

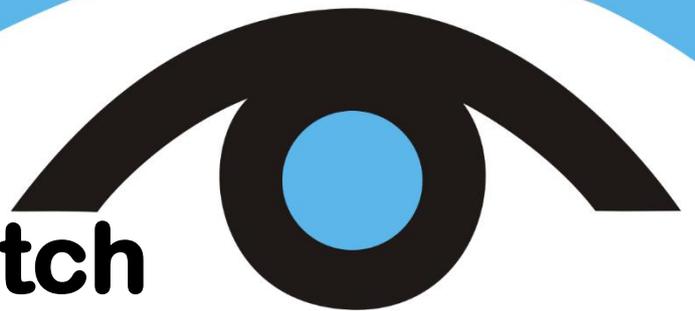


Seagrass-Watch

Proceedings of a workshop for monitoring
seagrass habitats in the Kimberley region,
Western Australia

*Broome Lotteries House, Broome, Western Australia
22-24 August 2025*

Len McKenzie & Rudi Yoshida



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Front cover photos (left to right): *Enhalus acoroides* (Chile Creek, Aug07) by Len McKenzie; sea star in *Halophila ovalis* and *Halodule uninervis* meadow (Town Beach, Aug18) by Len McKenzie; and, *Halophila ovalis* and *Halodule uninervis* (Town Beach, Apr25) by Alex Gibson.

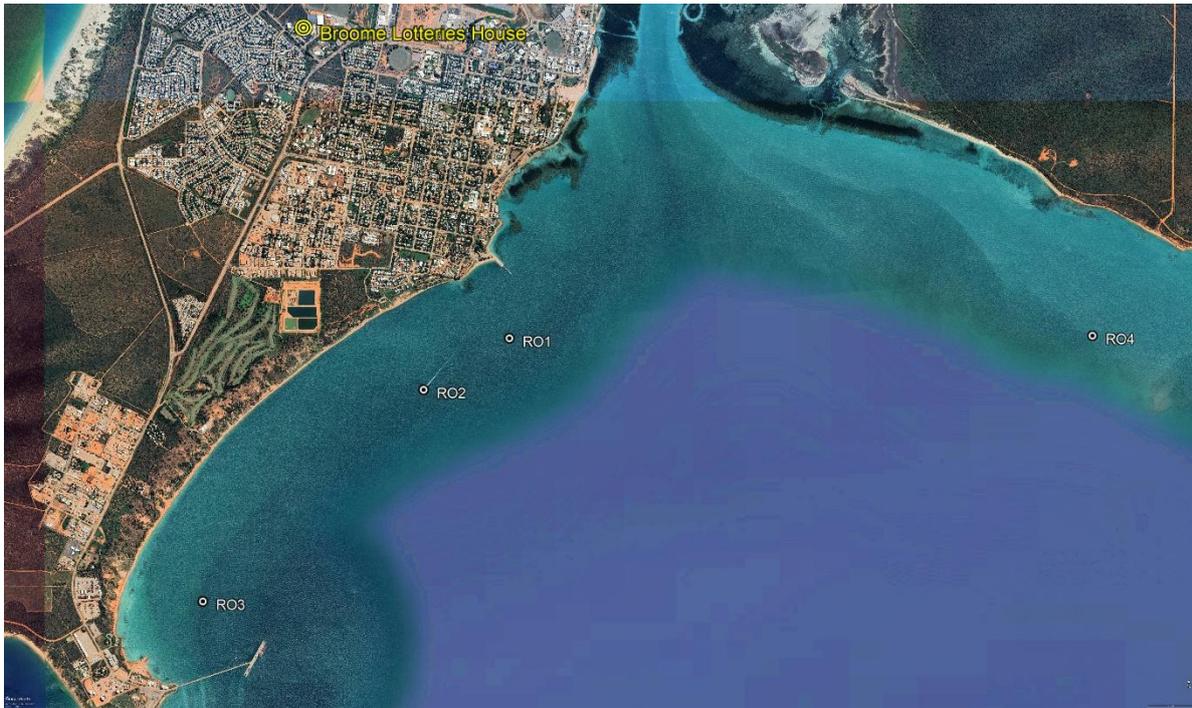
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Seagrass-Watch acknowledges the Djugun and Yawuru peoples as the Traditional Custodians and Owners of *Rubibi* (the town of Broome) along with the surrounding lands and sea country on which we conduct this workshop. We honour their enduring connection and Cultural Heritage, which includes responsibility for their Sacred Land and Sea Country, Totems, Language, and Songlines. We pay our respects to the peoples, the cultures and the Elders past and present.

Overview

Seagrass-Watch is a global seagrass observing network, where scientists, coastal managers and local stakeholders from across the globe collaborate to assess the status of their seagrass meadows to provide an early warning of coastal ecological decline. The program started in 1998 in Australia, using standardised global monitoring protocols, and has so far expanded to include 445 sites and 33 countries. Anyone can participate in Seagrass-Watch, as it responds to local needs, and includes elements of citizen science. Seagrass-Watch is a monitoring program that brings people together for seagrass conservation.

Seagrass-Watch implements a globally standardised seagrass assessment and monitoring protocol, that has a rigorous quality assurance and quality control procedure to ensure data is of the highest quality and that time and resources are not wasted. The only condition is that on-ground data collection must be overseen by a qualified scientist or trained and competent participant (18 years or over). The program identifies areas important for seagrass species diversity and conservation. The information collected can be used to assist the management of coastal environments and to prevent significant areas and species being lost.

Monitoring seagrass resources is important for two reasons: it is a valuable tool for improving management practices; and it allows us to know whether resource status and condition is stable, improving or declining. Successful management of coastal environments (*including seagrass resources*) requires regular monitoring of the status and condition of natural resources. Early detection of change allows coastal management agencies to adjust their management practices and/or take remedial action sooner for more successful results. Monitoring is important in improving our understanding of seagrass resources and to coastal management agencies for:

- *exposing coastal environmental problems before they become intractable,*
- *developing benchmarks against which performance and effectiveness can be measured,*
- *identifying and prioritising future requirements and initiatives,*
- *determining the effectiveness of management practices being applied,*
- *maintaining consistent records so that comparisons can be made over time,*
- *developing within the community a better understanding of coastal issues,*
- *developing a better understanding of cause and effect in land/catchment management practices,*
- *assisting education and training, and helping to develop links between local communities, schools and government agencies, and*
- *assessing new management practices.*

Seagrass-Watch monitoring efforts are vital to assist with tracking global patterns in seagrass health, and assess the human impacts on seagrass meadows, which have the potential to destroy or degrade these coastal ecosystems and decrease their yield of natural resources. Responsive management based on adequate information will help to prevent any further significant areas and species being lost. To protect the valuable seagrass meadows along our coasts, everyone must work together.

The goals of the Seagrass-Watch program are:

- *to educate the wider community on the importance of seagrass resources*
- *to raise awareness of coastal management issues*
- *to build the capacity of local stakeholders in the use of standardised scientific methodologies*
- *to conduct long-term monitoring of seagrass & coastal habitat condition*
- *to provide an early warning system of coastal environment changes for management*
- *to support conservation measures which ensure the long-term resilience of seagrass ecosystems.*

This workshop is for experienced participants who may plan to participate and/or lead in seagrass monitoring events or conduct seagrass extension activities. Presentations are targeted at participants with a moderate proficiency in English and an education level of year 12 to first year university. As part of the Level 1 workshop we will:

- *study seagrass biology;*
- *learn seagrass taxonomy;*
- *discuss the present knowledge of seagrass ecology, including importance and threats;*
- *gain knowledge of monitoring;*
- *learn about the Seagrass-Watch program and techniques for monitoring seagrass resources; and*
- *become skilled at conducting a Seagrass-Watch field monitoring event.*

The following information is provided as a training guide and a reference for future Seagrass-Watch monitoring activities. For further information, please do not hesitate to contact us at

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Photo: Mikael Eriksson

Workshop trainers



Len McKenzie

Len is the Director of Seagrass-Watch and a Principal Researcher with James Cook University. He is a seagrass Technical Advisor for the CMS Dugong MoU, Project Manager of the Great Barrier Reef 2050 Plan Marine Monitoring Program – Inshore Seagrass Monitoring, a full member on the SCOR Working Group 158 for Coordinated Global Research Assessment of Seagrass System (C-GRASS), member of the IUCN Seagrass Specialist and Sirenian Specialist Groups, and principal investigator for a series of projects involving the assessment and sustainable use of coastal habitats. Len has over 25 years' experience as a researcher on seagrass ecology, assessment and fisheries habitats. This includes experience globally in seagrass research, resource mapping/ assessment, and biodiversity. He has provided information on seagrass ecosystems that has been vital in management of seagrass resources of the Great Barrier Reef, South East Asia and the Indo-Pacific. He has also advised on fisheries and coastal resource-use issues for managers, fishing organisations, conservation and community groups. Len is a qualified trainer and assessor (Cert IV TAE40110). Len is also the Secretary of the World Seagrass Association.

Current Projects

- Great Barrier Reef Marine Monitoring Program: inshore seagrass
- A blueprint for scalable seagrass ecosystem mapping
- Seagrass Thermal Risk Project & Model Development
- Seagrass mapping and monitoring in Wuthathi Sea Country
- Wuthathi Custodians Strengthening Capacity to Manage Country (*NGaachi*) and Sea (*Karakara*) Integrated Catchment and Foreshore Monitoring Projects
- Scaling Seagrass Restoration on the Great Barrier Reef
- Building local capacity for sustainable livelihoods and community-based conservation of seagrass-linked threatened marine megafauna including dugong and wedgefish in the Bazaruto Seascape, Mozambique
- Expanding Traditional Owner led seagrass monitoring and restoration – Woppaburra TUMRA



Rudi Yoshida

Rudi is the Seagrass-Watch Data Manager/Admin officer and a Researcher with James Cook University. Rudi has over 20 years' experience in seagrass related research and monitoring. He is also a core member of Seagrass-Watch HQ, and ensures data submitted is managed and QA/QC protocols applied. He is also responsible for maintenance of the Seagrass-Watch website and assists with training workshops.

Current Projects

- Great Barrier Reef Marine Monitoring Program: inshore seagrass
- Scaling Seagrass Restoration on the Great Barrier Reef
- Building local capacity for sustainable livelihoods and community-based conservation of seagrass-linked threatened marine megafauna including dugong and wedgefish in the Bazaruto Seascape, Mozambique
- Expanding Traditional Owner led seagrass monitoring and restoration – Woppaburra TUMRA

Agenda - Level 1 (basic)

Friday 22nd August 2025 (Broome Lotteries House)

0830 - 0900	<i>Sign in</i>
0900 - 0915 (15min)	Welcome & Introduction
0915 - 0945 (30min)	Seagrass Biology and Taxonomy
0945 - 1030 (45min)	Seagrass Identification
1030 - 1100 (30min)	<i>Break</i>
1100 - 1145 (45min)	Seagrass Identification <i>continued</i>
1145 - 1230 (45min)	Seagrass Biology 2 and Ecology
1230 - 1315 (45min)	<i>Lunch</i>
1315 - 1445 (90min)	Seagrass importance
1445 - 1515 (30min)	Seagrass monitoring
1515 - 1530 (15min)	Wrap up for day

Saturday 23rd August 2025 (Broome Lotteries House & Town Beach)

1015 - 1030 (15min)	recap day 1
1030 - 1145 (75min)	Seagrass-Watch: how to sample
1145 - 1200 (15min)	<i>Break</i>
1200 - 1315 (75min)	Seagrass-Watch: how to sample 2
1315 - 1330 (15min)	Risk assessment
1330 - 1515 (1hr 45min)	<i>Lunch and relocate to Town Beach</i>
1515 - 1530 (15min)	<i>Meet up at Town Beach/Walk out to site</i>
1530 - 1730 (2hrs)	Field exercise: Seagrass-Watch monitoring <i>Where:</i> Town Beach (RO1) (<i>low tide: 1719 1.47, Sunset 1742</i>) <i>What to bring:</i> <ul style="list-style-type: none"> • <i>hat, sun protection</i> • <i>dive booties or old shoes that can get wet</i> • <i>drink/refreshments</i>
1730 - 1745 (15min)	Wrap up for day

Sunday 24th August 2025 (Broome Lotteries House)

1000 - 1015 (15min)	recap day 2
1015 - 1130 (75min)	Seagrass threats
1130 - 1215 (45min)	Seagrass-Watch: QAQC
1215 - 1245 (30min)	<i>Lunch</i>
1245 - 1345 (60min)	Seagrass-Watch: how data is used
1345 - 1400 (15min)	Broome Seagrass Community Monitoring Project (Alex Gibson)
1415 - 1430 (15min)	Discussion and close of Level 1 Training

Assessment requirements

To successfully attain a **Certificate of Achievement**, you will need to demonstrate you have the knowledge, skills, abilities and experience to competently conduct monitoring using Seagrass-Watch protocols.

Successful achievement must to be demonstrated across 9 core units, by completing:

- 1 a training workshop (classroom, laboratory and field), and
- 2 three post workshop monitoring events (within 12 months)

Training workshop (6 units)

Demonstrates you have the knowledge, skills and abilities to conduct monitoring.

Classroom (4 units): attendance + achieve 80% of formal assessment (multiple choice, open book)

Laboratory (1 unit): identify 3 local seagrass species correctly and demonstrate how to preserve seagrass samples for an herbarium

Field (1 unit): perform the following to the satisfaction of the trainer:

- lay out a site and quadrat placement
- description of sediment & comments
- estimation of seagrass cover
- identification of seagrass species
- estimation of seagrass species composition
- measuring seagrass canopy height
- estimation of macro algae cover
- estimation of epiphyte cover
- taking a quadrat photo
- accurately record data

3 post workshop monitoring events (3 units)

Demonstrates you have the experience and competency to conduct monitoring on your own

Must be completed within 12 months: starting no sooner than 1 month after the training workshop. Tentative monitoring events (dates) to be nominated within 1 month of a training workshop. Minimum of 1 site, maximum of 5 sites, per monitoring event assessed. Sites must be sampled within a 2-week period each sampling event. Each monitoring event/period must be separated by at least 1 month, regardless of number of sites monitored. Each participant must assess a minimum of 1 transect per site per sampling event (name must be clearly legible on field datasheet). *A Certified participant can oversee data collection, however, participant being assessed must collect the required data along transect and the name of Certified participant must be clearly legible on datasheet.*

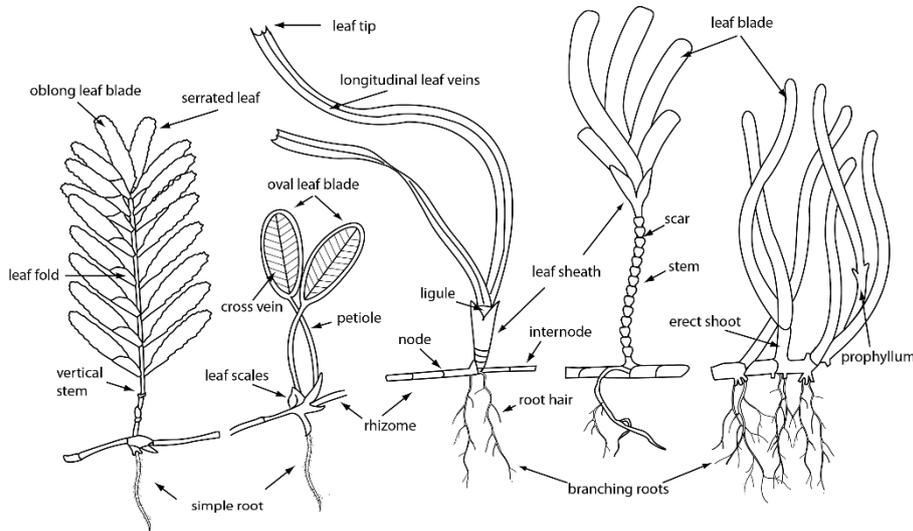
Original datasheets, photos, etc, must be submitted to Seagrass-Watch HQ within 2 weeks after each monitoring event. Data submitted must be compliant and must pass QAQC by achieving the following:

- correct description of sediment & comments
- seagrass cover estimates within acceptable limits
- correct seagrass species identification
- correct seagrass species compositions
- correct seagrass canopy height measures
- macro algae cover estimates within acceptable limits
- epiphyte cover estimates within acceptable limits
- compliant quadrat photos

Once all QAQC has been completed and the participant has demonstrated they have the skills, ability, experience and competency to conduct monitoring, a certificate will be issued by Seagrass-Watch HQ.

Background

Seagrasses are unique flowering plants that have evolved to live in sea water. Seagrasses belong to a group of plants known as angiosperms (flowering plants).



Composite illustration demonstrating morphological features used to distinguish main taxonomic groups.

Various common names are applied to seagrass species, such as turtle grass, eelgrass, tape grass, spoon grass and shoal grass. These names are not consistently applied across countries.

Like terrestrial (land living) plants, a seagrass can be divided into its leaves (which contain veins), rhizome, roots (buried in the substrate), and reproductive parts such as flowers and fruits. Algae do not have veins in their leaves nor do they possess roots (anchoring to the surface of the substrate by a holdfast) or produce flowers or seeds.

These marine plants are called “seagrass” because most have ribbon-like, grassy leaves. There are many different kinds of seagrasses and some do not look like grass at all. Seagrass range from the size of your fingernail to plants with leaves as long as 7 metres. Some of the shapes and sizes of leaves of different species of seagrass include an oval (paddle or clover), a fern, a long spaghetti like leaf and a ribbon. Species that have a paddle or fern shaped leaf are called *Halophila*. Ones that have a ribbon shaped leaf are the *Cymodocea*, *Thalassia*, *Thalassodendron*, *Halodule* and *Enhalus*. Spaghetti-like seagrass is called *Syringodium*. At the base of a leaf is a sheath, which protects young leaves. At the other end of a leaf is the tip, which can be rounded or pointed. The vertical stem, found in some species, is the upright axis of the plant from which leaves arise (attach). The remnants of leaf attachment are seen as **scars**.

Seagrass leaves lack stomata (microscopic pores on the underside of leaves) but have thin cuticle to allow gas and nutrient exchange. They also possess large thin-walled aerenchyma (air channels). Aerenchyma are specialised tissue having a regular arrangement of air spaces, called lacunae, that both provide buoyancy to the leaves and facilitate gas exchange throughout the plant. Leaves have a very thin cuticle, which allows gas and some nutrient diffusion into them from the surrounding water. Seagrass leaves also contain **veins** (lignified conducting tissue that transports water, nutrients and photosynthetic products around the plant) (i.e. an internal vascular system). Veins can be across the leaf blade or run parallel to the leaf edge.

Seagrass are marine flowering plants

Seagrasses have roots, stems and leaves

Seagrass is different to seaweed (algae) as seagrass have an internal vascular system, true roots and produce flowers, fruits and seeds

Leaves of different seagrass species can be shaped like a flattened ribbon, look like a fern, round like a clover, or even spaghetti shaped

Seagrass have veins and air channels in their leaves and rhizomes so they can carry water, food and absorb gases

Also within the leaves are chloroplasts, which use the sun's light to convert carbon dioxide and water into oxygen and sugar (photosynthesis).

The roots and horizontal stems (**rhizomes**) of seagrass are often buried in sand or mud. They anchor the plant, store carbohydrates and absorb nutrients. Roots can be simple or branching and all have fine hairs to help absorb nutrients. Rhizomes are formed in segments with leaves or vertical stems rising from the joints, called nodes. Sections between the nodes are called internodes. Seagrasses depend upon the growth of rhizomes to increase the area they occupy. This vegetative growth is the most common mode of growth for seagrasses. Although the rhizome mainly runs horizontally, some lateral branches are more or less erect and bear leaves (erect shoots). Sometimes the leaves are on a special type of stalk, called a petiole.

The roots and rhizomes of seagrasses are well endowed with aerenchyma and the lacunae are extensive and continuous with leaf tissues. **Oxygen** transport to the roots creates an oxic environment around the roots (in the sediment), facilitating nutrient uptake.

Seagrasses are flowering plants (angiosperms) which have flowers and pollination systems that are well adapted for pollination via water. Seagrass form tiny flowers, fruits and seeds. Most seagrasses have separate male and female plants. In most species, flowers are small, white and are borne at the base of the leaf clusters. The stamens (male parts) and pistils (female parts) extend above the petals to facilitate pollen release and pollination respectively.

Most seagrasses reproduce by pollination while submerged and complete their entire life cycle underwater. Pollination in seagrasses is hydrophilic (aided by water), and can occur by: (i) pollen transported above water surface (e.g., *Enhalus*); (ii) pollen transported on water surface (e.g., *Halodule*), or; (iii) pollen transported beneath water surface (e.g., *Thalassia*).

Seagrass pollen grains are elongated into a filamentous shape. The filamentous nature of pollen grains facilitates transport within the water medium, mainly by water currents. *Halophila* and *Thalassia* have spherical pollen grains, but they remain joined together in long chains, giving the same effect as having elongated, filamentous pollen grains.

After fertilization, the ovary of the female flower develops into a fruit. In seagrasses, fruit development and fruit structure are as diversified as their flowering patterns and floral structures. In general, the seeds, ranging in the size from 0.3 to 0.5mm in some *Halophila* species to more than 1–2 cm in *Enhalus*, are furnished with a nutrition reserve and sink rather than float. The number of seeds within a fruit also varies from 1 (e.g. *Halodule uninervis*) up to 25 (e.g. *Halophila ovalis*).

Seagrass taxonomy

Taxonomy can be challenging for seagrasses due to their significantly reduced and variable morphologies. Since the mid-1800s, seagrasses have been classified within the angiosperms. A pivotal taxonomic study on seagrasses was published in 1970 by Cornelis den Hartog, titled "The Sea-Grasses of the World". Since that time, the number and composition of genera has remained largely unchanged. Taxonomy updates, including genera and species names and all the previous names used for each species, can be found at the International Plant Name Index (www.ipni.org).

Seagrasses rely on light to convert carbon dioxide and water into oxygen and sugars (photosynthesis)

Roots can be simple or branching and all have fine hairs to help absorb nutrients

Seagrass pump oxygen into the sediment via their roots

Seagrass are angiosperms. Seagrass have flowers, fruits and seeds

Pollination occurs in the water

Pollen from male seagrass flowers is mainly dispersed to female seagrass flowers by water currents

Seagrass-Watch primarily adheres to the classifications established by Cronquist (1981) and den Hartog (1970), while utilizing the family and genus names that are currently recognized by the Angiosperm Phylogeny Group (APG III).

Seagrasses are monocotyledons, which includes flowering plants whose seeds contain only one embryonic leaf, or cotyledon. Seagrasses are not true grasses (true grasses belong to the family Poaceae), but are rather more closely related to other aquatic plants such as duckweeds, pondweeds, peace lilies, the taro plant and world's largest inflorescence *Titan arum* (aka. corpse flower), in the order Alismatales. Note: waterlilies, family Nymphaeaceae, are basal angiosperms with the stem anatomy of dicots (an organized ring of vascular tissue) and therefore, not a monocot.

Seagrasses evolved approximately 100 million years ago from land plants that returned to the sea in at least four separate lineages. Thus, seagrasses are not a taxonomically unified group but a 'biological' or 'ecological' group. The evolutionary adaptations required for survival in the marine environment have led to convergence (similarity) in morphology.

Worldwide, there are about 12 major divisions, consisting of approximately 60 species (possibly up to 72) of seagrass. The highest concentration of species occurs in the Indo-West Pacific region.

Seagrass requirements for growth

Seagrasses require light, nutrients, carbon dioxide, substrate for anchoring, tolerable salinity, temperature and pH to survive. The requirements for a seagrass to be able to exist in the marine environment include:

1. adaptation to life in saline (salty) medium
2. growth when completely submerged
3. anchoring system able to withstand the forces of wave action and tidal currents
4. hydrophilous pollination (pollination aided by water).

The need for physiological adaptations to life in sea water is obvious when one considers that seagrasses evolved from land plants, and most land plants are unable to tolerate even small quantities of salt. In contrast to land plants, some seagrasses can tolerate a salinity range from 4 to 65 parts per thousand (2x seawater concentration). Typically, seagrasses grow best in salinities of 35 parts per thousand. Not all species tolerate all salinities equally well, and salinity tolerance may be a factor promoting different species distributions along salinity gradients, e.g., going up estuaries. Some seagrasses can survive in a range of conditions encompassing fresh water, estuarine, marine, or hypersaline (very salty). A limiting factor for many intertidal seagrasses is osmotic impacts resulting from hypersalinity due to evaporation

Seagrasses being plants need light for photosynthesis. Light availability is the most dominant overriding factor in seagrass growth. Seagrasses have high minimum light requirements (e.g. 10-20% of surface irradiance on average, 4.4% minimum and 29% maximum depending on species) because: (i) they have a high respiratory demand to support a large non-photosynthetic biomass (e.g. roots, rhizomes); (ii) they lack certain pigments and therefore can utilise only a restricted spectral range; and (iii) they must regularly oxygenate their root zone to compensate for anoxic sediment. However, light in the intertidal can be in excess of requirements and excess light can cause temporary photo damage. UV exposure can also have significant impacts on seagrasses.

Seagrasses are not true grasses

Seagrasses are closely related to peace lilies and the taro plant

Seagrass evolved 100 million years ago from land plants that returned to the sea

There are around 60 species of seagrass found in oceans throughout the world

Seagrasses need plenty of sun and clean water to grow.

Seagrasses are physiologically adapted to life in sea water

Seagrasses can tolerate a range of salinities. Some species are less tolerant than others

Light availability is the most important factor determining seagrass growth

Seagrasses require between 10-20% of surface light to grow

Temperature influences the rate of growth and the health of plants, particularly at the extremes. As tropical water temperatures increase (above 35°C) the rate of photorespiration increases reducing the efficiency of photosynthesis at a given CO₂ concentration. The cause of thermal stress at higher temperatures (38°C to 42°C) is the disruption of electron transport activity via inactivation of the oxygen producing enzymes (proteins) of photosystem II. Above these temperatures many proteins are simply destroyed in most plants, resulting in plant death.

Temperature also controls the range of pH and dissolved carbon dioxide (CO₂) concentrations in the water column; factors critical in plant survival in the marine environment.

Seagrasses require inorganic carbon for growth. They uptake inorganic carbon at the leaf surface via two pathways which are species-specific. Some species use bicarbonate (HCO₃⁻) as an inorganic carbon source (e.g. *Halophila ovalis*, *Cymodocea rotundata*, *Syringodium isoetifolium* and *Thalassia*), whereas others use enzymes to make CO₂ available as the inorganic carbon source (e.g. *Enhalus acoroides*, *Halodule*, *Cymodocea serrulata*).

Seagrasses require two key nutrients, nitrogen and phosphorous, for growth. In the coastal regions, seagrasses appear to be primarily limited by nitrogen and secondarily by phosphorus. The demand for nutrients by seagrasses appears seasonally dependent. During the growing season the demand for nutrients is high, however during the senescent season elevated nutrients may become toxic.

The availability of nutrients to seagrasses may also be dependent on sediment quality / geochemistry. Bioavailability of nutrients is dependent on particle size and type. For example, clay content influences sediment adsorptive capacity - the more clay the greater the adsorptive capacity - and, calcium carbonate binds phosphorus, limiting its bioavailability.

Sediment quality, depth and mobility are important factors for seagrass composition, growth and persistence. Most seagrasses live in sand or mud substrates where their roots and rhizomes anchor the plants to the sea floor. Some seagrasses, such as *Cymodocea* spp., prefer deeper sediments while others can tolerate a broad range of sediment depths. Colonising seagrasses such as *Halophila* spp. and *Halodule* spp. are better suited to mobile sediments than larger species. The biogeochemical characteristics of sediment that can affect the nutrient content/binding capacity, organic content and oxygen levels. Seagrasses are unable to grow in sediments of high organic content.

Currents and hydrodynamic processes affect almost all biological, geological and chemical processes in seagrass ecosystems at scales from the smallest (physiological and molecular) to the largest (meadow wide). The pollination of seagrass flowers and dispersal of vegetative material and seeds depends on currents. Without current flows, vegetative material and seeds will not be transported to new areas, and species will not be exchanged between meadows. Factors such as the photosynthetic rate of seagrasses depend on the thickness of the diffusive boundary layer that is determined by current flow, as is the sedimentation rate. Both influence growth rates of seagrass, survival of seagrass species and overall meadow morphology.

Water temperature influences the rate of growth and the health of seagrass

Seawater temperatures above 35°C will stress tropical seagrass. Death occurs at temperatures above 42°C

Seagrass require inorganic carbon for growth

Seagrass uptake carbon via two different pathways

Seagrass require two key nutrients, nitrogen and phosphorous, for growth

Nutrient availability to seagrass is dependent on the type of sediment they grow in

Most seagrass live in sand or mud sediments

Sediment movement can determine the presence of seagrass species

Tidal currents are important for pollination, dispersal and exchange of gases from the water to the plant

Where are seagrasses found?

Seagrasses are found in oceans throughout the world. They occur in tropical (hot), temperate (cool) and the edge of the arctic (freezing) regions.

Seagrass are mainly found in sheltered bays, estuaries and coastal waters from the mid-intertidal (shallow) region down to depths of 50 or 60 metres. Most species are found in clear shallow inshore areas between mean sea-level and 25 metres depth.

Seagrasses survive in the intertidal zone especially in locations sheltered from wave action or where there is pooling of water at low tide, (e.g., reef platforms and tide pools), which protects seagrass from elevated temperatures and drying.

Seagrasses inhabit all types of ground (substrates), from mud to rock. The most extensive seagrass meadows occur on soft substrates like sand and mud.

The depth range of seagrass is most likely to be controlled at its deepest edge by the availability of light for photosynthesis. Exposure at low tide, wave action and associated turbidity and low salinity from fresh water inflow determines seagrass species survival at the shallow edge.

Seagrass plants form small patches that develop into large continuous meadows. These meadows may consist of one or many species: sometimes up to 12 species present within one location.

How are seagrasses important to the marine ecosystem?

Seagrass communities are one of the most productive and dynamic ecosystems globally. Seagrasses may significantly influence the physical, chemical and biological environments in which they grow by acting as ‘ecological engineers’. They provide habitats and nursery grounds for many marine animals and act as substrate stabilisers.

Seagrass meadows are highly productive. They have been documented to create habitat complexity compared with unvegetated areas, providing up to 27 times more habitable substrate, as well as providing refuge and food for a range of animals. About 40 times more animals occur in seagrass meadows than on bare sand.

One of the most important roles of seagrasses is providing a nursery area, food and shelter for fish and prawns which are valuable to fisheries. Juveniles of some important species which depend on seagrass meadows include fish such as perch, mullet, whiting, tailor, bream, snappers, emperors and sweetlips. Commercial penaeid prawns such as red spot king, brown tiger, grooved tiger and endeavour also live in seagrass meadows as juveniles. Tropical rock lobsters also live in seagrass meadows as juveniles. Shellfish such as some oysters and pearl shell may be more likely to settle and survive where there is seagrass. Juvenile and adult sandcrabs and flathead are just two species which spend most of their lives in seagrass meadows, where there is not only food but also protection from strong tidal currents and predators. Larger predatory animals such as herons, cormorants, sharks, barramundi, salmon, crocodiles, etc, are also attracted to the seagrass meadows by the schools of forage fish which seek shelter there.

Seagrass are commonly found in estuaries, shallow coastal locations, and on reef-tops.

Seagrass are mainly found in clear shallow inshore areas between mean sea-level and 25 metres depth.

The depths that seagrass are found underwater depends on the light availability (water clarity)

Seagrass plants form small patches that develop into large meadows

Seagrasses are important habitat and feeding grounds for marine organisms.

About 40 times more animals occur in seagrass meadows than on bare sand.

Seagrasses are important nursery grounds for fish, and they support many human commercial activities.

Seagrass meadows are a major food source for a number of herbivores and are considered very productive pastures of the sea. The dugong (*Dugong dugon*) and the green turtle (*Chelonia mydas*) mainly feed on seagrass. An adult green turtle eats about two kilograms (wet weight) of seagrass a day while an adult dugong eats about 28 to 40 kilograms (wet weight) a day. Although dugongs and turtles will feed on any seagrass species within their range, if a variety of species is available, they select seagrass species for food which are high nitrogen, high starch and low fibre. For example, the order of seagrass species preference for dugongs is *Halophila ovalis* > *Halodule uninervis* > *Thalassia hemprichii*. In sub-tropical and temperate areas, water birds such as black swans also eat seagrass.

Decomposing seagrasses provide food for benthic (bottom-dwelling) aquatic life. The decaying leaves are broken down by fungi and bacteria which in turn provide food for other microorganisms such as flagellates and plankton. Microorganisms provide food for the juveniles of many species of marine animals such as fish, crabs, prawns and molluscs.

The rhizomes and roots of seagrasses bind sediments on the substrate, where nutrients are recycled by microorganisms back into the marine ecosystem. The leaves of the grasses slow water flow, allowing suspended material to settle on the bottom. This increases the amount of light reaching the seagrass meadow and creates a calm habitat for many species.

Seagrasses are nutrient sinks, buffering or filtering nutrient, sediment and chemical inputs from land based pollution to the marine environment. Seagrasses uptake nitrogen and phosphorus from coastal run-off that, in overabundance, can lead to algal blooms that can impair water quality.

Seagrasses play a vital role in mitigating climate change by sequestering (capturing and storing) carbon. They, along with other coastal and marine ecosystems like mangrove forests, tidal marshes, and macroalgae beds, contribute to what is known as blue carbon. Seagrasses are highly efficient at absorbing carbon dioxide from seawater during photosynthesis and incorporating the carbon into their biomass. A significant portion of this carbon is then stored in the seagrass meadows' sediments. Because seagrass sediments are saturated with water, this helps maintain an anaerobic state, which prevents aerobic microbial carbon oxidation and release, resulting in carbon accumulation over time and, therefore, creating long term carbon reservoirs that can last for centuries to millennia. Seagrasses can sequester carbon up to 35 times faster than tropical rainforests. Coastal seagrass meadows are estimated to hold up to 83,000 metric tons of carbon km⁻¹, with the median global soil C_{org} stock estimated to be 24.2 (12.4 – 44.9) Mg C_{org} ha⁻¹ in the top 30 cm of soil.

Interactions with mangroves and coral reefs

Tropical seagrasses are important in their interactions with mangroves and coral reefs. All these systems exert a stabilizing effect on the environment, resulting in important physical and biological support for the other communities.

Barrier reefs protect coastlines, and the lagoon formed between the reef and the mainland is protected from waves, allowing mangrove and seagrass communities to develop. Seagrasses trap sediment and slow water movement, causing suspended sediment to fall out. This trapping of sediment benefits coral by reducing sediment loads in the water.

Dugongs can eat up to 40kg of seagrass per day.

Dugongs and turtles select seagrass species for food which are high nitrogen, high starch and low fibre

Seagrasses also contribute to the productivity of ecosystems via the detrital food pathway

Seagrass roots & rhizomes stabilise sediments and help prevent erosion

Seagrasses slow water flow and increase water clarity

Seagrass help reduce nutrient, sediment and chemicals pollution from coastal waters

The retention of carbon within seagrass meadow sediments contributes significantly to climate change mitigation

Seagrasses, mangroves and coral reef interact, providing physical and biological support for other communities

Mangroves trap sediment from the land, reducing the chance of seagrasses and corals being smothered. Sediment banks accumulated by seagrasses may eventually form substrate that can be colonized by mangroves. All three communities trap and hold nutrients from being dispersed and lost into the surrounding oceanic waters.

The value of seagrasses

The value of ecosystem goods and benefits (contributions) is a controversial topic in today's literature. Ecosystem services are the structures and processes by which the environment produces contributions to our quality of life, that we often take for granted. For seagrasses, it includes services such as clean water, preventing erosion, and habitat for fisheries. The economic values of seagrass meadows are very large, although not always easy to quantify. Seagrass meadows are rated the 3rd most valuable ecosystem globally (on a per hectare basis), only preceded by estuaries and wetlands. The average global value of seagrasses for their nutrient cycling services and the raw goods they provide has been estimated at US\$ 28,916 ha⁻¹ yr⁻¹ (in 2007 dollars).

In the last decade, seagrass carbon storage capacity (blue carbon) has emerged as a significant factor in valuation. The carbon stored in seagrasses is estimated to be valued at ~USD12,000 ha⁻¹, on par with the annual value of other ecosystem services provided by seagrasses. A study focusing on Caribbean seagrasses estimated their total annual value at USD255 billion, with USD88.3 billion specifically attributed to carbon storage. Although all seagrass species contribute to blue carbon, the capacity for carbon storage varies significantly based on their growth form, biomass, and the specific environmental conditions they inhabit. Carbon storage in seagrass meadows is also strongly location-dependent, even within the same species.

What causes seagrass areas to change?

Tropical seagrass meadows vary seasonally and between years, and the potential for widespread seagrass loss has been well documented. Factors which affect the distribution of seagrass meadows are sunlight and nutrient levels, water depth, turbidity, salinity, temperature, current and wave action.

Seagrasses respond to natural variations in light availability, nutrient and trace element (iron) availability, grazing pressure, disease, weather patterns, and episodic floods and cyclones. The dynamic nature of seagrass meadows in response to natural environmental variation complicates the identification of changes caused by humans.

What threatens seagrass?

Seagrass meadows can be easily damaged. Approximately 58% of seagrass meadows globally, have lost part of their distribution. According to reports, the documented losses in seagrass meadows globally since 1980 are equivalent to two football fields per hour.

Some losses are natural due to storms and herbivores, however, most losses are the result of human activities. Human pollution has contributed most to seagrass declines around the world.

The most widespread and pervasive cause of seagrass decline is a reduction in available light. Processes that reduce light penetration to seagrasses include pulsed turbidity events during floods, enhanced suspended sediment loads and elevated nutrient concentrations. Poor farming practices can result in

Seagrass meadows are rated the 3rd most valuable ecosystem globally (more valuable than mangroves or coral reefs)

Seagrass ecosystems are increasingly recognised as valuable assets in the growing blue carbon market

Seagrasses can change due to both natural and human impacts

People can damage or destroy seagrass by pollution (sewage, oil spills, litter, and coastal runoff) and physical destruction (dredging, bait & clam digging, boat propellers and anchors/moorings).

excess sediments and fertilizers washing down creeks to the sea. Sewage discharge and stormwater runoff from urban development can elevate nutrients in coastal areas. Boating activity may also stir up sediment, reducing light levels. Phytoplankton and fast-growing macroalgae are also better competitors for light than benthic plants and their biomass can shade seagrasses during progressive eutrophication.

Oil and trace metal contamination can exert direct toxic effects on some seagrass species. Seagrasses are able to bioaccumulate the trace metals and this can have ramifications for grazers such as dugongs.

People can also physically damage or destroy seagrass. Coastal development for boat marinas, shipping ports and housing generally occurs on the coast in areas which are sheltered and seagrass like to grow. Seagrass meadows are either removed or buried by these activities. Coastal developments can also cause changes in water movement. Dredging boat channels to provide access to these developments not only physically removes plants, but can make the water muddy and dump sediment on seagrass. Litter and rubbish can also wash into the sea if not properly disposed. Rubbish can physically and chemically damage seagrass meadows and the animals that live within them.

Boating and fishing activities can physically impact or destroy seagrasses. Boat anchors and their chains can dig into seagrass. Propellers can cut into seagrass meadows and unbalance the rhizome mat. Storms can further exacerbate the damage by the physical force of waves and currents ripping up large sections of the rhizome mat. Uncontrolled digging for bait worm can also physically damage seagrasses and some introduced marine pests and pathogens also have the potential to damage seagrass meadows.

One of the other significant impacts to seagrass is climate change. The major vulnerability of seagrass to climate change is loss of seagrass in the coastal zone, particularly near river mouths and in shallow areas. The greatest impact is expected to result from elevated temperatures, particularly in shallower habitats where seagrasses grow (e.g., affecting distribution, timing of flower and seed production, and reducing photosynthesis). In addition, reduced light penetration from sediment deposition and resuspension are expected due to more intensive cyclones/hurricanes and elevated flooding frequency and amplitude. This will result in even greater seagrass losses, and changes in species composition are expected to occur particularly in relation to disturbance and recolonisation. Following such events, a shift to more ephemeral species and those with lower minimum light requirements is expected.

Poor farming practices can result in catchment runoff which can damage seagrass by elevating nutrients, reducing available light and releasing herbicides.

Coastal development can have a major impact on seagrass meadows

Climate change can threaten intertidal seagrass by increased seawater temperature and greater physical disturbance from storms

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Seagrass in the Kimberley region of Western Australia

Updated from McKenzie 2007^[1]

The Kimberley region of Western Australia extends from the border with the Northern Territory in the north east, to near Cape Keraudren (Eighty Mile Beach) in the south. The marine ecosystems are characterised within the North-West Marine Bioregion^[2]. Seagrasses are a significant component in the coastal marine ecosystems^[3-6] and their contribution to the total primary carbon production is critical to regionally important dugong and turtle populations. The most recent estimate from 2017 calculated the dugong population for the Kimberley region to be approximately 12,600 ±601 animals, with an average density of 0.25 ±0.02 km² over 67,163 km² of coastal waters^[7].

The Kimberley coast displays wide variation and is a significant component of the region's physical setting. It is a typical drowned river valley system, with wide sandy beaches which give way to mudflats. Embayments and sounds grade shorewards into mangrove lined tidal flats. Mangrove inlets and tidal creeks are interspersed with coastal cliffs. Some embayments such as Cambridge Gulf and King Sound extend well inland. There are numerous offshore islands and much of the coast remains uninhabited.

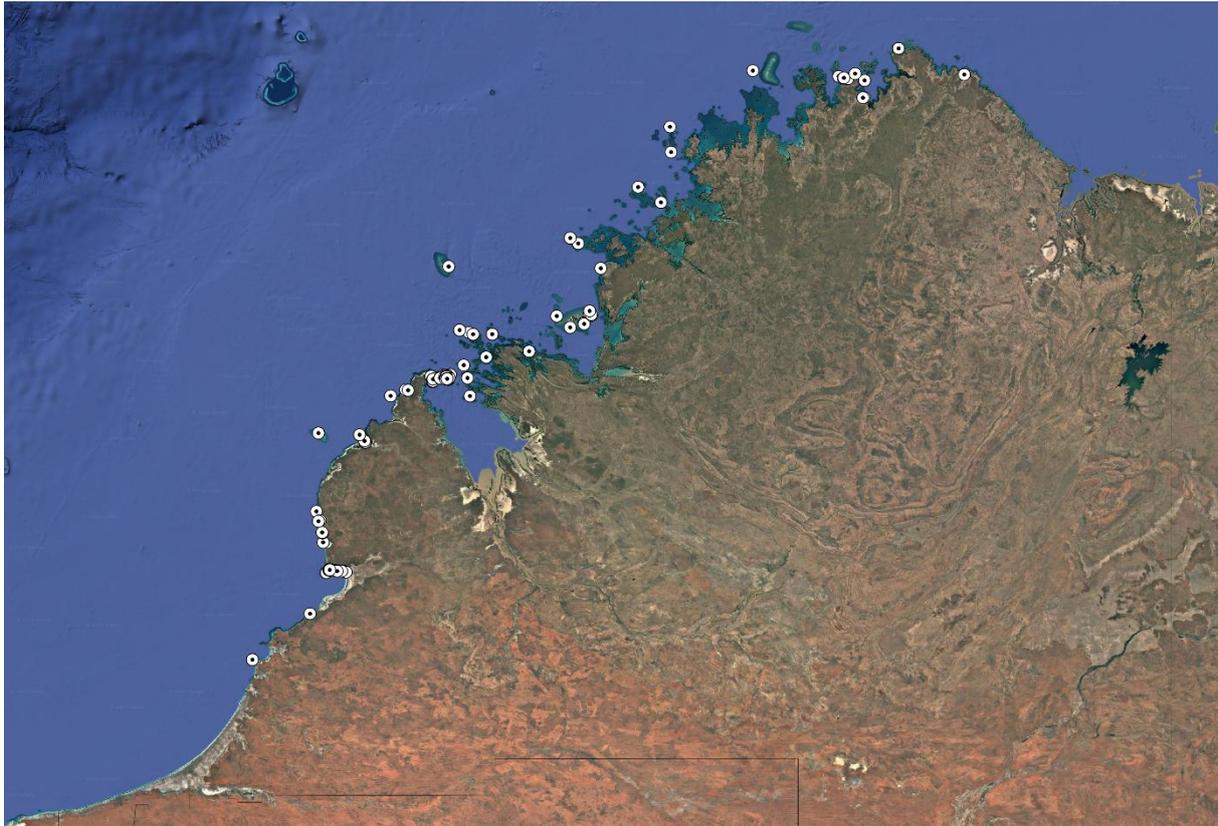
The Kimberley coast region of Western Australia has both arid and wet tropical environments (annual average rainfall <200 mm and >1000 mm respectively). The marine environment is influenced by the warm, south-equatorial current that flows from the east through the south east Asian and northern Australian region. The coast is prone to large tidal variation from <1 to 11m^[8]. In King Sound, the highest tides reach 11 m. Strong tidal flows, together with summer river discharges, dramatically influence the coastal environment.

Western Australia has the highest diversity of seagrasses in the world, with 25 species represented^[8-10]. These are generally divided into temperate and tropical distributions, with Shark Bay representing the biogeographical overlap. The oldest seagrass specimen record for the Kimberley is *Thalassia hemprichii*, which was collected offshore, from the fringing reef at Cartier Island by K.F. Kenneally in 1977^[11]. Today, twelve seagrass species are represented in the Kimberley (*Thalassia hemprichii*, *Thalassodendron ciliatum*, *Enhalus acoroides*, *Halophila ovalis*, *Halodule uninervis*, *Halophila minor*¹, *Cymodocea angustata*, *Syringodium isoetifolium*, *Cymodocea serrulata*, *Halophila spinulosa*, *Halodule pinifolia* and *Halophila decipiens*), one of which is endemic (*Cymodocea angustata*) and two of the species (*Halodule pinifolia* and *Halophila minor*) under review for synonymy^[9, 10, 13].

Seagrass distribution throughout the region is most likely influenced by shelter, sediment characteristics, water turbidity and tidal exposure. Seagrass meadows are mostly found in the sheltered bays along the southern mainland coast. Extensive terracing of these expanses of the intertidal zone often result in seagrass high in the intertidal^[10]. The majority of the meadows are low to moderate in abundance, and are dominated by colonising and opportunistic species, *Halophila* and *Halodule* respectively. Seagrasses either occur sparsely in coral reef environments or can attain high biomasses on mudbanks or within high intertidal lagoons, where water is ponded during the falling tide. The environments are otherwise too extreme (tidal movement/turbidity/ freshwater runoff in the wet season) for seagrass survival^[14]. Subtidal populations of

¹ *Halophila minor* was originally reported as *H. ovata*, however taxonomists now regard *H. ovata* in the Indo-western Pacific as only present in the South China Sea and Micronesia (12. Kuo, J. 2000, Taxonomic notes on *Halophila minor* and *H. ovata*. *Biologia Marina Mediterranea*, 7(2), 79-82.).

seagrasses are poorly known, but it appears that the northern Kimberley does not have the seagrass richness recorded for the southern Kimberley.



Seagrass occurrence records in the nearshore Kimberley region, 1984 to 2022. Data from [8, 15-20]

The overall extent of seagrass meadows in the Kimberley remains uncertain. A preliminary, unvalidated benthic vegetation map was created by Janet Anstee from CSIRO in 2015. This map utilised spectral classification of Landsat 8 imagery (captured in September 2014), along with a small number of ground-based seagrass observations, documented occurrences of dugongs and turtles, and surrogate variables for seagrass, including bathymetry and light attenuation/turbidity. This predictive model estimated that the “likely/probably” seagrass area spans approximately 382 km² [21]. The Anstee seagrass map is regarded as only a preliminary “first pass” model, as calibration and validation was incomplete. The map also had a significant uncertain spectral class of “possibly” seagrass covering an additional 199 km², located mainly in Wunambal Gaambera (Uunguu) sea country in the far north, that requires extensive field validation [22].

Eighty Mile Beach (Nyangumarta and Karajarri sea country)

Eighty Mile Beach is an extensive stretch of remote coastal country located between Cape Keraudren and Jinmarnkur (Cape Missiessy). A key ecological feature is the vast intertidal sand and mudflats that extend up to four kilometres wide in many parts at low tide and provide a rich source of food for many species. Eighty Mile Beach is regarded as one of the most significant areas in Australia for migratory shorebirds within the East Asian-Australasian flyway and is listed as a wetland of significance under the Ramsar Convention. The intertidal and sub-tidal zones of Eighty Mile Beach are largely unvegetated, with no published or publically available data verifying the occurrence of seagrass [23]. However, seagrass communities of note are found west of Cape Keraudren and to the north.

Jinmarnkur (Cape Missiessy) to Gourdon Bay (Karajarri sea country)

Karajarri people are the traditional owners of the land and intertidal zone along the southwest Kimberley coast, from Thangoo pastoral lease in the north to Malamburr Well in the south (northern end of Eighty-mile beach) ^[24]. The coastal region is rich in diverse habitats, including beaches, tidal creeks, bays, *parnany* (reefs), and *wirntirri* (seagrass meadows). These vital areas serve as breeding and feeding grounds for threatened and migratory *wilarr* (sea turtle) species, such as the Olive Ridley, Hawksbill, Loggerhead, and Green turtles. Additionally, dugongs and Snubfin Dolphin inhabit the near-shore areas^[24].

The only published records (including herbarium specimens) of seagrass in the region are from adjacent to Cape Bossut, where five species are recorded: *Thalassodendron ciliatum*, *Halodule uninervis*, *Cymodocea angustata*, *Syringodium isoetifolium*, *Halophila decipiens* and the northwestern Australian endemic species *Cymodocea angustata* ^[8]. *Thalassodendron ciliatum* was reported growing directly on rock, particularly in areas subjected to fast currents. The remaining species were reported from rock pools with a sediment veneer at the mid-tide level.

Karajarri Rangers are currently assisting with seagrass mapping across their sea country as part of the National Environment Science Program (NESP).

Bangarangara to Willie Creek, including Roebuck Bay (Yawuru sea country)

Roebuck Bay is a tropical marine embayment with extensive, highly biologically diverse, intertidal mudflats. The Bay is bounded to the north-west by the township of Broome (population 14,660 in 2021) and extends to Sandy Point in the south.

Seagrass communities are a critical component of the Roebuck Bay marine system, forming extensive meadows in the lower intertidal areas, particularly in the northern Bay ^[8, 25]. Dugongs and green turtles use the bay as a feeding and migration transit area. Aerial surveys in 2009 from Lagrange Bay in the south to Cape Leveque in the north by Woodside Petroleum, estimated the dugong population of Roebuck Bay to be 542 (SE: ± 216) animals in the late wet season (March), 709 (95% CI: 455 – 952) in the dry season (July) and 531 (95% CI: 274 – 811) in September ^[26]. These were significantly higher than the 50-100 individuals previously reported in 1984 ^[27]. The 2009 surveys also reported that Roebuck Bay supported the greatest number of calves in the region and in all survey periods ^[26]. The most recent survey was conducted in May 2017, as an addition to the WAMSI Kimberley Marine Research Program, and the estimated dugong population was $1,085 \pm 124$ animals, a mean density of $0.18 \pm 0.02 \text{ km}^{-2}$. This classified Roebuck Bay as an abundance ‘hotspot’ for dugongs ^[7]. The abundance estimates in May 2017 and the July 2009 survey (~eight years prior) where they overlapped (encompassing Roebuck Bay Marine Park) indicate that there has been no significant change in density, suggesting that cultural harvests had been sustainable over that period ^[28].

Roebuck Bay is also a major nursery for fishes and crustaceans, supporting an exceptionally high biomass and diversity of benthic invertebrates (approximately 300 – 500 species), placing it among the most diverse mudflats known in the world ^[29]. A large section of Roebuck Bay is a declared Ramsar area, as it is one of the most important sites for shorebird conservation in the East Asian-Australasian Flyway in Australia and globally.

For the Yawuru people, the Bay is of immense cultural importance due to the important food and culturally important species it contains many which rely on seagrass (e.g., dugong), as well as the many connections to dreaming stories, law and other spiritual and cultural practices ^[30].

Roebuck Bay has a very large tidal range which exposes around 160 km^2 of mudflat, approximately 45% of the total bay area, with tides travelling at up to $20 \text{ cm} \cdot \text{sec}^{-1}$ mid cycle ^[31, 32]. Most of the mudflat area is inundated by each high tide and at times, spring tides and/or

cyclones may cause the adjoining coastal flats to become inundated. The tidal system is semi-diurnal with an average tidal amplitude of 5.7m. Tidal range varies from c. 1 m on neap tides to 10.5 m on the highest spring tides. These factors dominate the intertidal ecology.

The extensive seagrass meadows in the northern regions of Roebuck Bay, particularly in the Town Beach area, are dominated by *Halophila ovalis* and *Halodule uninervis*, with a further two species (*Halodule pinifolia* and *Halophila minor*) under review for synonymy^[13]. The most vigorous stands of seagrass grow in areas that are exposed for less than two hours at low tide^[33].



Mixed *Halophila ovalis* and *Halodule uninervis* meadow adjacent to Mangrove Point inner anchorage area, Roebuck Bay - 01 August 1984 (tide 0.3m). Photos: R Prince DCLM (from Prince 1986).



Mixed *Halophila ovalis* and *Halodule uninervis* meadow adjacent to Mangrove Point inner anchorage area, Roebuck Bay – September 2007 (L) & October 2012 (R) . Photos: Len McKenzie.



Halophila ovalis (above left) and *Halodule uninervis* (above right) meadow adjacent to Mangrove Point, Roebuck Bay - 01 August 1984. Photos: R Prince DCLM (from Prince 1986).



Halophila ovalis (above left) and *Halodule uninervis* (above right) meadow adjacent to Mangrove Point, Roebuck Bay – 3 September 2007. Photos: Len McKenzie.



Dugong feeding trails in mixed *Halophila ovalis* and *Halodule uninervis* meadow adjacent to Mangrove Point inner anchorage area, Roebuck Bay:

Left - 01 August 1984. Photo: R Prince DCLM (from Prince 1986), Right – 30 September 2012. Photo: Rudi Yoshida.

Willie Creek to Cape Bertholet (Jabirr Jabirr/Ngumbarl sea country)

North of Roebuck Bay, isolated *Halodule uninervis* patches have been reported at Barred Creek (Cape Boileau) and monospecific meadows of *Syringodium isoetifolium* at Quondong Point, in rock pools with coarse sediments ^[33].



Halodule uninervis meadow (above left) in pool on raised terrace, Barred Creek (Cape Boileau - 28 July 1984) and *Syringodium isoetifolium* meadow (above right), Quondong Point (29 July 1984). Photo: R Prince DCLM (from Prince 1986).

The majority of the area around Coulomb Point consisted of fine sand substratum (70% sand coverage), from the shallow water out to the extent of the survey boundary, with patches of sand waves and dunes seen in the shallower water transects.

The presence of seagrass had been suggested in the subtidal areas adjacent to James Price Point due to the presence of dugongs ^[33], however this was not verified until the area was examined between November 2007 and December 2008 as part of a benthic habitat survey to identify

possible locations for a proposed common-user liquefied natural gas (LNG) hub precinct in the Kimberley region ^[34].

