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Development of methods for the evaluation and monitoring of seagrass habitat structure

Prepared for the Coastal Management Branch of the Department for Environment & Heritage SA
and the
Adelaide & Mount Lofty Natural Resources Management Board

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TABLE OF CONTENTS

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This work presents a new and integrative method for assessing seagrass habitat structure using standard sampling techniques. As such, the open-minds and lateral thinking required of Jason Tanner and Sue Murray-Jones, who provided feedback throughout the method development, is appreciated. Furthermore, I'm grateful to Jackie Dupavillon for the long hours she spent analysing video transects through seagrass, which provided the data needed to 'road test' the habitat structure calculations. Many thanks are due to the South Australian Department for Environment & Heritage, and the Adelaide & Mount Lofty Natural Resources Management Board, for providing research funds, and in particular Sue Murray-Jones, Doug Fotheringham, and Tony Flaherty for their continued and enthusiastic support of seagrass research in South Australia.

EXECUTIVE SUMMARY

It is widely accepted that seagrass meadows play a key role in maintaining the ecology and environment of coastal regions throughout the world. Consequently, estimating the amount of seagrass habitat, and detecting any changes in abundance over time, have often become critical components of coastal monitoring programs.

Many different methods have been used to quantify seagrass habitat structure, with most often focussing on one or two variables perceived as being of greatest importance (e.g. biomass, percent cover, etc.) to describe the overall condition or 'health' of the seagrass meadow(s) studied. The aims of this work were to

1) Review previous and current research of seagrass habitat structure (e.g. cover, biomass, morphometrics, epiphyte load, etc.) done in South Australia to understand the range of techniques used and variables of interest, and to identify any common elements among them.

2) Develop a new and integrative method for quantifying seagrass habitat structure that uses multiple habitat variables, can be applied using different sampling techniques, and provides data that are directly comparable to data from other locations and times, including past data sets.

A review of past and current research on seagrass meadows in South Australia revealed a variety of approaches and variables of interest. *In situ* sampling by SCUBA divers or snorkelers using standard sampling methods (quadrats, transects, etc.) is the most common approach, with seagrass often harvested to determine biomass and morphometrics (e.g. leaf length and density). Video transect sampling has become more popular over time and has the added advantage of providing an archived record. Since this method is remote, seagrass area (percent cover) and species identity are the most common variables sampled. Aerial and satellite image analysis have also been used on occasion, usually to examine changes in the area of seagrass and changes in nearshore margins of meadows.

The review of seagrass research in South Australia was used to inform the development of a new method for quantifying seagrass habitat structure, termed H'. Essentially, H' integrates multiple variables (area, density, species identity, continuity, and proximity) and evenly weights them to a single dimensionless number (H') that is scaled from 0 to 100. A value of 100 indicates seagrass with excellent structure, with structure deteriorating as H' approaches zero. Importantly, data for the calculation of H' can be gained using in situ sampling (divers),

video transects, and possibly also aerial or satellite images (a modified H’ would most likely be needed for aerial/satellite data). Example calculations of H’ are given using several hypothetical examples, and a procedure for incorporating further variables into an assessment of seagrass habitat structure is provided.

1. INTRODUCTION

Seagrass beds are an iconic feature of tropical and temperate coasts around the world, typically creating extensive biogenic habitats for a broad range of fish and invertebrate taxa (Bruno & Bertness 2001; Gillanders 2006), as well as providing a number of important ecosystem services (e.g. carbon sequestration, nutrient cycling, coastal stabilization; Romero et al. 2006). However, seagrasses are also susceptible to many natural and anthropogenic disturbances, with extensive loss of seagrass most commonly experienced on urbanized coasts (e.g. Clarke & Kirkman 1989; Walker et al. 2006).

Given their valuable ecological roles and the ability for human activities to disrupt them, the evaluation and monitoring of seagrass habitats has become common in many parts of the world (Duarte & Kirkman 2001; McKenzie et al. 2001; Bryars & Rowling 2008), and is often done to detect changes in habitat parameters (e.g. loss or gain), identify possible causes, implement measures to manage changes (e.g. mitigate impact), and to quantify subsequent effects (e.g. recovery of habitat). Most often, the magnitude of seagrass loss following a disturbance (either natural or anthropogenic in origin) and the rate of recovery are of great interest to managers, researchers, and numerous other stakeholders such as fishers and coastal property owners (e.g. McArthur & Boland 2006).

Many different methods have been used to monitor seagrass and quantify seagrass habitat structure, with most often focussing on one or two variables perceived as being of greatest importance (e.g. biomass, percent cover, etc.) to describe the overall condition or 'health' of the seagrass meadow(s) studied. Focussing on one variable may be informative, but may fail to capture significant changes to seagrass habitats. For example, sampling seagrass biomass during some type of disturbance regime (e.g. construction of a marina) may reveal small-scale changes, but is unlikely to detect larger-scale fragmentation and loss of meadows, which is information that is arguably more relevant for coastal managers. Indeed, a method that integrates multiple variables would be a step towards a more comprehensive assessment of temporal and spatial trends in overall seagrass habitat structure.

Given this context, the aims of this work were to

1) Review previous and current research of seagrass habitat structure (e.g. cover, biomass, morphometrics, epiphyte load, etc.) done in South Australia to understand the range of techniques used and variables of interest, and to identify any common elements among them.

2) Using the information identified in the review, develop a new and integrative method for quantifying seagrass habitat structure that uses multiple habitat variables, can be applied using different sampling techniques, and provides data that are directly comparable to data from other locations and times, including past data sets.

