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A multi-decade time series of kelp forest community structure at the California Channel Islands

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Abstract. Studies of temperate rocky reef communities have added much to our understanding of ecology. However, data on these reef communities can be difficult to obtain; wind, waves, and poor underwater visibility often prevent research diving, and even under the best conditions only a few hours a day can be spent underwater collecting data. Here, we present data on temperate subtidal reef communities at 33 sites, almost half of which the National Park Service has sampled annually since 1982. We present core data sets describing the population dynamics of 16 fish, 37 invertebrate, and 15 algal taxa. We include supplementary data sets documenting the size structure of key species, the relative abundance of all fish, the recruitment of selected invertebrates, and the subtidal water temperature at each site through time. Taken together, these data provide one of the most comprehensive descriptions of nearshore reef community dynamics ever assembled.

Key words: California Channel Islands; kelp forest; long-term monitoring; marine protected areas; subtidal reef ecology.

The complete data sets corresponding to abstracts published in the Data Papers section of the journal are published electronically in *Ecological Archives* at <http://esapubs.org/archive> (the accession number for each Data Paper is given directly beneath the title).

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INTRODUCTION

The ocean waters surrounding the California Channel Islands include many shallow nearshore reefs. Giant kelp (*Macrocystis pyrifera*) is commonly, but not always, a dominant fixture here (Engle 1994, Cavanaugh et al. 2011). Biotic communities on these reefs vary in space due to differences in depth, substrate, temperature, nutrients, and exposure to waves. In addition to seasonal variation (not measured in this study), rocky reef communities may vary from year to year due to recruitment events, physical disturbance from waves, fluctuations in the climate (including El Ninos and shifts in the Pacific Decadal Oscillation) and community dynamics such as disease outbreaks or changes in grazer behavior (Lafferty 2004).

Humans also affect this ecosystem in space and time. Most of the area is open to commercial and recreational fishing (e.g. Schroeter et al. 2001), and it also supports other recreational activities such as diving and boating. Marine communities may also be affected by chronic and acute pollution from mainland waste disposal and adjacent offshore petroleum development. The five northern California Channel Islands are primarily under the management and jurisdiction of the National Park Service and Nature Conservancy, while the California Department of Fish and Wildlife has jurisdiction over the living marine resources within 3 miles of the island.

To assist in protecting and managing these nearshore ecosystems, the National Park Service created the kelp forest monitoring program (KFMP) in 1982. Every summer since then, the KFMP has tracked the populations of key species of algae, invertebrates and fishes at locations throughout the park. The resulting data on subtidal community structure and dynamics are nearly unparalleled in their completeness and spatio-temporal extent. These data have contributed substantially to management actions, such as the State of California's decision to close several abalone fisheries in 1997 and the decision to create marine protected areas within the National Park in 2003. The data have also been the basis of a number of general ecological insights (e.g., Reed et al. 2000, Lafferty 2004, Byrnes et al. 2006).

Despite its proven usefulness, several characteristics of this monitoring dataset have made it challenging to analyze. The KFMP has refined its methods several times (e.g., Davis et al. 1996). These improvements have focused on obtaining the best data possible given a fixed amount of effort, but have come at some cost to the overall consistency and simplicity of the dataset. Researchers wishing to use these data have needed to work closely with the program's extensive documentation, understanding how and when sampling size changed, what species have been counted with which methods in which years, and how choices about which species to count and at what taxonomic resolution have changed over time.

In this data paper, we have summarized observations from five different sampling methods into three core datasets that record the abundance of more than 60 key taxa over a 30 year period. We have corrected for changes in sampling method, changes in taxonomic resolution and other

inconsistencies, seeking to make the data easy to use and help researchers avoid potential pitfalls. In addition to these core datasets, we present seven supplementary datasets that record the size structure of key species and provide additional information about fish and kelp densities, patterns of invertebrate recruitment and historical water temperatures. These supplementary data provide valuable information about the processes that underlie the community dynamics described in the core datasets.

The data might be used to describe how these rocky reef communities have changed over time, to evaluate local management practices and human impacts, and to detect the effects of larger-scale anthropogenic effects such as global climate change and ocean acidification. They also give considerable insight into the ecology and population status of the particular species being monitored. Regardless of the use, we strongly recommend that researchers contact the coordinator of the KFMP when planning analyses to gain a better understanding of the dataset and the system.

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Class I. Data set descriptors

- A. Data set identity
- B. Data set identification code
- C. Data set description
 - 1. Data set originator
 - 2. Abstract
- D. Key words

I.A. Data set identity: Subtidal community data from the Channel Islands National Park's kelp forest monitoring program.

I.B. Data set identification code: KushnerEtAl2013-KFMP.

I.C. Data set description

I.C.1. Data set originator

Individual: David J. Kushner
Role: Program Manager, Corresponding Author
Organization: Channel Islands National Park
Position: Marine Biologist
Address: 1901 Spinnaker Dr.
Ventura, CA 93001
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I.C.2. Abstract:

Studies of temperate rocky reef communities have added much to our understanding of ecology. However, data on these reef communities can be difficult to obtain; wind, waves and poor underwater visibility often prevent research diving, and even under the best conditions only a few hours a day can be spent underwater collecting data. Here, we present data on temperate subtidal reef communities at 33 sites, almost half of which the National Park Service has sampled annually since 1982. We present core datasets describing the population dynamics of 16 fish, 37 invertebrate and 15 algal taxa. We include supplementary datasets documenting the size structure of key species, the relative abundance of all fish, the recruitment of selected invertebrates and the subtidal water temperature at each site through time. Taken together, these data provide one of the most comprehensive descriptions of nearshore reef community dynamics ever assembled.

I.D. Key words: *Kelp Forest, Long-term Monitoring, California Channel Islands, subtidal reef ecology, marine protected areas*

Class II. Research origin descriptors

A. Project description

1. Objectives
2. System description
3. Guidelines for use of data

II.A.1. Objectives: When the United States Congress passed legislation creating the Channel Islands National Park (CINP), the National Park Service (NPS) was charged with conducting “an inventory of all terrestrial and marine species, indicating their population dynamics, and probable trends as to future numbers and welfare” (16 USC § 410FF-2, 1980). Shortly after the park was created in 1980, the NPS initiated several ecological inventorying and monitoring programs, including the kelp forest monitoring program (KFMP), focusing on the ecological communities found on shallow rocky reefs around the five northernmost Channel Islands. The KFMP takes a population dynamics approach to describing the status of communities on these reefs, monitoring the abundance of selected species in the same locations every year. In addition to these records of population status the KFMP collects supplementary data from each of these locations to help describe the biological and physical processes that govern community dynamics on these reefs.