Seasonally-abundant subtidal *Halophila* communities and turf or mat green algae were identified on the inshore flat sandy patches between subtidal sand dunes and waves ^[34]. These subtidal meadows were first observed during surveys undertaken by the former Department of Environment and Conservation in November 2007, when seagrass abundance was seasonally high. Repeat surveys of some locations where seagrass was found in November 2007 were undertaken in April 2008 but no seagrass was recorded. Seagrass had re-established in these areas by June 2008 and surveys by DEC in December 2008 found prolific seed production in *Halophila* sp, suggesting that recruitment from seed may be a very important process for sustaining these seagrass Communities ^[35].

The offshore flat sandy areas from Quondong Point to Coulomb Point were found to have almost exclusively bioturbated habitat dominated by sand dunes and waves. No seagrass or other marine plants have been reported in these habitats.

Cape Bertholet to Embalgun (Jabirr Jabirr/Ngumbarl, Nyul Nyul and Nimanburr sea country)

A few isolated patches of *Enhalus acoroides* have been reported on the reef flat on the south side of West Island in the Lacepedes group, and *Halophila ovalis* has been observed off the reef edge in the channel (R Prince, Pers. Comm.). *Halophila spinulosa* which is usually found in deeper water (to 45 m depth) has been reported in shallower water in areas of rapid tidal movement either in patches between larger species or as sparse populations at Tooker Point (Alligator Creek) and Sandy Point (Beagle Bay) ^[8]. Extensive *Halophila minor* meadows have also been reported to occur in the shallower waters at Tooker Point, Alligator Creek, and Sandy Point, Beagle Bay ^[8]. Dugongs and their feeding trails have been observed in the area.

Seagrass was reported in the inshore areas of Perpendicular Head during a benthic habitat survey to identify possible locations for a proposed common-user liquefied natural gas (LNG) hub precinct in the Kimberley region ^[34]. Small isolated patches of unidentified *Halophila* species were observed throughout the area where flat sandy substrates dominated. Most of the inshore areas of Perpendicular Head were dominated by green turf or mat algae and patches of red algae.

No seagrass has been reported in the deeper waters of the region (15-20m) where the seabed is predominantly made up of fine sand (70% coverage) interspersed with small patches of sand waves and dunes ^[34].

Pender Bay to Carlisle Head (Bardi and Jawi sea country)

The coastal seabed between Cape Borda and Swan Point (tip of Dampier Peninsula) is predominately low (< 0.5m) and high (0.5-2m) relief reef structure separated by patches of coarse sand, sand waves and dunes ^[34]. Seagrass (unidentified *Halophila*) is present in relatively high coverage within the small bays in the northern part of this region in June 2008 ^[34]. Green algae (turf and mat) are also common in the shallow and intertidal areas along the coast. Little biohabitat is present in offshore areas where the substrate was mostly fine sand and some coarse sand patches.

Located south of Cape Leveque, the Chile Creek seascape is significantly influenced by the high tidal range (9.6m). Dense patches of *Enhalus acoroides* with *Halophila ovalis* and *Halodule uninervis* are found scattered amongst the large tidal pools that remain during the low spring tides (www.seagrasswatch.org).



Enhalus acoroides meadow (above left) and *Halophila ovalis* (above right), Chile Creek (31 August 2007).
Photo: Len McKenzie.

East of Swan Point is King Sound, which encompasses the Fitzroy River estuary and is the receiving basin for the Fitzroy River. This region is macro-tidal with low wave energy. There are extensive tidal flats subject to extreme variations in turbidity and tide fluctuations throughout the area. There are also numerous islands in the region. The northern reaches of the sound include the Buccaneer Archipelago. The region is an important area for dugongs, which have been reported from One Arm Point in the King Sound since 1688 ^[36, 37].

The most diverse seagrass meadows in the Kimberley region have been reported on the reef platforms in the One Arm Point – Sunday Island area, where ten species were reported (*Thalassia hemprichii*, *Thalassodendron ciliatum*, *Enhalus acoroides*, *Halophila ovalis*, *Halodule uninervis*, *Halophila minor*, *Cymodocea serrulata*, *Cymodocea angustata*, *Syringodium isoetifolium* and *Halodule pinifolia*) ^[8].

At One Arm Point, meadows are dominated by *Thalassia hemprichii* with *Halophila ovalis*, *Halodule uninervis* and *Halophila minor*. *Cymodocea serrulata* occurs on a raised reef platform at Sunday Island (protected from wave action) as a continuous canopy, or with *Enhalus acoroides* and *Thalassodendron ciliatum* ^[8]. *Enhalus acoroides* occurs in isolated patches in coarse sediments on raised reef platforms



Thalassia hemprichii meadow on reef platform. Above left: Sunday Island channel, 6 August 1984. Photo: R Prince DCLM (from Prince 1986). Above right: One Arm Creek, 1 September 2007. Photo: L McKenzie.



Mixed *Thalassia hemprichii* and *Halophila ovalis* meadow, a. One Arm Point – 4 August 1984; b. Sunday Island channel, southern end – 6 August 1984. Photos: R Prince DCLM (from Prince 1986).



Halophila ovalis meadow on reef platform, One Arm Creek, 1 September 2007. Photo: L McKenzie.



Enhalus acoroides meadow, a. One Arm Point – 1 September 2007; b. Sunday Island, southern end – 6 August 1984. Photos: L McKenzie and R Prince DCLM (from Prince 1986).



Mixed *Thalassia hemprichii* and *Halodule uninervis* meadow, One Arm Point: left – 4 August 1984. Photo: R Prince DCLM (from Prince 1986). Right, 1 September 2007. Photo: L McKenzie.

Thalassia hemprichii and *Enhalus acoroides* are the most abundant seagrasses recorded in lagoons of the perched reefs of One Arm Point, Jalan (Tallon Island) and Iwany (Sunday Island). A study which assessed seagrass abundance and growth rates on five occasions between

November 2013 and November 2015 found high temporal and spatial variable across the area. The abundance (measured as biomass and shoot density) and growth (measured as leaf extension) of *T. hemprichii* and *E. acoroides* did not follow any evident seasonal or temporal pattern, with the exception of seasonal leaf production for *E. acoroides* at Jalan and seasonal shoot density for *T. hemprichii*^[38]. Flowers of both species were only observed in November 2013. Leaf extension rates were high for both species relative to typical seagrass growth rates, with some measurements exceeding several centimetres per leaf per day. Productivity of *T. hemprichii* varied from around 0.001 to 0.005 g per shoot per day (reflecting leaf extension rates from 5 to 26 mm per shoot per day), while *E. acoroides* ranged from 0.0025 to 0.015 g per shoot per day (leaf extension rates from 6 to 30 mm per shoot per day)^[38].

Seagrasses in the terraced lagoons of Tallon Island (*Jalan*) and Sunday Island (*Iwany*) have some of the highest rates of grazing than anywhere else in the world — with rates of consumption more than ten times the rates of growth at some locations^[39]. This was particularly pronounced for *Thalassia hemprichii*, which were heavily grazed by rabbitfish and green turtles. In contrast, consumption of the seagrass *Enhalus acoroides* was on average lower than growth, as it was rarely grazed^[39].

Carlisle Head to Hoon Creek (Jabirr Jabirr/Ngumbarl, Nyul Nyul and Nimanburr sea country)

There is currently no information regarding seagrass in the southern part of King Sound. This area features vast tidal flats that experience significant variations in turbidity and extreme tidal fluctuations, making it an unfavourable habitat for seagrasses.

Helpman Islands to Koolan Island (Mayala sea country)

No seagrass is reported in southern King Sound, specifically from the Helman Islands to Cascade Bay area. However, seagrass was reported in 1994 to occur on the islands located in the northeastern portion of King Sound. *Halophila ovalis* was reported on the intertidal reef flat at Long Island, while *Enhalus acoroides* was found in a mangrove channel on the western side of Mermaid Island and on the reef flat adjacent to mangroves on Gregory Island^[15].

Seagrasses are also scattered throughout the Buccaneer Archipelago. In November 1994, *Enhalus acoroides* was reported from a sheltered fringing reef on Hidden Island, mixed with *Thalassia hemprichii* on an intertidal flat between Admiral Island and King Hall Island^[15]. Further north, *Thalassia hemprichii* was reported at a sheltered fringing reef on Fraser Island in October 2011 and from the western side of Caffarelli Island in November 1994^[15]. In the eastern part of the archipelago, *Thalassia hemprichii* was also reported at Irvine Island^[15]. It is likely that seagrass occur in many of the sheltered bays featuring fringing reefs or shallow sandbanks, particularly those bordered by mangroves.

Kimbolton to Cape Wellington (Dambimangari sea country)

Dambimangari are saltwater people who have inhabited the coast for many thousands of years. Their sea country covers 11,896 km², and seagrass habitats support fish and culturally important species such as *warlinya* (dugong) and *juluwarra* (sea-turtle)^[40].

Three species of seagrass have been reported across Dambimangari sea country: *Enhalus acoroides*, *Halophila decipiens* and *Thalassia hemprichii*. The rarest among them, *Halophila decipiens*, was only observed in an intertidal zone at the Champagny Islands in October 2011^[15]. *Enhalus acoroides* was reported in November 1994 at Talbot Bay and Ngalaguru (High Clifty) Island, located in the southern and central sections of the region, respectively^[15].

The most commonly found seagrass is *Thalassia hemprichii*. Initially recorded on the reef flat near High Clifty Islands in May 1987, it has since been collected from various locations across the expansive intertidal reef flat surrounding Montgomery Reef^[15]. It was reported in July 1990 from the sandy regions on the southeastern edge of the reef flat, then again on the eastern side in November 1994. Additionally, in October 2009, reports emerged from several locations: the mid-tide breakwater area in the northwest, the intertidal rocky zone in the south, and the intertidal sand and rock areas in the northeast^[15]. In the north of the region, *Thalassia hemprichii* has been reported in the intertidal habitats at Slate Island and on an algal reef of the eastern side of Wildcat Reef, in November and December 1996, respectively^[15].

Cape Wellington to western Napier Broome Bay (Wunambal Gaambera (Uunguu) sea country)

Jala (seagrass) areas are recognised as important for *mangguru* (marine turtles) and *balguja* (dugong) in Wunambal Gaambera sea country^[41]. However, in August 2008, a reconnaissance survey by the Department of Environment and Conservation (DEC) around Anjo Peninsula, failed to find any seagrass at points examined in Vansittart Bay, or in western Napier Broome Bay (including West Bay, Deep Bay and Mackenzie Anchorage)^[42, 43].

In May 2012 during a participatory mapping exercise with community members, Uunguu Rangers, and Wunambal Gaambera Aboriginal Corporation members, a number of locations were identified by participants who knew of seagrass^[44]. For example, TOs reported regularly observing dugong in the area offshore from, and within, the Wobinbeyi Creek area of Deep Bay (south western Napier Broome Bay).

During August 2013, Uunguu rangers mapped the occurrence of seagrass in Wobinbeyi following Seagrass-Watch mapping protocols using a drop-camera and a van Veen grab^[17, 45-48]. The only meadows located in the bay were subtidal, in the southern portion of the bay near Wobinbeyi Creek. No intertidal meadows were present. Three seagrass species were confirmed: *Halophila ovalis*, *Halodule uninervis* and *Syringodium isoetifolium*^[17]. Two meadows of *H. ovalis*/*H. uninervis* meadows were mapped, the extent of which was approximately 5 hectares. Using drop-cam, long-term monitoring was established in Wobinbeyi using modified Seagrass-Watch subtidal monitoring protocols^[49, 50], where 10 points were assessed by conducting three drops (quadrats) at each point^[51]. On the 28 August 2013, the initial monitoring event reported seagrass cover ranging from 10 to 35% (average 25.5%), with *H. ovalis* and *H. uninervis* occurring at approximately equal percentages throughout the meadow^[17]. No macroalgae was observed within the seagrass meadow and epiphyte (leaf algae) cover was low.

In August 2013, a survey of the waters surrounding Mary Island (Vansittart Bay) was conducted to assess seagrass presence using a viewing bucket (bathyscope) and a van Veen grab sampler. On the western side of the island, three small, isolated patches of seagrass were identified: one patch comprised of *Syringodium isoetifolium*, while the other two were *Halophila ovalis*^[44]. The seagrass coverage at these locations varied between 3% and 5%. More recently, Uunguu Rangers have also collected specimens of *Halophila ovalis* adjacent to Guy Point^[43].

An aerial survey of dugongs in waters shallower than 20 m deep conducted between September and October 2015, revealed two significant dugong abundance 'hotspots' in the Kimberley, both located within Wunambal Gaambera sea country. These hotspots were the area around Bigge Island in the south, with a dugong density of $0.58 \pm 0.05 \text{ km}^{-2}$, and the region around Anjo Peninsula and Napier Broome Bay in the north, exhibiting a density of $0.72 \pm 0.08 \text{ km}^{-2}$ ^[22].

Napier Broome Bay to Adolphus Island, Cambridge Gulf (Balangarra sea country)

Much like the rest of the Kimberley, the area from Napier Broome Bay to Adolphus Island experiences a macrotidal regime, leading to strong horizontal currents in its shallow coastal

waters. These tidal flows create turbulent mixing, which can be further affected by prevailing winds and episodic events such as tropical cyclones. The interplay between these flows and the intricate coastline—comprising headlands, bays, offshore islands, and reef systems—shapes the physical oceanography of the region. However, in contrast to southern regions of the Kimberley, the maximum astronomical tidal range here is under 3m, marking it as one of the smallest tidal ranges in the Kimberley. Consequently, its impact on marine mixing is expected to be less pronounced^[43].

The annual average rainfall in Kalumburu is approximately 1,220 mm, with around 90% of this precipitation occurring from November to March each year. Two major contributory catchments in the region cover ~8,400 km² and ~15,670 km² and are drained by the King Edward and Drysdale rivers, respectively^[43]. During the wet season, terrestrial runoff leads to increased turbidity, sediment deposition, and contributes to marine carbon and nutrient reserves. These processes, in turn, enhance productivity in the inshore ecosystem^[43].

Published records of seagrass occurrence across the region are limited. At least two species are confirmed: *Enhalus acoroides* and *Halophila decipiens*^[15]. *Enhalus acoroides* was reported from a peninsula southeast of Cape Londonderry in November 1995, and *Halophila decipiens* from near the mouth of the King George River, Koolama Bay, in June 2013^[15]. There are no published maps of seagrass meadows in the region, but large meadows are reported by TOs around Cape Londonderry, where *abil* (dugong) and *mangkuru manya* (marine turtles) feed^[52].

Seagrass is likely to occur in the eastern portion of southern Napier Broome Bay (Balangarra sea country), as dugongs are reported to occur throughout the area and seagrass meadows have been mapped in the western portion Wunambal Gaambera sea country of the bay.

Cambridge Gulf to Joseph Bonaparte Gulf

There are no published records of seagrass in Cambridge Gulf.

The inner western portion of Joseph Bonaparte Gulf is not expected to support significant seagrass meadows due to unsuitable environmental conditions, which include highly turbid water conditions and the mobile nature of the sediments^[53, 54]. A survey of intertidal seagrasses carried out by the WA Museum did not record any seagrasses in the Joseph Bonaparte Gulf, and no evidence of drift material was found at any of the sites surveyed^[55].

SEAGRASS-WATCH IN THE KIMBERLEY REGION

To provide an early warning of change, long-term monitoring has been established in Roebuck Bay and Dampier Peninsula as part of the Seagrass-Watch, global seagrass assessment and monitoring program (www.seagrasswatch.org)^[56]. Establishing a network of monitoring sites in the Kimberley region provides valuable information on temporal trends in the health status of seagrass meadows in the region and provides a tool for decision-makers in adopting protective measures. It encourages local communities to become involved in seagrass management and protection. Working with both scientists and local stakeholders, this approach is designed to draw attention to the many local anthropogenic impacts on seagrass meadows which degrade coastal ecosystems and decrease their yield of natural resources.



Seagrass-Watch monitoring at Town Beach (Roebuck Bay):
left - September 2007 and right – August 2018 (Photos: L McKenzie)

The following is a summary of the current status of Seagrass-Watch monitoring in the Kimberley region.

Roebuck Bay

Monitoring: ongoing, *triannual*

Principal watchers: Broome Seagrass Community Monitoring project & Seagrass-Watch HQ

Location: intertidal sand flat in the northern section of the bay between Town Beach and the port.

