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Perceptions of seagrass ecosystem health and potential indicators for monitoring

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NICK WOOD

A Thesis Submitted in Partial Fulfilment of the Requirement for the Award of Bachelor of Science (Honours) Environmental Management

Edith Cowan University

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USE OF THESIS

Abstract

A range of seagrass characteristics were assessed for potential use as indicators of ecosystem health. Shoot density, shoot width, maximum shoot length, above and below ground biomass, percentage canopy cover, leaf area index, leaf extension rate, meadow productivity, epiphyte biomass, epiphyte species richness, percentage of calcium carbonate in epiphytic material and percentage of nitrogen in leaf tissue were all measured in "healthy" and "unhealthy" *Posidonia angustifolia* meadows in Cockburn and Warnbro Sounds, from June through to August 1998. A questionnaire was used to determine which meadows researchers and managers in the seagrass ecology field in Perth perceived to be healthy or unhealthy. Seagrass meadows were then compared according to several indicator criteria, primarily whether they showed any differences between perceived healthy and unhealthy meadows.

A second questionnaire was undertaken to obtain an understanding of which variables researchers and managers felt were important in formulating a perception of seagrass ecosystem health. These perceptions were then compared with the measurable data for each variable. This was to provide an indication of whether the decisions made and influenced by these people on the management of seagrass ecosystems are based on comprehensive and accurate information.

The sites perceived to be healthy, corresponded with previous data on the region which indicated they were less nutrient enriched, had higher light attenuation and less phytoplankton in the water column than those perceived to be unhealthy.

There were only two variables to show significant differences between the perceived healthy and unhealthy sites, maximum shoot length and above ground biomass. These two variables and only two others, shoot density and percentage canopy cover adhered to at least four of the six indicator criteria, with maximum shoot length adhering to all six.

These results differed to the perceptions of researchers and managers, with the exception of shoot density and percentage canopy cover. Epiphyte composition and epiphyte biomass were the other two variables considered to be important in formulating a perception of the health of a seagrass meadow.

Information from this study suggests that management of *Posidonia angustifolia* meadows should centre around the measurement of maximum shoot length and above ground biomass. The vastly different results obtained from the questionnaire suggested that current seagrass monitoring in Western Australia may be in adequate. Further study on monitoring *Posidonia angustifolia* and Western Australia's other dominant seagrass species is thus recommended to ensure management decisions are based on data that are as close to reality as possible.

Declaration

I certify that this thesis does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signature ....

Date ....10/2/99..........

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1.1 - Introduction

1.1.1 - Seagrass Significance

Seagrass meadows are found in most sheltered, shallow, soft bottomed marine coastlines throughout the world (Phillips and McRoy 1990). Australia has some of the largest seagrass meadows in the world (Walker and McComb 1992, Environment Australia 1997a) and with more than 30 species is a centre of diversity (Environment Australia 1997a)). The Western Australian coastline supports more than 20,000 km^2 of more than 25 seagrass species (Environment Western Australia 1997). From tropical and sub-tropical species in the state's north to temperate species along the southern coast, seagrass ecosystems are a vital component of the marine environment of Western Australia (Kirkman and Walker 1989).

Seagrass meadows are among the most productive systems in the ocean (Hillman et al. 1989). They support faunal assemblages by providing shelter and food resources (Howard et al. 1989). These assemblages include rare and threatened species such as the Leafy Sea Dragon, *Phycodurus equus* (Environment Australia 1997a) and commercially important species such as the Western Rock Lobster, *Panulirus cygnus* (Walker and McComb 1992). Seagrass ecosystems provide a stable surface for epiphyte growth, which in turn provide additional habitat and contribute a source of calcium carbonate to the sediment (Walker and

Woekerling 1988, Borowitska and Lethbridge 1989, Walker et al. 1991). They also increase sediment stabilisation due to extensive rhizome mats and through leaf baffling (Kirkman 1987, Lukatelich et al. 1987, Hastings et al.1995). Furthermore they are an important nutrient pool and contribute to the detrital food chain (Lukatelich et al. 1987, Klumpp et al. 1989, Hastings et al. 1995).

Commercially, seagrass in Western Australia is important for two reasons. As mentioned above, the Western Rock Lobster utilises seagrass as a nursery area. The Western Rock Lobster fishery is the most important single-species fishery in Australia, contributing approximately 20% of the total value of the country's fisheries economy (Penn and Jacoby 1997). The sediments found in Cockburn Sound and surrounding coastal areas are rich in calcium carbonate, partially due to organisms such as epiphytes, which grow on seagrasses. This calcium carbonate is mined in Perth waters and used for commercial lime by Cockburn Cement (Cockburn Cement Limited 1996).

Recreationally, seagrass meadows in Perth coastal waters are used extensively for a range of marine activities. Recreational fishing of a wide variety of fish, crustaceans and molluscs is undertaken over seagrass beds. Furthermore, activities such as swimming, SCUBA diving and snorkelling utilise the unique aesthetic qualities of the meadows (SMCWS 1996).

1.1.2 - Decline

In recent years, there have been significant declines in the health of seagrass meadows. Throughout Australia, there has been a loss of at least 45,000ha (Walker and McComb 1992, Shepherd et al., 1989). Within Western Australia there have been noteworthy losses, in particular at Cockburn Sound where 97% of *Posidonia* meadows have been lost since 1962. This extensive loss has been attributed to nutrient inputs from waste discharged into the sound (Cambridge et al. 1986, Cambridge and McComb 1984), see Figure 1.1. This increase in nutrient availability results in phytoplankton blooms and enhanced epiphyte growth (Dennison et al. 1993). The increased algal growth results in a reduction in light reaching the seagrass leaves. The lack of light leads to increased pressure on the photosynthetic ability of the plant (Masini et al. 1995) and has numerous detrimental effects on the plant, including reduced productivity, number of shoots, length of shoots, overall biomass and decline in meadow cover (Neverauskas 1987, Neverauskas 1988, West 1990, Masini and Manning 1997, Gordon et al. 1994). Resulting from this are several flow-on effects to the ecosystem, such as reduced habitat in the form of cover and food, less stable sediment and reduced input of calcium carbonate to the sediment (Walker et al. 1991, Hastings et al. 1995).

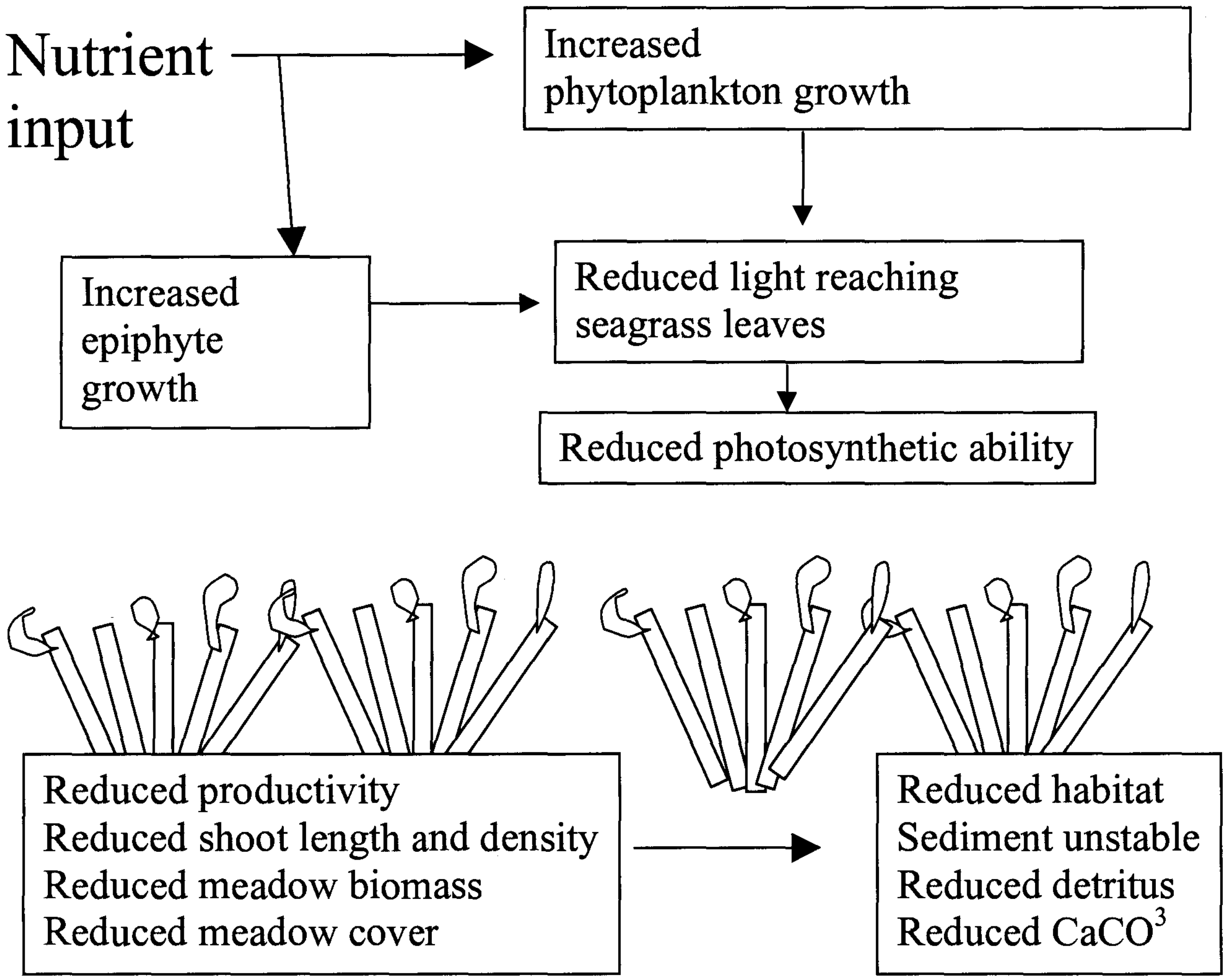


Figure 1. 1 - Flow diagram showing process of decline in seagrass meadows due to increased nutrient inputs.

1.1.3 - The Need for Effective Monitoring

The Group of Experts on the Scientific Aspects of Marine Pollution, part of the United Nations concluded in 1990 that the state of the marine environment could further deteriorate in the following decade if waste inputs were allowed to increase unchecked (GESAMP 1990). In Australia, loss of marine and coastal habitat has been identified as one of the most serious issues affecting Australia's marine environment (Zann 1995). Industrial waste and 95 percent of Perth's reticulated wastewater is currently discharged into Perth coastal waters. With the projected increase in population in Perth of about 50% in the next 30 years, and corresponding increase in commercial and industrial activity, waste inputs are expected to increase (WA Planning Commission 1995). In conjunction with these increases there will be increasing pressure placed on seagrass ecosystems.

To ensure further declines in seagrass meadows do not continue, early changes must be detected. This entails the establishment of comprehensive monitoring protocols for the long term management of the state's coastal waters. Protocols are generally established with a specific management objective/s in mind for a particular ecosystem. The first step in the development of the protocol is identification of the threats to the managed ecosystem. Then follows the formation of hypotheses, which use ecological indicators to link threats back to the management objective (Horwitz and Davis, in press).

This need for monitoring protocols has been outlined recently with seagrass workshops both statewide and nationally (Environment Australia 1997a, Environment Australia 1997b). The Department of Environment, Sport and Territories recently concluded that seagrass monitoring needs to be improved, with standardised, cost effective methods (DEST, 1996). Generally, management agencies (Environment Australia, 1997a, Department of Environmental Protection, 1997, Sims and Nicholl, 1997) and the scientific community (Okey 1996, Wrona and Cash, 1996, Vora, 1997, Hart 1997) agree that monitoring should be undertaken at an ecosystem level. Effective ecosystem monitoring requires that all the different components of an ecosystem and their interactions must be considered.

This approach to monitoring can generally provide an indication of the 'health' of ecosystems. Ecosystem health is the dominant approach to ecosystem monitoring (Scrimgeour and Wicklum, 1996, Sanchez-Jerez and Ramos-Espla, 1996, Attrill and Depledge, 1997, Lavery and Westera 1998). The Department of Environmental Protection has outlined the management objective of maintaining ecosystem integrity, or ecosystem health (DEP 1997).

It is difficult to define ecosystem health and it almost impossible to find a definition that can be used for monitoring. Defining and monitoring of ecosystem health has been undertaken from numerous perspectives. It has been described as homeostasis (Chapman 1992, Ferguson 1994), diversity or complexity (Vora 1997), stability (Rapport 1990), resilience (Angermeier and

Karr 1994) and scope for growth (Joergensen 1995). These concepts are explained further in Section 2.

None of these definitions have been widely accepted within the scientific community though. An adequate definition of ecosystem health would require a complex integration of all its components, balanced so each is correctly weighted (Norton 1991, Costanza et al 1992, Woodley et al. 1993). For management though, this sort of definition would be practically useless as it would not be possible to quantify. It is generally accepted that some component that is representative of the ecosystem should be used to give an indication of that system's health (Attrill and Depledge 1997, Vora, 1997, Hart 1992, Hart and Campbell 1991). These components, or indicators, as they are referred to, should adhere to certain criteria, such as being representative of the entire ecosystem, responsive to change, have been measured before and are easily measured (Yen and Butcher 1997). This aspect is dealt with in more detail in Section 3.

No review has been undertaken regarding which indicators are the most appropriate for monitoring seagrass ecosystem health. It is this aspect of a protocol, indicators for seagrass ecosystem monitoring that was dealt with in this project. The formation of an entire monitoring protocol is outside the scope of the project and so it was attempted to breach the gaps in the DEP's management plan. It was aimed to take a two pronged approach at this, by actually measuring the effectiveness of a range of potential indicators and by providing more concrete ideas as to what factors influence managers' and researchers' perceptions of health. In its entirety the project hoped to contribute a platform from which managers could build a complete protocol for the monitoring of seagrass ecosystem health.

1.2 - Aims

The two main aims to this project then were:

1 – To ascertain which variables are the most effective for determining seagrass ecosystem health by

- Measuring actual variables at perceived healthy and unhealthy *Posidonia angustifolia* meadows and classing them according to certain indicator criteria.
- Establishing which of these variables, researchers and managers in the seagrass ecology field consider important in developing a perception about the relative "health" of seagrass meadows.

2 – To compare the measurable results and the perceptions to recommend a sub set of indicators for use in monitoring seagrass ecosystem health.

The following section describes the process of site selection and gives the perceptions of researchers and managers regarding indicators for seagrass ecosystem health. The measurement of actual variables and evaluation as indicators of ecosystem health is given in section 3. The final section provides an integration and comparison of the perceptions and measurable data and presents recommendations for management.

Section 2 - Questionnaires to Determine Perceptions of Seagrass Ecosystem Health

2.1 - Introduction

Monitoring at an ecosystem level is arguably the dominant approach used in the management of ecological systems (Steedman 1994, Scrimgeour and Wicklum 1996, Shrader-Frechette 1994). An ecosystem approach is needed because complex ecosystems must be assessed in ways that reflect their overall performance and not just that of a single desired species. A primary element of the ecosystem approach is that it incorporates the concept of health (Costanza et al. 1992, Woodley et al. 1993). Ecosystem health is a highly contentious issue. It is extremely difficult to define and it is almost impossible to use a definition for management.

Ecosystem health is most easily defined as an absence of disease (Woodley et al. 1993). However, this is not a useful definition as it is difficult to quantify the health of different ecosystems according to it. Therefore what is required is a definition that states more positively the characteristics of a healthy system.

One such attempt is the concept of homeostasis (Chapman 1992, Ferguson 1994). That is, any and all changes represent a change in health. However, natural variation is hard to discern from anthropogenic change and we frequently know too little about ecosystems to determine whether they have changed. Also, ecosystems are dynamic, constantly changing naturally, so the concept of any change being unhealthy change is seriously flawed .