II.A.2. System description: This study focuses on shallow (< 20 m deep) rocky reefs in the CINP. The waters of CINP give refuge to an ecologically diverse collection of species. The park is located at the boundary between two major biogeographical provinces: the Oregonian province to the north and the Californian to the south. The western park islands, San Miguel and Santa Rosa, are regularly subject to the cooler waters of the California Current. Waters around the eastern park islands of Anacapa and Santa Barbara come from the south along the mainland coast and are typically warmer. Around Santa Cruz Island, there is a broad transition zone influenced by waters from the north and south (Figure 1).

Prevailing winds and the bathymetry of adjacent basins also greatly influence marine communities in the park. Strong north winds and winter swells buffet the north sides of the islands, while the biota of the southern coasts reflects their more sheltered location. Upwelled nutrients from 2,000 meter-deep basins to the south and west of the park contribute to exceptionally productive food webs and create temperature regimes that differ significantly from the relatively shallow northern sides of the islands.

II.A.3. Guidelines for use of data: This dataset is part of the ongoing Kelp Forest Monitoring Program. Researchers using these data are encouraged to contact the corresponding author (David Kushner) concerning questions, improvements, and, when appropriate, collaboration. The first author has been managing the National Park Service’s kelp forest monitoring program since 1992 and can provide more details on the sampling methodology and the natural history of the system. Additionally, he keeps track of past and ongoing analyses to help reduce duplication of effort (see also section V.C. *Publications using the data set*).

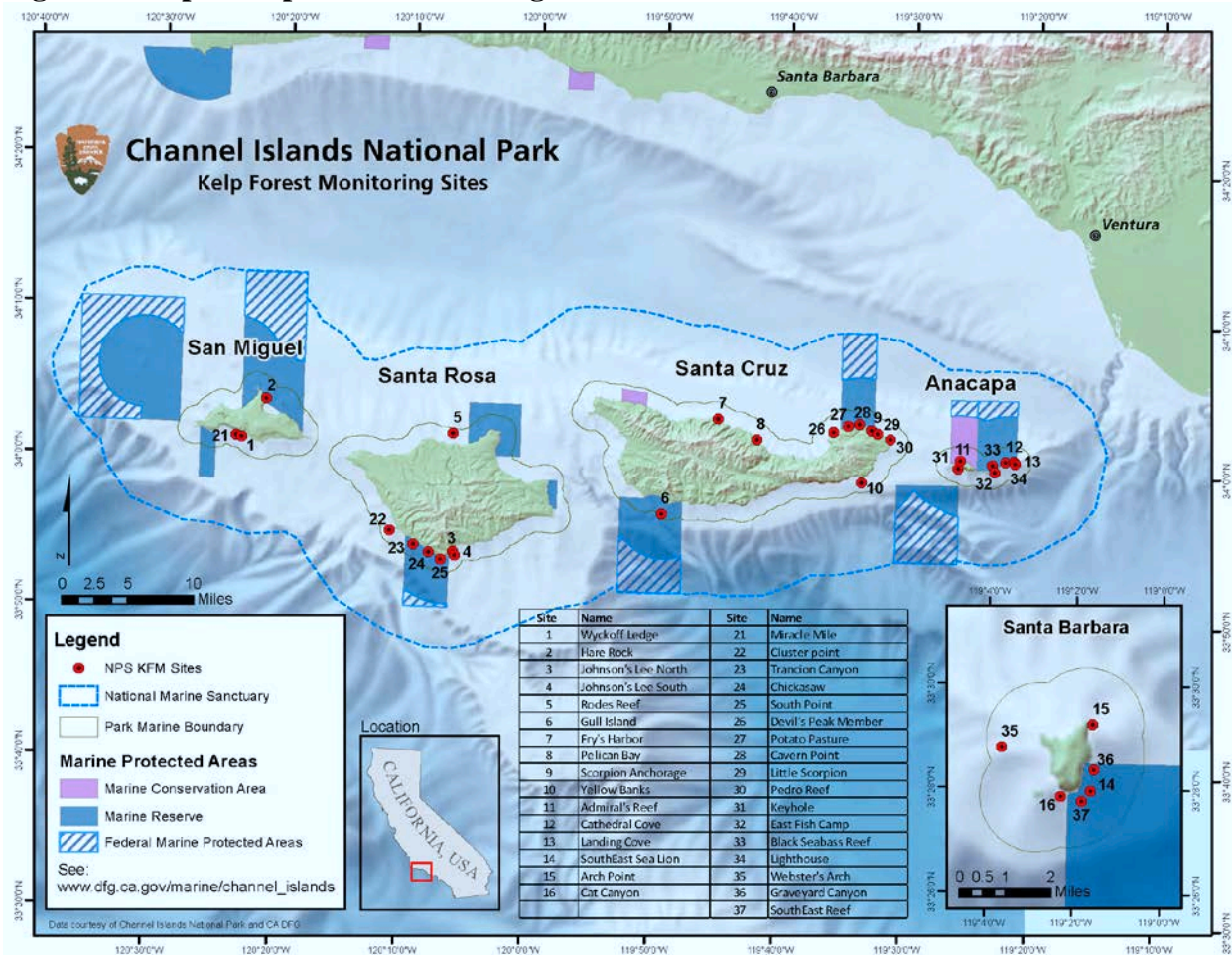
B. Monitoring design

1. Site selection and layout

2. Human impacts
3. Monitoring method selection
4. Choice of species to be monitored
5. Monitoring design metadata

II.B.1. Site selection and layout: The Channel Islands National Park’s Kelp Forest Monitoring Program began in 1982 and has grown over time to include 33 sites. A single permanent transect at each site is sampled annually, between May and October. A map of the park and monitoring site locations is given in Figure 1.

Figure 1: Map of kelp forest monitoring site locations



The initial 16 monitoring sites were selected from throughout the CINP; 13 sites were established in 1982, one in 1983 and two in 1986. As described below, site selection was not random, and, as a result, average densities for the sites should not be used to extrapolate to average conditions in the system. They are better suited for tracking changes over time, or matching biological communities to site characteristics.

The initial sites were distributed on both the north and south sides of each of the islands, and chosen to cover the east-west transition from the Californian to the Oregonian biogeographic

provinces. Within these broad parameters, sites were selected based on the presence of continuous patches of rocky habitat (typically more than 100 m in long-shore extent) and because they were known to be good habitat for giant kelp forests (i.e., giant kelp was known to be present at all sites in 1982 or shortly prior). Of the initial 16 sites, two were placed within a no-take marine reserve on Anacapa Island (#12 and #13), and a third placed in a nearby seasonal closure on Anacapa Island (#11).