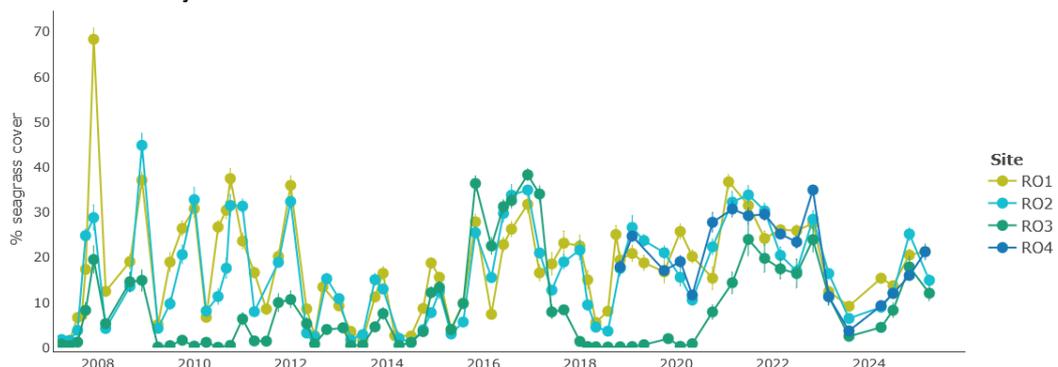
Site codes: RO1, RO2, RO3, RO4

Issues: coastal development, vessel movement, stormwater and urban runoff

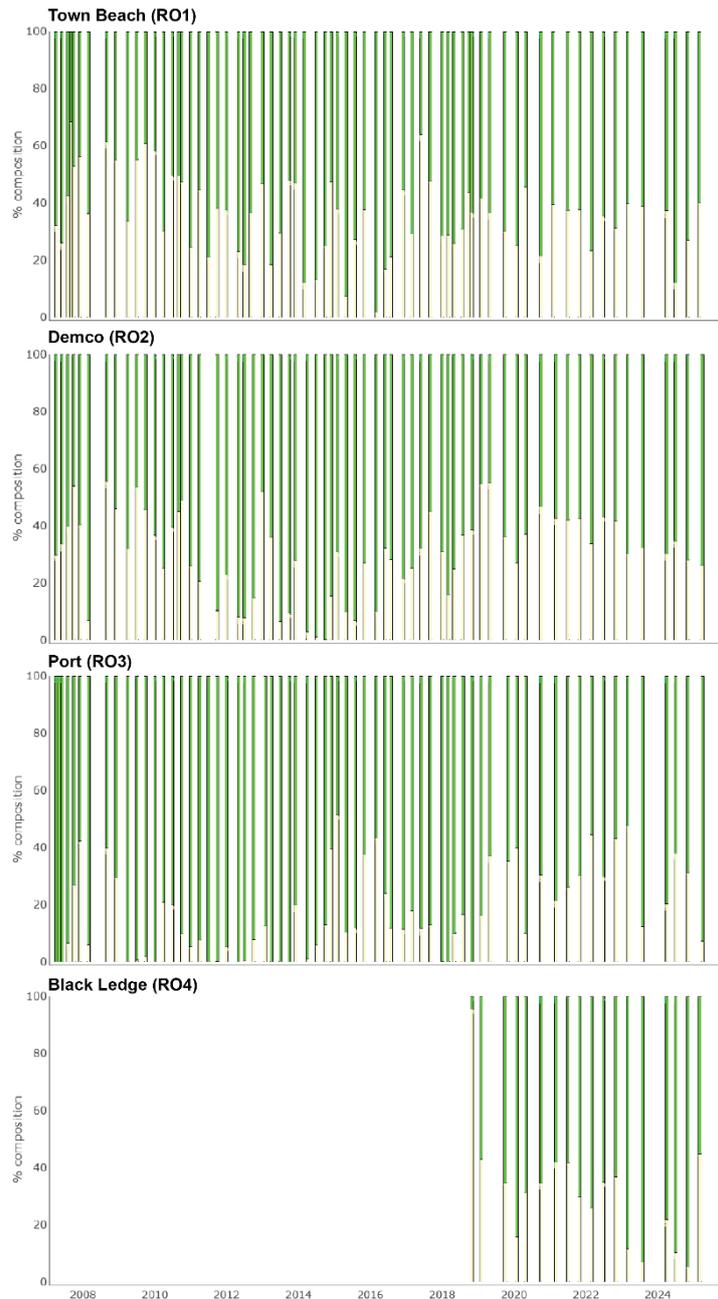
Comments: Extensive seagrass meadows occur in the northern regions of Roebuck Bay, particularly in the Town Beach area, and are dominated by *Halophila ovalis* and *Halodule uninervis*. Most abundant sections are where pooling of water occurs at low tide. Dugong feeding trails are common. All but one of the sites (RO4) are located within the Port of Broome. Site RO4 is located within the Yawuru Nagulagun / Roebuck Bay Marine Park. No sites are located within the dedicated Ramsar wetlands.

Status (Apr25):

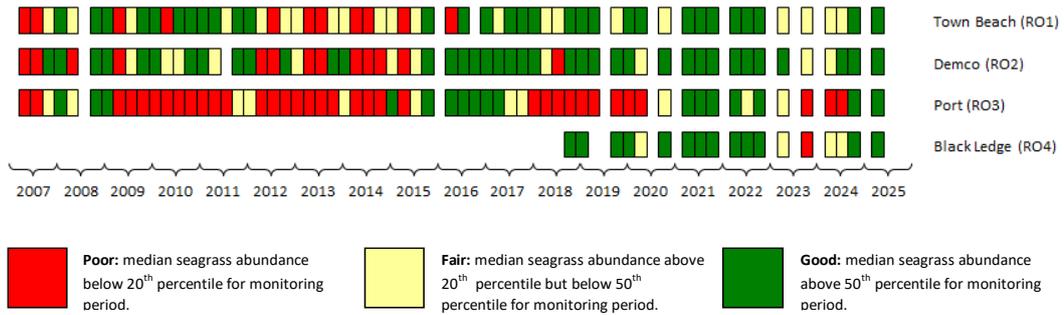
- seagrass abundance (% cover) follows a unimodal pattern of growth annually, with higher abundances in *Laja* (late Sep-November) and early *Man-gala* (December-March) and lower in late *Wirralburu* (May-June) and *Barrgana* (June-August) seasons of each year.
- although seagrass abundance fluctuated between years, there were no detectable long-term trends at any site.



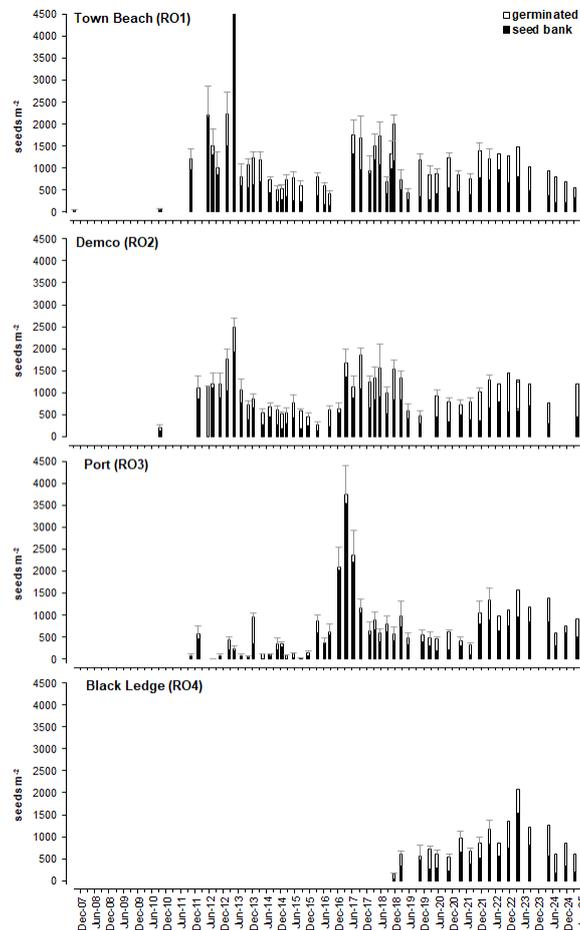
- the opportunistic foundational species *Halodule uninervis* dominates the meadows in both abundance and canopy height. The colonising species *Halophila ovalis* fluctuated seasonally in composition, declining in the wet season (monsoon and late-monsoon).



- seagrass abundance indicators were derived for RO1 and RO2 ^[57] as the variance for the 50th and 20th percentiles levelled off around 24 samples (i.e. sampling events), suggesting this number of samples was sufficient to provide a reasonable estimate of the true percentile value.
- using the seagrass guidelines values, seagrass state was determined for each monitoring event at each site by scoring the median values relative to the percentiles. As RO3 was not suitable as a reference site (due to adjacent impacts), the guidelines values for RO2 were substituted.
- seagrass abundances declined to a Fair state across all sites in early 2023, falling to Poor at RO3 and RO4 by August of that year. In early 2024, abundances began to recover at all sites, except for RO3, which only started its recovery in late 2024. By the end of 2024, all sites had reached a Good state and have maintained this status, despite a minor seasonal dip in early 2025.
- seagrass abundance relative to the guidelines indicates that the seagrass meadows across Roebuck Bay are currently in a **Good** state. Furthermore, these meadows have consistently maintained a **Good** state at all long-term monitoring sites since the dry season (over the past six months).

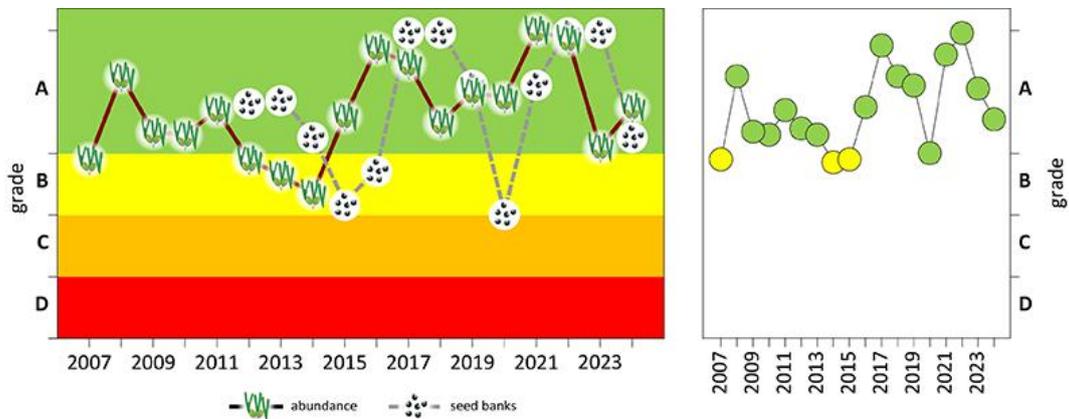


- Epiphyte abundance is generally similar across all sites, being significantly higher in 2007–2009 and 2013–2014. Abundances appear greater in late-dry/early monsoon of each year, most likely owing to increasing daylight paired with moderate temperatures.
- A seed bank of the foundation seagrass *Halodule uninervis* persists at all sites, and although highly variable, densities appeared higher in the wet (December to May), after the main seagrass growing period (August to December). Analysis suggests that meadows may require only a moderate seed bank for recovery capacity, and that greater sized seed banks provide greater probability of recovery (i.e. greater probability of viable seeds) but not necessarily greater abundance [13].



- A report card was developed in 2017 using two indicators of seagrass condition, based on their significance to seagrass resilience: abundance, which represents the state of the seagrass to resist stressors; and seed banks, which represents the capacity of the seagrass to recover from loss/disturbance [13].
- The report card illustrates the annual relative health of seagrass in Roebuck Bay, and shows that seagrass condition has fluctuated over the 18 years of monitoring. When monitoring was established in 2007, seagrass was rated as **Fair**. However, it improved to a **Good** state (Grade A) the following year and maintained that status until 2014. In 2014, the condition declined back to **Fair** due to lower abundances and fewer seeds, but by 2016, seagrass had bounced back to a **Good** state (Grade A), where it has remained ever since. Although the seagrass state remained **Good** in 2020, it recorded its lowest score in five years due to declining seed banks.

In 2021 and 2022, the improving seagrass abundance coupled with a large persistent seed bank indicated resilient meadows. In 2023, seagrass abundance declined, but the persistent seed bank enabled abundance to start recovering in 2024. By the end of 2024, while the seagrass remained in a **Good** state, the slightly depleted seed banks and recovering abundances may slightly reduce the meadows' resilience to unfavourable environmental conditions.



Annual report card for Roebuck Bay seagrass condition 2007 to 2024: a, individual indicators; b, combined index. Reporting scores are categorised to a four point scale; ■ = good (≥ 60 -100), ■ = fair ($\geq 40 < 60$), ■ = poor ($\geq 20 < 40$), ■ = very poor ($0 < 20$). NB: Scores are unitless.

Dampier Peninsula

Monitoring: suspended

Principal and past watchers: Bardi Jawi Land and Sea Rangers

Location: One Arm Point

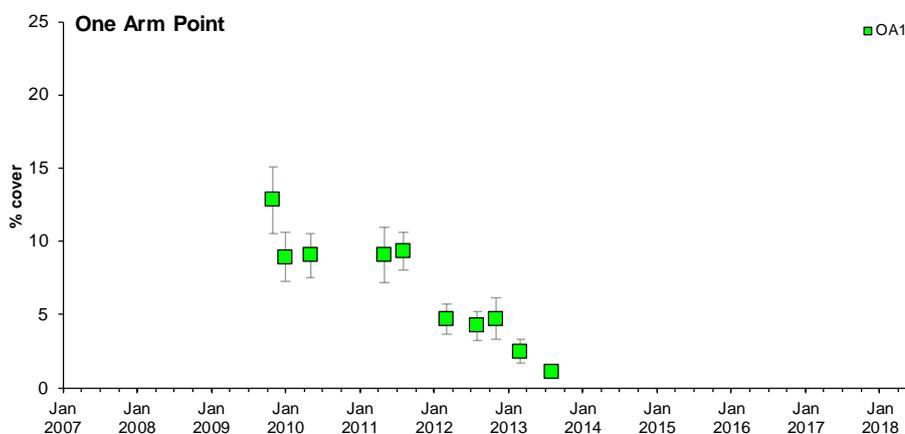
Site code: OA1

Issues: none identified

Comments: The most diverse seagrass meadows in the Kimberley region have been reported on the reef platforms in the One Arm Point. Dugongs and turtles are often reported feeding on these meadows.

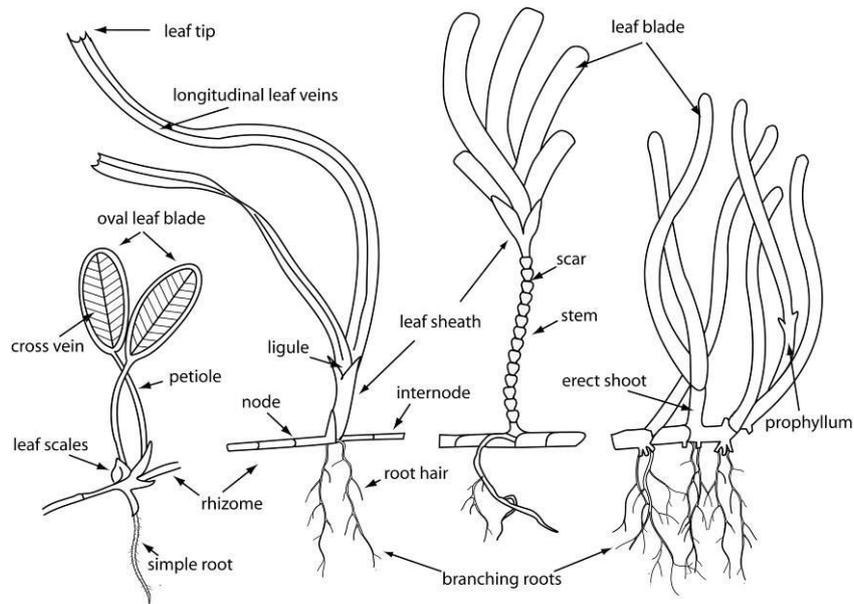
Status (unknown):

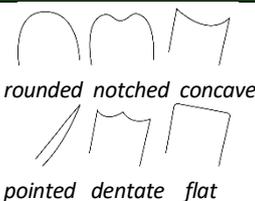
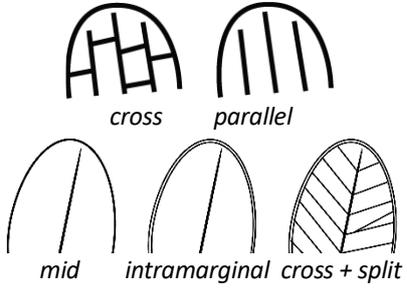
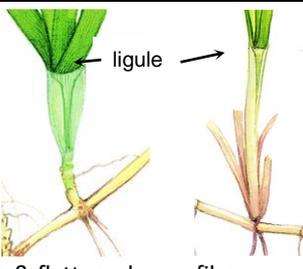
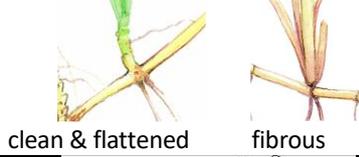
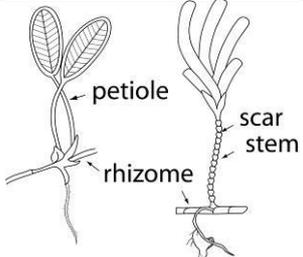
- only 1 site established (no replication due to size of meadow)
- site only contains *Thalassia hemprichii*
- abundances in 2013 were the lowest since monitoring was established in 2009.
- long-term trend suggests seagrass abundance was declining.



For more information, visit <https://www.seagrasswatch.org/western-australia/>

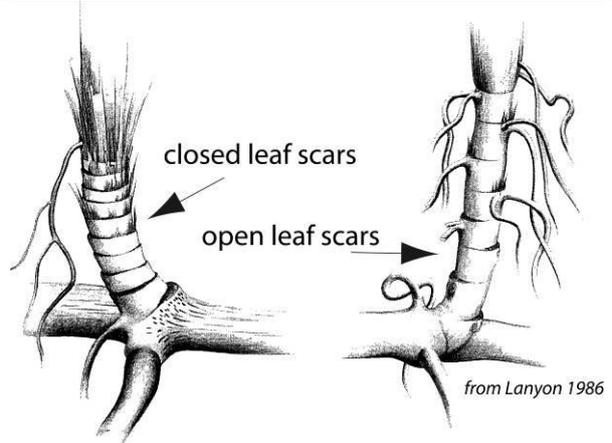
Parts of a seagrass plant



Leaf		
Tip	<p>End of leaf with a variety of shapes and some may be dentate (having toothed-like projections).</p> <p>For identification use young leaves, as old leaves are easily damaged or cropped.</p>	 <p>rounded notched concave pointed dentate flat</p>
Veins	<p>Used by the plant to transport water, nutrients and photosynthetic products. The pattern, direction and placement of veins in the leaf blade are used for identification.</p> <ul style="list-style-type: none"> • cross-vein: perpendicular to length of leaf • parallel-vein: along the length of the leaf • mid-vein: prominent central vein • intramarginal-vein: around inside edge • split-vein: cross-veins that fork 	 <p>cross parallel mid intramarginal cross + split</p>
Edges	The edges of the leaf can be either serrated, smooth or inrolled	 <p>serrated smooth inrolled</p>
Ligule	Membranous structure found at the junction of the blade and sheath. Clasps leaf sheaths, aiding protection of enclosed younger plant parts.	 <p>ligule</p>
Sheath	A modification of the leaf base that protects the newly developing tissue. The sheath can entirely circle the vertical stem or rhizome (continuous) or not (non-continuous); fully or partly cover the developing leaves and be flattened or rounded.	 <p>clean & flattened fibrous</p>
Attachment	The leaf can attach directly to the rhizome, where the base of the leaf clasps the rhizome, or from a vertical stem or stalk (petiole) e.g. <i>Halophila ovalis</i> .	 <p>petiole rhizome scar stem</p>

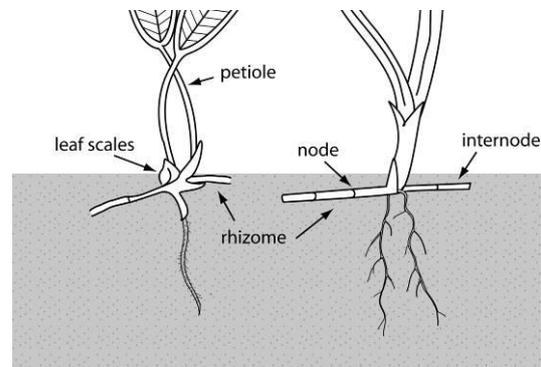
Stem

The vertical stem, found in some species, is the upright axis of the plant from which leaves arise (attach). The remnants of leaf attachment are seen as scars. Scars can be closed (*entirely circle the vertical stem*) or open (*do not entirely circle the vertical stem*).



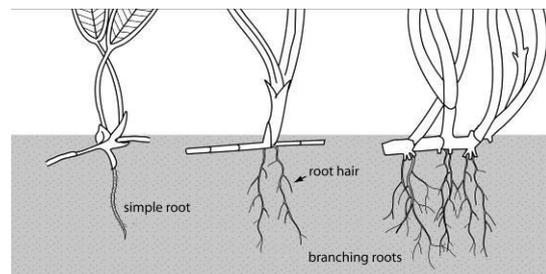
Rhizome

The horizontal axis of the seagrass plant, usually in sediment. It is formed in segments, with leaves or vertical stem arising from the joints of the segments, the nodes. Sections between the nodes are called internodes. Rhizomes can be fragile, thick and starchy or feel almost woody and may have scars where leaves were attached.



Root

Underground tissues that grow from the node, important for nutrient uptake and stabilisation of plants. The size and thickness of roots and presence of root hairs (very fine projections) are used for identification. Some roots are simple or cordlike, others may be branching, depending on seagrass species.



Notes:

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A guide to the identification of tropical Western Australia's seagrasses

Adapted from Waycott et al 2004 [58].

Leaves cylindrical



cylindrical

Syringodium isoetifolium

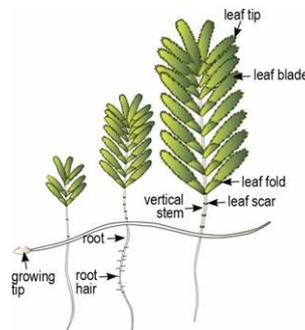
- leaves noodle/spaghetti like and taper to a point
- leaves contain air cavities
- leaves 7-30cm long
- inflorescence is a "cyme"

Leaves oval to oblong



oval to oblong

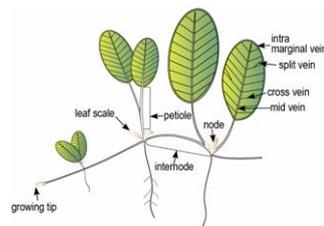
obvious vertical stem with more than 2 leaves



Halophila spinulosa

- leaves arranged opposite in pairs
- leaf margin serrated
- shoots can be up to 15cm long
- 10-20 pairs of leaves per shoot
- leaf 15-20mm long and 3-5mm wide

leaves with petioles, in pairs



Halophila decipiens

- fine hairs on both sides of leaf blade
- leaf margins finely serrated
- leaf apex rounded to slightly pointed
- leaf 10–25mm long and 3–10mm wide
- 6-8 cross vein pairs

*Halophila minor**

- less than 8 pairs of cross veins
- leaf 5-15mm long and 3.5-6mm wide
- leaf margins smooth
- no leaf hairs
- occasional cross vein branching

Halophila ovalis

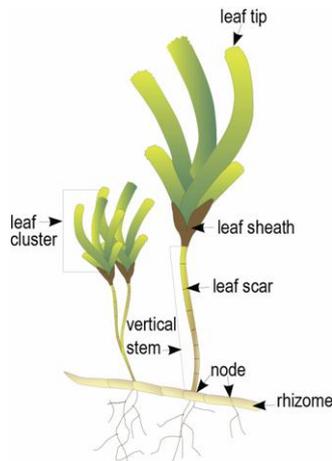
- 8 or more pairs of cross veins
- leaf 5-40mm long and 5-20mm wide
- leaf margins smooth
- no leaf hairs

Leaves strap-like

Leaves can arise from vertical stem



straplike



Cymodocea angustata

- leaf tapers toward apex, with widely spaced serrations
- leaf with <13 longitudinal veins
- leaf sheath slightly obconical and scars open - not continuous around upright stem
- one unbranched root at each node on rhizome

Cymodocea serrulata

- leaf tip rounded with serrated edge
- leaf 4-9mm wide with 13-17 parallel veins
- leaf sheath broadly flat and triangular, not fibrous
- leaf scars not continuous around upright stem

*Halodule pinifolia**

- leaf tip rounded
- leaf blades narrow, 0.25-1.2mm wide
- leaf with 3 distinct parallel veins, sheaths fibrous
- rhizome usually white with small black fibres at the nodes

Halodule uninervis

- leaf tip tri-dentate or pointed, not rounded
- leaf blades 0.5-5mm wide
- leaf with 3 distinct parallel veins, sheaths fibrous
- rhizome usually white with small black fibres at the nodes

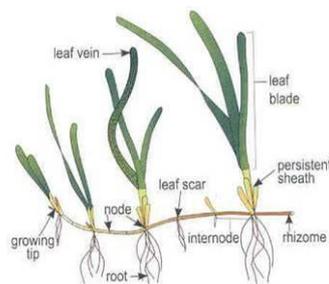
Thalassia hemprichii

- leaf tip rounded, may be slightly serrated
- leaf 4-12mm wide with 9-11 parallel veins
- leaf with small (1-2mm long) red flecks
- leaf often distinctly curved, ligule absent
- rhizome thick with distinct triangular shaped nodes
- one short root per rhizome node

Thalassodendron ciliatum

- distinct upright stem
- clusters of curved leaves (>5 mm wide), margins serrated
- stem & roots arising at each fourth rhizome internode
- stem and rhizome woody

Leaves always arise directly from rhizome



Enhalus acoroides

- large plant, leaves >30 cm long, >1 cm wide
- in-rolled edges of leaves with rounded tip
- long black bristles protruding from thick (1.5cm) rhizome
- roots cordlike and not branched/ramified, arising from the axillary buds of the ventral leaves
- often grows in a ring or patch

Monitoring a seagrass meadow

Monitoring is the repeated observation of a system, usually to detect change. It is an integrated activity to evaluate the condition of the physical, chemical and biological character of the environment. Environment monitoring programs provide coastal managers with information and assist them to make decisions with greater confidence.

Environmental monitoring programs are ideally designed to: quantify the causes of change; examine and assess acceptable ranges of change for the particular site; and to measure levels of impacts.

Common drivers (reasons) for monitoring include: community interest; government policies such as Coastal Strategies and Plans, Oceans Policy, State of the Environment Reporting (SoE), Water Quality guidelines or Best Practice Guidelines; and Government Legislation (e.g., Fish Habitat Protection).

Users of the monitoring program information/results are diverse, including for example: the general public, environmental regulators - legislators, resource managers and scientists.

There are a number of issues to consider when implementing a monitoring program, including: ensure the protocols used have explicit objectives; clearly identified responsibilities of the partners (e.g. Gov agencies, consultants, First Nations and community groups); a clear and defensible rationale for using the parameters that are measures (e.g. physico/chemico, biological indicators); to have a baseline (first) assessment / measure against which subsequent changes can be measured/compared; knowledge of spatial and temporal variation prior to designing the program (i.e. pilot study); clearly defined field protocols; data management procedures, ensure the level of change and accuracy of the detection is appropriate (as will vary according to the methodology); selection of statistical tools; and a mechanism to reduce and manage errors (i.e. QA/QC program).

Appropriate Quality Assurance/Quality Control (QA/QC) procedures are an integral component of all aspects of sample collection and analysis in monitoring programs. This includes participation in relevant inter-laboratory studies, proficiency testing, and the use of standard reference materials. Monitoring programs often include the following guidelines for implementation by data collectors and reporters:

- appropriate methods must be in place to ensure consistency in field procedures to produce robust, repeatable and comparable results including consideration of sampling locations, replication and frequency;
- all methods used must be fit for purpose and suited to a range of conditions;
- appropriate accreditation of participating laboratories or provision of standard laboratory protocols to demonstrate that appropriate laboratory QA/QC procedures are in place for sample handling and analysis;
- participation in inter-laboratory performance testing trials and regular exchange of replicate samples between laboratories;
- rigorous procedures to ensure 'chain of custody' and tracking of samples;
- appropriate standards and procedures for data management and storage; and
- a process to ensure data collectors are aware of any errors and provide an opportunity to clarify or correct data.

Monitoring seagrass

Seagrasses are often at the downstream end of catchments, receiving runoff from a range of agricultural, urban and industrial land-uses. Seagrass communities are generally susceptible to changes in water quality and environmental quality that make them a useful indicator of environmental health. Seagrass make good **bioindicators** of environmental health because they are:

- widely distributed,
- sessile plants which show measurable and timely responses to external stressors/impacts (rather than relocating to a less stressful environment) and,
- integrative of environmental conditions.

Several factors are important for the persistence of healthy seagrass meadows, these include: sediment quality and depth; water quality (temperature, salinity, clarity); current and hydrodynamic processes; and species interactions (e.g., epiphytes and grazers). Seagrass generally respond in a typical manner that allows them to be measured and monitored. In reporting on the health of seagrasses it is important to consider the type of factors that can affect growth and survival. Factors include:

- increased turbidity reduces light penetration through the water, interfering with photosynthesis and limiting the depth range of seagrass;
- increased nutrient loads encourages algal blooms and epiphytic algae to grow to a point where it smothers or shade seagrasses, thereby reducing photosynthetic capacity;
- increased sedimentation can smother seagrass or interferes with photosynthesis;
- herbicides can kill seagrass and some chemicals (e.g., pesticides) can kill associated macrofauna;
- boating activity (propellers, mooring, anchors) can physically damage seagrass meadows, from shredding leaves to complete removal;
- storms, floods and wave action can rip out patches of seagrasses.

Seagrass-Watch

A method for monitoring seagrass resources is used in the Seagrass-Watch: Global Seagrass Observing Network. This method uses globally standardised measurements taken from sites established within representative meadows to monitor seagrass condition. The number and position of sites can be used to investigate natural and anthropogenic impacts.

Seagrass-Watch is one of the largest seagrass monitoring programs in the world. Since its genesis in March 1998 in Australia, Seagrass-Watch has expanded internationally to more than 26 countries. Currently 445 sites have been established across 26 countries, with active monitoring at 298 sites (85 sites suspended and 62 archived). To learn more about the program, visit www.seagrasswatch.org.

Seagrass-Watch aims to raise awareness on the condition and trend of nearshore seagrass ecosystems and provide an early warning of major coastal environment changes. Participants of Seagrass-Watch are scientists and volunteers from a wide variety of backgrounds who all share the common interest in marine conservation. Most participants are associated with universities & research institutions, government (local & state), non-government organisations or established local stakeholder groups.

Seagrass-Watch integrates with existing scientific programs to protect this important marine ecosystem for the benefit of the global community. The program has a strong scientific underpinning with an emphasis on consistent data collection, recording and reporting. Seagrass-Watch identifies areas important for seagrass species diversity and conservation and the

information collected is used to assist the management of coastal environments and to prevent significant areas and species being lost.

Seagrass-Watch methods were developed to be rigorous, yet relatively simple and easy to use. Each of the parameters used have been carefully chosen with a clear and defensible rationale. The protocols used have explicit objectives and the sampling strategy is prepared using baseline and knowledge of spatial and temporal variation. This ensures data is of the highest quality and that time and resources are not wasted. The only condition is that on ground data collection must be overseen by a qualified scientist or trained and competent participant (18 years or over). After comprehensive training, participants can produce reliable data. Training includes both formal and informal approaches. Formal training is conducted by Seagrass-Watch HQ for participants 18 years of age and over, and includes lectures and on-site assessments with a tiered level of certification for competency. Formally trained participants are certified to supervise on-site monitoring and demonstrate (i.e. informally train) monitoring methods. At least a professional scientist or a formally trained volunteer must be present at each monitoring event. Evidence of competency is securely filed at Seagrass-Watch HQ.

QUALITY ASSURANCE-QUALITY CONTROL

Seagrass-Watch has an accepted Quality Assurance-Quality Control program in place to ensure that the program is producing data of high quality, and that time and resources are not wasted. Seagrass-Watch HQ has systems in place to manage the way Seagrass-Watch data is collected, organised, documented, evaluated and secured. The Seagrass-Watch program collects and collates all data in a standard format. By using simple and easy methods, Seagrass Watch ensures completeness (the comparison between the amounts of valid or useable data originally planned to collect, versus how much was collected). Standard seagrass cover **calibration sheets** are used to ensure precision (the degree of agreement among repeated measurements of the same characteristic at the same place and the same time) and consistency between observers and across sites at monitoring times to ensure percentage covers are close to a true or standardised value.

Other QAQC procedures include the selection of intertidal seagrass sites which are **permanently marked** with either plastic star pickets or an accurate ($\pm 3\text{m}$) GPS waypoint. Labels identifying the sites and contact details for the program are attached to these pickets. This ensures that the same site is monitored each event and that data can be compared between periods of time.

Ongoing standardisation of observers is achieved by on-site refreshers of standard percentage covers by all observers prior to monitoring and through *ad hoc* comparisons of data returned from duplicate surveys (e.g. either a site or a transect will be repeated by Seagrass-Watch HQ scientists – preferably the next day and unknown to local observers). Any discrepancy in these duplicates is used to identify and subsequently mitigate bias. For the most part, uncertainties in percentage cover or species identification are mitigated in the field via direct communication (as at least one experienced/certified observer is always present), or the collection of voucher specimens (to be checked under microscope and pressed in herbarium) and the use of a digital camera to record images (protocol requires all quadrats are photographed) for later identification and discussion.

Seagrass-Watch HQ has implemented a quality assurance management system to ensure that data collected is organised and stored and able to be used easily. All data (datasheets and photographs) received are entered onto a relational database on a secure server. Receipt of all original data hardcopies is documented and filed within the Seagrass-Watch File Management System, a formally organised and secure system, and housed at James Cook University. Seagrass-Watch HQ operates as custodian of data collected from other participants and provides an evaluation and analysis of the data for reporting purposes. Access to the IT system

and databases is restricted to only authorised personnel. Provision of data to a third party is only on consent of the data owner/principal.

Seagrass-Watch HQ checks all data for completeness, consistency and accuracy. All data submitted to Seagrass-Watch HQ it is first checked for compliance:

- *legible original datasheets,*
- *good quality quadrat photographs (high resolution),*
- *voucher specimens (if required) and*
- *completed MS Excel spreadsheet.*

Validation is provided by checking observations against photographic records to ensure consistency of observers and by identification of voucher specimens submitted. In accordance with QA/QC protocols, Seagrass-Watch HQ advises observers via an official Data Notification of any errors encountered/identified and provides an opportunity for correction/clarification (this may include additional training).

Once Seagrass-Watch HQ has completed all checks, a field in the Master database identifies data as either passed, quarantined, non-compliant or not-passed. Non-compliant data is used for large-scale summary reporting only if the data quality is deemed acceptable, i.e. if it was collected by a scientist or formally trained participant, then the scans/copies of datasheets are sufficient (*only if originals are not available*), and/or that the quadrat images were acceptable to complete QAQC, etc. If data quality is unacceptable, the data is either not entered into the Master database or remains quarantined/not-passed (excluded from analysis & reporting). If predominantly non-compliant data is used for detailed analysis and reporting at a site or location/region, it is marked on the outputs with a notice of non-compliance (e.g., site graphs). If officially requested data is non-compliant, a note in the metadata advises of non-compliance and includes a caveat to "use with caution". Any data considered unsuitable (e.g. nil response to data notification within thirty days) is quarantined or removed from the database.

Seagrass-Watch employs a proactive approach to monitoring, involving ongoing training for observers and the continued development of new methods and refinement of existing methods, including location/habitat specific calibration sheets, operation & validation of autonomous temperature and light loggers, etc. Quality data reassures the data users (e.g., coastal management agencies) that they can use the data to make informed decisions with confidence.

DATA PROPERTY AND OWNERSHIP

All raw data collected throughout the Seagrass-Watch program is the property of the individual/group/institution (*Principal*) who collected it, and Seagrass-Watch Ltd is custodian. When a Principal (*data collector*) submits data to Seagrass-Watch HQ, they do so under the proviso that Seagrass-Watch HQ can conduct a data quality assessment as part of the Seagrass-Watch program's QAQC protocols and that the validated data is available for condition and trend reporting at location, regional, state, national and global scales (e.g., State of the Environment). Copies of raw data are provided to third parties only when permission from the Principal is provided.

Ownership of data within the Seagrass-Watch program is determined by mutual agreement based on who is collecting the raw data, whether the data undergoes a quality assessment as part of Seagrass-Watch QAQC protocols and the funding sources that support the monitoring:

- **Raw Data** ownership (intellectual property rights) lies with the Principal (*data collector*). Seagrass-Watch Ltd is custodian of the Raw Data.
- **Validated Data** ownership (intellectual property rights) is shared between the Principal and Seagrass-Watch Ltd.

All data interpretation is conducted by Seagrass-Watch HQ. This ensures that the interpretation of data is consistent, unbiased and of scientific merit. Seagrass-Watch HQ also encourages peer review of published results.

Apart from the regional & state-wide report cards, the data has also been used for:

- understanding and responding to impacts from catchment runoff^[59, 60], coastal developments (e.g., marina constructions) and dredging proposals.
- Understanding natural levels of change^[61-63] and supporting marine habitat conservation (e.g., GSS Ramsar Wetland, Cooloola World Heritage area, and Great Sandy Marine Park).

Seagrass-Watch monitoring efforts are vital to assist with tracking global patterns in seagrass health, and assessing human impacts on seagrass meadows, which have the potential to destroy or degrade these coastal ecosystems and decrease their value as a natural resource. Responsive management based on adequate information will help to prevent any further significant areas and species being lost. To protect the valuable seagrass meadows along our coasts, the community, government and researchers have to work together.