In essence, the review of past and present seagrass research in South Australia identifies the trends in seagrass research methods and variables most commonly perceived as important in describing seagrass structure and condition. The new method for quantifying seagrass habitat structure has been developed to be inclusive of as many commonly sampled variables as possible. Additionally, it is independent of time and space such that the output values calculated today can be compared to those of past and future work, which is most useful for identifying changes to seagrass meadow structure over time.

2. HISTORICAL SAMPLING OF SEAGRASS IN SOUTH AUSTRALIA

South Australia boasts impressive coastal habitats, but they are not immune to change. Seagrasses have experienced substantial decline in some areas, particularly off the coast of Adelaide where more than 5000 ha have been lost since the 1950s (Seddon 2002; Westphalen et al. 2005).

A number of sampling techniques have been used for research on seagrass habitats in South Australia. Bryars & Rowling (2008) conducted an exhaustive review of seagrass research off Adelaide's coast, citing studies that use data from as far back as the 1930s. Upon inspection, and including the study of Bryars & Rowling, it is clear that the majority of work has been done using *in situ* sampling by divers for some or all of the study (21 out of 26 studies cited). Moreover, the use of quadrat (8 studies) and transect (6 studies) based sampling is common, with three studies using spot dives to observe habitat type or species (i.e. presence-absence data). The habitat variables most commonly sampled include species composition, area (extent) of habitat, density of shoots, above-ground biomass, and leaf morphometrics (length, width, etc), with epibiotic load and seagrass productivity also sampled on occasion.

In situ sampling using underwater video is another method (4 of 26 studies cited), where area of habitat and species composition are primarily sampled. Likewise, analysis of aerial photographs has been used with considerable success to map the area of habitat and changes in the nearshore margins of seagrass beds (4 of 26 studies cited).

Studies of seagrass in regional South Australia have generally used similar methods and sampled similar variables (Appendix A). Again, the majority of studies have used *in situ* sampling by divers using quadrats and/or transects (6 of 9 studies), with remote video sampling and aerial photography to identify species distribution also used (3 of 9 studies). One recent study by Miller & Wright (2008) made use of video sampling, satellite imagery, and acoustic sounding to quantify seagrass species distribution and density in the Investigator Group of islands.

The variables typically sampled are similar to those sampled on Adelaide's coast, including species composition, distribution and density, leaf morphometrics (length & width), and biomass of seagrass and epibiota. Bryars & Wear (2008) also sampled the density of flowering individuals and densities of herbivorous gastropods, the latter being related to the abundance of algal epiphytes found on seagrass leaves.

3. RECENT AND CURRENT SAMPLING OF SEAGRASS IN SOUTH AUSTRALIA

3.1 South-East

In the context of assessing potential impacts of freshwater drainage from land on seagrass condition, Wear et al. (2006) sampled seagrass beds at numerous locations in the state's south-east but concentrated on sampling in Lacepede and Rivoli Bays where drains discharge directly into seagrass meadows. Their approach used divers to harvest *Posidonia sinuosa* and/or *P. australis* at the sediment level using 10 quadrats (25 × 25 cm) at each site in October 2004 and April/May 2005. The photosynthetic activity of seagrasses was also sampled *in situ* using PAM fluorometry. Harvested seagrass was processed in the laboratory, where leaf length, width, area, density, and epiphyte load were identified as useful for detecting effects of altered environmental conditions. In addition, a number of water quality parameters were tested (salinity, temperature, turbidity, nutrient concentration, pesticides/herbicides, and chlorophyll a) to identify possible mechanisms for effects of freshwater drains of seagrasses.

Video transects were undertaken to identify habitat types at fixed positions either side of the freshwater drains. Transects were ~ 50 m long with images sampled for habitat type (e.g. seagrass, macroalgae, sand etc.), density, and epiphyte cover. In addition, historical profile lines were sampled (and new lines established) to quantify long-term changes in seafloor height, which can be useful for understanding changes in seagrass abundance given the tendency of seagrasses to trap sediments.

Based on the results of this work, a seagrass monitoring program for the region was outlined to enable the detection of future changes in seagrass distribution and condition. Numerous techniques were recommended, including the monitoring of profile lines to detect change in the nearshore seagrass line, aerial photography to map large-scale changes in seagrass distribution, and the sampling of seagrass leaf/shoot density and leaf length. Concurrent sampling of water quality to correlate with seagrass variables was also recommended.

3.2 Kangaroo Island

One of the more comprehensive seagrass monitoring programs currently being done is managed through the Kangaroo Island Natural Resources Management board (Danny Brock & Martine Kinloch, pers. comm.). This program uses a grid of fixed sampling points, with 50 m-long video transects recorded from each point (i.e. similar to the method of Bryars & Rowling 2008). The video camera is positioned face-down, so that individual frames from the video footage can be captured and analysed for seagrass species composition, percent cover, and cover of epiphytes. In a typical 50 m transect, ten such frames are sampled.

The intensity of sampling on Kangaroo Island is governed by the landscape-scale distribution of seagrass, as well as the resources available. For locations with extensive cover (e.g. Emu Bay), sampling intensity is maximised (e.g. 60 fixed sampling points across the bay). In locations where seagrass beds are more fragmented (e.g. Western Cove), sampling is stratified to occur within extant seagrass beds so that time and resources are not wasted sampling bare sand. Regardless of spatial sampling intensity, each location is intended to be sampled every 2 – 3 years on a rotational basis.

3.3 Environmental Protection Authority (EPA)

The South Australian EPA has also been involved in several seagrass sampling projects. As of March 2009, the EPA was reviewing its sampling methods with a likely outcome being a switch from SCUBA-based methods to video-based methods (Sam Gaylard, pers. comm.). Since the new video-based sampling methods are yet to be formalised, only the current SCUBA-based methods are reported here.