In 2001, the Miracle Mile site (#21) at San Miguel Island was added to the KFMP for the purpose of monitoring abalone populations. This site was selected by a commercial fisherman based on its exceptionally high density of the red abalone, *Haliotis rufescens*. In 2005, the park received funding to expand its monitoring within and adjacent to several newly established marine protected areas (MPAs) at the Channel Islands. The KFMP added 16 new sites located inside or adjacent to four of the newly established MPAs: Santa Barbara Island State Marine Reserve, Anacapa Island State Marine Reserve, Scorpion State Marine Reserve, and South Point State Marine Reserve. These four MPAs were chosen for additional monitoring because they were accessible, contained existing KFMP monitoring sites and were in areas most likely to be impacted by fishing. New sites were established to complement existing sites so that at least three sites were inside and three adjacent to each of the four MPAs. Permanent sampling locations at these sites were placed in areas of continuous rocky reef. All 33 kelp forest monitoring sites and their locations (WGS 84) are described in [Table 1](#). This information is also available in a format that can be read by geospatial software such as Google Earth ([Sites.kml](#)). Links to an underwater video transect done at each site in 2010 are provided in [Table 1](#), videos from other years are available from the NPS or at www.pyrifera.marinemap.org.

Monitoring at each site is focused on a permanent 100-meter transect, typically laid out parallel to the shoreline along a rough depth isobath. Permanent transects were used to reduce within-site variability in the time series and thus provide measurements of population dynamics with time as the primary independent variable. Each transect is marked by a 12 mm diameter lead-filled woven nylon line permanently affixed to the bedrock with stainless steel eyebolts positioned every 10 meters along the transect. Transects are relocated using GPS and diver search; while individual eyebolts have been lost and needed to be replaced from time to time, the permanent line has allowed the transect location to be accurately relocated in all such cases. The transect depths at the original 16 sites vary from site to site, spanning a range from 5-18 meters. Transects at sites established in later years were placed between 7-17 meters in depth.

II.B.2. Human impacts: Many species monitored here are harvested commercially or recreationally. In particular, large and valuable fisheries exist for spiny lobster (*Panulirus interruptus*), California sheephead (*Semicossyphus pulcher*), red sea urchins (*Strongylocentrotus franciscanus*) and sea cucumbers (*Parastichopus parvimensis*). Although most of the sites are open to fishing and have no special restrictions on harvest beyond those common throughout southern California, several sites are currently within marine protected areas where harvest is restricted (Airamé et al. 2003, Davis 2005). All of the protected areas were established in 2003 except the area at the east end of Anacapa Island which predates the monitoring program and includes two of the original monitoring sites. A list of the special restrictions on harvest at each site (if any) and the dates those restrictions were implemented is given in [Table 2](#).

II.B.3. Monitoring method selection: The great diversity of organisms and physical habitats associated with kelp forests require multiple sampling approaches to effectively document species population dynamics. Sampling methods were designed to maximize accuracy and precision while preserving an observer’s ability to efficiently sample several target species at once. Additionally, sampling techniques were designed to minimize variation among observers and impacts on the populations of organisms being monitored. Some details of the sampling techniques have been revised several times since the project started. Most notably, several methods have changed their sampling effort one or more times as the result of ongoing power analyses and review of the data. These changes in sampling intensity have been noted in the metadata and in the datasets.

II.B.4. Choice of species to be monitored: The primary objective in selecting taxa for monitoring was to provide a representative cross section of the ecological guilds present in the CINP kelp forests. There are currently 15 algal, 37 invertebrate, and 16 fish taxa specifically targeted in the monitoring, and all fish are monitored with supplementary methods. The species monitored and the datasets in which they appear can be found in [Table 3](#). Though many common organisms are identified to the species level, some are identified only to a coarse taxonomic level (e.g. green algae).

II.B.5. Monitoring design metadata: The tables describing general monitoring methods described above are also available below as comma-separated values files.

[Table 1: Monitoring sites and their coordinates](#)

[Table 2: History of special fishing restrictions](#)

[Table 3: Species monitored by method](#)

C. Data processing and presentation

1. Core community structure datasets
2. Supplementary datasets
3. Additional documentation and data

II.C.1. Core community structure datasets: We present data on kelp forest community structure in a format that can be easily analyzed, and so have taken steps to construct datasets that are consistent through time. To achieve this we have combined data from different sampling methods where possible, removed species and sites that were sporadically measured and corrected for changes in sampling effort over time. This has resulted in three summarized “core community structure datasets”: benthic density (calculated from counts of organisms in 1 m² quadrats, 5 m² quadrats and band transects), benthic cover (calculated from random point contact data), and fish density (calculated from visual fish transects). In each of these datasets, the abundance of each species or taxa sampled is expressed as a mean for each site on each sampling date with associated variance where appropriate. Full details on both the methods used to collect these data and the steps taken to process and summarize the raw measurements are given below. Note that the sampling design has been consistent since 1996, so users concerned about changes in sampling effort can limit their analysis to data collected after that year.

II.C.2. Supplementary datasets: In addition to the core data discussed above, the KFMP collects several other forms of data that are not simple measures of abundance. We provide these data in seven separate datasets: *roving diver fish counts*, *fish size-frequency*, *invertebrate size-frequency*, *giant kelp size-frequency*, *giant kelp supplemental density*, *artificial recruitment module data* and *subtidal temperature data*. These data have not been summarized to a single number for each site and year, so will likely require some processing by users. Although the data are of high quality, many of these datasets are complex and we caution users of these data to carefully read the methods to understand how sampling was done.

II.C.3. Additional documentation and data: Considerable additional documentation is available for the KFMP, including the sampling protocols used to guide field teams, annual reports describing changes in the system, and video transects from 1983-2011 for each site. These are available from the National Park Service website (www.nps.gov/chis), and from a dedicated data visualization website (www.pyriferamap.org). Additional data including the unprocessed field data can be obtained by contacting [David Kushner](#), or the current superintendent of the Channel Islands National Park.

D. Monitoring methods and data

1. Core community structure datasets:

- a. **Benthic density data**
 - i. **Benthic density summary procedures**
 - ii. **1 m² quadrat monitoring methods**
 - iii. **5 m² quadrat monitoring methods**
 - iv. **Band transect monitoring methods**
- b. **Benthic cover data**
 - i. **Benthic cover summary procedures**
 - ii. **Random point contact monitoring methods**
- c. **Fish density data**
 - i. **Fish density summary procedures**
 - ii. **Visual fish transect monitoring methods**

II.D.1. Core community structure datasets

II.D.1.a. Benthic density data

[Table 4A](#): Definition of column headers in the benthic density data

[Table 4B](#): Definition of variables in the benthic density data

[Benthic density data](#): ASCII file in comma separated values format

II.D.1.a.i. Benthic density summary procedures: Benthic density data are collected by counting the number of individuals in a fixed area and dividing that count by the area sampled. This form of monitoring is used to estimate the abundance of larger benthic organisms such as sea stars and kelps as well as some small benthic fish. In the KFMP, three separate methods are used at each site to estimate benthic densities (1 m² quadrats, 5 m² quadrats and band transects, sampling 1-2 m², 5 m² and 40-60 m² respectively). Because the sampling intensities for these methods have varied through time, data are summarized as the mean density (per m²) of each

taxa at the site, averaged over all replicates within the site for a given year. Also included are the standard errors in density calculated across the sampling replicates, the number of replicates and the area sampled in each replicate.

Different methods are used to count different species, and in some cases the method used to count a particular species changed over time. By combining the densities estimated from each method into a single dataset, we assemble continuous time series of the abundance of each species for which density estimates were made. In the few cases where the same species was sampled by multiple methods at the same site in the same year, we used the method that sampled the largest area.

Some species have been added to the monitoring protocols during the 30+ years of monitoring. Thus the absence of these species from the data early in monitoring cannot be taken as evidence of absence. For this reason, instead of a 0 or blank, the code “NA” is entered into the dataset as the density for species in years they were not counted. Different size classes of several kelps were counted separately for the later portion of the monitoring. However we have summed across age classes to obtain consistent categories throughout this dataset.

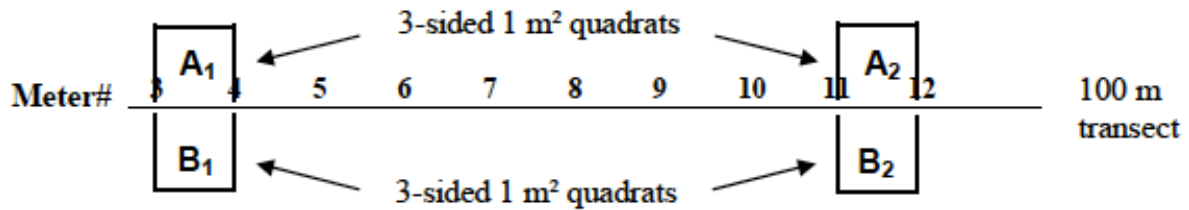
II.D.1.a.ii. 1 m² quadrat monitoring methods: 1 m² quadrats have been sampled since 1982 by counting the number of individuals of each target species occurring within a set of small quadrats at each site. Currently 12 quadrats are sampled, with pairs of quadrats placed every 8.33 m (rounded to the nearest whole meter) along the main transect (Figure 2). Over the course of the program, sample size has varied from 12 to 40 quadrats, and the area of each replicate quadrat has varied from 1 m² to 2 m² (Table 5).

Table 5: 1 m² quadrat sampling intensity by year.

Year	# Quadrats	Size
1982	30	1 m ²
1983-1984	40	1 m ²
1985-1995	20	2 m ²
1996-2011	12	2 m ²

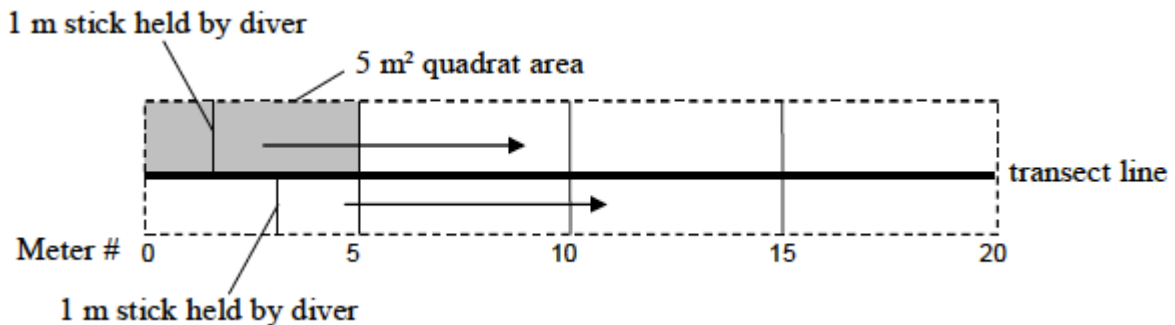
Placement of quadrats is based on a stratified random design, with new points on the transect chosen every year, although the exact method of stratification has changed over time. For this monitoring method, observers place two 1 m² frames adjacent to the main transect, so that they form a 2 m² area (e.g., A₁ and B₁ in Figure 2) using the transect line as the fourth side of each quadrat. When sampling, divers place the frames, then withdraw to allow island kelp fish, gobies and other easily disturbed species to emerge from crevices before approaching the quadrats slowly. Fishes within the quadrat are counted first; additional fish that enter the quadrat after this first count are ignored. Divers search under ledges and in cracks for all target organisms but do not conduct invasive sampling (e.g., turning over rocks, sifting through sand, etc.).

Figure 2. Placement of 1 m² quadrats under current design



II.D.1.a.iii. 5 m² quadrat monitoring methods: 5 m² quadrats have been sampled since 1996 by counting the number of individuals of each target species occurring within a set of 5 m² sampling areas at each site. This sampling method was added to improve sampling of key species that are too rare to be regularly encountered in 1 m² quadrats, but too numerous to quickly count in the larger band transects. The 100 m transect is divided into 20 segments, each associated with two 5 m by 1 m sampling areas, placed one on either side of the transect (e.g., Figure 3). Divers search the habitat thoroughly for target species, including cracks and crevices but do not conduct any invasive sampling (e.g., turning over rocks, sifting through sand, etc.).

Figure 3. Placement of 5 m quadrats along the transect line.



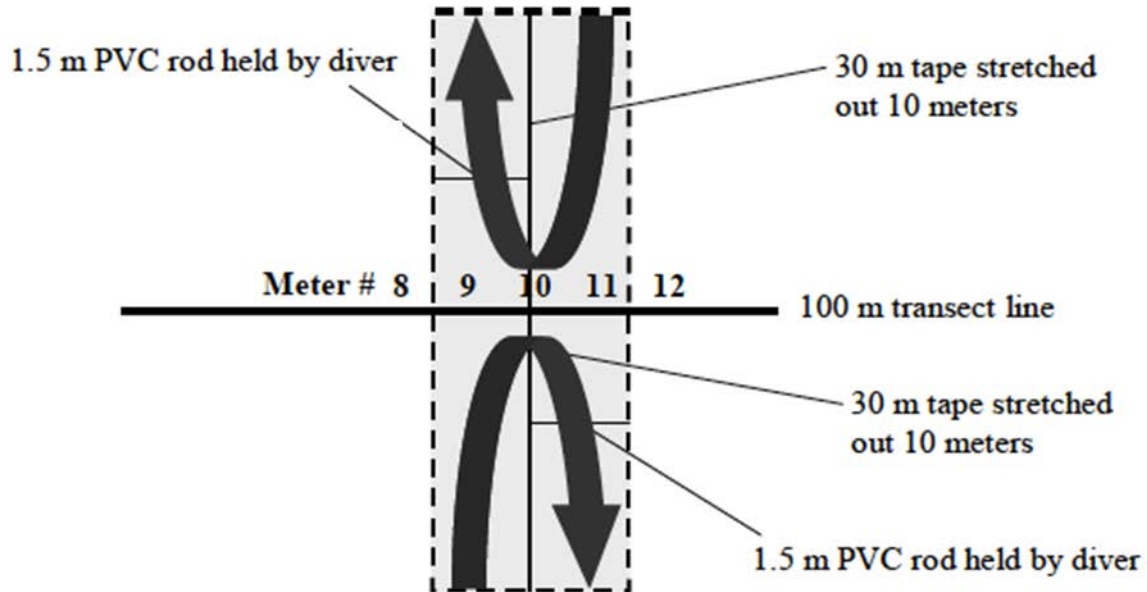
II.D.1.a.iv. Band transect monitoring methods: Band transects have been sampled since 1983 by counting the number of individuals of each target species occurring within a set of band transects at each site. Currently 12 bands are sampled, each covering 60 m², but sampling intensity has varied over time (Table 6).

Table 6: Band transects sampling intensity by year.

Year	# Band Transects	Band Transect Size
1983-1984	10	40 m ²
1985-2011	12	60 m ²

Placement of bands is based on a stratified random design, with different points on the main transect chosen every year for sampling. At each sampling point, divers run measuring tapes 10m in each direction, perpendicular to the 100 m transect line, sampling organisms first within 1.5m of one side of the tape and then within that distance of the other tape (Figure 4, before 1985 only 1m on each side was sampled). Divers search the habitat thoroughly, including cracks and crevices, however, they do not conduct any invasive sampling (e.g., turning over rocks, sifting through sand, etc.).

Figure 4. Example of band transect placement under current design.



Shaded portion indicates the area sampled. Arrows indicate direction diver swims.

II.D.1.b. Benthic cover data

[Table 7A](#): Definition of column headers in benthic cover data

[Table 7B](#): Definition of variables in the benthic cover data

[Benthic cover data](#): ASCII file in comma separated values format

II.D.1.b.i. Benthic cover summary procedures: Percent cover data for sessile benthic biota (e.g., bryozoans, understory macroalgae) are collected using a random point contact (RPC) method, in which a set of randomly chosen points are superimposed over the bottom and the species contacted by each point are recorded. The number of times each species was counted is divided by the total number of points to give the percent of the bottom occupied by that species. The physical substrate is also categorized during the RPC process and the cover of each substrate is recorded in this dataset. The benthic cover dataset contains the mean percent cover of each target organism, averaged across all RPC units sampled at that site, the standard error in percent cover calculated across the RPC units and information about the number of RPC units sampled and the number of points per unit. The sampling intensity for this method has changed through

time, but by summarizing the data as an average percent cover for the site, we have corrected for this variation in effort.

Some species have been added to this method’s target species list during the 30 years of monitoring. Thus the absence of these species from the data early in the monitoring cannot be taken as evidence of absence. The code “NA” is entered into the dataset as the percent cover of species in years they were not counted. Several species which were not distinguished individually early in the monitoring were later sampled separately. However, we have aggregated such species groups in the benthic cover data so that taxonomic resolution is consistent throughout the dataset.

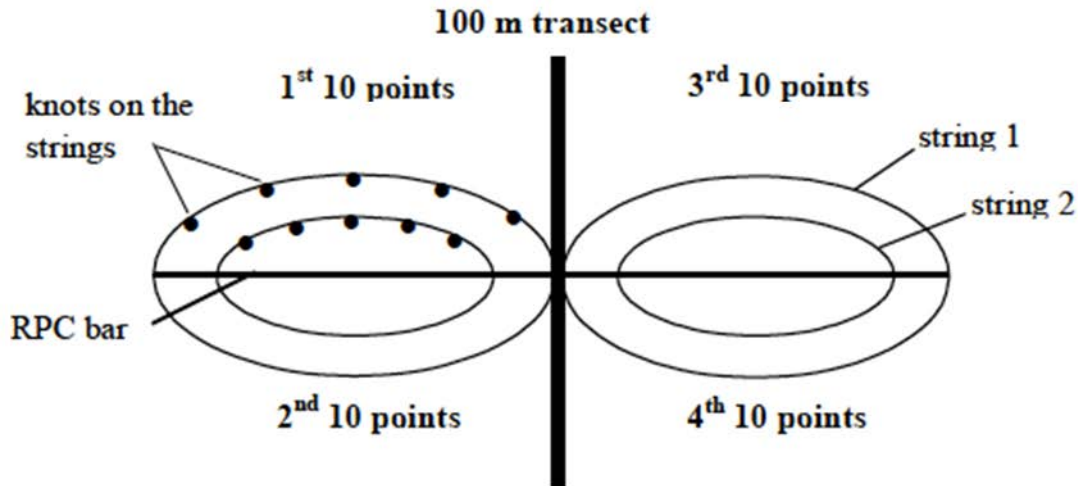
II.D.1.b.ii. Random point contact monitoring methods: Benthic cover data are collected in RPC units of 40 points distributed around a given location on the main transect. Currently 15 units placed approximately every 6.6 m (rounded to the nearest meter) along the transect are sampled at each site, but the intensity of sampling has varied over time (Table 8). Placement of RPC units follows a stratified random design, with new locations on the transect chosen every year, although the exact method of stratification has changed over time. Again, this introduces an element of year to year variation not due to actual changes over time.

Table 8: RPC sampling intensity by year.

Year	Replicates	Points per replicate
1982	25	20
1983	40	10
1984	10	50
1985-1995	25	40
1996-2011	15	40

To perform this sampling, a diver uses an “RPC bar” a 1.5 m rod with 2 strings attached, each string with 5 knots. One string is 1.8 m long and the other measures 1.2 m. The long string attaches to the ends of the bar and the short string attaches 25 cm from each end. At each sampling location, the diver places the RPC bar perpendicular to the transect line (Figure 5), holds the RPC bar in place and stretches the string taut at each knot perpendicular to the bar. This forms a triangle with the bar as one edge and the knot as the opposite vertex. The diver then imagines a line running vertically through the knot from the substrate up to one meter above the substratum and identifies all organisms that intersect this imaginary line. The diver identifies all organisms under or above the knots on both strings on one side of the bar, giving a total of ten points. Next, the diver moves the strings to the opposite side of the RPC bar for another 10 points, then places the bar on the other side of the transect line and repeats the process (Figure 5).

Figure 5: Orientation of RPC bar and strings during sampling.



The diver counts each species only once per point even if multiple individuals of the same species intersect that point. Because of this method of counting multiple layers, total cover of all species can exceed 100% (and usually does), but the cover of any individual species cannot be greater than 100%. The one exception is the category “Macrocystis, Pterygophora, and Eisenia combined” (species code 2008). Each species in this category is counted separately and then these counts are added, so percent covers of as high as 300% are possible for this combined-species category (if all points intersect all three species). Attached or sessile animals providing cover are recorded as “Miscellaneous Invertebrates.” Motile invertebrates (except for *Ophiothrix spiculata* and *Pachythyone rubra*, which are counted with “Miscellaneous Invertebrates”), are not counted but are moved to determine what is underneath. The diver also identifies the substrate type encountered at each point.