THE GOALS OF THE PROGRAM ARE:

- *To educate the wider community on the importance of seagrass resources*
- *To raise awareness of coastal management issues*
- *To build the capacity of local stakeholders in the use of standardised scientific methodologies*
- *To conduct long-term monitoring of seagrass & coastal habitat condition*
- *To provide an early warning system of coastal environment changes for management*
- *To support conservation measures which ensure the long-term resilience of seagrass ecosystems.*

Notes:

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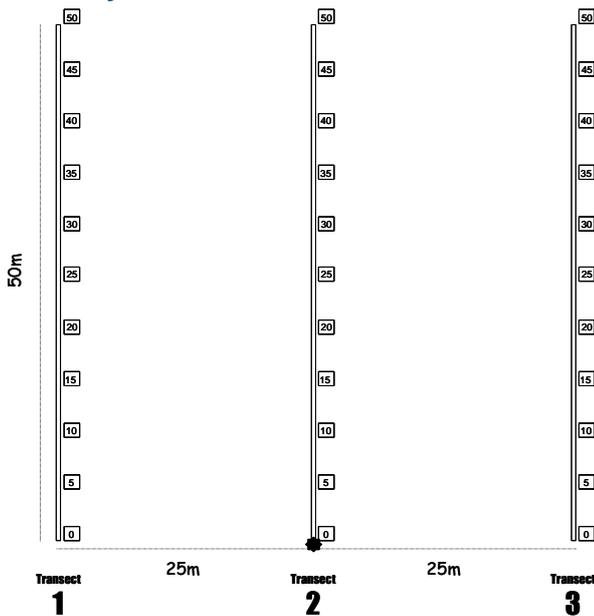
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Permanent-transect monitoring protocols

Source: McKenzie et al. 2003⁽⁴⁹⁾ (www.seagrasswatch.org/manuals/)

Site layout



Quadrat code = site + transect+quadrat

e.g. R01225 = Roebuck Bay, site 1, transect 2, 25m quadrat

Pre-monitoring preparation

Make a Timetable

Create a timetable of times of departure and arrival back, and what the objective of the day is and what is to be achieved on the day. Give a copy of this to all participants involved in advance so they can make their arrangements to get to the site on time. List on this timetable what the participants need to bring.

Have a Contact Person

Arrange to have a reliable contact person to raise the alert if you and the team are not back at a specified or reasonable time.

Safety

- Assess the risks before monitoring - check weather, tides, time of day, etc.
- Use your instincts - if you do not feel safe then abandon sampling.
- Do not put yourself or others at risk.
- Wear appropriate PPE clothing and footwear.
- Be sun-smart.
- Be aware of dangerous marine animals.
- Have a first aid kit on site or nearby
- Take a mobile phone or marine radio

Necessary equipment and materials

- 3x 50metre fibreglass measuring tapes
- 6x 50cm plastic tent pegs
- Compass
- 1x standard (50cm x 50cm) quadrat
- 3x monitoring datasheets
- Clipboard, pencils & 30 cm ruler
- Waterproof camera
- Quadrat photo labeller
- Percent cover standard sheets
- Seagrass identification sheets

Each sampling event

Within the site, lay out the three 50 metre transects parallel to each other, 25 m apart and perpendicular to shore (see site layout). Within each of the quadrats placed for sampling, complete the following steps:

Step 1. Take a Photograph of the quadrat

- Photographs are taken of **every quadrat** along each transect. Use a quadrat free of strings and place the photoquadrat labeller beside the quadrat and the tape measure, with the correct site code displayed.
- Take the photograph from an angle as **vertical** as possible, which includes the entire quadrat frame, quadrat labeller and tape measure. Fill the field of view as best as possible and avoid having any shadows or patches of reflection off any water in the field of view. Check the photo taken box on datasheet for quadrat.

Step 2. Describe sediment composition

- Dig your fingers into the top centimetre of the substrate and feel the texture. Describe the sediment by noting the grain size in order of dominance (e.g., Sand, Fine sand, Fine sand/Mud).

Step 3. Describe other features and ID/count of macrofauna

- Note and count (whole numbers - never use < or > symbols) any features which may be of interest (e.g. gastropods, hermit crabs, dugong excavating, turtle cropping, crab burrows, worm holes) within the comments column.
- Note features such as ripples across the sediment surface (indicates the level of sediment movement from wave action)
- If water covers half or more of the quadrat, measure depth in cm.

Step 4. Estimate seagrass percent cover

- Looking down on the quadrat from above, estimate the total percentage of the seabed (substrate) within the quadrat covered by seagrass leaves. Estimate the footprint/shadow provided by the seagrass shoots.
- Always use the percent cover photo standards (calibration sheets) as your guide, estimating cover as accurate as possible, e.g. 27%, 61%. Remember, the lower the cover, the more accurate the measures.
- If cover is below 3%, you can count the seagrass shoots and calculate percent cover using the rule of approx 1 shoot = 0.1%. Please note: this will be greater for shoots of larger sized species.

Step 5. Estimate seagrass species composition

- Identify the species of seagrass within the quadrat and determine the percent contribution of each species (always start with least abundant species, total composition must equal 100%).
- Use seagrass species identification keys provided and use more than 1 feature to identify each species.

Step 6. Measure seagrass canopy height

- Measure canopy height (in centimetres) of the dominant strap-leaf species, ignoring the tallest 20%.
- Measure from the sediment to the leaf tip of 3 shoots, entering all 3 measures onto datasheet.

Step 7. Estimate algae percent cover

- Looking down on the quadrat from above, estimate the total percentage of the seabed (substrate) within the quadrat covered by macroalgae (independent of seagrass cover)
- Macroalgae is **not attached** to seagrass leaves and may be attached to rocks, shells or may be drifting.

Step 8. Estimate epiphyte percent cover

- Epiphytes are algae **attached** to seagrass blades and often give the blade a furry appearance.
- First estimate how much of an average seagrass leaf surface is covered, and then how many of the leaves/shoots in the quadrat are covered. For example, if 20% of the blades are 50% covered by epiphytes, then quadrat epiphyte cover is 10%. Use the epiphyte matrix to assist you.
- Do not include epifauna with epiphytes. Epifauna are sessile animals attached to seagrass blades – record % cover of epifauna in the comments or an unused/blank column – do not add to epiphyte cover.

Step 9. Take a voucher seagrass specimen if required

- Place seagrass specimen in a labelled plastic bag with a little seawater and a waterproof label. Select a representative specimen of the species and ensure that you have all the plant parts including the rhizomes and roots. Collect plants with fruits and flowers structures if possible.

Step 10. Move to next quadrat

- Repeat steps 1 to 8 for the remaining 32 quadrats

Step 11. Monitoring seed banks (an indicator of meadow resilience)

- Using the seed corer, sample sediment to a depth of 10cm every 10m along five transects, 12.5m apart.
- Release each core into a sieve, wash away the sediment and count the number of seeds retained.

At completion of monitoring

Step 1. Before leaving the site

- Check data sheets are filled in fully.
- Remove equipment from site (e.g. non-permanent pegs)

Step 2. Wash & pack gear

- Rinse all tapes, pegs and quadrats with freshwater and let them dry. Do this after every day of monitoring.
- Review supplies for next sampling and request new materials if needed.
- Store gear in a safe and dry place for next sampling event.

Step 3. Press any voucher seagrass specimens if collected

- The voucher specimen should be pressed as soon as possible after collection. Do not refrigerate >2 days.

Step 3. Submit all data

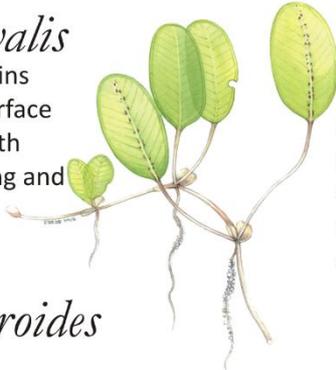
- Data can be entered into the MS-Excel file downloadable from www.seagrasswatch.org.
- Upload full resolution quadrat photos, high resolution scans of datasheets and data files to a file hosting service or similar.
- If required, mail original datasheets and herbarium sheets

Seagrass-Watch HQ
For postal or email address, see
<https://www.seagrasswatch.org/contact/>

Ho SEAGRASS SPECIES CODES

Ho *Halophila ovalis*

- 8 or more cross veins
- no hairs on leaf surface
- leaf margins smooth
- leaves 5-40mm long and 5-20mm wide



Hd

Halophila decipiens

- leaf margins finely serrated
- hairs on both sides of leaf blade
- leaf apex slightly pointed
- leaf 10–25mm long, 3–10mm wide
- 6-8 cross vein pairs



Ea

Enhalus acoroides

- very long (>30cm) ribbon-like leaves with inrolled leaf margins
- thick rhizome with long black bristles and cord-like roots



Th

Thalassia hemprichii

- ribbon-like, curved leaves 10-40cm long
- leaf tip rounded, slightly serrated
- short black tannin cells, 1-2mm long, in leaf blade
- thick rhizome with scars between shoots



Hu

Halodule uninervis

- trident leaf tip
- 1 central vein
- usually pale rhizome, with clean black leaf scars



Hp

Halodule pinifolia

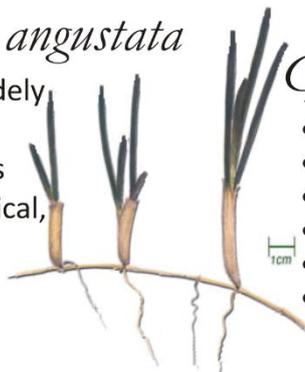
- rounded leaf tip
- 1 central vein
- usually pale rhizome, with clean black leaf scars



Ca

Cymodocea angustata

- leaf tapers toward tip, widely spaced serrations
- leaf <13 longitudinal veins
- leaf sheath slightly obconical, scars open
- one unbranched root per node



Cs

Cymodocea serrulata

- serrated leaf tip
- wide leaf blade (4-9mm wide)
- leaves 6-15cm long
- 13-17 longitudinal veins
- robust/strong rhizome
- triangular shaped sheath



Si

Syringodium isoetifolium

- narrow spaghetti-like leaves
- cylindrical in cross section, 1-2mm diameter
- leaves contain air cavities
- leaf tip tapers to a point
- leaves 7-30cm long
- fleshy white rhizomes



Hs

Halophila spinulosa

- leaves arranged in opposite pairs
- leaf margin serrated
- shoot 15-20cm height
- 10-20 pairs of leaves per shoot



SEAGRASS-WATCH MONITORING



ONE OF THESE SHEETS IS TO BE FILLED OUT FOR EACH TRANSECT YOU SURVEY

START of transect (GPS reading)

Latitude: Longitude:

OBSERVER: Beverly Citizen DATE: 17/2/21
 LOCATION: Burren Heads
 SITE code: BHT1 TRANSECT no.: 2
 START TIME: 1304 END TIME: 1340

Quadrat (metres from transect origin)	Sediment (eg. mud/sand/shell)	Comments (eg 1lx gastropods, 4x crab holes, dugong, feeding trails, herbarium specimen taken)	Seagrass coverage (%)	% Seagrass species composition			Canopy height (cm)	% Algae cover	% Epi- cover
				HO	HU	ZC			
1 (0m)	Sand	SCx3 DFTx1 HCx1	40	30	70	0	5417	5	33
2 (5m)	Fs/S	GASx2 Ray pt x2	33	50	50	0	61616	10	18
3 (10m)	CS	Hcx3	0			0	-	0	-
4 (15m)	m/s	CHx10	0			1cm	-	17	-
5 (20m)	m/s	Turtle cropping GASx3	18	5	90	5	71516	12	57
6 (25m)	m/s/sh	SCx3 mwx2	36	90	90	10	81616	2	95
7 (30m)	Fine Sand	CHx9 GWSx1	48	100			3cm	0	10
8 (35m)	CS/S	Nothing	0.7		100		2.5cm	0	36
9 (40m)	FS	HCx2	23	96	4		5.5, 5.6	5	38
10 (45m)	S/m	GWSx2	41	3	97		81817	3	90
11 (50m)	mud	CHx2 SCx1	16	3	7	90	71718	38	95

END of transect (GPS reading) Latitude: Longitude:
 FS = Fine Sand Sh = shell
 CS = Coarse Sand
 m = mud
 S = Sand
 SC = Sea Cucumber DFT = Dugong feeding trail
 HC = Hermit Crab
 GAS = Gastropod
 CH = Crab Hole
 mw = mud worm
 CW = Green worm

Making a herbarium press specimen

Herbaria are repositories of preserved and labelled plant specimens, arranged to allow easy access and archival storage. The specimens are typically in the form of herbarium sheets: pressed and dried plants that have been attached to a sheet of heavy paper together with a data label. A herbarium specimen is simple in form and low-tech in preparation, yet it preserves a wealth of valuable information. If properly stored, a herbarium specimen will last for centuries without much deterioration. Specimens document the variation in form and geographical range of species. Herbaria also document valuable historical collections, such as "type specimens", the original specimens on which a plant's Latin name is based. Many herbarium specimens record the existence of plants in habitats now developed and lost.

COLLECTION

Before collecting any seagrass specimens, ensure you have the appropriate permits. In Western Australia, seagrasses are conserved/protected as a fish habitat under the WA Fish Resources Management Act (FRMA) 1994, requiring a permit from the Department of Primary Industries and Regional Development (DPIRD) for their collection/destruction (visit dpiird.wa.gov.au). Once you have the FRMA permit or exemption permit approved, if the collections are to occur in a Marine Park or conservation area, a Regulation 61 flora taking licence from DBCA (Department of Biodiversity, Conservation and Attractions) is also required, as the plants will be protected under the Conservation and Land Management (CALM) Act 1984. A Reg 61 Licence allows collection of flora for non-commercial purposes, such as research, education, art and hobby, specimen lodgement (visit dbca.wa.gov.au).

In the field, collect a handful of representative seagrass shoots, including the leaves, rhizomes and roots. Keep in mind that it is not always possible to get a successful classification if you do not have particular parts such as flowers, fruits, seeds and roots, so try to select shoots which have these features. Ideally, collect plants with growing tips (apical meristems) as they contain higher concentrations of DNA which could aid genetic identification in the future.

Specimens should be pressed as soon as possible after collection. If it is more than 2 hours before you press the specimen, then you should refrigerate to prevent any decomposition. Do not refrigerate longer than 2 days, press the sample as soon as possible.

Pressing

Tools

First you will need some clean white cartridge-type paper (photocopy paper will suffice) and herbarium sheets (if available). You will also need forceps, scissors/scalpel, a dish of clean fresh water and a herbarium press. It is not difficult to build a home-made press, keeping in mind that what must be accomplished is to keep the specimens squeezed between layers of paper (newspapers or blotting paper) until they are totally devoid of the original content of water. The upper and lower parts of the press might be made of heavy cardboard or thick plywood or equivalent material. A more advanced kind of press might be built for an optimal drying of your plants. This press can be made with two wooden boards with screws and nuts placed at each corner: turning the nuts the two boards will come closer pushing together the paper with the plants. This kind of press can be built at home or bought in some art tools stores.

Preparation

Wash the seagrass specimen in clean fresh water and carefully remove any debris, epiphytes or sediment particles.

Arrangement

It is very important that the seagrass specimen be arranged so that you can immediately see all the main characters of that particular species; so do not focus only at the aesthetics of the mounted specimen. It is advisable to arrange specimens before being placed in the press as once dried, plant specimens can easily be broken if handled without care. The best manner to place the plants on the mounting sheets is to align them with the right side of the page (or diagonally if space is required) and to have the heaviest parts and specimens at the bottom. Leaves can be folded in larger specimens if a larger press is not available. It is better to leave an empty space at the borders of the mounting sheets; but you can either arrange your specimens (along with the label) in a regular way from page to page, or stagger the specimens at different positions on each sheet, so that each group of sheets will have a more equally distributed pressure.

Labels

Each specimen must have a label on its own sheet, which should include the taxonomic denomination (*at least family, genus and species*) along with information on the date and place of collection. The name of the collector and of the individual who did the determination should also be added. Use permanent and water resistant ink (black or blue) to write your labels; otherwise a pencil can be used (medium lead). Specimen labels should include:

- species name (*if known*)
- location & site code (*if applicable*)
- date collected
- latitude/longitude
- water depth
- % seagrass cover
- sediment type
- other seagrass species present
- name of collector and who identified the specimen
- comments -*such as presence of flowers/fruits or ecological notes*

Place the label on the lower right hand corner of the paper.

Drying

Place another clean sheet of paper over the specimen and place within several sheets of newspaper. As circulating air is very important to get your specimens dried in a short time, the assemblage of specimen/paper should be placed within two sheets of corrugated cardboard and then into a herbarium press. Corrugated cardboard ensures air can penetrate and speed up the drying process. If no corrugated cardboard is available, keep the filled press size small.

Once in the herbarium press, wind down the screws until tight (*do not over tighten*). If you do not have a press, the specimens can be pressed by putting some heavy object on top, i.e. bricks or large books. It is important that the plants are put under sufficient pressure; otherwise more time will be required to achieve a good desiccation, besides they could be damaged by dampness and moulds.



The press should be exposed to a gentle heat source, avoiding excessive heat that will "cook" the specimens. Sometimes it is possible to use the heat from the sun. In this case the presses should be small. If fire is the heat source, keep the press at a safe distance to prevent fire starting on the press.

Changing the paper is a very important step. In the first three or four days a paper change should take place every day, then you can leave more time between changes. If you neglect the change of paper the plants will take more time to lose their water content, besides they could be damaged if the paper stays wet for a few days. When changing the paper you must keep the specimens intact and ensure the label travels with the specimen. The minimum time required for complete drying ranges from two to four days or more. Once a specimen has become dry and stiff, it can be mounted and placed into the herbarium.

Mounting

Once the specimen is completely dry, you will need to mount it to herbarium sheets if available or a new clean white cartridge-type paper.

There are different ways to mount the specimens to the herbarium sheets, such as strapping, gluing, or pinning. We recommend the strapping method using removable adhesive tape (e.g. Magic Tape). The tape pulls off easily, leaves behind no messy residue, and can be pulled up and moved around. To fix the specimen to the mounting paper, lay small strips of tape across a few sturdy parts of the plant (e.g. either end of rhizome or a stem) at a minimal number of points. This method will allow a certain degree of movement for further examinations, but the specimen will not fall from the mounting paper

Herbaria

Once the specimen is mounted it can be stored in a dry place or lodged in Herbaria. If you do not have an herbarium nearby (usually located at a University or Government agency), you can submit pressed specimens to Seagrass-Watch HQ.

Alternatively, you can email a scanned image of the pressed specimen. Please ensure that the scanned image is no less than 600 dpi and includes the specimen and label. Scanned images can be sent to hq@seagrasswatch.org and will be lodged in the Seagrass-Watch Virtual Herbarium seagrasswatch.org/herbarium/.

The Virtual Herbarium is an electronic gateway to the collections of the Seagrass-Watch HQ herbaria. The goals of the Virtual Herbarium are to make specimen data available electronically for use in biodiversity research projects; to reduce transport of actual specimens for projects where digital representations will suffice for study; and to provide a source of reference information for Seagrass-Watch participants.

Understanding sediment

Seagrasses, especially structurally large species, affect coastal and reef water quality by trapping sediments and acting as a buffer between catchment inputs and reef communities. Seagrass meadows have the ability to modify the energy regimes of their environments, and help stabilise sediment by trapping and binding the sediment. However, the trapping ability of seagrass is in reality an equilibrium established between deposition/sedimentation and erosion/resuspension.

