Annual time series of biomass for kelp forest species

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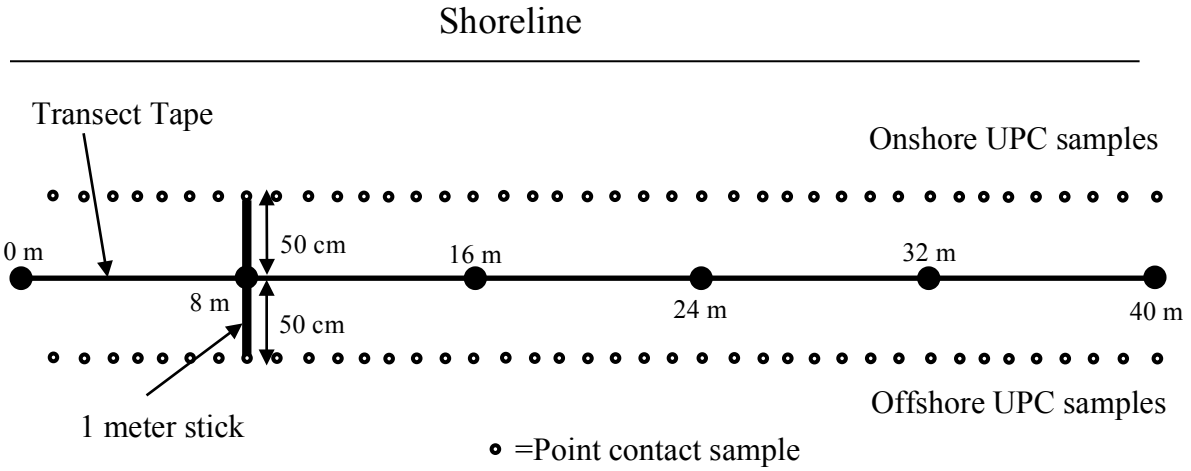
Overview: One of the main strengths of the long term ecological research program is that it allows us to evaluate changes in the ecological community against the background of natural long-term variability. This long-term context is particularly important when we seek to distinguish between changes caused by natural processes and those caused by human activities. SBC LTER has undertaken long-term measurements of the abundance of reef algae, invertebrates and fish within permanent transects at 11 kelp forest sites in the Santa Barbara Channel that have been converted to estimates of biomass. These data represent one of the core research activities of SBC LTER and they provide a comprehensive description of community structure and dynamics of kelp forest communities within our study region.

Experimental design: Time-series data on the abundance of ~250 species of algae, invertebrates and fish are collected each summer on replicate 40m x 2m permanent transects (n = 2 to 8 transects per site) at 9 mainland and 2 Santa Cruz Island reefs that have historically supported giant kelp forests. Data collection began in the summer of 2000 and continues annually in summer to provide information on community structure, population dynamics and species change.

Methods: The percent cover of algae and sessile invertebrates and the size specific density of common invertebrates, alga and reef fish are recorded along each transect. These field measurements of abundance are converted to estimates of biomass to facilitate comparisons among diverse groups. Detailed methods are provided below.

Percent cover of algae and sessile invertebrates: Percentage cover of algae and sessile invertebrates is determined by Uniform Point Contact (UPC) sampling. UPC data are collected at 80 points uniformly positioned within a 1 m wide area centered along each 40 m transect (Figure 1). A diver records all organisms intersecting an imaginary vertical line passing through each point and species percent cover is determined as the fraction of points a species intercepts x 100. A species is only recorded once at a given point even if it intersects the imaginary line multiple times. Using this technique the percent cover of all species combined on a transect can exceed 100%, but the percent cover of any individual species cannot. Species growing attached to other organisms are not counted, except those species growing on the ornate tube worm (*Diopatra ornata*). Mobile organisms occurring at a sampling point are not recorded. Only the holdfast is recorded to estimate the percent cover of the kelps *Macrocystis pyrifera*, *Pterygophora californica*, *Eisenia arborea, Egregia menziesii* and *Laminaria farlowii*; the blades and stipes of these species, which extend into the water column, are ignored if they intersected a sampling point. Unlike the sampling of algal and invertebrate density done in fixed quadrats and swaths, the number of taxa sampled by UPC is not fixed; instead all sessile species encountered are recorded. Species that are difficult to identify underwater are lumped into broader taxonomic categories (e.g., crustose coralline algae) to facilitate sampling.

Figure 1. Diagram of Uniform Point Contact Sampling showing 80 points sampled



Density and size of small algae and invertebrates: The density and mean size of a specified number of common small species of invertebrates and algae are sampled by divers in 1 m^2 quadrats positioned at each of the six permanent bolts along each transect (Figure 2). The list of species and size categories 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.

Figure 2. Schematic diagram showing the positioning of the 1 m^2 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

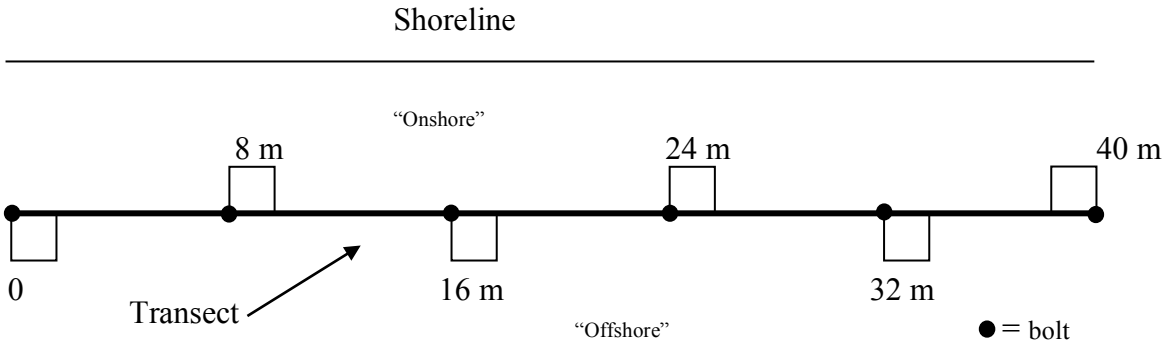


Table 1. List of species sampled in 1 m^2 quadrats

SP_CODE	GENUS	SPECIES	SIZE MEASUREMENT	COMMON_NAME AND DESCRIPTION
AMS	*Asterina*	*miniata*	diameter	Bat Star (<25mm)
*ANSP	*Anthopleura*	*spp.*	diameter	.
*BAEL	*Balanophyllia*	*elegans*	diameter	Orange Cup Coral
BLD		.	.	Unidentified juvenile kelp
*CECO	*Centrostephanus*	*coronatus*	diameter	
*CHOV	*Chaceia*	*ovoidea*	diameter	Wart Necked Piddock
*COCA	*Conus*	*californicus*	length	Califonia Cone Snail
*CUSP	*Cucumaria*	Spp.	diameter (tentacle)	.
CYJ	*Cystoseira*	*osmundaceae*	.	Bladder chain juvenile (< 5 cm diameter)
*CYSP	*Cypraea*	*spadicea*	length	Chestnut cowry
DIOR	*Diopatra*	*ornata*	.	Ornate tube worm
*DIS	*Dermasterias*	*imbricata*	diameter	Leather star juvenile(<25mm)
*EAJ	*Eisenia*	*arborea*	length	Southern sea palm juvenile (<5 cm stipe length).
*EGJ	*Egregia*	*menziesii*	length	Feather boa kelp juvenile (<1m height)
*EUPO	*Eudistylia*	*polymorpha*	diameter (tube)	Feather duster worm
*EUQU	*Eupentacta*	*quinquesemita*	length	White sea cucumber
*LA	*Lytechinus*	*anamesus*	diameter	White urchin
*LFJ	*Laminaria*	*farlowii*	length	Oar weed juvenile (<15cm blade width).
*LIGS	*Megastrea*	*spp.*	length	Wavey turbin snail juvenile (<9cm diameter)
*MIID	*Mitra*	*idae*	length	Ida's mitre
*MPJ	*Macrocystis*	*pyrifera*	0-33 cm, 34-66 cm, or 67-99 cm size categories	Giant kelp juvenile (<1m height)
*NONO	*Norrisia*	*norrisi*	length	Norris's top snail
*OKS	*Orthasterias*	*koehleri*	diamter	Rainbow star juvenile (<25mm)
*OPES	*Ophioplocus*	*esmarki*	disc diameter	Smooth brittle star
*OPSP	*Ophiothrix*	*spiculata*	arm length (>2.5cm)	Spiny brittle star
*PACA	*Parapholas*	*californica*	diameter	Scaleside piddock
*PAFI	*Pachycerianthus*	*fimbratus*	diameter	Tube dwelling anemone
*PAST	*Paracyathus*	*stearnsi*	diameter	Brown cup coral
*PBS	*Pisaster*	*brevispinus*	.	Short spined sea star juvenile (<25mm)
*PGS	*Pisaster*	*giganteus*	.	Giant spined sea star juvenile (<25mm)
*PHS	*Pycnopodia*	*helianthoides*	.	Sunflower sea star juvenile (<25mm)
*POPL	*Polyclinum*	*planum*	length	Elephant ear tunicate
*POS	*Pisaster*	*ochraceus*	.	Ochre's sea star juvenile (<25mm)
*PRUB	*Pachythyone*	*rubra*	length	Random foot cucumber
PTJ	*Pterygophora*	*californica*	length	Stalked kelp juvenile (<20 cm stipe length)
PTL	*Pterygophora*	*californica*	length	Stalked kelp subadult (>20 cm stipe length, < 7mm stipe width)