II.D.1.c. Fish density data

[Table 9A](#): Definition of column headers in fish density data

[Table 9B](#): Definition of variables in the fish density data

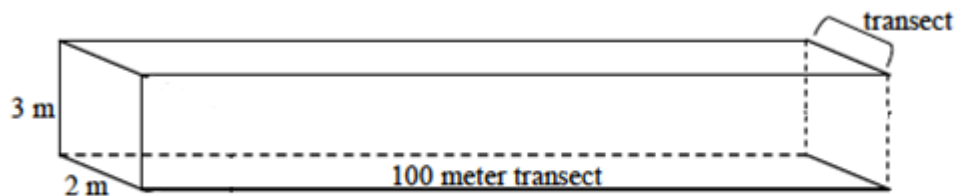
[Fish density data](#): ASCII file in comma separated values format

II.D.1.c.i. Fish density summary procedures: Fish density data are collected by counting the number of individuals in a single fixed plot at each site. This form of monitoring is used to estimate the abundance of 13 species of fish and is based on visual fish transect data. For each fish species counted in a given year, the fish density dataset contains the total count of that species; because these data are based on a single transect, no variability is reported. Occasionally the same plot was sampled on multiple dates within a single year; these counts are reported as separate entries in the fish density dataset. Sampling for *Semicossyphus pulcher* juveniles began in 1996. Thus their absence from the data early in the monitoring cannot be taken as evidence of absence. The code “NA” is entered into the dataset as the density in years they were not counted.

II.D.1.c.ii. Visual fish transect monitoring methods: To count fish, a diver swims along the main 100 m transect line, counting and recording all the individuals of a core set of species

within a 3 m tall x 2 m wide x 100 m long area in front of the diver. The diver records any fish seen within this area (Figure 6). Divers typically swim the 100 m transect in 5 minutes. Counts are differentiated by species and by age class—adults or juveniles, with juveniles defined as less than 10 cm in length, except for *Halichoeres semicinctus* and *Semicossyphus pulcher* for which juveniles must be less than 10 cm in length and have a white stripe, and *Hypsypops rubicundus* for which juveniles are not identified by size, but by the presence of blue spots. A few species are also differentiated by sex. Fish transects are conducted once or twice per summer at each site, as time allows, with a minimum of two weeks between sampling events.

Figure 6: Area covered by visual fish transects.



II.D.2. Supplementary datasets

- a. Roving diver fish count data
 - i. Roving diver fish count methods
- b. Fish size-frequency data
 - i. Fish size-frequency methods
- c. Invertebrate size-frequency data
 - i. Invertebrate size-frequency methods
- d. Giant kelp size-frequency data
 - i. Giant kelp size-frequency methods
- e. Giant kelp supplementary density data
 - i. Giant kelp supplementary density methods
- f. Artificial recruitment module data
 - i. Artificial recruitment module methods
- g. Subtidal temperature data
 - i. Subtidal temperature methods

II.D.2.a. Roving diver fish count data:

[Table 10A](#): Definition of column headers in RDFC data

[Table 10B](#): Definition of variables in the RDFC data

[RDFC data](#): ASCII file in comma separated values format

II.D.2.a.i. Roving diver fish count methods:

The roving diver fish count (RDFC) is a method for counting fish that covers a much larger area

than the visual transects and attempts to sample all fish species, instead of just the core set of species counted in visual fish transects. It also has the advantage that multiple counts are done by different observers at a site on most sampling dates. As such, the RDFC data provide more complete information on the total fish community than the fish transect data. Because the RDFC seeks to sample fish within a fixed area, it is tempting to convert these data into densities, but because sampling occurs over a fixed time (30 minutes) there are potential pitfalls with treating these data as density estimates.

The RDFC method produces two indices of fish abundance for each species: an abundance category (*single, few, common, many*) and a count of the number of individuals observed (see Table 11 for the relationship between categories and counts). The count data is a better index of abundance, but we retain data on abundance category since fish counts were only added to the RDFC protocol in 2003. Prior to that (from 1996 to 2002) only abundance categories were recorded. Even after 2003 there have been a few cases when observers recorded an abundance category instead of a count for a species—usually because there were too many fish for the observer to reliably count all of the species that were present. Fish are identified to species where possible, and in some cases are separated into adults and juveniles or males and females. Although the taxonomic resolution has remained constant over time, in many cases adults and juveniles were counted together prior to 1999 and separated into adult and juvenile categories from 1999 onward.

During the roving diver fish count, divers gradually swim around the transect line, covering the entire transect area in 30 minutes. The sampling area encompasses ten meters on both sides of the 100 m main transect yielding a total sampling area of 2000 m². Throughout the fish count, each diver attempts to search all habitats (i.e. bottom, midwater, under ledges, canopy, etc.) counting all fish observed. Divers attempted to count each fish only once, although some double counting likely occurs, particularly for more mobile species. Each observer is assigned an individual skill level rating based on their experience, but only data from the most experienced observers (i.e., “expert”) is included here. An “expert” is defined here as an observer who can confidently identify and count all species of fish that commonly occur at the Channel Islands. For each species, the total count or abundance category are recorded by each observer separately—there may be from 1-8 separate expert counts done at a site on one date and from 1-12 expert counts done at each site in a year.

Table 11: Definition of fish abundance categories

Abundance Category	Equivalent Count
Single	1
Few	2-10
Common	11-100
Many	100+

II.D.2.b. Fish size-frequency data:

Table 12A: Definition of column headers in the fish size-frequency data

Table 12B: Definition of variables in the fish size-frequency data
Fish size-frequency data: ASCII file in comma separated values format

II.D.2.b.i. Fish size-frequency methods:

The KFMP collects data on fish size-frequency to help capture changes in the size structure of the fish community that would not be apparent from simple counts. This sampling method is performed during or after the roving diver fish count with a minimum sampling time of 30 minutes. As with the RDFC, the observer will sample as much of the 2000 m² area (ten meters on either side of the 100 m permanent transect line) as possible. Within this area and time, the sizes of as many individuals as possible are estimated, prioritizing certain species as described below. Observers for this protocol are trained, tested and able to accurately estimate fish sizes underwater to within 20% of the actual total length (TL). Observers estimate the total length of fish to the nearest centimeter searching all habitats (i.e. bottom, midwater, under ledges, water column, canopy, etc.). When schools of fish of the same species are encountered at a site, the mean size of individuals in that group is estimated, as well as the number of fish in the group, and the size of the largest and smallest individuals.

All fish observed are measured except cryptic species (e.g., sculpins and sand dabs) and schooling baitfish (e.g., such as sardines, anchovies and smelt). Some measured species are given priority over others, with species ranked by priority categories from 1 (highest) to 4 (lowest) as indicated in the dataset. Fish species are prioritized to ensure that particular target species are sampled even if time does not allow for sampling all fish at the site. As of autumn 2012 it has been possible to sample the fish community completely for the top three priority levels, so the size structure of fish given priority 1, 2 or 3 can be considered complete (i.e., sizes were recorded for all fish of those species encountered).

II.D.2.c. Invertebrate size-frequency data:

Table 13A: Definition of column headers in the invertebrate size-frequency data
Table 13B: Definition of variables in the invertebrate size-frequency data
Invertebrate size-frequency data: ASCII file in comma separated values format

II.D.2.c.i. Invertebrate size-frequency methods: The KFMP collects data on the size structure of populations of key invertebrate species to help capture changes in those populations that might not be apparent from simple measures of abundance. The number of individuals measured has varied among species, sites and years. A diver records the sizes of individuals of each target species, completely searching swaths running parallel to the main transect, with the spacing and length of these swaths chosen to gather a representative sample from the entire 100 m transect line. When there are relatively low densities of the target species, the observer conducts one long swath; when densities are very high, observers may sample haphazardly placed areas as small as 0.5 m². In every case all target organisms within the chosen area are measured to ensure that an unbiased sample of sizes is obtained. For *Stylaster californica*, *Lophogorgia chilensis*, *Muricea fruticosa* and *Muricea californica* we report the estimated area of the fan in cm² based on measurements of height and width (made to the nearest centimeter) and assuming an oval fan shape. All other invertebrate measurements are made in centimeters—measuring the diameter of

the test for urchins, the longest dimension of the shell for gastropods and the distance from the mouth to the end of the longest arm for sea stars. Measurements are made to the nearest 0.1 cm *in situ* with minimal disturbance to the organisms, except for sea urchins, which are lifted (if possible) to search for juveniles under the spine canopy of large adults.

II.D.2.d. Giant kelp size-frequency data:

[Table 14A](#): Definition of column headers in the giant kelp size-frequency data

[Table 14B](#): Definition of variables in the giant kelp size-frequency data

[Giant kelp size-frequency data](#): ASCII file in comma separated values format

II.D.2.d.i. Giant kelp size-frequency methods: The KFMP collects data on the size structure of giant kelp, *Macrocystis pyrifera*, greater than 1 m tall at each site where it is present, to help capture changes in kelp populations that might not be apparent from simple measures of its abundance. Giant kelp sizes are measured within a swath running along the entire length of the permanent 100 m transect. If giant kelp are rare at the site all plants within 10 m of the transect will be sampled, otherwise a narrower swath is sampled, with a width chosen to include at least 100 individuals. Within the sampling area all plants encountered are measured. For each plant, the number of stipes one meter above the bottom is recorded, as well as the greatest diameter of the holdfast, measured to the nearest centimeter. In some cases holdfasts were not measured and the code “NA” indicates this.

II.D.2.e. Giant kelp supplementary density data:

[Table 15A](#): Definition of column headers in the giant kelp supplementary density data

[Table 15B](#): Definition of variables in giant kelp supplementary density data

[Giant kelp supplementary density data](#): ASCII file in comma separated values format

II.D.2.e.i. Giant kelp supplementary density methods: In addition to the data on *Macrocystis pyrifera* included in the benthic density dataset (section II.D.1.a.), the KFMP has collected additional data on the abundance of this species since 1996. The benthic density dataset, collected since 1982, reports the abundance of giant kelp adults and juveniles, with adults defined as plants with one or more stipes taller than 1 meter. It provides a very useful time series, but because it is derived from the 1 m² quadrats (section II.D.1.a.ii.) the total area sampled is small (less than 40 m²). Since 1996 the KFMP has recorded two additional metrics of kelp abundance, measured in the 5 m² quadrats (see section II.D.1.a.iii. for sampling methods): the density of adult giant kelp (plants greater than 1 m tall and possessing haptera above the primary dichotomy) and the density of sub-adult giant kelp (plants greater than 1 m tall without haptera above the primary dichotomy). Note that the adult and sub-adult plants counted here would both be considered “adult” in the core benthic density dataset. Since 2007 the KFMP has also estimated the density of stipes on plants greater than 1 m tall within the 1 m² quadrats (counting stipes without respect to what plant they are found on. Summer stipe density is a strong predictor of total giant kelp biomass and production (Reed et al. 2009). In the giant kelp supplementary density we report the mean of each measure of density at the site, averaged over

all replicates within the site for a given year. Also included are the standard error in density calculated across the sampling replicates, the number of replicates and the area sampled in each replicate.

II.D.2.f. Artificial recruitment module data:

Table 16A: Definition of column headers artificial recruitment module data

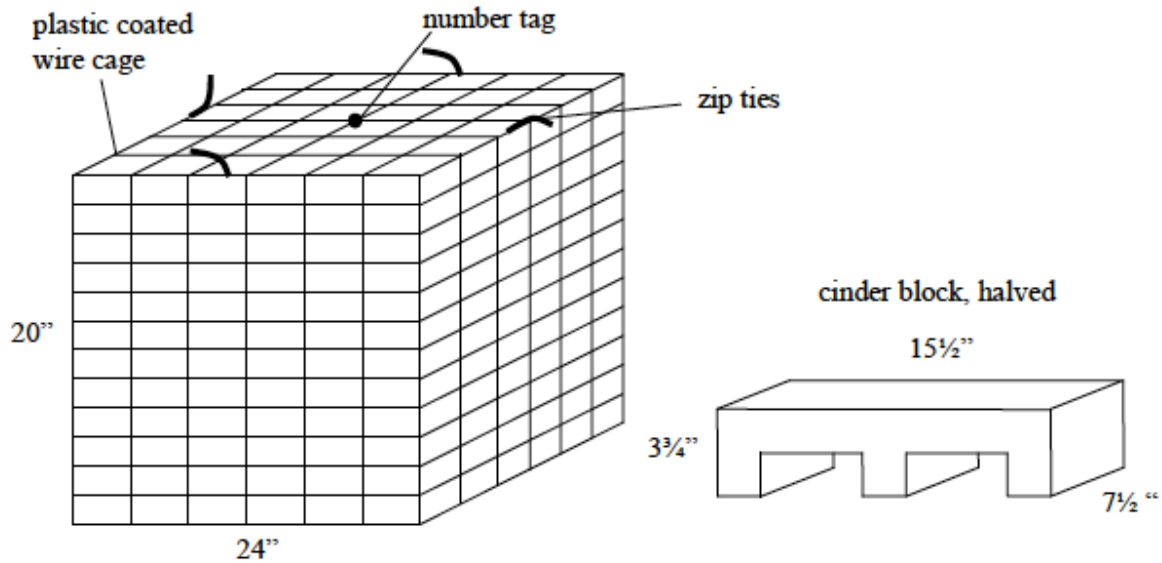
Table 16B: Definition of variables in the artificial recruitment module data

Artificial recruitment module data: ASCII file in comma separated values format

II.D.2.f.i. Artificial recruitment module methods: Artificial recruitment modules (ARMs) were placed at 11 sites starting in 1992 and selected organisms accumulating within them have been sampled each summer. The number and location of ARMs varies from site to site (typically 5-15 per site). Each artificial recruitment module consists of a wire cage made of 2" x 4" mesh wire (Figure 7) filled with 20 bricks that serve as recruitment substrates. Bricks are placed in the ARM in five layers with four bricks per layer arranged around the internal perimeter of the ARM, leaving an opening in the center of each row. Bricks are made by cutting a concrete cinder block in half longitudinally to produce 2 bricks, each with a cross section shaped like a lower case "m" (Figure 7). More details on the construction of the ARMs are given in Davis (1995).

To sample each ARM, the bricks are removed from the cage and all target organisms are collected, counted and sized to the nearest mm—measuring the diameter of the test for urchins, the widest dimension of the shell for gastropods and the distance from the mouth to the end of the longest arm for sea stars. *Parastichopus parvimensis* are not measured but are instead classified as larger or smaller than 10cm. Mean size and the associated standard error are reported for all species except *P. parvimensis*, for which only the fraction less than and fraction greater than 10cm are reported. If there are 200 or more *Strongylocentrotus purpuratus* or *S. franciscanus* per ARM, not all of the ARMs are sampled for these two species. In some cases, organisms are brought to the surface to be measured. After sampling all of the bricks and organisms are replaced in the ARM.

Figure 7: Example of an Artificial Recruitment Module (ARM).



II.D.2.g. Subtidal temperature data:

[Table 17A](#): Definition of column headers subtidal temperature data

[Table 17B](#): Definition of variables in the subtidal temperature data

[Subtidal temperature data](#): ASCII file in comma separated values format

II.D.2.g.i. Subtidal temperature methods: Since 1993 the KFMP has used automated loggers to measure water temperature at the monitoring sites over time. At each site, temperature loggers programmed to record temperature are bolted to the substrate. Loggers record temperature between 5 and 24 times a day, depending on logger memory capacity. Records are then averaged over each 24 hour period. The depth of the loggers at each site is listed in Table 1. In most years, two temperature loggers are deployed at each site. Loggers are serviced and data collected once per year during the summer sampling.

Upon retrieval, the data from the two loggers are compared and if the recorded temperatures differ by more than 0.2 C, the loggers are independently checked to determine which is most accurate and data from that logger is used. On the rare occasion that both loggers fail or are missing, no temperature data is entered into the dataset for that site and year, so there are a few gaps in the time series. Several brands of temperature logger have been used at different periods, with some overlap, including HoboTemp, StowAway, Tidbit and UTBI Tidbit V2 loggers (all made by the Onset Computer Corporation).

Class III. Data set status and accessibility

- A. Latest data update
- B. Latest metadata update
- C. Data verification
- D. Copyright or proprietary restrictions

III.A. Latest data update: The dataset may be periodically updated. All updates to the data have been logged in [Table 18A](#). Please check for the latest update before using the dataset.

III.B. Latest metadata update: The metadata may also be updated periodically. All updates have been logged in [Table 18B](#). Please check for the latest update before using the dataset.

III.C. Data verification: Field sheets were proofed for concerns after every day in the field as well as during data entry.

III.D. Copyright or proprietary restrictions: None

Class IV. Data set structural descriptors

- A. Data files
- B. Metadata tables

IV.A. Data Files:

[Benthic density data](#)

[Benthic cover data](#)

[Fish density data](#)

[RDFC data](#)

[Fish size-frequency data](#)

[Invertebrate size-frequency data](#)

[Giant kelp size-frequency data](#)

[Giant kelp supplementary density data](#)

[Artificial recruitment module data](#)

[Subtidal temperature data](#)

[To download a .zip file containing all data files in .csv format click here.](#)

(2024 kb, md5: 5F01E2DF6FB5BD5C00B8E4738565C08A)

IV.B. Metadata Files:

[Table 1:](#) Monitoring Sites and Their Coordinates

[Table 2:](#) History of special fishing restrictions

[Table 3:](#) Species Monitored by Method and Year Monitored

[Table 4A:](#) Definition of Column Headers in the Benthic Density Data

[Table 4B:](#) Definition of Variables in the Benthic Density Data

[Table 7A:](#) Definition of column headers in benthic cover data

[Table 7B:](#) Definition of variables in the benthic cover data

[Table 9A:](#) Definition of column headers in fish density data

[Table 9B:](#) Definition of variables in the fish density data

[Table 10A:](#) Definition of column headers in RDFC data

[Table 10B:](#) Definition of variables in the RDFC data

[Table 12A:](#) Definition of column headers in the fish size-frequency data
[Table 12B:](#) Definition of variables in the fish size-frequency data
[Table 13A:](#) Definition of column headers in the invertebrate size-frequency data
[Table 13B:](#) Definition of variables in the invertebrate size-frequency data
[Table 14A:](#) Definition of column headers in the giant kelp size-frequency data
[Table 14B:](#) Definition of variables in the giant kelp size-frequency data
[Table 15A:](#) Definition of column headers in the giant kelp supplementary density data
[Table 15B:](#) Definition of variables in the giant kelp supplementary density data
[Table 16A:](#) Definition of column headers in the artificial recruitment module data
[Table 16B:](#) Definition of variables in the artificial recruitment module data
[Table 17A:](#) Definition of column headers in the subtidal temperature data
[Table 17B:](#) Definition of variables in the subtidal temperature data
[Table 18A:](#) History of data updates
[Table 18B:](#) History of metadata updates

[To download a .zip file containing all metadata files in .csv format click here.](#)
(31 kb, md5: ECD4F8FE818547D5518C0B8C016770E9)

Class V. Supplemental descriptors

- A. Location of completed data forms
- B. Data entry verification procedures
- C. Publications using the data set

V.A. Location of completed data forms: Original field data forms are archived at the Channel Islands National Park office. All forms are scanned and stored electronically in PDF form on the park's network server.

V.B. Data entry verification procedures: See III.C.

V.C. Publications using the data set:

Babcock, R. C., N. T. Shears, A. C. Alcala, N. S. Barrett, G. J. Edgar, K. D. Lafferty, T. R. McClanahan, and G. R. Russ. 2010. Decadal trends in marine reserves reveal differential rates of change in direct and indirect effects. *Proceedings of the National Academy of Sciences of the United States of America* 107:18256-61.

Behrens, M., and K.D. Lafferty. 2004. Effects of marine reserves and urchin disease on southern Californian rocky reef communities. *Marine Ecology Progress Series* 279:129-139.

Byrnes, J., J. J. Stachowicz, K. M. Hultgren, A. Randall Hughes, S. V. Olyarnik, and C. S. Thornber. 2006a. Predator diversity strengthens trophic cascades in kelp forests by modifying herbivore behaviour. *Ecology letters* 9:61-71.

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