The diversity or complexity of an ecosystem has been used extensively in environmental monitoring (Vora 1997). The reasoning behind this is that more diverse ecosystems are more likely to resist harmful change and remain stable. This approach was used by Sanchez-Jerez and Ramos-Espla (1996) measuring epifauna communities in seagrass ecosystems. Derived directly from this is the concept of stability or resilience of an ecosystem, another approach for defining health. Healthy systems are thought to have the ability to withstand disease, or recover quickly after a perturbation (Rapport 1990, Angermeier and Karr 1994). Okey (1996) applied this approach to agroecosystem health. However, in using this approach, a dead system is healthier than a living one because it is more resilient to change. Therefore, to further enhance the definition, health should include the ability of a system to maintain its structure and patterns of behaviour in the face of disturbance (Holling 1973 and Holling 1986). The problem with this approach is how to measure it as it is not possible to measure the threshold level of stress that will cause a particular ecosystem to shift into a new mode (Regier 1989).

Health as vigour or scope for growth is a newer approach at measuring health. This entails measuring the overall energy flow within the ecosystem, that is, the difference between the energy required for system maintenance and the energy available to the system for all purposes. This attempts to determine the system's ability to cope with stress as well as overall level of activity and or organisation (Costanza et al. 1992). Joergensen (1995) developed a number of such measures of health and Xu (1996) applied these approaches to aquatic ecosystems.

Despite the efforts described above, none of these definitions have been widely accepted within the scientific community. An adequate definition of ecosystem health would require a complex integration of all its components, balanced so each is correctly weighted (Norton 1991, Costanza et al. 1992, Woodley et al. 1993). For management, this sort of definition would be practically useless as it would be impossible to quantify. Therefore, at present, the most commonly accepted approach to monitoring is based on measuring any discernable change which can not be attributed to natural variation (Attrill and Depledge 1997, Vora, 1997, Hart 1992, Hart and Campbell 1991).

In terms of monitoring for ecosystem health there are a number of generally agreed criteria that should be adhered to. First, valued ecosystem components must be measured. Everything cannot be measured, so indicators of the ecosystem's status should be selected. The application of indicators is currently the most widely used approach in ecosystem monitoring (Atrill and Depledge, 1997, Joergenson 1995, Sims and Nicholl, 1997). Second, these indicators should reflect those conceptual frameworks which exist regarding the ecosystem, such as information regarding the responses to certain threats. Third, all possible threats to an ecosystem that can be realistically measured should be monitored. Finally, the monitoring programme should be reproducible so it can be used in the future by other managers (Woodley et al. 1993, Wrona and Cash 1996).

Ecosystem monitoring can be undertaken using either a bottom-up or top-down approach (Scrimgeour and Wicklum, 1996, Munkittrick and McCarty, 1995). The "bottom-up" approach, relies on data produced from simple laboratory systems, to model changes in natural ecosystems. In a "top-down" approach, changes are directly assessed in the natural environment, followed by the identification of their causes. Cairns and Niederlehner (1995) suggest that successful environmental management will rely more on the development and broadening of top-down assessment methods.

These ideas and the actual monitoring programme they give rise to are highly dependent on the ecosystem being monitored. In relation to the *Posidonia* meadows in Perth coastal waters, further understanding is required as to best monitoring practices. The researchers who have worked on these meadows will have the best understanding of which variables are the most appropriate for monitoring seagrass ecosystem health. Furthermore, these people are making or at the least influencing decisions regarding how monitoring is taken place. Therefore, it is essential to gain an understanding of these peoples' perceptions of seagrass ecosystem health and in particular which indicators are most appropriate for its monitoring.

2.2 – Aims

1. To find out which sites were perceived by researchers and managers in the seagrass ecology field in Perth to be "healthy" and "unhealthy" in order to allow field work to be undertaken.
2. To ascertain which variables are potentially useful for monitoring, by establishing which of these variables, researchers and managers in the seagrass ecology field consider to be important in formulating a perception of seagrass ecosystem health.

2.3 - Methodology

There were two questionnaires formulated and distributed in this study. The first questionnaire was composed to determine which seagrass meadows in Western Australia were perceived by managers and researchers to be "healthy" and "unhealthy". The information determined from these was to be used to provide sites for Section 3, which aimed at measuring a number of variables to compare their usefulness at determining whether a meadow was "healthy" or "unhealthy". The second questionnaire was formulated to answer the aim of Section 2 and give an understanding as to which indicators are perceived by the managers and researchers in the seagrass field to be the most effective for monitoring seagrass ecosystem health. Furthermore, this information was compared with the information determined in Section 3 to answer the second aim and compare these perceptions with measurable data.

2.3.1 - Questionnaire 1 – Perceptions of Healthy and Unhealthy Seagrass Meadows in Western Australia

See Appendix A for full questionnaire

Distribution

The questionnaire was delivered to 31 people who had published a substantial amount of work in relation to seagrass in Western Australia. It was important to target these respondents as they would best understand the ecological processes occurring in WA seagrass meadows and thus would have a better understanding of which meadows are under threat of decline. Furthermore, they are the ones strongly influencing decision making on the basis of their perceptions and credentials.

Each respondent was called on the telephone and explained the rationale behind the project and the importance of the questionnaire. If they agreed to take part, they were faxed a copy of the questionnaire and a covering letter reiterating the information given over the phone. This information can be found in the covering letter in Appendix A. They were asked to return the questionnaire by mail or fax. The mail option was left open to any respondent who wished anonymity.

Formation

General questionnaire design was determined from Deschamp and Tognolini (1983).

Section 1: Respondent Information – This section determined the respondent's place of employment or study with an explanation of their capacity to work with seagrass. This information was requested to ensure they were a suitable candidate for filling out the questionnaire, namely that they had been involved in research or management of seagrass ecosystems in Western Australian coastal waters.

Section 2: Respondent Determined Healthy and Unhealthy Sites – Respondents were asked to provide 5 healthy and 5 unhealthy seagrass meadows within WA as this was precisely the information required for site selection.

Section 3: Classification of Given Sites into Healthy and Unhealthy – The respondents were given a list of the majority of seagrass meadows in Western Australia, determined from the literature (Cambridge and McComb, 1984, Kirkman and Manning, 1993, Kirkman and Walker, 1989). This additional section was provided to ensure that the perceptions regarding the majority of sites were given. The respondents were asked not to modify their answers to section 2 after completing section 3, as this extra information may have biased their original decision.

The respondents were not asked to qualify what they meant by "healthy" or "unhealthy", as this information was to be determined from a follow-up questionnaire.

Analysis

Section 1 – The information from section 1 was utilised solely to determine whether respondents were adequately qualified to take part in the questionnaire. Essentially if respondents indicated that they were not involved in research or management of seagrass ecosystems at a relevant agency they were excluded.

Section 2 – For each category, healthy and unhealthy, sites were given a point from each respondent according to whether they were classed in that category.

Section 3 – Each site was given a point according to whether it was chosen healthy or unhealthy. Arbitrary ratios of healthy vs. unhealthy picks were also determined for each site to ensure a particular site which had high tallies in both was not included. This was based on at least twice as many choices for a particular category, for example, if the ratio for healthy choices was below 2:1 and above 1:2 for unhealthy choices it was not included. A ratio was not required for Section 2 as few sites were chosen as "unhealthy" and "healthy".

Site Selection – The five highest tallies for healthy and unhealthy were determined for question 2 and 3. At this point the number of potential sites was narrowed by applying three criteria.

- Sites were restricted to the Perth metropolitan area due to time and cost restraints.
- Those sites determined from the literature to be impacted by threats other than light limitation were excluded.
- Sites without the species *Posidonia angustifolia* were excluded.

The three sites remaining with the highest rankings were chosen.

2.3.2 - Questionnaire 2 - Perceptions of Seagrass Ecosystem Health

See appendix B for full questionnaire.

<u>Distribution</u>

Participants in the initial questionnaire were telephoned and explained the rationale behind the project and the importance of the second follow-up questionnaire. If they agreed to take part, they were faxed or emailed a copy of the questionnaire and a covering letter reiterating the information given over the phone. They were asked to return the questionnaire by email, fax or mail. Again the mail option was left open in case anonymity was required.

Formation

As with the first questionnaire, the general questionnaire design was determined from Deschamp and Tognolini (1983).

Section 1 - Respondent Information - It was determined that the respondent's place of employment or study should again be included with an explanation of their capacity to work with seagrass. This was to reiterate their suitability for filling out the questionnaire. Furthermore, as *Posidonia* was the focus genus for the questionnaire and *Posidonia angustifolia* the project's focus species, it was necessary to be sure which species each respondent had experience working with.

Section 2 - Perceptions of *Posidonia* ecosystem health.

Q1 - An open question was used at the start of the questionnaire to obtain an understanding of the wide range of factors that influenced the different respondents perceptions of seagrass ecosystem health. The following two questions asked specifically for perceptions regarding the variables measured in Section 3, so this question was just to give an indication if there were any additional variables which should have been measured.

Q2 - The second question aimed to focus on particular variables that were measured in the project. The respondent was asked to provide an importance value for each of the variables, ranging from 0 to 4. The aim was to compare the respondents' perceptions on each variable with the effectiveness of each determined from Section 3. Three addition spaces were left for further variables that respondents believed influenced their perceptions. The respondents were asked not to modify their answers to section 1 after completing section 2, as this extra information may have biased their original decision.

Q3 - The third question focused on the actual sites used in the study and chosen from questionnaire 1. It was aimed to achieve a similar comparison to that determined for question 2, but on a more specific scale for each perceived unhealthy site.

Q4 - The final question was extremely broad aiming to attain a cross section of the views of the respondents in relation to ecosystem health and its use in monitoring. This question was asked to gain an understanding of whether monitoring the health of seagrass ecosystems is considered important, the approaches that should be taken and the limitations of these.

<u>Analysis</u>

Section 1

Q1 & 2 - As with the first questionnaire, information from section 1 was utilised solely to ensure respondents were adequately qualified to take part in the questionnaire.

Q3 - The number of respondents with experience monitoring each of the species was tallied.

Section 2

Q1 – The variables specified by the respondents were tallied up and ranked according to the frequency with which they were specified. These variables were then allocated an arbitrary importance value for monitoring. If the variable was selected less than five times it was considered unimportant, between five and ten times, of minor importance and those selected by more than ten respondents were considered important.

Q2, 3A, B & C – An average value for each variable was determined by adding each tally according to the rating it obtained and dividing by the number of respondents. For example, if there were four respondents which rated a particular variable 1, 2, 3 and 4 respectively, the average would be 1 + 2 + 3 + 4 = 10/4 = 2.5. Three categories were then formulated according to means determined. The range of possible means (0-4) was cleanly broken into these three categories as follows:

0 – 1.33 – no importance for monitoring

1.33 – 2.66 – some importance for monitoring

2.66 – 4 – great importance for monitoring

Q4 – The general perceptions of researchers and managers recorded from question 4 were collated and summarised.

2.4 - Results

2.4.1 - Questionnaire 1

Section 1

Those people who were asked to take part and the number that responded is given in Table 2.1.

Section 2

Shoalwater Bay and Success Bank were the two sites perceived most to be healthy with 13 selections (Table 2.2). The two sites most perceived to be unhealthy were Mangles Bay and Princess Royal Harbour with 19 and 18 selections respectively (Table 2.3).

Section 3

A large number of the sites were classed as healthy by almost half the respondents, with eleven sites chosen by ten or more respondents. In contrast only two sites were classed as unhealthy by ten or more respondents (Table 2.4)

Table 2.1 – Respondents to Questionnaires 1 and 2.

Organisation		
University	Edith Cowan University	Dr Paul Lavery
		Matt Vanderklift
		Mark Westera
	University of Western Australia	Dr Anne Brearly
		Dr Gary Kendrick
		Dr Di Walker
	Murdoch University	Dr Eric Paling
		Dr Mike van keulen
Management Authorities	Department of Environmental Protection	Craig Manning
	Department of Conservation and Land Management	Jenny Cary
		Dr Jeremy Coleman
		Dr Chris Simpson
	Water and Rivers Commission	Kathryn McMahon
		Dr Tom Rose
	CSIRO	Dr Charles Jacoby
		Dr Peter Jernakoff
Consultancies	Des Lord and Ass.	Dr Karen Hillman
		Dr Des Lord
	Sinclair Knight	Ian LeProvost
	Dames, Moore and LeProvost	Dr Peter Morrison
	Bowman, Bishaw and Gorham	Jeremy Fitzpatrick
		Mike Forde
		Dr Richard Gorham
NB: 23 out of 31 targeted	**were able to respond.**	

Table 2.2 – The number of respondents identifying sites as "healthy" from Section 2 of Questionnaire 1.

Site	Frequency
Augusta	2
Becher Point	7
Carnac Island	3
Esperance	2
Nth Garden Island	7
Geographe Bay	8
King George Sound	3
Marmion	10
Nth Rottnest Island	5
East Rottnest Island	4
Shark Bay	9
Shoalwater Bay	13
Success Bank	13
Warnbro Sound	2
Other (Sites tallied once)	20

Table 2.3 - The number of respondents identifying sites as "unhealthy" from Section 2 of Questionnaire 1.

Site	Frequency
Fish Rocks	3
Geographe Bay	3
James Point	13
Mangles Bay	19
Nth of Beenyup Outfall	3
Owen Anchorage	6
Oyster Harbour	10
Peel Harvey Inlet	2
Princess Royal Harbour	18
Southern Flats	4
Thompsons Bay	6
Woodman Point	8
Other	9

NB: 6 respondents provided only 4 unhealthy sites.

Table 2.4 – The number of respondents identifying sites as "healthy" and "unhealthy" from Section 3 of Questionnaire 1.

Site	Healthy	Unhealthy	Ratio H:U
Mangles Bay	2	13	0.154
James Point	2	9	0.222
Parmelia Bank	6	4	1.5
Success Bank	15	0	NA
Nth Garden	16	2	7
Woodman Point	2	8	0.25
Southern Flats	5	6	0.833
Mersey Point	10	2	5
Becher Point	13	1	13
Shoalwater Bay	14	1	14
Safety Bay	11	1	11
Thompsons Bay	7	4	1.75
Porpoise Bay	11	0	NA
Longreach Bay	11	1	11
Marjorie Bay	11	0	NA
Hillarys	13	2	6.5
Watermans	12	0	NA
Oyster Harbour	2	6	0.333
Princess Royal Harbour	4	10	0.4
King George Sound	11	1	11
Geographe Bay	8	1	8

Site Selection

Healthy

The five highest ranked healthy sites for Sections 2 and 3 of the questionnaire are shown in Table 5. The sites shown in bold are located within Perth Metropolitan Waters and those underlined contain meadows of the target species *Posidonia angustifolia*. The other sites were excluded and thus the sites chosen were:

- Shoalwater Bay
- Becher Point
- Nth Garden Island

Unhealthy

The five highest ranked healthy sites for Sections 2 and 3 of the questionnaire are shown in Table 2.6. The sites shown in bold are located within Perth Metropolitan Waters and those underlined contain meadows of the target species *Posidonia angustifolia*. The other site were excluded and thus the sites chosen were:

- Mangles Bay
- James Point
- Woodman Point

Table 2.5 – Ranking of the five sites with the highest tallies for "healthy" from Sections 2 and 3 of Questionnaire 1.

Ranking	Section 2	Section 3
1	**Shoalwater Bay and Success Bank**	**Nth Garden Island**
2	**Marmion Marine Park**	**Success Bank**
3	Shark Bay	**Shoalwater Bay**
4	Geographe Bay	**Becher Point and Hillarys**
5	**Nth Garden Island and Becher Point**	**Watermans**

Table 2.6 - Ranking of the five sites with the highest tallies for "unhealthy" from Sections 2 and 3 of Questionnaire 1.

Ranking	Section 2	Section 3
1	**Mangles Bay**	**Mangles Bay**
2	Princess Royal Harbour	Princess Royal Harbour
3	**James Point**	**James Point**
4	Oyster Harbour	**Woodman Point**
5	**Woodman Point**	Oyster Harbour

2.4.2 - Questionnaire 2

Overall, epiphyte biomass and shoot density were the considered the most effective in formulating a perception of seagrass ecosystem health, being deemed important from all the questions (Table 2.13). Epiphyte composition and percentage canopy cover were generally considered important, except for the open question and in the case of epiphyte composition for Mangles Bay. Of the other variables, only above ground biomass was consistently judged to be of minor importance by the respondents.

Section 1

Questions 1&2 – All the respondents were considered suitable for completing the questionnaire

Question 3 - The majority of respondents had worked with the target species of the project *Posidonia angustifolia* and all respondents had previous experience monitoring the target genus of the questionnaire *Posidonia* (Table 2.7).

Table 2.7 - Experience with different seagrass species.

Species	**Frequency**
Posidonia angustifolia	15
Posidonia sinuosa	19 (all)
Other *Posidonia* species	19 (all)
Other Seagrass species	19 (all)

Section 2

Question 1 – Epiphyte biomass and shoot density were the most frequently chosen variables for shaping perceptions of seagrass ecosystem health. Epiphyte composition, canopy height and associated community were less frequently chosen and there was a range of other variables that were selected five times or less (Table 2.8).

Table 2.8 - Factors important to shaping perceptions of seagrass ecosystem health

Factor	Frequency
Epiphyte biomass	14
Shoot density	12
Epiphyte calcareous vs. soft	8
Canopy height	8
Associated community	7
Productivity	5
Below ground biomass	5
Percent canopy cover	3
Areal extent of meadow	3
Above ground biomass	2
Water quality	2
Anthropogenic threats	2
Trophic structure and flow	2
Others	
Sediment redox potential	
Leaf necrosis	
Habitat integrity	
Presence of filter feeding epiphytes (hydroids, bryozoans)	
Presence of sea urchins	
Epiphyte distribution on leaf	
Physical parameters	
Seagrass species (pioneer vs. climax)	
Seagrass vigour	

The importance value of each is shown in Table 2.13. A range of additional variables emerged from the open question. Of these, only the associated community was considered important by more than 5 respondents.

Question 2 – Above ground biomass, productivity, epiphyte biomass, epiphyte composition and shoot density were generally considered either very or extremely important. Percentage canopy cover and shoot length were generally considered important. Below ground biomass was believed to have only some importance in formulating a perception of the health of an ecosystem. The remaining variables, shoot width, lacunal gas space and percentage of nitrogen in leaf tissue were all considered of little importance (Table 2.9).

Question 3 – There were very similar perceptions regarding the thirteen variables at all three sites.

3a – Above ground biomass, epiphyte biomass, shoot density and percentage canopy cover were generally considered either very or extremely important. Epiphyte composition was generally considered important. Productivity was considered of minor importance and the other variables were all deemed to be of no importance in formulating a perception regarding the health of the meadow (Table 2.10).

3b – Above ground biomass, epiphyte biomass, epiphyte composition, shoot density and percentage canopy cover were generally considered either very or extremely important.

Table 2.9 - Importance of selected variables in formulating a perception about seagrass ecosystem health.

No answer - 1

Variable	0	1	2	3	4	unsure	Mean
Above ground biomass	0	2	4	5	6	1	2.88
Below ground biomass	1	8	3	2	3	1	1.88
Productivity	0	1	3	5	8	1	3.18
Epiphyte biomass	0	0	3	7	8	0	3.28
Epiphyte composition	0	2	3	6	6	1	2.94
Shoot density	0	3	4	5	6	0	2.78
Percent canopy cover	1	3	7	4	3	0	2.72
Shoot width	9	6	1	0	1	1	0.706
Shoot length	4	3	8	2	0	1	1.47
Lacunal gas space	9	2	2	0	0	5	0.461
Percent nitrogen	6	5	3	0	0	4	0.786
Areal extent	0	0	0	0	2	0	NA
Habitat integrity	0	0	0	0	2	0	NA
Community composition	0	0	1	1	2	0	NA
Redox in sediment	0	0	0	1	0	0	NA
Leaf health	0	0	1	0	0	0	NA

Table 2.10 - Importance of selected variables in perceiving Mangles Bay as "unhealthy".

No answer - 3

Variable	0	1	2	3	4	unsure	Mean
Above ground biomass	4	0	4	3	5	0	2.31
Below ground biomass	10	1	2	0	0	3	0.385
Productivity	8	0	1	3	0	2	0.917
Epiphyte biomass	0	0	5	3	8	0	3.19
Epiphyte composition	3	2	1	4	4	2	2.29
Shoot density	1	0	2	5	6	2	3.07
Percent canopy cover	2	0	2	4	7	1	2.93
Shoot width	10	2	1	0	0	3	0.286
Shoot length	8	2	2	0	1	3	0.769
Lacunal gas space	10	1	1	0	0	4	0.25
Percent nitrogen	11	0	2	0	0	3	0.308
Areal extent	0	0	0	0	4	0	NA
Fine sediment	0	0	0	0	1	0	NA
Water quality	0	0	0	0	3	0	NA
Sediment redox	0	0	0	1	0	0	NA
Leaf health	0	1	0	0	0	0	NA
Habitat integrity	0	0	0	0	1	0	NA

Productivity was considered of minor importance and the other variables were all judged to be of no importance in formulating a perception regarding the health of the meadow (Table 2.11).

3c – Above ground biomass, epiphyte biomass, epiphyte composition, shoot density and percentage canopy cover were generally considered either very or extremely important. Productivity was considered of minor importance and the other variables were all deemed to be of no importance in formulating a perception regarding the health of the meadow (Table 2.12).

Relative Importance of Variables

Generally, the importance values for the general question were the same or similar to those for the three sites (Table 2.13). All the variables with the exception of epiphyte composition were classed at the same level of importance for all three sites. The closed question used a different importance scale, so these results were not directly compared. Epiphyte biomass, shoot density and canopy cover were classed as important variables for determining perceptions of seagrass ecosystem health generally and at all three sites. Epiphyte composition was classed as important generally and at all sites with the exception of Mangles Bay. Above ground biomass was classed as important generally but of only minor importance at all three sites. Below ground biomass and shoot length were both classed as of minor importance generally but no importance at any of the three

Table 2.11 - Importance of selected variables in perceiving James Point as "unhealthy".

No answer - 5

Variable	0	1	2	3	4	Unsure	Mean
Above ground biomass	3	0	1	4	4	2	2.5
Below ground biomass	9	1	2	0	0	2	0.417
Productivity	7	0	2	2	1	2	1.17
Epiphyte biomass	1	0	2	2	8	1	3.23
Epiphyte composition	1	2	1	5	4	1	2.69
Shoot density	1	1	2	3	5	2	2.83
Percent canopy cover	1	0	1	6	6	0	3.14
Shoot width	9	2	1	0	0	2	0.333
Shoot length	7	2	2	0	1	2	0.833
Lacunal gas space	10	1	1	0	0	2	0.25
Percent nitrogen	10	1	1	0	0	2	0.25
Areal extent	0	0	0	0	2	0	NA
Water quality	0	0	0	0	1	0	NA
Habitat integrity	0	0	0	0	1	0	NA
Sediment redox	0	0	0	1	0	0	NA
Leaf health	0	1	0	0	0	0	NA

Table 2.12 - Importance of selected variables in perceiving Woodman Point as "unhealthy".

Variable	0	1	2	3	4	unsure	Mean
Above ground biomass	4	0	2	5	4	2	2.33
Below ground biomass	11	1	2	0	0	3	0.357
Productivity	9	0	2	2	1	3	1
Epiphyte biomass	1	1	4	2	8	1	2.94
Epiphyte composition	1	3	1	7	4	1	2.62
Shoot density	2	0	0	6	6	3	3
Percent canopy cover	3	0	2	5	7	0	2.76
Shoot width	11	2	1	0	0	3	0.286
Shoot length	9	2	1	1	0	4	0.538
Lacunal gas space	12	2	0	0	0	3	0.143
Percent Nitrogen	12	0	1	1	0	3	0.357
Areal extent	0	0	0	1	2	0	NA
Water quality	0	0	0	0	1	0	NA
Habitat integrity	0	0	0	0	1	0	NA
Hearsay	0	0	0	0	1	0	NA
Sediment redox	0	0	0	1	0	0	NA
Leaf health	0	0	1	0	0	0	NA

Table 2.13 –Relative importance of variables in generating a perception of seagrass ecosystem health, generally and at the three perceived unhealthy sites.

	General	Mangles Bay	James Point	Woodman Point
Above ground biomass	I	MI	MI	MI
Below ground biomass	MI	NI	NI	NI
Productivity	I	NI	NI	NI
Epiphyte biomass	I	I	I	I
Epiphyte composition	I	MI	I	I
Shoot density	I	I	I	I
Percent canopy cover	I	I	I	I
Shoot width	NI	NI	NI	NI
Shoot length	MI	NI	NI	NI
Lacunal gas space	NI	NI	NI	NI
Percent nitrogen	NI	NI	NI	NI

I – Important for Monitoring, MI – Minor importance for monitoring, NI – Not important for monitoring.

sites. Shoot width, lacunal gas space and percentage of tissue nitrogen were considered unimportant generally and at all three sites.

Question 4 - The following general points were conceived regarding general perceptions of seagrass ecosystem health. A comprehensive list of all the points is given in Appendix B.

- Range of external factors to consider when monitoring seagrass ecosystems, including; distinguishing natural variation from anthropogenic variation, different species, threat to system,- 10
- Seagrass ecosystem health is a useful measure for monitoring - 5
- It can only be measured if there are excellent indicators - 4
- Made up of a number of factors, including trophic structure, seagrass characteristics, epiphytes - 3
- Used to explain why we monitor, how we do it and what the results mean on a conceptual level - 2
- Doesn't apply to seagrass ecosystems - 2
- Due to longevity of seagrass they are not useful as indicators
- The word "status" could be used rather than "health" when monitoring ecosystems.
- Must consider dynamic nature of seagrass meadows
- Important not to sample destructively
- Cost/time effective is the practical approach to monitoring

A complete list of the responses to question 4 is given in Appendix C

2.5 - Discussion

The researchers and managers in the seagrass ecology field who responded to questionnaire 2 had a range of views regarding the relevance of monitoring the health of ecosystems such as seagrass meadows. The general consensus was that it is essential to try and formulate some concept of the health of ecosystems. It is no longer appropriate in environmental management to just undertake research on one component of an ecosystem. If any one component is jeopardised, the rest of the ecosystem could collapse. The respondents tended to agree that all components and the links between these components were essential to each system. A comprehensive approach then is essential to ensure the maintenance of ecosystem structure and function.

It was suggested in the second questionnaire that status could possibly take the place of the controversial word 'health'. This would partially solve, or evade the problem of what health is. Although status is just a substituted word and the logistical problems would be the same, it suggests that ecosystems are not simply 'healthy' or 'unhealthy'. In this way systems could be compared on the basis of their characteristics, without having to have specific human developed labels. This method has been used recently on a *Posidonia sinuosa* meadow in Geographe Bay, south-western Australia (McMahon et al. 1997).

It was also emphasised in the second questionnaire that when monitoring any marine systems, there are limitless internal and external factors to consider. In particular, the extreme variability of marine systems makes monitoring difficult. It is essential to distinguish this natural variation from change caused by anthropogenic impacts.

There are further confounding factors when considering ecosystem monitoring. Although light reduction is generally considered to be the main cause of seagrass decline in Western Australia (Dennison et al. 1993, Masini et al. 1995), there are other causes, including, physical removal through sea floor dredging and boat mooring, urchin grazing and impacts of toxic pollutants (SMCWS 1996). These causes must also be considered when monitoring. Therefore, it was suggested that more information regarding seagrass ecosystems is required to refine and focus the monitoring practices already established. Comprehensive study would be necessary to ensure an extensive knowledge base. This would constitute information from long term studies to show seasonal and annual changes, and from laboratory manipulated experiments to establish the effects of anthropogenic impacts and the magnitude of these impacts (SMCWS 1996).

When monitoring ecosystems, it is logistically impossible to measure all components. This was stressed in the second questionnaire, with emphasis placed on realistic monitoring, given the constraints on time and funding available. Therefore, a balance must be obtained between taking everything into account and actually being able to monitor. Monitoring then has returned to measuring certain components, even though it is recommended that all components should be measured. The most realistic approach has been to try and determine indicators which could be used to provide an indication of the status of the ecosystem (Atrill and Depledge, 1997, Joergenson 1995, Sims and

Nicholl 1997, Dauer, 1993). The respondents from the second questionnaire were generally in agreement that indicators are the most practical method of ecosystem monitoring. It was emphasised that to ensure a comprehensive idea of the health of a system was obtained, only excellent indicators could be used.

It is also important to consider that different species of seagrass will respond differently to disturbances. Thus, it cannot be taken for granted that the same monitoring practices can be used for all species. In Western Australia, this is particularly important due to the diversity of seagrass species. These different species have a range of morphologies, growth rates and colonising speeds and thus using the same indicators for two different species would not be appropriate. Therefore, similar studies to the present one need to be undertaken to ensure these species can also be adequately monitored.

Sampling for minimal disturbance was strongly emphasised by respondents from one management agency in the second questionnaire. Seagrass, in particular more stable slow growing species such as found in the genus *Posidonia* take a long time to regrow after disturbances (Hastings et al. 1995). For this reason, it is evident that variables such as above and below ground biomass were not considered important for monitoring. These two variables are extremely destructive, and seagrass meadows will take considerable time to recover the lost material.

When considering which indicators to use for monitoring, epiphyte characteristics stood out. Epiphyte growth, as mentioned in Section 1 is recognised as one of the two major causes of a reduced light climate for seagrass, the other being phytoplankton in the water column. For this reason, it has been measured extensively in the past and was given as the major reason behind the decline in cover in Cockburn Sound (Cambridge and McComb 1984, Cambridge et al. 1986). It is likely that the prevalence of epiphyte measurement in the past contributed to its dominance in the questionnaire.

Shoot density and to a lesser extent percentage canopy cover, were the other variables to be considered important in questionnaire 2. Shoot density is easily measured, *in situ* or from extracted samples (Kirkman 1996, Phillips and McRoy 1990). Due to this fact and its responsiveness to change in light climate, it has been used considerably in the past (Kirkman 1987, West 1990, Silberstein et al., 1986, Fitzpatrick and Kirkman 1995, Gordon et al. 1994, Lavery and Westera 1998, Cambridge and Hocking 1997). Percentage canopy cover has been measured to a lesser extent (Lavery 1994, Lavery and Westera 1998, Heidelbaugh and Nelson 1996), but is also very easy to sample and has responded to change in the past. Again this prevalence of previous usage is the likely reason for the perceived importance in the questionnaire of these two variables. Additionaly, it was reinforced that perceptions were influenced by ease of measurement as well as response to change in light climate.

Generally, researchers and managers in the seagrass ecology field agree that it is essential to monitor ecosystem health, when considering seagrass meadows. Furthermore, the use of indicators was considered the most effective, in fact the only way to monitor these systems. In particular, characteristics which cause decline, such as epiphytes and those which require little sampling effort, such as shoot density and percentage cover were considered the most important in formulating a perception of the health of a seagrass ecosystem.

Section 3 - Assessment of the Usefulness of a Number of Variables for Monitoring *Posidonia angustifolia* Ecosystem Health.

3.1 - Introduction

This project arose from the need of the Department of Environmental Protection for effective seagrass monitoring in Cockburn Sound. The DEP requested Edith Cowan University undertake monitoring of *Posidonia* meadows in Cockburn Sound in 1994 and 1997. The researchers involved in this program have recognised the inadequacy of the current monitoring and the absence of a comprehensive management protocol (Lavery and Westera pers. comm.). In particular, there is no definite guidance on the best parameters to monitor .

In the past, a range of indicators have been measured from causes, such as light attenuation or nutrients (Silberstein et al., 1986, Abal and Dennison 1996, SMCWS 1996) through to response measurements, such as aspects of the seagrass itself, for example, shoot density (West 1990, Kirkman 1987, Silberstein et al., 1986, Fitzpatrick and Kirkman 1995, Gordon et al. 1994, Lavery and Westera 1998, Cambridge and Hocking 1997). There are advantages of measuring actual biological elements over physical or chemical properties. First, a biological element provides a direct measure of the condition of the main component of the system, that is the seagrass. Second, problems not due to that particular threat may also be uncovered and thirdly, this information can be utilised for assessment of restoration attempts (Dauer 1993, Abel 1993).

Another major factor to consider when monitoring in the marine environment is that due to a range of hydrodynamic factors, water column attributes are highly variable. To get a complete idea of the nutrient or light impacts, monitoring of these attributes would have to be undertaken at least every week all year round (Silberstein et al., 1986, Abal and Dennison 1996). From a management perspective, this sort of monitoring is only possible in areas that are already known to be under threat. It is essential to be able to have certain indicators that can be measured at any seagrass meadow, which may be perceived to be heading towards an "unhealthy" state. Furthermore, if effective indicators can be established, the time required for extensive water quality monitoring can be spread to other areas. Measurement of biological components tends to integrate water quality changes over long periods and can reduce the time required for monitoring (Dauer 1993). For these reasons, only biological elements were considered as possible indicators of the "health" of seagrass ecosystems.

In deciding which are the most appropriate variables to use as indicators, variables can be evaluated by comparing them according to a number of indicator criteria. There is very little literature explaining the criteria required for indicators based on measurement of a particular organism, i.e. seagrass parameters. Yen and Butcher (1997) provide a number of criteria for determining invertebrates which indicate whether freshwater ecosystems are disturbed. These are, sensitive to change, ease of measurement and previous study.

Due to the lack of criteria relating to marine systems this study will include these three criteria. These criteria are robust enough that they can be used for marine systems. Additionally, the variability of each parameter will be considered, as highly variable indicators change rapidly to natural as well as anthropogenic disturbance (Jacoby, 1993, SMCWS 1996). Also the extent to which destructive sampling is required was taken into account to ensure minimal disturbance to seagrass meadows. This is a view strongly advocated by the Department of Conservation and Land Management (Jennie Cary pers. comm.).

A range of indicators have been used for monitoring seagrass ecosystems in the past, from threats through to responses. Monitoring on meadows which are known to be under threat has focussed on measuring the actual threats to the system, such as nutrients in the water column and light attenuation (Silberstein et al., 1986, Abal and Dennison, 1996, SMCWS, 1996). Additionally, primary responses to these changes, such as epiphyte and phytoplankton qualities have also been measured at these meadows (SMCWS, 1996, Neverauskas, 1987, Neverauskas, 1988, Kendrick and Burt 1997). Secondary responses, such as characteristics of the seagrass itself have been measured on meadows which are believed to be under threat, as well as meadows whose status is unknown.

It is suggested, that a monitoring programme should include measurements of the threat to a system, as these should provide the first detectable changes (Hart 1992). Furthermore though, monitoring should include measurements of the responding variables, as these responses may not be due to the postulated threat (Dauer 1993).

However, as mentioned above, when monitoring marine systems, the variability is such that water column attributes (which generally provide the primary threat) need to be measured frequently and over long time periods to ensure an accurate idea of the status of the system is given. These sorts of intensive monitoring practices require extensive funding, which is not available to monitor a range of seagrass meadows and the reason why only the meadows known to be stressed are monitored in this way. For this reason, the more stable attributes of the system, which with the exception of epiphytes are responses, are more appropriate for monitoring programmes with an intention of gaining an idea quickly and easily of the state of any seagrass meadow.

Of the more stable attributes of seagrass meadows, there are a range which have been measured in the past, the majority of these being aspects of the seagrass itself. A substantial amount of work has centred on the productivity or growth of seagrass meadows (Gordon et al. 1994, Silberstein et al., 1986, Lavery and Westera 1998). The rationale behind this, is that plants under stress will be less able to put energy into growth (Hillman et al. 1989). Recently, the percentage of nitrogen in the leaf tissue of seagrasses has provided an indication of the photosynthetic stress a plant is under and is a possible indicator for the future (Abal et al. 1994, Cambridge and Hocking 1997).

Following on from the growth of the plant, much work has been done on structural attributes such as shoot density (Fitzpatrick and Kirkman 1995, Gordon et al. 1994, Lavery and Westera 1998, Cambridge and Hocking 1997), shoot width (Masini and Manning 1997, Neverauskas 1988, West 1990), shoot length (Masini and Manning 1997, Neverauskas 1988, West 1990, Gordon et al. 1994), percentage canopy cover (Lavery 1994, Lavery and Westera 1997, Heidelbaugh and Nelson 1996) and above (Hillman 1995, PCWS 1994, Kirkman 1987, Abal et al. 1994) and below ground biomass (Hillman et al. 1989). These attributes are likely to be affected in time with increased stress on the plants as growth rates are reduced. These attributes do not respond to change as quickly, but the changes they do show are more stable.

This section focuses on those attributes mentioned above, with the exception of those whose variability is such that they require more intensive measurement than is possible in an honours project, water column nutrients and light attenuation. These variables were compared according to the indicator criteria mentioned above to determine which are the most effective for monitoring seagrass ecosystems.

3.2 - Aim

To ascertain which variables are the most effective for determining seagrass ecosystem health by measuring actual variables at perceived healthy and unhealthy *Posidonia angustifolia* meadows and classing them according to certain indicator criteria.

3.3 - Methodology

3.3.1 - Research Plan

A number of variables were compared against a number of indicator criteria, determined from the literature. These criteria included

1. previous measurement
2. variability
3. ease of sampling
4. destructiveness of sampling.
5. response to change in light – based on the present study
   - based on previous studies

The first two criteria were to be determined from previous studies. The second two criteria were determined through measurement at perceived healthy and unhealthy seagrass meadows. The last criteria represented the major portion of this study, measured in the field. These results for the final criteria were further compared with previous studies.

Literature review

A literature review was undertaken to determine all the variables previously used for monitoring seagrass meadows. This involved obtaining and critiquing the few existing monitoring reviews (Phillips and McRoy, 1990 and Kirkman, 1996). Furthermore, the methods used in the many ecological studies on seagrass in Western Australia were analysed to determine potentially important variables to monitor, how to monitor them and their value as indicators of seagrass ecosystem health (Abal et al., 1994, Abal and Dennison, 1996, Cambridge and McComb, 1984, Cambridge et al., 1986, Cambridge and Hocking, 1997, Fitzpatrick and Kirkman, 1995, Gordon et al., 1994, Grice et al., 1996, Heidelbaugh and Nelson, 1996, Hillman et al., 1989, Hillman, 1995, Kendrick and Burt, 1997, Kirkman, 1987, Masini and Manning, 1997, Neverauskas, 1988, Neverauskas, 1987, PCWS, 1994, Silberstein et al., 1986, West, 1990). These studies were also used to evaluate each variable against three of the determined indicator criteria, previous measurement, response to change and variability.

Site selection

Six sites were chosen on the basis of information obtained from questionnaire 1 (see Section 2). The sites chosen were categorised as perceived healthy and perceived unhealthy. The coordinates are given in Table 3.1 and their locations in Figure 3.1

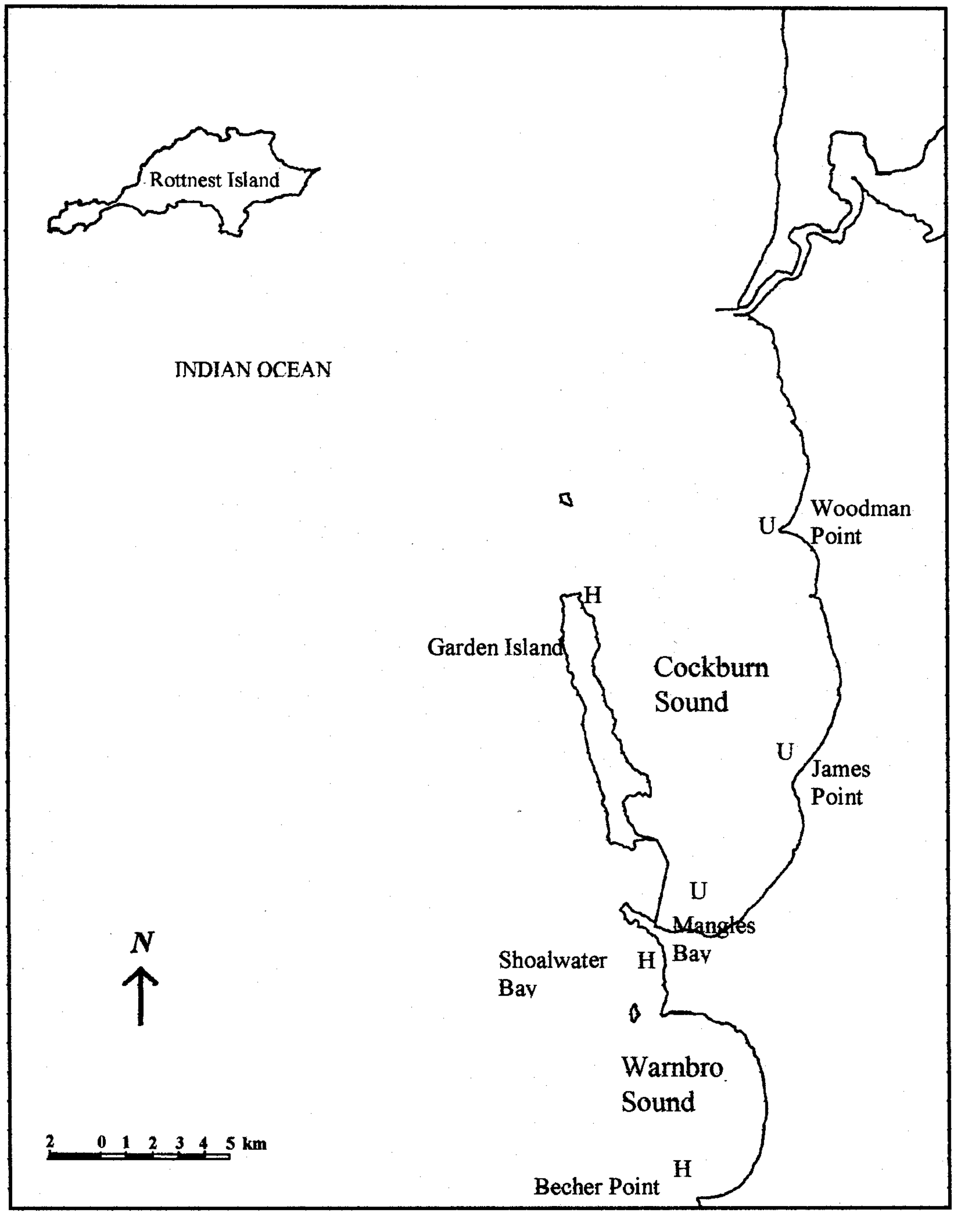
Table 3. 1 - Coordinates of the three perceived healthy and three perceived unhealthy sites.

Site		**Coordinates**
Healthy	North Garden Island	0374671 6440510
	Becher Point	0378467 6417948
	Shoalwater Bay	0376863 6427920
Unhealthy	Mangles Bay	0378714 6428467
	James Point	0381444 6437420
	Woodman Point	0380935 6443121

All the sites were found within Cockburn and Warnbro Sounds, to the south of Fremantle. These are deep basins (approximately 20 metres) with shallower margins up to 10 metres deep, which support seagrass meadows. Essentially, the sites perceived to be unhealthy were all located on the eastern edge of Cockburn Sound – Mangles Bay, James Point and Woodman Point. The sites perceived to be healthy were North Garden Island, and two sites in Warnbro Sound – Shoalwater Bay and Becher Point. The perceptions here were closely correlated with measurable reality. The Southern Metropolitan Coastal Waters Study (1996) found that meadows on the eastern edge of Cockburn Sound have lower light attenuation, are more nutrient enriched and have higher phytoplankton concentrations than other meadows in the region. From this information, the perceived healthy sites can assumed to have greater light availability than the perceived unhealthy sites.

The sites were very similar in terms of depth, ranging from 2.5 to 4 metres, and exposure.

Figure 3. 1 – Site map showing three perceived healthy (H) and three perceived unhealthy (U) *Posidonia angustifolia* meadows.



Mangles Bay is located in the South of Cockburn Sound. There is little water movement in this bay, due to the barriers, Garden Island and its causeway to the East. Seagrass was sampled at a depth of 3.5 metres.

James Point is located near the Eastern shoreline of Cockburn Sound. It is less protected than Mangles Bay and closer to the industrial area. Seagrass was sampled at a depth of 4 metres.

Woodman Point is located at the extreme North tip of Cockburn Sound. Seagrass was sampled in between the two groynes, near the CSBP wastewater outfall at a depth of 2.5 metres. This wastewater outfall was a major additional source of nutrients until 1984, when it was diverted to the Sepia Depression (SMCWS 1996). There is good water circulation at this site, as it is an open bay.

The North Garden Island site was located in the bay on the Western side of Garden Island just South of the Northern extreme. Water circulation is dependent on wind direction. Generally the water in this bay is well circulated. Seagrass was sampled at a depth of 2.5 metres at this site.

Shoalwater Bay is located to the south of Point Peron in Warnbro Sound. This site is well protected by Shag Rock to the East and Point Peron to the North and thus there is little water circulation. Seagrass was sampled to a depth of 3 metres at this site.

Becher Point is located at the southern extremity of Warnbro Sound. This site is less protected than the others, being exposed to winds from the North, South and West. Seagrass was sampled at a depth of 4 metres at this site.

Sampling Design

As mentioned above, six sites were broken into two categories, perceived healthy and unhealthy and a number of variables were measured at each. The following variables were measured – shoot length, shoot width, leaf area index, shoot density, above ground biomass, below ground biomass, epiphyte biomass, epiphyte species richness, percentage calcium carbonate in epiphytic material, leaf extension rate, meadow productivity, percentage canopy cover and percentage nitrogen content in leaf tissue. Each variable was replicated five times as shown in the design (Table 3.2)

Table 3. 2 – Sampling design for nested analysis of variance for chosen variables.

Treatment	**Perceived Healthy**			**Perceived Unhealthy**		
Site (Treatment)	NG	BP	SB	MB	JP	WP
Replicates	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

NG - North Garden Island, BP - Becher Point, SB - Shoalwater Bay, MB - Mangles Bay, JP - James Point, WP - Woodman Point.

3.3.2 - Field and Laboratory Work

Field work was undertaken in the period from the 22nd of June to the 14th of August. The variables were measured at each of the six sites or samples collected for later processing, using SCUBA units.

Percentage Cover

Photographs were taken using an underwater camera at 5 positions within the meadow. These positions were determined using a random numbers table to ascertain direction and distance. The camera was mounted on a metal frame, providing a field of view for each of the photographs of 50cm by 50cm. The photographs were observed under a 10x10 grid. Using the point intercept method (Phillips and McRoy 1990) the % cover in each quadrat was determined.

Above and Below Ground Biomass

All the above and below ground material was taken from 5 randomly chosen 25cm by 25cm quadrats. A pruning saw was used to cut through the rhizome mat at the edges of each quadrat to a depth of 30cm. All the material within the quadrat was then extracted using a garden trowel and placed in large plastic bags in an esky to reduce decomposition. Above ground material was scraped of epiphytes using a razor blade and separated from below ground material. Above and below ground material was then dried at 80°C for 24 hours. This material was then weighed and dried for another 4 hours before re-weighing to ensure constant weight.

Shoot Density, Width and Length

Before scraping, the shoots extracted for biomass measurements were counted. The twenty five longest shoots were measured. The widths of twenty five shoots were also measured. The leaf area index (surface area of seagrass leaves/area of seagrass meadow) was calculated by multiplying these two values together with shoot density.

Epiphyte Biomass

All shoots were scraped using a razor blade to remove algal epiphytes. These were placed in pre weighed, fired and desiccated crucibles, dried at 80 °C for 24 hours, desiccated for a further 12 hours and then dry weight was determined using a four decimal point balance. The material in the crucibles was then combusted at 550 °C for one hour, desiccated and ash free dry weight was measured. Two standards containing glucose were placed at the front and rear of the oven to allow for correction in the event of incomplete combustion and to ensure even heat distribution. The crucibles were then combusted at 950 °C for a further hour, desiccated and weighed to determine calcium carbonate content. Again standards were placed at the front and rear of the oven, this time containing calcium carbonate. On combustion:

$$CaCO_3\,(s) \xrightarrow{\text{heat}} CaO\,(s) + CO_2\,(g)$$

The difference between the final and initial weight equates to the mass of carbon dioxide gas produced. The mass of calcium carbonate is then calculated as

$$CaCO_3 = (\text{initial weight} - \text{final weight}) \times \frac{\text{Molecular weight }(CaCO_3)}{\text{Molecular weight }(CO_2)}$$

And further corrected for the percentage conversion standards.

Epiphyte Species Richness

The number of epiphytes on one shoot from each quadrat were differentiated and identified to species level where possible. The species richness was determined as the total number of species obtained from the five shoots at each site.

Percentage of Nitrogen in Leaf Tissue

A small portion of the dried above ground material was ground using a mortar and pestle. Two to four milligrams of each sample was weighed out and entered into a radio isotope spectrometer. The samples were completely combusted and the combustion products purified. The remaining nitrogen and carbon dioxide gases were then separated. The isotropic composition of these gases was then determined and compared to a known reference material. Only the percentage of nitrogen was required for this project.

Productivity

25 shoots within each of 5 randomly chosen quadrats were punched at the top of the leaf sheath and left for three weeks after marking each quadrat location with a small float. Each site was marked with a sub surface buoy and the coordinates were taken using a global positioning system. After three weeks, all the shoots were retrieved and returned to the laboratory. Within each bag of shoots punched for productivity, 25 shoots were measured from punch hole to the top of the leaf sheath. These values were then divided by the number of days left in the field to give a leaf extension rate per day. Meadow productivity per quadrat was determined by multiplying leaf extension rate by shoot density. When collecting data from Shoalwater, only one quadrat was found and thus the results obtained for this variable were not able to be adequately compared between the sites.

3.3.3 - Statistical Analysis

The comparison of seagrass ecosystem characteristics at perceived healthy and perceived unhealthy sites was achieved through a nested two factor ANOVA sampling design. Two independent variables were treatment and site nested within treatment (Table 3.2).

As there was limited data for productivity at Shoalwater Bay, the ANOVA was undertaken in three ways. Firstly, it was completed with Shoalwater having no replication. It was then completed excluding Shoalwater and comparing three unhealthy sites with two healthy. Finally, it was completed excluding Shoalwater Bay and Woodman Point to ensure the same number of sites were compared for each treatment.

Ease and destructiveness of sampling were simply compared through observations of the time, effort and damage required to measure each variable.

3.4 - Results

3.4.1 – Differences between perceived healthy and unhealthy sites

The majority of variables showed significant differences between either Treatments or Sites nested in Treatment, but no variables were significantly different according to both. The only two variables to show significant differences between Treatments were shoot length and above ground biomass. Significant differences between Sites nested in Treatment were found with the majority of variables, with the exception of shoot length, above ground biomass and percentage of calcium carbonate in epiphytic material. Percentage calcium carbonate was the only variable to have no significant differences between either Treatments or Sites nested in Treatment (Table 3.3).

Shoot Density

There were no real trends in density of shoots across the six sites or between the two treatments (Figure 3.2). The variability was high, with Shoalwater Bay having a standard deviation equal to 36 percent of the mean down to Woodman Point at 13 percent. Woodman Point had the greatest number of shoots with a mean of 138.4 over five quadrats more than three times as many as James Point with the lowest figure of 45.3. There was no significant difference between the two Treatments but the Sites nested within Treatment were considered different (Table 3.3).

Table 3. 3 – Statistical differences of variables between perceived healthy and unhealthy sites.

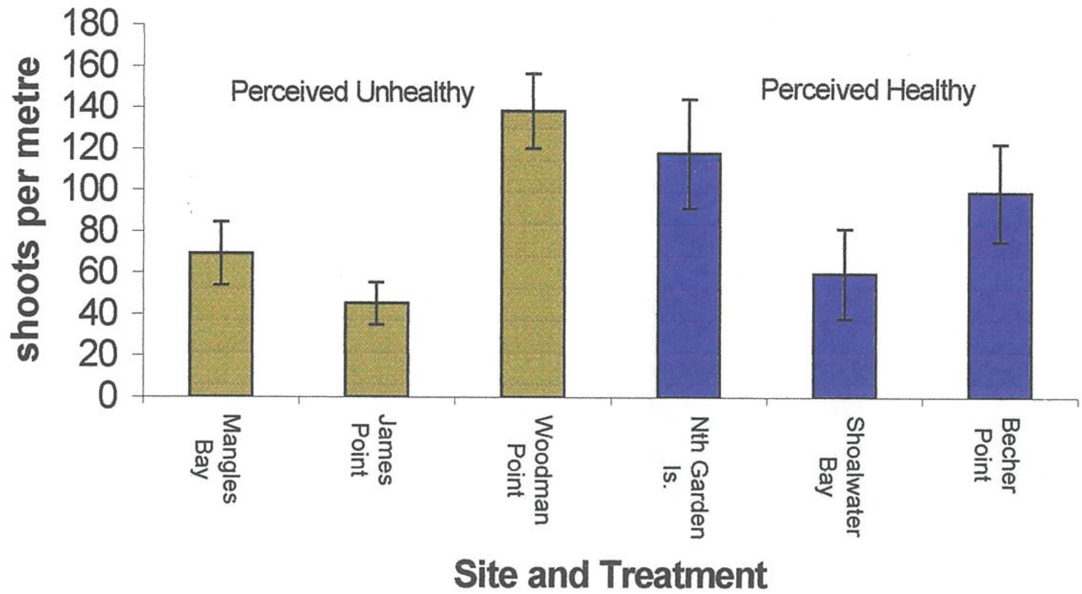
Shoot density	**Df**	**ss**	**ms**	**F-value**	**p-value**
Treatment	1	1140.83	1140.83	0.121	0.746
Site (treatment)	4	37860.53	9465.13	23.785	0.0001
residual	24	9550.8	397.95		
Shoot width					
Treatment	1	0.222	0.222	0.217	0.6655
Site (treatment)	4	4.082	1.02	4.087	0.0115
residual	24	5.992	0.25		
Max. Shoot length					
Treatment	1	147574.56	147574.56	33.08	0.0045
Site (treatment)	4	17878.04	4469.51	1.20	0.3348
residual	24	89.091.58	3712.15		
Leaf Area Index					
Treatment	1	19.66	19.66	1.992	0.231
Site (treatment)	4	39.46	9.87	10.15	0.0001
residual	24	22.33	0.972		
Above ground					
Treatment	1	4045.16	4045.16	7.783	0.0493
Site (treatment)	4	2078.89	519.723	1.597	0.2076
residual	24	7811.98	325.5		
Below ground					
Treatment	1	723.83	723.83	1.168	0.3406
Site (treatment)	4	2478.56	619.64	6.897	0.0008
residual	24	2156.15	89.84		
% Cover					
Treatment	1	1077.72	1077.72	3.895	0.1197
Site (treatment)	4	1106.79	276.70	6.723	0.0009
residual	24	987.73	41.16		

Continued ....

Table 3.3 – continued.

Leaf ex. rate 3x3					
Treatment	1	0.102	0.102	0.153	0.7156
Site (treatment)	4	2.655	0.664	6.201	0.0021
residual	24	2.141	0.107		
Leaf ex. Rate 3x2					
Treatment	1	0.255	0.255	0.291	0.6271
Site (treatment)	3	2.63	0.877	8.188	0.0009
residual	20	2.141	0.107		
Leaf ex. rate 2x2					
Treatment	1	0.862	0.862	1.307	0.3714
Site (treatment)	2	1.319	0.66	5.502	0.0152
residual	16	1.918	0.12		
Productivity 3x3					
Treatment	1	5308.98	5308.98	0.066	0.81
Site (treatment)	4	322009.89	80502.47	97.44	0.0001
Residual	24	16524.39	826.22		
Productivity 3x2					
Treatment	1	38602.01	38602.01	0.38	0.5813
Site (treatment)	3	304800.65	101600.22	122.97	0.0001
Residual	20	165424.39	826.22		
Productivity 2x2					
Treatment	1	146508.89	146508.89	5.182	0.1506
Site (treatment)	2	56548.26	28274.13	36.94	0.0001
Residual	16	12247.93	765.5		
Epi AFDW					
Treatment	1	0.184	0.184	0.11	0.7571
Site (treatment)	4	6.705	1.676	61.22	0.0001
residual	24	0.657	0.027		
% $CaCO_3$					
Treatment	1	0.837	0.837	0.019	0.8959
Site (treatment)	4	172.59	43.15	2.408	0.0774
residual	24	430.05	17.92		
% Nitrogen					
Treatment	1	0.048	0.048	0.172	0.6995
Site (treatment)	4	1.121	0.28	3.206	0.0304
residual	24	20.98	0.087		

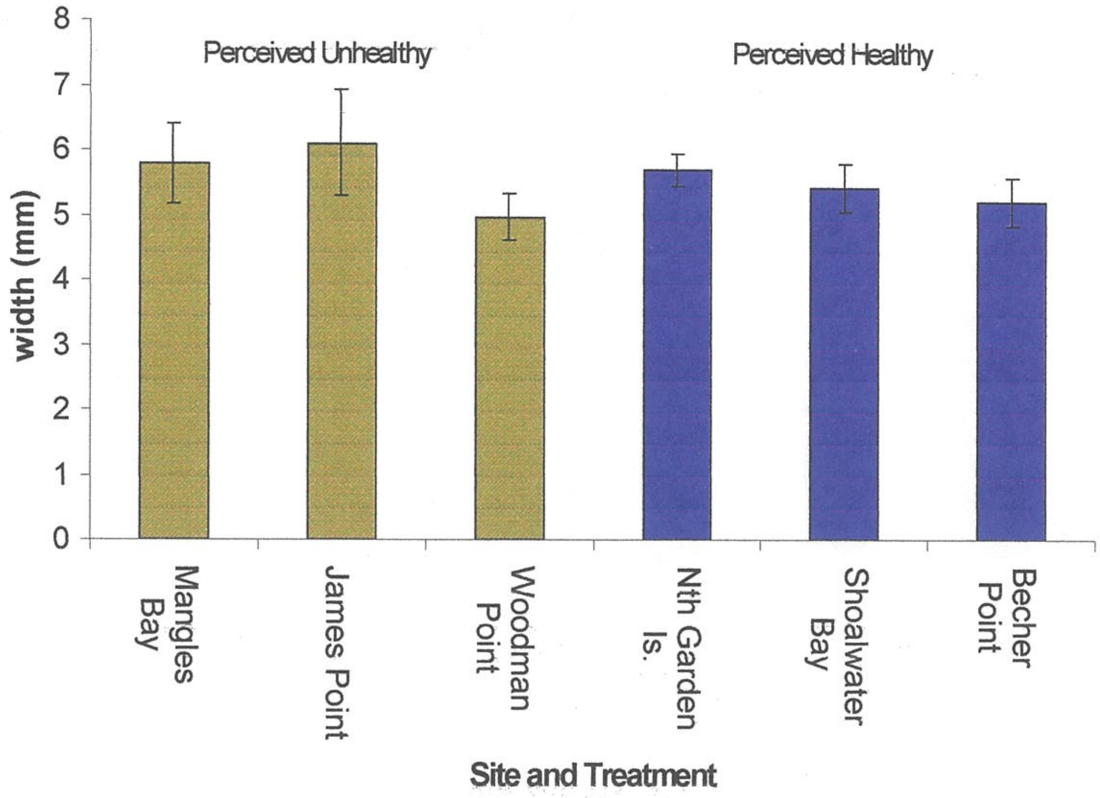
Figure 3.2 - Mean and Standard Deviation of Shoot Density at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Shoot Width

There was no trend in shoot width between either sites or treatments (Figure 3.3). The width of shoots ranged from 4.96mm at Woodman Point to 6.1mm at James Point. There was little variability within the quadrats, with standard deviations ranging from 4 percent of the mean at North Garden Island to 13 percent at James Point. There were no significant differences between Treatments but the Sites nested within Treatments were significantly different (Table 3.3).

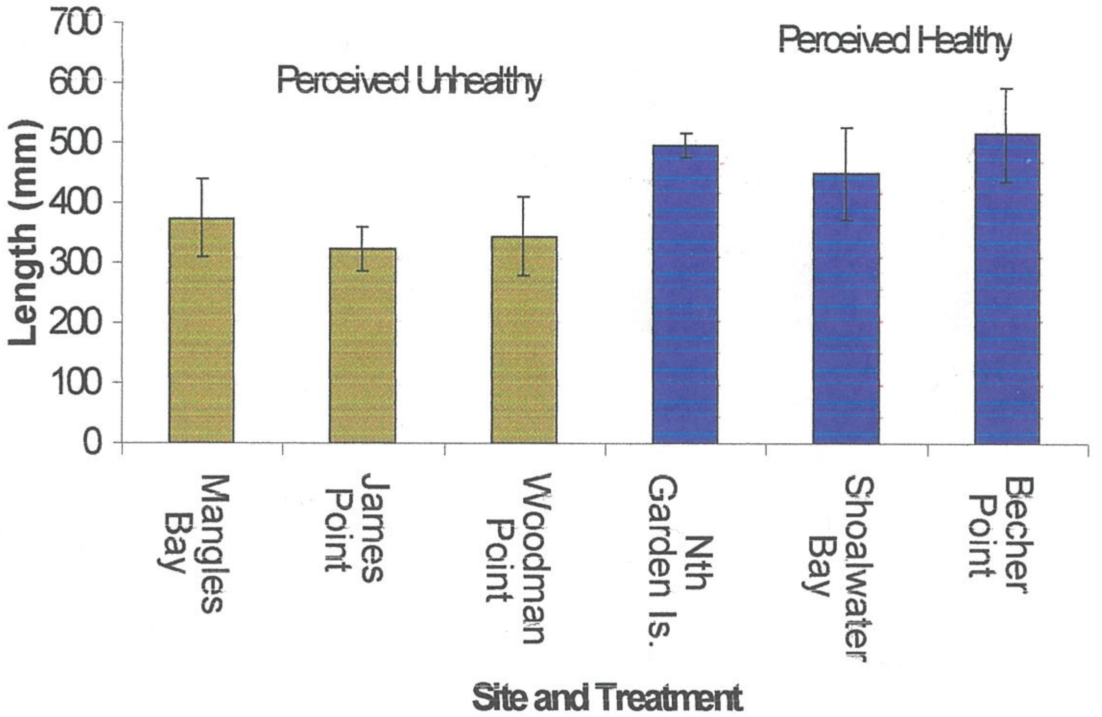
Figure 3.3 - Mean and Standard Deviation of Shoot Width at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Maximum Shoot Length

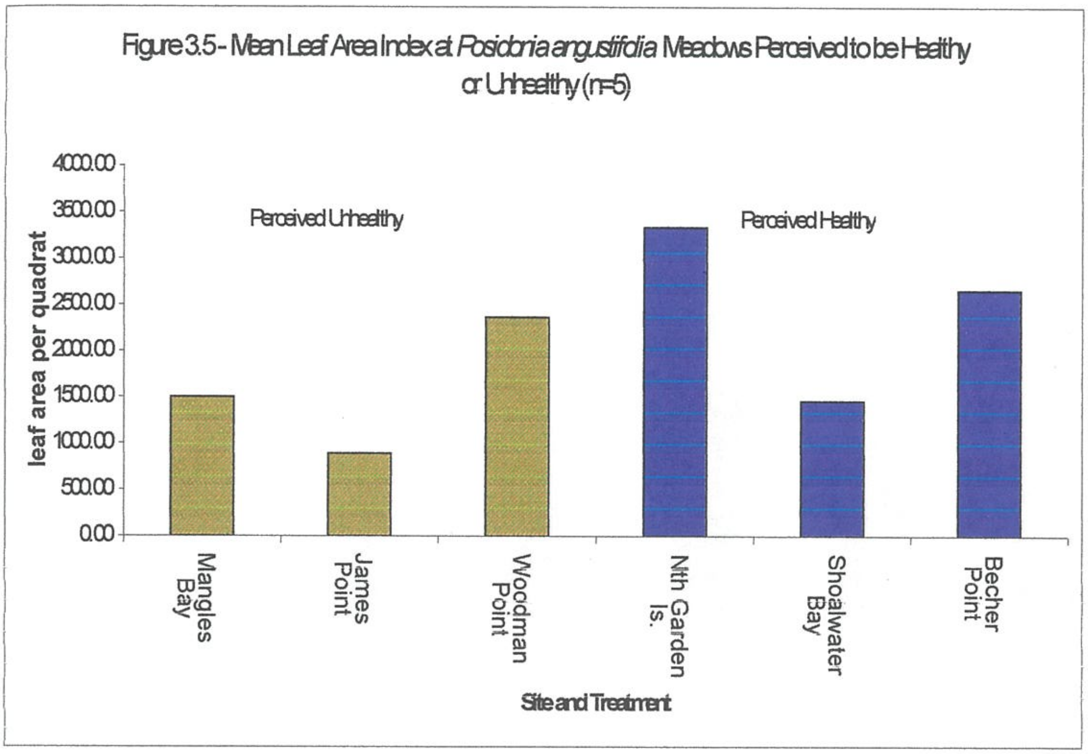
Shoots at perceived unhealthy sites were significantly shorter than those at healthy sites as can be seen graphically (Figure 3.4) and on the significance table (Table 3.3). Sites though showed no differences (Figure 3.4). Shoots ranged in length from a mean of 515.3mm at Becher Point to 322.4mm at James Point. Variability ranged between sites with North Garden Island having a standard deviation equal to 4 percent of the mean up to 17 percent at both Shoalwater and Mangles Bays.

Figure 3.4 - Mean and Standard Deviation of Maximum Shoot Length at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Leaf Area Index

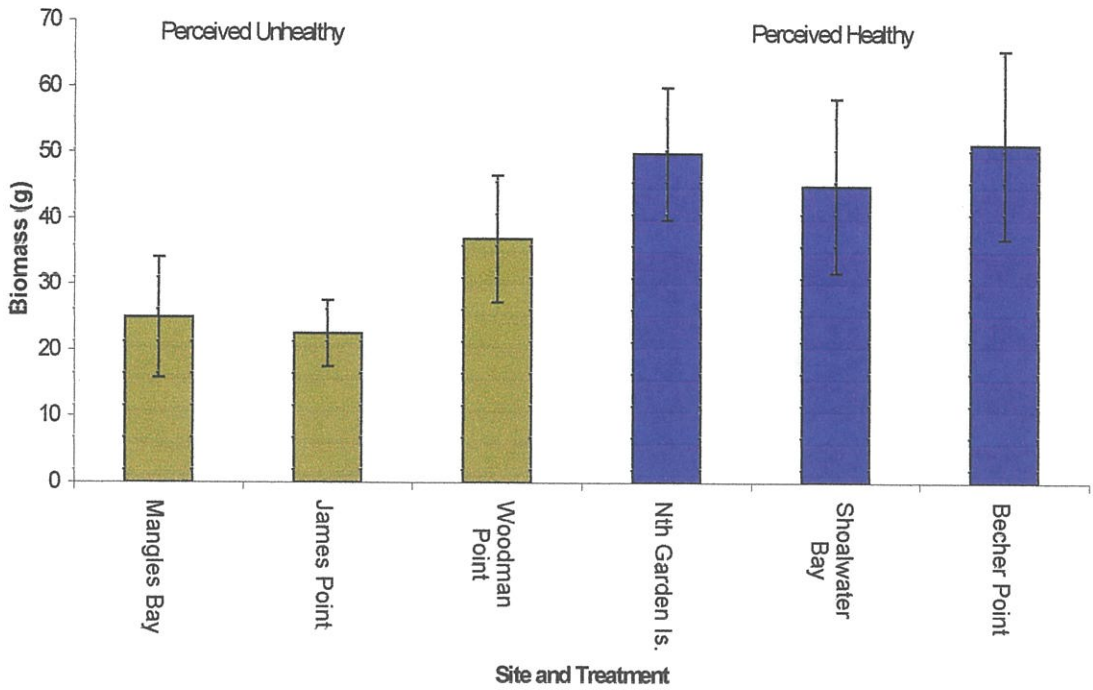
There were no trends in leaf area index across the six sites or between the two treatments (Figure 3.5). Values ranged from 5.31m^2 per m^2 of meadow at North Garden Island to 1.07m^2 at James Point. There were no significant differences between Treatments but the Sites nested within Treatment were found to be significantly different (Table 3.3).



Above Ground Biomass

There was a significantly larger amount of above ground material found at healthy sites than at unhealthy, as can be seen graphically (Figure 3.6) and statistically (Table 3.3). There were no significant differences found between Sites nested within Treatments (Table 3.3). Biomass values ranged from 22.5g/0.0625m^2 at James Point up to 51.3g at Becher Point. The variabilities were high at the majority of sites, with standard deviations ranging from 20 percent of the mean at North Garden Island to 60 percent at Shoalwater Bay.

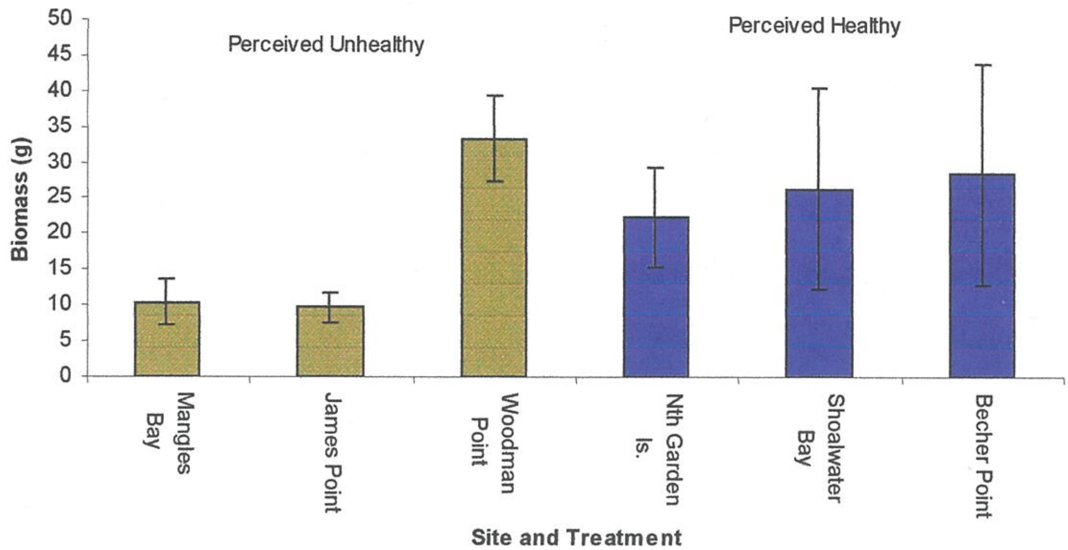
Figure 3.6 - Mean and Standard Deviation of Above Ground Biomass at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Below Ground Biomass

With the exception of Woodman Point, the healthy sites had greater quantities of below ground material than unhealthy (Figure 3.7). These differences were not statistically validated, but Sites nested within Treatments were statistically different (Table 3.3). Quantity of biomass ranged from 9.7g/0.0625m^2 at James Point to 33.4g at Woodman Point. Again, the variability within sites was high, with standard deviations ranging from 18% of the mean at Woodman Point to 55% at Becher Point.

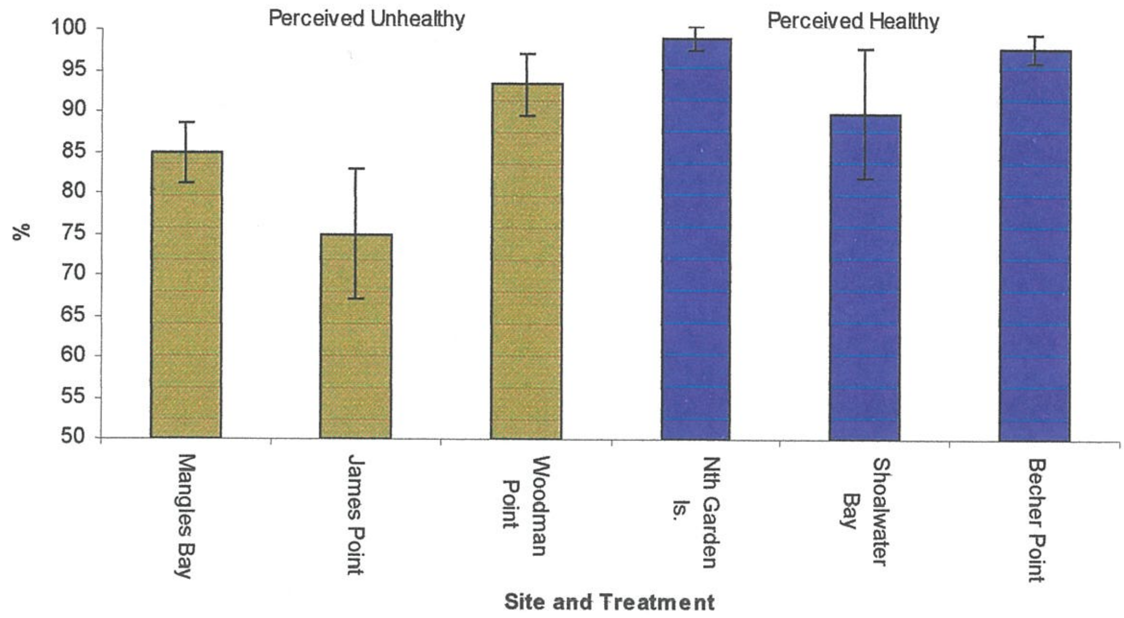
Figure 3.7 - Mean and Standard Deviation of Below Ground biomass at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Percentage Cover

Generally, there was greater canopy cover at healthy sites (Figure 3.8), but this was not statistically validated (Table 3.3). The Sites nested within Treatment were statistically different (Table 3.3). Means for cover over five quadrats ranged from 75 percent at James Point to 97.8 percent at Becher Point. There was little variation within sites, with standard deviations ranging from 1 percent of the mean at North Garden Island to 10 percent at James Point.

Figure 3.8 - Mean and Standard Deviation of Percentage Canopy Cover at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Leaf Extension Rate

There were no trends in leaf extension rate across the six sites (Figure 3.9). Values ranged from 2.1mm/day at James Point, to 2.9mm/day at North Garden Island. Standard deviations ranged from 2 percent of the mean at North Garden Island to 23 percent at Becher Point. At all three levels, there was no significant difference between Treatments, but Sites nested within Treatment were different (Table 3.3).

Productivity

There were no trends in productivity across the six sites (Figure 3.10). Values ranged from 67.9mm per quadrat at James Point to 381.4mm at Woodman Point. Variability was the same as for leaf extension rate. At all three levels, there were no significant differences between Treatments, but Sites nested within Treatment were significantly different (Table 3.3).

Figure 3.9 - Mean and Standard Deviation of Leaf Extension Rate at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)

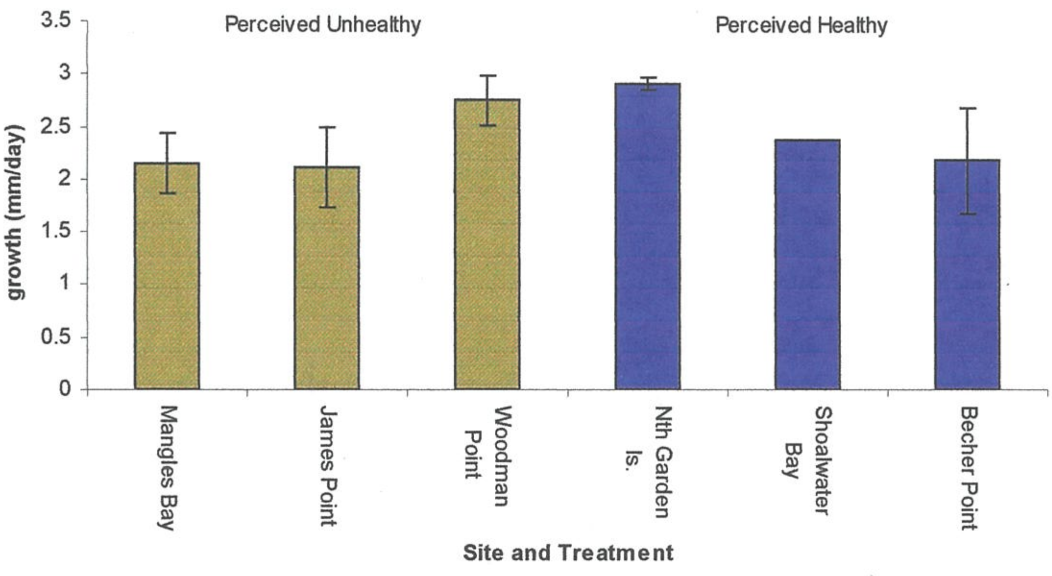
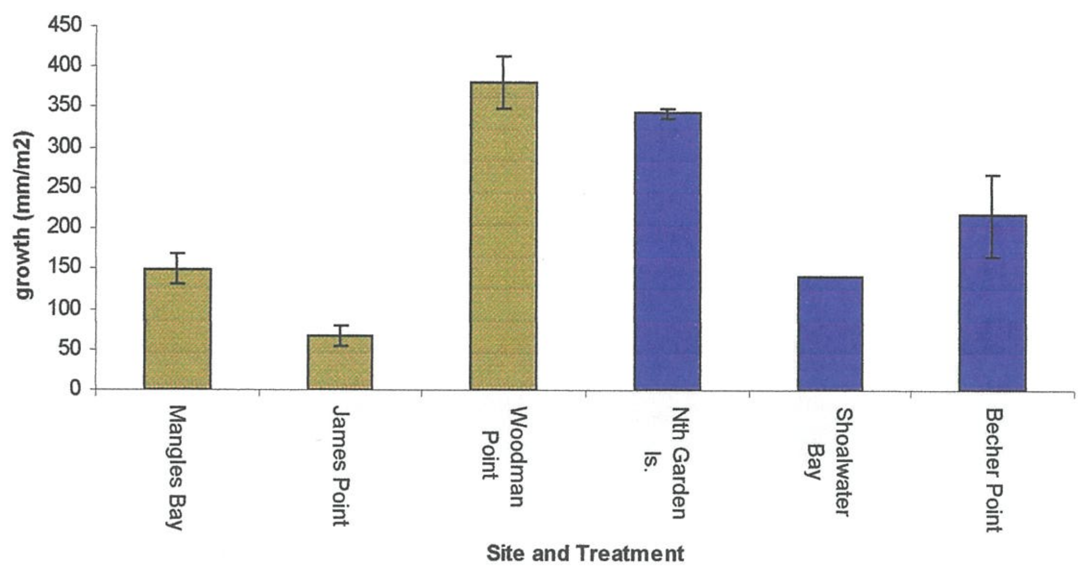


Figure 3.10 - Mean and Standard Deviation of Productivity at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Epiphyte Biomass

There were no trends in epiphyte biomass (Figure 3.11). Values ranged from 0.048 g/shoot at Woodman point down to 0.017 g/shoot and Becher Point. There were no statistical differences between Treatments, but the Sites nested within Treatment were statistically different (Table 3.3)

Percentage Calcium Carbonate in Epiphytic Material

There were no trends in percentage calcium carbonate across the six sites, (Figure 3.12). Shoalwater Bay was the clear outlier with a value of 79.6 percent, compared with the low value of 68.7 percent at North Garden Island. There was no statistical difference between either Treatments or Sites nested within Treatment (Table 3.3).

Figure 3.11 - Mean and Standard Deviation of Epiphyte Biomass per Shoot at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)

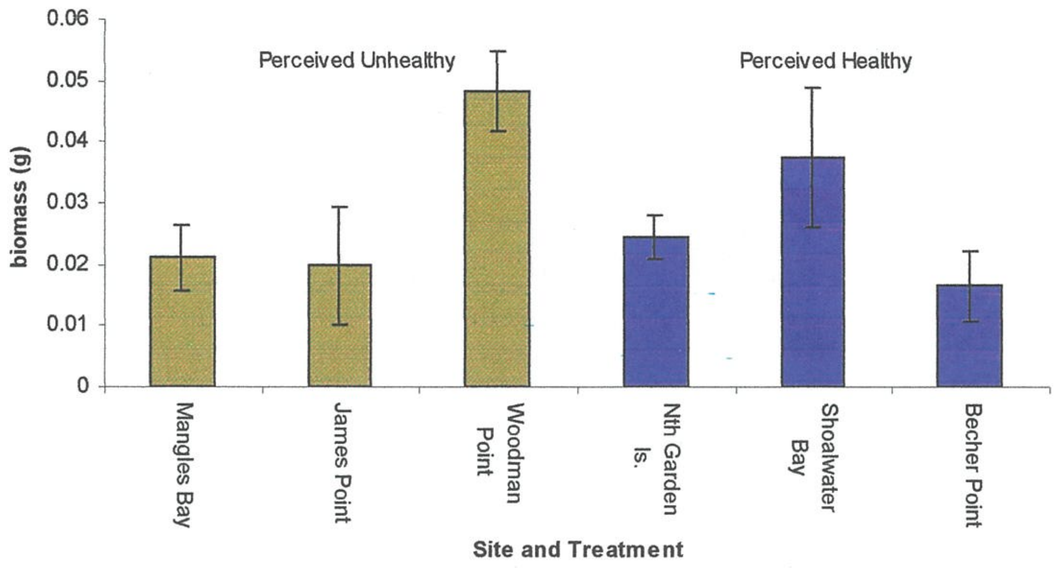
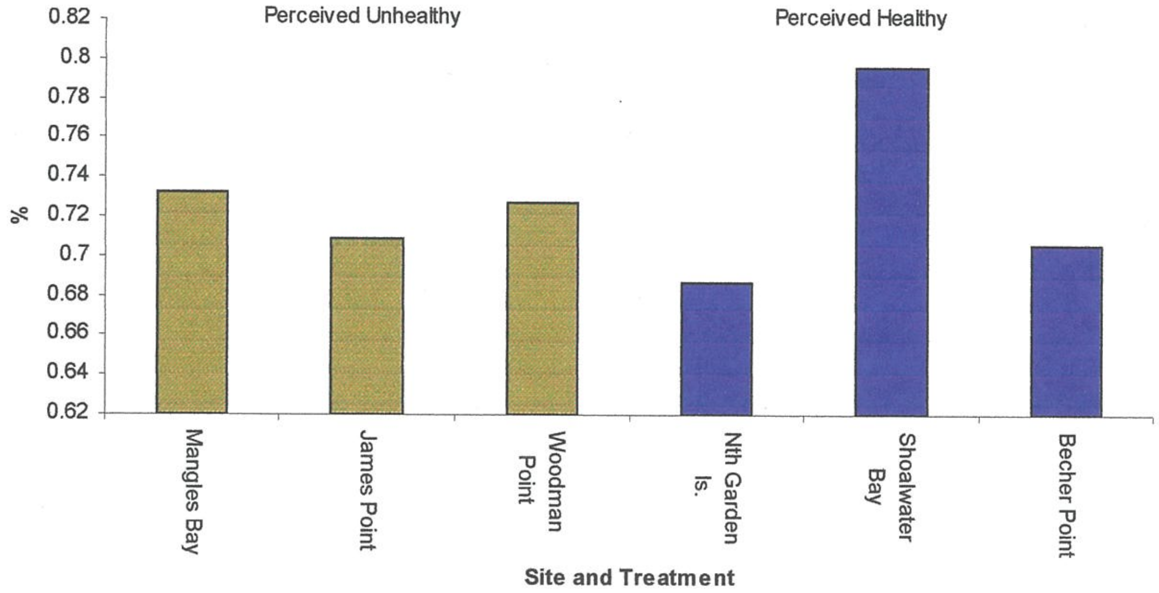


Figure 3.12 - Mean Percentage of Calcium Carbonate in Epiphytic Material at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



Epiphyte Species Richness

There were no clear trends in epiphyte species richness between the six sites (Figure 3.13). Becher Point had the highest number at 16 and Shoalwater the lowest at 8. A species list follows.

1. Audinella daviesii
2. Coralline encrusting algae
3. Sphaecelaria rigidula

27. Polysiphonia sp1

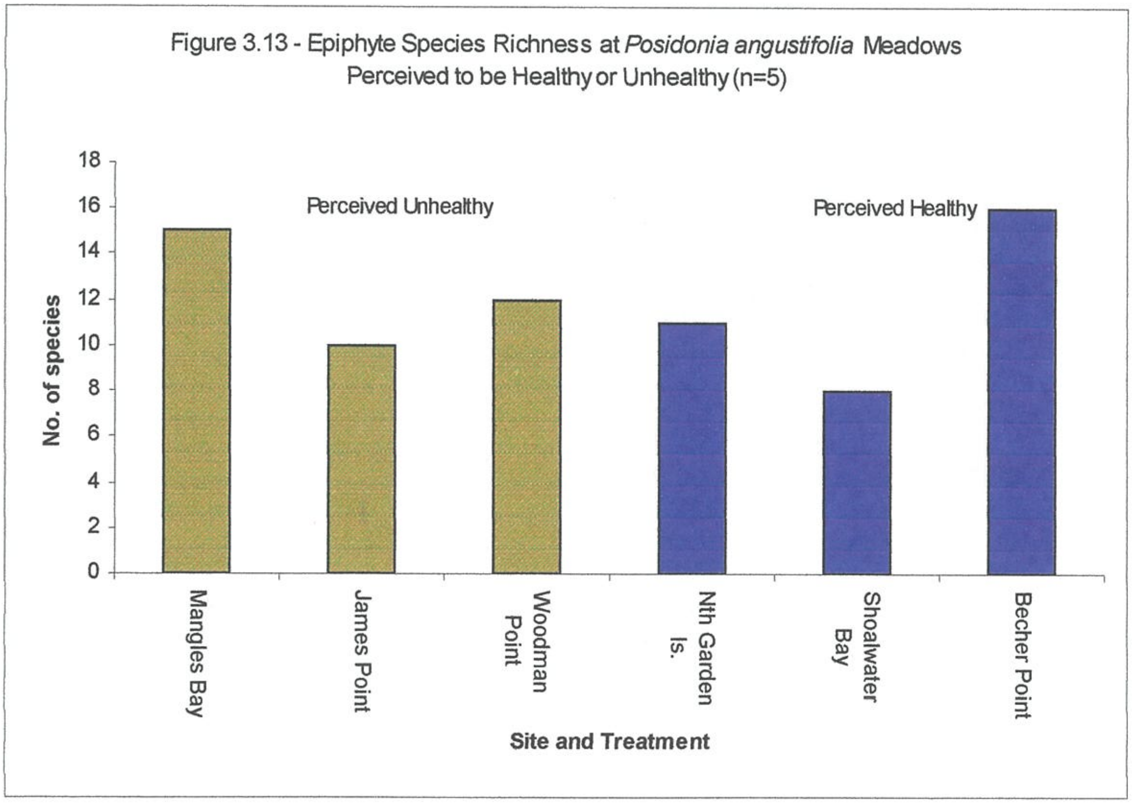
28. Bryopsis sp2

29. Enteromorpha paradoxa

30. Colpomenia

31. Anotrichium tenue

32. Anotrichium sp1



4. Giraudia robusta

5. Centroceras clavulatum

6. Haliptilum roseum

7. Laurencia sp1

8. Hypnea sp1

9. Ceramium puberlum

10. Callithamnion sp1

11. Chaetomorpha aerea

12. Cladosiphon filum

13. Laurencia sp2

14. Ceramium flaccidum

15. Cladophora laetevirens

16. Lophothalia sp1

17. Dictyopteris sp1

18. Herposiphonia secunda

19. Bryopsis sp1

20. Cladophora vagabunda

21. Delesseriaceae

22. Enteromorpha prolifera

23. Chaetomorpha sp1

24. Jania minuta

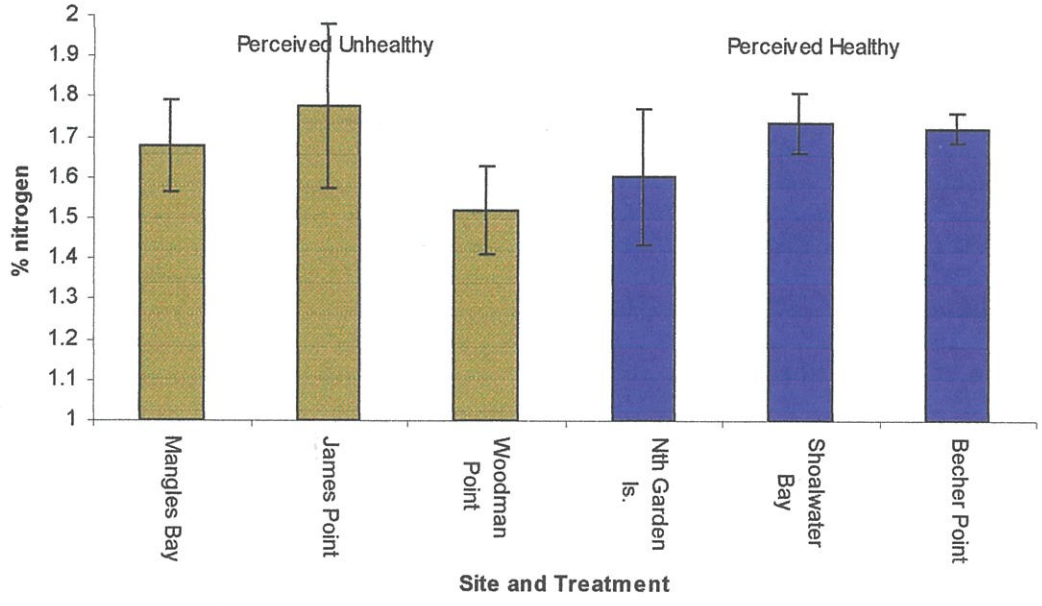
25. Champia sp1

26. Sphaeceleria cirrosa

Percentage Nitrogen in Leaf

There were no trends in percentage nitrogen between the six sites (Figure 3.14). Values ranged from 1.52 percent at Woodman Point to 1.73 percent at Shoalwater Bay. Variability was low, with standard deviations ranging from 2 percent of the mean at Becher Point to 12 percent at James Point. There was no significant difference between Treatments but Sites nested within Treatment were significantly different (Table 3.3).

Figure 3.14 - Mean and Standard Deviation of Percentage Nitrogen in Leaf Tissue at *Posidonia angustifolia* Meadows Perceived to be Healthy or Unhealthy (n=5)



3.5 - Discussion

3.5.1 – Differences between perceived healthy and unhealthy sites

The only two variables to show statistical differences between Treatments (sites perceived as either healthy or unhealthy) were maximum shoot length and above ground biomass. Shoots at the perceived healthy sites were able to grow significantly longer than at perceived unhealthy sites. The additional material found in these shoots may have influenced the differences in above ground material. Above ground biomass is likely to show differences due to stress because it takes into account all the growth characteristics. As mentioned above, this may have been affected though by the clear distinction shown by maximum shoot length. This difference in biomass was not reflected in the productivity measurements, possibly due to the fact that productivity was only measured over three weeks. Above ground biomass reflects change over longer time periods, suggesting productivity may have shown similar results if measured for longer.

Despite the prevalence of its use in the past, no epiphyte characteristics were found to be different between perceived healthy and unhealthy sites. This may have been due to the fact that sampling was undertaken in winter, whereas the majority of seagrass sampling is usually undertaken in summer. There are completely different assemblages of epiphytes found in different seasons (Kendrick and Burt 1997).

3.5.2 - Adherence to Indicator Criteria

In terms of indicator criteria, one variable stood out, shoot length, adhering to all the chosen criteria (Table 3.4). Three other variables showed possible promise, above ground biomass, shoot density and percentage canopy cover, each adhering to four out of the six criteria. Although the quantity of above ground biomass was significantly different between perceived healthy and unhealthy sites in this study, it requires destructive sampling, which takes a lot of time and effort. Shoot density and percentage canopy cover on the other hand are both relatively easy to sample, but the present study showed no significant difference between treatments and thus these variables could only be used in conjunction with others in a monitoring programme.

Table 3. 4 – Adherence of chosen variables to indicator criteria from current study and previous studies.

	Current Study			Previous Studies		
Variable	Response from this study	Non Destructive	Short Sampling Time	Previous Use	Response from Previous Study	Variability
Above Ground Biomass	X			X	X	X
Below Ground Biomass					X	X
Leaf Extension Rate		X		X	X	
Meadow Productivity		X		X	X	
Shoot Density		X	X	X	X	
Shoot Width		X	X			
Maximum Shoot Length	X	X	X	X	X	X
Canopy Cover		X	X		X	X
Leaf Area Index		X	X			
Epiphyte Biomass				X	X	
CaCO3 in Epiphyte				X	X	
Nitrogen in Leaf Tissue		X			X	

The X denotes adherence to that particular criteria.

Maximum Shoot Length

Canopy height or maximum shoot length has been monitored to a certain degree on *Posidonia* meadows (Masini and Manning 1997, Neverauskas 1988, West 1990, Gordon et al. 1994). The majority of studies have found it is responsive to changes in light climate (Masini and Manning 1997, Neverauskas 1998) as did the present study. However, West (1990) found there was no change with depth. Canopy height is easily measured and is not very destructive. These positive characteristics suggest that maximum shoot length is the ideal indicator for monitoring the health of seagrass ecosystems. However, there is inadequate knowledge as to why shoot length responds to change in light climate. There is a possibility that these changes were due to another factor. Therefore, more study of this variable under a range of conditions is required to justify its potential as an indicator. Even considering this though, the results of the present study, which suggest it is an exceptional indicator, can not be ignored and indicate it should be used in monitoring seagrass ecosystem health.

Biomass – Above Ground

Above ground biomass has been extensively measured in the past (Hillman 1995, PCWS 1994, Kirkman 1987, Abal et al. 1994, Cambridge and Hocking 1997) and has been found in the past to reflect change in light conditions. Neverauskas (1988) found a reduction of 20 percent in biomass after meadows were subjected to a reduction in light of 50 percent for six months. However, other studies have shown that biomass is highly variable. Kirkman (1996) and Hillman et al. (1989) both found that *Posidonia* biomass varied seasonally and West (1990) concluded that biomass could be affected by storm events. In terms of monitoring, above ground biomass is time consuming in the field and quite destructive with large sections of shoot material required for extraction. Laboratory analysis requires little effort but a least twenty four hours of drying. Above ground biomass was one of only two of the variables in the present study to show differences between perceived healthy and unhealthy meadows. For this reason in particular, it has potential as an indicator. Until less time consuming and destructive indicators are determined, above ground biomass should be an integral variable in monitoring seagrass ecosystem health.

Biomass – Below Ground

Below ground biomass of *Posidonia* species has had limited measurement (Hillman et al. 1989), mainly due to the extensive and destructive sampling required (Kirkman 1996). It has been found to reflect stress over larger time periods than above ground and does not display seasonal changes (Hillman et al. 1989). The lack of response in the present study and its extremely destructive and time consuming nature suggests this variable is inadequate for monitoring.

Productivity

Productivity is another variable that has been extensively monitored using a variety of different seagrass species (Gordon et al. 1994, Silberstein et al., 1986, Lavery and Westera 1998, Abal et al. 1994, Cambridge and Hocking 1997). It is highly responsive to change (Kirkman 1996) and as a result highly variable, especially seasonally (Hillman et al. 1989). Using the hole punch method has some impact on the seagrass, when extracting shoots for measurement and needs to be left for at least two weeks before measurement can be made (Phillips and McRoy 1990). The lack of response in the present study indicates that for productivity to be used in monitoring, steps need to be taken to account for its variability. Whether taking more replicates or measuring for longer time periods, the use of productivity would require more intensive, high cost monitoring.

Shoot density

Shoot density has been monitored more that any other aspect of seagrass ecosystems (West 1990, Kirkman 1987, Silberstein et al., 1986, Fitzpatrick and Kirkman 1995, Gordon et al. 1994, Lavery and Westera 1998, Cambridge and Hocking 1997), because it is easily measured and imposes little disturbance on the seagrass ecosystem, especially if measured in situ. More importantly, it is highly responsive to change in light climate (Kirkman 1996). Neverauskas (1988) found a significant decline of almost 75 percent in shoot density after twelve months at 50 percent of normal light. However, as with most variables that are so responsive, it is highly variable and requires a large number of replicates to determine differences (Heidelbaugh and Nelson 1996). The fact that shoot density showed no significant differences between sites perceived to be healthy and sites perceived to be unhealthy suggests it is inadequate for monitoring. However, it has been used extensively in the past and shown to respond to light changes, which indicates that it should not be ruled out as a possible indicator.

Leaf Width

Leaf width has also had limited monitoring in the past (Masini and Manning 1997, Neverauskas 1988, West 1990, Gordon et al. 1994). The majority of studies found it was not variable with differing light condition (Neverauskas 1988, West 1990, Gordon et al. 1994), only Masini and Manning (1997) found a change with depth. Again leaf width is easily measured and is not very destructive. The lack of significant difference in the present study and limited response to change in light climate in previous studies indicates shoot width is inadequate for monitoring seagrass ecosystem health.

Percentage Canopy Cover

Percent canopy cover has had limited use in monitoring in Western Australia (Lavery 1994, Lavery and Westera 1997, Heidelbaugh and Nelson 1996). However, Heidelbaugh and Nelson (1996) found that the fewest replicates and least sampling effort is required with this variable to detect changes due to altered light climate. Furthermore, it is a non-destructive monitoring method. Although no significant differences were shown between Treatments, it was observed that when one of the perceived unhealthy sites, Woodman Point was excluded, there seemed to be an obvious difference. This and the ease of monitoring required suggests that this variable could be used as a possible indicator.

Epiphyte Biomass

Epiphyte biomass, as dry weight or ash free dry weight, has been frequently used in monitoring (Cambridge et al. 1986, Silberstein et al. 1986, Neverauskas 1987, Neverauskas 1988, West 1990, Kendrick and Burt 1997, Cambridge and Hocking 1997). This variable can be considered both a cause and effect of deleterious changes in seagrass ecosystems. Epiphyte growth increases with increased nutrient input and this results in a reduction of light reaching the leaves of the seagrass (Cambridge et al. 1986, Silberstein et al. 1986, Neverauskas 1987). However, the amount of shading may not be proportional to epiphyte biomass itself being significantly dependent on the types of epiphytes on the leaf (Kendrick and Burt 1997). Large leafy epiphytes may contribute a substantial amount to the overall biomass, but not shade as much as crustose epiphytes. For this reason, the percentage of calcium carbonate is also measured, as the majority of crustose epiphytes are calcareous. Epiphyte biomass and percentage of calcareous epiphytes is seasonal and this should be taken into account for monitoring (Kirkman 1996). Additionally, this method is very destructive and requires a great deal of laboratory time to separate the epiphytes from the seagrass shoots (Phillips and McRoy

1990). Neither of these variables though showed any differences between perceived healthy and unhealthy meadows. Despite the fact that these have been used extensively in the past, the lack of response in this study and the extensive sampling time and destructive nature of sampling suggest epiphyte characteristics are poor indicators of seagrass ecosystem health.

Percentage of Nitrogen in Leaf

Little work has been undertaken on the percentage of nitrogen found in leaf material of seagrasses (Abal et al. 1994, Cambridge and Hocking 1997, Grice et al. 1996). However, the little which has been done has shown a decrease in tissue nitrogen with a reduction in light. Again tissue nitrogen is seasonally variable, but requires little destructive sampling (Cambridge and Hocking 1997). The lack of significant difference between Treatments and deficiency of previous measurement suggests that this variable at present should not be included in a monitoring programme. However, if more comprehensive study indicates response to change, this variable could be considered.

When considering which variables to include in a monitoring programme, a balance must be obtained between the selected indicator criteria (Jacoby 1993). The present study suggests that monitoring seagrass ecosystem health should centre around two variables, maximum shoot length and above ground biomass. Only these two could be included with any certainty because they were the only variables that adhered to the primary criteria of showing differences between the perceived healthy and unhealthy sites.

Monitoring though can not centre on only two indicators, especially considering the variability of marine systems and how little is known about the response of maximum shoot length. Other variables such as shoot density and percentage canopy cover could be tentatively included on the grounds that they have been used effectively in the past. The information from this study indicates these variables could form the basis of a programme for monitoring seagrass ecosystem health. This is just a preliminary conclusion though and further study under a variety of conditions and over a greater timeframe is needed for verification.

Section 4 – Comparison of Perceptions and Measurable Data Regarding Indicators for Seagrass Ecosystem Health and Conclusions for Management

4.1 - Aim

To compare measurable results and the perceptions of researchers and managers in the seagrass ecology field to recommend a sub set of indicators for use in monitoring seagrass ecosystem health.

4.2 - Discussion

Generally, the perceptions of managers and researchers in the field of seagrass ecology regarding effective indicators for monitoring seagrass ecosystem health were very different to measurements obtained through fieldwork and the literature review (Table 4.0).

Table 4 – Summary of most effective variables for monitoring seagrass ecosystem health according to 1) perceptions of managers and researchers in the seagrass ecology field, 2) Differences shown between perceived healthy and unhealthy meadows, 3) Adherence to indicator criteria.

1) Perceptions	**2) Actual Differences**	**3) Adherence to Indicator Criteria**
Epiphyte Biomass	Maximum Shoot Length	Maximum Shoot Length
Shoot Density	Above Ground Biomass	Above Ground Biomass
Epiphyte Composition		Shoot Density
Percentage Canopy Cover		Percentage Canopy Cover

There was no overlap between the perceptions and measurable data, with neither maximum shoot length or above ground biomass considered important for monitoring by researchers and managers. When comparing perceptions and compliance to indicator criteria, only shoot density and percentage canopy cover were considered important by researchers and managers and adhered to 4 indicator criteria. This apparent conflict between measurable reality and perceptions has dire consequences for management. This suggests that there may be inadequacies in the indicators monitored at present. These indicators did not show changes in meadows perceived by researchers and managers to be healthy and unhealthy. If this is the case, an inaccurate picture of what constitutes a healthy seagrass meadow is being portrayed. The major ramification of this is that seagrass meadows may be too far in decline before these changes are detected.

Maximum shoot length and above ground biomass, the two variables which showed differences between perceived healthy and unhealthy sites were rarely considered important at all by researchers and managers. In the case of above ground biomass, this is interesting, because it has been used extensively in the past (Hillman 1995, PCWS 1994, Kirkman 1987, Abal et al. 1994, Cambridge and Hocking 1997). This may have been due to the fact that this variable has been shown to be affected seasonally (Hillman et al. 1989, Kirkman 1996) and by storm events (West 1990). Furthermore, the sampling time and effort and the damage caused to the meadow from this measurement would also have influenced these perceptions. Maximum shoot length has been used to a lesser extent than above ground biomass and so the lack of support for this variable is less surprising. However, despite these perceptions, the fact that this variable was the only one to adhere to all six indicator criteria, suggests that it is essential to include it in any seagrass ecosystem health monitoring programme. There is inadequate knowledge at present why this variable responds to light, assuming that is what it is responding to and thus, more study is required on this variable.

The strong emphasis which researchers and managers placed on the use of epiphytes was completely unfounded by my results. The results of extensive studies in the late 1970's and early 1980's concluded that nutrient enrichment and thus increased algal growth was the major cause of seagrass decline in Cockburn Sound

(Cambridge and McComb 1984, Cambridge et al. 1986, Silberstein et al., 1986). These studies further concluded that epiphytes were the major algal growth and thus caused the seagrass decline. This established a paradigm in seagrass monitoring, suggesting measurement of epiphytes as imperative for monitoring.

It is possible that the lack of difference between perceived healthy and unhealthy meadows was due to the season. The majority of marine work is undertaken in summer, while this study was undertaken in winter. Winter storms generally strip seagrass shoots of the larger epiphytes, resulting in a different assemblage to summer (Cambridge 1979). Generally, when there is higher energy (winter) larger filamentous red and brown algae dominate, and low energy (summer), crustose coralline algae dominate (Kendrick 1991). However, even if this is the case, it still suggests that the use of epiphytes as indicators of seagrass ecosystem health is severely flawed due to their seasonal nature. That is, they may only be useful for monitoring in summer. Furthermore, increased phytoplankton growth in the water column also influences the amount of light available for seagrass to use for photosynthesis. Thus, measuring epiphytes will only provide a partial indication of the reduction in light availability. Taking this even further, light reduction, while the main cause of seagrass decline, is not the only cause. Measuring epiphytes and phytoplankton together may not give any indication of loss due to physical removal, urchin grazing or toxicity.

These differences between perceptions and measurable reality are important when considering the monitoring of seagrass ecosystems. The respondents to my questionnaire were from the universities and management agencies which administer Perth's coastal waters. These people are either making management decisions or influencing them and the evidence from my study suggests that many of their perceptions do not follow what the measurable data has shown. Without adequate knowledge, or with incorrect knowledge of what indicators to measure, seagrass meadows may decline too much for restoration before changes are detected.

4.2.1 - Conclusions for Management

Although my study provided only two variables which could be used as indicators of seagrass ecosystem health, more measurements are required as part of a monitoring programme. The range of factors which confound the measurement of marine systems suggests that using only two variables in a monitoring programme may provide an inaccurate picture of the health of the system being measured.

The extent to which large scale monitoring can be undertaken is highly dependant on funding. Where adequate funding is available, a more rigorous approach can be utilised. From my study this would include such indicators as: maximum shoot length and above ground biomass. Including information from other studies shoot density, percentage canopy cover, and assuming monitoring is undertaken in summer and winter, epiphyte biomass and composition would also be included. More realistically, where a short time period and limited funds are available for monitoring, fewer variables which require less sampling effort should be measured. From my study, this would include only maximum shoot length, with shoot density and percentage canopy cover included due to recommendations from previous studies.

To more accurately determine which variables are the most effective for monitoring, a more comprehensive, long term study needs to be implemented. This would include all of the variables measured in this study at the same sites, but would be undertaken over a period of several years to account for seasonal and inter-annual variation. Inclusive in this study, would be the measuring of these variables under laboratory conditions to determine whether those variables which are a feature of seagrass plants do respond to disturbance in a predictable way under controlled conditions. Additional studies would also be required for different seagrass species. Although seagrass species in the same genus are generally similar in morphology, growth rates and responses to disturbance, species in different genera can differ markedly. The information determined from this study though would be useful in providing the general structure of the monitoring required.

This study has indicated that there are differences between perceptions and measurable data. It is essential then to ensure the findings of this study, and the recommended study, are made available to the decision makers. In this way it is hoped that the perceptions of the decision makers and those who influence decisions are based on information that is as close to reality as is possible.

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Appendix A

A Targeted Questionnaire for Seagrass Managers and Researchers on their Perceptions of Health for Seagrass Meadows in Western Australia

Covering Letter

Nick Wood
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100 Joondalup Drive
Joondalup 6027

To Whom It May Concern,

I am currently undertaking an honours project on seagrass monitoring with Paul Lavery at Edith Cowan University. The objective of this project is to determine which are the most effective variables for differentiating between healthy and unhealthy meadows.

Before the sites for the study can be chosen, the issue of health must be addressed. As health is difficult to quantify, the questionnaire on the following pages was designed to ascertain which meadows in Western Australia are perceived by managers and researchers in the field to be healthy and unhealthy.

The questionnaire is simple and completion should be straight forward. I would appreciate it if you could return the completed questionnaire by the end of the week. It can be faxed to the number [redacted], or mailed to the following address.

Nick Wood
[redacted]

If there are any queries or additional comments to either the questionnaire or my project, please do not hesitate to call on [redacted] Thank you very much for your input.

Yours Sincerely,
Nick Wood

Questionnaire 1

Section 1 – Personal Information

1) Department/Organisation/University

....

2) In what capacity do you work with seagrass?

....

Section 2 – Healthy and Unhealthy Seagrass Sites

1) Please list 5 seagrass meadows within Western Australia which you perceive from experience to be unhealthy.

1 – ....

2 – ....

3 – ....

4 – ....

5 – ....

2) Please list 5 seagrass meadows within Western Australia which you perceive from experience to be healthy.

1 – ....

2 – ....

3 – ....

4 – ....

5 – ....

3) Please classify the following seagrass meadows as either healthy or unhealthy. See attached maps for site locations. If an area comprises a range of healthy and unhealthy please specify. Refrain from modifying your answers to question 2.

Cockburn Sound

Mangles Bay H/U

James Point H/U

Parmelia Bank H/U

Success Bank H/U

Nth Garden Island H/U

Southern Flats H/U

Warnbro Sound

Mersey Point H/U

Becher Point H/U

Shoalwater Bay H/U

Safety Bay H/U

<u>Rottnest Island</u>

Thomson Bay H/U

Porpoise Bay H/U

Longreach Bay H/U

Marjorie Bay H/U

<u>Marmion Marine Park</u>

Hillarys H/U

Watermans H/U

<u>Albany</u>

Oyster Harbour H/U

Princess Royal Harbour H/U

King George Sound H/U

<u>Busselton</u>

Geographe Bay H/U

<u>Comments on Question 3</u>

....

....

Appendix B

Perceptions of *Posidonia* Ecosystem Health

Covering Letter

To Whom It May Concern,

My name is Nick Wood, I am an honours student at Edith Cowan University working with Dr Paul Lavery. The objective of my project is to determine which, if any variables are useful in reflection researchers or managers perceptions of 'healthy' and 'unhealthy' *Posidonia angustifolia* meadows. It is hoped that this information will be useful for management agencies such as the DEP in determining whether a meadow is heading towards a state which may be perceived as less healthy.

Firstly, I would like to thank you very much for completing the questionnaire I sent you earlier in the year. Your contribution was greatly appreciated. To refresh your memory, you were asked to provide a list of seagrass meadows in Perth, which you perceived to be either healthy or unhealthy. This was extremely useful in determining sites to compare for a variety of variables. I chose these sites according to the presence of *Posidonia angustifolia*, location within the metropolitan area and of course from the collation of the questionnaire.

The following sites were chosen -

Healthy
1. Shoalwater Bay
2. Becher Point
3. North Garden Island

Unhealthy
1. Mangles Bay
2. James Point (Kwinana)
3. Woodman Point

I am currently undertaking a follow up questionnaire to try and obtain an understanding of what the respondents based their perceptions on and to seek your comments on the issue of ecosystem health. This is at both a conceptual and management level.

My project is using *Posidonia angustifolia* as the focus species, so if you do not have any experience with this species, please fill out the questionnaire according to the species you do have experience with. If you require confidentiality you can send the questionnaire to me at [redacted]. Otherwise you can email me at [redacted]. If possible can you please return the questionnaire by the end of next week?

If you have any problems with the questionnaire, please do not hesitate to call me on [redacted] or email. Again your assistance is greatly appreciated.

Yours Sincerely,

Nick Wood.

Part 1 - Personal Information

1. In what capacity do you work with seagrass?

   Manager ☐

   Researcher ☐

   Other (Please specify) ☐ ....

2. Department/Organisation/University of employment/research.

   ....

3. