Monitoring Kelp Forest Ecosystems

A Guidebook to Quantifying Biodiversity, Ecosystem Health, and Ecosystem Benefits

KELP FOREST ALLIANCE

OCEAN WISE

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Ocean Wise acknowledges that we are headquartered on the traditional, ancestral, and unceded lands and waters of the xʷməθkʷəy̓ə (Musqueam) Sḵwxwú7mes (Squamish), and səl̓ílwətaɬ (Tsleil-Waututh) Peoples.

In addition to the explicit consideration stated in this document, we acknowledge that all conservation works involving the traditional lands and seas of Indigenous people must be co-developed, create space for leadership, and integrate Traditional Ecological Knowledge into the decision-making process. We kindly invite any person or group to contact us to provide comments on this document and/or develop new kelp conservation programs.

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SUMMARY

This guidebook is intended to equip the global community with practical knowledge contributing to the protection and restoration of kelp forests around the world.

Kelp forests (Orders Laminariales and Fucales) are important marine ecosystems for subtropical, temperate, and arctic oceans around the world. These underwater forests support marine biodiversity by being home to thousands of fish species, invertebrates, and other algae. Kelp forests also provide direct and in-direct benefits to 750 million people residing within 50 km of a kelp forest. Notably, kelp forests are a key source of primary production on rocky reefs, cycling nutrients from the water, producing oxygen, changing the pH, and supporting the local environment.

Humans rely on kelp forests for food, numerous by-products, the fisheries they support, as well as cultural and spiritual connections to the sea. Kelp forests are also the focus of scientific research, marine management programs, restoration projects, and conservation finance initiatives. However, due to a multitude of local and global stressors, approximately 50% of kelp forests around the world have been degraded over the last half century.

The Kelp Forest Alliance and Ocean Wise have created this guidebook to provide an overview of the different methodologies for monitoring kelp forest ecosystems, provide instructions for restoration practitioners and stewards of kelp forests. Any project that monitors kelp forest ecosystems should find this guide to be a valuable resource to track the extent, health, and associated benefits of kelp forests. As the field grows, the standardized approaches described here will help information sharing, synthesis studies, and the communication of the benefits of kelp forest ecosystems. The guidelines are presented as the best available information and will be updated as the field grows with new technologies and research.

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ACRONYMS AND ABBREVIATIONS

Acronym/ Abbreviation	Term
°C	Degree Celsius
AI	Artificial Intelligence
AUV	Autonomous Underwater Vehicle
BA	Biomass accumulated
BACI	Before-After-Control-Impact
BRUV	Baited remote underwater video systems
C	Carbon
cm	Centimetres
CO_2	Carbon Dioxide
DFO	Department of Fisheries and Oceans
DW	Dry Weight
e.g.	For example
eDNA	Environmental DNA
EMODnet	European Marine Observation and Data Network
FAIR	Findable, Accessible, Interoperable, and Reusable
FW	Convert fresh weight
g	Grams
GBIF	Global Biodiversity Information Facility
GIS	Geographic information system
GPS	Global Positioning System
ha	Hectare

Acronym/ Abbreviation	Term
ICOAD	International Comprehensive Ocean and Atmosphere Dataset
ID	Identification
IMOS	Integrated Marine Observing System
KFA	Kelp Forest Alliance
kg	Kilograms
km	Kilometres
km^2	Square kilometres
L	Length
LiDAR	Light Detection and Ranging
m	Metres
m^2	Square metres
Max N	Maximum number of species or individuals seen in a single video frame
mg/L	Milligrams per litre
mm	Millimetre
N	Nitrogen
N/a	Not Applicable
NPP	Net Primary Productivity
Num	Number of People
P	Phosphorus
pH	Expression of acidity in a solution
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans

Acronym/ Abbreviation	Term
ppm	Parts per million
PPT	Parts per thousand
PSU	Practical salinity unit
QA/QC	Quality assurance and quality control
ROV	Remote underwater vehicle
SCUBA	Self-Contained Underwater Breathing Apparatus

Acronym/ Abbreviation	Term
SI	International System of Units
t	Tonnes
UPC	Unified point contact
W	Weight
μmol	Micromoles

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CHAPTER

1.0 INTRODUCTION

1.1 WHY MONITOR KELP FOREST ECOSYSTEMS

As key marine habitats along approximately 36% of the world's coastlines (Figure 1, Jayathilake & Costello, 2021), kelp forests support immense biodiversity (Teagle et al., 2017), have cultural significance to many Indigenous Peoples and coastal communities, and influence the chemical and physical characteristics of coastal ecosystems (Cuddington et al., 2009). The extent, condition, and services provided by kelp forest ecosystems therefore have significant impacts on ocean health as well as the wellbeing of coastal and non-coastal societies (Bennett et al., 2016; Blamey & Bolton, 2018; Eger et al., 2023).

Economically, kelp forests provide between USD $64,000 and $147,000 per hectare per year and are globally worth $500 billion (Eger et al., 2023). Changes in kelp forest extent and condition are often linked to changes in cultural and commercially important species such as abalone, lobster, and other fishes (Frimodig & Buck, 2017; Giri & Hall, 2015; Mayfield et al., 2012). Kelp forest loss is linked to local biodiversity loss; key coastal fisheries often closed following the decline of a kelp forest, such as in California (Reid et al., 2016) and Japan (Eger et al., 2020). Kelp forest decline can also reduce tourism, cultural identities, nutrient and carbon cycling, jobs, recreational opportunities, and other benefits provided by kelp forests. Monitoring kelp forest ecosystems can therefore provide understanding about changes in these benefits and create appropriate management plans if those benefits are at risk.

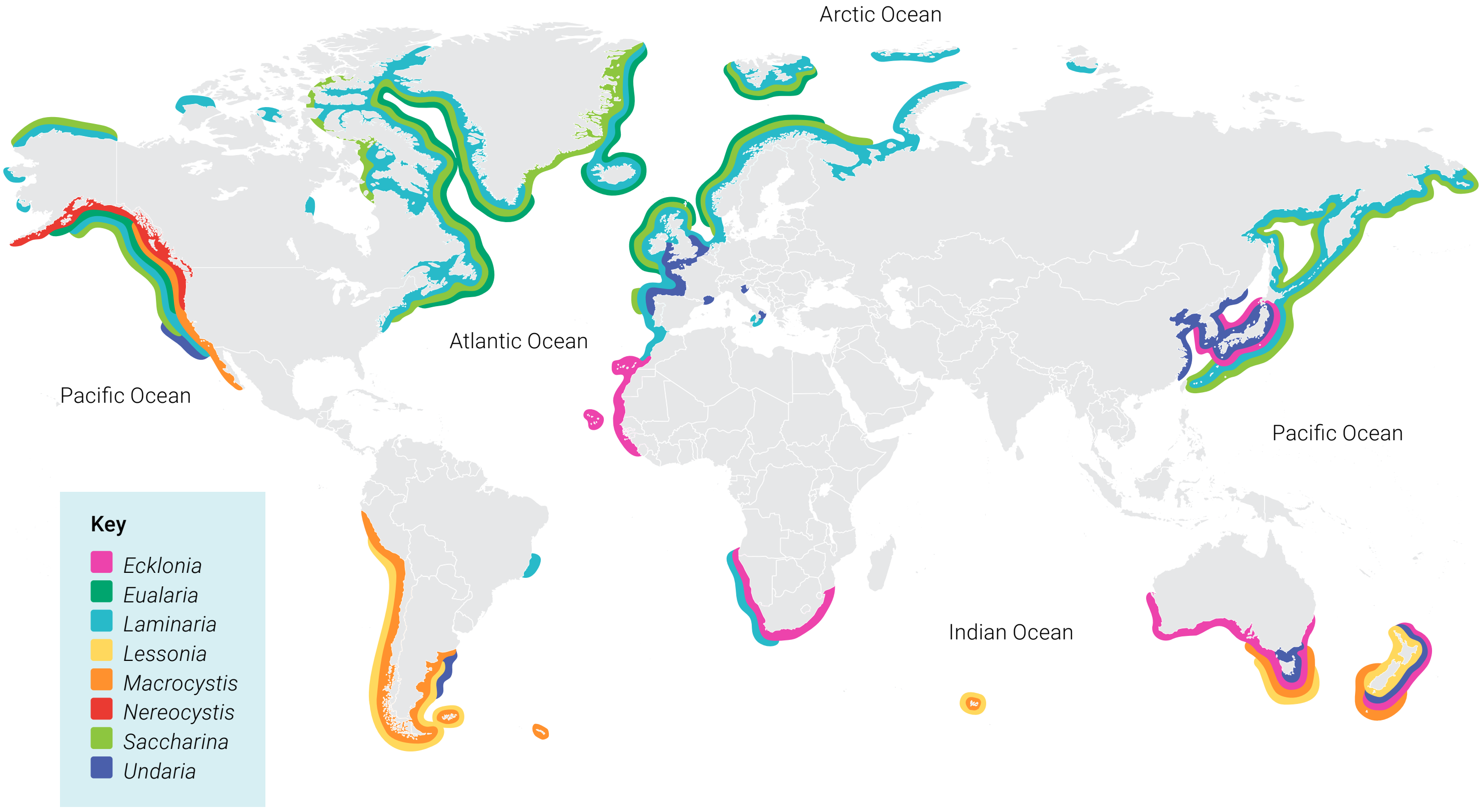

Figure 1. Global map of kelp forest distribution. This map was modified and adapted from Smale (2019), Eger et al. (2022), and Eger et al. (2023).

1.1.1 RESEARCH AND LONG-TERM MONITORING

Attributes and functions of kelp forests inherently interest ecological researchers. Robustly and consistently monitoring these ecosystems provides quality data for addressing scientific research questions and testing ecological theories. Collecting standardized information also enables better data pooling, easier collaborations, and easier answering of questions to be answered at regional and/or global scales. Repeated standardized data collection at the same site over time provides valuable information about seasonal variability, ecosystem health, and the drivers of that health.

1.1.2 CONSERVATION TRACKING

Marine managers require data on kelp forest ecosystems to assess the outcomes of interventions such as protection or restoration, to create environmental accounts, to inform management strategies and priorities, and ultimately to track progress towards local and international management targets such as the targets two and three (i.e., 30x30) of the Kunming-Montreal Global Biodiversity Framework.

1.1.3 DECISION MAKING

As ecosystem services are increasingly considered in decision making, these services are increasingly given a market or economic value, either to communicate their importance or create financial instruments such as carbon or biodiversity credits to fund conservation and restoration efforts. Good ecological data is the foundation of any such instrument and a monitoring and verification framework is needed to report and validate the creation of any kelp forest finance mechanism.

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1.1.4 CONSERVATION FINANCE

Private organizations are increasingly considering conservation finance mechanisms such as carbon credits, biodiversity credits, payments for ecosystem services, and blue bonds. While the specifics of these mechanisms differ, they are based on quantifying and then monetizing attributes of an ecosystem (e.g., carbon capture, biodiversity, fisheries production). A monitoring and reporting framework therefore underpins the development and use of any of these mechanisms. Eger et al. (2022) have outlined steps and processes related to kelp forest restoration.

1.1.5 MONITORING BY DIFFERENT END USE

The needs of a monitoring program will vary depending on the nature of the project involved. For example, a research program might need short-term, highly detailed information, while a conservation program might need longer-term data focused on only one or two key indicator variables over a larger area. Table 1 provides a summary of how a monitoring program might be designed to meet different end users' needs.

Table 1. Different requirements for different motivations for monitoring.

	Research & Monitoring	Conservation Tracking	Decision Making	Conservation Finance
Frequency	Low	High	High	Low–Medium
Accuracy	High	Medium	High	High
Scale	Low	Medium–High	High	Low–High

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1.2 DEVELOPING A KELP FOREST MONITORING AND VERIFICATION FRAMEWORK

As the need for quality data on the extent, condition, and benefits of kelp forest ecosystems increases, it is imperative that we develop a standardized approach for collecting such information. Using a standardized reporting framework can help understand the impact of conservation interventions, inform evidence-based decision making, reduce reporting biases, allow for standardized tracking of restoration projects globally and comparability of data, ensure sufficient information is collected, and increase information-sharing across projects.

The purpose of this guidebook is to:

- Develop a standardized monitoring and reporting framework for kelp forest ecosystems around the world.
- Ensure the framework is applicable across sectors and user types.
- Encourage the adoption of such a framework.
- Describe the methods for monitoring kelp forest extent, condition, and benefit.
- Provide recommendations about the most cost-effective approaches currently available for monitoring and reporting.
- Identify areas of rapid development that may change how kelp forests are monitored in the future.
- Encourage the management, protection and restoration of kelp forests.

CHAPTER

2.0 PRINCIPLES OF MONITORING AND REPORTING

Monitoring kelp forest ecosystems and their associated benefits involves in-water, on-water, and land-based or aerial observations and measurements. In-water surveys use people, cameras, or a combination of the two to assess kelp forests under the water; examples include Self-Contained Underwater Breathing Apparatus (SCUBA) surveys, snorkel surveys, automated underwater vehicles, or towed and/or stationary cameras. On-water surveys are conducted by a powered or unpowered vessel from the surface, for instance, a kayak or a boat. Above-water surveys are done from the air and include drone surveys, aerial imaging, and satellite imaging, and must be processed by software or personnel. No one method is perfectly suited for all applications, and each has pros, cons, and relative expenses. This guidebook provides an overview of the different approaches, gives basic instructions for their application, and provides insights into the costs associated with each.

2.1 OBJECTIVES

When designing a monitoring program connected to a conservation intervention, there are several key concepts that are important to consider to help determine if the intervention resulted in the desired changes. Establishing clear objectives and using systematic and standardized monitoring protocols before and after the intervention are critical (Gleason et al., 2021).

The motivations for a conservation intervention are to alter or maintain a key parameter, (e.g., maintain or increase kelp forest area or biodiversity, or reduce a problematic species). It is best practice to assess the selected parameters against a 'reference' ecosystem (e.g., healthy kelp forest density) or a preselected target (e.g., jobs created). Therefore, an important first step for any intervention is to identify the objectives or reference conditions that will determine success. A reference ecosystem or site will ideally be a healthy, local, natural kelp forest that has similar environmental parameters as the intervention site and is representative of the intervention objectives (e.g., contains the relevant species). Other objectives can be value-based but should be determined by what is desirable and achievable (e.g., water pollution concentrations, jobs created, tourism visits, research questions answered, etc.).

Defining clear objectives helps determine whether the desired outputs have been achieved or maintained. This ensures the most efficient use of monitoring resources and can aid adaptive management or flexible decision-making.


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2.2 MONITORING PERIOD

Kelp forests are naturally dynamic ecosystems (Weigel & Pfister, 2019), and the outcomes of conservation interventions may take years to materialize (Figure 2). Monitoring programs should therefore be long-term and collect adequate information to make robust assessments about the impacts of conservation interventions (e.g., restoration, pollution clean-up, etc.) as well as the long-term condition of the ecosystem. If monitoring is related to a conservation intervention, monitoring should begin before the intervention and continue for a duration that encompasses short (less than one year) and medium-term (one to five years) goals, as the recovery of marine ecosystems and their associated services can take over a decade (Neubauer et al., 2013; White et al., 2020). The duration of other monitoring projects depends on the project's requirements. Whereas scientific research projects may only require a single season or year of data sampling, long-term monitoring programs assess and report on the ecosystem for decades.

2.3 SEASONALITY AND MONITORING

To ensure the accuracy of habitat monitoring programs, it's important to consider the seasonality and frequency of sampling, which is sometimes overlooked. Natural variations in environmental and biological metrics can occur due to seasonal changes, leading to misinterpretation of impacts from restoration activities such as animal presence or changes in water quality. Seasonality also influences the kelp's reproductive cycles, growth patterns, and perennial or annual survival. Therefore, monitoring of specific metrics should align with seasonal patterns and annual monitoring should take place at the same time each year. Additionally, monitoring frequency should be tailored to the metric being assessed. For instance, lower-frequency sampling, such as monthly or seasonal, may suffice for metrics like adult canopy cover. However, higher-frequency sampling, such as weekly monitoring, may be required for metrics where responses are more rapid or unknown, such as the survival of out-planted juvenile kelp.


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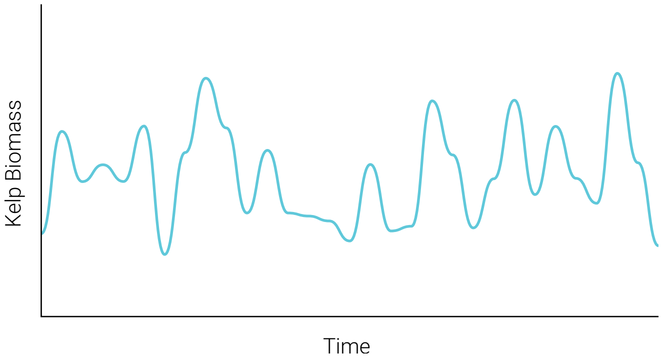

Figure 2. Natural population dynamics of a kelp forest ecosystem.

Seasonal variation in ecosystem services varies across localities. However, as a general rule, you may expect to find certain seasonal patterns:

- **Spring:** During this period of growth, which coincides with spawning season for some animals, kelp biomass may be high.
- **Summer:** Biodiversity may be highest in summer as transient species move in with the warmer waters. Summertime may maintain high levels of growth, but high temperatures can cause stress and kelp die-off, notably in heatwave years.
- **Fall:** In the fall, some kelp may experience a second round of growth as the water cools.
- **Winter:** In the cold winter months, kelp grows at a very slow rate, but cool waters may support higher densities. Annual kelp will die off during this period. Late winter may be the start of the reproductive cycle.

2.4 ADDITIONALITY AND THE BEORE-AFTER-CONTROL-IMPACT DESIGN

Additionality describes the extent to which a phenomenon occurs as a result of an intervention that would not have happened without it. To assess the impact of a conservation intervention, monitoring should be conducted both before and after the intervention at the intervention site, as well as at a control site. A "Before-After-Control-Impact" or BACI approach can be applied in kelp restoration hypothesis testing. The control site should represent the pre-restoration conditions, typically an unrestored area or unimpacted site.

A BACI approach, combined with a reference site as a target, enables fair comparisons between different sites and their conditions over time, allowing for accurate evaluation of restoration effectiveness. This approach not only evaluates improvements at the restoration site but also assesses the trajectory of recovery and how the restored site performs relative to the reference site. To enable valid comparisons, control and natural reference sites should be sampled at the same time of year and have similar physical characteristics to the restoration site, such as flow, exposure to wave action, tidal height, salinity, water temperature, substrate type and rugosity, and water depth. We suggest prioritizing temperature, depth, wave exposure, and salinity if it is not possible to match all the characteristics. When pre-restoration monitoring is not feasible, comparing the restored and control sites becomes even more crucial, and findings should be supplemented with comparisons to a reference kelp forest, where possible.

Projects that are aimed at maintaining a single parameter (e.g., biodiversity), mitigating a stressor (e.g., improving water quality), or simply monitoring conditions, may choose not to monitor a reference site if it is not necessary for their project objectives.

Figure 3. Illustration of patch dynamics and kelp bed boundaries in kelp forest ecosystems

2.5 ESTABLISHING PROJECT BOUNDARIES

Before monitoring starts, it is important to delineate the site boundaries so that there is a clear definition of the monitoring area (Figure 3). This distinction will determine the space over which monitoring should occur and if project objectives have/have not been met. We recommend that all projects use discrete spatial units or management areas. Larger projects may combine these units for a more comprehensive assessment, but creating individual spatial units allows for more thorough consideration of the outcomes of the restoration project. A spatial unit may be a kelp forest at a distinct location or marine feature, such as a cove, bay, headland, jetty, beach, or contiguous coastline. These units should be defined using calibrated GPS coordinate systems.

2.6 HOW TO USE THIS GUIDE TO MONITOR A KELP FOREST

The core attributes of a kelp forest habitat can be broken into two elements: the extent and the condition. The extent refers to the size of the habitat (i.e., the area footprint), while the condition refers to the state (i.e., health of that habitat within the defined area). Monitoring both is required to robustly assess the outcomes of a restoration project. There are numerous variables that should be measured, but each additional measurement requires more time and resources. We recognize that not all projects will want or be able to measure all these variables. Projects should therefore consider which elements are most important to them and decide on a monitoring plan before starting restoration.

Costs are inevitably an important factor when determining which variables to monitor. The exact cost of monitoring will vary between years, regions, and approaches. Nevertheless, we provide rough approximations of the cost per hectare (ha) (Table 2) for the monitoring methods outlined in this document. These costs are then summarized at the end of each section.

Table 2. Relative and approximate costs of monitoring methods, standardized per hectare.

Cost	USD per hectare (ha)
Low	< $1000
Medium	$1000–2000
High	$2000–5000
Very High	> $5000


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2.7 SIX KEY PARAMETERS FOR KELP FOREST MONITORING

We recommend that every project monitor and record the "key parameters" when possible. These are the most valuable metrics assessing the extent and health of a kelp forest ecosystem, project success, and project inputs. Depending on their goals, projects may track additional parameters beyond these six. Users should see the sections below for information on additional parameters to monitor.

Users should also choose how often they wish to measure these parameters. We recommend endeavouring to capture seasonal variation if possible. If this is not possible, projects should compare values from the same season. We provide minimum monitoring suggestions below (Table 3). It is always better to have more sample points, but projects must balance this with higher costs. Consider that winter may have the lowest biomass, spring is a period of growth, summer may be exposed to extreme heat events, and that many species have seasonal variation in their reproduction.

Table 3. Key parameters and monitoring frequency.

Parameter	Reason	Frequency (With intervention)	Frequency (Without intervention)
Area Extent	Understanding what size area you are monitoring.	• Before intervention • 2–4x/year in the first 2 years • 1x/year after 2 years	1–2x/year
Kelp Density	Understanding of the "health" of the kelp forest.	• Before intervention • At least 2x/year in the first 2 years • 1x/year after 2 years	1–2x/year
Biodiversity and Animal Density (Fish and Invertebrates)	Understanding of the species in a kelp forest as well as their productivity.	• Before intervention • 2–4x/year in the first 2 years • 1x/year after 2 years	1–2x/year
Water Temperature	A common stressor and cause of failure for restoration projects	• Before intervention • 2–4x/year in the first 2 years post intervention • 1x/year after 2 years	1–2x/year
Herbivore Population Size	A common stressor and cause of failure for restoration projects	• Before intervention • 2–4x/year in the first 2 years post intervention • 1x/year after 2 years	1–2x/year
Cost of Activity, Including People Employed in Conservation	An important factor to understand the resources required and the social benefits of restoration	• 1x/year	1–2x/year

2.8 WORKFLOW

Below are the details of a basic workflow for projects monitoring the six key parameters provided in Table 3.

KELP FOREST EXTENT

Canopy forming kelp (e.g., *Macrocystis* and *Nereocystis*)

- Kelp forest is less than approximately 10 ha: On-water survey
- Kelp forest is between 10 and 100 ha: Drone aerial survey
- Kelp forest is > 100 ha: Satellite aerial imagery

Non-canopy forming kelp: visible from the surface

- On-water survey with a snorkeler to verify kelp boundaries

Non-canopy forming kelp: not visible from the surface

- SCUBA surveys if the kelp forest is < 4 ha
- Autonomous Underwater Vehicle (AUV) or drop camera surveys for kelp forests > 4 ha

Intertidal kelp

- Drone aerial survey
- On foot with a Global Positioning System (GPS) unit

ECOLOGICAL CHARACTERISTICS

Pelagic biodiversity

- Video (suggested minimum of 8 transects) or visual transect surveys (minimum of 2 transects)

Benthic biodiversity, sea urchin population, and kelp density

- Photo or visual quadrat surveys (suggested minimum of 8 minimum transects, 8 quadrats per transect)

ENVIRONMENTAL CONDITIONS

Establish baseline environmental conditions, prioritize as follows:

- Use existing permanent sensors arrays (< 20 kilometres [km] from site)
- Collect information from global data derived from satellites and models
- If high accuracy is desired, install in water monitor for temperature, point samples for salinity and pH

PROJECT INPUTS

Dollars, including currency, spent on the project

- Salary
- Materials
- Capital costs (e.g., equipment, boats)
- Facility costs (e.g., lab fees)

SITE CHARACTERISTICS

These data help describe the ecological and physical characteristics of the site and help compare data across projects. Some characteristics of a site will not change over time and only need to be collected once. Projects should record:

- Maximum, minimum, and average depth of the site
- Wave exposure
- Substrate composition (e.g. rocks, pebbles, sand, etc.)

CHAPTER

3.0 SURVEY BASICS

3.1 LOGISTICS

Sampling should be conducted to minimize variation between sampling dates (Sections 2.3 and 2.4). Another way to minimize variation is to sample at the same time of day (photoperiod), tide height, and incoming versus outgoing tide. Each of these variables should be documented in your sampling records.

3.2 TRANSECTS

The transect and quadrat method is a very popular method in ecological science. This method relies on surveying a limited area of an ecosystem to get an approximate idea of the conditions for the entire ecosystem.

A transect is an area of the ecosystem used to observe or measure the natural environment. Transects typically vary between 10 and 50 metres (m) in length and are often paired with quadrats (Figure 4, Section 3.3). The task being completed will often determine how many transects you can safely fit in a dive survey performed with one tank of air. Transects are either limited by depth or air consumption, as slower or more deep tasks will allow for fewer or shorter transects per dive.

To define the area in which the user will record species, users must also identify the visual width of the transect. Typical widths are 2–5 m, depending on the visibility. If the visibility is less than this value, the transects should not be conducted.

Note that when completing visual surveys for pelagic and benthic biodiversity, we recommend conducting pelagic surveys before benthic surveys.

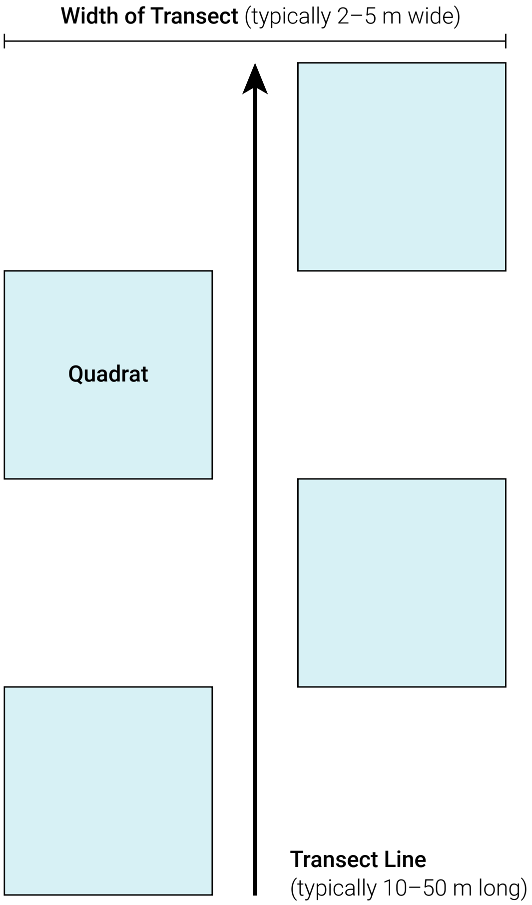

Figure 4. Diagram of a basic transect design.

It is important that transects be surveyed in similar habitats at similar depths. Transects should be run over comparable sections of kelp forests and users are not surveying extremely different habitats, for example, 20 m of sand and 30 m of kelp. If you cannot find continuous habitat patches to run the transect, record which species were recorded in which habitat zone. Similarly, transects should be done at the same depth or similar depths. If you must vary the depth by transect, ensure that the depth of each transect is recorded.

3.2.1 SETTING A TRANSECT

Transects may be laid out using a spooled measuring tape or using a pre-measured, weighted line. The spooled measuring tape can only be laid out and retrieved in the water. The weighted line may be deployed or retrieved from the boat and is also more suitable in areas with high wave actions.

3.3 QUADRATS

Quadrats are simply a square box that may be thought of as a sampling unit. Since it would take too much time to count every kelp or every fish in a kelp forest, we use quadrats to take standardized measures and make inferences about the unsurveyed areas. Quadrats are typically placed at set intervals along a transect (Figure 4) and the user either counts, estimates the area covered, or photographs the contents of the quadrats (i.e., what is laying inside of it). The size of the quadrat varies by what is being measured. If something is high in density or requires a high processing time per quadrat (e.g., removing all kelp biomass), users may select a smaller quadrat (10–25 centimetres [cm] in length and width, 0.01–0.0625 square metres [m^2].) If the user is counting benthic invertebrates or taking a photo for later processing, they may wish to use a larger quadrat (25–100 cm in length and width, 0.0625–1 m^2).

It is important to place the quadrat at the marked intervals along the transect. It may be tempting to shift the quadrat so there is more to count, but this movement will bias the sample and skew the results.

Users can also use quadrats to record depth and different substrate types across the transect.

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3.4 BASIC TOOLS

A transect tape is a measuring tape on a spool so that it can be reeled in and out while being laid across the seafloor.

A quadrat is usually made from one inch (2.4 cm) PVC tubing or rebar. These may have four sides or be simplified down to two sides to make them easier to place in complex marine environments.

3.4.1 DATA QUALITY-CONTROL AND MANAGEMENT

All data should be checked for completeness in the field after it is collected. Users may also take a photograph of the datasheets to act as a backup. Ensure that all data records are digitized as soon as possible and stored with either a local backup or a cloud-based backup (Section 10.0).

Subsequent quality assurance and quality control (QA/QC) checks are an essential part of data management before analysis/reporting. QA/QC processes aim to eliminate errors that may occur when transcribing datasheets to a digital format. General procedures are outlined below:

- Once data are collected, select a person to review datasheets in the field and ensure that everything is entered.
- Enter data into a database or spreadsheet.
- Always compare what is on the datasheets to what is in the database/spreadsheets and not the other way around.
- Be sure to double-check every number so that missing values or values that were added accidentally can be identified and fixed.
- When errors are found, make note of them, and correct them within the database. Keep all changes and notes in a separate spreadsheet as part of your records.
- If needed, refer to the person who collected the data to resolve any discrepancies.

CHAPTER

4.0 KELP FOREST VARIABLES

There are many elements, services, and stressors related to kelp forest ecosystems. Few projects will be able to regularly monitor all these parameters; therefore, projects will therefore need to select the parameters of greatest interest that can be monitored within the project's capacity. We provided instructions on how to monitor the following parameters below (Table 4).

4.1 HABITAT MAPPING

The size (i.e., area) of a kelp forest ecosystem is a core metric when assessing the health of the ecosystem. The size is defined as the area within a polygon that wraps around the perimeter of a kelp forest. This metric is often used to indicate the scale of success for restoration projects or management approaches. Provided the project has density-based estimates (e.g., X value/m^2) of the ecosystem services, the area of kelp forest can be used to estimate the total benefits provided by a restoration project or management approach.

4.1.1 DELINEATING A KELP FOREST

Determining the size of the kelp forest will depend on the scale of the project. This determination is further complicated by the fact that kelp forests are often patchy habitats and may have gaps in coverage but could still be considered a single unit. We recommend that projects create spatial units based on a single location (e.g., cove, beach, headland, point, bluff, etc.) and set a fixed distance, after which they consider a new unit of kelp forest to begin. For instance, if there is 10–50 m of bare rock habitat between aggregations of kelp, these two patches could be considered separate, and the bare rock area would not be included in the assessment. Conversely, if there was 2 m of non-kelp forest habitat between the patches, they could be considered functionally the same forest, and the small amount of bare rock is considered in the area assessment (Figure 3). While it is desirable to map the habitat while noting small scale gaps in canopy cover, this requires high resolution data, which may not be

Table 4. Overview of metrics included in this guidebook.

Kelp Characteristics	Regulating Services	Provisioning Services	Cultural Services	Biophysical and Stressors
Kelp Area	Primary Production	Harvested Kelp	Community Engagement	Temperature
Kelp Density	Carbon Uptake	Standing Stock Biomass	Science and Education	Salinity
Kelp Biomass	Nutrient Cycling	Secondary Production	Cultural Connection	pH
Percent Cover	pH Regulation	Biodiversity	Existence Value	Nutrient Levels
	Sedimentation Rate		Recreational Visits	Herbivory
			Person Hours	Disease and Fouling

feasible or economical. Therefore, projects may need to make coarser assessments of kelp habitat areas which ignore such small gaps in canopy cover (10–50 m).

You can determine the area of a kelp forest by charting the perimeter and using spatial mapping software or simple geometry to calculate the size of the restored kelp forest. There are several ways to chart the perimeter of the kelp forest, which we will discuss next.

4.1.2 REPORTING UNITS

We recommend reporting the area of a kelp forest using the International System of Units (SI) such as m^2, ha, or km^2.

4.1.3 MEASUREMENT OPTIONS

The four options for mapping the area of a kelp forest are:

1. In-Water
2. On-Water
3. Aerial
4. On Foot (intertidal only, not covered in this document)

4.1.3.1 IN-WATER

Mapping the perimeter of a kelp forest in water provides the greatest accuracy and may be required for subtidal habitats that are too deep to map using aerial imagery. Conversely, mapping kelp forests in water is limited by the scale that can be covered, either by a boat or a swimmer.

In-water mapping is done by a snorkeler, SCUBA diver, AUV, or towed underwater vehicle. Snorkelers may also use GPS points to map the perimeter while SCUBA divers rely on surveying methods as GPS typically does not work underwater (See Section 11.0 for new technologies). Autonomous and towed video cameras may also be used so long as they are georeferenced on the surface.

4.1.3.2 ON-WATER

On-water methods include using powered or unpowered watercraft to navigate around the edges of the kelp forest while charting perimeter points, either using a GPS or survey equipment.

4.1.3.3 AERIAL SURVEYS

Aerial surveys may be completed using satellites, low altitude aerial imagery, drone surveys, or Light Detection and Ranging (LiDAR). These approaches are more expensive (save freely available satellite data) but can cover the greatest area. They may however be restricted by depth and are best suited for surface canopy forming kelp species (e.g., *Macrocystis*).

4.1.4 BASIC INSTRUCTIONS FOR HABITAT MAPPING

4.1.4.1 AERIAL IMAGERY

A comprehensive overview of mapping canopy forming kelp can be found here. Aerial imagery can be obtained from satellites, via LiDAR and low flying aircraft, and drones. LiDAR and low flying aircraft data usually must be contracted and is therefore expensive. Drone data must be manually collected but provides the opportunity to collect high resolution data with a much lower cost than low flying aircraft.

To obtain aerial imagery from satellites, consult popular databases with freely available information such as LANDSAT or Copernicus. Higher resolution, paid imagery is also available (e.g., Planet Labs). Always make sure to check the date of the imagery as well as its resolution (e.g., LANDSAT 8 had a resolution of 15–30 m).

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Estimating kelp forest area using aerial imagery requires knowledge and expertise in geoinformation software (e.g., ArcGIS, QGIS, etc.). Due to the complexities involved, this guidebook does not provide specific information on this process. However, in short, there are two options: manual classification and automated or supervised classifications.

Manual Classification

1. Import aerial imagery.
2. Georeference images with appropriate datum.
3. Manually create a polygon around the space that you believe is a kelp forest.
4. Calculate the area of that polygon.

Automated or Supervised Classifications

1. Import aerial imagery.
2. Georeference images with appropriate datum.
3. Start the classification process by selecting training points that you know to be kelp forest.
4. Run the remote sensing software to make predictions about kelp forest on unclassified images.
5. Calculate the area of the cells that are classified as kelp forest.

We note that you may also run unsupervised classifications, but this is not recommended as it produces more errors.

If you are a smaller project with a limited area to measure, it is easier to manually classify kelp cover. If you are a larger project, it is more time efficient to train yourself or your team to run the automated classification process.

Further details on how to do the automated classification may be found here.

4.1.4.2 IN-WATER SURVEYS

While in-water surveys may be required to map subtidal kelp forests, this approach can only be applied over smaller kelp forests of less than 1–2 ha in a single dive. Larger forests will require multiple dives.

Steps for a SCUBA In-Water Survey

1. Locate the edge of the kelp forest.
2. Record the compass direction in which the edge of the kelp forest continues.
3. Mark a starting dot on a piece of waterproof paper or underwater slate along with the first declination (compass direction).
4. Place the weighted end of the transect tape at the starting point.
5. Swim the edge of the kelp forest, letting out the measuring tape.
6. Continue swimming until the edge of the forest deviates noticeably (more than 30° for 10 m).
7. Once the edge deviates, stop swimming, mark a new dot, and record the distance measured between the last two points on the paper/slate.
8. Gently reel in the transect tape, taking care not to harm benthic life as you do so.
9. If the measuring tape runs out before a change in direction is noted, note the distance elapsed, reel in the tape, and then follow step seven in the same direction.
10. Take a new declination and repeat the process.
11. Once complete, calculate the area of the polygon that you have charted. The area may be calculated by using geometric calculates (e.g., area of triangle, rectangle, etc.) or by importing the image into a GIS software and georeferencing the polygon and calculating the shape.

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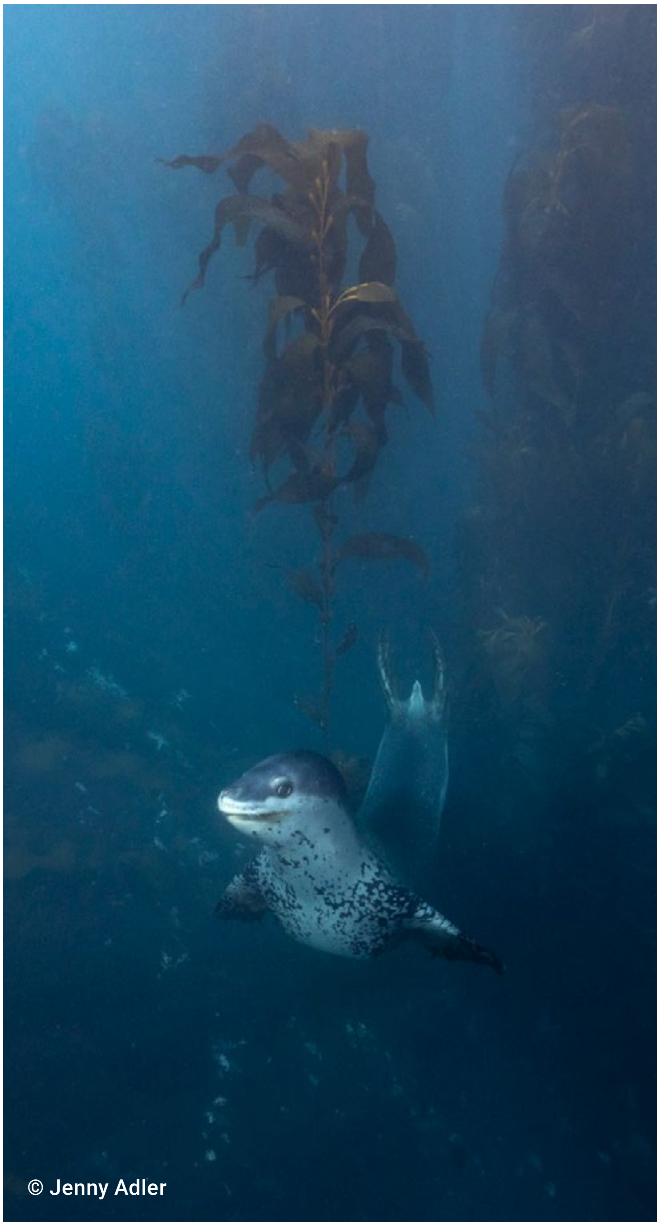
Steps for In-Water Survey with Drop Cameras

The core principle is to move along the perimeter of the kelp forest or map a grid, dropping the camera to the depth of the kelp forest and determining where the edge of the forest is. These points are then mapped with a GPS at the surface. Most drop cameras require an external power source, so projects will be limited to using powered watercraft with a power source. These cameras also require adequate visibility (greater than 3 m) to identify the edge of a kelp forest.

Identify the broader area around the kelp forest or kelp forest patch you intend to monitor. This should encompass the entire forest and some surrounding areas for context. The two steps involved are perimeter mapping and measurement grid creation. We discuss both below.

Map the Perimeter

1. Find the perimeter edge of the kelp forest or kelp forest patch you intend to monitor. Use your GPS to map the perimeter. Waterproof cases and floats are advisable for any GPS units used around water.
2. If your GPS has an accurate tracking function, enable it at your first monitoring point and disable it when you have traversed the length of the perimeter. If not, go to Step 3 below.
3. If your GPS has no tracking function, use your GPS to drop the first pinpoint. Ensure the GPS is calibrated to the highest accuracy possible. This process may require waiting for the device to lock onto the correct number of satellites. Follow the perimeter edge of the kelp forest.
    a. Slowly motor with the camera on, feeding live video.
    b. Assuming you are following a continuous line of kelp forest, create a new GPS point every 20–50 m.
    c. Stop once you have found a break in the kelp forest.
    d. Place a GPS point.
    e. Assess the next direction to follow and repeat the above steps until you have completed the polygon.



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4. Once you have returned to your starting pin, note the titles of the pins. Titles are often sequential numbers: for instance, 113–246. Alternatively, if your GPS allows you to create polygons, close the loop and create the polygon.
5. Import the pins into a geographic information system (GIS) software.
6. Select the pins related to a single kelp bed and convert them into a polygon.
7. Calculate the area of that polygon.

Creating a Measurement Grid

1. Create a Grid Overlay on the Area
    a. Using GIS software or physical map, overlay a grid on the mapped area. The size of the grid squares should be based on the size of the kelp forest and the resolution needed.
    b. Each square in the grid represents an individual area to be monitored with the camera.
2. Map the Grid
    a. Start at the first grid square, using your GPS to navigate accurately.
    b. Slowly move over the grid square with the camera on, capturing live video or taking photographs.
    c. Record the benthic substrate at the centre of the grid cell. Take GPS coordinates at each corner of the grid square or at regular intervals within the square for more detailed mapping.
3. Move to Subsequent Grid Squares
    a. Proceed to the next grid square following a logical sequence (e.g., row-by-row or column-by-column) to ensure complete coverage.
    b. Repeat the camera recording process for each grid square.
4. Marking Incomplete or Unclear Areas
    a. If any areas within a grid square are not clearly visible or mapped due to underwater conditions, mark these as incomplete in your records for potential re-examination.
5. Complete the Grid Mapping
    a. Continue the process until every grid square covering the kelp forest and surrounding area has been mapped.
6. Data Compilation and Analysis
    a. Import GPS data and camera footage into GIS software.
    b. Use the software to stitch together the camera footage or images from each grid square, creating a comprehensive map of the kelp forest.
    c. Analyse the compiled data to assess the health, density, and spread of the kelp forest.
7. Area Calculation and Reporting
    a. Calculate the total area covered by the kelp forest within the grid.
    b. Generate a report summarizing the findings, including any notable features or changes in the kelp forest.

Steps for In-Water Survey using AUVs/ROVs

Using automated or remote underwater vehicles (AUV and ROV, respectively) to map kelp forests is most appropriate for deep water species and projects with substantial budgets. Operating these vehicles requires considerable technical expertise outside the scope of this guide. However, AUVs/ROVs are now publicly available for less than $10,000 USD. As costs decrease and the body of knowledge about operations and output processing increases, AUVs/ROVs may become increasingly useful tools for mapping subtidal kelp species. If the project is operating for many years and there will be repeated surveys, the initial investment, although high, may prove worthwhile.

It may still be necessary for them to have a link to the surface to mark GPS points. Some newer models may have the ability to measure distances, but they will not be georeferenced. In this case the user would get the area (e.g., m^2) but not the polygon on the map.

4.1.4.3 ON-WATER SURVEYS

For safer operations, we recommend working in teams of at least two people.

Steps for On-Water Survey using Boats

1. Secure a powered or unpowered watercraft.
    a. Unpowered watercraft may be desirable for systems with high surface canopy cover that can ensnare boat motors. Kayaks, paddleboards, or canoes are good for this process over small scales. Larger scale monitoring will require a powerboat.
    b. You may also snorkel from the surface to get a better view of the subtidal kelp. If you choose this option, ensure your GPS is waterproof, in a waterproof case, and attached to a float and a line to ensure that it is not lost to the ocean.


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2. Find the perimeter edge of the kelp forest or kelp forest patch you intend to monitor.
    a. Use your GPS to drop the first pinpoint.
        i. Ensure the GPS is calibrated to the highest accuracy possible. This process may require waiting for the device to lock onto the correct number of satellites.
        ii. Follow the perimeter edge of the kelp forest, dropping a GPS pin every 10–20 m.
        iii. Once you have returned to your starting pin, note the titles of the pins. Titles are often sequential numbers, for instance, 113–246. Alternatively, if your GPS allows you to create polygons, close the loop and create the polygon.
        iv. Import the pins into a GIS software.
        v. Select the pins related to a single kelp bed and convert them into a polygon.
        vi. Calculate the area of that polygon.
    b. Use the GPS tracking function and ensure that you turn it off once you have completed the parameter of the kelp forest.

4.1.5 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of habitat mapping has various associated costs (Table 5), as well as pros and cons for implementation (Table 6).

Table 5. Projected costs for habitat mapping methods.

Method	Cost
Aerial: Drone Contractor	Medium
Aerial: Drone Images In-House	Low
Aerial: Existing Imagery	Low
On-Water: Drop Camera	Low
On-Water: GPS Point	Medium
In-Water: SCUBA	High

Table 6. Pros and cons for kelp forest mapping options.

Measurement Technique	Pros	Cons	Reference
Aerial Imagery (Drone, Satellite, Plane)	• Covers large areas	• Cannot detect deep water kelp • Potentially low spatial resolution • No associated biodiversity or kelp density data • High expertise required to process	Moro-Sota et al., 2020
In-Water Surveys (Snorkel)	• Highly accurate • Depending on visibility, may see subtidal kelp • Can obtain biodiversity and density data. • Less training required to process	• Covers a small area • Slower than aerial or boat-based surveys • Only possible for shallow kelp in good visibility	Edgar & Stuart-Smith, 2014
SCUBA	• Highly accurate • Accesses subtidal kelp	• Covers a very small area • Even slower than snorkel surveys • Requires diving qualifications	Anderson et al., 2007
Autonomous Underwater Vehicles (AUVs) and Underwater Videos (towed)	• Covers significant area • Can obtain biodiversity and density data	• High processing time • Expensive	Marzinelli et al., 2015
On-Water Visual Surveys (Watercraft)	• Covers more area than snorkel or scuba diver • May be cost-effective if using non-powered vessels (e.g., kayaks)	• Powered vessels may become tangled in surface canopy kelp • Powered vessels have higher operating costs	Berry et al., 2019

4.2 MEASURING DENSITY OF KELP FORESTS

The density of a kelp forest may be used as a proxy for the health or condition of that ecosystem. Density is defined as the number of juvenile or adult kelp stipes per unit of area, most typically measured in m^2. When comparing within species, higher density kelp forests are more productive, support higher biodiversity, and generally provide greater ecosystem services than lower ones. Measurement reporting units for density are number per unit of area (e.g., cm^2, m^2, ha, km^2). Juvenile kelp may be measured using cm^2, but we suggest m^2 for measuring the density of adult kelp.

4.2.1 MEASUREMENT OPTIONS

Unless you are measuring intertidal kelp forests at low tide, in-water survey methods are required to obtain measurements of density. As such, it is generally more expensive and laborious to measure the density of a kelp forest compared to the area. Measurement options for density include:

1. Diver Visual Surveys
2. Transect and Quadrats
3. Diver Photography Surveys
4. Drop Cameras
5. Autonomous Underwater Vehicles
6. Towed Underwater Videos

4.2.1.1 DIVER VISUAL SURVEYS

Divers may manually count the density of a kelp forest during underwater visual surveys. Quadrats and transects are the suggested approach (Figure 4). The basic setup for this approach is to run parallel lines known as transects across the kelp bed and repeatedly stop at set distances, lay down a square of a set size called a quadrat, and count the number of kelp in that quadrat. The number of transects, the length of transects, the number of quadrats, and the distance between the transects and the quadrats can vary and may be set by the user. These may be adjusted depending on the size of the kelp forest and the time available underwater.

4.2.1.2 TRANSECT AND QUADRATS

There is no definitive answer to how many transects and quadrats should be used to measure a project. Patchy, newly grown, or restored kelp forests may require more transects and quadrats due to their high variability. Projects may adapt the below approach to their own needs.

We suggest eight 50 m transects, 2 m in width, with eight evenly spaced quadrats along each transect. If eight is too intensive, we suggest a minimum of four. Quadrats typically measure between 0.1 m and 2 m long and wide. A larger quadrat captures a more representative area but is more difficult to manage underwater and may become caught or entangled. Additional transects and quadrats may be used if time and resources allow. Additional surveys will typically reduce sampling bias and minimize the variance of the values reported.

The number of holdfasts with a stipe or stipes (some holdfasts are fused) are then recorded on waterproof paper attached to a clipboard.

4.2.1.3 DIVER PHOTOGRAPHY SURVEYS

Users may photograph quadrats if there is not sufficient time to count the holdfasts in the water, or they do not have underwater paper or slates to record information. This approach is only possible if holdfasts are visible with the diver floating over top of the quadrat, however often, kelp blades will prevent users from clearly photographing the quadrat from directly above. Users may overcome this issue if there is sufficient water movement that pushes the blades momentarily to the side or if the blades may be moved manually. It is important to ensure that all holdfasts within the quadrat can be seen clearly in each image otherwise it is not possible to estimate kelp density from the photographs. If you cannot get a clear picture, do not attempt to use this method.

4.2.1.4 DROP CAMERAS

It is currently unlikely that restoration will take place at depths where drop cameras are required. Drop cameras equipped to measure density are most appropriate for deep water species and projects with substantial budgets; however, operating drop cameras requires considerable technical expertise outside the scope of this guidebook.

4.2.1.5 AUTONOMOUS UNDERWATER VEHICLES (AUVS)

New technologies are rapidly making underwater drones with high resolution video and photography capabilities available at lower and lower costs. Using AUVs means that divers do not have to get in the water and oftentimes, they can be deployed from shore. There is a significant upfront cost in buying an AUV – from thousands to tens of thousands of dollars – but the monitoring costs are significantly reduced on each site visit. Users should run the AUV in the same pattern as video or diver surveys, though they may wish to expand the area covered, as the AUV often has more bottom time than diver.

4.2.1.6 TOWED UNDERWATER VIDEOS

Towed underwater video surveys are less technologically complex than AUVs but require a boat to pull the video apparatus through the water. This trade-off entails lower costs to purchase the equipment but more restrictions in how they can be operated. For example, AUVs can operate in shallower waters, and use a more consistent speed than a boat. Users can still use towed videos to capture a larger area than with SCUBA or visual surveys.

4.2.2 BASIC INSTRUCTIONS FOR MEASURING KELP DENSITY

4.2.2.1 DIVER VISUAL SURVEYS

See the instructions for biodiversity surveys (Section 5.1).

4.2.2.2 DIVER PHOTO/VIDEO SURVEYS

See the instructions for biodiversity surveys (Section 5.1).

4.2.2.3 AUTONOMOUS UNDERWATER SURVEYS

The instructions for this method will vary depending on the AUV used. However, in short, they should follow the same principles as the diver video surveys detailed in Section 5.1.2.2 though the length of the transect may be extended to reflect the range of the AUV.

4.2.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of density measurement has various associated costs (Table 7), as well as pros and cons for implementation (Table 8).


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Table 7. Projected costs for kelp density measurement options.

Method	Cost
Diver Visual Surveys	Low
Diver Photo/Video Surveys	Medium
Autonomous Underwater Surveys	Very High
Towed Video Surveys	Very High
Drop Cameras	Very High

Table 8. Pros and cons of kelp density measurement options.

Measurement Technique	Pros	Cons	Reference
Diver Visual Surveys	• Low tech • Instant data • High accuracy	• Requires divers • Time intensive • Limited coverage	Edgar & Stuart-Smith, 2014
Diver Photo/ Video Surveys	• Does not require in-water counting • Less time in the water	• Data processing time • Potentially less accurate than visual surveys	Smith et al., 2021
Autonomous Underwater Surveys	• Cover larger areas • Costs are dropping	• Expensive • Still have limited coverage • Data processing	Bewley et al., 2012
Towed Video Surveys	• Cover largest areas	• Tech and equipment intensive • Data processing time	Marzinelli et al., 2015
Drop Cameras	• Can reach very deep kelp	• Very small sample area • Expensive • Data processing time • Unlikely to be needed for most restoration projects	Caselle et al., 2018

4.3 MEASURING BIOMASS OF KELP FORESTS

Biomass is defined as the wet or dry weight of kelp in a defined area. Units of biomass are reported as weight per unit of area. We suggest reporting weights in grams (g) and area in m^2, but alternatives are kilograms (kg), tonnes (t), hectares (ha), and square kilometres (km^2).

4.3.1 MEASUREMENT OPTIONS

Biomass is most accurately measured by removing kelp from the water and weighing it on the surface, on land, or in the lab. Biomass measurements should be paired with density measurements so that fewer kelp individuals are removed. We suggest that users remove 10–30 kelp individuals depending on the size variation at their site. If individuals are similar in size, fewer collections are needed, but if there is substantial variation in the size of kelp individuals, users will need to collect more individuals to get a representative sample. Whenever possible, the number of kelp removed from the water should be minimized.

If users do not need exact values, or do not want to/cannot remove individual kelp, they may use established allometry relationships that relate the dimensions of a kelp plant (e.g., height, width, etc.) to its weight (see Section 4.3.2.2).

Users can collect the kelp after they count density or do it on separate dives.

4.3.1.1 TRANSECT-QUADRAT

For biomass measurement, we recommend the transect-quadrat method with, ideally, eight 50 m long transects. The number of quadrats will vary depending on how many kelp are being removed. Simply divide the total number of kelp you would like to collect by four to determine how many kelp you should remove per transect. For example, if you have 20 kelp collected in a transect, divide the number 20 by four and remove five kelp for that transect. Next, divide the length of the transect by the number of kelp per transect to get the spacing of the collections. For example, for a 50 m long transect and five kelp removed, that is one collection every 10 m.

Alternatively, you may haphazardly sample a consistent (homogeneous) kelp forest by swimming and selecting individuals at random.

Once a sample is collected from a quadrat, it may be sent straight to the surface or kept with the diver using a mesh bag. Because kelp is generally quite voluminous, we suggest that users minimize the amount of kelp material they carry with them while diving. Samples may be returned to the surface using lift bags, surface lines, or by being passed off to a free diver if available.

Transects should run across a section of the reef with consistent characteristics, for example the slope and depth.

Once users have collected the kelp, they can obtain either its wet weight or dry weight. Wet weights are obtained by removing excess water and fouling organisms (e.g., other algae, bryozoans) and then placing the kelp on a scale. You may wish to use a simple spring scale as they are durable; the precision required does not necessarily require an electronic scale. Dry weight measurement is necessary for true productivity calculations, but requires putting the kelp in a drying oven, typically for 12–24 hours, but perhaps longer if required.

Users may obtain estimates of dry weights by using previously published ratios between wet weights and dry weights.

4.3.1.2 ECHOGRAMS

Echograms can estimate the biomass of kelp forests. They are sonar or acoustics monitoring tools that use sound waves to record measurements and ultimately create displays of marine habitat features. Emerging research suggests that using echograms achieves an accuracy of 67% to 74%, which may be sufficient for some monitoring programs (Blight et at., 2011; Shao et al., 2017; Kartveit et al., 2022).

4.3.1.3 MEASURING BIOMASS WITH ALLOMETRY RELATIONSHIPS

Allometry allows users to get non-destructive estimates of biomass. Users can either create these relationships themselves or rely on published works. These relationships rely on correlations between length, width, and weight – in other words, allometric relationships between body size and shape of an organism. While the statistics of these relationships is beyond the scope of this document, a suite of statistical methods is available including linear models (Bolker et al., 2009), regression trees (Elith et al., 2008), and Generalized Additive Models (Pedersen et al., 2019). Each can be used to create formulas or predictions for weight based on physical parameters. The programming language R is a popular, open-source program to run these analyses.

4.3.1.4 LIGHT ATTENUATION (INTERTIDAL ONLY)

There is now a method for determining kelp biomass using light attenuation. This work is only validated for intertidal species – namely, *Fucus* – but may prove useful as a low-cost, non-destructive sampling method in those ecosystems. See Johnson (2022) for further details.

4.3.2 BASIC INSTRUCTIONS FOR BIOMASS MEASUREMENT

4.3.2.1 TRANSECT-QUADRAT WITH KELP COLLECTION

Decide if you are processing the sample in the field or the lab. Field measurements will be simple and more time-efficient but will not be as accurate as lab measurements. Your choice of sample or field processing also depends on whether you are measuring wet or dry weights. If you are only measuring wet weights, then field measurements may be most appropriate.

1. Determine how many kelp you would need to remove. We suggest 10 to 30 per site.
2. Divide the length of the transect by the number of kelp required to get the number of kelp samples per transect.
3. Randomly select quadrats from the density measurements.
4. Remove a random kelp individual from each quadrat.
5. Pat dry and remove any fouling organisms.
6. Measure the wet weight of each individual.
7. (Optional) Place the individuals in a drying oven to determine the dry weight.
8. Multiply the average weight of a kelp by the number of kelp per m^2 to get biomass per m^2.

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4.3.2.2 ALLOMETRY

When length-to-biomass ratios are available, calculate allometry as follows:

1. Determine how many kelp you would like to measure. We suggest 10 to 30 per site.
2. Divide the length of the transect by the number of kelp to get the number of kelp per transect.
3. Divide the length of the transect by the number of kelp per transect to get the quadrat spacing.
4. Follow the steps for running transects and quadrats as outlined in Section 3.0.
5. Measure the stipe length and lamina (blade) length of a random kelp individual from each quadrat.
6. Convert these values into biomass using previously published ratios.

Allometry instructions when creating your own length-to-biomass relationships:

1. Follow the kelp collection instructions (Steps 1–6).
2. Run regression models of kelp weight versus stipe length, stipe circumference, and blade length.

4.3.2.3 SONAR

Deploying a vehicle to collect sonar data as well as interpreting the sonar data is a moderately complex process and requires a level of expertise not possessed by the average marine ecologist. Therefore, the steps for this method are not outlined here but discussed by Kartveit et al. (2022).

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4.3.3 PROJECTED COSTS AND COMPARISON OF METHODS

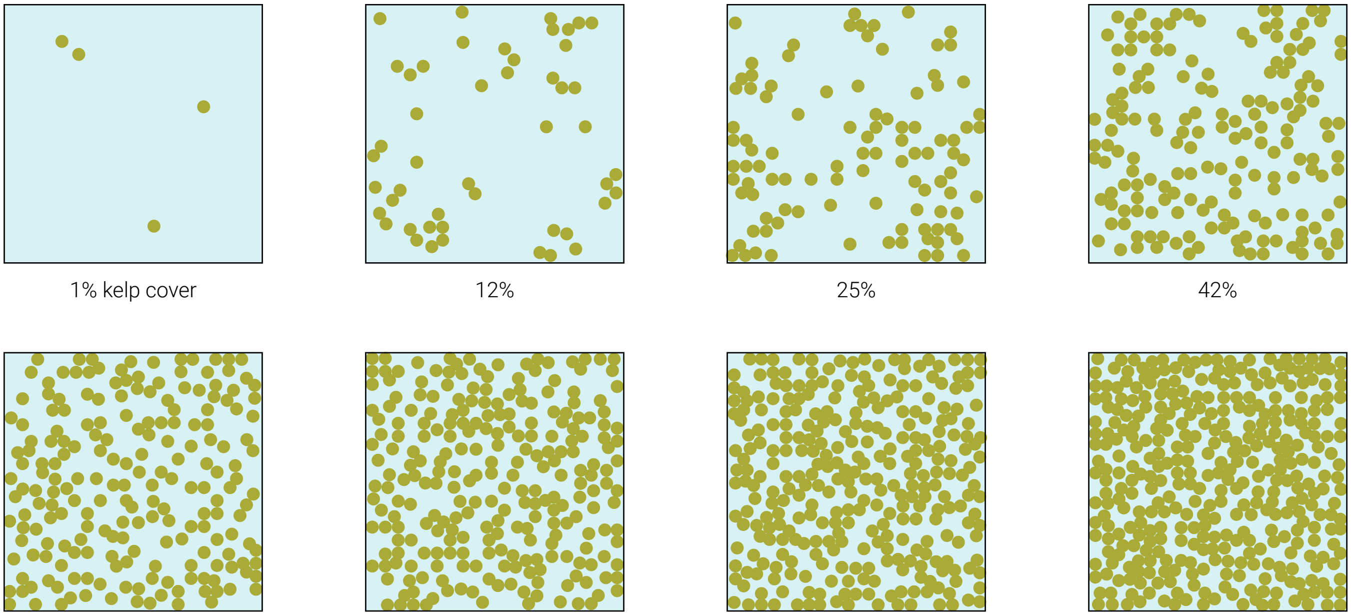
Each method of biomass measurement has various associated costs (Table 9), as well as pros and cons for implementation (Table 10).

Table 9. Projected costs for kelp biomass measurement options.

Method	Cost
In-Water: SCUBA Allometry	High
In-Water: SCUBA Collection	High
Sonar	Unavailable

Table 10. Pros and cons for kelp biomass measurement options.

Measurement Technique	Pros	Cons	Reference
Direct Collection	• Most accurate	• Destructive	Kelp Ecosystem Ecology Network, 2024
Allometry Relationships	• Less time and resource-intensive • Non-destructive	• Less accurate • Statistical experience needed if developing your own proxies	Kim et al., 2017
Sonar	• Scalable to large areas • More cost-efficient than divers	• Less accurate • Often requires proprietary software	Kartveit et al., 2022



1% kelp cover

12%

25%

42%

50%

62%

75%

90%

Figure 5. Visual guide for estimating percent cover of kelp forest ecosystems.

4.4 MEASURING PERCENT COVER OF KELP

Kelp's percent cover is defined as the percentage of the seafloor that is covered by kelp forest (Figure 5). In a conservation context, this area should be restricted to potential kelp habitat (i.e., rocky reef, suitable depth) and should not include non-suitable habitat (e.g., sand). Percent cover may also be used as a measure of kelp forest condition or health. Percent cover is reported in percentage (%).

4.4.1 MEASUREMENT OPTIONS

Divers or snorkelers may visually estimate percent cover using the transect and quadrat methods, or via unified point contact (UPC).

4.4.1.1 TRANSECT AND QUADRAT

For the quadrat method, users should assess how much of the quadrat is covered by the blades of the kelp species of interest. Because percent cover will change as water moves back and forth, care should be taken in areas with significant wave action. Users should aim to assess the cover when the kelp is vertical.

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4.4.1.2 *UNIFIED POINT CONTACT (UPC)*

For the UPC method, divers or snorkelers collect data directly under the metre tape, every 0.5 m or 1 m. Data should be blindly recorded for this method to avoid bias. To do this, surveyors use a marked point, a dropped weight, or close their eyes and record the item immediately under a pointed finger. Data recorded includes substrate (e.g., sand or rock), living cover (e.g., sessile invertebrate or algae), and relief (height between the most shallow and most deep quadrats).

Divers or snorkelers can also take photographs and more robustly assess the percent cover using computer programs (e.g., CoralNet). As with the visual surveys, the photographs should be taken when the kelp is vertical and not when it is bent or swayed with the movement of the water.

Similarly, users may also swim the length of the transect with a video camera and assess the percent cover on the computer using a software program.


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4.4.2 BASIC INSTRUCTIONS FOR KELP PERCENT COVER MEASUREMENT

4.4.2.1 *DIVER OR SNORKEL SURVEYS*

Follow the instructions for the biodiversity video survey (Section 5.1.2.2). Percent cover may be analysed from the photo quadrats described in that section.

1. Once you have obtained the photo quadrats, upload the images to an image viewing software, such as CoralNet or Coral Point Count (Kohler & Gill, 2006). These resources use a semi-automated algorithm to analyse the photo quadrats. In short, you will assign points (randomly or systematically) to each image and then classify each point as kelp cover or an alternative category. The percentage of points that are kelp can be translated into percent cover.

Alternatively, follow the instructions from the biodiversity visual surveys (Section 5.1.2.1) and instead of taking photos, visually assess how much of the quadrat is covered by kelp and record this on your data sheet.

1. As with the photo quadrats, assess how the kelp is swaying back and forth. Make your assessment when it is most vertical and stationary.
2. This approach is recommended if you are only interested in percent cover. If you are collecting information on other variables (e.g., kelp, fish, and/or invertebrate diversities), the photo quadrat approach would be a more suitable approach.

4.4.2.2 *DROP CAMERAS OR REMOTE OR AUTONOMOUS VEHICLES*

You may obtain videos or photos of the kelp forest using drop cameras or remote or autonomous vehicles.

Data collection steps for drop cameras/remote or autonomous vehicles are as follows:

1. Survey across a transect.
2. Select sampling or quadrat points.
3. Take a photo quadrat or video still of the kelp forest from directly above the sea floor.
4. Process the imagery as described above.

4.4.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of percent cover measurement has various associated costs (Table 11), as well as pros and cons for implementation (Table 12).

Table 11. Projected costs for percent cover measurement options.

Method	Cost
SCUBA: Photo Quadrats	Low
SCUBA: Visual	Low
UPC	Low
Remote or Autonomous Video Surveys	Very High

Table 12. Pros and cons for percent cover measurement options.

Measurement Technique	Pros	Cons	Reference
Diver/Snorkel Visual Surveys	• Lower cost • Little processing time	• Lower accuracy	Kelp Ecosystem Ecology Network, 2024
Unified Point Contact (UPC)	• Little equipment • Easy to train	• Requires taxonomic knowledge • May require post-sampling processing time	Partnership for Interdisciplinary Studies of Coastal Oceans, 2023
Diver/Snorkel Video Surveys	• More accurate than visual	• Higher cost than visual	Duffy et al., 2019
Remote or Autonomous Video Surveys	• Maybe able to sample larger distances • Advances in AI may mean that processing can be done automatically • Potential for highest accuracy	• Most expensive percent cover measurement technique	Bewley et al., 2012


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CHAPTER

5.0 HABITAT SERVICES

5.1 BIODIVERSITY

Biodiversity refers to the number of different taxonomic or functional units of organisms living in a kelp forest. It is reported in number of species, number of functional species, presence, or absence of notable species.

Common Indices of Biodiversity

Species richness: A rarefied or non-rarefied number of species found within a defined area such as m^2, ha, or km^2.

Diversity: A measure of the relative abundance and number of different species in an ecosystem. Shannon Diversity Index and Simpon's Index are some of the most common.

Functional diversity: A variety of measures (e.g., number, evenness, dispersion) of functional units of species (e.g., body length, trophic group) in an ecosystem.

Endangered or iconic species: The presence or absence of species of particular interest, typically of economic, cultural interest or species that are listed on assessment schemes.

5.1.1 BIODIVERSITY MEASUREMENT OPTIONS

The options for measuring biodiversity include:

1. In-water visual surveys
2. In-water video surveys
3. Towed video surveys
4. Automated video surveys
5. Quadrats
6. Epifauna
7. eDNA
8. Baited remote underwater video (BRUV) surveys

5.1.1.1 VIDEO OR VISUAL SURVEYS

We do not detail instructions for identifying organisms down to the species level, but assume that users are knowledgeable about their local taxonomy. If users are not familiar with the biodiversity present in their region, we suggest they consult the appropriate field guide or take photos and/or videos that can allow for retrospective identification.

Fish and mobile invertebrates, such as lobsters, may be identified using underwater visual surveys. These surveys may be done entirely visually, or they may also include a video recording to identify species partially or wholly. In-water surveys are much more time efficient as the values are complete at the end of the dive, but they may not be as accurate as video surveys that allow users to cross-reference a species' identity.

Surveys are usually broken down into different sections of the water column. Benthic surveys focus on species living in the kelp, on or very near to the seafloor. Mid-water surveys capture species living above the kelp canopy. Open-water surveys capture species living near the surface; however, these surveys are not commonly used for kelp.

Users should record a species identity and abundance on a waterproof slate or datasheet. It may be helpful to prepopulate sheets with common species in the area to avoid writing down names while underwater.

We also suggest that users run a separate survey for benthic and cryptic species, ideally following the mid-water fish survey. These surveys should be run across the same transect as the in-water fish surveys. Instead of swimming in a straight line over the transect, users should take time to search crevices, nooks, overhangs, and other features that might contain organisms. It is highly recommended that users have an underwater torch for this component, especially if visibility is low.

Video surveys should follow the methods described in Section 5.1.2.2.

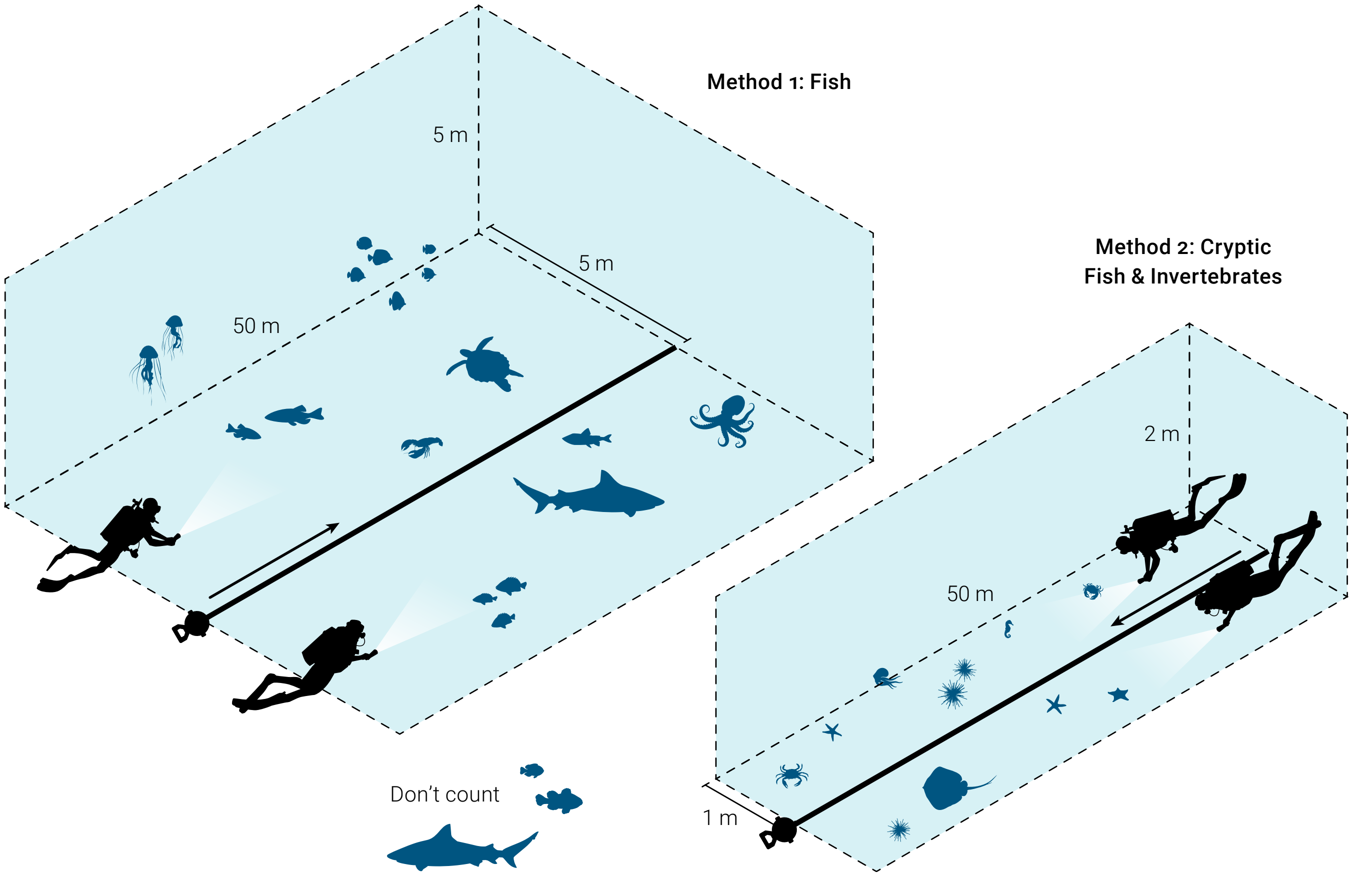


Figure 6. Reef Life Survey illustration of the transect method and dimensions used to count fish and invertebrates in water. This figure was adapted from Reef Life Survey (2023).

5.1.1.2 *EDNA*

Environmental DNA (eDNA) is a technique that detects the presence of a plant or animal DNA in a medium (e.g., water or soil). It can reduce sampling times and help identify species that were not visually observed during the survey. This fact makes it particularly appealing for monitoring rare, cryptic, highly mobile, or nocturnal species. However, eDNA has several core limitations:

1. It can only detect presence and does not quantify abundance.
2. Seawater is a well-mixed medium and the DNA therefore isn't necessarily from a given location (e.g., a restoration site).
3. It requires a DNA database for analysis, which might not be available for less common species.
4. It is a technically complex and expensive process; for more details, see Gold et al. (2021) and Port et al. (2016).

5.1.2 BASIC INSTRUCTIONS FOR BIODIVERSITY MEASUREMENT

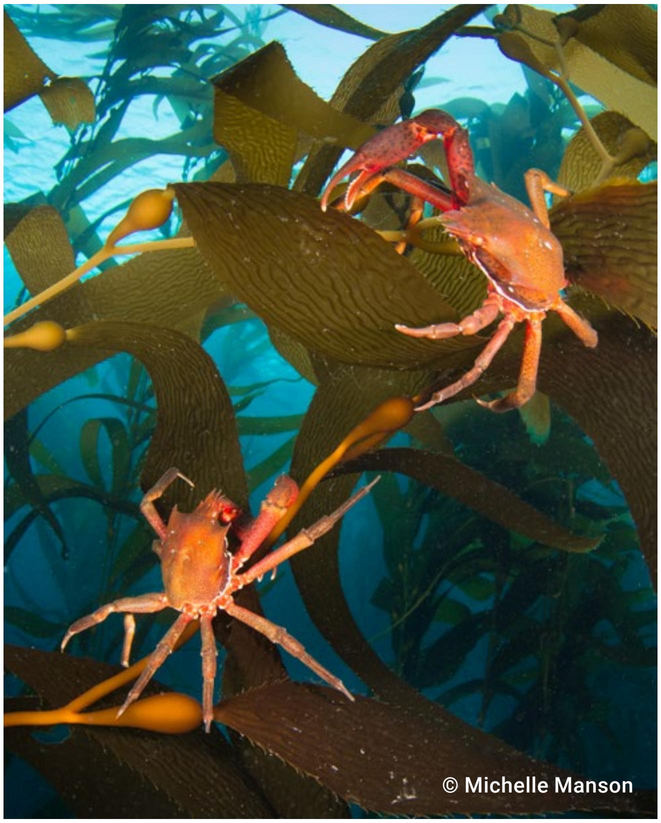
5.1.2.1 *VISUAL TRANSECT SURVEYS FOR FISH AND BENTHIC DIVERSITY*

Two divers should work together to efficiently sample fish, mobile invertebrate biodiversity, and benthic cover. These methods are based on the Reef Life Survey approach and will allow data to be compared to the Reef Life Survey dataset (Figure 6). A minimum of 5 m of underwater visibility is required to use this method effectively.

See Section 3.2 for choosing your starting location.

Projects should aim for two complete pairs of pelagic and benthic transects per dive.

1. Divers 1 and 2 swim while laying out the transect line for 50 m (see Section 3.2.1). Divers record pelagic biodiversity as they swim.
   a. Diver 1 counts fish on one side of the transect line and diver 2 counts on the other side.
   b. Divers only count fish within 5 m, horizontally, of the transect line and 5 m, vertically, from the sea floor. Divers should note if visibility is less than 5 m.
   c. Record the size-category of total fish length (from snout to tip of tail, or longest distance, including for stingrays). The size-classes of total fish length commonly used are 2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 50.0, 62 cm, and above. The length of any fish longer than 62 cm should be estimated to the nearest 12 cm and individually recorded. Divers should practice identifying the length of objects underwater before completing these surveys.
   d. Data is recorded directly on the data sheets.
   e. If a species is unidentifiable, take a photo for later identification. Rare species may also be recorded.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2. Once complete, the divers swim the transect one more time and record invertebrates greater than 2.5 cm and cryptic fish, rolling the transect tape up as they go.
   a. Divers should use the same formation as before but are now only counting individuals within one horizontal metre of the line and two vertical metres of the seafloor.
   b. Divers should look under rocks and overhangs and into crevices and tunnels. We highly recommend an underwater torch.
   c. Record the size-category of any organisms observed. Record carapace or test size for crabs, lobsters, sea urchins, or abalone. The measurement groups used are 2.5, 5.0, 7.5, 10.0, 12, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 50.0, and 62 cm, and above. Estimate lengths of animals larger than 62 cm to the nearest 12 cm and record individually.
   d. Do not record fish that you encountered during the previous survey. This survey only intends to capture fish that hide among rocks and the seafloor.

Divers may also record kelp density on the benthic transect. They can either count kelp holdfasts in the field or take a photo quadrat. We recommend taking a measurement every 5 m. Physical quadrats will provide more precise measurements; otherwise, a standard point and shoot camera positioned 50 cm directly above the reef captures an area of approximately 30 cm^2. Once that transect is complete, repeat the survey on a newly placed transect, as described in Section 3.2 and Section 3.3.

Figure 7. Example of a stereo video camera system for recording video to measure biodiversity and length.

5.1.2.2 VIDEO SURVEYS FOR FISH AND BENTHIC DIVERSITY

If users are not confident that they can count and measure fish efficiently underwater, they may use video surveys instead. These surveys cannot replace the benthic biodiversity surveys.

