i>parvimensis</i>	agitated length	Warty sea cucumber
*PBL	<i>Pisaster</i>	<i>brevispinus</i>	diameter	Short spined sea star adult (> 25 mm)
*PGL	<i>Pisaster</i>	<i>giganteus</i>	diameter	Giant sea adult (> 25 mm)
*PHL	<i>Pycnopodia</i>	<i>helianthoides</i>	diameter	Sun star adult (> 25 mm)
*POL	<i>Pisaster</i>	<i>ochraceus</i>	diameter	Ochre sea star adult (>

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Last Modified: 8/24/2020

				25 mm)
*PTCA	<i>Pterygophora</i>	<i>californica</i>	number of blades >30cm	Stalked kelp adult (>20 cm stipe length)
*PUPR	<i>Pugettia</i>	<i>producta</i>	carapace width	Kelp crab
* denotes an estimate of the mean size is recorded				