Guidelines for the rapid assessment of seagrass habitats in the western Pacific

McKenzie, L.J.

Department of Primary Industries Queensland, Northern Fisheries Centre, PO Box 5396, Cairns Qld 4870

CRC Reef, PO Box 772, (level 6, Northtown on the mall, Flinders St), Townsville, QLD 4810

July 2003

First Published 2003

Disclaimer

Information contained in this publication is provided as general advice only. For application to specific circumstances, professional advice should be sought.

The Department of Primary Industries, Queensland has taken all reasonable steps to ensure the information contained in this publication is accurate at the time of publication. Readers should ensure that they make appropriate enquires to determine whether new information is available on the particular subject matter.

For bibliographic purposes, this document may be cited as

> *McKenzie, L.J. (2003) Draft guidelines for the rapid assessment of seagrass habitats in the western Pacific (QFS, NFC, Cairns) 43pp*

Produced by the Marine Plant Ecology Group, QDPI,
Northern Fisheries Centre, Cairns, 2003.

Enquires should be directed to:
Len McKenzie
Northern Fisheries Centre,
PO Box 5396
Cairns, QLD 4870 Australia
len.mckenzie@dpi.qld.gov.au

Table of Contents

Chapter 1.

Overview of Seagrass Mapping

Information on seagrass distribution is a necessary prerequisite to managing seagrass resources. To make informed management decisions, coastal managers need maps containing information on the characteristics of seagrass resources such as where species of seagrasses occur and in what proportions and quantities, how seagrasses respond to human induced changes, and whether damaged meadows can be repaired or rehabilitated. Additionally, coastal managers may also need to know where seagrasses might have occurred for the purposes of recovery, restoration and to allow for natural spatial dynamics.

Knowledge of the extent of natural changes in seagrass meadows is also important so that human impacts can be separated from normal background variation (Lee Long *et al.* 1996). Changes can occur in the location, areal extent, shape or depth of a meadow, but changes in biomass, species composition, growth and productivity, flora and fauna associated with the meadow, may also occur with, or without a distributional change (Lee Long *et al.* 1996).

Seagrass resources can be mapped using a range of approaches from *in situ* observation to remote sensing. The choice of technique is scale and site dependent, and may include a range of approaches. Earlier standards for seagrass mapping, e.g., Phillips and McRoy (1990) and Walker 1989, are being superseded as improvements in navigation and remote sensing technology and sampling design lead to more efficient and precise methods for mapping. Recent published descriptions of methods for mapping coastal seagrasses include English *et al.* (1994), Coles *et al.* (1995), Dobson *et al.* (1995), Kirkman (1996), Lee Long *et al.* (1996c), Short and Burdick (1996).

The need to map and monitor the meadows of seagrass over a range of spatial and temporal scales, is therefore of prime importance in assessing the status of coastal systems. The first step is to provide baseline maps that document the current extent, diversity and condition of the seagrasses. The next step is to establish monitoring programs designed to detect disturbance at an early stage, and to distinguish such disturbance from natural variation in the meadows (Kirkman 1996; Lee Long *et al.* 1996; Kendrick *et al.* 2000).

Chapter 2.

Pre-mapping considerations

The most important information that is required for management of seagrass resources is their *distribution*, i.e. a map. The following section provides a guide of how to plan and then map the seagrass resources in a region or locality.

When planning a mapping task, there are several issues that need to be considered.

2.1. Scale

The selection of an appropriate scale is critical for mapping. Mapping requires different approaches depending on whether survey area is relative to a region (tens of kilometres), locality (tens of metres to kilometres) or to a specific site (metres to tens of metres).

The next consideration is that scale includes aspects both of extent and resolution. In both broad and large scale approaches, the intensity of sampling will be low (low resolution), with a statistical sampling design that allows the results to be extrapolated from a few observations to the extent of the study area. For finer scale examinations of seagrass meadows, the sampling intensity required can be high with greater precision (high resolution).

Scale also influences what is possible with a limited set of financial and human resources. The financial, technical, and human resources available to conduct the study is also a consideration.

2.2. Accuracy

Determining the level of detail required when mapping an area also depends on the level of accuracy required for the final map product. Errors that can occur in the field directly influence the quality of the data. It is important to document these. GPS is a quick method for position fixing during mapping and reduces point errors to <3m in most cases. It is important for the observer to be as close as possible to the GPS aerial receiver to minimise position fix error.

2.3. Choosing a Survey/Mapping strategy

The selection of a mapping scale represents a compromise between two components. One is the maximum amount of detail required to capture the necessary information about a resource. The other is the logistical resource available to capture that level of detail over a given area.

To map the extent of seagrass meadows requires methods that are used on terrestrial vegetation with allowances for the difficulties of working through water. Some of these difficulties are:

- At a depth greater than 2-3 m mainly blue light penetrates.
- All light is attenuated to different degrees through water.
- Light is refracted through water.
- For ground truthing, there are difficulties in working underwater, and
- Sun reflection and angle must be taken into account

The mapping of seagrass areas generally involves at some stage the interpretation of remotely sensed data, whether from an aircraft or satellite, and then interpreting the images onto hardcopy or computer, coupled with field (proximal/*in situ*) assessment to provide "ground truth".

The remote sensing of seagrasses and their related environments is based on the principle that a remote sensor can "see" the substrate and the vegatation growing on or in that substrate. A remote sensing instrument measures light from the sun after it has passed through the atmosphere, interacted with the target, and has been reflected back through the atmosphere to where it is measures by a sensor mounted on an aircraft or a satellite. Whether a benthic feature such as seagrass can actually be discriminated depends on the spectral optical depth of the water column, on the brightness and density of the seagrass and the spectral contrast between it and the substrate, as well as on the spectral, spatial and radiometric sensitivity of the remote sensing instrument. As the remote sensing image usually covers a much larger area than the fieldwork, extrapolation is performed using a variety of either subjective or statistically developed techniques. Unfortunately, there is no guarantee that extrapolations are valid.

The most traditional remote sensing technique is aerial photographs. Visual interpretation of air photographs can be time consuming and require specialist knowledge of the species, their habitat preferences and the area being mapped. Often, aerial photographs are used as only as basemaps onto which seagrass meadows can be mapped to provide a more superior visualisation of the area as apposed to simple line/contour maps.

Assessements from aerial techniques are performed by experienced seagrass experts, where as sophisticated digital multi- or hyperspectral remote sensing requires a combination of mathematical, software, hardware, physics and biogeochemistry skills. Such resources can be beyond the means of most western Pacific agencies.

Mapping seagrass resources using remote techniques however is beyond scope of this guide. If you are interested in remote sensing techniques, for a more thorough discussion of mapping from satellite and airborne scanners and an explanation of the various uses for mapping at different scales, it is recommended you consult publications by Kirkman (1996) and McKenzie et al (2001)

It is recommend that aerial photos be used as one of a number of tools available to assist the mapping process. Other tools should include proximal/in situ observation (ground truthing, diver/video observations) and GIS to determine the location and extent and coverage pattern of seagrass meadows. McKenzie et al (2001) provided a decision tree to facilitate the formulation of a survey/mapping strategy.

Table 2.1. A decision tree. The data capture methods used to map the distribution of seagrass meadows vary according to the information required and the spatial extent.
From McKenzie et al. 2001.

What is the size of the region or locality to be mapped?

Less than 1 hectare	1
1 hectare to 1 km^2	2
1km^2 to 100 km^2	3
greater than 100 km^2	4

1. Fine/Micro-scale (Scale 1:100 1cm = 1m)

Intertidal	aerial photos, *in situ* observer
Shallow subtidal (<10m)	*in situ* diver, benthic grab
Deepwater (>10m)	SCUBA, real time towed video camera

2. Meso-scale (Scale 1:10,000 1cm = 100m)

Intertidal	aerial photos, in situ observer, digital multispectral video
Shallow subtidal (<10m)	in situ diver, benthic grab
Deepwater (>10m)	SCUBA, real time towed video camera

3. Macro-scale (Scale 1:250,000 1cm = 250 m)

Intertidal	aerial photos, satellite
Shallow subtidal (<10m)	satellite & real time towed video camera
Deepwater (>10m)	real time towed video camera

4. Broad-scale (Scale 1:1,000,000 1cm = 10 km)

Intertidal	satellite, aerial photography
Shallow subtidal (<10m)	satellite, aerial photography & real time towed video camera
Deepwater (>10m)	real time towed video camera

Generally, an area can be mapped from a field survey using a grid pattern or a combination of transects and spots. When mapping a region of relatively homogenous coastline between 10 and 100 km long, it is recommended that transects should be no further than 500-1000 m apart. For regions between 1 and 10 km, it is recommended to use transects 100-500 m apart and for localities less than 1 km, 50-100 m apart is recommended. This however may change depending on the complexity of the regional coastline, i.e., more complex, then more transects required.

To assist with choosing a mapping strategy, it is a good idea to conduct a reconnaissance survey. An initial visual (reconnaissance) survey of the region/area will give you an idea as to the amount of variation or patchiness there is within the seagrass meadow. This will influence how to space your ground truthing points.

Reconnaissance surveys can be done in the field (using a boat or aircraft) or simply using aerial photographs and marine charts. This pre-mapping activity will help give more accurate information regarding the location and general extent of seagrass meadows to be mapped.

When mapping, ground truthing observations need to be taken at regular intervals (usually 50 to 100m apart). The location of each observation is referred to a point, and the intervals they are taken at may vary depending on the topography.

When ground truthing a point, there are a variety of techniques that can be used depending on resources available and water depth (free dives, grabs, remote video, *etc*). First the position of a point must be recorded, preferably using a GPS. A point can vary in size depending on the extent of the region being mapped. In most cases a point can be defined as an area encompassing a 5m radius. Although only one observation (sample) is necessary at a ground truth point, replicate samples spread within the point (possible 3 observations) to ensure the point is well represented is recommended.

Observations recorded at a point should ideally include some measure of abundance and species composition. Also record the depth of each point and other characteristics such as a description of the sediment type, or distance from other habitats (reefs or mangroves).

Chapter 3.

Field survey of seagrass meadows

3.1. Introduction

The objective of the field survey is to determine the edges/boundaries of any seagrass meadow and record information on species present, % cover, sediment type, and depth (if subtidal). Field surveys are also essential if using remote methods like aerial photographs to evaluate image signatures observed, or examine areas where the imagery does not provide information (e.g., such as in areas of heavy turbidity), and produce reference information for later accuracy assessment.

There are a number of methods for ground truthing, including underwater towing, bounce free-dives, benthic grabs and bathyscopes (Kirkman 1990). The type of method is also dependent on the type of environment.

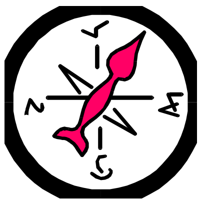
Regardless of method, the first and most important parameter to measure is position. This can be done relatively easily today by using a GPS.

3.2. Determining geographic position

- Geographic position is determined usingusing a GPS or compass. If using a hand-held compass to determine the position, use at least 3 permanent landmarks or markers as reference points. Record the compass bearings and mark the reference markers on the map. Roughly mark the point on the chart and assign it a code.

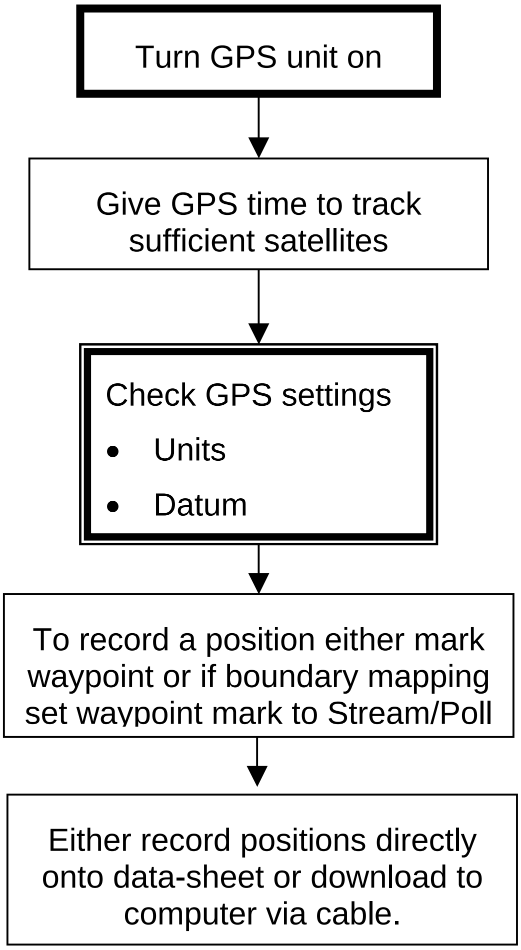
3.2.1. Using a compass

- Hold the compass in front of you at chest height and level to allow the needle to travel freely.
- Turn to the direction for which you want to take a bearing.
- Allow the needle to stabilise.
- Move the bezel (wheel) on the compass until the bezel arrow is over the needle and pointing to zero degrees, indicating north.



- Your bearing is the intersection of the bezel and the red arrow on the base plate.
- Record the bearing on your data sheet, e.g., 80°.

3.2.2. Using a GPS



Trouble shooting & hints

- When position fixing it is important to give the GPS antenna a clear signal of the sky. A GPS needs to receive signals from a number of satellites (usually more the 4) to take an accurate fix. Be aware that when using a GPS amongst high terrain, signals from some the satellites may be blocked or unclear.
- It is important to give the GPS sufficient time to position fix. If you are moving when the position is fixed, it may add error. The less movement, the greater the accuracy. Give the GPS at least 5-10 seconds to position fix.
- GPSs that are more accurate when moving, are those which have the ability to "stream" or "poll". These can be useful when boundary mapping. If the GPS does not "stream" then the operator will need to take a waypoint every few metres.
- Ensure the GPS units are known to the user, as it is often common to miss read decimal minutes as minutes and seconds (e.g., 14° 36.44' is not the same as 14° 36' 44").
- When using a GPS for the first time or in a new region (world zone), ensure the almanac is set correctly. Most GPSs today will detect that they are in a new region, and will automatically download the new almanac which may take approximately 15 minutes.
- When position fixing a subtidal ground truth point with a GPS, it is important for the observer to be as close as possible to the GPS antenna to minimise position fix error. This can be difficult in small boats under conditions of strong wind and current.
- Global Positioning Systems (GPS's) have the ability to record your location on the earths surface using different datums (different fixed starting points). Datums that record positions in longitudes/latitudes coordinates you could be familiar with include WGS (World Geodetic System) or AGD (Australian Geodetic Datum). You can choose which datum (AGD or WGS) your GPS screen shows. Both are equally correct to use. However, if you are trying to find coordinates from a map which are written down as AGD, and your GPS is following WGS – there could be up to 160m discrepancy. Check out and know your GPS - CONSISTENCY IS THE KEY.

3.3. Mapping an intertidal meadow

3.3.1. Necessary material and equipment

You will need:

- ❑ *Hand held compass or portable Geographic Positioning System (GPS) unit*
- ❑ *Standard 50 centimetre x 50 centimetre quadrat (preferably 5mm diameter stainless steel).*
- ❑ *Seagrass identification and percent cover sheets (see Appendix)*
- ❑ *Clipboard with pre-printed data sheets and pencils.*
- ❑ *Suitable field clothing & footware (e.g., hat, dive booties, etc)*
- ❑ *Aerial photographs or marine charts (if available) of the locality*
- ❑ *Plastic bags - for seagrass samples with waterproof labels*
- ❑ *Weatherproof camera (optional)*

3.3.2. General field procedure

First, define the extent of the study area. Check the tides to help you plan when is the easiest time to do the mapping, e.g., spring low is best for intertidal meadows. If mapping can be conducted at low tide when the seagrass meadow is exposed, the boundaries of meadows can be mapped by walking around the perimeter of each meadow with single position fixes recorded every 10-20metres depending on size of the area and time available. An important element of the mapping process is to find the inner (near to the beach) and outer (towards the open sea) edges of the seagrass meadow. To survey an area quickly, it is possible to work from a hovercraft or helicopter.

Alternatively, an area can be mapped using a grid pattern or a combination of transects and spots. When mapping a region of relatively homogenous coastline between 10 and 100 km long, it is recommend that transects should be no further than 500-1000 m apart. For regions between 1 and 10 km, it is recommend transects 100-500 m apart and for localities less than 1 km, it is recommend 50-100 m apart. This however may change depending on the complexity of the regional coastline, i.e., more complex, then more transects required. Transects do not have to be accurately measured using a tape.

Observations need to be taken at regular intervals (usually 50 to 100m) along transects. The location of each observation is referred to a point, and the intervals they are taken at may vary depending on the topography. Estimate distances between points, rather than using a tape measure. As the distribution of seagrass is depth dependent (depth limits vary between regions and localities due to water clarity), it is advise that representative points be sampled within each depth category (e.g., 0.5m to 10m intervals depending on topography). In some cases the sampling may need to be stratified (the number of points greater in some depth categories than others) when the probability of finding seagrass varies between strata.

3.3.3. Field survey point measures

Step 1. Geographic position

When arriving at a point, the first thing that should be recorded is the position of a point, preferably using a GPS. If a GPS is not available, use a handheld compass to determine the bearing, with reference to at least 3 permanent landmarks or marker established as reference points.

A point can vary in size depending on the extent of the region being mapped. In most cases a point can be defined as are area encompassing a 5m radius.

When ground truthing a point, there are a variety characteristics beside the geographic position that should be recorded.

Step 2. General information

When at a mapping point, the minimum information required on the mapping datasheet includes:

- Record the observer, location (e.g., name of bay), date and time.
- Record the water depth if the point is subtidal (this can be later converted to depth below mean sea level).

Step 3. Describe sediment composition

- Next, note the type of sediment
- To assess the sediment, dig your fingers into the top centimetre of the substrate and feel the texture. Remember that you are assessing the surface sediment so don't dig too deep!!
- Describe the sediment, by noting the grain size in order of dominance (e.g., Sand, Fine sand, Fine sand/Mud).
    - mud - has a smooth and sticky texture. Grain size is less than 63 µm
    - fine sand - fairly smooth texture with some roughness just detectable. Not sticky in nature. Grain size greater than 63 µm and less than 0.25mm
    - sand - rough grainy texture, particles clearly distinguishable. Grain size greater than 0.25mm and less than 0.5mm
    - coarse sand - coarse texture, particles loose. Grain size greater than 0.5mm and less than 1mm
    - gravel - very coarse texture, with some small stones. Grain size is greater than 1mm.
- If you find that there are also small shells mixed in with the substrate – you can make a note of this.

Step 4. Seagrass characteristics

Observations recorded at a point should ideally include some measure of seagrass abundance (at least % cover or a visual estimate of biomass) and species composition. Percentage seagrass cover is the easiest measure of abundance and observers should use a set of standard measures to ensure consistency.

An alternative measure of abundance is a visual estimate of biomass (Mellors 1991). In this method observers record an estimated rank of seagrass biomass and species composition in replicates of a 0.25 m^{-2} quadrat per point. Observers ranks are then regressed against a set of harvested ranks for which the above-ground dry biomass (g DW m^{-2}) is measured. The regression curve representing the calibration of each observer's ranks is then used to calculate above-ground biomass from all estimated ranks during the survey. For a detailed worked example, see Appendix IV.

Although only one observation (sample) is necessary at a ground truth point, it is recommend to take replicate samples spread within the point (possible 3 observations) to ensure the variation of point characteristics are well represented.

- At the mapping point, haphazardly toss a quadrat within an area of an approximate 5 metre radius around you.
- Within the quadrat complete the following:

Estimate seagrass percent cover

- Estimate the total cover of seagrass within the quadrat – use the percent cover photo standards as a guide (Appendix II)

Estimate seagrass species composition

- Identify the species of seagrass within the quadrat and determine the percent contribution of each species to the cover.
- Use seagrass species identification keys provided (Appendix III).

Replicate quadrats

- Haphazardly toss the quadrat another two times within the point area, recording the data for each of the quadrats.

Step 5. Estimate algae percent cover

- Estimate the percentage cover of algae in the quadrats. Algae are seaweeds that may cover or overlie the seagrass blades. Algal cover is recorded using the same visual technique used for seagrass cover.

Step 6. Describe other features and ID/count of macrofauna

- Also note any other features which may be of interest (e.g., dugong feeding trails, number of shellfish, sea cucumbers, sea urchins, evidence of turtle feeding). The detail of identifications and comments is at the discretion of the observer.

Step 7. Take a photograph

Photographs provide a permanent record and can ensure consistency between observers.

- Photographing every quadrat would be expensive, so instead it is recommend that you photograph a quadrat from every 10th mapping point (ie. 10% of the mapping points will have a quadrat that has been photographed) or if the meadow changes or if there is something unusual. It is best to photograph a quadrat from two angles:
  - from directly above and
  - from 45-60 degrees (navel height?)
- Make sure the photo details are noted on the data sheet so the photo can be matched with the quadrat details.
- Another option is to video the quadrats and analyse back at home or in the laboratory.