The steps and formation are the same as for visual transects (Section 5.1.2.1), except:

1. Locate a stereo video camera system (i.e., two video cameras mounted on the same unit and pointed in the same direction, as shown in Figure 7). See Goetze et al. (2019) for more details on sourcing the necessary components.
2. Swim the same transect patterns, but use video cameras, as opposed to counting fish in real time.
3. Turn the camera on before entering the water.
4. Have someone clap while recording to allow the camera footage to be synced up (if using length measurement software).
5. Show your fingers to the camera before starting each transect; show the number of fingers that corresponds to the transect number (i.e., one finger for first transect, two fingers for the second transect, etc.).
6. Swim slowly along the transect line at a speed of three seconds per metre (20 m per minute).
7. Once you have reached the end of the transect line, wave in front of the camera or point it at the surface to indicate the transect is over.
8. Repeat this process for all the transects.

The videos may then be loaded into a software called EventMeasure which will allow you to identify and measure the length of each fish observed in the video. Only count fish in that 10 m x 5 m box used in the visual surveys. As discussed, users still need to complete the benthic and photo quadrat surveys separately. We advise to complete the video survey first to avoid startling any fish.

5.1.2.3 QUADRATS AND BIODIVERSITY SURVEYS

Smaller animals or other organisms (i.e., epifauna) which grow or live on the kelp itself may require specific surveys because they are often overlooked in swim over surveys.

Larger epifauna (e.g., snails, sea stars, limpets, etc.) may be sampled using quadrats and can be counted using the same quadrats as those used to measure density.

Sampling of smaller epifauna (e.g., amphipods, isopods, and larval stages) usually requires removing the kelp plant, transporting it to the lab, and rinsing it over a sieve to collect the organisms, which can then be identified and counted immediately or preserved (e.g., in Industrial Methylated Spirit or similar) and processed at a later date. This sampling is destructive and kills both the kelp and the organisms. Therefore, it should only be done when absolutely necessary, and with as few kelp removed as possible.

5.1.2.4 BAITED AND UNBAITED REMOTE VIDEOS

Remote videos may be done without divers, which reduces their costs. Cameras are attached to an apparatus that contains an attractant to lure animals towards the camera, which is stationary. Because it is stationary, this method cannot be used to get an estimate of individuals per unit area, and data collected through this approach is only comparable to other data collected with the same method. Data collected using this method, rather being expressed per unit area, is often measured in soak time (i.e., how long the camera was in the water) or Max N (i.e., maximum number of species/individuals seen in a single video frame).

Users may select to use baited video cameras or unbaited video cameras. Baited cameras contain a food source (often oily fish or squid) that attracts predatory organisms towards the camera. Since this approach aggregates these animals, it biases the sample, and species counts from baited videos should only be compared to other counts obtained using baited methods. Unbaited videos result in a more random biodiversity sample, but should also only be compared to other counts obtained using unbaited approaches. See Langlois et al. (2020) for further details.

The baited remote underwater vehicle (BRUV) methodology described below focuses on animals near the bottom, but BRUVs may be modified to capture pelagic species as well, though that method is not described here.

Steps to Capture Remote Videos using a Baited Remote Underwater Vehicle (BRUV):

1. Preparation
    a. Choose a suitable underwater camera and housing for your study. Using two cameras allows for length measurements to be gathered from the video footage.
    b. Set up appropriate lighting, if needed, to ensure adequate illumination of the field of view.
    c. (Optional) Determine the bait type and quantity to attract the target species.
    d. Assemble the BRUV rig with the camera, bait, and any additional components such as weights, floats, or anchors.
2. Deployment
    a. Select the study sites and transects based on your research objectives.
    b. Record environmental variables such as temperature, salinity, and depth at each deployment site.
    c. Deploy the BRUV by lowering it to the desired depth, ensuring it is stable and well-positioned on the seafloor.
    d. Allow the BRUV to record for a predetermined duration, typically ranging from 30 minutes to several hours.
3. Retrieval
    a. Retrieve the BRUV using the attached line or marker buoys.
    b. Carefully clean and inspect the equipment to ensure it remains in good working condition.
4. Video analysis
    a. Review and catalogue the video footage, noting the start and end times, location, and any relevant observations.
    b. Identify and count the target species present in a video frame considering factors like species behaviour, size, and abundance.
    c. Measure environmental variables such as habitat type, complexity, or substrate composition, if relevant to your study.

5.1.2.5 EDNA

See Gold et al. (2022) for a detailed breakdown of the process, but in short:

1. Ensure you have the correct primers for your target taxa, a comprehensive reference database, and the correct sampling and lab protocols to avoid spoiling your samples.
2. Run local pilot studies to determine how well the process works in your environmental context.
3. Run field surveys to visually assess species richness and validate the eDNA numbers in the project area.


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5.1.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of biodiversity measurement has various associated costs (Table 13), as well as pros and cons for implementation (Table 14).

Table 13. Projected costs for biodiversity measurement options.

Method	Cost
SCUBA Video Survey	Medium
SCUBA Visual Survey	Low
Towed Video	Medium
Quadrats	Medium
Epifauna	Medium
eDNA	Low
BRUVs	Medium


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Table 14. Pros and cons for biodiversity measurement options.

Measurement Technique	Pros	Cons	Reference
In-Water Visual Surveys	• Data available instantly • Lower cost • Better for benthic organisms	• Less accurate • Requires some training • Must still carry a camera to identify unknown species • Covers a smaller area compared to towed/ automated	Edgar & Stuart-Smith, 2014
In-Water Video Surveys	• Higher accuracy • Ability to check species' identification	• High processing time • Some equipment and software required • Cannot survey cryptic or benthic species • Covers a smaller area	Smith et al., 2021
Towed Video	• Covers a larger area	• Requires a boat • Misses benthic and cryptic species • Difficult in shallow depths	Galaiduk et al., 2017
Automated Video Surveys	• Covers a larger area • May be automated	• Expensive • Range may be limited currently	Mallet and Pelletier, 2014
Quadrats	• Counts small and very small animals (e.g., epifauna)	• Time-intensive • Counting epifauna usually requires destructive sampling	Leclerc et al., 2016
Epifauna	• Counts very small animals (about 1mm)	• Very time-intensive • Destructive for both kelp and animals	Tuya et al., 2014
eDNA	• High accuracy for presence-absence • Detects even if not visible, good for rare, mobile, or nocturnal species	• High startup and processing costs • Presence-absence only • Correct reference libraries are needed • Cannot associate results to specific square metre areas	Gold et al., 2021
BRUVs	• May attract rare species. • No diver required • May attract more benthic species	• Cannot measure per unit area • Unadvisable to compare to other sampling approaches	Cappo et al., 2006; Langlois et al., 2020

CHAPTER

6.0 REGULATING SERVICES

6.1 PRIMARY PRODUCTION

Primary production is defined as the amount of biomass that is created by an individual kelp or an area of kelp over a given period. It is reported in Net Primary Productivity (NPP), which is measured using a weight (e.g., grams or kilograms), area (e.g., m^2, ha, or km^2), and time (e.g., day, month, or year). The weight is usually dry weight, not fresh (i.e., wet) weight.

6.1.1 MEASUREMENT OPTIONS FOR PRIMARY PRODUCTIVITY IN KELP

There are two main proxy measures of NPP in kelp: (1) the growth or elongation of the blade, also referred to as extension of the lamina, that assesses biomass accumulation over time, and (2) regrowth in cleared plots or restored areas.

6.1.1.1 BLADE ELONGATION

The elongation rate is estimated using the hole punch method (King et al., 2020). Briefly, this method requires users to randomly select kelp individuals within the forest and punch a small hole, about 5 cm in size, above the base of the blade (i.e., the meristem). Users then return months later, place another hole at the new base of the blade, and measure the distance between the two holes to determine how much the kelp has grown.

6.1.1.2 REGROWTH

New growth in a restored area (year one)

If there was no kelp at your site before restoration, the first year of sampling will not require any kelp removal. Subsequent years will require removal or the hole punch method (Section 6.1.2.3). In the first year, you may simply remove a sample of kelp that has grown in the previously bare areas and assess the time since the restoration took place to get a growth rate.

Note that users should only remove kelp if the population appears healthy and can afford to lose an individual and may wish to use the hole punch method in restored or sensitive areas.

Regrowth in a cleared area (years two and above)

Users can measure NPP of kelp by clearing a defined area of reef (e.g., 1 m^2) and then examining the biomass that regrows in a given period (e.g., one year). Users must clearly delineate the area of reef that is being cleared and re-measured. They may mark their areas with weighted floats, markers driven or drilled into the seafloor, waterproof paints, or coloured marine epoxy. This approach, measuring NPP of kelp by clearing the reef, requires significant time as the user must wait for the kelp to regrow.

In addition to these field measurement approaches, there are literature-based proxies that can be used. All these options are described in more detail below in Section 6.1.2.

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6.1.2 BASIC INSTRUCTIONS FOR MEASURING KELP PRIMARY PRODUCTION

6.1.2.1 GROWTH IN A RESTORED AREA

The following method assumes that prior to restoration, the substrate was bare rock. If there was kelp present before the restoration action, it will need to be cleared before using this method.

1. Determine how many kelp need to be sampled. We suggest 10 to 30 per site. Fewer kelp may be sampled at the start if the number of individuals is limited.
2. Divide the length of the transect by the number of kelp to get the number of kelp per transect.
3. Divide the length of the transect by the number of kelp per transect to get the quadrat spacing.
4. Follow the steps for running transects and quadrats as described in Section 3.2 and Section 3.3.
5. Count and record the number of kelp in each quadrat.
6. Remove a randomly or haphazardly selected kelp individual from each quadrat.
7. Return the collected kelp to the lab.
8. Scrape any fouling organisms from the kelp, such as other algae, bryozoans, etc.
9. Pat kelp dry using paper towels, clothes, or newspaper.
10. Record the wet weight of each individual.
11. (Optional) Place individuals in a drying oven to determine the dry weight.
12. Multiply the weight per kelp by the per m^2 density to get biomass/m^2 then divide this by the length of time since the restoration activity to get biomass/m^2/year.

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6.1.2.2 REGROWTH IN A CLEARED AREA

If you are clearing kelp from an area, note that the method is destructive; therefore, perform this method only in areas where kelp can recover and only after obtaining the correct permits and permissions. It can be potentially damaging to use this method for small, restored plots as it may destroy a significant portion of the biomass.

1. Select two to six random plots to remove kelp biomass:
    a. Plots may be 1 to 8 m^2 in diameter.
    b. We suggest doing this in late summer, as much of the yearly growth has occurred by then. Winter is not recommended, as many kelp die back or shrink in the winter.
    c. Space the plots 5 to 25 m apart.
    d. Mark the plots with subsurface markers and surface GPS points.
2. Remove all the kelp plants from each plot:
    a. Scrapers with wide, thin blades are a useful tool for doing this.
    b. Users may wish to make a second visit to ensure that they removed all the kelp from each plot.
3. Assess yearly growth to determine if the plot has reached adult size. The return time will vary by kelp species and location, but is often one to three years.
    a. Users should be sampling a mature kelp forest.
    b. Use nearby healthy kelp forests to determine what reference kelp densities and individual lengths should be.
    c. Time the follow-up visits to occur at the same time of year as the first clearing.
4. Take four to eight quadrats (0.25–2 m^2 depending on kelp size and density) and randomly place them in the cleared plot:
    a. Avoid the edge of the plot to avoid edge effects.
    b. Count the number of kelp in each quadrat to determine kelp density.
    c. Remove five to 20 kelp and bring them back to the lab to measure their wet and/or dry weight.
    d. Determine a kg/m^2 value.
    e. Divide the value by the number of days or years between the initial clearing and the collection date to obtain $kg/m^2/year$.
    f. Convert fresh weight (FW) to dry weight (DW) using known FW:DW ratios (Wickham et al., 2019) for each species, or develop a site and/or species specific one by oven-drying the heaviest basal segment for biomass accumulation at 60°C for 48 hours, or until consistent weight is reached.

6.1.2.3 HOLE PUNCH METHOD

1. Start this work during the peak growth season for your kelp species and area, which is often early spring.
2. Select a starting point in the middle of the kelp forest.
3. Take a GPS point and leave a marker on the seafloor:
   a. Markers may be attached to the seafloor by tying ropes around features, or by gluing, drilling, hammering or otherwise securing a visible object to the sea floor. If the area is not extremely wave-exposed, you may weight a marker down using a large brick or other heavy object. These markers are not meant to float on the surface, but are used to help you relocate your location during follow-up monitoring.
4. Haphazardly select kelp for sampling, ensuring 2 m between each kelp.
5. Select a kelp at each sampling interval on the transect (e.g., every 2.5 m).
6. Tag these individuals. Flagging tape, cable ties, colour elastics or other distinct items may be used to tag each individual.
7. Place one hole punch at 5 cm from the base (closest to the stipe) of the lamina (blade) and place a second hole punch 10 cm from the base of the lamina.
8. Return any time within weeks to a year, and collect the marked individuals:
   a. Ensure any markers are also removed.
   b. Record the number of days between the initial punch and the collection date.
9. Return to the lab:
   a. Measure the new distance of the holes from the base of the lamina (i.e., meristem).
   b. Slice three 5-cm-long strips off from the widest part of the kelp blade and weigh them. Take the heaviest measurement.
10. Calculate the daily biomass accumulation as follows:
    a. Biomass accumulated (BA) = e*FW / 5 * t:
       i. FW = fresh weight of 5 cm strip (grams)
       ii. e = distance of the holes from the base of lamina (cm)
       iii. t = number of days between the hole punch and the collection of kelp
       iv. BA = daily biomass accumulated, in grams of growth/day
11. Kelp does not grow evenly throughout the year, and therefore you will need to understand what percentage of its annual growth occurred during your sampling period to avoid overestimating annual growth. There are two options to assess growth in a year:
    a. You may attempt to follow the same individual kelp for one year, but risk losing the individual if it is eaten or torn off the seafloor. Alternatively, you can conduct the hole-punch method during the main growth season and the low growth season to record the maximum and minimal laminal extension rates in the year.
    b. You can also find published growth curves in the literature.
    c. For example, you sampled from the beginning of spring to the beginning of summer (three months or 90 days):
       i. The literature suggests that this period accounts for 80% of the growth.
       ii. Get the annual growth rate by multiplying the biomass accumulated (BA) by dividing the number of sampling days (90) by the percent of growth (80). The equation to use is: Annual growth = Daily BA * (90/80).
12. Convert FW to DW using known FW:DW ratios (Wickam et al., 2018) for each species, or develop a site and/or species specific ratio by oven-drying the heaviest basal segment for biomass accumulation at 60°C for 48 hours, or until consistent weight is reached.


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6.1.2.4 LITERATURE PROXIES

Past studies have established estimates for how the biomass of a kelp individual relates to its yearly production. These are known as "biomass to production ratios," and they depend on the species, location, and yearly growing conditions. Therefore, users should take caution when extrapolating results. Nevertheless, using these ratios can save considerable effort and resources.

How to use biomass to production ratios

1. Obtain the biomass per m^2.
2. Find previously published biomass to production ratios:
   a. Find a ratio for your species or genus.
   b. Attempt to find a ratio calculated in similar environmental conditions as your site.
3. Convert biomass (kg/m^2) into production ($kg/m^2/year$) using the ratio.

6.1.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of primary productivity measurement has various associated costs (Table 15), as well as pros and cons for implementation (Table 16).


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Table 15. Projected costs for primary productivity measurement options.

Method	Cost
SCUBA: Plot Clearing	High
SCUBA: Biomass Proxy	High
SCUBA: Chambers	Very High
SCUBA: Hole Punch	High

Table 16. Pros and cons of primary production measurement options.

Measurement Technique	Pros	Cons	Reference
Plot Clearing	• More accurate	• Destructive	Kelp Ecosystem Ecology Network, 2024
Hole Punch for Blade Extension	• Less destructive • Lower cost	• Must find exact same blades	Smale et al., 2020
Chambers	• Most accurate	• Not scalable • Expensive	Rodgers et al., 2015
Literature Proxies	• Fast • Low-cost • Scalable	• Less accurate	Field et al., 1980

6.2 CARBON UPTAKE

Carbon uptake is defined as the amount of carbon taken up from the water and transferred into biomass. This value does not equate to the amount of carbon (C), or carbon dioxide (CO_2) sequestered or captured. See Kelp Forest Alliance (2023) for a report on the link between net primary production (NPP) and carbon sequestrations. Carbon uptake is reported in grams of C per unit area of kelp forest per unit time. Multiply by 3.66 to get values in units of CO_2.

6.2.1 BASIC INSTRUCTIONS FOR MEASURING CARBON UPTAKE

The first step in calculating the carbon uptake is calculating the NPP on a dry weight basis. Once NPP has been obtained, users can calculate carbon uptake by multiplying NPP by the carbon content of the kelp.

Carbon content is obtained in the lab using an elemental analyser and may not be accessible for many projects. Fortunately, there is existing information about the carbon content of different kelp species available.

6.2.1.1 ELEMENTAL COMPOSITION

Users calculating the carbon content themselves should be aware that the content value changes in different parts of the kelp. For example, the carbon content of the stipe is typically lower than the blade. In addition, the carbon content can vary seasonally.

Calculating Elemental Composition

1. Collect representative samples of the kelp tissue you want to analyse, such as blades or stipes. Take multiple samples to account for variability within and among individuals (a minimum of three per site but up to 10).
2. Rinse the samples with fresh water to remove any debris, epiphytes, or salt. Pat samples dry with a clean towel or paper towel to remove excess water.
3. Dry the kelp samples in an oven at 60°C (140°F) until they reach a consistent weight. This process typically takes 24 to 48 hours, depending on the thickness of the samples. Drying removes moisture from the samples, which is essential for accurate carbon content measurement.
4. After the samples are completely dry, weigh them using an analytical balance to obtain their dry weight.
5. Grind the dried samples into a fine powder using a grinder or mortar and pestle. This step ensures a uniform distribution of the kelp tissue and improves the accuracy of carbon content analysis.
6. Use one of the below methods to determine the carbon content in the kelp samples:
    a. Elemental analysis: In this method, a small amount of the homogenized sample is placed in an elemental analyser, which uses combustion to break down the sample into its constituent elements. The carbon content is then measured as a percentage of the total sample weight.
    b. Combustion method: In this method, a known amount of the homogenized sample is combusted in a furnace at high temperatures (typically around 900-1000°C) in the presence of oxygen. The carbon in the sample is converted into carbon dioxide (CO_2), which is then trapped and quantified using various techniques, such as gas chromatography or infrared absorption.
7. Calculate the carbon content of the kelp samples based on the results of the chosen analysis method. This value is usually expressed as a percentage of the sample's dry weight or as the mass of carbon per unit mass of the dry sample (e.g., mg C/g dry weight).

6.2.1.2 PROXIES FROM THE LITERATURE

Estimates of the carbon content of many kelp species are published in the literature and may be used in lieu of field measurements if the budget is limited (Table 17).

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Table 17. Examples of carbon content estimates in kelp species.

Genus	Carbon content	Region	Reference
Alaria	31–32%	Alaska	Umanzor & Stephens, 2023
Saccharina	24–25%	Alaska	Umanzor & Stephens, 2023
Ecklonia	36%	Australia	Atkinson & Smith, 1983
Laminaria	29%	Scotland	Schiener et al., 2015
Laminaria	29%	California	Atkinson & Smith, 1983
Nereocystis	20–28%	British Columbia	Rosell & Srivastava, 1985
Nereocystis	24%	California	Atkinson & Smith, 1983
Macrocystis	29%	California	Atkinson & Smith, 1983

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6.2.2 PROJECTED COSTS AND COMPARISON OF METHODS

In addition to the cost estimates provided in the NPP section above (Section 6.1.3), the cost of determining carbon uptake includes the cost of sending samples to a laboratory for carbon content determination. This cost is variable, and it depends on the country, availability of laboratories with analytical carbon analysers, and the cost of chemicals for analyser calibration.

Each method of carbon measurement has pros and cons for implementation (Table 18).

Table 18. Pros and cons for carbon measurement options.