The design used by the EPA involved divers running out three 50 m-long transects from a fixed point (each transect positioned at 120º angles). For each transect, the percent cover and species identity of seagrass were sampled. Additionally, seagrass was harvested at each site using a minimum of 10 quadrats (25 × 25 cm), with shoot density, leaf length, leaf area, and epiphyte load (dry weight) being sampled from each replicate.

4. SELECTING METHODS AND VARIABLES

The choice of sampling technique involves a trade-off between the type or quantity of data sampled and the spatial/temporal extent over which that information is gathered. Sampling with divers facilitates detailed sampling of numerous variables but is typically restricted to a small area and discrete time unless extensive (and often costly) spatio-temporal sampling programs are adopted. On the other hand, aerial photographs provide broad spatial coverage, but data are usually restricted to defining the area or limits of seagrass distribution (species identity may not even be possible to determine), and may be limited by water clarity at the time of image capture. Sampling remotely using video sits somewhere between these two methods, with advantages over using divers, such as the ability to sample deep habitats and to sample more extensively, but often requiring a large time commitment post-sampling to acquire the data from captured footage. However, an advantage of video techniques is that a long-term record exists from which additional data can be obtained at a future date. Ultimately, the choice of method and variables sampled will depend on the specific question that needs answering.

From work done in South Australia and around the world, it is clear that seagrass habitats can be measured and assessed in numerous ways, including the quality of within-habitat characteristics (e.g. density, height, and photosynthetic performance of plants: Beer et al. 2001; Duarte & Kirkman 2001), measures of habitat distribution and abundance (e.g. the size, number, and isolation of habitat patches: McKenzie et al. 2001), and broader ecosystem-level performance (e.g. the maintenance of biodiversity, nutrient cycling: Edgar et al. 2001; Romero et al. 2006). The sheer number of variables provides a challenge to the efficient sampling and assessment of seagrasses because the volume of information can be overwhelming, and assessing the ecological significance of change in any one variable can be problematic (i.e. change in one variable can appear minor against many other variables, but may be quite important).

A solution is to focus on one variable perceived as having the greatest relevance, yet this approach increases the risk of ‘missing’ other important changes (e.g. if number of patches is the sampled variable, any change in the area of those patches would be missed while the number of patches remains constant). Ultimately, the development of one or a few indices that incorporate most or all variables of relevance and can be compared across time and space would be ideal.

To identify appropriate variables to sample, it is useful to understand the structure of seagrass beds and the nature of seagrass loss and recovery. Some seagrasses form extensive and continuous monospecific meadows, but many often exist as a mosaic of patches of different size, shape, species identity, and age (Duarte et al. 2006). Variation can also be substantial in numerous small-scale features, such as seagrass growth rates and photosynthetic efficiency (Zimmerman 2006), but the focus here will be on larger-scale variables (e.g. area of habitat, number of patches, species composition) because they are easier to measure, faster to sample, and usually more relevant to addressing questions of overall habitat structure.

Documented cases of seagrass loss typically describe the initiation or continuation of fragmentation within beds (Duarte et al. 2006; Walker et al. 2006), likely increasing the number of patches while concurrently reducing the overall area of habitat. Notably, losses caused by anthropogenic factors (e.g. sewage discharge, eutrophication) often occur over larger areas and for a longer duration than those caused by natural disturbances (e.g. storms), with potential to greatly increase the time needed for natural recovery (e.g. ~ 200 years for recovery of *Posidonia* after 15 years of discharge of sewage sludge at Port Adelaide, South Australia: Bryars & Neverauskas 2008). A primary outcome of disturbance is the creation of bare sand patches that can become ‘blowouts’ (*sensu* Clarke & Kirkman 1989), which further impact seagrasses as the destabilized sediments are eroded by wave action. Importantly, natural recovery does occur (Walker et al. 2006), and often begins with the colonisation of disturbed areas by faster-growing genera such as *Halophila* and *Heterozostera* before slower-growing but competitively dominant genera return (*Amphibolis* and *Posidonia*) (Clarke & Kirkman 1989).

5. METHOD FOR THE ASSESSMENT OF SEAGRASS HABITAT STRUCTURE

5.1 Approach

Many variables can describe the structure of any particular habitat, but the challenge is to use a comprehensive approach that integrates multiple variables yet remains cost-effective and simple to use. The following method is designed to provide maximum data return on minimal time investment. It involves sampling a suite of variables that describe numerous aspects of seagrass habitats (i.e. it is comprehensive), yet is easy to learn and use. Importantly, results can be readily compared among sites and times.

In essence, the method has two main components: sampling to provide data for the habitat structure index (H′) described below (quantifying habitat-scale parameters), and sampling to provide data for individual-scale parameters that have been consistently sampled in previous work (e.g. seagrass biomass, leaf length, epiphyte load, etc.). One could conceivably focus on either component depending on external constraints (e.g. funding availability), though it is recommended to sample both components whenever possible to provide comprehensive estimates.

In designing this method, the ability to utilize past data or at least make logical comparisons was an explicit consideration. As such, this method draws as much as possible from past and current techniques described above, while striving to minimise time and financial commitments. Although yet to be tested, it also appears highly likely that data from recent sampling of seagrasses in South Australia will be able to be retrofitted for use in all or part of the proposed method (e.g. calculation of H′) (Danny Brock & Sam Gaylard, pers. comm.).

In essence, this method uses standard *in situ* sampling based on transects and quadrats to provide data on 10 commonly sampled habitat variables:

- Area*
- Continuity*
- Proximity*
- Percentage cover*
- Species composition*
- Biomass
- Shoot density
- Leaf density
- Leaf length
- Biomass of epibiota

* used in the calculation of an integrated habitat structure index, H′ (see below).

Many of these variables have commonly been sampled in past and present seagrass research in South Australia (as identified above) and around the world (Short & Coles 2001). Furthermore, many of these variables are recommended measures for monitoring seagrasses in South Australia (Wear et al. 2006; Bryars & Wear 2008). Some variables (e.g. continuity, proximity) are rarely analysed but represent integral components of the calculation of the seagrass habitat structure index (H′) described in further detail below.

Variables that describe seagrass ecophysiology (e.g. photosynthetic efficiency, nutrient uptake, growth rate, etc.) have been quantified in previous research and certainly represent another important aspect of seagrass condition. However, such variables are not included in this design because i) collecting such data often requires expensive and relatively rare pieces of equipment (e.g. diving PAM fluorometers), ii) training divers in the correct use of such equipment is time consuming, iii) sampling protocols can require near-ideal conditions for accurate and reliable measurements, iv) sampling often requires lengthy attention to a particular plant, or repeated visits to particular plants which increases the risk of relocation failure, and v) the time-consuming nature of such work can dramatically reduce the spatial and temporal extent of sampling.

5.2 Field sampling protocol

Sampling may be achieved using divers, video sampling, or a combination of both. Upon arrival at the study site, 50 m × 1 m belt transects that originate within existing seagrass are to be sampled by divers or by video. For video sampling, it is recommended that the camera is pointed face-down so that percentage cover of seagrass can be accurately quantified (as described above for sampling on Kangaroo Island). To minimise possible bias due to depth gradients, it is recommended that sampling is either consistently done within defined depth limits at each site (e.g. between 7 – 10 m depth), or that depth is explicitly incorporated into the sampling design (e.g. comparison between seagrass shallower and deeper than 10 m depth).

In each 1 m^2 of the transect, two variables must be sampled: species identity (at least to genus level) and their respective % cover (using a visual estimate or otherwise). From these two variables, all necessary metrics can be gained to calculate the habitat structure index, H′.

If using divers, the dominant species of seagrass should then be harvested from the site. When using divers to quantify transects, it is recommended that seagrass is concurrently sampled from five randomly chosen 1 m^2 quadrats along each transect (or the maximum number of quadrats if less than five are available). Within each 1 m^2, all seagrass within a single 25 × 25 cm quadrat should be harvested, ensuring shoots are cut at their base (i.e. at the sediment level), and that all leaves and epibiota remain attached. If video is used to quantify transects, divers can haphazardly sample ten 25 × 25 cm quadrats from the site. Regardless of the method, all samples must be kept separate.

If using divers only, it is anticipated that two divers each sampling 25 m of the transect would probably be the most efficient method, although this is a flexible arrangement. To provide meaningful data, workers should aim to sample four transects at each site and time (two transects is the minimum, providing 10 seagrass samples per site, similar to sample sizes in previous work). Note that these numbers may be revised depending on site-specific variation in sampled parameters (greater variance will likely require more samples).

An advantage of this approach is that multiple replicate transects may be obtained where one or several long transects are used in the sampling design. For example, if five transects each measuring 500 m in length are sampled from a single site, then one could either i) take one 50 m transect from within each of the 500 m-long transects, and obtain five replicates for the site, or ii) take multiple 50 m-long transects from each 500 m-long transect (it's recommended that each replicate be at least 50 m apart) to obtain five replicates per 500 m transect and 25 replicates for the site. In the former option, variation of seagrass habitat variables is estimated at the scale of the site only. For the latter option, variation is estimated for both the site and at the smaller scale of each transect. One must be careful when considering estimates of variation within a transect, however, since sampling across environmental gradients (e.g. depth) is likely to increase variation substantially. In such circumstances, it may be possible to stratify within-transect variation by depth (though a reduction in the number of replicate 50 m transects will occur), and thereby incorporate depth, or any other gradient of interest, into the sampling design. In any case, sampling in this fashion may offer a way to boost replication within a given site. This method also offers considerable flexibility for 'mining' data sets such as existing video transects, and facilitating structure assessments from previous research.

When sampling has finished, there should be five bags of seagrass samples per transect, and enough data so that it is possible to produce a diagram of each transect that looks similar to the following (for convenience, this example shows a transect of 20 × 1 m^2):

P 100	P 90	P 60	P 20			A 70	A 90	A 90	A 100	A 100	A 60	A 10		P 50	P 50	P 60	P 50		P 30

Where each square represents a 1 m^2 quadrat that shows the type of habitat (P = *Posidonia*, A = *Amphibolis*) and the % cover of seagrass in that quadrat (e.g. 100, 60, etc). Empty quadrats indicate that no seagrass was present.

5.3 Sample processing

There are two main tasks following field sampling.

1) Calculation of habitat structure index

The habitat structure index is calculated using information collected from transects (i.e. species identity and % cover). Ultimately, these data will be used to quantify five habitat variables:

i) Area (A) – the total amount of seagrass sampled within the transect (in the example above, A = 5.1 m^2 of *Posidonia* + 5.2 m^2 of *Amphibolis* = 10.3 m^2 of seagrass in the transect)

ii) Continuity (C) – the number of patches of seagrass habitat within the transect (in the example above, C = 4)

iii) Proximity (P) – the distance between patches of seagrass within the transect (in the example above, P = 2, 1, and 1 m)

iv) Percentage cover (K) – the average percentage cover of seagrass within the transect (based on sampled values shown in the transect above)

v) Species identity (S) – the average value of species present in the transect (see calculations below).

All five variables are integrated into a single index, H′, which ranks the seagrass habitat structure in each transect on a scale of 0 to 100 (100 being excellent, 0 being poor). The rationale, equations, and example calculations are shown below. Importantly, H′ is weighted against variation in all five variables, resulting in a comprehensive and directly comparable index based on relatively simple sampling effort (i.e. species identity and percent cover).

2) Processing of seagrass samples

The second task is to process the harvested seagrass samples in the laboratory. Here, the following variables are sampled:

i) Shoot density – the number of shoots in each sample

ii) Leaf density – the number of leaves in each sample

iii) Leaf length – the length of 5 representative leaves in each sample

iv) Epibiotic biomass – the dry weight of all epibiota present in each sample. Epibiota need to be scraped off leaves carefully so as not to remove seagrass biomass as well (a scalpel may work well). Epibiota are then oven-dried (e.g. 70 ºC for 48 hours).

v) Seagrass biomass – the dry weight of seagrass in each sample. After epibiota have been scraped off, all leaves are then oven-dried (e.g. 70 ºC for 48 hours).

5.4 Data analysis

Once processed, each transect sampled will be represented as a multivariate data set that collectively describes the 10 habitat parameters listed above. While any single variable can be compared among replicates, it is useful to represent each replicate as a single point in multivariate space to capture all sampled variables and to visualize the structure of seagrass habitat in each replicate relative to all others.

To do this, established multivariate tools should be used (e.g. nMDS ordination) to identify the distance (dissimilarity) among replicates, which can be easily related to the structure of seagrass in each replicate to identify places and times where seagrass structure is relatively good or poor. Formal analyses to test for differences among treatments, and the key habitat variables driving those differences, will also follow well-grounded methods in multivariate statistics (e.g. PERMANOVA, SIMPER) (Clarke & Warwick 2001; Anderson et al. 2008).

Following the protocols outlined herein, seagrass meadow structure can be tracked through time and across space to quantify changes, identify possible causative agents, implement any necessary mitigation strategies, and quantify their effectiveness.

5.5 Rationale and calculation of the seagrass habitat structure index, H′

The goal of the habitat structure index (H′) is to take the complexity of reporting on five distinct habitat variables and reduce it to the simplicity of one number that has a meaningful ranking and is directly comparable among samples. In creating this index, a primary goal was to ensure a relatively simple, fast, and cost-effective method could be used that would not only sample all the necessary data at once, but would also require minimal training.

The method of calculation of H′, with examples shown in Appendix B, is modified from a similar method developed by Bogaert et al. (2000) for calculating fragmentation indices within terrestrial forest habitat. This modified method has been designed for subtidal seagrass habitats in particular, but could conceivably be used in any biogenic habitat.

H′ integrates a specific metric for each of five habitat variables: Area, Continuity, Proximity, Percentage cover, and Species identity. The calculation also includes a scalar to provide each transect (or site or time) a convenient score out of a possible 100 points (100 being habitat of perfect structure, with structure worsening as H′ approaches 0).

Note that all example values shown below are for the 50 × 1 m transect method described above.

Area, A

The metric for the area of seagrass is calculated as:

$$A = (A_{obs}/A_{max}) \times 100 \quad (1)$$

Where:

A_{obs} = the observed total area of seagrass habitat sampled within the transect

A_{max} = the maximum possible area of seagrass to sample (this corresponds to the transect length, i.e. 50 m^2)

In practice, individual quadrats will often support less than 100 % cover of seagrass, as well as mixtures of seagrass species in varying amounts. As an example, consider a single 1 m^2 quadrat with 45 % cover of *Amphibolis* and 20 % cover of *Heterozostera*. A_{obs} for this quadrat is calculated as the proportion of the quadrat that is covered by seagrass (45 % *Amphibolis* + 20 % *Heterozostera* = 65 % seagrass = 0.65 m^2 of the 1 m^2 quadrat, thus A_{obs} = 0.65 m^2). The calculated A_{obs} for each quadrat are then summed along the length of the transect to give A_{obs} for the entire transect (see Appendix B for example calculations).

Continuity, C

The metric for the continuity of seagrass is calculated as:

$$C = [(C_{max} - C_{obs})/(C_{max} - C_{min})] \times 100 \quad (2)$$

Where:

C_{max} = the total number of 1 m^2 quadrats with seagrass in them, regardless of seagrass abundance

C*obs* = the observed number of seagrass patches within a transect (delineated by the presence of other non-seagrass habitats)
C*min* = the minimum possible number of patches of seagrass (i.e. 1 patch)

Proximity, P
The metric for proximity of seagrass patches is calculated as:

$$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times 100 \quad (3)$$

Where:
P*max* = the maximum possible distance between a single patch of seagrass and another patch or the end of the transect (i.e. P*max* = 50 m – 1m = 49 m)
P*obs* = the sum of the observed smallest and largest distances between patches (e.g. if the distances between 4 patches of seagrass are 1 m, 3 m, 3m, and 5m, then P*obs* = 1 + 5 = 6)
P*min* = the minimum possible distance between two patches of seagrass or between a patch of seagrass and the end of the transect (i.e. P*min* = 1 m)

Percentage cover, K
The metric for the percentage cover of seagrass is calculated as:

$$K = (K_{obs}/K_{max}) \times 100 \quad (4)$$

Where:
K*obs* = the observed integrated cover value of the seagrass sampled within the transect
K*max* = the maximum possible cover value of the transect

Cover values are calculated by integrating estimates of seagrass abundance across the transect. Each 1 m^2 quadrat supporting seagrass in the transect is assigned a value according to its percentage cover. Following precedent from previous research (e.g. Bryars & Rowling 2008), quadrats with > 90 % cover are given a value of 3 (high value), those with 40 – 90 % cover are given a value of 2 (medium value), while those with < 40 % cover are given a value of 1 (low value). The number of quadrats of each % cover class in the transect is then multiplied by its value, with the resulting total across all three classes divided by A*max* to produce the average cover value for the transect (K*obs*).

e.g. if a transect contains 20 quadrats of seagrass at > 90 % cover, 15 quadrats of seagrass at 40 – 90 % cover, and 10 quadrats of seagrass at < 40 % cover, then:

K*obs* = (20×3 + 15×2 + 10×1)/50 = 100/50 = 2

By extension, K*max* = 50 quadrats of seagrass at > 90 % cover = (50×3)/50 = 150/50 = 3

Also note that the species identity of seagrass is not considered for calculating K, i.e. the % cover of all species in each quadrat is summed before assigning the cover value for that quadrat.

Species identity, S

The metric for seagrass species identity is calculated as:

S = (S*obs*/S*max*) × 100 (5)

Where:
S*obs* = the observed integrated species value of the seagrass sampled within the transect
S*max* = the maximum possible species value of the transect

Similar to the calculation of K, the species of seagrass is assigned a number according to its perceived value. These numbers are based on observations of seagrass succession following disturbance, which typically occurs as the colonisation of bare space by *Halophila*, followed by *Heterozostera*, and finally by *Amphibolis* and *Posidonia* (Clarke & Kirkman 1989). Accordingly, *Amphibolis* & *Posidonia* are assigned a value of 3, *Heterozostera* a value of 2, and *Halophila* a value of 1. The area of each species in the transect (conveniently identified when calculating A) is then multiplied by its value, with the resulting total across all species divided by A*max* to produce the average species value for the transect (S*obs*).

e.g. if a 50 × 1 m transect contains 25 m^2 of *Posidonia*, 5 m^2 of *Heterozostera*, and 15 m^2 of *Halophila*, then:

S*obs* = (25×3 + 5×2 + 15×1)/50 = 100/50 = 2

By extension, S*max* = 50 m^2 of *Posidonia* and/or *Amphibolis* = (50×3)/50 = 150/50 = 3

Habitat structure index, H′

Once metrics for all five habitat variables are known, it is a simple matter of calculating the raw habitat structure index (H) using the Euclidean distance of the five integrated data points to define the sample's position in multivariate space relative to a common origin. This is done using the equation:

$$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)} \qquad (6)$$

The final step is to apply a scalar to H so that the final habitat structure index, H′, assigns each transect a value from 0 to 100 (100 = perfect structure, while structure worsens as H′ approaches 0). H′ can then be directly compared among all samples. The value of this scalar depends on the length of the transect, the minimum sampling unit size (i.e. the 1 m^2 quadrat), and on the number of metrics used in the calculation of H. As such, it will need to be adjusted accordingly for any departures from the method described herein.

For a 50 × 1 m^2 transect using the five habitat variables described above, the scalar is 0.4453. This is calculated by dividing 100 by the H value a transect of perfect structure such that all subsequent calculations of H can be referenced to this perfect transect. The specific calculation for a 50 m transect supporting 100 % cover of *Posidonia* and/or *Amphibolis* in all 1 m^2 quadrats is: $H = \sqrt{(100^2 + 100^2 + 102.083^2 + 100^2 + 100^2)} = 224.546$, and so the scalar = 100/224.546 = 0.4453.

Therefore,

$$H' = H \times 0.4453 \qquad (7)$$

Some detailed example calculations of H' are shown in Appendix B.

6. CONCLUDING REMARKS

This work highlights the wide range of techniques used and variables sampled in past and current research of seagrass habitats in South Australia. Although a number of approaches have been used, the most common techniques have been to use SCUBA divers to directly measure and/or harvest seagrass for later analysis, as well as remote video sampling to potentially sample larger areas in less time and provide an archived record. Variables commonly sampled include species identity, estimates of abundance (percent cover, biomass, density), and morphometrics (leaf length, width, etc.)

While no single method can effectively capture all information about seagrass habitat structure, a method that integrates as many variables as possible and reduces them to a single comparable number may permit more comprehensive assessments of spatiotemporal trends in seagrass habitats that are interpretable at scales relevant to coastal managers. To this end, the seagrass habitat structure index (H') described herein represents a first attempt to integrate multiple commonly sampled variables (area, species identity, etc.) using standard and relatively quick sampling methods. Furthermore, data to calculate H' can be acquired in different ways (e.g. SCUBA divers as well as remote sampling) and can potentially be collected from archived data sets for temporal comparisons. Indeed, perhaps the greatest advantage of this method is that H' can be directly compared across space and time to identify meaningful changes in seagrass habitat structure.

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Appendix A. Review of South Australian seagrass research done in regional South Australia (i.e. outside of Adelaide's coastal waters).

Author & Year	Study site(s)	Method	Variables sampled
Baker & Edyvane (2003)	Nuyts Archipelago & Investigator Group	SCUBA divers using 1 m^2 quadrats placed on replicate transects	Percent cover and biomass of macroflora (seagrasses and algae)
Bryars & Wear (2008)	Investigator Group & Waterloo Bay	SCUBA divers using 25 × 25 cm quadrats to harvest seagrass	Species composition, aboveground biomass, leaf density, leaf length, epiphyte load, seagrass flowering, gastropod densities
Keuskamp (2004)	Louth Bay	SCUBA divers harvesting seagrass from experimental replicates	Leaf length, leaf width, biomass of epiphytes
Miller & Wright (2008)	Investigator Group	Satellite imagery, acoustic sounding & video sampling	Species distribution and density
Seddon et al. (2000)	North-eastern Spencer Gulf	Aerial photographs	Species distribution and density
Shepherd & Womersley (1976)	St Francis Island, Nuyts Archipelago	SCUBA divers using transects	Species composition and distribution
Shepherd & Womersley (1981)	Waterloo Bay	SCUBA divers using transects & spot dives	Species composition, distribution, and density
Tanner (2005)	Gulf St Vincent	Remote video transects & spot dives	Species composition, distribution and abundance of benthic habitats
Tanner & Wear (in review)	Lacepede Bay	SCUBA divers using 25 × 25 cm quadrats to harvest seagrass	Leaf length, leaf width, leaf density, and epiphyte biomass

Appendix B. Example calculations of H′

Consider the following nine hypothetical transects sampled using the design described above, except transects are 20 m long instead of 50 m (20 m is used below because of space limitations). The calculated H′ is shown above each transect, with the worked calculations shown below. Each square represents 1 m^2, the species are identified as P = *Posidonia*, A = *Amphibolis*, Hz = *Heterozostera*, Ha = *Halophila*, and the adjacent number is the percent cover of that species in the quadrat (e.g. 100 P = 100 % cover of *Posidonia*).

Example A: H' = 100

100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P

Example B: H' = 87.702

100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	50 P	50 P	50 P	50 P	50 P	50 P	50 P	50 P	50 P	50 P

Example C: H' = 59.163

100 P	100 P	100 P	100 P	100 P						100 P	100 P	100 P	100 P	100 P					

Example D: H' = 94.412

100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz	100 Hz

Example E: H' = 90.895

100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha

Example F: H’ = 94.412

100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 P	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha	100 Ha

Example G: H’ = 21.093

									100 P			100 P							

Example H: H’ = 20.677

									100 Ha			100 Ha							

Example I: H’ = 59.274

100P	60P 40Hz	20P 50Hz	50Hz	10Hz				50Ha	50Ha					10A 50Hz	50A 10Hz	90A 10P	50A 50P	100P	100P

Example A

$A = (A_{obs}/A_{max}) \times 100$

$= (20/20) \times 100$

$= 100$

$C = [(C_{max} - C_{obs})/(C_{max} - C_{min})] \times 100$

$= [(20 - 1)/(20 - 1)] \times 100$

$= 100$

$P = [(P_{max} - P_{obs})/(P_{max} - P_{min})] \times 100$

$= [(19 - 0)/(19 - 1)] \times 100$

$= 105.556$

$K = (K_{obs}/K_{max}) \times 100$

$= [(\{20\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$

$= (3/3) \times 100$

$= 100$

$S = (S_{obs}/S_{max}) \times 100$

$= [(\{20\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$

$= (3/3) \times 100$

$= 100$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(100^2 + 100^2 + 105.556^2 + 100^2 + 100^2)}$

$= 226.146$

$H' = H \times 0.4422$ (NOTE: scalar is calculated for a 20 m transect)

$= 100$

Example B

$A = (A_{obs}/A_{max}) \times 100$

$= (15/20) \times 100$

$= 75$

$C = [(C_{max} - C_{obs})/(C_{max} - C_{min})] \times 100$

$= [(20 - 1)/(20 - 1)] \times 100$

$= 100$

$P = [(P\mathit{max} – P\mathit{obs})/(P\mathit{max} – P\mathit{min})] \times 100$

$= [(19 – 0)/(19 – 1)] \times 100$

$= 105.556$

$K = (K\mathit{obs}/K\mathit{max}) \times 100$

$= [(\{10\times3 + 10\times2 + 0\times1\}/20)/3] \times 100$

$= (2.5/3) \times 100$

$= 83.333$

$S = (S\mathit{obs}/S\mathit{max}) \times 100$

$= [(\{15\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$

$= (2.25/3) \times 100$

$= 75$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(75^2 + 100^2 + 105.556^2 + 83.333^2 + 75^2)}$

$= 198.334$

$H' = H \times 0.4422$

$= 87.702$

Example C

$A = (A\mathit{obs}/A\mathit{max}) \times 100$

$= (10/20) \times 100$

$= 50$

$C = [(C\mathit{max} – C\mathit{obs})/(C\mathit{max} – C\mathit{min})] \times 100$

$= [(10 – 2)/(10 – 1)] \times 100$

$= 88.889$

$P = [(P\mathit{max} – P\mathit{obs})/(P\mathit{max} – P\mathit{min})] \times 100$

$= [(19 – 10)/(19 – 1)] \times 100$

$= 50$

$K = (K\mathit{obs}/K\mathit{max}) \times 100$

$= [(\{10\times3 + 0\times2 + 0\times1\}/20)/3] \times100$

$= (1.5/3) \times100$

$= 50$

$S = (S_{obs}/S_{max}) \times100$

$= [(\{10\times3 + 0\times2 + 0\times1\}/20)/3] \times100$

$= (1.5/3) \times100$

$= 50$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(50^2 + 88.889^2 + 50^2 + 50^2 + 50^2)}$

$= 133.796$

$H' = H \times 0.4422$

$= 59.163$

<u>Example D</u>

$A = (A_{obs}/A_{max}) \times100$

$= (20/20) \times100$

$= 100$

$C = [(C_{max} – C_{obs})/(C_{max} – C_{min})] \times100$

$= [(20 – 1)/(20 – 1)] \times100$

$= 100$

$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times100$

$= [(19 – 0)/(19 – 1)] \times100$

$= 105.556$

$K = (K_{obs}/K_{max}) \times100$

$= [(\{20\times3 + 0\times2 + 0\times1\}/20)/3] \times100$

$= (3/3) \times100$

$= 100$

$S = (S_{obs}/S_{max}) \times100$

$= [(\{0\times3 + 20\times2 + 0\times1\}/20)/3] \times100$

$= (2/3) \times100$

$= 66.667$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(100^2 + 100^2 + 105.556^2 + 100^2 + 66.667^2)}$

$= 213.510$

$H' = H \times 0.4422$

$= 94.412$

Example E

$A = (A_{obs}/A_{max}) \times 100$

$= (20/20) \times 100$

$= 100$

$C = [(C_{max} – C_{obs})/(C_{max} – C_{min})] \times 100$

$= [(20 – 1)/(20 – 1)] \times 100$

$= 100$

$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times 100$

$= [(19 – 0)/(19 – 1)] \times 100$

$= 105.556$

$K = (K_{obs}/K_{max}) \times 100$

$= [(\{20 \times 3 + 0 \times 2 + 0 \times 1\}/20)/3] \times 100$

$= (3/3) \times 100$

$= 100$

$S = (S_{obs}/S_{max}) \times 100$

$= [(\{0 \times 3 + 0 \times 2 + 20 \times 1\}/20)/3] \times 100$

$= (1/3) \times 100$

$= 33.333$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(100^2 + 100^2 + 105.556^2 + 100^2 + 33.333^2)}$

$= 205.556$

$H' = H \times 0.4422$

$= 90.895$

Example F

$A = (A_{obs}/A_{max}) \times 100$

$= (20/20) \times 100$

$= 100$

$C = [(C_{max} – C_{obs})/(C_{max} – C_{min})] \times 100$

$= [(20 – 1)/(20 – 1)] \times 100$

$= 100$

$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times 100$

$= [(19 – 0)/(19 – 1)] \times 100$

$= 105.556$

$K = (K_{obs}/K_{max}) \times 100$

$= [(\{20\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$

$= (3/3) \times 100$

$= 100$

$S = (S_{obs}/S_{max}) \times 100$

$= [(\{10\times3 + 0\times2 + 10\times1\}/20)/3] \times 100$

$= (2/3) \times 100$

$= 66.667$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(100^2 + 100^2 + 105.556^2 + 100^2 + 66.667^2)}$

$= 213.510$

$H' = H \times 0.4422$

$= 94.412$

Example G

$A = (A_{obs}/A_{max}) \times 100$

$= (2/20) \times 100$

$= 10$

$C = [(C_{max} – C_{obs})/(C_{max} – C_{min})] \times 100$
$= [(2 – 2)/(2 – 1)] \times 100$
$= 0$

$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times 100$
$= [(19 – 11)/(19 – 1)] \times 100$
$= 44.444$

$K = (K_{obs}/K_{max}) \times 100$
$= [(\{2\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$
$= (0.3/3) \times 100$
$= 10$

$S = (S_{obs}/S_{max}) \times 100$
$= [(\{2\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$
$= (0.3/3) \times 100$
$= 10$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$
$= \sqrt{(10^2 + 0^2 + 44.444^2 + 10^2 + 10^2)}$
$= 47.700$

$H' = H \times 0.4422$
$= 21.093$

Example H

$A = (A_{obs}/A_{max}) \times 100$
$= (2/20) \times 100$
$= 10$

$C = [(C_{max} – C_{obs})/(C_{max} – C_{min})] \times 100$
$= [(2 – 2)/(2 – 1)] \times 100$
$= 0$

$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times 100$
$= [(19 – 11)/(19 – 1)] \times 100$
$= 44.444$

$K = (K_{obs}/K_{max}) \times 100$

$= [(\{2\times3 + 0\times2 + 0\times1\}/20)/3] \times 100$

$= (0.3/3) \times 100$

$= 10$

$S = (S_{obs}/S_{max}) \times 100$

$= [(\{0\times3 + 0\times2 + 2\times1\}/20)/3] \times 100$

$= (0.1/3) \times 100$

$= 3.333$

$H = \sqrt{(A^2 + C^2 + P^2 + K^2 + S^2)}$

$= \sqrt{(10^2 + 0^2 + 44.444^2 + 10^2 + 3.333^2)}$

$= 46.759$

$H' = H \times 0.4422$

$= 20.677$

<u>Example I</u>

$A = (A_{obs}/A_{max}) \times 100$

$= (9.5/20) \times 100$

$= 47.5$

$C = [(C_{max} – C_{obs})/(C_{max} – C_{min})] \times 100$

$= [(13 – 3)/(13 – 1)] \times 100$

$= 83.333$

$P = [(P_{max} – P_{obs})/(P_{max} – P_{min})] \times 100$

$= [(19 – 7)/(19 – 1)] \times 100$

$= 66.667$

$K = (K_{obs}/K_{max}) \times 100$

$= [(\{6\times3 + 6\times2 + 1\times1\}/20)/3] \times 100$

$= (1.55/3) \times 100$

$= 51.667$

$S = (S_{obs}/S_{max}) \times 100$

$= [(\{6.4\times3 + 2.1\times2 + 1\times1\}/20)/3] \times100$

$= (1.22/3) \times100$

$= 40.667$

$H = \sqrt{}(A^2 + C^2 + P^2 + K^2 + S^2)$

$= \sqrt{}(47.5^2 + 83.333^2 + 66.667^2 + 51.667^2 + 40.667^2)$

$= 134.046$

$H' = H \times 0.4422$

$= 59.274$