Step 8. Collect a voucher specimen

- Collect a voucher specimen of each seagrass species you encounter for the day (only 1 or 2 shoots which have the leaves, rhizomes and roots intact). Label each specimen clearly and put into a plastic bag.

3.3.4. Continue mapping

- Move on to the next mapping point and repeat the process. The number of mapping points you survey will be entirely up to you. If you need to accurately map an area, then intensive surveying (sample lots of mapping points) is recommend. It is also beneficial to try to get a good spread of mapping points over the area, as some of the changes in the seagrass meadow will not necessarily be obvious.

3.3.5. At completion of field mapping

Step 1. Clean & pack gear

- When you return from the field even though you will be tired it is worth checking through the information you have gathered to make sure there are no data gaps.

- Before returning the sampling kit, ensure it is clean, batteries removed from GPS, equipment rinsed with fresh water and let dry before long term storage,

Step 2. *Press any voucher seagrass specimens if collected*

- The voucher specimen should be pressed as soon as possible after collection. If it is going to be more than 2 hours before you press the sample then you should refrigerate to prevent any decomposition. Do not refrigerate longer than 2 days, press the sample as soon as possible.
- Wash seagrass sample in clean water and carefully remove any debris, epiphytes or sediment particles. Divide the sample into two complete specimens.
- Layout specimen on a clean sheet of white paper, spreading leaves and roots to make each part of the specimen distinct.
- Fill out specimen labels (2) with point information (including: location & point code, lat/long, depth, %cover, substrate, other species present, collector, comments) and place the label on lower right hand corner of paper.
- Place another clean sheet of paper over the specimen, and place within several sheets of newspaper.
- Place the assemblage of specimen/paper within two sheets of cardboard and then place into the press, winding down the screws until tight (do not over-tighten).
- Allow to dry in a dry/warm/dark place for a minimum of two weeks. For best results, replace the newspaper after 2-3 days.

3.4. Mapping shallow-subtidal (<10m) meadows

Check the tides to help you plan when is the easiest time to do the mapping, e.g., neap tides are best for subtidal meadows.

3.4.1. Necessary material and equipment

You will need:

- ❑ *Small boat, with outboard motor and safety equipment*
- ❑ *Hand held compass or portable Geographic Positioning System (GPS) unit*
- ❑ *Standard 50 centimetre x 50 centimetre quadrat (preferably 5mm diameter stainless steel).*
- ❑ *Seagrass identification and percent cover sheets (see Appendix)*
- ❑ *Clipboard with pre-printed data sheets and pencils.*
- ❑ *Suitable free-diving (snorkelling) equipment*

- ❑ *Depth measuring equipment (eg. depth sounder)*
- ❑ *Bathyscope (not essential)*
- ❑ *Benthic grab (e.g., van Veen)*
- ❑ *Aerial photographs or marine charts (if available) of the locality*
- ❑ *Plastic bags - for seagrass samples with waterproof labels*
- ❑ *Weatherproof camera (optional)*

3.4.2. General field procedure

If water clarity and seagrass abundance is high, then the boundaries of subtidal meadows can be mapped from a boat driven slowly (1-2 kts) around the perimeter of each meadow with single position fixes recorded every 20-30m. A bathyscope can be used to assist in identification of the presence of continuous or sparse meadows and the determination of deep edge meadows. Abundance or cover estimated can also be visually assessed.

If the water clarity is low, and/or the seagrass abundance low and highly variable, then a different strategy is employed. An area can be mapped ideally using a grid pattern or a combination of transects and spots, in the same manner as when mapping an intertidal meadow.

The most commonly used and simplest ground-truth method is in situ observation through free diving or snorkelling. Any direct observation of the bottom is limited by the amount of time a person can spend snorkelling or their field of view when in the water. The diver swims to the bottom, or as deep as is required to recognise the seagrass, presence or absence or species. If nothing is growing on the bottom the diver can turn back without having to go to the full depth of the bottom. Free-dives are also useful for obtaining a vegetation or sediment sample.

Where depth or poor visibility prohibits free-diver estimates, a small benthic grab or dredge is a useful tool for determining the bottom type. This dredge can be used in boats from small inflatables to ocean going research vessels. Benthic grabs can also be used to sample the sea floor and samples of sediment can also be obtained. Long *et al.* (1994) tested the use/efficacy of a modified "orange-peel" grab in different sediment and vegetation types, and reported acceptable results.

3.5. Mapping deep-water (>10m) meadows

3.5.1. Necessary material and equipment

You will need:

- ❑ *Large boat*
- ❑ *Underwater video camera (video recorder) and sled*
- ❑ *Geographic Positioning System (GPS) unit, hand held compass or RADAR*
- ❑ *Depth measuring equipment (eg. depth sounder)*
- ❑ *Benthic grab (e.g., van Veen)*
- ❑ *Clipboard with pre-printed data sheets and pencils.*
- ❑ *Plastic bags - for seagrass samples with waterproof labels*

3.5.2. General field procedure

A deep-water area can be mapped ideally using a grid pattern or a combination of transects and spots. The approach is very similar to mapping an intertidal or shallow subtidal meadows, however the points will be generally further apart and the replication at a point will be significantly reduced. When ground-truthing a point, there are a variety of techniques that can be used depending on resources available and water depth (SCUBA, benthic grab, remote camera/video, etc).

Self Contained Underwater Breathing Apparatus (SCUBA) can be used to conduct *in situ* assessment of deep-water points. This however, can be restrictive due to the number of points that can be assessed in a day, and the restrictions imposed by diving at depth. Safety should be foremost when conducting *in situ* assessment using SCUBA, paying particular attention to tidal regimes, turbidity, sea-state, dangerous marine animals and other human activities and impacts. Local knowledge of the above factors should always be sought. It is strongly recommend that diving policies be developed by each organisation and national safety standards be met.

Due to the restrictions of working at depth, virtually all deep-water mapping is conducted remotely. One remote method uses active acoustic sensors that characterise the sea-floor by transmitting a pulse of sound energy downward into the water column and then collecting the return echoes for analysis. This method requires specialised sensors and technical expertise to interpret, and is considered beyond the scope of this guide. For more information we recommended Lee Long et al. (1998) and Urick (1983).

The other common method is Real Time Towed Video Camera. Underwater video is a widely used tool for seagrass mapping (Coles et al. 2000, Lee Long et al. 1996a, Norris et al. 1997). The record provided by underwater video provides information on seagrass presence and abundance, the species of seagrass and the nature of the non-vegetated bottom. The system is useful in deepwater environments where SCUBA diving is restricted and in localities where dangerous marine animals are a significant threat.

Chapter 4.

Creating the map

The simplest way to map a seagrass meadow is to draw the boundaries on a paper marine chart from the GPS positions of the ground truth points. The problem with this type of mapping however is that the final map is in a format that does not allow manipulation and transformation. A paper map is permanent, which makes it difficult for future seagrass mapping studies to be compared, queried and analysed. If resources are available, it is recommend that the data be transferred to a digital format and a Geographic Information System (GIS) be used.

4.1. Geographic Information Systems (GIS)

GIS are software systems of highly accurate digital maps that can be overlaid to reveal relationships that might not otherwise be detected on traditional paper maps. Digitally-stored cartographic databases can be altered much quicker than hard copies and shared data can be standardised. The key element of a GIS is the separation of differing data sets into thematic layers. GIS software provides the functions and tools needed to store, analyse, and display geographic information.

Two of the most common GIS packages are ArcInfo® (including ArcView®) and MapInfo®. Mapping seagrass meadows with a GIS can help to identify emergent patterns or relationships in geographically referenced data. For further reading on the application of GIS to aquatic botany, see Lehmann and Lachavanne (1997).

4.2. Creating the basemap and importing captured data

A basemap is the spatial framework by which all other information is referenced. Basemaps are generally boundary files which are fundamental building blocks for any mapping system. For example, basemaps may be coastlines or property tenure boundaries. Basemaps are constructed from georeferenced features on plans or remote images. Sometimes basemaps can be sourced from government planning agencies or private contractors who specialise in planning.

If no basemaps are available or are difficult to access (e.g., limited funds), an aerial photo or paper topographic chart can be used. It is also advised to be aware of copyright restrictions and possible infringements.

The first task is to scan the aerial photographs (or charts) typically using a flat-bed scanner (a resolution of 300 dpi is usually sufficient) to produce a digital raster image. Once scanned, aerial photographs can be pasted together in most standard image/drawing packages to create larger images. Ensure the final image includes some topographic features spread over the entire image: such as major or minor roads, coastlines, buildings, jetties or piers. If the ground truthing included determining the position fixes of such topographic features, then these can be used as ground control points. Using ground control points, the digital images can now be fixed or rectified in space. Maximum spread of ground control points over an image will result in a more accurate rectification. This image now becomes the basemap for the GIS layers.

It is possible to map seagrass meadows directly from raster images using image analysis programs (e.g., Optimas® and ENVI®) or the user can trace (digitise) the boundary. Alternatively, the boundary can be determined by importing the ground truthed points and using contour mapping programs (e.g., Surfer® and S-Plus®). All these techniques require a combination of software, hardware, mathematical, physics and biogeochemistry skills which is beyond the scope of this guide.

An easier alternative is importing the seagrass position data (ground truthed points) from the database in which it has been entered and overlaying it on a basemap derived from a scanned and rectified aerial photograph. Once imported, it can be linked in overlapping layers to form a mosaic covering the whole region or locality.

4.3. Boundary Determination

Boundaries of meadows can be determined based on the positions of survey points and the presence of seagrass, coupled with depth contours and other information from aerial photograph interpretation. Errors that to be considered when interpreting GIS maps include those associated with digitising and rectifying the aerial photograph onto the basemap and those associated with GPS fixes for survey points.

In certain cases seagrass meadows form very distinct edges that remain consistent over many growing seasons. However, in other cases the seagrass tends to grade from dense continuous cover to zero cover over a continuum that includes small patches and shoots of decreasing density. Boundary edges in patchy beds derived from aerial imagery or direct observation are vulnerable to interpreter variation.

Sometimes, it can be assumed that light limits the deeper edge of seagrass beds and, in this case, bathymetric measures can map this boundary. The light limiting depth to most seagrasses is usually the Secchi disc depth (Dennison and Kirkman, 1996).

Given the uncertainty surrounding the determination of meadow edges it is suggested that each mapping effort include its own determination as to what it considers seagrass habitat based on the purpose of the mapping As long as the logic is clearly described and the results are repeatable, the data should be suitable for baseline characterisation or change detection. Using the GIS, meadow boundaries can be assigned a "quality" value based on the type and range of mapping information available for each area and determined by the distance between survey points and GPS position fixing error. These meadow boundary "errors" can be used to estimate the likely range of area for each meadow mapped (Lee Long *et al.* 1996b, McKenzie *et al.* 1996, 1998, 2001).

4.4. Map accuracy

The expected accuracy of the map product gives some level of confidence in using the data. Traditional methods can carry an inherently large capacity for mapping error because of the need for spatial interpolation between the data points. Inaccurate maps can also result in poor management decisions (Bruce et al. 1997). Mapping accuracy can be divided into the two general classes of thematic and spatial accuracy.

Thematic accuracy is a determination of the correctness of the features identified on the map product. This covers whether a patch of seagrass was correctly labelled as seagrass in the map or whether it was incorrectly labelled as algae or some other feature.

Spatial accuracy is a measure of the positional correctness of boundaries and features in a map product. For seagrass mapping, high levels of both thematic and spatial accuracy are critical. With the advent of GPS, spatial accuracy has greatly improved. However, care must be taken not to enlarge a map beyond its stated scale and try to make decisions from this artificially enlarged map. The need for rectification has been emphasised throughout this chapter and estimates of accuracy should be given with each mapping project. At sea, control points are difficult to find for rectification purposes so that spatial errors increase in magnitude the further from controls the point of interest is.

The accuracy of a map also needs to consider temporal effects. Rarely are maps generated at a time close to the date at which field accuracy assessment occurs. This can make assessing the thematic or spatial accuracy of a map more difficult. It is particularly noticeable when seagrass beds undergo large seasonal changes.

4.5. Data visualisation and output

If the data contains information of greater resolution than presence or absence, it can be used to in digital elevation modelling programs (such as Surfer® and S-plus®). Digital elevation models can be created with information such as seagrass abundance, water depth, etc.

Detailed data capture information can enable maps to be constructed from more features than simply presence and absence. Maps of different seagrass communities or habits for example, can be constructed by using information such as seagrass species composition, seagrass abundance, sediment type and other associated flora and fauna.

The final map can be presented on screen and in hard copy. The final maps need a clear legend describing the features highlighted, a scale, and a source. The maps are best accompanied by any caveats on data reliability, eg., changes in data quality during sampling because of physical changes such as sea state. This is important when data is loaded into a GIS that is used by managers. GIS data also requires a use-by date. Original (master) copies of final GIS maps are usually stored in two places: the source laboratory and a regional or central archive. Always attach a metadata file or script to each map, and include the correct form of citation to be used for acknowledging the data source.

4.6. Metadata

Metadata is information about the data and not to be confused with a summary of the data. Metadata describes data source, data reliability, conditions of use, limits on interpretation and use-by date, and usually includes the correct form of citation to be used for acknowledging the data source. It holds information about the quality of the data. The project metadata for all spatial data should have some statement about the accuracy of a map product. The Australian New Zealand Land Information Council has a very useful guide for metadata (http://www.anzlic.org.au/).

References

Bridges, KW, C McMillan. 1986. The distribution of seagrasses of Yap, Micronesia, with relation to tide conditions. Aquatic Botany 24: 403-407.

Bruce E, I Elliot, D Milton. 1997. Methods for assessing the thematic and positional accuracy of seagrass maps. Mar. Geod. 20:175-193.

Coles, RG, WJ Lee Long, LJ McKenzie. 1995. A Standard for Seagrass Resource Mapping and Monitoring in Australia. In: Australian Marine Date Collection and Management Guidelines Workshop, 5-6 December 1995. CSIRO Marine Laboratories, Hobart, Tasmania. URL: http://www.environment.gov.au/marine/coastal_atlas/documentation/standards/general/coles.html

Coles, RG, WJ Lee Long, BA Squire, LC Squire, JM Bibby. 1987. Distribution of seagrasses and associated juvenile commercial penaeid prawns in northeastern Queensland waters, Australaia. Aust. J. Mar. Freshwater Res. 38: 103-120.

Coles, RG, WJ Lee Long, LJ McKenzie, AJ Roelofs, G De'ath. 2000. Stratification of seagrasses in the Great Barrier Reef world heritage area, northeastern Australia, and the implications for management. Biol. Mar. Medit. 7: 345-348.

Coles R G, Lee Long W J, Watson R A and Derbyshire K J 1993 Distribution of seagrasses, and their fish and penaeid prawn communities, in Cairns Harbour, a tropical estuary, northern Queensland, Australia. *Aust. J. Mar. Freshwater Res.* 44: 193-210.

Congalton R. 1988. A comparison of sampling schemes used in generating error matrices for assessing the accuracy of maps generated from remotely sensed data. Photogram. Eng. Rem. Sens. 54: 593-600.

Dennison, WC, H Kirkman. 1996. Seagrass survival model. pp. 341-344. In: J Kuo, R Phillips, DI Walker, H Kirkman (eds) Seagrass Biology: Proceedings of an international workshop, Rottnest Island, Western Australia, 25-29 January 1996. Faculty of Science, The University of Western Australia.

Dobson, JE, EA Bright, RL Ferguson, DW Field, LL Wood, KD Haddad, H.III Iredale, JR Jensen, VV Klemas, RJ Orth, JP Thomas. 1995. NOAA Coastal Change Analysis Program (C-CAP) Guidance for Regional Implementation. NOAA Technical Report NMFS 123. 92 pp.

Dreyser, LE. 1993. Evaluation of remote sensing techniques for monitoring giant kelp populations. Hydrobiologia 260/261: 307-312

English, S, C Wilkinson, V Baker. 1994. Survey Manual for Tropical Marine Resources. ASEAN-Australia marine science project: living coastal resources. Australian Institute of Marine Science, Townsville. 368 pp.

Fortes, MD. 1998. Indo_West Pacific affinities of Philippine seagrasses. Bot. Mar. 31:237-242.

Fonseca M S and Fisher J S 1986 A comparison of canopy friction and sediment movement between four species of seagrass with reference to their ecology and restoration. *Mar. Ecol. Prog. Ser.* **29**:15-22.

Hyland, SJ, AJ Courtney, CT Butler. 1989. Distribution of seagrass in the Moreton Region from Coolangatta to Noosa. QDPI Information Series QI89010. Queensland Department of Primary Industries, Brisbane. 42 pp.

Jagtap, TG, AG Untawale, SN Inamdar. 1994. Study of mangove environment of Maharashtra coast using remote sensing data. Indian J. Mar. Sci. 23: 90-93.

Kelly, MG. 1980. Remote sensing of seagrass beds. pp. 69-85. In: RC Phillips, CP McRoy (eds). Handbook of Seagrass Biology: An Ecosystem Perspective. Garand STMP Press, New York.

Kennedy, M. 1996. The Global Positioning System and GIS: An introduction. Ann Arbor Press, Inc. Chelsea, Michigan. 267 pp.

Kirkman, H. 1990. Seagrass distribution and mapping. pp 19-25. In: RC Phillips, CP McRoy (eds). Seagrass research methods: Monographs on oceanographic methodology 9, UNESCO Paris.

Kirkman, H. 1996. Baseline and monitoring methods for seagrass meadows. J. Env. Mgt. 47: 191-201.

Lehmann, A, JB Lachavanne. (eds.) 1997. Special Issue: Geographic Information Systems and remote sensing in aquatic botany. Aquat. Bot. 58: 195-440.

Lee Long, WJ, JE Mellors, RG Coles. 1993. Seagrasses between Cape York and Hervey Bay, Queensland, Australia. Australian J. Mar. Freshw. Res. 44: 19-31.

Lee Long, WJ, RG Coles, LJ McKenzie. 1996a. Deepwater seagrasses in northeastern Australia - how deep, how meaningful? pp. 41-50. In: J. Kuo, RC Phillips, DI Walker, H Kirkman. (eds) Seagrass Biology: Proceedings of an International Workshop, Rottnest Island, Western Australia 25-29 January, 1996. Faculty of Sciences, The University of Western Australia.

Lee Long, WJ, LJ McKenzie, RG Coles. 1996b. Seagrass communities in the Shoalwater Bay region, Queensland - Spring (September) 1995 and Autumn (April) 1996. Queensland Department of Primary Industries Information Series QI96042. QDPI, Brisbane. 36 pp.

Lee Long, WJ, LJ McKenzie, MA Rasheed, RG Coles. 1996c. Monitoring seagrasses in tropical ports and harbours. pp. 345-50. In: J. Kuo, RC Phillips, DI Walker, H Kirkman. (eds.) Seagrass Biology: Proceedings of an International Workshop, Rottnest Island, Western Australia 25-29 January, 1996. Faculty of Sciences, The University of Western Australia.

Lee Long, WJ, RG Coles, LJ McKenzie. 2000. Issues for seagrass conservation management in Queensland. Pacific Conservation Biology 5: 321-328.

Lee Long, WJ, AJ Hundley, CA Roder, LJ McKenzie. 1998. Preliminary Evaluation of an Acoustic Technique for Mapping Tropical Seagrass Habitats. Great Barrier Reef Marine Park Authority Research Publication No. 52, 30 pp.

Lehmann, A, JM Jaquet, JB Lachavanne. 1997. A GIS approach of aquatic plant spatial hetergeneity in relation to sediment and depth gradients, Lake Geneva, Switzerland. Aquat. Bot. 58: 347-361.

Long, BG, TD Skewes, IR Poiner. 1994. An efficient method for estimating seagrass biomass. Aquat. Bot. 47: 277-292.

McKenzie L.J., Finkbeiner, M.A. and Kirkman, H. (2001) Methods for mapping seagrass distribution. Chapter 5 pp. 101-122 IN Short, F.T. and Coles, R.G. (eds) 2001. Global Seagrass Research Methods. Elsevier Science B.V., Amsterdam. 473pp.

McKenzie, LJ, MA Rasheed, WJ Lee Long, RG Coles. 1996. Port of Mourilyan Seagrass monitoring, Baseline Surveys - Summer (December) 1993 and Winter (July) 1994. EcoPorts Monograph Series No 2. PCQ, Brisbane. 51 pp.

McKenzie, LJ, WJ Lee Long, AJ Roelofs, CA Roder, RG Coles. 1998. Port of Mourilyan Seagrass Monitoring - First 4 Years. EcoPorts Monograph Series No 15. Ports Corporation of Queensland, Brisbane. 34 pp.

Norris, J, S Wyllie-Echeverria, T Mumford, A Bailey, T Turner. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquat. Bot. 58: 3-4.

NOS/NMFS Centre for Coastal Fisheries and Habitat Research. 1999. Progress Report Essential Fish Habitat: Deepwater seagrass beds of the west Florida Shelf-an overlooked essential fish habitat. Unpublished Internal report, Nov. 1999.

Phillips, RC, CP McRoy. 1990. Seagrass Research Methods. Monographs on oceanographic methodology 9. UNESCO, Paris. 210 pp.

Sheppard, C, K Matheson, J Bythell, P Murphy, C Blair-Meyers, B Blake. 1995. Habitat assessment in the Caribbean for management and conservation-use and assessment of aerial photography. Aquat. Cons. 5: 277-298.

Short F T 1987 Effects of sediment nutrients on seagrasses: Literature review and mesocosm experiment. *Aquat. Bot.* **27**: 41-57.

Short, F.T. and Coles, R.G. (eds) 2001. Global Seagrass Research Methods. Elsevier Science B.V., Amsterdam. 473pp.

Short, FT, CA Short. 1984. The seagrass filter: purification of coastal water. *In* VS Kennedy (ed.) The Estuary as a Filter. Academic Press. pp. 395-413.

Short, FT, S Wyllie-Echeverria. 1996. Natural and human-induced disturbance of seagrasses. Environmental Conservation 23(1): 17-27.

Short, FT, RG Coles, C Pergent-Martini. 2001. Global Seagrass Distribution. Chapter 1, pp. 5-30. *In:* FT Short, RG Coles (eds.) Global Seagrass Research Methods. Elsevier Science B.V., Amsterdam.

Short, FT, DM Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. Estuaries 19: 730-739.

Stoms, DM, FW Davis, CB Cogan. 1992. Sensitivity of wildlife habitat models to uncertainties in GIS data. Photogram. Eng.Rem. Sens. 58: 843-850.

Tsuda, RT, S Kamura. 1990. Comparative review on the floristics, phytogeography, seasonal aspects and assemblage patterns of the seagrass flora in Micronesia and the Ryukyu Islands, Galaxea 9:77-93.

Thomas, M, P Lavery, RG Coles. 1999. Monitoring and assessment of seagrass. pp. 237-268. In: A. Butler, P Jernakoff (eds.) Seagrass Strategic Review and Development of an R and D plan. A national Review for the Fisheries Research and Development Council. CSIRO Publishing, Collingwood, Australia.

Udy, JW, WC Dennison, WJ Lee Long, LJ McKenzie. 1999. Responses of seagrasses to nutrients in the Great Barrier Reef, Australia. Mar. Ecol. Prog. Ser. 185: 257-271.

Urick, RJ. 1983. Principles of Underwater Sound. 3rd Edn. Mcgraw-Hill, New York. 423 pp.

Virnstein, RW. 2000. Seagrass management in Indian River Lagoon, Florida: dealing with issues of scale. Pac. Cons. Biol. 5: 299-305.

Walker, DI. 1989. Methods for monitoring seagrass habitat. Victorian Institute of Marine Science Working paper No. 18, Melbourne. 21 pp.

Watson R A, Coles R G and Lee Long W J 1993 Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland, Australia. *Aust. J. Mar. Freshwater Res.* **44**: 211-21.

Appendix I

Data sheets

SEAGRASS MAPPING

Recorder: .... Vessel: .... Date: ....../..../.......

Site#: ....Location.......................................
Lat ....°.................**S** Long ....°.................**E**
Time............*hrs* Depth:.........*m* Observer.................
Sediment: .... Algae (%).............................
Algae (*spp./comp*) ....
Comments: ....
....

% cover	Species / % composition of cover

Site#: ....Location.......................................
Lat ....°.................**S** Long ....°.................**E**
Time............*hrs* Depth:.........*m* Observer.................
Sediment: .... Algae (%).............................
Algae (*spp./comp*) ....
Comments: ....
....

% cover	Species / % composition of cover

Site#: ....Location.......................................
Lat ....°.................**S** Long ....°.................**E**
Time............*hrs* Depth:.........*m* Observer.................
Sediment: .... Algae (%).............................
Algae (*spp./comp*) ....
Comments: ....
....

% cover	Species / % composition of cover

Site#: ....Location.......................................
Lat ....°.................**S** Long ....°.................**E**
Time............*hrs* Depth:.........*m* Observer.................
Sediment: .... Algae (%).............................
Algae (*spp./comp*) ....
Comments: ....
....

% cover	Species / % composition of cover

Site#: ....Location.......................................
Lat ....°.................**S** Long ....°.................**E**
Time............*hrs* Depth:.........*m* Observer.................
Sediment: .... Algae (%).............................
Algae (*spp./comp*) ....
Comments: ....
....

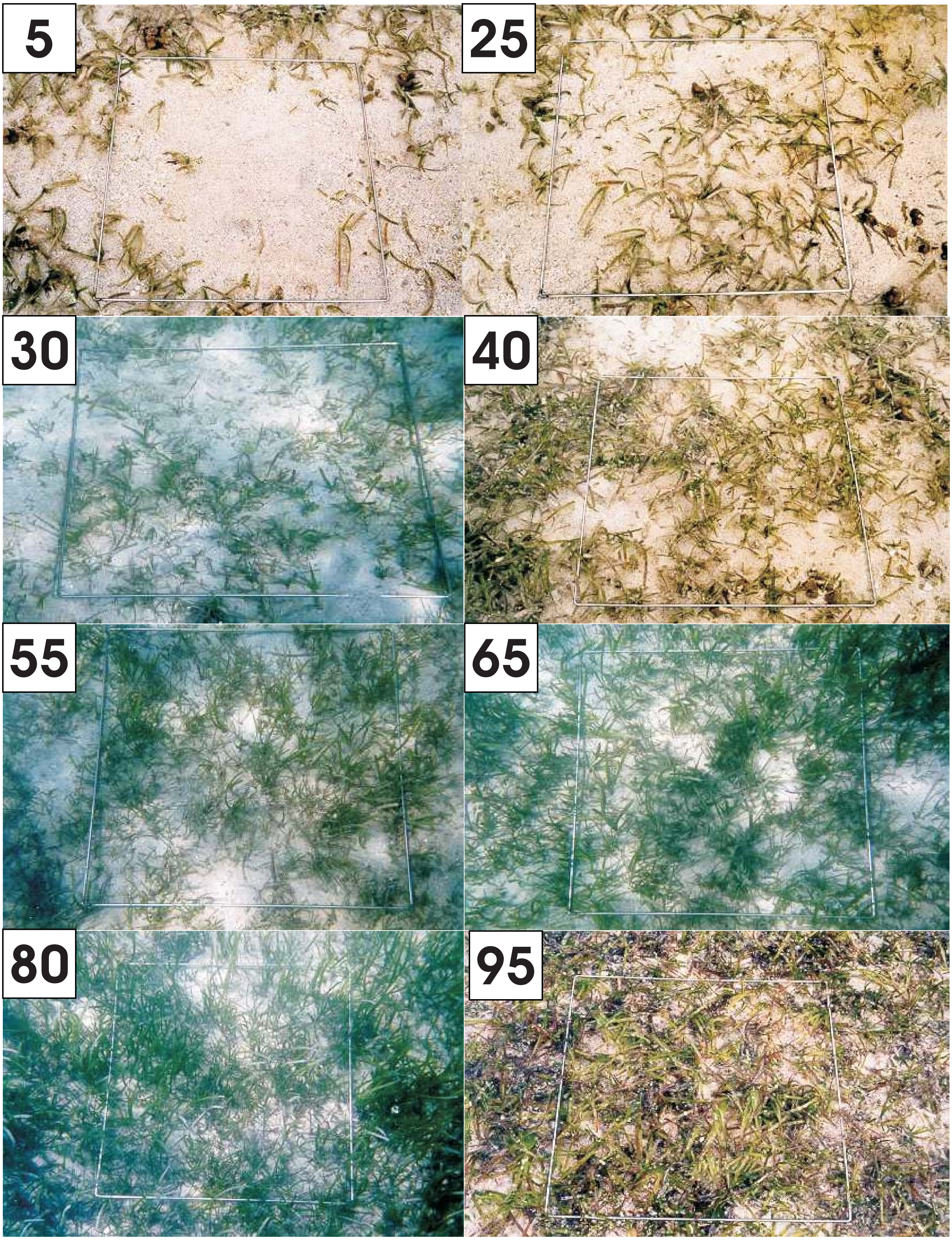
% cover	Species / % composition of cover

Site#: ....Location.......................................
Lat ....°.................**S** Long ....°.................**E**
Time............*hrs* Depth:.........*m* Observer.................
Sediment: .... Algae (%).............................
Algae (*spp./comp*) ....
Comments: ....
....

% cover	Species / % composition of cover

Appendix II
Seagrass percent cover standards

Seagrass Percentage Cover



Appendix III

Seagrass identification sheets & key

SEAGRASS SPECIES CODES

Cs *Cymodocea serrulata*

- Serrated leaf tip
- Wide leaf blade (5-9mm wide)
- Leaves 6-15cm long
- 13-17 longitudinal veins

Cr *Cymodocea rotundata*

- Rounded leaf tip
- Narrow leaf blade (2-4mm wide)
- Leaves 7-15 cm l o n g
- 9-15 longitudinal veins
- Well developed leaf sheath

Ea *Enhalus acoroides*

- Very long ribbon-like leaves with inrolled leaf margins
- Thick rhizome with long black bristles and cord-like roots
- Leaves 30-150 cm long

Th *Thalassia hemprichii*

- Short black bars of tannin cells on leaf
- Thick rhizome with scars between shoots
- "Sickle" shaped leaves
- Leaves 10-40 cm long

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

Hx

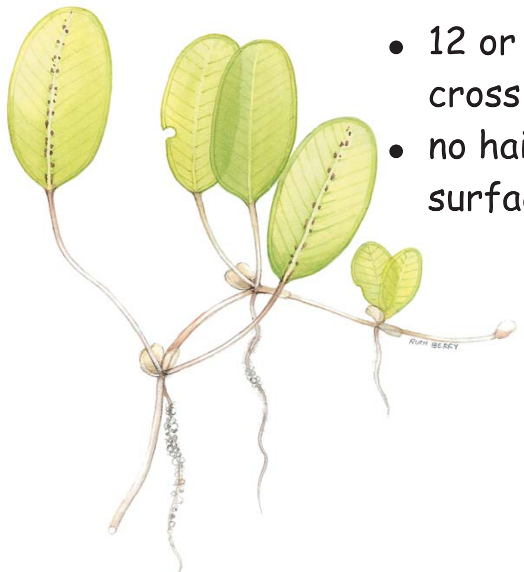
Hu or **Hp** species cannot be distinguished (i.e., not sure of the ID)

Compiled by the Marine Plant Ecology Group, Northern Fisheries Centre CAIRNS, AUSTRALIA July 2002

SEAGRASS SPECIES CODES

Ho

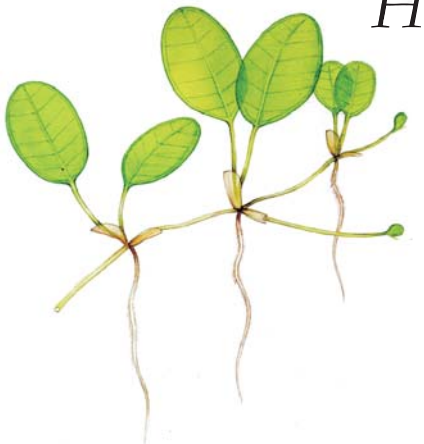
Halophila ovalis



- 12 or more cross veins
- no hairs on leaf surface

Hm

Halophila minor



- Less than 12 pairs of cross veins
- Small oval leaf blade

Hy

Ho or **Hm** species cannot be distinguished (i.e., not sure of the ID)

Si

Syringodium isoetifolium

- Cylindrical in cross section
- leaf tip tapers to a point
- Leaves 7-30cm long

Hd

Halophila decipiens

- Small oval leaf blade 1-2.5cm long
- 6-8 cross veins
- Leaf hairs on both sides

Tc

Thalassodendron ciliatum

- cluster of leaves on elongate shoot
- "Sickle" shaped leaves with serrated tip
- ligule present
- rhizome "woody"

Compiled by the Marine Plant Ecology Group, Northern Fisheries Centre CAIRNS, AUSTRALIA July 2002

Key for Sterile Material of Queensland Seagrasses

1. Leaves petiolate or compound, or strap-shaped without a ligule (i.e. a tongue-like structure
   at the junction of leaf blade and sheath) (Hydrocharitaceae) 2

   Leaves linear to strap-shaped and ligulate, neither petiolate nor compound 4
2. Leaves strap-shaped, neither compound nor petiolate 3

   Leaves compound or petiolate *Halophila*

   A. Plants with erect lateral shoots bearing a number of leaves B

      Plants without erect, lateral shoots, but one pair of petiolate leaves at each rhizome node C

   B. 10-20 pairs of distichous leaflets on an erect lateral shoot, blade with dense serrated margin *H. spinulosa*

      3 leaves per erect lateral shoot node; blade with sparse serrated margin *H. tricostata*

   C. Leaf blade longer than petiole; blade margin finely serrated, blade surface usually hairy *H. decipiens*

      Leaf blade normally shorter than petiole; blade margin entire, blade surface naked D

   D. Leaf blade oval to oblong, less than 5mm wide, cross veins up to ten pairs *H. minor*

      Leaf blade oval to elliptical, more than 5mm wide, cross veins more than 10 pairs *H. ovalis*
3. Rhizome more than 1cm in diameter, without scales, but covered with long black bristles
   (fibre strands); roots cord-like *Enhalus acoroides*

   Rhizome less than 0.5mm in diameter, covered with scales, but no fibrous bristles; root
   normal *Thalassia hemprichii*
4. Leaf blade more or less terete *Syringodium isoetifolium*

   Leaf blade linear, flat, not terete 5
5. Plants with elongated erect stem bearing terminal clustered leaves; rhizome stiff, woody; root
   stiff *Thalassodendron ciliatum*

   Plants with a short or no erect stem, bearing linear leaves; rhizome herbaceous; root fleshy 6
6. Rhizome bearing short erect stems; leaf sheath finally falling and leaving a clean scar, blade
   apex usually serrated or dentated; roots arising not in groups 7

   Rhizome without erect stems; leaf sheath persistant, remaining as fibrous strands covering rhizomes; blade apex truncate, neither serrated nor dentated; roots arising in 2 distinct
   groups of 4-8 at each node *Zostera capricornii*
7. Leaf blade with 3 veins *Halodule* 8

   Leaf blade with more than 7 veins *Cymodocea* 9
8. Leaf apex tridentate, with median tooth blunt and well developed lateral teeth *H. uninervis*

   Leaf apex more or less rounded, lateral teeth weak *H. pinifolia*
9. Leaf scars closed; blade apex rounded with no or weakly serated *C. rotundata*

   Leaf scars open; blade apex blunt with strongly to moderately serrated *C. serrulata*

(Prepared by J Kuo, UWA, Apr. 94)

Appendix IV

An alternative method for estimating seagrass abundance

A detailed worked example:

A group of 3 experienced observers were requested to map the distribution and abundance of seagrass meadows within a bay. The group had been requested by DPI to use the seagrass biomass ranking method of Mellors (1991). The survey was conducted over a 1 week period. At the beginning of the survey, the 3 observers gathered together to decide on the "*standard ranks*" for the study. As one of the observers had been to the area before, they went to a meadow which had both the greatest and lowest above-ground biomass that they expected to see within the bay. They placed a quadrat over an area they all agreed was the highest biomass (referred to as "**standard rank 5**") then another quadrat over an area they all considered was comparatively low biomass (referred to as "**standard rank 1**"). Then using this approach they found an area they all agreed was mid-way between the 5 and 1 (referred to as "**standard rank 3**"), and similarly set up standard ranks **2** and **4**. The standard ranks they set up were what they believed to be a "linear" relationship between the ranks and the above-ground seagrass biomass. They also took photos of the standard rank quadrats so they could refer back during the week of surveying if required.

The observers then proceeded to survey the bay. Each observer recorded their own visual estimate ranks independently of the other observers estimates, and ranks were each estimated to one decimal place. The observers surveyed 1100 points with 3 biomass estimates at each point (a point was agreed to be an area of 5 m radius). At the end of the survey the observers gathered at another meadow which had the highest and lowest biomasses, similar to those found during the survey. At this location the observers threw down 10 quadrats, spread over the range of biomasses observed. Each observer then independently ranked the above-ground biomass in each quadrat, in the same way as they did during the survey. After each observer had ranked each quadrat (being careful not to discuss and compare ranks with other observers), each quadrat was harvested and taken back to the laboratory for sorting.

In the laboratory, the above-ground biomass was separated from the below-ground biomass for each harvested calibration sample (the entire sample was separated, no subsampling). The above-ground component was then dried and weighed to 2 decimal places.

The observer's ranks of the calibration quadrats were then regressed against the actual above-ground biomass for the calibration quadrats (g dry wgt m^{-2}) (see Table 1).

Table 1. Biomass and respective observer ranks for each calibration quadrat.

Calibration Quadrat	Above ground Biomass (g dry wgt $0.25m^{-2}$)	Observer1	Observer2	Observer3
1	1.55	1.3	1.1	0.5
2	1.95	0.2	0.2	0.1
3	8.75	4.5	4.6	4.8
4	10.93	3.9	3.6	4.3
5	7.18	4.3	4.2	4.4
6	4.93	2.4	2.20	2.1
7	6.53	2.5	3.8	2.4
8	3.95	2.1	2.4	1.4
9	0.7	0.8	0.6	0.2
10	1.01	0.5	0.8	0.4
r^2		0.89	0.94	0.92

A regression is a mathematical equation that allows us to predict values of one dependent variable (in this case the actual above-ground biomass) from known values of one or more independent variables (ie. the observers ranks).

From a plot of each observers ranks against actual above-ground biomass (Figure 1), it appears that quadrat # 4 was an outlier (it was well outside the 95% confidence limits). This means that all the observers had ranked quadrat # 4 too low - possibly because many of the shoots may have been covered with sediment, making estimation difficult, *etc*). After quadrat # 4 was removed, a regression for each observer was calculated (Table 2).

Table 2. Regression of observers ranks

Observer	Regression
Observer1	*Biomass* = 1.7908 x *Rank* + 0.3601
Observer2	*Biomass* = 1.7227 x *Rank* + 0.2520
Observer3	*Biomass* = 1.5888 x *Rank* + 1.1836

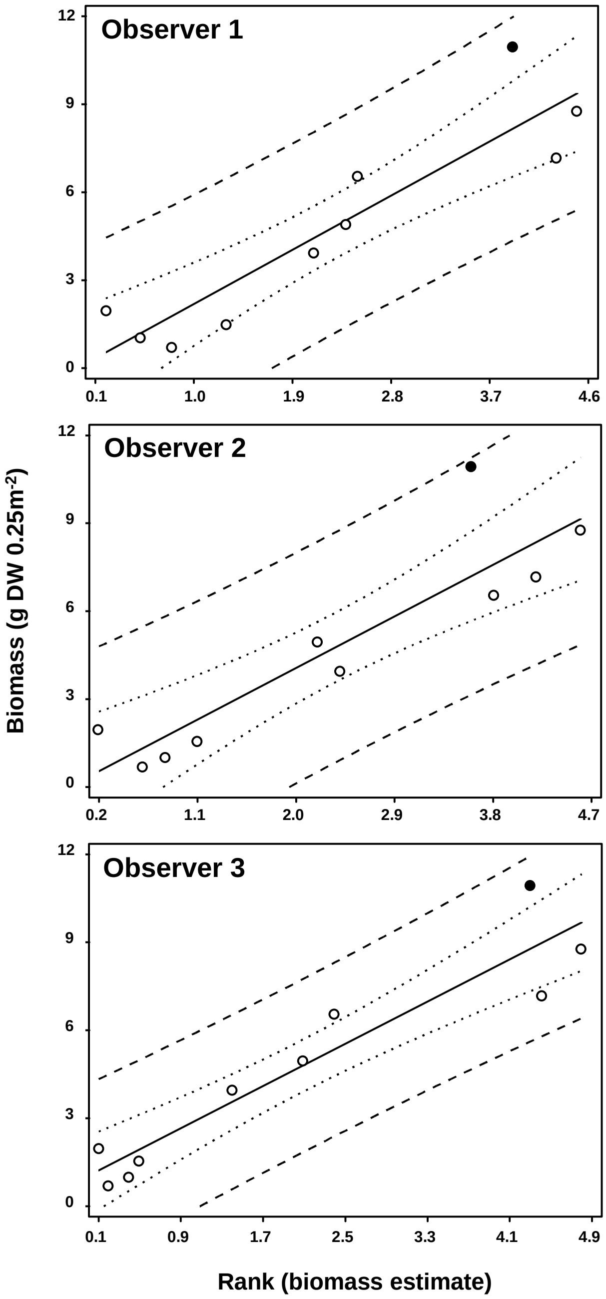


Figure 1. Linear regressions to explain the relationship between observer rank and above ground seagrass biomass. (filled circles signify outlier).