Measurement Technique	Pros	Cons	Reference
Carbon Analysis with a Standard Elemental Analyser	• Most accurate	• Costly • Not scalable	Umanzor & Stephens, 2023
Carbon Analysis with a High-Temperature Drying Oven (Combustion Method)	• Usually inexpensive and easy to do	• Needs many replicates to obtain robust results	Bertsch & Ostinelli, 2019
Proxies	• Fast • Cost-efficient • Scalable	• Not as accurate	Eger et al., 2023

Table 19. Pros and cons for nutrient uptake measurement options.

Measurement Technique	Pros	Cons	Reference
Nitrogen or Phosphorus Analysis with a Standard Elemental Analyser	• Most accurate	• Costly • Not scalable	Umanzor & Stephens, 2023
Proxies	• Fast • Cost-efficient • Scalable	• Not as accurate	Eger et al., 2023

6.3 NUTRIENT UPTAKE

Nutrient uptake refers to the amount of nutrients taken up from the water and transferred into biomass. It is reported in grams of nitrogen (N) and/or phosphorus (P) per unit time.

6.3.1 MEASUREMENT OPTIONS FOR NUTRIENT UPTAKE

The approach for calculating nitrogen or phosphorus uptake is the same as that of carbon described in Section 6.2, except that users must use the percent composition of these elements instead.

6.3.2 BASIC INSTRUCTIONS

See instructions for measuring carbon uptake (Section 6.2.1).

6.3.3 PROJECTED COSTS AND COMPARISON OF METHODS

As in the carbon uptake section (Section 6.1.3), nutrient uptake determination includes the costs estimates provided in the NPP section above in addition to the cost of determining nutrient uptake, which would include the cost of sending samples to a laboratory for N and P content determination. This cost is variable, and it depends on the country, availability of laboratories with analytical analysers, and cost of chemicals for analyser calibration.

Each method of nutrient uptake measurement has pros and cons for implementation (Table 19).

6.4 PH REGULATION

pH regulation is defined as the change in the pH value of surrounding seawater. This data is reported in difference of (delta) pH from one time point to the next.

6.4.1 MEASUREMENT OPTIONS FOR PH REGULATION

The pH of the water is either measured with a probe or a chemical reaction kit. The former can be done in situ, while the latter requires a water sample collection and can be performed in the lab.

6.4.2 BASIC INSTRUCTIONS

See water collection and measurement instructions in the nutrient levels section (Section 9.4.2).

6.4.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of pH measurement has various associated costs (Table 20), as well as pros and cons for implementation (Table 21).

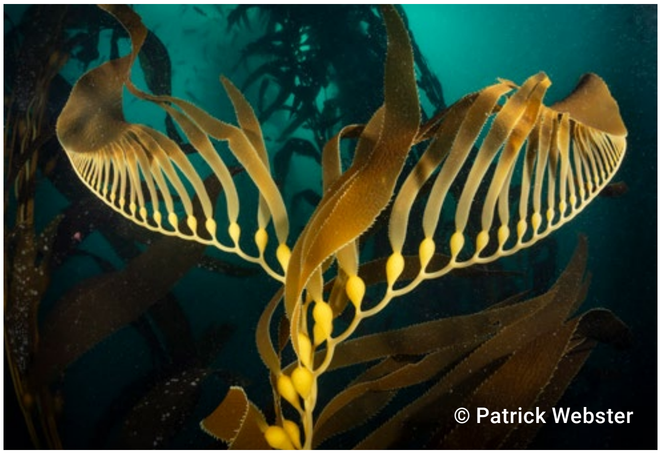
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Table 20. Projected costs for pH measurement options.

Method	Cost
pH Strip	Low
In-Water	Medium
GIS Layer	Low
Lab Analysis	Low
Arrays or Sensors	Initial: Very High Ongoing: Medium

Table 21. Pros and cons of pH measurement options.

Measurement Technique	Pros	Cons	Reference
Water Samples: pH Strip	• Very cost-effective • Simple	• Least accurate real-time measurement • Location and day specific	Verhoeven, 2020
In-Water Measure	• Accurate if calibrated • Precise location	• Expensive equipment • Fine calibration needed • Location and day specific	Rérolle et al., 2012
GIS Layers	• Large spatial distribution • Historic time series	• Poor coverage • Not specific to real-time conditions • Not relevant for before-and-after comparisons • Limited availability	Parker, 2016
Water Samples: Lab Analysis	• Very accurate • Relatively affordable	• Lab processing times • Location and day specific	Robillard et al., n.d.
Arrays or Sensors	• Time series data • Accurate values	• Restricted to sensor location • pH effects are localized	Rérolle et al., 2012

6.5 SEDIMENT REGULATION

Sedimentation plays an important role in marine ecosystems and can stabilize or denude habitats. Sediments are transported by ocean currents and waves which themselves are modified by benthic features such as kelp forests. Depending on the situation, increased sedimentation may be considered a service or disservice. Sediment regulation is reported in units of weight such as grams (g) or kilograms (kg).

6.5.1 MEASUREMENT OPTIONS FOR SEDIMENT REGULATION

Sedimentation is measured using sediment traps that are placed on the seafloor and left for a set time period.

6.5.2 BASIC INSTRUCTIONS FOR SEDIMENT REGULATION

6.5.2.1 SEDIMENT TRAPS

Sediment traps deployed within kelp forests are most commonly constructed of PVC piping with a height of between 30–60 cm and a diameter of 2.5–10 cm. The bottom end of the tube is sealed, and a mesh baffle is secured on the top end of the tube. Traps can be deployed at the sites by securing them to concrete stands, sandbags, or other weights (Figure 8). Depending on the sediment regime of the area, traps may need to be collected/emptied on a weekly, fortnightly, or monthly basis. To collect the sediment from within a trap, place the trap within a sealable plastic bag and transport it to the lab where the sediment can be flushed out and processed. Sediment should be dried in an oven at 60–70 °C until it reaches a consistent mass. This can then be used to estimate deposition rates, as well as being processed for particle size analysis and organic content.

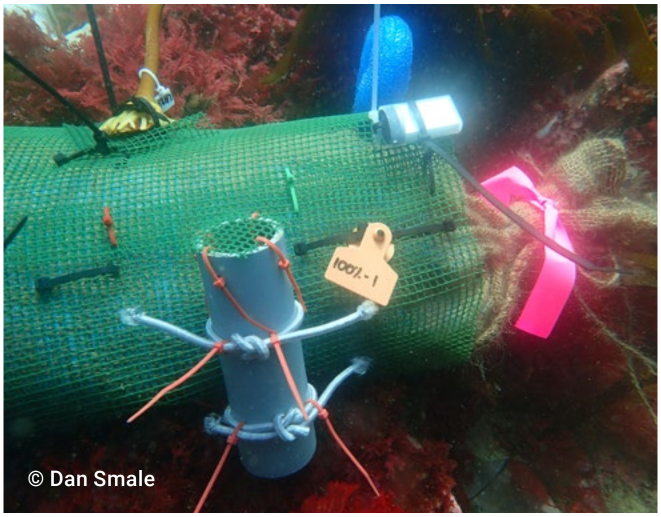
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Figure 8. Example of a sediment trap attached to a sandbag in situ.


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Assemble a unit like that depicted above (More details in Szmytkiewicz & Zalewska, 2014):

1. Lower it on the seafloor using a diver (or by hand on intertidal reefs).
2. Position the unit in a representative patch of reef.
3. Take a GPS point where you deployed the sediment trap.
4. Return at an appropriate time point to retrieve the trap, whether weekly, fortnightly, or monthly, depending on trap size and sediment regime. To retrieve the trap, place it in a sealable plastic bag and take it to the lab where the contents can be flushed out.
    a. Even the best-designed traps may be lost due to storms and unusually high wave action.

Note that sediment traps may be a convenient location to attach data loggers, such as for temperature (Section 9.1.2).

6.5.3 PROJECTED COSTS

Sediment traps are rated as a medium cost.

SECTION

7.0 PROVISIONING SERVICES

7.1 HARVESTED KELP

Harvested kelp is kelp biomass that is removed or collected for human use. It is reported in weight (either wet weight or dry weight) per unit area.

7.1.2 BASIC INSTRUCTIONS FOR HARVESTED KELP MEASUREMENT

7.1.2.1 FISHERY REPORTS

These reports are most commonly released by the local fisheries management agency. Report values may require 6–18 months to be released, so this information is not instantly available. Further, the reports are for larger regions, and users are often unable to attribute the benefits back to a specific kelp forest.

7.1.2.2 BEACH SURVEYS

Users may visit harvest locations and directly survey resource extraction during the harvest period. This method may be done once for a snapshot or repeatedly over the season to gain a better understanding of day-to-day or month-to-month harvest variation.

7.1.2.3 INDUSTRY SURVEYS

Users may directly contact industry bodies and cooperate or collaborate with them to gain access to harvest records.

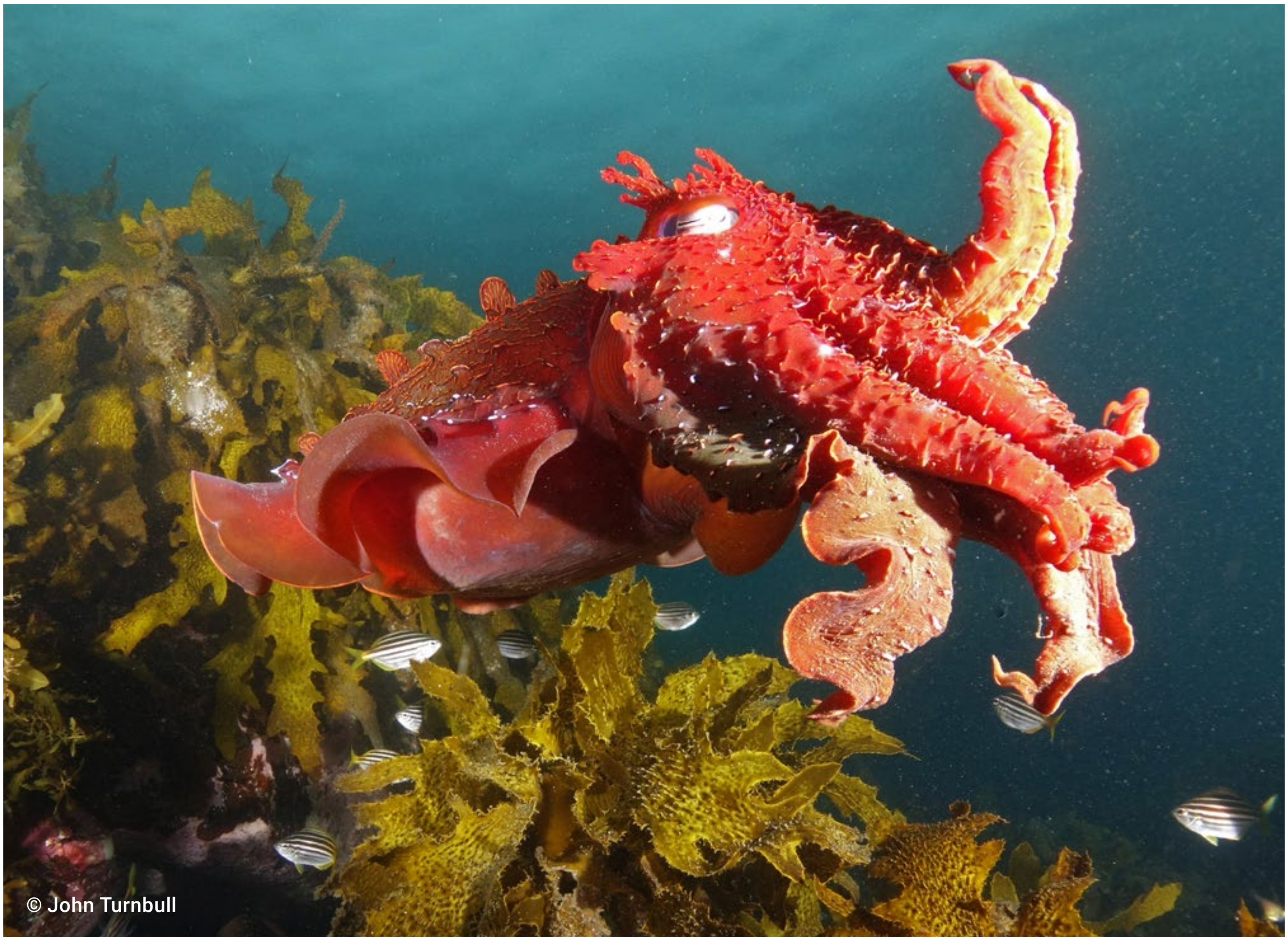
7.1.3 PROS AND CONS FOR EACH MEASUREMENT OPTION

Table 22. Pros and cons of harvested kelp measurement options.

Measurement Technique	Pros	Cons	Reference
Fishery Reports	- Standardized - Industry standard - Wide geographic range	- Time lag - May miss smaller operations or unregistered use - Not area-specific	Australian Department of Agriculture, Water, and the Environment, 2020
Beach Surveys	- More accurate for a specific location	- Time-intensive - Difficult to replicate across large areas	New South Wales Department of Primary Industries, n.d.
Industry Surveys	- Very specific - May provide data for a larger area	- Reliant on industry participation - Time-intensive	Lauzon-Guay et at., 2021

7.2 FISH AND INVERTEBRATE STANDING STOCK BIOMASS

Fish and invertebrate standing stock biomass refers to a snapshot (standing stock) of the fish or invertebrate biomass present in an ecosystem. Standing stock biomass is reported in weight per unit area for fish and large invertebrates, and in weight per kelp individual or biomass for epifauna and small invertebrates.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7.2.1 MEASUREMENT OPTIONS FOR FISH AND INVERTEBRATE STANDING STOCK BIOMASS

Sampling of kelp forest biodiversity is covered in greater detail in the biodiversity section (Section 5.1) and is a requisite for the approaches described below.

Removing fish or invertebrates from a reef to determine their biomass is typically not sustainable for long-term monitoring programs. Users may capture or estimate the animal length and then use established, weight-length relationships to estimate the biomass of the fish.

Length estimates may be done in the water by snorkelers or divers. This approach is less accurate but the most time efficient. Before surveying, users should train themselves to identify known lengths underwater to better estimate the fish length. Users can use fish cutouts or simple sticks with known lengths as tools to practice assessing length.

Stereo underwater video surveys are a more time-intensive, but more accurate method for obtaining fish biomass. Simply put, the user swims an apparatus containing two synced cameras which are recording along the transect line. This video is then later loaded into specialized software (e.g., EventMeasure) allowing calculation of fish length and identity.

Users may wish to separate their monitoring into different depth sections. These may include animals found adjacent to the seafloor, animals found mid-water, and animals found on or near the surface.

New technology means that these surveys may soon be done remotely or autonomously with AUVs/ROVs running the surveys and recording the video. Further advances may also automate the identification of species and estimate their length.

7.2.2 BASIC INSTRUCTIONS FOR MEASURING FISH AND INVERTEBRATE STANDING STOCK BIOMASS

See Section 5.1 for full details on counting biodiversity.

1. Once you have the length and identity of the individuals, obtain the weight length parameters for the species you observed. These parameters are available on FishBase. You may also use an R package called rfishbase to efficiently attach parameters to your data. If data is not available for the specific species, you can use parameters from other species in the same genus or family.
2. Compute the weight of each individual using the equation $W = a*L^b$ where W = weight, L = length, a and b are parameters.
3. Certain invertebrates may also have parameters available (e.g., Sealifebase). If they do not, common weights may be found in the literature.

7.2.3 PROS AND CONS OF EACH MEASUREMENT OPTION

Each method of fish and invertebrate standing stock biomass measurement has pros and cons for implementation (Table 23).


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Table 23. Pros and cons for fish and invertebrate standing stock biomass measurements options.

Measurement Technique	Pros	Cons	Reference
Weighing Fish/ Invertebrates Directly	• Species and location specific	• Not scalable • Destructive or invasive sampling • Should only be done once • Resource-intensive	Yu et al., 2022
In-Water Visual Surveys	• Data available instantly • Lower cost • Better for benthic organisms	• Less accurate • Requires some training • Must photograph or guess if species ID is unknown	Edgar & Stuart-Smith, 2014
Video Surveys	• Higher accuracy • Ability to check species ID	• High processing time • Some equipment and software required • Poor results for cryptic and benthic species	Smith et al., 2021

7.3 FISH AND INVERTEBRATE BIOMASS PRODUCTION

The annual rate of biomass production in fish and invertebrates is reported in weight per unit area per unit time.

7.3.1 BASIC INSTRUCTIONS TO MEASURE FISH AND INVERTEBRATE BIOMASS PRODUCTION

Measuring the secondary production of a fish or invertebrate is a complex process that may be too expensive for most projects.

Rather, projects can use established relationships between an organism's standing stock biomass (i.e., weight) and its biomass production. These relationships are available at a coarse level for all organisms (e.g., fish versus invertebrates) and may be available at a higher resolution for select species.

It is possible to calculate productivity of fish and invertebrates by collecting project-specific data, but it is resource-intensive. All methods, however, require catching, tagging, weighing, and releasing individual fish, and repeating the process at a later date. As a result, very few, if any, projects have the resources to undertake such monitoring at ecologically meaningful scales.

See the basic instructions for measuring fish standing stock biomass in Section 7.2.2. Generally, the steps are to:

1. Obtain fish biomass per m^2.
2. Transform the biomass values into production values using biomass to production ratio values (Jenkins, 2015).

7.3.2 PROS AND CONS FOR EACH MEASUREMENT OPTION

Each method of annual biomass production measurement has pros and cons for implementation (Table 24).

Table 24. Pros and cons of annual biomass production measurement options.

Measurement Technique	Pros	Cons	Reference
Production Ratios	• Low-cost • Scalable	• Values are often given for large groups (e.g., fish vs. invertebrates)	Jenkins, 2015; zu Ermgassen et al., 2016
Weight Measurements Over Time	• More accurate • Individual-specific	• Not scalable • Often impossible in open marine systems	Alatorre-Jacome et al., 2012


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CHAPTER
8.0 CULTURAL SERVICES

8.1 COMMUNITY ENGAGEMENT

Community engagement is defined as number of volunteers (hours) working on a project, including unpaid community or citizen scientists. It is quantified by reporting the number of hours devoted to conservation or monitoring efforts.

8.1.1 MEASUREMENT OPTIONS FOR COMMUNITY ENGAGEMENT

Projects should record the number of volunteers or volunteer hours spent working on a project. The simplest way to do this is to have each volunteer submit a work log where they track the hours they spend on the project.

If you do not have work logs, you may randomly sample a group of volunteers and ask them how long they have spent working on the project in the last month or year. You may then multiply the average of your sample over the total number of volunteers involved in the project. The sample size of the group required will vary with the size of your project, but a rough rule is to aim for 25% of the volunteer force.

8.1.2 PROS AND CONS OF EACH MEASUREMENT OPTION

Each method of community engagement measurement has pros and cons for implementation (Table 25).

Table 25. Pros and cons of community engagement measurement options.

Measurement Technique	Pros	Cons
Self-Reporting	• Accurate • Simple • Can be built into other project reporting	• Cannot be done retroactively • Relies on volunteers to log
Random-Sample Surveys	• Can be done retrospectively	• Less accurate • More resource intensive

8.1.3 BASIC INSTRUCTIONS FOR RANDOM SAMPLING TO MEASURE COMMUNITY ENGAGEMENT

While detailed instructions on conducting a random sample survey are beyond the scope of this guidebook, users will want to ensure that:

1. They are taking a truly random sample of the total population.
2. The questions are clear, unbiased, and unambiguous.
3. They have obtained consent from survey participants.