*PTTR	*Pteropurpura*	*trialata*	length	Three-winged murex
*SAHO	*Sargassum*	*horneri*	length	Adults (>5cm length)
*SAMU	*Sargassum*	*muticum*	length	Adults (>5cm length)
*SHJ	*Sargassum*	*horneri*	length	Juveniles (< 5cm length)
*SMJ	*Sargassum*	*muticum*	length	Juveniles (< 5cm length)
*SFL	*Strongylocentrotus*	*franciscanus*	diameter	Red urchin adult (>25mm)
*SFS	*Strongylocentrotus*	*franciscanus*	diameter	Red urchin juvenile (<25mm)
*SKE	*Small Kelletia*	.	length	Kellet's welk
*SPL	*Strongylocentrotus*	*purpuratus*	diameter	Purple urchin adult (>25mm)
*SPS	*Strongylocentrotus*	*purpuratus*	diameter	Purple urchin juvenile (<25mm)
*STMO	*Stylela*	*montereyensis*	siphon diameter	Stalked tunicate
*TEAU	*Tethya*	*aurantia*	diameter	Orange puffball sponge
*TESP	*Tegula*	*spp.*	length	Turbin snail
*URLO	*Urticina*	*lofotensis*	diameter	White-spotted rose anemone
*URPI	*Urticina*	*piscivora*	diameter	Fish eating anemone

* an estimate of mean size is recorded

Density and size of large algae and invertebrates: The density and average size of a select group of larger common algae and mobile invertebrates that are not easily counted in 1 m^2 quadrats are counted in four contiguous 20 m x 1m swaths that run parallel and adjacent to the 40 m transect (Figure 3). 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 3. Schematic diagram showing the position of the four 20 m x 1 m swaths relative to the 40 m transect.

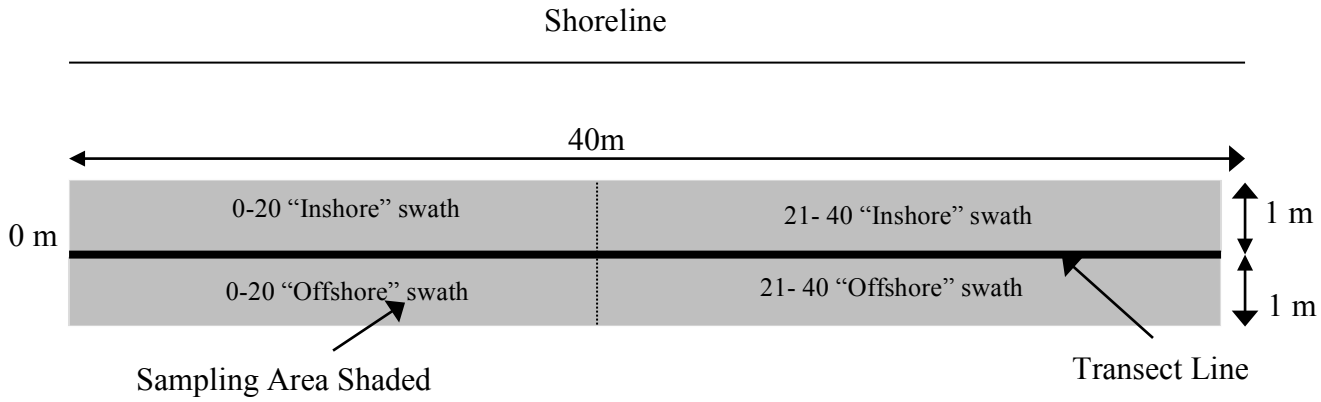


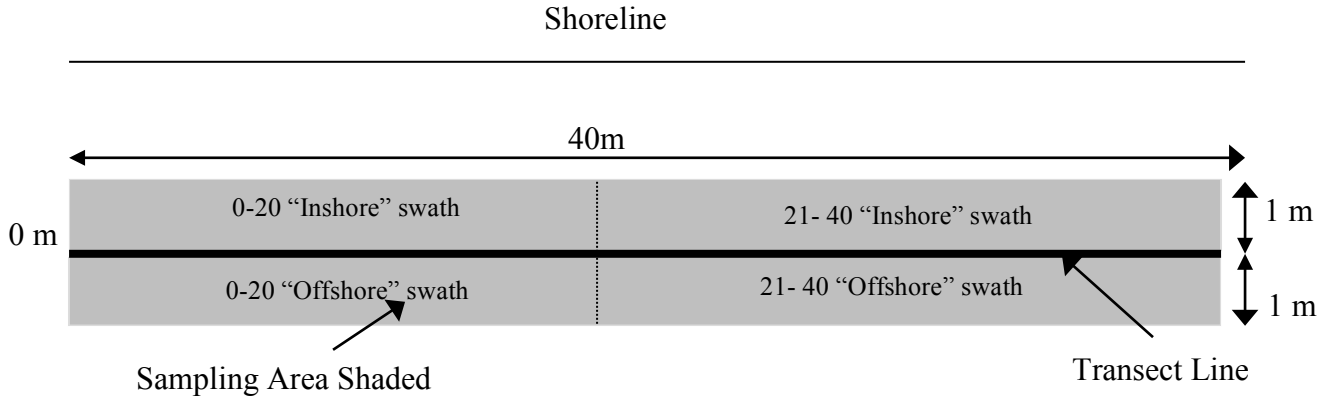
Table 2. List of species sampled in 20m x 1m swaths

SP_CODE	GENUS	SPECIES	SIZE	COMMON_NAME
*AML	*Asterina*	*miniata*	diameter	Bat star adult(> 25 mm)
*APCA	*Aplysia*	*californica*	agitated length	Sea hare
*APVA	*Aplysia*	*vaccaria*	agitated length	Spotted sea hare
*CASP	*Cancer*	spp.	carapace width	Cancer crab
*CRGI	*Crassadoma*	*gigantea*	diameter	Giant scallop
*CUKE	*Parastichopus*	*californicus*	agitated length	California cucumber
CYOS	*Cystoseira*	*osmundaceae*		Bladder chain adult (> 5 cm height)
*DIL	*Dermasterias*	*imbricata*	diameter	Leather star adult (> 25 mm)
*EA	*Eisenia*	*arborea*	number of blades >30cm	Southern sea palm adult (>5 cm stipe length)
*EGME	*Egregia*	*menziesii*	number of fronds > 1m tall	Feather boa kelp adult (>1m height)
*HACO	*Haliotis*	*corrugata*	length	Pink abalone
*HACR	*Haliotis*	*cracherodii*	length	Black abalone
*HAKA	*Haliotis*	*kamtschatkana*	length	Pinto abalone
*HARU	*Haliotis*	*rufescens*	length	Red abalone
*KEKE	*Kelletia*	*kelletii*	length	Kellet's welk
*LAFA	*Laminaria*	*farlowii*	length	Oar weed adult (>15cm blade width)
*LIGL	*Megastrea*	spp.	diameter	Wavey turbin snail adult (> 25 mm)
*LOCH	*Lophogorgia*	*chilensis*	width	Red gorgonian
*LOGR	*Loxorhynchus*	*grandis*	carapace width	Sheep crab
*MECR	*Megathura*	*crenulata*	length	Giant key hole limpet
*MUCA	*Muricea*	*californica*	width	California golden gorgonian
*MUFR	*Muricea*	*fruticosa*	width	Brown gorgonian
*OCTO	*Octopus*	spp.	greatest arm length	Octopus
*OKL	*Orthasterias*	*koehleri*	diameter	Rainbow star adult (> 25 mm)
*PAIN	*Panulirus*	*interruptus*	carapace length	California spiny lobster
*PAPA	*Parastichopus*	*parvimensis*	agitated length	Warty sea cucumber
*PBL	*Pisaster*	*brevispinus*	diameter	Short spined sea star adult (> 25 mm)
*PGL	*Pisaster*	*giganteus*	diameter	Giant sea adult (> 25 mm)
*PHL	*Pycnopodia*	*helianthoides*	diameter	Sun star adult (> 25 mm)
*POL	*Pisaster*	*ochraceus*	diameter	Ochre sea star adult (> 25 mm)
*PTCA	*Pterygophora*	*californica*	number of blades >30cm	Stalked kelp adult (>20 cm stipe length)
*PUPR	*Pugettia*	*producta*	carapace width	Kelp crab

* an estimate of the mean size is recorded

Density and size of giant kelp: The density of giant kelp fronds > 1 m tall is recorded in four contiguous 20 m x 1m swaths that run parallel and adjacent to each 40 m transect (Figure 4). Each plant with at least half of its holdfast located within the sampling area is counted and the number of fronds > 1 m tall on each plant is recorded. The greatest diameter of the holdfast for each adult plant (holdfast > 20 cm) is also recorded.

Figure 4. Schematic diagram showing the position of the four 20 m x 1 m swaths relative to the 40 m transect.



Density and size of reef fish: The number and size of reef fish are recorded within a 2 m wide swath centered along each transect extending 2 m off the bottom. A diver swims the length of the 40 m transect approximately 1m above the bottom at a constant deliberate speed and records reef-associated fish passing through the sampling area. Baitfish are not recorded. Fish size is measured as total length (TL) estimated to the nearest cm. Care is taken by the diver to not count the same individual more than once if it leaves and re-enters the sampling area. Surveys are carried out by only a select number of highly trained divers whose sampling techniques have been standardized in order to minimize observer bias. The horizontal visibility along the transect is measured and recorded for each sampling event. The number of fish taxa sampled is not fixed as all species of reef fish encountered in the sampling area are recorded. Species that are difficult to identify underwater are lumped into broader taxonomic categories (e.g., flatfish in the family Bothidae) to facilitate sampling.

Several species of small bottom-dwelling fish are difficult to accurately count and size during the reef fish survey due to their cryptic appearance and behavior. Individuals in a select group of these species are counted and sized in a separate survey in four contiguous 20 m x 1 m swaths centered on the 40 m transect (Figure 5). A diver carefully searches the area within each swath taking time to look on the undersides of ledges and in crevices, and within understory vegetation for select species of small cryptic fish which are purposely not counted in the reef fish survey. Understory algae are brushed aside during the search, but no organisms or boulders are physically moved. Size is recorded as total length (TL) to the nearest cm. The species of small cryptic fish counted in this survey are listed in Table 3.

Figure 5. Schematic diagram showing the position of the four 20 m x 1 m swaths relative to the 40 m transect.

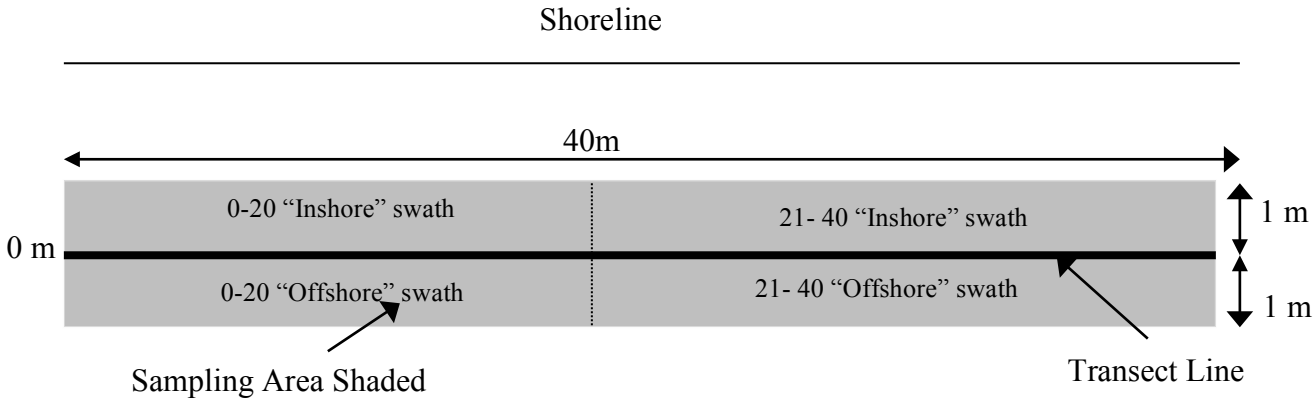


Table 3. Species list of small cryptic fish surveyed.

SP_CODE	GENUS	SPECIES	COMMON_NAME
AHOL	Alloclinus	*holde*r	Island kelpfish
CLIN	Gibbonsia	spp.	Crevice kelpfish
CNIC	Rhinogobius	*nicolsii*	Blackeye goby
COTT	Cottid	spp.	Sculpins
CSTI	*Citharicthys*	*stigmaeus*	Pacific sanddab
LDAL	*Lythrypnus*	*dalli*	Bluebanded goby
LHIR	*Leiocottus*	*hirudo*	Lavender sculpin
NBLA	*Neoclinus*	*blanchardi*	Sarcastic fringehead
OPIC	*Oxylebius*	*pictus*	Painted greenling

Annual time series of biomass for kelp forest species: Annual field measurements of percent cover or size specific density were converted to biomass (g m^2) for each alga and invertebrate surveyed using the taxon specific relationships of Reed et al 2009, Harrer et al 2013 and Reed et al 2016. Fish size specific density was converted to biomass using literature based relationships (Walford 1932, Young 1963, Quast 1968b, Thorson 1976, DeMartini et al 1987, Love 1990, Taylor 1997, Love and Johnson 1999 and fishbase.org.). Percent cover or size specific density of rare species was converted to biomass using relationships derived for morphologically similar taxa. In the event that no size data was available to be coupled with field measures of taxon density, mean taxon size at a specific site was used to calculate taxon biomass at that site.

Biomass of algae: Annual measurements of percent cover for crustose alga, low lying turfs and foliose algae were converted to de-calcified dry biomass (g m^2) using the equations of Harrer et al 2013. Frond density of adult *Macrocystis pyrifera* along permanent transects was converted to de-calcified dry biomass (g m^2) using the equation of Reed et al 2009. Size specific density measurements of understory kelps, invasive fucoids and juvenile *M. pyrifera* were converted to de-calcified dry biomass (g m^2) using the equations of Harrer et al 2013. Estimates of juvenile biomass and adult biomass were summed for each taxon. In the event that no size data was available to be coupled with taxon density, mean size recorded at a specific site was used to calculate biomass.

Estimates of de-calcified dry biomass were converted to wet biomass (g m^2) and ash free dry biomass (g m^2) by applying laboratory derived conversion ratios established for each representative taxon.

Biomass of invertebrates: Annual measurements of percent cover for colonial species (e.g. compound ascidians, bryozoans, sponges) and small aggregating taxa (e.g. hydrozoans, anthozoans, polychaetes) were converted to wet biomass (g m^2) using the equations of Reed et al 2016. Annual measurements of size specific density of solitary species were also converted to wet biomass using the equations of Reed et al 2016. Estimates of wet biomass were converted to de-calcified dry biomass (g m2) and ash free dry biomass (g m2) using taxon specific conversion factors provided in Reed et al 2016.

Biomass of fish: Annual measurements of size specific density of all reef fish surveyed were converted to wet biomass (g m^2) using literature based relationships between length and wet mass (Walford 1932, Young 1963, Quast 1968b, DeMartini et al 1987, Love 1990, Love and Johnson 1999 and fishbase.org). Estimates of wet mass for bony fish were converted to bone-in dry mass (g m^2) and ash free dry mass (g m^2) using an average conversion factor from Taylor 1997. Estimates of wet mass for elasmobranchs were converted to dry mass (g m2) and ash free dry mass using an average conversion factor from Thorson 1976.

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