Using the regression for each observer, the field ranks estimated by each observer were converted to above-ground biomass (g dry wgt m-2). All calculations of seagrass abundance within the bay were then done using the g dry wgt m-2 values.

Further comments:

- Mellors (1991) *does not recommend using integers, or categories.* An observer can estimate to 1 decimal place without difficulty (I suppose if you rank on a scale from 0.1 to 5.0 you in fact have 50 categories??)

- There is no need for observers to agree in the field after the standard ranks have been established. You do not want a single regression for all observers pooled. This is because *observers will always differ* - there is no point observers practicing to get the same rank. What is important is that **each observer has their own regression**, and that **each observer rank the same way each time**. In fact it is best that observers do not compare ranks at all when surveying an area, as this causes *bias*.
- The only values you are concerned with in the end is the above-ground biomass (g dry wgt m^{-2}). The ranks only mean something to the particular observer who estimated them. **Only the converted biomass estimates should be used for analysis.**
- Re-calibration should be done for each sampling/survey event (*what an observer ranks this week may differ from what they rank next month*) and at different locations.
- There are instances when 2 sets of standard ranks have to be used within the same survey (1 set for low abundance meadows (eg. *Halophila*), 2^{nd} set for high abundance meadows (eg. *Zostera*)) as this allows greater accuracy for biomass estimates.

Appendix V

Selected publications

Chapter 5

Methods for mapping seagrass distribution

Len J. McKenzie, Mark A. Finkbeiner, Hugh Kirkman

5.1 Chapter Objective

To describe techniques for the mapping of intertidal and subtidal seagrass meadows at different scales and accuracy.

5.2 Overview

The traditional function of a map is to the show physical features on part of the earth's surface. By incorporating additional geographically related information however, maps can be used to portray much more than simple geography.

Accurate information on seagrass distribution is vital as a prerequisite to managing seagrass resources. The type of questions asked by managers determines the sampling design for surveys of seagrass habitats. Coastal managers may require maps at large scales to help select Marine and Estuarine Protected Areas (MEPAs) or highlight vulnerable areas to an oil spill, etc. Alternatively, they may require maps at finer scales to assist with coastal development decisions, such as where to put marinas, harbours, effluent outfalls, exploratory mining and mariculture developments, etc. Maps at several different scales may also be required to assist with monitoring the health status of seagrass habitats. The importance of having well defined questions before trying to answer them with mapping cannot be over-emphasised.

Informed management decisions need maps containing information on the characteristics of seagrass resources (such as species composition, abundance, type of meadow) and not be limited to presence/absence distribution. The methods for determining seagrass characteristics are covered in other chapters, but should be considered when choosing and implementing a mapping strategy.

Seagrass resources can be mapped using a range of approaches from in situ observation to remote sensing. The choice of technique is scale and site dependent, and may include a range of approaches. There will be variations in sampling design and methodology to accommodate differences between tropical and temperate seagrass biology. Earlier standards for seagrass mapping, e.g., Phillips and McRoy (1990) and Walker (1989) are being superseded as improvements in navigation and remote sensing technology and sampling design lead to more efficient and precise methods for mapping. Recent published descriptions of methods for mapping coastal seagrasses include English et al. (1994), Coles et al. (1995), Dobson et al. (1995), Kirkman (1996), Lee Long et al. (1996c), Short and Burdick (1996).

Initial mapping surveys may also provide the baseline information for monitoring programs. Such mapping surveys may be at various levels of detail, accuracy, and expense. In some cases, intensive data collection may be needed so that an initial estimate of spatial variability is available for developing a monitoring program with a predetermined ability to detect a level of change. GIS basemaps provide a quick, precise, drafting and mapping tool, and provide the best data presentation, analysis, interpretation and storage systems.

Satellite and aerial imagery are useful for mapping dense seagrass meadows in the clear waters of temperate regions, but in the tropics they are ineffective for detecting seagrasses of low biomass (or low canopy height) and/or in turbid water. Turbid, low visibility waters require different data collection and data protocols to those of clear-water regions. Differences in approaches between temperate and tropical areas may also be necessary because of differences in seagrass species and habitat types.

The intent of this chapter is to describe considerations that must be made when mapping seagrasses and to present the most commonly used methods. We do not provide a recipe book of the full range of mapping methods. Issues of scale and accuracy are explained while the sources of error and the kinds of ground truth required and their method of acquisition are detailed. Modern techniques using global positioning systems (GPS) and the use of underwater video are explained. Satellite imagery and its uses are described and conventional aerial photography is discussed and the advantages and disadvantages listed. Underwater mapping is an evolving science, and particularly in water over about 3 m in depth, has many problems that are not found in terrestrial mapping.

5.3 Pre-mapping Considerations

5.3.1 Spatial resolution (scale)

The selection of an appropriate scale is critical for mapping. First, the reason for the mapping needs to be clearly defined, as it is important in selecting an observation/mapping scale. Often, the reason for mapping requires approaches at multiple scales. The question of how much seagrass is present would require different approaches depending on whether the question was relative to a region (macro-scale: tens of kilometres), locality (meso-scale: tens of metres to kilometres) or to a specific site (fine-scale: metres to tens of metres).

The next consideration is that scale includes aspects both of extent and resolution. In both broad and large (macro) scale approaches, information from a low-resolution remote sensor or widely distributed field verification may be sufficient. The intensity of sampling will be low (low resolution), with a statistical sampling design that allows the results to be extrapolated from a few observations to the extent of the study area. For finer scale examinations of seagrass meadows, the sampling intensity required can be high with greater precision providing smaller levels of detectable change (high resolution).

Scale may determine the overall approach to sampling intensity and influences what is possible with a limited set of financial and human resources. The financial, technical, and human resources available to conduct the study is a consideration. The scale of the approach depends on the scale of the question; see Virnstein (2000) for a more detailed discussion.

5.3.2 Accuracy

Determining the level of detail required mapping an area also depends on the level of accuracy required for the final map product. Errors that can occur in the field directly influence the quality of the data. It is important to document these. GPS is a quick method for position fixing during mapping and reduces point errors to <3m in most cases. It is important for the observer to be as close as possible to the GPS aerial receiver to minimise position fix error. Working from small boats under conditions of strong wind and current can make this difficult.

It is essential for the valid interpretation of a map that the estimates of error and reliability are documented and travel with each map, measure of seagrass areal extent, and other seagrass parameter estimates.

5.3.3 Choosing a Survey/Mapping Strategy

The selection of a mapping scale represents a compromise between two components. One is the maximum amount of detail required to capture the necessary information about a resource. The other is the logistical resource available to capture that level of detail over a given area.

Once the question for mapping is well defined, the scale and type of imagery can be chosen. Table 5-1 is a decision tree for beginning a mapping process. For maps of fish habitat type, oil spill contingency plans, choosing Marine Environment Protected Areas, general coastal management, extent of seagrass as an absence or presence map, a scale of 1:250,000 may be suitable and this can be obtained from satellite imagery. More precise maps for these purposes require aerial photos but these will need to be digitised and rectified to be accurate at a scale of 1:10,000. A finer scale than this is required if events such as annual changes in seagrass cover are to be monitored. Of course, large changes in seagrass cover can be detected at greater scales, but by the time they are seen it will usually be too late for management to initiate action.

5.4 Data Capture

To map the extent of seagrass meadows requires methods that are used on terrestrial vegetation with allowances for the difficulties of working through water. Some of these difficulties are:

- At a depth greater than 2-3 m mainly blue light penetrates.
- All light is attenuated to different degrees through water.
- Light is refracted through water.
- For ground truthing, there are difficulties in working underwater, and
- Sun reflection and angle must be taken into account

The mapping of seagrass areas generally involves at some stage the interpretation of remotely sensed data, whether from an aircraft or satellite, and then interpreting the images onto hardcopy or computer, coupled with field (in situ) assessment to provide "ground truth".

We recommend using aerial photography, in situ observation (ground truthing, diver/video observations) and GIS to determine the location and extent and coverage pattern of seagrass meadows. These are essentially the same methods currently used by the National Oceanic and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) to monitor change in terrestrial land cover and nearshore benthic resources within coastal environments of the United States (see http://www.csc.noaa.gov/crs/ccap_index.html).

Table 5-1. A decision tree. The data capture methods used to map the distribution of seagrass meadows vary according to the information required and the spatial extent.

What is the size of the region or locality to be mapped		
	Less than 1 hectare	1
	1 hectare to 1 km^2	2
	1km^2 to 100 km^2	3
	greater than 100 km^2	4
1. Fine/Micro-scale (Scale 1:100 1cm = 1m)		
Intertidal		aerial photos, in situ observer
Shallow subtidal (<10m)		in situ diver, benthic grab
Deepwater (>10m)		SCUBA, real time towed video camera
2. Meso-scale (Scale 1:10,000 1cm = 100m)		
Intertidal		aerial photos, in situ observer, digital multispectral video
Shallow subtidal (<10m)		in situ diver, benthic grab
Deepwater (>10m)		SCUBA, real time towed video camera
3. Macro-scale (Scale 1:250,000 1cm = 250 m)		
Intertidal		aerial photos, satellite
Shallow subtidal (<10m)		satellite & real time towed video camera
Deepwater (>10m)		real time towed video camera
4. Broad-scale (Scale 1:1,000,000 1cm = 10 km)		
Intertidal		satellite, aerial photography
Shallow subtidal (<10m)		satellite, aerial photography & real time towed video camera
Deepwater (>10m)		real time towed video camera

5.4.1 Remote Assessment

Introduction

Remote sensing refers to capturing images of the extent of seagrass from various airborne or satellite platforms in forms such as photos or digital data. Remote sensing is not always effective or possible (Hyland et al. 1989, Long et al. 1994). Kirkman (1996) discusses mapping from satellite and airborne scanners and explains the various uses for mapping at different scales.

Two of the most popular satellite remote sensing data sources currently in use are Landsat Thematic Mapper (TM) and SPOT (Le Système Pour l'Observation de la Terre). The TM sensor is sensitive to blue wavelength light (band 1) that is valuable for its ability to travel through the water column. The SPOT pan sensor collects data in the green and red parts of the spectrum. Satellite imagery has however been limited for mapping seagrasses, as the large pixel sizes (10-30m in the case of Landsat TM and SPOT imagery) cannot detect small meadows. These small meadows may become identifiable as the resolution of satellite imagery is improved.

Projects considering the use of satellite acquired images are generally broad- or macro-scaled (an individual Landsat TM scene covers an area over 34,000 km^2, whereas the SPOT pan sensor has a smaller scene size of 60 km^2) and nationally funded; purchasing and analysing multiple images from Landsat TM or SPOT can be prohibitively expensive as they are distributed at cost of acquisition.

There are examples of the successfulness of macro-scale aquatic mapping using satellite remote sensing data; see Dreyser (1993) and Jagtap et al. (1994). However, Thomas et al. (1999) have been critical of the application of remote sensing to seagrass mapping.

Other remote sources that have been shown to have promise for seagrass mapping projects include airborne scanners and Digital Multispectral Video (DMSV). Airborne scanners cover a range of spectral bands with high resolution (1 m) (Kirkman 1996) and digital multispectral video (DMSV) consists of one or more video cameras usually linked to a computer so that operators can see the images in real time. Airborne scanners can also be expensive and although the DMSV technique takes frames much like an aerial photograph, the lenses are not as precise and free of aberrations as those for aerial photos. The format is not as easy to handle as the 22 x 22 cm aerial photographs in analog state.

A lesser known and under used source of remote sensing data are Earth looking photographs taken by astronauts from low orbit. NASA photographs taken from low Earth orbit can provide information relevant to mapping seagrasses at a variety of scales. The data source is now more accessible due to improvements in digitising technology, Internet file transfer, and availability of image processing software. Orbital photographs from the late 1960's to the present are available at a single searchable location on the Internet (http://eol.jsc.nasa.gov/sseop/). As these photographs are in the public domain, they are available at cost of reproduction. The photographs however, are much more variable in angle and scale than the automated data. If needed, they can be georeferenced by the user. The preferred remote data capture method we recommend however, is aerial photography.

Aerial Photography - the Preferred Method

Aerial photography can be conducted at a variety of scales and in a range of formats (e.g., colour, black and white and infra-red) and has become the most common source for seagrass mapping studies (e.g., Kelly 1980, Kennedy 1996, Lehmann et al. 1997, Stoms et al. 1992).

The spatial resolution in most aerial photography is extremely high and is usually more than sufficient to capture even small features. The National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program (C-CAP) recommends aerial photography to map seagrass on a nation-wide basis in the U.S. (Dobson et al. 1995).

Runs of aerial photos can be commissioned for a particular purpose but are often readily available through various government agencies and commercial contractors. Photography should be acquired when the plane is as vertically above the target as is possible. The best photos are obtained using specifically equipped aircraft, which fly at a steady altitude (approximately 1800m is used to capture 1:12,000 aerial photos), with the camera centered within the under-fuselage on a level platform to ensure the image is a vertical perspective. The scale of the imagery can be adjusted to suit the requirement and geographic extent of a given study area and chosen when aerial photo runs are commissioned. Flightlines should be planned with reference to aeronautical and nautical charts to include all areas known to have seagrass.

NOAA recommends Aerocolor 2445 colour-negative film, Aerocolor 2448 colour-reversal film and Aerographic 2405 black and white negative film in that order of priority. Conventional colour film is typically filtered to remove the effects of haze. Each standard 9 x 9 inch (22cm) aerial photograph overlaps with its neighbour by 60% which allows stereoscopic interpretation, facilitates interpretation from the most central part of the photograph and compensates for loss of coverage due to sunlight. Sidelap of 30% ensures contiguous coverage by flight lines.

Some knowledge of the study area is useful before the imagery is acquired. Types and location of benthic features that may be confused with seagrass, turbidity, haze, daily patterns of wind speed and direction and progression of sun angle through the day should all be known and considered before the flight. The final decision as to whether to photograph should be based on the pilot's appraisal of target conditions.

The advantages of aerial photography are:

- High spatial resolution
- Spatial resolution (as determined by the scale) can be selected based on individual project objectives.
- Flexible acquisition- A project can be planned to specifically capture imagery at the most optimal time of day and under the best environmental conditions.
- Low technology information extraction- Seagrass maps can be made from aerial prints or diapositives with little technical hardware or software resources, but it is not appropriate, in most cases, to attempt to map from aerial photos without first digitising and rectifying them.
- Stereometry can greatly enhance mapping (Sheppard et al. 1995).

Some disadvantages of this type of remote sensing are:

- Cost- The fine spatial resolution provided by the photographs comes at the cost of obtaining a large number of frames.
- It is produced in an analogue format and must be scanned if any computer enhancement, image processing or rectifying is anticipated.
- Distortion- The nature of the camera lens and position, roll, yawl and tilt of the plane introduces some distortion into the imagery that is removed by rectifying.

Mapping aquatic systems solely from aerial photographs is vulnerable to several sources of error. Bruce (1997) divides these into environmental error (indirectly manifested as interpreter error) and data capture error. The error minimisation begins with being able to interpret the patterns on the image.

Assuming that clouds and atmospheric effects are not a problem, there remain water column effects and habitat characteristics that should be considered during the project planning stage to produce imagery of the highest quality that will facilitate correct interpretation. The following environmental variables should be considered:

- Turbidity plumes- To avoid problems with turbidity, imagery should be acquired only when no recent rain events or strong winds have occurred.
- Sea surface conditions- Low or no wind conditions are optimal to imaging submerged features; we recommend only acquiring imagery when winds are below 10 knots (16 km/h).
- Sun reflection- to minimise sun glint on aerial images, the aircraft mission should only be scheduled when sun elevation is between 30 and 42 degrees above the horizon.
- Seasonal changes- Seagrasses often undergo significant changes in standing crop over a growing season. When comparisons are being made or will be made any aerial mission or satellite, image capture should be scheduled during the same seasons. Care must be taken, however, to avoid confusion brought on by the growth of algae either as epiphytes on the seagrass or as phytoplankton in the water.
- Tidal stage- Aerial missions for shallow seagrass, where tides are greater than 1 m, should be scheduled within ±2 hours of the lowest tide.

Trouble Shooting and Hints

The dark signature that seagrasses typically produce in aerial photographs can be confused with anoxic sediments, algal accumulations, deeper water, rocky outcrops, coral reefs and shellfish assemblages etc. To minimise confusion with these features, the interpreter needs all available reference information about the study site prior to beginning the mapping. Ground truth data are essential

Interpreter error can be introduced when multiple individuals interpret the same imagery and produce differing map products or where the same individual makes a second interpretation of the same imagery. Congalton (1993) found that interpreter error introduced up to 41% of the thematic error observed in a three-class forest type map. Some interpretation error will always exist in remote sensing. Ways to minimise it are to have one individual do as much of the work as possible. A high level of training and extensive time in the field will also minimise this type of error. When it is necessary to use multiple analysts, photointerpretion keys and a classification system with well-defined and observable boundaries will do much to ensure interpretation consistency. A review process that allows crosschecks between analysts will also help. The difficulty in interpreting underwater signatures means that in most cases spectral differences cannot be used. Blue wavelengths are the only ones that will penetrate water more than about 2 m for practical purposes.

5.4.2 Ground Truthing

Introduction

Any seagrass mapping should have a well-designed ground sampling/verification process incorporated as part of the project. The purposes of the field (in situ) observation are to:

- Evaluate image signatures in the initial review of the remotely sensed data.
- Examine areas where the imagery does not provide information about the bottom, such as in areas of heavy turbidity.
- Produce reference information for the later accuracy assessment.

Ground truthing is essential, as it is difficult to distinguish reefs, algae and deep holes from dense meadows. There are a number of methods for ground truthing, including underwater towing, bounce free-dives, benthic grabs and bathyscopes (Kirkman 1990). The method is also dependent on the type of environment. Regardless of method, the first and most important parameter to measure is position. Today this can be accomplished relatively easily by using a GPS.

Global Positioning Systems

The GPS is a small handheld unit which allows accurate positioning by using satellite transmissions to determine its position on the earth's surface. When a GPS records a position it is called a fix or waypoint (Table 5-2). Most GPS store waypoints in their memory so that the unit can be used to navigate back to that point. Accurate positioning is invaluable for ground truthing mapped sites and for verifying interpretation of remotely sensed images. To ground truth a remotely sensed image, first the image must be rectified into the real world (assigned positional coordinates) using ground control point information collected using the GPS.

Ground control points are features on the ground for which an accurate geographical position can be determined and that are easily distinguished on aerial imagery. Good control points are not likely to change position over time, and include jetties, street corners, bridge abutments, and emergent rocks. Poor ground control points are features such as curves in shorelines, river shores, or submerged features, also channel markers, buoys, and floats that change position with the tide. The distribution of ground control points is determined by the analyst and specifically chosen to meet project needs, however the even distribution of control points throughout the study area is also important.

Once the aerial photograph (or other remotely sensed image) is rectified onto the earth's surface, a GPS can be used to navigate to a feature in the field to confirm the characteristics of that feature.

One source of error in the use of GPS for field verification of seagrass and other submerged habitats is the offset and positional uncertainty between the receiver, necessarily at the surface, and the actual habitat to be observed on the bottom. Usually this offset is not large; however, in deeper water and in spatially heterogeneous environments this may be a factor. Simple geometric calculations can be made to compensate for this offset. (NOS/NMFS 1999).

The advent of inexpensive yet accurate GPS integrated into a Geographic Information System has increased accuracy of ground truthing and provides a more cost-effective and accurate approach to seagrass mapping at a relatively small scale (such as an estuary). By georeferencing seagrass meadow boundaries and their attributes using GPS, boundaries can be measured with accuracy (±1-5 m) with confidence.

Because much modern mapping relies on GPS for source information, low quality or poorly documented GPS measurements can affect the quality of later positional accuracy. Typical GPS collection software has routines that address these issues.

In the case of submerged features, positional inaccuracy can result from the refraction of light rays through the water column, a phenomenon is dependent on the depth of the feature, and its position in the image. For most seagrass mapping however, the refractory effect should not be more than a few meters when shallow seagrass meadows are mapped.

Table 5-2. Operation chart for global positioning systems.

Turn GPS unit on

↓

Give GPS time to track sufficient satellites and download almanac *(if necessary)*

↓

Check GPS settings
- Units
- Datum
- Altitude
- True or magnetic north

↓

To record a position either mark waypoint or, if boundary mapping, set waypoint mark to Stream/Poll

↓

Either record positions directly onto data-sheet or download to computer via a cable

Trouble Shooting and Hints - Using a GPS

- When fixing a position it is important to give the GPS antenna a clear signal of the sky. A GPS needs to receive signals from a number of satellites (usually more the 4) to take an accurate fix. When using a GPS in mountainous coastal areas, signals from some the satellites may be blocked or unclear.
- It is important to give the GPS sufficient time to position fix. If you are moving when the position is fixed, it may add error. The less movement, the greater the accuracy. Give the GPS at least 5-10 seconds to position fix.
- Some GPS units are quite accurate when moving; these have the ability to “stream” or “poll”. These can be useful when boundary mapping. If the GPS does not “stream” then the operator will need to take a waypoint every few metres.
- Ensure the GPS units are known to the user, as it is often common to misread decimal minutes as minutes and seconds (e.g., 14° 36.44’ is not the same as 14° 36’ 44”).

- When using a GPS for the first time or in a new region (world zone), ensure the almanac is set correctly. Most GPSs today will detect that they are in a new region and will automatically download the new almanac, which takes approximately 15 minutes.
- When position fixing a subtidal ground truth site with a GPS, it is important for the observer to be as close as possible to the GPS antenna to minimise position fix error. In small boats under conditions of strong wind or current this can be difficult.
- When downloading the data, check the GPS settings and take note of the datum (fixed starting point). GPS record your location on the earth's surface using a reference point or datum. The datum establishes your positions in latitude/longitude coordinates relative to e.g., WGS (World Geodetic System) or an alternative such as AGD (Australian Geodetic Datum). You can choose which datum (AGD or WGS) your GPS screen shows. Both are equally correct. However, if you are trying to find coordinates from a map which are recorded as AGD, and your GPS is following WGS, there could be up to 160 m discrepancy.
- When purchasing a GPS, consider not only the accuracy of the unit, but also its robustness. Field conditions can be demanding on equipment, and often water resistant units may be better.

Mapping an Intertidal Meadow

Necessary Material and Equipment

- GPS or hand held compass
- Standard 50cm x 50cm quadrat
- Datasheets

Intertidal Field Assessment

Determine the extent of the study area, whether it is a region or specific locality. If mapping can be conducted at low tide when the seagrass meadow is exposed, the boundaries of meadows can be mapped by walking around the perimeter of each meadow with single position fixes recorded every 10 seconds (GPS set to "Stream" or “Poll”). To survey an area quickly, it is possible to work from a hovercraft or helicopter.

Alternatively, an area can be mapped using a grid pattern or a combination of transects and spots. When mapping a region of relatively homogenous coastline between 10 and 100 km long, we recommend that transects should be no further than 500-1000 m apart. For regions between 1 and 10 km, we recommend transects 100-500 m apart and for localities less than 1 km, we recommend 50-100 m apart. However, number of transects may change depending on the complexity of the regional coastline; i.e., more complex, then more transects required.

Observations need to be taken at regular intervals (usually 50 to 100 m) along transects. The location of each observation is referred to a site, and the intervals they are taken at may vary depending on the topography. As the distribution of seagrass is depth dependent (depth limits vary between regions and localities due to water clarity), we advise that representative sites be sampled within each depth category (we have used 0.5 m to 10 m intervals depending on topography). In some cases the sampling may need to be stratified (the number of sites greater in some depth categories than others) when the probability of finding seagrass varies between strata.

When ground truthing a site, there are a variety of techniques that can be used depending on resources available and water depth (free dives, remote video, etc.). First the position of a site must be recorded, preferably using a GPS. Otherwise use a handheld compass to determine the bearing, with reference to at least 2 permanent landmarks or marker established as reference points. A site can vary in size depending on the extent of the region being mapped. In most cases a site can be defined as are area encompassing a 5 m radius. Only one observation (sample) is necessary at a ground truth site; we recommend replicate samples spread within the site (possibly 3 observations) to ensure the site is well represented.

Observations recorded at a site should ideally include some measure of abundance (at least a visual estimate of biomass or % cover) and species composition. Also record the depth of each site (this can be later converted to depth below mean sea level) and other characteristics such as a description of the sediment type (e.g., shell grit, rock, gravel, coarse sand, sand, fine sand or mud).

To map an area of approximately 100 ha, we recommend a grid pattern of transects approximately 50 m apart. Then ground truthing every 50 m along the transect from its origin to the meadow boundary.

Mapping Shallow-subtidal (<10 m) Meadows

Necessary Material and Equipment

- Small boat, with outboard motor and safety equipment
- GPS or hand held compass
- Bathyscope or standard 50 cm x 50 cm quadrat
- Benthic grab (e.g., van Veen)
- Datasheets
- Suitable free-diving (snorkelling) equipment

Shallow Field Assessment

If water clarity and seagrass abundance is high, then the boundaries of meadows can be mapped from a boat driven slowly (1-2 kts) around the perimeter of each meadow with single position fixes recorded every 4 seconds (GPS set to "Stream"). A bathyscope can be used to assist in identification of the presence of continuous or sparse meadows and the determination of deep edge meadows. Abundance or cover estimated can also be visually assessed.

If the water clarity is low, and/or the seagrass abundance low and highly variable, then a different strategy is employed. An area can be mapped ideally using a grid pattern or a combination of transects and spots, in the same manner as when mapping an intertidal meadow (e.g., Lee Long et al. 1993).

The most commonly used and simplest ground truth method is in situ observation through bounce dives or snorkelling. The diver signals the type of habitat to a crew in a boat. Any direct observation of the bottom is limited by the amount of time a person can spend snorkelling or their field of view when in the water. The ground truthing of maps prepared from aerial photography or satellite can be done by bounce dives, i.e., the diver swims to the bottom, or as deep as is required to recognise the seagrass, presence or absence or species. If nothing is growing on the bottom the diver can turn back without having to go to the full depth of the bottom. Bounce dives are useful for obtaining a vegetation or sediment sample.

In an exercise to map the southern part of Australia, we used a traced laminated map from satellite imagery, which was prepared earlier with eastings and northings grid lines on it. Areas of uncertainty, representative areas and checks were plotted and bounce dives carried out at these places by navigating to them with GPS.

Where depth, poor visibility or lack of dive time prohibits diver estimates, a small benthic grab or dredge is a useful tool for determining the bottom type. A simple dredge that can be pulled by hand consists of a small Bruce anchor with a net fitted to its shaft and blades. This is pulled along the bottom usually at the drift speed of the boat. The operator can feel when it has contacted the bottom and should allow about 15 seconds to obtain a sample. This dredge can be used in boats from small inflatables to ocean going research vessels. Benthic grabs can also be used to sample the sea floor and samples of sediment can also be obtained. Long et al. (1994) tested the use/efficacy of a modified "orange-peel" grab in different sediment and vegetation types, and reported acceptable results.

Mapping Deep-water (>10m) Meadows

Necessary Material and Equipment

- Large boat
- Underwater video camera (video recorder) and sled
- GPS, compass or Radar
- Depth measuring equipment (e.g., depth sounder)
- Benthic grab (e.g., van Veen)
- Datasheets

Deep Field Assessment

A deep-water area can be mapped ideally using a grid pattern or a combination of transects and spots, much in the same manner as when mapping an intertidal or shallow subtidal meadow. However, the sites will be generally further apart and the replication at a site will be significantly reduced. When ground truthing a site, there are a variety of techniques that can be used depending on resources available and water depth (SCUBA, benthic grab, remote camera/video, etc.).

SCUBA can be used to conduct in situ assessment of deep-water sites. However, SCUBA can be restrictive due to the number of sites that can be assessed in a day, and the restrictions imposed by diving at depth. Safety should be foremost when conducting in situ assessment using SCUBA, paying particular attention to tidal regimes, turbidity, sea-state, dangerous marine animals and other human activities and impacts. Local knowledge of the above factors must always be sought. We strongly recommend that diving policies be developed by each organisation and national safety standards be met.

Due to the restrictions of working at depth, virtually all deep-water mapping is conducted remotely. One remote method uses active acoustic sensors that characterise the sea-floor by transmitting a pulse of sound energy downward into the water column and then collecting the return echoes for analysis. The advantages of using acoustic energy over visual or other mediums lies in the fact that sound travels underwater without appreciable attenuation relative to optical methods in the sea. Acoustic signals are less affected than light by turbidity or depth. The major disadvantages with acoustic survey techniques are that different seagrass communities can appear similar in habitat structure. Detailed information on seagrasses (such as general seagrass health, epiphyte cover, canopy height, dugong feeding trails, fruiting and flowering), and fine scale changes in community structure, are not recorded in an acoustic survey and still require observation and sampling by divers or video. Acoustic surveys require specialised sensors and technical expertise to interpret, and are considered beyond the scope of this chapter. For more information, we recommended Lee Long et al. (1998) and Urick (1983).

The other common method is real time towed video camera. Underwater video is a widely used tool for seagrass mapping (Coles et al. 2000, Lee Long et al. 1996a, Norris et al. 1997). Towed video technology is used as a direct mapping tool and for ground truth of remotely sensed images. Underwater video provides a record of seagrass presence and abundance, the species of seagrass and the nature of the non-vegetated bottom. The system is useful in deepwater environments where SCUBA diving is restricted and in localities where dangerous marine animals are a significant threat.

An underwater video camera housed within a sled can be towed from a small boat along a section of the seafloor. If possible, real time cameras (an image is transmitted directly to the surface) and video should be used, allowing observations to be made real time, and also warning the camera operator of any impending dangerous obstacles. Video tows are often set up to cross habitat boundaries so that the trends and changes between the habitats are captured. The images transmitted from the cameras can be recorded to magnetic digital media, such as DVCam tapes. Encoding instruments can put a co-ordinate stamp from a GPS unit directly on the video tape, greatly assisting later comparison with rectified map data and supports subsequent change detection across the same area. Once converted to a digital format, the video data is suitable for storing with other digital map data and more sophisticated analysis of individual video frames can be accomplished.

5.5 Creating the Map

5.5.1 Introduction

The simplest way to map the distribution of seagrasses is to trace features from aerial photography, using the ground truth data as a guide. Alternatively, draw the meadows on a paper marine chart from the GPS positions of the ground truth sites. The problem with this type of mapping however is that the final map is in a format that does not allow manipulation and transformation. The layout of a paper map is permanent, which makes it difficult for future seagrass mapping studies to be compared, queried and analysed. If resources are available, we recommend that the data be transferred to a digital format and a Geographic Information System be used.

5.5.2 Geographic Information Systems (GIS)

GIS are software systems of highly accurate digital maps that can be overlaid to reveal relationships that might not be detected on traditional paper maps. Digitally stored cartographic databases can be altered much quicker than hard copies and shared data can be standardised. The key element of a GIS is the separation of differing data sets into thematic layers. GIS software provides the functions and tools needed to store, analyse, and display geographic information. Although there are many applications on the market that can display geographic data, true GIS applications must have the following components:

- tools for the input and manipulation of spatial data
- a database management system (DBMS)
- tools that support geographic query, analysis, and visualisation.

Two of the most common GIS packages are ArcInfo® (including ArcView®) and MapInfo®. Mapping seagrass meadows with a GIS can help to identify emergent patterns or relationships in geographically referenced data. For further reading on the application of GIS to aquatic botany, see Lehmann and Lachavanne (1997).

GIS provide three distinct functions; data capture, manipulation and modelling. Data is put into the GIS in a digitised format that can be produced by scanning an image (such as a paper-based map or aerial photograph) and is used to reproduce a raster bitmap of the original. Raster images are stored as bitmaps of pixel values. Raster maps can be automatically converted into a vector form by detecting features displayed in the scanned original (typically by colour value), and converting these points into vector data.

Creating the Basemap and Importing Captured Data

The first task is to scan the aerial photographs typically using a flat-bed scanner (a resolution of 300 dpi is usually sufficient) to produce a digital raster image. Once scanned, aerial photographs can be pasted together in most standard image/drawing packages to create larger images. Ensure the final image includes some topographic features spread over the entire image: such as major or minor roads, coastlines, buildings, jetties or piers. If the ground truthing included determining the position fixes of such topographic features, then these can be used as ground control points. Using ground control points, the digital images are fixed or rectified in space. Maximum spread of ground control points over an image will result in a more accurate rectification. This image now becomes the basemap for the GIS layers. Seagrass areas can be mapped directly from raster images using image analysis programs (e.g., Optimas® and ENVI®) or the user can trace (digitise) the boundary. Alternatively, the boundary can be determined by importing the ground truthed sites and using contour mapping programs (e.g., Surfer® and S-Plus®). We recommend importing the seagrass position data (ground truthed sites) from the database in which it has been entered (e.g., MicroSoft® Access) and overlaying it on a basemap derived from a scanned and rectified aerial photograph. Once imported, it can be linked in overlapping layers to form a mosaic covering the whole region or locality.

Boundary Determination

Boundaries of meadows can be determined based on the positions of survey sites and the presence of seagrass, coupled with depth contours and other information from aerial photograph interpretation. Errors that to be considered when interpreting GIS maps include those associated with digitising and rectifying the aerial photograph onto the basemap and those associated with GPS fixes for survey sites. In certain cases seagrass meadows form very distinct edges that remain consistent over many growing seasons. However, in other cases the seagrass tends to grade from dense continuous cover to no cover over a continuum that includes small patches and shoots of decreasing density. Boundary edges in patchy beds derived from aerial imagery or direct observation are vulnerable to interpreter variation.

Sometimes, it can be assumed that light limits the deeper edge of seagrass beds; in this case, bathymetric measures can map this boundary. The light limiting depth to most seagrasses is usually the Secchi disc depth (Dennison and Kirkman, 1996).

Given the uncertainty in identifying meadow edges, it is suggested that each mapping effort include its own determination as to what it considers seagrass habitat based on the purpose of the mapping As long as the logic is clearly described and the results are repeatable, the data should be suitable for baseline characterisation or change detection. Using the GIS, meadow boundaries can be assigned a "quality" value based on the type and range of mapping information available for each area and determined by the distance between survey sites and GPS position fixing error. These meadow boundary "errors" can be used to estimate the likely range of area for each meadow mapped (Lee Long et al. 1996b, McKenzie et al. 1996, 1998).

5.5.3 Map Accuracy

The expected accuracy of the map product gives some level of confidence in using the data. Inaccurate maps may result in poor management decisions (Bruce et al. 1997). Mapping accuracy can be divided into the two general classes of thematic and spatial accuracy. Thematic accuracy is a determination of the correctness of the features identified on the map product, covering whether a patch of seagrass was correctly labelled as seagrass in the map or

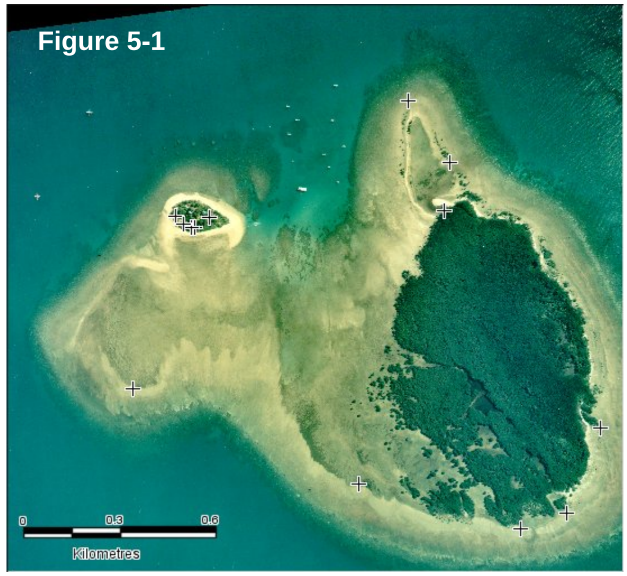
Example of Mapping Seagrass Distribution

Distribution of seagrass communities of the Low Isles, 29-31 July 1997.

Step 1 (Site identification and scale)

Low Isles is currently zoned within the Cairns Section of the Great Barrier Reef Marine Park (Queensland, Australia) and includes a National Park and Buffer Zone. Information on the distribution of the seagrass habitats was required to assist with Great Barrier Reef Marine Park Authority marine park planning as increases in visitor numbers and boat use were an issue of concern for marine park managers.

Low Isles is an inshore reef of the Great Barrier Reef. There have been several major faunistic and floral surveys of Low Isles, beginning in 1928-1929 when the Great Barrier Reef Committee collaborated with the Royal Society of London to coordinate the first major biological expedition to the Great Barrier Reef. Subsequent surveys were in 1958 and 1978. Although seagrasses were recorded in these surveys, the distribution of seagrass habitats was not determined. In July 1997 a survey of the Low Isles was conducted to map the distribution and abundance of seagrass communities and create a GIS of Low Isles and its associated benthic communities for future management. Due to the management needs, a fine /micro-scale (Scale 1:5,000 1cm = 1m) approach was required.



Step 2 (Aerial photos)

Historical aerial photos were accessed and a new aerial photograph was commissioned (altitude 1830 m, scale 1:12,000).

Step 3 (Choose and position fix ground controls)

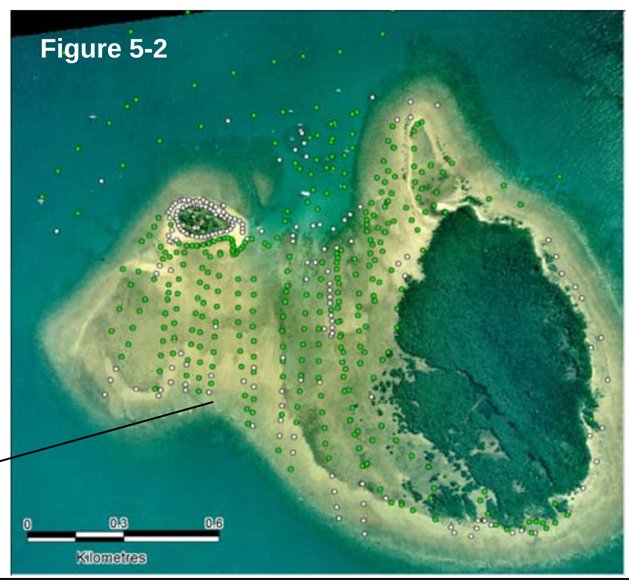
Ground control points were identified from aerial photographs and a differential GPS was used to determine their position accurately (±3m).

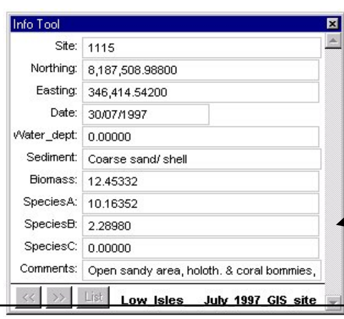
Step 4 (Digitise and rectify photo)

The aerial photos were scanned on a flat bead scanner at 300 dpi and saved as Tagged Image Files (tif). The scanned images were then imported into the GIS package MapInfo® and rectified to the ground control points (see crosses in Figure 5-1).

Step 5 (Ground truth)

A grid pattern for sampling was established with transects across the reef flat and lagoon approximately 50 m apart. Survey sites were ground truthed every 50 m along each transect (see circles in Figure 5-2).

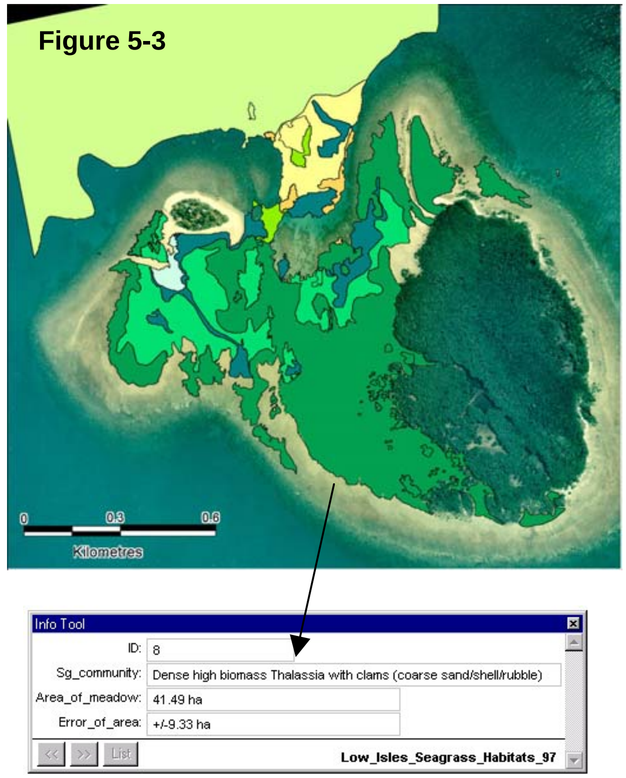




A differential GPS was used to locate each survey site. Estimates of above-ground seagrass biomass (3 replicates of a 0.25 m^2 quadrat, see Chapter 7), seagrass species composition, water depth and sediment depth/characteristics were recorded at each survey site.

Step 6 (Import to GIS and overlay data)
All survey site data was entered into a GIS. All maps and GIS outputs were produced using Australian Map Grid (AMG) Zone 55 projection (Figure 5-2).

Step 7 (Map and verify)
Boundaries of seagrass meadows were determined based on the positions of survey sites, depth contours, and on information from aerial photograph interpretation (see Figure 5-3). Boundaries were digitised manually into a polygon layer of the GIS, and information concerning each meadow attached. Errors that should be considered when interpreting GIS maps include those associated with digitising and rectifying the aerial photograph onto the basemap and GPS fixes for survey sites.



Step 8 (Create metadata file)
A metadata "readme file" was created compliant with the core elements of the ANZLIC Guidelines, including information on the dataset (e.g., custodian name), description (e.g., study details, geographic extent), status (date collected), quality (positional accuracy) and contact information.

Step 9 (Run statistical checks and error estimation)
Each seagrass meadow was assigned a meadow boundary quality value based on the type and range of mapping information available for each area and determined by the distance between survey sites and GPS position fixing error. These meadow boundary "error of area" values were used to estimate the likely range of area for each meadow mapped, and were entered into the information section of each meadow.

Step 10 (Assist management)
The results were then complied into a technical report and provided to the Marine Park Authority for marine park planning.

whether it was incorrectly labelled as algae or some other feature. Spatial accuracy is a measure of the positional correctness of boundaries and features in a map product. For seagrass mapping, high levels of both thematic and spatial accuracy are critical.

With the advent of GPS, spatial accuracy has greatly improved. However, care must be taken not to enlarge a map beyond its stated scale and try to make decisions from this artificially enlarged map. The need for rectification has been emphasised throughout this chapter and estimates of accuracy should be given with each mapping project. At sea, control points are difficult to find for rectification purposes; spatial errors increase in magnitude the further the site of interest is from controls.

The accuracy of a map also needs to consider temporal effects. Rarely are maps generated at a time close to the date at which field accuracy assessment occurs, making assessment of the thematic or spatial accuracy of a map more difficult. Temporal effects are particularly noticeable when seagrass beds undergo large seasonal changes.

5.5.4 Data Visualisation and Output

If the data contains information of greater resolution than presence or absence, it can be used to in digital elevation modelling programs (such as Surfer® and S-plus®). Digital elevation models can be created with information such as seagrass abundance, water depth, etc.

Detailed data capture information can enable maps to be constructed from more features than simply presence and absence. Maps of different seagrass communities or habits for example, can be constructed by using information such as seagrass species composition, seagrass abundance, sediment type and other associated flora and fauna.

The final map can be presented on screen and in hard copy. The final maps need a clear legend describing the features highlighted, a scale, and a source. The maps are best accompanied by any caveats on data reliability, e.g., changes in data quality during sampling because of physical changes such as sea state. This is important when data is loaded into a GIS that is used by managers. GIS data also requires a date. Original (master) copies of final GIS maps are usually stored in two places: the source laboratory and a regional or central archive. Always attach a metadata file or script to each map, and include the correct form of citation to be used for acknowledging the data source.

5.5.5 Metadata

Metadata is information about the data and not to be confused with a summary of the data. Metadata describes data source, data reliability, conditions of use, limits on interpretation and date, and usually includes the correct form of citation to be used for acknowledging the data source. It holds information about the quality of the data. The project metadata for all spatial data should have some statement about the accuracy of a map product. The Australian New Zealand Land Information Council has a very useful guide for metadata (http://www.anzlic.org.au/).

5.6 Discussion

The use of the GPS has facilitated the production of precisely geo-referenced images that can be incorporated into GIS database for analysis of seagrass distribution and characteristics. The incorporation of GPS and GIS technologies has lead to the development of spatial database systems for seagrass that can be queried, updated, manipulated and analysed, something previously inconceivable. The use of GIS technologies, involving the quantitative expression of spatially consistent data, provides advanced analytical capabilities and the ability to address complex systems in entirely different new ways.

The majority of previous seagrass mapping studies using GIS were conducted using solely a raster format interpreted using remote sensing and photogrammetry techniques, with pixel size varying from 15-30m. The accuracy of many of these studies is questionable, due to the limited or non-existent ground truthing. In many studies uncorrected GPS readings were used to record features and their attributes (Lehmann et al. 1997), leading to the publication of numerous studies with high uncertainties in GIS outputs, due to the uncertainties in the data input. Stoms et al. (1992) suggested that the usefulness of GIS technologies is limited by data availability and quality rather than by technical obstacles. Quality of the output is affected by the accuracy associated with the spatial resolution of the source data.

Although we tend to think of visual displays from GIS databases as the digital equivalent of map-making, there are significant differences and opportunities that exist. The spatial database is structured in a format allowing future seagrass mapping studies to be compared, queried and analysed. The layout of a paper map is permanent, but visual displays in the GIS can be manipulated and transformed in a free form and zoomable display.

The use of GIS in seagrass mapping has resulted in significant improvements in monitoring seagrass resources and their respective management. GIS has enabled relatively accurate comparisons of historical and current spatial studies. For example Udy et al. (1999) examined the historical changes in the distribution of seagrass meadows using aerial photographs, ground truthing and GIS, and reported seagrass expansion in the back-reef area NW of Green Island (Australia) from 1.1 ±0.3 ha in 1959 to 22.5 ±1.7 ha in 1994. Future comparisons will be conducted with relative ease, as the historical information is archived in a suitable format.

One of the largest programs integrating GIS and maps of seagrass resources is NOAA Coastal-Change Analysis Program. The project is a cooperative state and federal effort to map benthic resources throughout the coastal regions of the United States. The primary goal is to establish an ongoing and consistent national database of coastal benthic data that document changes and trends over time. The focus of the benthic habitat mapping project is on living resources in the near-shore estuarine and marine environments such as seagrass meadows, coral reefs, hard bottom areas, shellfish beds, and algal communities. The geographic scope extends from the limit of tidal influence seaward to the state jurisdictional line 3 miles offshore. C-CAP digital map products are used in a variety of ways. One of the most important is change detection. By comparing maps of the same areas taken on different dates, alterations from man-made and natural occurrences are readily apparent. Such analysis also helps scientists and coastal resource managers draw correlations between changes in upland environments and nearshore aquatic habitats.

References

Bruce E, I Elliot, D Milton. 1997. Methods for assessing the thematic and positional accuracy of seagrass maps. Mar. Geod. 20:175-193.

Coles, RG, WJ Lee Long, LJ McKenzie. 1995. A Standard for Seagrass Resource Mapping and Monitoring in Australia. *In:* Australian Marine Date Collection and Management Guidelines Workshop, 5-6 December 1995. CSIRO Marine Laboratories, Hobart, Tasmania. URL: http://www.environment.gov.au/marine/coastal_atlas/documentation/standards/general/coles.html

Coles, RG, WJ Lee Long, LJ McKenzie, AJ Roelofs, G De'ath. 2000. Stratification of seagrasses in the Great Barrier Reef World Heritage Area, Northeastern Australia, and the implications for management. Biol. Mar. Medit. 7: 345-348.

Congalton R. 1988. A comparison of sampling schemes used in generating error matrices for assessing the accuracy of maps generated from remotely sensed data. Photogram. Eng. Rem. Sens. 54: 593-600.

Dennison, WC, H Kirkman. 1996. Seagrass survival model. pp. 341-344. *In:* J Kuo, R Phillips, DI Walker, H Kirkman (eds) Seagrass Biology: Proceedings of an international workshop, Rottnest Island, Western Australia, 25-29 January 1996. Faculty of Science, The University of Western Australia.

Dobson, JE, EA Bright, RL Ferguson, DW Field, LL Wood, KD Haddad, H.III Iredale, JR Jensen, VV Klemas, RJ Orth, JP Thomas. 1995. NOAA Coastal Change Analysis Program (C-CAP) Guidance for Regional Implementation. NOAA Technical Report NMFS 123. 92 pp.

Dreyser, LE. 1993. Evaluation of remote sensing techniques for monitoring giant kelp populations. Hydrobiologia 260/261: 307-312

English, S, C Wilkinson, V Baker. 1994. Survey Manual for Tropical Marine Resources. ASEAN-Australia marine science project: living coastal resources. Australian Institute of Marine Science, Townsville. 368 pp.

Hyland, SJ, AJ Courtney, CT Butler. 1989. Distribution of seagrass in the Moreton Region from Coolangatta to Noosa. QDPI Information Series QI89010. Queensland Department of Primary Industries, Brisbane. 42 pp.

Jagtap, TG, AG Untawale, SN Inamdar. 1994. Study of mangove environment of Maharashtra coast using remote sensing data. Indian J. Mar. Sci. 23: 90-93.

Kelly, MG. 1980. Remote sensing of seagrass beds. pp. 69-85. *In:* RC Phillips, CP McRoy (eds). Handbook of Seagrass Biology: An Ecosystem Perspective. Garand STMP Press, New York.

Kennedy, M. 1996. The Global Positioning System and GIS: An introduction. Ann Arbor Press, Inc. Chelsea, Michigan. 267 pp.

Kirkman, H. 1990. Seagrass distribution and mapping. pp 19-25. *In:* RC Phillips, CP McRoy (eds). Seagrass research methods: Monographs on oceanographic methodology 9, UNESCO Paris.

Kirkman, H. 1996. Baseline and monitoring methods for seagrass meadows. J. Env. Mgt. 47: 191-201.

Lehmann, A, JB Lachavanne. (eds.) 1997. Special Issue: Geographic Information Systems and remote sensing in aquatic botany. Aquat. Bot. 58: 195-440.

Lee Long, WJ, JE Mellors, RG Coles. 1993. Seagrasses between Cape York and Hervey Bay, Queensland, Australia. Australian J. Mar. Freshw. Res. 44: 19-31.

Lee Long, WJ, RG Coles, LJ McKenzie. 1996a. Deepwater seagrasses in northeastern Australia - how deep, how meaningful? pp. 41-50. *In:* J. Kuo, RC Phillips, DI Walker, H Kirkman. (eds) Seagrass Biology: Proceedings of an International Workshop, Rottnest Island, Western Australia 25-29 January, 1996. Faculty of Sciences, The University of Western Australia.

Lee Long, WJ, LJ McKenzie, RG Coles. 1996b. Seagrass communities in the Shoalwater Bay region, Queensland - Spring (September) 1995 and Autumn (April) 1996. Queensland Department of Primary Industries Information Series QI96042. QDPI, Brisbane. 36 pp.

Lee Long, WJ, LJ McKenzie, MA Rasheed, RG Coles. 1996c. Monitoring seagrasses in tropical ports and harbours. pp. 345-50. *In:* J. Kuo, RC Phillips, DI Walker, H Kirkman. (eds.) Seagrass Biology: Proceedings of an International Workshop, Rottnest Island, Western Australia 25-29 January, 1996. Faculty of Sciences, The University of Western Australia.

Lee Long, WJ, AJ Hundley, CA Roder, LJ McKenzie. 1998. Preliminary Evaluation of an Acoustic Technique for Mapping Tropical Seagrass Habitats. Great Barrier Reef Marine Park Authority Research Publication No. 52, 30 pp.

Lehmann, A, JM Jaquet, JB Lachavanne. 1997. A GIS approach of aquatic plant spatial hetergeneity in relation to sediment and depth gradients, Lake Geneva, Switzerland. Aquat. Bot. 58: 347-361.

Long, BG, TD Skewes, IR Poiner. 1994. An efficient method for estimating seagrass biomass. Aquat. Bot. 47: 277-292.

McKenzie, LJ, MA Rasheed, WJ Lee Long, RG Coles. 1996. Port of Mourilyan Seagrass monitoring, Baseline Surveys - Summer (December) 1993 and Winter (July) 1994. EcoPorts Monograph Series No 2. PCQ, Brisbane. 51 pp.

McKenzie, LJ, WJ Lee Long, AJ Roelofs, CA Roder, RG Coles. 1998. Port of Mourilyan Seagrass Monitoring - First 4 Years. EcoPorts Monograph Series No 15. Ports Corporation of Queensland, Brisbane. 34 pp.

Norris, J, S Wyllie-Echeverria, T Mumford, A Bailey, T Turner. 1997. Estimating basal area coverage of subtidal seagrass beds using underwater videography. Aquat. Bot. 58: 3-4.

NOS/NMFS Centre for Coastal Fisheries and Habitat Research. 1999. Progress Report Essential Fish Habitat: Deepwater seagrass beds of the west Florida Shelf-an overlooked essential fish habitat. Unpublished Internal report, Nov. 1999.

Phillips, RC, CP McRoy. 1990. Seagrass Research Methods. Monographs on oceanographic methodology 9. UNESCO, Paris. 210 pp.

Sheppard, C, K Matheson, J Bythell, P Murphy, C Blair-Meyers, B Blake. 1995. Habitat assessment in the Caribbean for management and conservation-use and assessment of aerial photography. Aquat. Cons. 5: 277-298.

Short, FT, DM Burdick. 1996. Quantifying eelgrass habitat loss in relation to housing development and nitrogen loading in Waquoit Bay, Massachusetts. Estuaries 19: 730-739.

Stoms, DM, FW Davis, CB Cogan. 1992. Sensitivity of wildlife habitat models to uncertainties in GIS data. Photogram. Eng.Rem. Sens. 58: 843-850.

Thomas, M, P Lavery, RG Coles. 1999. Monitoring and assessment of seagrass. pp. 237-268. *In:* A. Butler, P Jernakoff (eds.) Seagrass Strategic Review and Development of an R and D plan. A national Review for the Fisheries Research and Development Council. CSIRO Publishing, Collingwood, Australia.

Udy, JW, WC Dennison, WJ Lee Long, LJ McKenzie. 1999. Responses of seagrasses to nutrients in the Great Barrier Reef, Australia. Mar. Ecol. Prog. Ser. 185: 257-271.

Urick, RJ. 1983. Principles of Underwater Sound. 3rd Edn. Mcgraw-Hill, New York. 423 pp.

Virnstein, RW. 2000. Seagrass management in Indian River Lagoon, Florida: dealing with issues of scale. Pac. Cons. Biol. 5: 299-305.

Walker, DI. 1989. Methods for monitoring seagrass habitat. Victorian Institute of Marine Science Working paper No. 18, Melbourne. 21 pp.

L.J. McKenzie, Northern Fisheries Centre, QDPI, PO Box 5396, Cairns, 4870, Queensland, AUSTRALIA <mckenzl@dpi.qld.gov.au>

M.A. Finkbeiner, NOAA Coastal Services Centre, 2234 South Hobson Ave., Charleston, SC 29405-2413, USA <mfinkbeiner@csc.noaa.gov>

H. Kirkman, UNEP East Asian Seas Regional Coordinating Unit, 10th Flr. UN ESCAP Building, Rajdamnern Av. Bangkok, THAILAND 1200 <kirkman.unescap@un.org>

ERIN, National Marine Information System,
Data Collection and Management Guidelines - Marine Biology and Fisheries
(http://www.environment.gov.au/marine/coastal_atlas/documentation/standards/general/coles.html)

A Standard for Seagrass Resource Mapping and Monitoring in Australia

Robert G. Coles, Warren J. Lee Long and Len J. McKenzie
[A]Queensland Department of Primary Industries, Northern Fisheries Centre, PO Box 5396, Cairns Qld 4870
Tel. 070 529888 Fax. 070 351401
CRC Reef Research, James Cook University, Townsville, Qld 4811
[A]*Address for correspondence*

November 1995

Abstract

Seagrass habitat loss and recognition of the value of seagrass habitats to fisheries in the 1970's and 1980's were the cause for early growth in seagrass research. Developments in seagrass research and data collection standards quickened in pace from the mid-1980's. Turbid, low visibility waters of much of Australia's tropical north coast require different data collection and data protocols to those of clear-water temperate regions. Further differences in approaches between temperate and tropical Australia are also necessary because of differences in seagrass species and habitat types. Measures of seagrass depth range, plant productivity, tissue condition/ nutrient content, biomass, shoot density, etc., can be chosen or adapted to suit the habitat types of any particular region. Regardless of locality, a minimum set of data required for seagrass collection would include:- a sample of seagrass plant lodged with a herbarium for future reference; a latitude and longitude; collector; depth; sediment type; samples of reproductive material and other species present. If collected in addition, seagrass biomass is recorded as g dw m^{-2}. Biomass may be recorded separately for above- and below-ground parts of the plant, although the components measured depend on the species and its growth habit. It may be necessary to record separately leaves and stems for some large species. Other useful measures of abundance include shoot density and leaf-area index or a simple estimate of percentage cover of the bottom. Change in seagrasses can be measured as a change in shoot density; a change in biomass, above- or below-ground; increase or decrease in productivity; species composition; depth range or location of a meadow; change in area or shape of meadows and in associated flora and fauna. Sampling designs for monitoring can include:- stratified; random; systematic or adaptive approaches; and transects, randomised or fixed location of sampling sites according to local conditions and needs. A sampling design for monitoring is tailored to the question being asked, the precision required and the parameters of the habitat being studied. Baseline surveys may need intensive data collection so that initial estimates of spatial variability are available for developing an effective monitoring program. Collection of data on physical attributes such as temperature, salinity, light and nutrients are useful in interpreting changes. Satellite and aerial photo-imagery and use of rectified digital images on GIS basemaps makes for quicker, more precise, drafting and mapping, and more useful data presentation, analysis, interpretation and storage. Differential GPS is a quick method for position fixing during mapping and reduces point errors to <3m in most cases. It is essential that estimates of error and reliability accompany each seagrass map, measure of seagrass aerial extent, and other seagrass parameter estimates. Metadata should be attached to GIS archives to describe data source, data reliability, conditions of use, limits on interpretation and use-by date, and usually includes the correct form of citation to be used for acknowledging the data source.

Introduction

Seagrasses play a vital role in supporting coastal marine communities and in maintaining diverse flora and fauna. They support coastal fisheries productivity and play a role in maintaining coastal water quality and clarity. Fisheries and coastal zone planners in Australia today take into account these values in planning for conservation management of seagrass resources.

Seagrass research in Australia has only recently included a range of studies from cellular to organism, population, community and regional resource level. There has been little formal development and testing for national data collection standards. A standard for seagrass data collection was developed for the ASEAN-Australia Marine Science Project: Living Coastal Resources workshops (English *et al.*, 1994) and a UNESCO guide to seagrass research methods (Phillips and McRoy, 1990) describes techniques for a wide range of research needs from applied to theoretical applications.

We draw on this information for the present paper which addresses the protocols for seagrass resource mapping and monitoring and comments on the collection of essential voucher or reference specimens for taxonomy. Earlier standards for seagrass mapping (eg., Walker 1989) are now part of a growing selection of alternative approaches as improvements in navigation and remote sensing technology and sampling design lead to more efficient and precise methods for mapping. In particular, accessibility to differential global positioning system (GPS) technology has given easy access to more precise position fixes. New methods of assessing seagrass abundance (eg., estimates of biomass techniques, *cf*. Mellors, 1991) enable more sites to be sampled within less time and with considerably less destructiveness. Modifications of grab designs (eg., Long *et al.* 1994) may improve opportunities for sampling in localities where diving is unsafe because of sharks or crocodiles or ineffective because of poor visibility. New equipment for improving divers' visual range in turbid conditions will have impacts on sampling in tropical coastal waters.

The present paper summarises and discusses methods for seagrass data collection and resource mapping and monitoring in Australian waters. The issues, methods and techniques detailed are also relevant to macroalgae.

Sampling Strategy

Published descriptions of methods for mapping and monitoring coastal seagrasses are very recent, eg., Kirkman (1996), Coles and Lee Long (1995) and Lee Long *et al.* (1996). Recognising the differences between tropical and temperate seagrass biology, there will be differences in sampling design and methodology. Our suggested national standard sampling strategy for seagrass resource mapping and monitoring is based on the following background principles.

Background principles for sampling strategies

Baseline mapping programs are best designed with monitoring in mind, and include intensive sampling to allow for the possibility of high levels of temporal and spatial variability. Measures of spatial variability calculated within baseline mapping will influence the design of monitoring programs and the statistical rigour of any tests for detecting change. Baseline data sets must therefore include sufficient density of seagrass data points to enable a reasonable measure of the natural spatial, and temporal variability within the habitat. Monitoring (routine measuring to determine status or condition) requires a different set of information to mapping, and the temporal and spatial scales most suitable for monitoring depend on the questions asked.

Techniques used for sampling aquatic vegetation are variations of those used for terrestrial communities. The difference is that for seagrasses and algae a sampling strategy takes into account the problems of working on the sea-bed. These include limited time for sampling (based on dive tables, or exposure at low tide), limited visibility, difficulty in relocation of sites, high costs of vessel charter and variable sea states. Typically, seagrass habitats in Australia can be in remote locations and may include the added thrill of dangerous marine animals.

Seagrasses can change in several ways. There can be a change in:- shoot density; biomass;

meadow area; meadow shape; species composition; plant productivity and depth distribution. There can be changes in the location of a meadow or a change in the associated fauna and flora, or a combination of some or all of these at small or large spatial and/or temporal scales. These changes may occur naturally and possibly on a regular seasonal basis. There is little information on the range of natural seasonal and year-to-year variability in seagrasses, and this information is a prerequisite to distinguishing human impacts. The seagrass parameters chosen for study depend on the questions to be answered. Seagrass parameters which represent indexes of impact can be monitored at local scales on permanent sites or throughout the meadow. These parameters can include seagrass tissue nutrients/elements (eg., Chlorophyll a, CHO's, C:N:P), plant productivity (eg., growth rates) or seagrass depth range. If it is necessary to know the changes in size of seagrass resources, distribution (maps) and abundance measures (eg., biomass, shoot density) are necessary for the whole meadow. The required precision and intensity of sampling effort will be less for regional scale studies.

Designing sampling programs

We suggest a hierarchy of information is required. To scope the extent of the existing resource, remotely captured (eg. satellite or aerial photography) images combined with ground truthing and specimen collection would be a priority. Locations and areas which support seagrass resources of special importance which are under threat or areas for which more information is required could be identified from this data. At these select sites, detailed sampling would include species composition and estimates of means and variances for parameters such as above-ground biomass or percent cover. The choice of sampling designs (eg. systematic, stratified, multistaged or adaptive), and location of sites (eg. transects, haphazard, random or fixed approaches), will depend on the peculiarities of each study situation. Attention should be drawn to the problems of pseudo-replication, spatial autocorrelation, assigning suitable controls and the difficulties in meeting all the requirements for parametric tests.

Seagrass biomass (above-ground), total area, percent ground cover, and species composition have been the most commonly chosen parameters for monitoring. Measuring seagrass growth parameters (eg. plant growth rates, plant tissue C:N:P, carbohydrate composition) provides greater insight into the causes of change in seagrass abundance. Physical environmental parameters which most often influence seagrass growth are:- light (Photosynthetically Active Radiation), turbidity, depth, temperature, salinity and sediment nutrients. Information on these parameters help in assessing the causes and scale of seagrass loss and the mechanisms for seagrass recovery. Turbidity, light (PAR), salinity and temperature are often included in monitoring, but require more frequent measurements according to the time periods over which they vary and affect seagrass growth and survival (Dennison *et al*. 1993).

The type of information to be collected on coastal habitat types such as seagrass meadows is dependent on the use expected for the data; the questions likely to be asked of the data; and the accuracy and precision of the answers required. Monitoring is easiest to apply to a specific environment concern such as the change likely to seagrasses from a port or harbour development. To measure regional changes it is our view that mapping using qualitative information on spatial distribution and repeated twice a year or at a suitable pre-determined time interval may provide a broad but sufficient indication of change. If changes in the area of seagrass measured this way continued in one direction for three or more sampling intervals, resources could be diverted to investigate the cause of change and, if possible and necessary, to remove the causal agent and at that point in time establish a more detailed monitoring program.

A useful basis for sampling is that adopted recently by the ASEAN-Australia Marine Science Project: Living Coastal Resources (English *et al*., 1994). This details the physical and biological parameters to be monitored, and provides examples of field sampling design, sampling methodology, sample processing, data recording, processing and analysis, with notes on safe procedures. Sampling methodologies detailed in the UNESCO monograph 'Seagrass Research Methods' (Eds. Phillips and McRoy 1990) are also recommended.

Equipment and Field Techniques

Remotely captured (satellite and vertical air-photo) images for seagrass distribution and abundance can be digitised and rectified to geo-coordinates for use on a Geographic Information System (GIS). Acoustic survey techniques are showing promise for mapping and monitoring densely vegetated meadows, but require much more improvement to detect low vegetation cover.

We have regularly used methodologies developed by Mellors (1991) to measure and record change in seagrass biomass and species composition (McKenzie *et al*., 1995). Other methods are described by Long *et al*. (1994) and Saito and Atobe (1970). The method adopted by any particular study will depend on the biological, logistic, cost-benefit, environmental and safety priorities of the study.

A technique developed for intertidal algae (Saito and Atobe, 1970) uses ranked estimates of vegetation cover in quadrats, including detailed assessments of species composition, for each sampling site. Rank estimates of above-ground biomass can also be used, as in Mellors (1991), and this technique is recommended for collecting seagrass biomass estimates from numerous sites, without harvesting large numbers of samples. 5 to 10 reference quadrats can be harvested at the end of a sampling event, to calibrate each persons' visual estimates against actual seagrass biomass measures. Incorporating estimates of species composition in quadrats (Saito and Atobe, 1970), makes the Mellors (1991) method even more useful. Care is required during every estimation of vegetation biomass and composition, but the errors inherent in visual estimates are acceptable if a sufficiently large number of sites are observed.

Where poor visibility prohibits visual estimates, grabs are an alternative for sampling seagrasses. Long *et al.* (1994) tested the use/efficacy of a modified "orange-peel" grab in different sediment and vegetation types, and report acceptable results. We have recently however developed an apparatus for making visual estimates in low visibility waters in northeastern Queensland and expect to publish this method in the near future.

Equipment needed for sample collection

Satellite and aerial-photo images are commercially available, or special aerial photo runs can be arranged. Minimum requirements for ground surveys, include maps/charts (and aerial photos), GPS units (with differential capability if possible), depth measuring instruments, compass, quadrats and data sheets. We regularly use quadrats 50 cm x 50 cm as they are the largest size comfortable for diving operations, although smaller quadrats may be necessary in some circumstances, depending on the seagrass species. The researcher must also be aware of cumulative errors when multiplying measures from small quadrats to per metre square units. Vessels and diving gear are needed for subtidal work. Equipment for harvesting seagrass for biomass measures include:- 5 - 10 quadrats; collecting bags; knives (for cutting rhizomes around edges of quadrats); labels and plastic bags.

Calibration of equipment and samples

Within the Mellors (1991) method, 5 to 10 quadrats - equal in size to the sample quadrats, and across the full range of biomasses observed during the survey - are ranked by each observer, harvested and biomass measured. Estimates of seagrass biomass are calibrated by calculating a regression equation for each observer. The regressions are for observer rank against actual dry weight biomass. Calibrations may need to be repeated for different seagrass species if plant physiology varies. As the Mellors (1991) visual estimates of seagrass biomass are calibrated to actual biomass measures within each survey, data can be cross calibrated with other surveys of seagrass biomass.

Depth measuring instruments are regularly calibrated and depth measures are standardised to depths relative to mean sea level (MSL), using the tidal plane information for each survey locality. The depth of the echo-sounder transducer below the water surface needs to be accounted for.

Spatial resolution

The scale decided upon for mapping or monitoring may determine the overall approach to sampling intensity and influences what is possible with a limited set of financial and human resources. If mapping for resource inventories is on a large scale (eg. the Great

Barrier Reef World Heritage Area) then the intensity of sampling will be low and may detect only broadscale changes. Satellite imagery and aerial photography are useful for mapping where dense seagrasses can be seen on large scales (Kirkman, 1996; Hyland, Courtney and Butler 1989; Long *et al.*, 1994), but cannot always be used to successfully map or monitor seagrass biomass (Walker, 1989) or identify seagrasses of low density, or in water too deep or too turbid for remote sensing (Hyland, Courtney and Butler 1989). This may include vast areas of important seagrass in northern Australia.

If examination of seagrass meadows is required at a finer scale (eg., a port or harbour), the sampling intensity can be higher with greater precision than large-scale or remote areas and smaller levels of change may be detectable. If good quality remote sensing information or aerial photographs are available a stratified sampling design may be possible, requiring less field samples for the same resolution.

Temporal resolution

Seagrass abundance and distribution can change quite dramatically depending on time of year (a six-fold increase in biomass was recorded by McKenzie (1994) between seasons). This information is necessary in designing monitoring programs to measure inter-annual variability of seagrass meadows. A pilot study is recommended if time permits. Seagrass leaf turnover rates can be as quick as 15 days in tropical conditions but much slower (up to hundreds of days) in temperate regions (Hillman *et al.* 1989). Sampling during only one season may miss seasonal seagrass species, and sampling in Winter is likely to record the smallest sustainable distribution for the year. Sampling during the period late Spring to early Summer, at least in the tropics, gives an idea of the highest abundances and greatest distributions.

It is important to ensure seagrass abundance is measured during a period of little seasonal change, and/or monitored at the same time each year and/or measured frequently. Sampling intensity can be concentrated and unevenly spread if the expected change is related to a point source or seagrass species respond differently to the same environmental change. It may be possible to monitor on a different spatial scale to that in the original baseline if sufficient information is available on the likely response of the system. In some cases it is difficult to find a statistical difference in biomass and abundance between adjacent months. Sampling twice or three times a year may be necessary.

Sample storage & labelling

Historically, seagrass voucher specimens have been stored dry pressed on herbarium paper. Specimens can be kept damp in cold storage for short term or fixed in a preservative for longer terms. Freezing larger specimens may result in a deteriorated, "mushie" end-product and is not recommended for taxonomic specimens. Standard procedure is to fix and store in 5-10% seawater formaldehyde. Specimens collected for reproductive section can be stored in 5-10% gluteraldehyde, or in alcohol : acetic acid (3:1) for chromosome analysis. Specific requirements are best discussed with the taxonomist as methods may vary with species type and size or with the investigative procedure. Minimum requirements for labelling include species name, preservative, collector, date, location, latitude and longitude, depth, sediment type and co-occurring species.

Sample and data storage in the field

Seagrass biomass samples for calibrating divers' estimates are stored refrigerated in plastic bags but should be processed within days. We use manually completed hard-copy field data sheets so that special notes and sketches can be incorporated. Total reliance on electronic data may not be possible in a small vessel. Electronically collected GPS data can be downloaded and backed up frequently in the field.

Measuring problems and data quality

It is important to be aware of possible sources of errors that can occur in the field as they directly influence the quality of the data. It is important to document these errors and ensure that this documentation travels with the data. Commonly encountered problems in the field when using the Mellors (1991) visual estimates technique require the following precautions to be taken.

1. Two sets of standard ranks may be necessary when the biomass between meadows varies greatly due to the species composition of a meadow (eg., a high biomass *Zostera* meadow verses a low biomass *Halophila*

meadow). In such a circumstance it is often better to assign standard ranks to individual observers who are instructed to only examine meadows of equivalent biomass (eg., one observer ranks the *Zostera* meadows, while another observer ranks the *Halophila* meadows). This allows finer resolution of biomass estimation and finer levels of detectable change.

2. A photographic record of the standard set of ranks is useful for observers to review when mapping is over several days. This eliminates the chances of 'drift' in estimation.
3. It is necessary to calibrate after every mapping exercise, to eliminate the effects of any "drift" in estimations.
4. When position fixing with a GPS it is important for the observer to be as close as possible to the GPS aerial to minimise position fix error. This can be difficult in small boats under conditions of strong wind and current.
5. Conduct the calibration exercise in the same type of environment as the sampling was conducted so that visual estimates for calibrations reflect the conditions experienced during sampling.

Some Practical Guidelines for Field Work

Guidelines for seagrass sampling are site dependant and local knowledge may be required. Safety should be foremost when sampling the marine environment, paying particular attention to tidal regimes, turbidity, sea-state, dangerous marine animals and other human activities and impacts. Local knowledge of the above factors should always be sought. We strongly recommend that diving policies be developed by each organisation and national safety standards be met.

Documenting physical conditions during sampling

Climatic conditions, sea state, water visibility may effect the quality of data collected and should be recorded. Notes on any peculiarities of a site are also very useful in later validation of data and for general interpretation of patterns observed during field studies.

Data Processing and Reporting

Database management

Relational databases are useful for storage and management of data. A protocol for verification of data and a reliability index is required. The data should be accompanied by any caveats on data reliability, eg., changes in data quality during sampling because of physical changes such as sea state. This is important when data is loaded into a GIS system which is used by managers. GIS data also requires a use-by date. Taxonomic data should be associated with a collector and source of reference material so species revision can be included, or species identification checked at a later date. Original (master) copies of final GIS maps should be stored in two places: the source laboratory and a regional or central archive. Always attach metadata and 'readme' files to GIS files the above-mentioned information on data source, data reliability, conditions of use, limits on interpretation and use-by date. Metadata also includes the correct form of citation to be used for acknowledging the data source.

Assessing change

The size of change in the seagrass habitat that can be detected will depend on the resources available. Measuring a change induced by human activity against a background of natural variability can be difficult as little information is available on natural variability in the tropics and variability may be site and species specific. When assessing the downstream effect of coastal development the amount of change that is economically important may be different to what would be considered ecologically important. Even in countries with advanced research resources, detecting induced year-to-year changes of up to 25% in the tropics is in most cases unrealistic. A 50% year-to-year change in seagrass biomass normally would be detectable against natural change and would be important enough to prompt habitat management concern.

The level of significance (based on the Type I error) and level of assurance (based on the Type II error) in measuring and detecting changes are also important in calculating the most appropriate monitoring design. While it is preferable for the probabilities of both Type I and II errors to be as small as possible, a reduction in the probability of a Type I error inevitably results in an increase in the probability of a Type II error. In monitoring environmental factors such as seagrass abundance, accepting a high probability of Type II error is likely to be more costly in environmental terms than the risk of a Type I error (Peterman, 1990; Fairweather, 1991), ie., it is better to say there is a difference when one does not exist (being over-cautious) than to say there is no difference when in fact a difference does exist. The probability of a Type I error is best risked in an attempt to reduce the probability of a Type II error.

Summary and Conclusions

The use of standards/ guidelines for seagrass data collection and management in Australia is ad hoc and accords to regional and local conditions and available resources. Standards can be adopted across regions of similar species groups, climatic or ecological patterns. Differences between tropical and temperate seagrass systems may require minor regional variations to the implementation of a national standard.

The recommended minimum procedure for ground surveys is use of the Mellors (1991) visual estimates of above-ground vegetation biomass, with estimates of species composition included. This has advantages of sampling numerous sites without having to harvest and process large numbers of samples. It is also the preferred method in sensitive or protected seagrass/ algae meadows. Quantitative (harvested) samples may be more appropriate for smaller experimental studies. The most commonly utilised measures for species which form high canopies still appear to be estimates of percent ground cover or shoot density. Remote sensing is less effective for mapping and monitoring for low vegetation cover, deep water or high. Cost, safety, remoteness, spatial and temporal scale and the questions being asked influence sampling design. Estimates of error and a use-by date are essential, and should where possible be attached to all archived databases and GIS maps.

Acknowledgments

Support for seagrass research in northern Queensland is provided by the Queensland Department of Primary Industries, the Co-operative Research Centre for Sustainable Use of the Great Barrier Reef, the Ports Corporation of Queensland and the Great Barrier Reef Marine Park Authority.

References

Coles, R.G. and Lee Long. W.J. (1995). Marine/coastal biodiversity in the tropical island Pacific region: Population development and conservation priorities. Proceedings of the workshop on Coastal and Marine Biodiversity in the island Pacific, Honolulu, Hawaii, in November 1994: Volume 11, Population, Development, and Conservation Priorities. (In press).

Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S., Bergstrom, P.W. and Batiuk, R.A. (1993). Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. *BioScience*. 43: 86-94.

English, S., Wilkinson, C. and Baker, V. (1994). "Survey Manual for Tropical Marine Resources. ASEAN-Australia marine science project: living coastal resources". (Australian Institute of Marine Science, Townsville.) 368 pp.

Fairweather, P.G. (1991). Statistical power and design requirements for environmental monitoring. *Australian Journal of Marine and Freshwater Research* **42**: 555-567.

Hillman, K., Walker, D.I., Larkum, A.W.D. and McComb, A.J. (1989). Productivity and nutrient limitation. *In*: Biology of Seagrasses. A treatise on the biology of seagrasses with special reference to the Australian region. Eds. A.W.D. Larkum, A.J. McComb and S.A. Shepherd. pp 635-685. Elsevier, Amsterdam.

Hyland, S.J., Courtney, A.J. and Butler, C.T. (1989). "Distribution of seagrass in the Moreton Region from Coolangatta to Noosa". QDPI Information Series QI89010. (Queensland Department of Primary Industries, Brisbane.) 42 pp.

Kirkman, H. (1996). Baseline and monitoring methods for seagrass meadows. *Journal of Environmental Management*. **47**: 191-201.

Lee Long, W.J., McKenzie, L.J., Rasheed, M.A. and Coles, R.G. (1996) Monitoring seagrasses in tropical ports and harbours. Proceedings of the International Seagrass Biology Workshop, Rottnest Island, Western Australia 25-29 January, 1996. Eds. J. Kuo, R.C. Phillips, D.I. Walker and H. Kirkman. University of Western Australia. pp. 345-50.

Long, B.G, Skewes I.D. and Poiner I.R. (1994). An efficient method for estimating seagrass biomass. *Aquatic Botany* **47**: 277-292.

McKenzie, L.J. (1994). Seasonal changes in biomass and shoot characteristics of a *Zostera capricorni* Aschers. dominant meadow in Cairns harbour, northern Queensland. *Australian Journal of Marine and Freshwater Research* **45**: 1337-52.

McKenzie, L.J., Rasheed, M.A., Lee Long, W.J. and Coles, R.G. (1995) "Port of Mourilyan seagrass monitoring, baseline surveys, Summer (December) 1993 and Winter (July) 1994". Ports Corporation of Queensland Environmental Monograph Series. (PCQ: Brisbane) (In press).

Mellors, J.E. (1991). An evaluation of a rapid visual technique for estimating seagrass biomass.. *Aquatic Botany* **42**: 67-73.

Peterman, R.M. (1990). Statistical power analysis can improve fisheries research and management. *Canadian Journal of Fish and Aquatic Sciences* **47**: 2-15.

Phillips, R.C. and McRoy, C.P. (1990). "Seagrass Research Methods". Monographs on oceanographic methodology 9. (UNESCO, Paris). 210 p.

Saito, Y. and Atobe, S. (1970). Phytosociological study of intertidal marine algae. I. Usujiri Benten-Jima, Hokkaido. *Bulletin of the Faculty of Fisheries, Hokkaido University* **21**: 37-69.

Walker, D.I. (1989). "Methods for monitoring seagrass habitat". Victorian Institute of Marine Science Working paper No 18. 21 p.

SEAGRASS BIOLOGY: PROCEEDINGS OF AN INTERNATIONAL WORKSHOP

Rottnest Island, Western Australia, 25 - 29 January 1996 pp 345-350
Editors: John Kuo, Ronald C. Phillips, Diana I. Walker and Hugh Kirkman

Monitoring Seagrasses in Tropical Ports and Harbours

WARREN J. LEE LONG, LEN J. MCKENZIE, MICHAEL A. RASHEED and ROBERT G. COLES
Queensland Department of Primary Industries, Northern Fisheries Centre. PO Box 5396.
Cairns Qld 487O. Australia

Key words: Seagrass, tropical, monitoring, coastal management, mapping.

Abstract

Ecologically and economically important seagrass habitats are often insheltered coastal sites threatened by port and harbour development. These seagrass habitats provide population and community parameters which can be readily measured and as a result are useful for monitoring downstream impacts from catchment and port development activities. Environment monitoring programs which are appropriately designed to detect realistic levels of change, enable port and coastal management agencies to make decisions with greater confidence. The design of sampling programs to obtain baseline data on seagrass distribution and abundance must include sufficient numbers of samples to enable a calculation of the minimum monitoring effort required to detect changes which are statistically and biologically meaningful. With little information on natural inter-annual variability in tropical seagrasses, we consider an inter-annual change of-at least 50% in areal extent or 70% in above-ground biomass sufficient to prompt management action. Other reasons that should prompt a management response include significant changes in species composition, seagrass growth characteristics, or depth distribution, or a trend in one direction for anyone of these parameters over three successive sampling periods. Measures of change in these coastal resources need to be presented along with advice on legislative measures for protection of seagrasses. Marine environment planning and management processes with community consultation, legislative power, and support from education and enforcement will help to maintain community and government concern for the protection of our limited seagrass resources.

INTRODUCTION

Coastal zone managers increasingly recognise the importance of seagrasses in coastal marine communities for supporting diverse flora and fauna, in supporting coastal fisheries productivity (Fortes 1990; Coles et aI.. 1993; Watson, Coles and Lee Long, 1993), in stabilising sediments and maintaining coastal water quality and clarity (Ward, Kemp and Boynton, 1984; Fonseca and Fisher, 1986), In the tropics, turtles and sirenians (Dugong dugon) are direct grazers of seagrasses (Lanyon, Limpus and Marsh, 1989), The importance of these endangered species and the demonstrated value to fisheries has ensured ongoing management for seagrass conservation in north eastern Australia,

Seagrasses are often at the downstream end of catchments, receiving runoff from a range of agricultural, urban and industrial land-uses. Their ecological values and location in areas likely to be developed for harbours and ports have made seagrasses a potential target for assessing environmental health and impacts on coastal systems. The ideal "bio-indicator" must, however, show measurable and timely responses to environmental impacts. Seagrass habitats in ports provide sessile plants - individuals, populations and communities - which can all be easily measured. Seagrass plants generally remain in place so that the prevailing anthropogenic impacts can be monitored.

Altered seagrass depth distribution in Chesapeake Bay (Dennison *et al.* 1993) was the "indicator" when runoff-impacts on water quality caused changes in light penetration and consequently affected seagrass abundance and distribution patterns. Improved knowledge of the relationships between various seagrass growth characteristics and environmental parameters such as light and nutrients (eg. Short, 1987; Dennison *et al.* 1993) provide very useful tools for monitoring environmental impacts on coastal seagrass systems.

Our work focuses at the level of seagrass populations and communities. We discuss how seagrass abundance, species composition and distribution patterns can be monitored to assess environmental change and detect impacts in coastal localities. We present this approach as an adjunct to measurements on seagrass plants, such as growth characteristics and tissue composition.

There is a paucity of baseline mapping, surveys, and monitoring of seagrasses. Measures of seagrass loss - natural or human-induced - have been opportunistic and mostly after the event. Many baseline data sets are also inadequate for quantifying subsequent change. We obtain detailed baseline measures of seagrass abundance and distribution, to establish and design monitoring programs to reliably detect change. This approach considers the changes at a "whole-of- meadow" level - in assessing environmental impacts.

Increased requirements for accountability in coastal management decisions have caused greater need for statistical rigour in design of sampling programs for monitoring environmental impacts. We discuss some of the issues which require thorough consideration in determining an appropriate sampling design.

MEASURING CHANGES IN SEAGRASS MEADOWS

The expected use of the data, the questions likely to be asked of the data, and the accuracy and precision of the answers required determine the type of information we collect from coastal seagrass habitats. Government agencies and coastal zone managers need to know the extent of natural change in seagrasses. The impacts - particularly habitat losses - from catchment and port activities can then be separated from normal background variation.

Seagrass meadows can change in several ways. There can be a change in biomass without a change in area; a change in area, or shape, depth or location of a meadow; a change in species composition, plant growth and productivity, the fauna and flora associated with the meadow, or a combination of some or all of these. These changes will also occur naturally and on a regular seasonal basis. Environment monitoring programs require knowledge of these patterns of natural change. They also require cost-effective data collection, selection of appropriate parameters and scales, and measures of change which are statistically appropriate for determining if management action is required.

We suggest that a hierarchy of information is required. Initially, the extent of the existing resource can be assessed using aerial photography images combined with ground surveys. Locations and areas which support seagrass resources, or areas for which more information is required should be identified. For most localities, baseline maps of seagrass resources either do not exist, or do not provide sufficient detail to enable reliable detection and assessment of change.

Baseline mapping, the next step, should aim to provide a data set suitable for developing a monitoring program, and where statistically valid measures of change can be gained. At ports in northern Queens- land, initial surveys of seagrass meadows include numerous sites on each meadow so that a useful estimate of the spatial variability within each meadow can be obtained. These estimates are important for calculating the optimum sampling effort required during monitoring to detect various levels of change.

Sampling designs for monitoring, the last step, can now be developed to ensure that various levels of change can be detected. It is important to design programs to detect levels of change which are realistically set, and statistically valid, so that port and coastal management agencies can make decisions with a measurable risk assessment.

A good understanding of the influences of climatic factors, light, temperature, nutrients, and water quality on seagrass growth can provide additional information which will allow a more meaningful interpretation of likely causes of change. This will consequently enable management decisions and actions to be directed towards the causes of impacts. If there is no existing information on the response of seagrasses to physical environmental factors, they may need to be incorporated in the monitoring program. Measures of change in seagrass distribution, abundance, growth patterns, productivity, morphology or nutrient content, is of limited value without information on the likely influencing factors, including factors that possibly pre-date the changes in seagrasses.

MAPPING AND MONITORING

In mapping the aerial extent of the seagrass meadows, it is necessary to determine the relative importance of different seagrass areas. Effort within long-term monitoring programs can then be focussed on the meadows which are important from ecological or economic points of view. In the process, spatial scale and the information required need to be considered.

Scale

With limited financial and human resources, spatial scale influences what is possible. Small-scale and local seagrass meadows can be mapped and monitored more accurately than large-scale and remote meadows. Satellite imagery and aerial photography are useful for mapping where dense seagrasses can be seen on very large scales (Kirkman, 1990; Hyland, Courtney and Butler, 1989; Long, Skewes and Poiner, 1994), but cannot always be used successfully to map or monitor seagrass biomass (Walker, 1989) or identify seagrasses of low density, or in water too deep or too turbid for remote sensing (Hyland *et al.* 1989). In these instances ground surveys (walking, diving or grabs) are essential.

When the total seagrass resources of a locality are mapped, it is not necessary to monitor all of them in order to assess environmental impact. It is more cost effective to focus monitoring effort on priority areas or meadows. Selecting "monitoring meadows" requires some knowledge of the biology of species present and habitat! ecological or economic value of the different meadows.

Information Required

Choosing the most efficient and appropriate parameter(s) to monitor is equally important. Seagrass species composition and its abundance, eg., biomass (above-ground), total area, or percent ground cover, can be measured quickly and have been the most commonly chosen parameters. Seagrass growth parameters (eg. plant growth rates, plant tissue C:N:P, carbohydrate composition) are proving useful for obtaining insight into the causes and mechanisms of change in seagrass abundance.

At the "meadow level", measures of species composition, and estimates of means and variances for parameters such as above-ground biomass or percent cover, can be easily obtained. Techniques which involve visual estimates of above-ground seagrass biomass (eg., based on Mellors, 1991) are recommended, because they enable observers to obtain numerous records of above-ground biomass within meadows without collecting and processing numerous biomass samples. Estimates of above-ground seagrass biomass and species composition are recorded for each sample quadrat, and observers' estimates are calibrated against actual seagrass biomass from 5 to 10 samples which are harvested and measured. It is ideal to have information on additional parameters (eg., below- ground biomass), but these are often expensive and labour-intensive to collect. Ratios of above-ground: below-ground biomass can be obtained at permanent sites if resources are sufficient.

Physical parameters measured usually include depth (below MSL) and sediment composition. - Turbidity, light (PAR), salinity and temperature should ideally be included in monitoring, but require more frequent measurements according to the time periods over which they vary and affect seagrass growth and survival (Dennison *et ai.*, 1993). Depth at which seagrasses occur can be a useful indicator of impact (Dennison *et al.* 1993) and may change according to light attenuation in the water column.

CAUSES OF CHANGE

Monitoring programs should ideally be designed to quantify the causes of change; examine and assess acceptable ranges of change for the particular site; and measure critical levels of impacting agents. Intensive monitoring of large areas or large suites of parameters is often prohibitively expensive and requires considerable expertise in the systems being studied. Monitoring is easiest to apply in a specific environmental concern such as the change likely to occur in seagrasses resulting from a particular port or harbour development. To measure regional changes it is our view that mapping using qualitative information on spatial distribution and repeated biannually or at a suitable pre-determined time interval may provide a broad but sufficient indication of change. If changes in, for example, the area of seagrass measured this way continued in one direction for three or more sampling intervals, resources could be diverted to investigate the cause of change and, if possible, to remove the causal agent.

QUANTIFYING CHANGE

The size and types of change in a seagrass habitat that can be detected depend on the sampling design of both baseline surveys and monitoring programs. That is, sufficiently detailed information on baseline seagrass abundance (eg., biomass), species and areas are required from which to measure change. Baseline data sets must include sufficient density of seagrass data points to enable a reasonable measure of the natural spatial, and temporal variability within the habitat. The size of spatial variability measured in the baseline survey will influence the statistical design and sampling intensity required to detect changes through subsequent surveys.

Once the locations and features of individual monitoring meadows have been clearly established, the location and number of sites for monitoring seagrass parameters in the meadow(s) must be determined. Measuring a change (eg., in biomass) induced by human activity against a background of natural variability can be difficult and variability may be site and species specific. Spatial distribution of sampling sites can be concentrated and unevenly spread particularly if the expected change is related to a point source or different seagrass species respond differently to the same environmental change. It may be possible to monitor on a different spatial scale to that in the original baseline if sufficient information is available on the likely impacts and nature of response of the system.

In some cases the use of "repeated measures" at "permanent sites" may help to reduce spatial variability within monitoring, so that temporal change can be tested for more efficiently. When permanent sites (either points or transects) can be set up in seagrass meadows they must be properly located and sufficient in number to ensure that changes detected are representative of the whole meadow or the parts of the meadow being monitored. Permanent sites in seagrass meadows are not always logistically possible. Tropical seagrass meadows are naturally more dynamic than their temperate counterparts and may change shape markedly between years, without necessarily changing their abundance. Some fixed sites in this case may indicate that a large change has occurred, where in fact the meadow has simply moved.

If, for any reason, permanent sites cannot be used, and the changes that are likely to occur over parts of a meadow are unknown, it will be necessary to have sampling sites across the whole meadow. In this case the "whole meadow" is the monitoring unit and to enable detection of any change, a sampling design will require sites randomly (or haphazardly) spread across the whole meadow. If an adequate measure of spatial variability within the seagrass meadow is calculated from the baseline survey, it is possible to mathematically determine the required minimum number of randomly located sites, and sample units at each site, sufficient to detect any desired amount of temporal change for the meadow.

In summary, if a particular impact from a point source or localised impact is expected, monitoring at fixed sites may be best. If the response of a seagrass meadow is less predictable, fixed sites or transects (ie., repeated measures design) combined with numerous sites randomly or haphazardly spread across the meadow (random design) will be necessary. In either case it is advisable to sample heavily in the baseline study so that levels of variability in the meadow can be used to mathematically determine the minimum number of sites and replicates necessary for detecting statistically significant changes.

An impact can usually be assumed when change in seagrass abundance or distribution is correlated with some likely impacting agent. Control sites can also be used to identify whether changes are induced or natural, but it is uncommon to find ideal control sites in any marine environment study. If control sites are available a single control is always less reliable than multiple controls in seeking statistical comparison with impacted sites.

An understanding of natural seasonal change is necessary in designing sampling programs to detect annual changes. In Papua New Guinea, variation in standing crop for five species was about two-fold for *Cymodocea serrulata* and three-fold for *Halodule uninervis* (Brouns, 1987). Mellors, Marsh and Coles (1993) reported only a two-fold seasonal change in all species at Green Island (17ºS), on the Great Barrier Reef, associated primarily with changes in temperature and light availability. In coastal meadows of *Zostera capricorni* at nearby Cairns Harbour, McKenzie (1994) recorded a 6-fold increase in above- ground biomass from winter to late spring. Some tropical *Halophila* species may be annuals and be almost completely absent at times of the year, leading to very large seasonal biomass changes (Kuo, Lee Long and Coles, 1993). In particular, it is important to ensure seagrass abundance is measured during a period of little seasonal change, and/or monitored at the same time each year.

The characteristics of seasonal and inter-annual changes in other tropical seagrasses are still poorly understood, but in many cases sufficient to make decisions on what approximate level of change in seagrass abundance should prompt environment management action. When assessing impacts on coastal seagrasses, the amount of change that is considered economically important may be different to what would be considered ecologically important. There is little information available on ecology of tropical seagrasses, in particular regarding inter-annual changes and impacts on seagrass abundance. Natural inter-annual change in tropical seagrasses appears to be relatively large. At Cairns Harbour (17°S), above-ground biomass at *Zostera capricorni* sites varied up to 70% between years (McKenzie, 1994). In the Gulf of Carpentaria *(16°S)* Poiner *et al.* (1989) detected inter-annual changes of up to approximately 50% in mean above-ground seagrass biomass at a control site. We consider at least a 50-70 % change in above-ground seagrass biomass would normally be sufficient to prompt management action.

In testing for differences in seagrass abundance between any two sampling events for any particular seagrass meadow, statistical rigour is increasingly essential. The level of significance (based on the Type I error) and level of assurance (based on the Type II error) in measuring and detecting changes are both important in calculating an appropriate sampling design. The probability of a Type I error is chosen prior to a test and is usually set at 5%. The probability of a Type II error depends on the choice of the Type I error probability. While it is preferable for the probabilities of both Type I and II errors to be as small as possible, a reduction in the probability of a Type I error inevitably results in an increase in the probability of a Type II error. In monitoring environment factors such as seagrass abundance, accepting a high probability of Type II error is likely to be more costly in environment terms than the risk of a Type I error, (Peterman, 1990; Fairweather, 1991). It is better to say there is a difference when it does not exist (being over-cautious) than to say there is no difference when in fact a difference does exist. The probability of a Type I error is best risked in an attempt to reduce the probability of a Type II error. We generally set the probability of a Type I error at 10% and a Type II of 10%. That is, we attempt to design sampling programs for monitoring such that a given percentage change in the mean will be detected at the 90% level (Type I error of 10%) with 90% assurance of detecting a true difference of this size (Type II error of 10%).

Interpreting changes in distribution (aerial extent) of seagrass also requires consideration of the errors involved in mapping the edges of seagrass meadows. It is difficult to calculate a standard error or 95% confidence limits value on estimates of seagrass area, but all studies should include some reference to the expected sizes of errors in position fixing, line drawing, etc. The spatial intensity of sample sites used in map- ping usually has a large effect on the estimated meadow shape and size. Through persistent attention to the problems of mapping error, it is usually possible to quickly develop field methods which will reduce these errors to reasonable size.

DISCUSSION AND CONCLUSIONS

Methods and sampling designs will continue to be modified and improved and the approach described here is not intended as a standard suitable or all situations. We recognise that sampling designs are largely influenced by logistics, safety issues and resource limitations. There is still a great need to test the precision and efficiency of various sampling methods. Priority should be placed on selecting appropriate parameters for study, so that the study results and subsequent environmental assessments are ecologically meaningful.

Useful collecting methods and approaches for de- signing monitoring programs include those adopted recently by the ASEAN-Australia Marine Science Project: Living Coastal Resources (English, Wilkinson and Baker 1994). This details physical and biological parameters which can be monitored, field sampling designs, sampling methodology, sample processing, data recording, processing and analysis, with notes on safe procedures. Mellors (1991) and Long *et al.* (1994) provide sampling methods of particular use in mapping and monitoring seagrass abundance. A choice of seagrass research methodologies is provided in a recent UNESCO handbook (Phillips and McRoy, 1990). Continual advances in technology will enable improvements in sampling efficiency and design. Access to aerial photography and differential global positioning system (GPS) equipment will have huge impacts on precision of mapping and position fixing.

Information on seagrasses can now be stored and analysed using Geographic Information Systems (GIS) and presented in a form understandable by managers concerned with catchment, port and coastal environments. GIS software can be used to present, analyse and interpret data on changes in seagrass meadows. Alternatively, hand-drawn maps, if provided with measures of scale, can be digitised at a later date for monitoring purposes. As data in GIS systems may be used later by organisations unfamiliar with the original program, it is essential that the underlining data bases include estimates of precision and are kept up to date.

Cost effective and statistically valid results in map- ping and monitoring seagrass habitats will be increasingly required as the community seeks accountable actions from managers of the coastal environment. Where effective monitoring programs are still difficult to achieve, community education on the values of seagrass habitats and of likely development impacts will help to achieve responsible management of the marine ecology in many ports and harbours.

ACKNOWLEDGEMENTS

We thank Mr David Reid for instructive input into sampling and statistical design. Support for seagrass monitoring programs in northern Queensland is provided by the Queensland Department of Primary Industries, the Co-operative Research Centre for Sustainable Use of the Great Barrier Reef and the Ports Corporation of Queensland.

REFERENCES

Brouns J J W M 1987 Growth patterns in some Indo-West-Pacific seagrasses. *Aquat. Bot*. 28: 39-61.

Coles R G, Lee Long W J, Watson R A and Derbyshire KJ 1993 Distribution of seagrasses, and their fish and penaeid prawn communities, in: Cairns Harbour, a tropical estuary, north Queensland, Australia. *Aust. J. Mar. Freshwater Res.* 44: 193- 210.

Dennison W C, Orth R J, Moore K A, Stevenson J C, Carter V, Kollar S, Bergstrom P Wand Batiuk R A 1993 Assessing water quality with submersed aquatic vegetation: Habitat requirements as barometers of Chesapeake Bay health. *BioScience.* 43: 86-94.

English S, Wilkinson C and Baker V 1994 Survey manual for tropical marine resources. ASEAN-Australia marine science project: living coastal resources. 368 p. Australian Institute of Marine Science, Townsville.

Fairweather P G 1991 Statistical power and design requirements for environmental monitoring. *Aust. J. Mar. Freshwater Res*. 42: 555-567.

Fonseca M S and Fisher J S 1986 A comparison of canopy friction and sediment movement between four species of seagrass with reference to their ecology and restoration. *Mar. Ecol. Prog. Ser*.29:15-22.

Fones M D 1990 Seagrasses: A resource unknown in the ASEAN region. United States Coastal Resources Management Project. Education Series No 6. 46 p.

Hyland S J, Courtney A J and Butler C T 1989 Distribution of seagrass in the Moreton Region from Coolangatta to Noosa. QDPI Informatipn Series QI89010. Queensland Department of Primary Industries, Brisbane. 42 p.

Kirkman H 1990 Seagrass distribution and mapping. In: Seagrass Research Methods - Monographs on oceanographic methodology. Eds R C Phillips and C P McRoy. pp 19-25. UNESCO, Paris.

Kuo J, Lee Long W J and Coles R G 1993 Fruits and seeds of *Halophila tricostata* Greenway (Hydrocharitaceae), wi~h special notes on its occurrence and biology. Aust. J. Mar. Freshwater Res. 44: 43-57.

Lanyon J, Limpus C J and Marsh H 1989 Dugongs and turtles; grazers in the seagrass system. In: Biology of seagrasses. A treatise on the biology of seagrasses with a special reference to the Australian region. Eds A W D Larkum, A J McComb and S A Shepherd. pp 610-634. Elsevier, Amsterdam.

Long B G, Skewes I D and Poiner 1 R 1994 An efficient method for estimating seagrass biomass. *Aquat. Bot*. 47: 277-292.

McKenzie L J 1994 Seasonal changes in shoot characteristics of a *Zostera capricomi* Aschers. dominant meadow in Cairns harbour, northern Queensland. *Aust. J. Mar. Freshwater Res*. 45: 1337-1352.

Mellors J E 1991 An evaluation of a rapid visual technique for estimating seagrass biomass. *Aquat. Bot.* 42: 67-73.

Mellors J E, Marsh H and Coles R G 1993 Intra-annual changes in seagrass standing crop, Green Island, northern Queensland. *Aust. J. Mar. Freshwater Res*. 44: 19-32.

Peterman R M 1990 Statistical power analysis can improve fisheries research and management. Can. J, Fish. *Aquatic Sci.* 47: 2-15.

Phillips R C and McRoy C P 1990 Seagrass Research Methods, Monographs on oceanographic methodology 9. UNESCO, Paris. 210 p.

Poiner I R, Walker D I and Coles R G 1989 Regional studies- Seagrasses of tropical Australia. In: Biology of seagrasses. A treatise on the biology of seagrasses with a special reference to the Australian region. Eds A W D Larkum, A J McComb and S A Shepherd. pp 279-296. Elsevier, Amsterdam.

Short F T 1987 Effects of sediment nutrients on seagrasses: Literature review and mesocosm experiment. *Aquat. Bot.* 27: 41-57.

Walker D I 1989 Methods for monitoring seagrass habitat. Victorian Institute of Marine Science Working paper No 18. 21 p.

Ward L G, Kemp W M and Boynton W R 1984 The influence of waves and seagrass communities on suspended particulates in an estuarine embayment. *Mar. Geo*. 59: 85-103.

Watson R A, Coles R G and Lee Long W J 1993 Simulation estimates of annual yield and landed value for commercial penaeid prawns from a tropical seagrass habitat, northern Queensland, Australia. *Aust. J, Mar. Freshwater Res*. 44: 211-221.