Extensive information is contained in Fowler Jr. (2013), and more accessible steps are documented by SurveyMonkey, a common online tool for conducting surveys.


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8.2 SCIENCE AND EDUCATION

Here, we define science and education in terms of the number of people or hours spent with an educational focus. Time may be during the restoration itself, at events about the restoration process, or visiting and learning about the site following restoration.

8.2.1 MEASUREMENT OPTIONS FOR SCIENCE AND EDUCATION

Ideally, projects will have good data on the attendance of any outreach or education projects that they do. This data may be converted into hours spent by multiplying the number of participants by the length of the program or outing. You may also wish to connect with any schools or universities that may be using the site as a teaching or field trip location.

If your content is digital, there are numerous services for tracking the views and uptake of your materials (e.g., Google Analytics, Twitter trends, LinkedIn trends, etc.)

8.3 CULTURAL AND SPIRITUAL CONNECTION

Quantifying and measuring a person or community's spiritual or cultural connection to an ecosystem or kelp forest is often not possible. However, there are some methods to quantify how connected a person feels to an ecosystem. These methods involve surveys that ask how a person feels about an ecosystem. Users may wish to understand if a person or community's connection with nature has increased or not following the conservation project. These surveys are typically qualitative, rather than quantitative.


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8.3.1 MEASUREMENT OPTIONS FOR CULTURAL AND SPIRITUAL CONNECTION

Projects should survey people living near or interacting with the restoration site before and after restoration.

8.3.2 BASIC INSTRUCTIONS FOR MEASURING CULTURAL AND SPIRITUAL CONNECTION

Designing social surveys requires ethical consideration, prior, and informed consent, as well as rigorous planning to ensure that the survey examines a representative sample. Social surveys must also be free to complete. We do not recommend trying to do these surveys if you have no training. It is best to employ a team to do the survey for you.

8.3.2.1 CN-12 SURVEY

The CN-12 is a brief and multidimensional instrument developed to measure an individual's connection with nature across four dimensions:

1. Affective
2. Cognitive
3. Experiential
4. Behavioural

Further details are discussed by Hatty et al. (2020).

8.3.2.2 INCLUSION OF NATURE IN SELF (INS) SCALE

This single-item, graphical scale measures the extent to which an individual perceives themselves as part of nature by selecting the degree of overlap between two circles representing the self and nature. Further details are discussed by Martin & Czellar (2016).

8.3.2.3 NATURE RELATEDNESS SCALE (NR-6 OR NR-18)

The Nature Relatedness Scale assesses an individual's affective, cognitive, and behavioural connection with the natural world. The shorter NR-6 version consists of six items, while the NR-18 has 18 items. Nisbet & Zelenski (2013) provide further details.

8.4 EXISTENCE VALUE

The existence value is the value a person places on knowing that a species, ecosystem, or ecological community exists and persists. This value is beyond the value they may get from visiting or experiencing an ecosystem, and is measured economically, whether reported in dollars or other currency.

8.4.1 MEASUREMENT OPTIONS FOR EXISTENCE VALUE

Existence values are most used in cost-benefit decisions that consider the outcomes of different actions or an action versus an inaction. They can be measured using willingness to pay surveys. These surveys ask participants how much they are willing to pay to ensure that an ecosystem remains intact or that one is restored.

8.4.2 BASIC INSTRUCTIONS FOR MEASURING EXISTENCE VALUE

Designing willingness-to-pay surveys requires ethical consideration, fair and informed consent, as well as rigorous planning to ensure that projects examine a representative sample. We do not recommend trying to do these surveys if you have no training. Rather, it is best to employ a team to do the survey for you.

Broadly, when creating these surveys you will need to:

1. Define the objective.
2. Identify your target demographics (e.g., age, location, etc).
3. Choose your valuation method (Champ et al., 2003).
4. Create a questionnaire.
5. Deliver the questionnaire.

8.5 RECREATIONAL SNORKEL AND DIVE VISITS

Scuba and snorkel visits are the number of people or time spent diving or snorkelling in a kelp forest. They can be measured in terms of a count, or in days or hours.


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8.5.1 MEASUREMENT OPTIONS FOR RECREATIONAL SNORKEL AND DIVE VISITS

Users can choose to quantify the quantity of these activities (i.e., number of visits), economic value (i.e., dollars or other currency), or both.

Field surveys can be used to get a measure of the number of visitors to a kelp forest. Surveys should take place at representative times throughout the year. For instance, visits are likely to be higher on weekends compared to weekdays, or in summer compared to winter. Therefore, multiple and representative surveys should be carried out during the study.

Surveys may be done in person, waiting at a popular dive site, and recording the number of people that visit the kelp forest, or by installing a video camera and monitoring the footage later.

A coarser approximation may be obtained by contacting local dive operators and requesting information on the number of dive tanks that they have rented or tours completed to a specific location. If you wish to allocate this information to a specific kelp forest, users will need to further survey their customers and get an approximation of what percentage of dive tanks are being used at specific dive sites (with or without kelp forests).

Calculation of the economic costs of these trips may be achieved by using willingness to pay surveys or by collecting data on travel costs.


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8.6 PERSON HOURS

Socioeconomic factors refer to the number of people hours, both paid and unpaid, involved in the monitoring activity. This includes the employment hours and the salary value of those hours. These factors should be monitored from the beginning of the project, reported in Person Hours related to Intervention Activity.

Measuring the economic impact of a single restoration monitoring project is difficult. It is hard to precisely determine how much of a fisher's catch is attributable to a single kelp forest or how much ecotourism is drawn to a region because of one restoration site. Therefore, we do not provide specific guidelines for measuring economic impact.

8.7 PROJECT IMPACTS ON THE COMMUNITY

Marine management is a place-based activity that impacts local communities and requires resource allocations that may otherwise be used to improve the quality of life, so community support is crucial. Outreach and communication about conservation, marine management, the value of healthy ecosystems, and a project's connections to people can help maintain this support.

Projects are encouraged to produce communication tools such as videos, posters or outreach talks that discuss kelp forest ecosystems. Ideally, these materials will incorporate some of the information collected here, such as the area of kelp restored, or the number of species found in a local kelp forest.

CHAPTER

9.0 ENVIRONMENTAL CONDITIONS AND STRESSORS

Monitoring the physical parameters of the ocean over time can provide important information about drivers of changes in the kelp forest structure and abundance. For example, increasing temperatures beyond the thermal tolerance of a kelp species often correspond to declines in its abundance. Understanding variation in environmental conditions and potential stressors is a key component of kelp forest monitoring and underpins management and restoration approaches. Attempting kelp restoration in an area where the environmental conditions driving initial kelp decline still persist is considered a poor use of resources, as restoration is unlikely to be successful.

9.1 TEMPERATURE

Sea surface temperature is one of the most monitored marine environmental metrics. This information is either derived from satellites, arrays of semi-permanent to permanent sensors, or project-based sensors. Project needs will help determine the most suitable data source. Sea surface temperature is reported in degrees Celsius.

9.1.1 MEASUREMENT OPTIONS FOR TEMPERATURE

9.1.1.1 LONG TERM MONITORING DATA

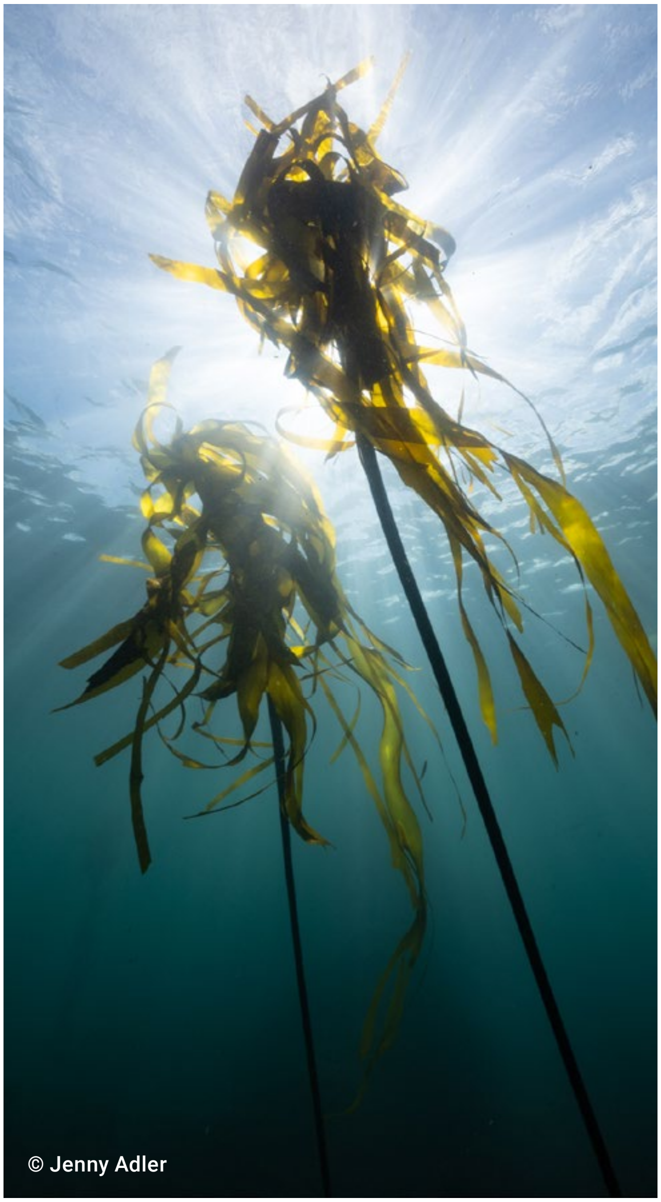
Advances in remote sensing technology mean that sea surface temperature data are available in near real-time, all around the globe. This data is available at spatial resolutions of 9 km and 25 km.

9.1.1.2 IN-WATER DATA LOGGERS

Hobo is a commonly used model of in-water data logger. These are relatively low-cost units that are installed on site to collect temperature data. More expensive units may also collect data on additional parameters (e.g., pH, light, etc.). Some models require a computer connection to read data, while others have wireless functionality and could be streamed in situ.

9.1.1.3 MONITORING ARRAYS

Many countries have now invested in real-time monitoring sensors or arrays in their coastal waters. These sensors are in-water measures of sea temperature and other parameters. Data is often freely available from the environment or ocean branch of your government (e.g., Australia: IMOS, Canada: DFO). If no local data is available, the International Comprehensive Ocean and



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Atmosphere Dataset (ICOAD) provides an open-source database at a resolution of 1 km x 1 km with monthly summaries of several key ocean metrics including temperature. This data is available as monthly averages and thus lag real time observations by two to six weeks.

9.1.1.4 SUGGESTIONS

If finer-scale data is required, projects can install their own continuous temperature monitoring unit. There are a number of these available on the market and projects should consider if they require real-time monitoring, the length of time the sensor will be left in the water, and of course, the project budget.

Handheld probes provide the greatest accuracy, but are expensive, and can only provide single time point results. Portable sensors are often less costly, can be left in the water for extended periods of time (i.e., months), are deployable at exact locations and depths, and once collected, provide continuous data from the study period. In addition, fixed sensors can be installed near your study site, but require a fixed cable connection and may be best used off docks or other marine structures. While also expensive, they provide real-time information, do not need to be removed, and produce highly accurate results.

Projects will most likely want something simple and low cost, with continuous data, with reasonable accuracy. We suggest the use of portable sensors that can be installed at the restoration site and collected later. The main risk with these sensors is that if they leak or are dislodged, the data is lost. Therefore, we suggest you carefully consider where to locate them.

The second suggestion would be to look at the real-time sensor information. Sea temperatures are highly correlated and the sea temperature at one location is likely to resemble the temperature at another location. Therefore, if you do not need high-resolution data, we suggest you look at the remote sensing or array data available for your area. A key downside of the remote-sensing data is that it requires someone with GIS and remote sensing capabilities to process and interpret.

Maurer (2002) discusses remote sensing of temperature for users wishing to learn more.

9.1.2 BASIC INSTRUCTIONS FOR MEASURING TEMPERATURE

9.1.2.1 INSTALLING A TEMPORARY WATER MONITOR

1. Preparation
    a. Identify an appropriate location on the rocky reef that represents the area's temperature conditions and is accessible for deployment and retrieval. Consider depth, water circulation, and potential disturbances (e.g., strong currents, boat traffic). Depths may vary, but consistency is important.
    b. Set up the logger's sampling rate, deployment start time, and any other relevant settings using the manufacturer's software.
2. Assemble the mounting materials
    a. Obtain a suitable mounting device, such as a stainless steel or PVC pipe, a metal or plastic mesh cage, or a heavy-duty cable tie. The chosen mounting device should be sturdy, non-corrosive, and resistant to marine growth.
    b. Acquire additional mounting materials, such as marine epoxy, zip ties, or cable ties, as needed for securing the logger and mounting device to the rocky reef.
3. Deploy the logger
    a. Dive to the chosen location on the rocky reef, carrying the logger and any required mounting materials.
    b. Clean the mounting area by removing any loose debris, algae, or marine growth to ensure a secure attachment.
    c. Attach the logger to the mounting area, ensuring it is securely attached.
4. Monitor and retrieve the logger
    a. Periodically check the logger's attachment and condition during any subsequent dives or using remote underwater cameras.
    b. When it is time to retrieve the logger, carefully detach it from the mounting area and bring it to the surface. If collecting multiple loggers from a site, ensure their location is noted (e.g., by placing them in labelled bags or adding coloured zip-ties). Follow the manufacturer's instructions for downloading the temperature data.

9.1.3 PROJECTED COSTS AND COMPARISON OF METHODS

A Hobo water logger can be purchased for approximately $200 USD.

Each method of sea water temperature measurement has pros and cons for implementation (Table 26).


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Table 26. Pros and cons for sea water temperature measurement options.

Measurement Technique	Pros	Cons	Reference
In-Water Loggers (Hobo)	Site-specific Instant measures High accuracy	More costly	Onset Computer Corporation, 2018
Long-Term Monitoring Data	Available worldwide Continuous data	Low resolution May be extrapolated to your site	International Comprehensive Ocean and Atmosphere Dataset, 2024
Monitoring Arrays	High accuracy Continuous data	May not be set up near your restoration site	Integrated Marine Observing System, 2024


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9.2 SALINITY

Salinity refers to the amount of dissolved salts in water, measured in parts per thousand (i.e., PPT or practical salinity unit [PSU]).

9.2.1 MEASUREMENT OPTIONS FOR SALINITY

The measurement options for salinity are the same as temperature (Section 9.1.1) with many of the probes measuring both metrics at the same time. Global open-source data measuring salinity is available with eight-day running averages at a spatial resolution of 70 km.

9.2.2 BASIC INSTRUCTIONS FOR MEASURING SALINITY

See instruction for water temperature (Section 9.1.2).

9.2.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of salinity measurement has various associated costs (Table 27), as well as pros and cons for implementation (Table 28).

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Table 27. Projected costs of each salinity measurement option.

Method	Cost
Water Quality Multimeter	High
Salinity Tester	Low
Long-Term Sensor or Monitoring Array	Low

Table 28. Pros and cons of salinity measurement options.

Measurement Technique	Pros	Cons	Reference
Water Quality Multimeter	• Site-specific • Instant measures • Highest accuracy	• Very costly	YSI Inc., n.d.a.
Salinity Tester	• Site-specific • Instant measures • High accuracy • Much lower cost	• Standalone unit • Less accurate than a meter • Surface sample only	Hanna Instruments, n.d.
Long-Term Sensor or Monitoring Array	• Available worldwide • Continuous data	• Low resolution • Distance to your location varies	Integrated Marine Observing System Data Network, 2024

9.3 PH LEVELS

pH measures how acidic or basic a substance or solution is. It is reported as a unitless number on the pH scale.

9.3.1 MEASUREMENT OPTIONS FOR PH

The pH of the water is either measured with a probe or a chemical reaction kit. The former can be done in situ, while the latter requires collecting a water sample and can be done in the lab.

9.3.2 BASIC INSTRUCTIONS FOR PH MEASUREMENT

See water collection and measurement instructions in Section 9.4.2.

9.3.3 PROJECTED COSTS AND COMPARISON OF METHODS

Each method of pH measurement has various associated costs (Table 29), as well as pros and cons for implementation (Table 30).

Table 29. Projected costs of each pH measurement option.

Method	Cost
Water Strips	Low
Simple Probe	Low
Multi-Meter and Probe	Medium
Deployable Multi-Parameter Logger	Very High

Table 30. Pros and cons of pH measurement options.

Measurement Technique	Pros	Cons	Reference
Water Samples: Strip	• Very cost-effective • Simple	• Least accurate real-time measurement, often in half-pH increments • Location and day specific	Precision Laboratories, 2019
In-Water Measure	• Accurate if calibrated • Precise location	• Expensive equipment, sometimes extremely expensive • Fine calibration needed • Location and day specific	Surface: YSI Inc., n.d.a.; Submersible: YSI Inc., n.d.b.
GIS Layers	• Large spatial distribution • Historic time series	• Historic averages • Not specific to real-time conditions	Azab, 2012
Water Samples: Lab	• Very accurate • Relatively affordable	• Lab processing times • Location and day specific	Robillard et al., n.d.
Arrays or Sensors	• Time series data • Accurate values	• Restricted to sensor location	Rérolle et al., 2012


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9.4 NUTRIENT LEVELS

Nutrient levels in seawater are typically measured by the concentration of nitrogen and phosphorus in the water. These measurements may be further broken down into measures of ammonia (NH_4+), nitrate (NO_3-), or phosphate (PO_3-). While certain amounts of these compounds are required to sustain kelp growth and maintain a healthy ecosystem, nutrient concentrations that are too high can stimulate overgrowth of phytoplankton, bacteria, and other algae that reduce the clarity of the water column and reduce primary production. Further, when the biological material created by these bloom events decomposes, the oxygen levels in the water are significantly reduced and can result in anoxic zones that are inhospitable to life. Nutrient levels are reported in milligrams per litre (mg/L), parts per million (ppm), or micromoles (μmol).

9.4.1 MEASUREMENT OPTIONS FOR NUTRIENT LEVELS

9.4.1.1 IN THE FIELD

Certain probes can be calibrated to measure nutrient concentrations directly in the field (e.g., YSI Multiparameter Digital Water Quality Meter, Hanna Instruments Environmental Monitoring Chemical Test Kit) but must be well-maintained and calibrated with each use. It is important to ensure that sensors are compatible with saltwater use. Using an in-water probe is the most accurate option.

Chemical test kits are a disposable, lower-cost alternative to a water probe. These kits work by combining a seawater sample with a catalyst and assessing the colour change to a known standard. These are common items for saltwater aquariums.

9.4.1.2 LAB ANALYSIS

If you do not have a sensor, do not wish to invest in one, and want a very precise measurement, you may take water samples and send them to the lab for analysis.

9.4.2 BASIC INSTRUCTIONS FOR MEASURING NUTRIENT LEVELS

9.4.2.1 IN THE FIELD: WATER PROBE

It is best to make the probe measurements from a watercraft as to avoid disturbing the water. Similarly, sampling should be done from the front of the boat and before any divers or snorkelers have been in the water. Lower the probe into the water approximately one metre in depth and wait until the probe provides a consistent measurement over a five-second period. It is best practice to take multiple measurements across the extent of the kelp forest and generate an average value. If it is only possible to obtain a single measurement, it is best obtained from the centre of the kelp forest or restoration area.

9.4.2.2 IN THE FIELD: CHEMICAL KIT

Follow the procedure described for the lab analysis to collect the water sample. After collecting the water sample, follow your chemical analysis kit's instructions.