Studies have shown that sediment characteristics are important in determining seagrass growth, germination, survival, and distribution. As part of Seagrass-Watch, field descriptions of sediment type collected 0-2 cm below the sediment/water interface are determined by visual and tactile inspection of (wet) samples and constituents (primary descriptors) differentiated according to the Udden – Wentworth grade scale.

Grain size classes used, based on the Udden – Wentworth grade scale ^[64].

	Fine-medium Clay	0 – 0.002 mm
	Coarse Clay	0.0021 – 0.004 mm
Mud	Very Fine Silt	0.0041– 0.008 mm
	Fine Silt	0.0081 – 0.016 mm
	Medium Silt	0.0161 – 0.031 mm
	Coarse Silt	0.0311 – 0.063 mm
	<hr/>	
	Very Fine Sand	0.0631 – 0.125 mm
	Fine Sand	0.1251 – 0.250 mm
Sand	Medium Sand	0.2501 – 0.500 mm
	Coarse Sand	0.5001 – 1.000 mm
	Very Coarse Sand	1.0001 – 2.000 mm
<hr/>		
	Granules	2.0001 – 4.000 mm
Gravel	Pebbles and larger	>4.0001 mm

In Seagrass-Watch, the primary descriptors relate to the size of the sediment grains: gravel (>2000µm); coarse sand (>500 µm); sand (>250 µm); fine sand (>63 µm); and mud (<63 µm).

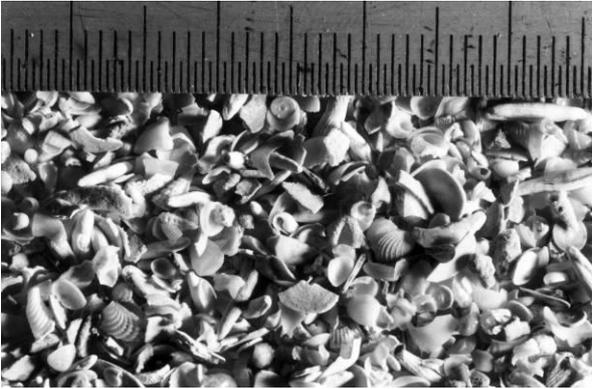
The sediment **Primary Descriptors** are written down from left to right in decreasing order of abundance: e.g. Mud/Sand is mud with sand, where mud is determined as the dominant constituent (by volume).

mud	<i>has a smooth and sticky texture.</i>
fine sand	<i>fairly smooth texture with some roughness just detectable. Not sticky in nature.</i>
sand	<i>rough grainy texture, particles clearly distinguishable.</i>
coarse sand	<i>coarse texture, particles loose.</i>
gravel	<i>very coarse texture, with some small stones.</i>

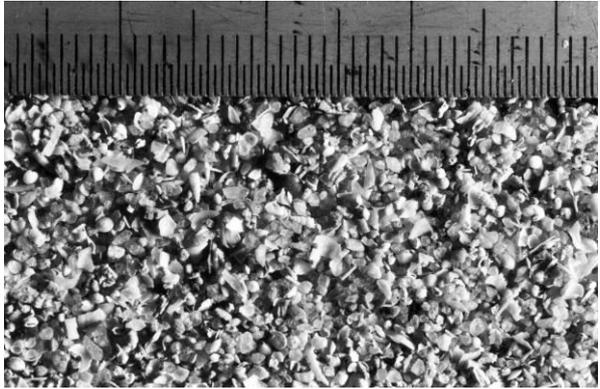
Sediment type **Modifiers** are also commonly used, however these are recorded in the comments section. Modifiers include: coral, shell grit, forams, diatoms, etc.

The visual/tactile estimation method used in Seagrass-Watch is a simple yet relatively accurate measure of the sediment grain size which can be used for quantitative assessments ^[65],

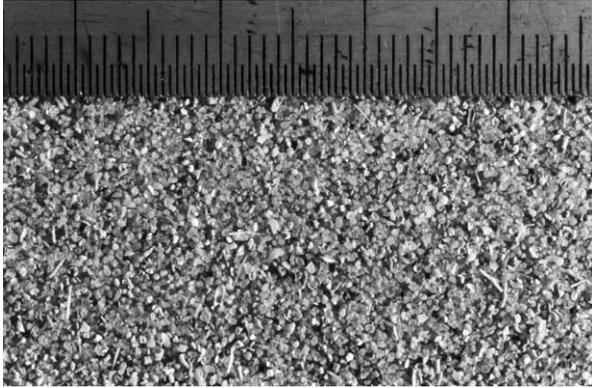
<https://bit.ly/3pTowW>.



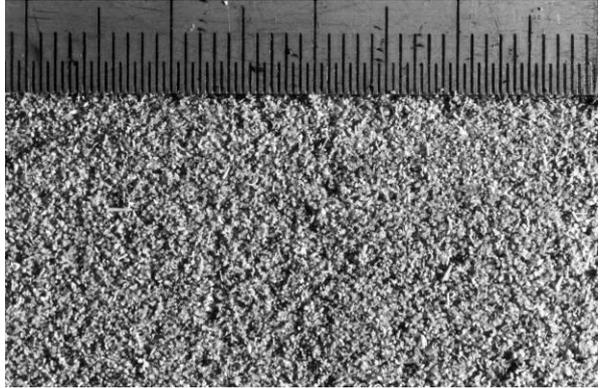
gravel (>2mm)



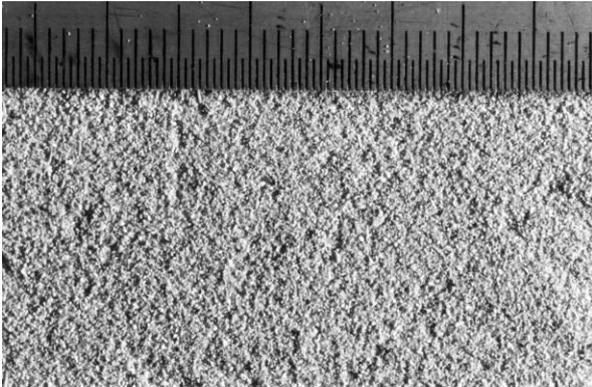
very coarse sand (1 - 2 mm)



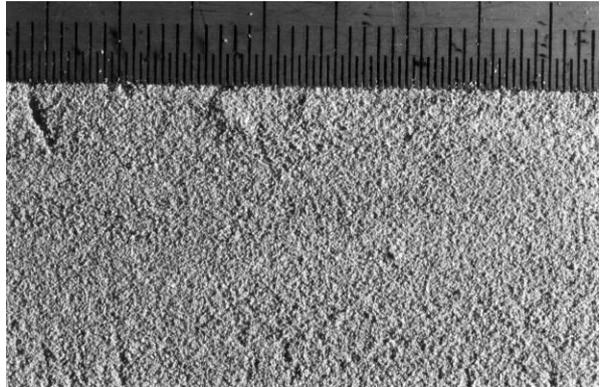
coarse sand (0.5 - 1 mm)



medium sand (0.25 - 0.5 mm)



fine sand (0.125 - 0.25 mm)



very fine sand (0.063 - 0.125mm)

Notes:

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Seagrass conservation

Threats to seagrass habitats

Destruction or loss of seagrasses have been reported from most parts of the world, often from natural causes, e.g., high energy storms. However, destruction commonly has resulted from human activities, e.g., as a consequence of eutrophication or land clamation and changes in land use. Increases in dredging and landfill, construction on the shoreline, commercial overexploitation of coastal resources, and recreational boating activities along with anthropogenic nutrient and sediment loading has dramatically reduced seagrass distribution in some parts of the world. Anthropogenic impacts on seagrass meadows continue to destroy or degrade coastal ecosystems and decrease the function and value of seagrass meadows including their contribution to fisheries. It is possible global climate change will have a major impact. Efforts are being made toward rehabilitation of seagrass habitat in some parts of the world: transplantation, improvement of water quality, restrictions on boating activity, fishing and aquaculture, and protection of existing habitat through law and environmental policy.

Management

Seagrasses do not exist in nature as a separate ecological component from other marine plants and are often closely linked to other community types. In the tropics the associations are likely to be complex interactions with mangrove communities and coral reef systems. In temperate waters, algae beds, salt marshes, bivalve reefs, and epiphytic plant communities are closely associated with areas of seagrass. Many management actions to protect seagrasses have their genesis in the protection of wider ecological systems or are designed to protect the overall biodiversity of the marine environment.

Seagrasses are also food for several marine mammal species and turtles, some of which (such as the dugong (*Dugong dugon*) and green turtle (*Chelonia mydas*)) are listed as threatened or vulnerable to extinction in the IUCN Red List (www.iucnredlist.org). Seagrasses are habitat for juvenile fish and crustaceans that in many parts of the world form the basis of economically valuable subsistence and/or commercial fisheries. The need to manage fisheries in a sustainable way has itself become a motivating factor for the protection of seagrasses.

Methods of direct protection range from legislative instruments and associated legal sanctions through to education ^[66]. These can be separated into three approaches: a proscriptive legal approach; a non-proscriptive broad based approach ranging from planning processes to education; and a reactive approach designed to respond to a specific issue such as a development proposal. These may overlap and be used simultaneously in many cases. It is these three approaches that Seagrass-Watch supports for the protection/conservation of seagrass.

Reactive (on-ground)

Reactive processes generally occur in response to a perceived operational threat such as a coastal development proposal ^[66]. Reactive processes can include port contingency planning, risk management plans and environmental impact assessments.

Prescriptive (informing, advising or directing)

Prescriptive management of seagrass issues focuses on relevant laws, regulations, and legal principles which can range from local laws to a Presidential Decree, or Executive Order. Regulations can directly safeguard seagrasses or can

protect them indirectly by protecting habitat types (all aquatic vegetation) or by influencing a process, e.g., prevention of pollution ^[66].

In some locations, protection is often strongest at the village or community level. This may be by Government supported agreements or through local management marine area level. For example, sea country management protects seagrass through a combination of traditional knowledge, scientific monitoring, and collaborative management practices. This includes mapping and monitoring seagrass health, implementing water quality improvements, and engaging in restoration efforts. In these cases, successful enforcement is dependent on community support for the measure.

Non-prescriptive (planning & education)

Non-prescriptive methods of protecting seagrasses are usually part of planning processes and may have a strong extension/education focus ^[66]. Providing information is important as it enables individuals to voluntarily act in ways that reduce impacts to seagrasses. Non-prescriptive methods range from simple explanatory guides to complex industry codes of practice.

Coastal management decision making is complex, and much of the information on approaches and methods exists only in policy and legal documents that are not readily available. There may also be local or regional Government authorities having control over smaller jurisdictions with other regulations and policies that may apply. Many parts of South East Asia and the Pacific Island nations have complex issues of land ownership and coastal sea rights.

Approaches to protecting seagrass tend to be location specific or at least nation specific (there is no international legislation directly for seagrasses as such that we know of) and depend to a large extent on the tools available in law and in the cultural approach of the community. There is, however, a global acceptance through international conventions (Ramsar Convention; the Convention on Migratory Species of Wild Animals; and the Convention on Biodiversity) of the need for a set of standardised data/information on the location and values of seagrasses on which to base arguments for universal and more consistent seagrass protection.

Indigenous concepts of management of the sea differ significantly from the introduced Western view of the sea as common domain, open to all and managed by governments ^[67]. Unlike contemporary European systems of management, indigenous systems do not include jurisdictional boundaries between land and sea. Indigenous systems have a form of customary ownership of maritime areas that has been operating in place for thousands of years to protect and manage places and species that are of importance to their societies.

Marine resource management these days should, therefore, attempt to achieve the following interrelated objectives: a) monitor the wellbeing (e.g. distribution, health and sustainability) of culturally significant species and environments (e.g. dugong, marine turtles, fish, molluscs, seagrass *etc.*); and b) monitor the cultural values associated with these culturally significant species and environments ^[68].

To realize objective a) we believe the following also needs to be accomplished if the successful management of coastal seagrasses is to be achieved.

1. Important fish habitat is known and mapped,
2. Habitat monitoring is occurring,
3. Adjacent catchment/watershed impacts and other threats are managed,
4. Some level of public goodwill/support is present,
5. Legal powers exist that are robust to challenge,
6. There is effective enforcement and punishment if damage occurs.

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Useful web links

Seagrass-Watch Official Site www.seagrasswatch.org

SeagrassSpotter A conservation and education tool that could lead to new discoveries about one of the ocean's most under-appreciated habitats – seagrass. With SeagrassSpotter, ocean enthusiasts around the world can become citizen scientists who contribute to marine conservation with just a few taps of their phone. <https://seagrassspotter.org/>

Project Seagrass A marine conservation charity dedicated to ensuring that seagrass meadows are protected globally, for the biodiversity and people that depend on them. <https://www.projectseagrass.org/>

Dugong & Seagrass Research Toolkit Helps you refine your research questions and provide you with a list of recommended techniques and tools to answer them. Designed for use by marine natural resource managers and decision-makers and for dugong and seagrass researchers, the Toolkit will show you which techniques are the most effective and efficient for your team capacity, budget and timeline. <http://www.conservation.tools/>

World Seagrass Association A global network of scientists and coastal managers committed to research, protection and management of the world's seagrasses. <https://worldseagrass.org/>

Seagrass forum A global forum for the discussion of all aspects of seagrass biology and the ecology of seagrass ecosystems. Because of their complex nature, discussion on all aspects of seagrass ecosystems is encouraged, including: physiology, trophic ecology, taxonomy, pathology, geology and sedimentology, hydrodynamics, transplanting/restoration and human impacts. lists.murdoch.edu.au/mailman/listinfo/seagrass_forum

Integration and Application Network (IAN) A website by scientists to inspire, manage and produce timely syntheses and assessments on key environmental issues, with a special emphasis on Chesapeake Bay and its watershed. Includes lots of helpful communication products such as fact sheets, posters and a great image library. <https://ian.umces.edu/>

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Risk Assessment



Let someone else know where and for how long you will be sampling

Assess the risks before monitoring

Use your instincts - if you do not feel safe then abandon sampling.

Do not put yourself or others at risk.

Adult supervision is required if children are involved

Hazard	Risk	Control
Sun	Sunburn	<ul style="list-style-type: none"> • wear hat with good cover • use sunscreen (preferably 40+). • wear appropriate clothing (long sleeved shirt).
	Eye strain Dehydration	<ul style="list-style-type: none"> • sunglasses (preferably polarised lenses) • take a water bottle/drink (water) • take regular breaks to drink water
	Exposure	<ul style="list-style-type: none"> • wear proper clothing and footwear depending on the weather
Beware of holes, oysters, broken glass, etc.	Cuts & twisted ankles	<ul style="list-style-type: none"> • use common sense when walking to and from a site • don't stray from designated clear walking tracks on way to site • walk at own pace • watch where you step • wear proper footwear e.g., diving booties or old shoes with tough sole and good grip. • have a first aid kit on site or nearby and re-acquaint yourself with the treatment of marine stings (e.g., jellyfish, stonefish)
Be aware of dangerous marine animals. (e.g. snakes, stonefish, cone shells, sting-ray, crocodiles, mosquitos etc)	Marine stings	<ul style="list-style-type: none"> • be on the lookout and avoid contact with any dangerous animal • wear proper footwear depending e.g., diving booties or old shoes with tough sole and good grip.
	Bites	<ul style="list-style-type: none"> • have a first aid kit on site or nearby and re-acquaint yourself with the treatment of marine stings (e.g., jellyfish, stonefish) • wear appropriate clothing (long sleeved shirt) and/or apply Insect repellent which is available
	Attacks	<ul style="list-style-type: none"> • conduct sampling when site is fully exposed • if crocodiles occur in your area, check with local Parks & Wildlife before conducting sampling (preferably the day prior) • if sampling at night, each participant to have adequate personal light (torch) • have a dedicated observer to check for crocodiles • if walking, do not venture into water of poor clarity deeper than ankles
Deep mud	Stranded/stuck	<ul style="list-style-type: none"> • communication device (i.e. mobile phone working in area or marine radio)
	Exhaustion	<ul style="list-style-type: none"> • do not over exert yourself - move at your own pace
	Bacterial infection	<ul style="list-style-type: none"> • wash hands and feet carefully upon return
Tide & Weather	Stranded/stuck	<ul style="list-style-type: none"> • check weather, tides, time of day, etc. and avoid extreme weather conditions • ensure appropriate time is available to conduct sampling • ensure suitable tides • communication device (i.e. mobile phone working in area or marine radio)
Other beach/water users	Verbal or physical abuse	<ul style="list-style-type: none"> • do not approach if other users acting suspiciously • be courteous to other users • act professionally so as not to arouse suspicion • ensure monitoring sign clearly displayed • if you feel uncomfortable or in any way unsafe, abandon sampling and leave the area.
	Risks to Third Parties/General Public:	<ul style="list-style-type: none"> • ensure that all monitoring equipment is stored safely or gathered together on site when not in use
Equipment (eg, clip-boards, tapes, pegs etc)	Scratches	<ul style="list-style-type: none"> • handle equipment with care and use it appropriately according to the task.
Postural Compromise (eg, lifting and carrying equipment, bending and reaching while monitoring)	Sore back	<ul style="list-style-type: none"> • use correct techniques (bending the knees). • work at your own pace. • ensure equipment is evenly distributed among the buckets.
Seed coring (digging, sieving sediment)	Scratches	<ul style="list-style-type: none"> • look where placing hands. • use equipment appropriately
General Health	special needs (heart condition, diabetes, etc)	<ul style="list-style-type: none"> • ensure fitness via verbal enquiry • ensure you have notified the co-ordinator of pre-medical conditions. • if you are uncertain of a particular task, please do not attempt to do it.

SEAGRASS-WATCH SERVICES

Research, Educate, Collaborate

01



Mapping

Seagrass-Watch can assist you in effectively planning, mapping and producing detailed seagrass maps of your area of interest.



02



Monitoring

More than 25 countries participate in the Global Seagrass Observing Network. Seagrass monitoring is currently occurring over 445 sentinel sites and growing. Our Team can help you develop long-term monitoring strategies effectively.



03



Research

Seagrass-Watch has a strong scientific underpinning with an emphasis on consistent data collection, recording and reporting. Our team offers critical seagrass ecology research services, including monitoring, mapping and publishing.



04



Training

Our training builds the capacity and upskills participants to collect information critical for management and protection of important marine resources. This includes subtidal monitoring, transect-based monitoring and drone use.



The program encourages collaboration and partnerships between communities, scientists and environmental managers.



Global Seagrass Observing Network

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