9.4.2.3 LAB ANALYSIS

Collect your water samples in clean, sterile containers (e.g., plastic, metal, or glass). The sample is best collected from a watercraft to avoid contaminating the sample. Unscrew the top of your container, being careful not to touch the insides, and then place it as deep in the water as is feasible for your arm length. Once the container is full, pull it out of the water, empty it, and repeat this process three times. After the third fill, you may cap the container and place it in a dark, cool location (e.g., a freezer box). The water samples should then be sent to the lab for analysis.

9.4.3 PROJECTED COSTS AND COMPARISON OF METHODS

See previous water quality cost estimates (Section 9.3.3).

Each method of nutrient level measurement has pros and cons for implementation (Table 31).

Table 31. Pros and cons of nutrient level measurement options.

Measurement Technique	Pros	Cons	Reference
Field: Water Probe	• Very accurate • Can easily collect multiple samples per site	• Very high initial cost • Regular maintenance and calibration required	YSI Inc., n.d.a.
Field: Chemical Kit	• Lowest cost per sample • Can also collect multiple samples per site	• Less accurate • Single use only	Hanna Instruments, 2024
Lab Analysis	• Highest accuracy	• High cost per sample • Extended processing time per sample • May be unavailable locally depending on lab capabilities	Robillard et al., n.d.


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9.5 HERBIVORY LEVELS

Kelp may be regularly grazed by herbivores such as sea urchins, snails, some fish, and abalone. Herbivory level is measured as the amount of kelp consumed per unit area per unit time. Reporting units are activity (bites per unit time) and/or weight (grams or kilograms consumed).

9.5.1 MEASUREMENT OPTIONS FOR HERBIVORY LEVELS

The most common way to measure herbivory in a kelp forest is by using assays. These are kelp materials that are transplanted to the site and collected after a period of time. Assays may also be filmed to determine the grazing rate and/or the identity of the grazers.

9.5.2 BASIC INSTRUCTIONS FOR MEASURING HERBIVORY LEVELS

Ideally, collect a small amount of kelp material from the same kelp forest in which you are interested in measuring herbivory. You may also use cultured kelp or kelp collected from a nearby kelp forest if required. One individual should be used per assay.

First, record the wet weight biomass of each kelp individual. After, you will transport the kelp individual to the study site and secure it to the seafloor. A quick and simple approach is to tether the individual to a lead weight and simply let it rest on the seafloor. Other approaches may use epoxy, bolts, or lines to secure the kelp to the seafloor. Assays are run over a short period of time, so the attachment method does not need to be highly secure. Assays may be run for hours to days depending on the herbivory level; higher herbivory rates require shorter assay time periods. If you are using video cameras, your camera's battery life will be a limiting factor for assay time.

Once the desired time has elapsed, return to the location, collect the kelp, and record its new wet weight biomass. Subtract this value from the original biomass to determine the biomass that was grazed. Visual signs of grazing are small semi-circles and may be found on the exterior or interior of the blade (Figure 9).

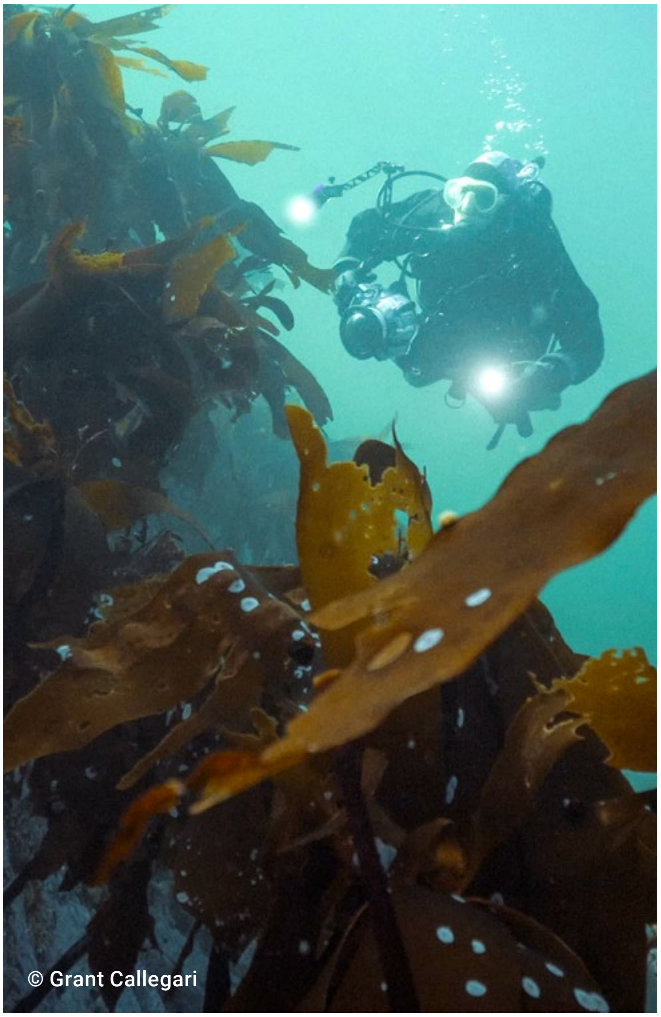
If you are using a video camera, set the camera up so that it has a full view of the kelp individual and ensure that it is securely anchored on the seafloor. You can place cameras on the seafloor by using modified tripods or metal plates with camera attachments. After retrieval, you may review the footage to determine the species of the grazers and the bite rate per hour. For most purposes, the biomass consumed is the most important metric.

We suggest that multiple assays are completed per site and that they are sufficiently spaced apart. The assays may be placed inside or outside of the kelp forest.

9.5.3 PROJECTED COSTS

Costs are largely dependent on salaries and diver time.

Figure 9. Example of grazing signs on kelp.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9.6 DISEASE AND FOULING

Disease, infection, or fouling manifests on the surface of kelp blades. Disease may be seen on the blade as discolouration, tearing, or coarse surfaces. Disease and fouling are reported as percent (%) of kelp blade fouled.

9.6.1 MEASUREMENT OPTIONS FOR KELP DISEASE AND FOULING

Kelp blades must be visually inspected to determine the level of disease or fouling. Ideally this is done in water as it prevents the removal of the blade, but if necessary, it may also be done on land.

Make a simple visual assessment to determine what percentage of the blade is discoloured, fouled, or damaged (Figure 10).

9.6.2 BASIC INSTRUCTIONS FOR MEASURING KELP DISEASE AND FOULING

1. Remove random kelp blades as described in the hole punch method section.
2. Visually assess what percentage of the blade is fouled or diseased.


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Figure 10. Image of fouled kelp blade.

CHAPTER

10.0 DATA REPOSITORIES

10.1 DATA PRINCIPLES

We encourage all projects to follow the Findable, Accessible, Interoperable, and Reusable or FAIR data principles.

Findable

- **F1:** Data and metadata should be assigned a unique and persistent identifier, such as a Digital Object Identifier or DOI.
- **F2:** Metadata should be rich, descriptive, and registered or indexed in a searchable resource, such as a data repository or catalogue.
- **F3:** The identifier should link to the metadata, allowing users to access information about the data even if the data itself is not available.
- **F4:** Include metadata in the data, allowing it to be easily discovered and accessed by humans and machines.

Accessible

- **A1:** Data and metadata should be retrievable using a standardized communications protocol that is open, free, and universally implementable.
    - » **A1.1:** The protocol should allow for authentication and authorization where necessary, ensuring data security and access control.
- **A2:** Metadata should always be accessible, even when the data is no longer available, to provide a record of the dataset's existence and characteristics.

Interoperable

- **I1:** Data should use a formal, accessible, shared, and broadly applicable language to facilitate data exchange and integration.
- **I2:** Data should use vocabularies that follow FAIR principles, ensuring consistency and compatibility across different datasets.
- **I3:** Data should include qualified references to other data and metadata, establishing relationships and connections between datasets.

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Reusable

- **R1:** Data and metadata should have clear and accessible data usage licenses, specifying any restrictions, conditions, or requirements for use.
    - » **R1.1:** Metadata should provide accurate and relevant information about the data, such as provenance, context, and any applicable standards.
    - » **R1.2:** Metadata should be associated with detailed, accurate, and explicit data quality information to enable users to assess the dataset's suitability for their purposes.
    - » **R1.3:** Data should be stored in a format that maximizes its potential for reuse, such as open, non-proprietary, and widely adopted formats.

The FAIR data principles provide a framework for managing, sharing, and preserving research data in a manner that promotes discoverability, accessibility, and reusability. By adhering to these principles, researchers and institutions can contribute to more efficient and collaborative research practices, ultimately enhancing the impact and value of their data.


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10.2 DATA REPOSITORIES

Wherever possible, we encourage users to share and upload their data to community-based data repositories so that it may help inform marine management. There are several data repositories available depending on the information that has been collected, the most common of which are for fish and invertebrate surveys.

Kelp Forest Alliance

The Kelp Forest Alliance (KFA) is a knowledge driven not-for-profit dedicated to protecting and restoring the world's kelp forests. It hosts an interactive and accessible data platform for monitoring and tracking the outcomes of kelp restoration and conservation interventions. All the data outlined in this guidebook should be shareable with the Kelp Forest Alliance. Further, logging your data here allows you to connect with hundreds of other kelp restoration experts around the world.

The Kelp Forest Alliance database aligns with the standards in this guidebook.

Partnership for Interdisciplinary Studies of Coastal Oceans

The Partnership for Interdisciplinary Studies of Coastal Oceans or PISCO is a long-term research and monitoring program focused on understanding the coastal marine ecosystems along the West Coast of the USA, notably California and Oregon. You may contribute biodiversity data and some basic metadata to this program. PISCO has its own data collection standards; following the suggestions in this guidebook may not be enough to qualify your data for inclusion.

Reef Check

Reef Check (RC) is a volunteer-based, citizen science program aimed at monitoring the health of rocky reef ecosystems from Baja California to British Columbia. The goal of RC is to provide accurate and timely information on the status of these ecosystems, engage local communities in the conservation process, and support the sustainable management of marine resources. You may contribute biodiversity data and some basic metadata to this program. Reef Check has its own data collection standards and following the suggestions in this guidebook may not qualify your data for inclusion.

Reef Life Survey

The Reef Life Survey (RLS) program is a global, volunteer-based, citizen science initiative aimed at assessing and monitoring the biodiversity and abundance of marine life in shallow water ecosystems, such as coral reefs, rocky reefs, and temperate kelp forests. You may contribute biodiversity data and some basic metadata to this program. This guidebook uses the Reef Life Survey method for quantifying animal biodiversity at restoration sites and should thus be compatible for inclusion. However, users must be certified by existing RLS members before being able to add their data. The Reef Life Survey methods for biodiversity should match the methods described in this guidebook.

European Marine Observation and Data Network (EMODnet)

European Marine Observation and Data Network (EMODnet) is a comprehensive, collaborative initiative designed to gather, standardize, and disseminate marine data across Europe's diverse marine environments, including the North-East Atlantic, the Mediterranean, the Black Sea, and the Baltic Sea. It operates by integrating data from over 160 organizations, encompassing a wide range of marine disciplines such as bathymetry, geology, biology, chemistry, and human activities. A key aspect of EMODnet's function is its commitment to data standardization and quality. This involves the application of rigorous quality assurance and control processes to ensure data accuracy and consistency. All data are formatted into standardized, interoperable formats with comprehensive metadata, allowing for easy integration and use in a variety of applications. EMODnet adheres to international interoperability standards, ensuring that its data can seamlessly interact with other data systems. To contribute data to EMODnet, data providers must align with its standardized protocols and formats, ensuring that all data integrated into the network meet its high-quality standards. This rigorous approach to data standardization makes EMODnet a valuable and reliable resource for marine and coastal management, policymaking, scientific research, and public awareness initiatives across Europe. The guidelines in this document will not necessarily comply with EMODnet standards.

Global Biodiversity Information Facility (GBIF)

An international open data infrastructure, which provides access to data on all types of life on Earth, the Global Biodiversity Information Facility or GBIF aggregates biodiversity data from a wide array of sources, including museums, research institutions, and individual researchers, focusing on species occurrence records and environmental data. Central to GBIF's operation is its commitment to data standardization, ensuring consistent and accurate data integration. This involves the use of Darwin Core, a standardized format for biodiversity data, rigorous quality checks, and comprehensive metadata provision. GBIF emphasizes interoperability and easy data accessibility, with a user-friendly portal for data search and download. Contributors to GBIF must adhere to its standardized protocols and formats, making it a crucial global resource for biodiversity data, supporting research, conservation, and policy-making efforts worldwide. The guidelines in this document will not necessarily comply with GBIF standards.


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CHAPTER

11.0 TECHNOLOGIES TO WATCH

Environmental monitoring technologies for marine systems are developing rapidly that may help to overcome some of the issues outlined in this document. We outline some recent advances in this section.

Integration of AI and Machine Learning

- Advanced Pattern Recognition: AI can be trained to recognize patterns and anomalies in kelp forest ecosystems, such as changes in kelp density, disease outbreaks, or invasive species encroachment. This can lead to early detection of marine issues and more effective management responses.
- Predictive Modelling: Machine learning models can analyse historical data to predict future changes in kelp forests, such as responses to climate change or human activities. This predictive capability is crucial for developing adaptive management strategies.

Satellite Remote Sensing

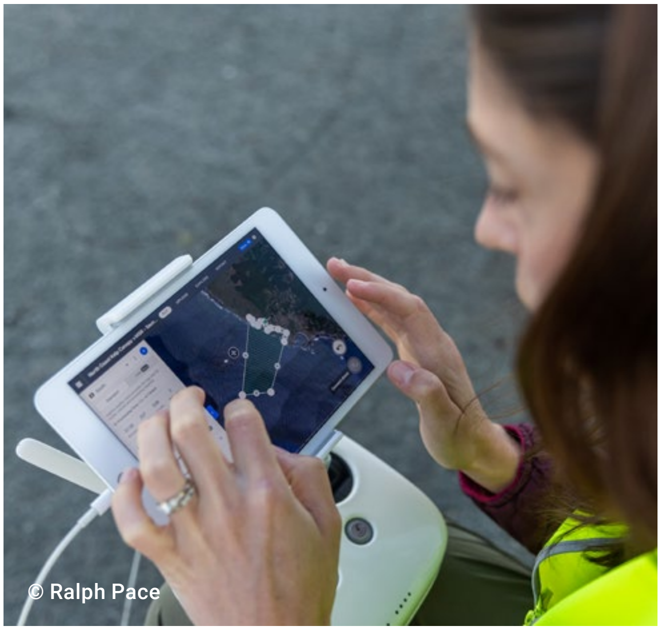
- High-Resolution Monitoring: Modern satellites can capture images at a resolution high enough to monitor individual kelp plants, allowing for detailed assessments of kelp forest health and dynamics.
- Temporal Analysis: Regular satellite passes provide an opportunity to monitor changes over time, offering insights into seasonal variations, long-term trends, and the impacts of events like storms or El Niño.

Advanced Sensor Technologies

- Multi-Parameter Monitoring: Next-generation sensors can simultaneously measure multiple environmental parameters, providing a holistic view of the conditions within kelp forests.
- Real-Time Data Transmission: These sensors can be equipped with wireless communication technologies, enabling real-time data transmission and immediate analysis, which is crucial for timely decision-making.

Genetic and Molecular Tools

- Species-Specific Identification: eDNA techniques can identify species with high precision, including those that are rare or difficult to observe, enhancing our understanding of biodiversity.



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- Monitoring Genetic Health: Beyond species identification, these tools can assess the genetic diversity and health of kelp populations, which is vital for understanding resilience to environmental stressors.

Citizen Science and Crowdsourcing

- Diverse Data Collection: Citizen scientists can collect a wide range of data, from water quality measurements to photographic documentation of species, contributing to a more comprehensive dataset.
- Engagement and Education: These initiatives also serve as powerful tools for public engagement and education, fostering a community of stewards who are invested in the health of kelp forests.

Collaborative Networks and Data Sharing

- Global Data Repositories: Establishing global data repositories can facilitate the sharing of large datasets, allowing for more comprehensive and collaborative research efforts.
- Standardization of Methods: Promoting standardized data collection and analysis methods across different regions and projects ensures that data can be aggregated and compared globally.

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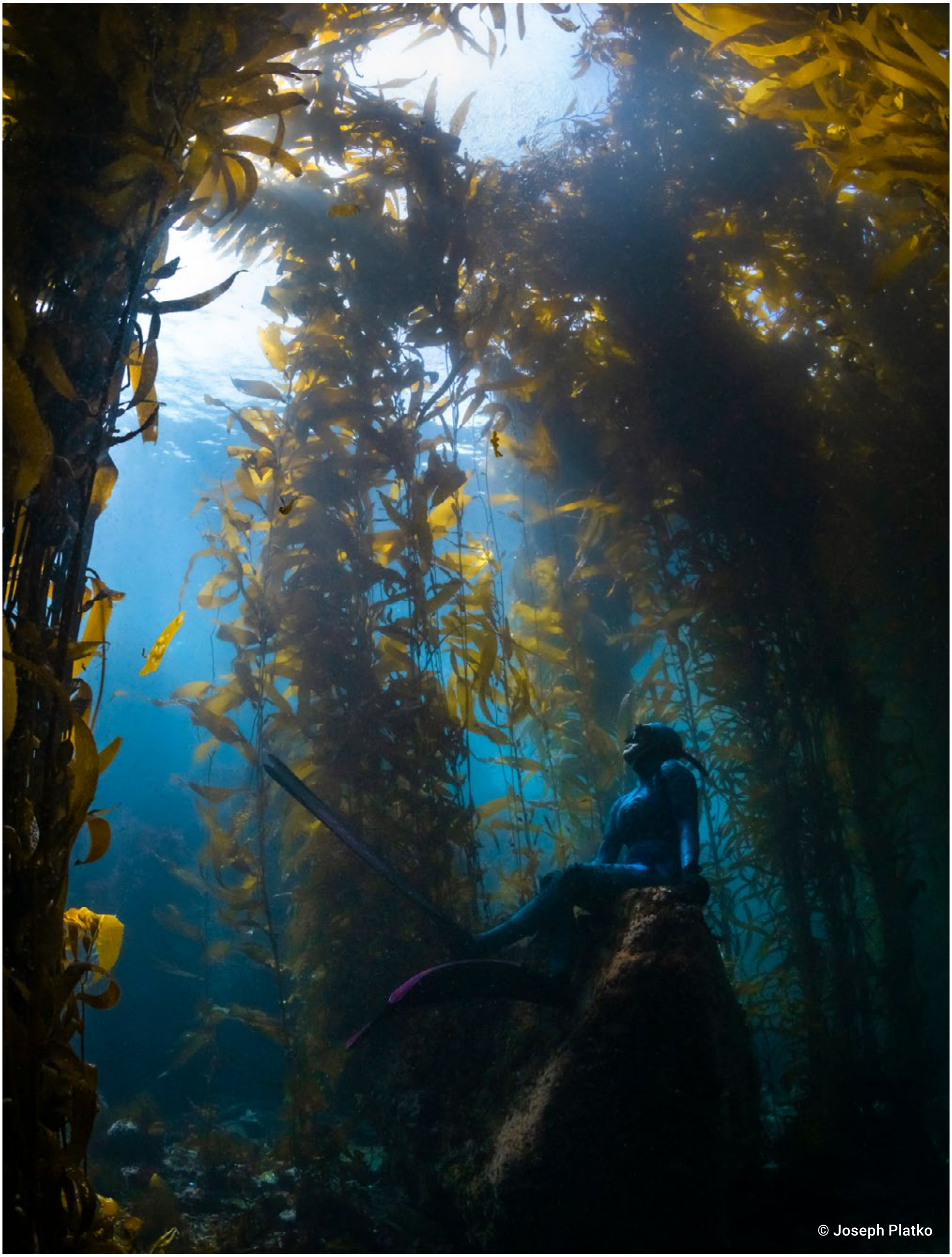

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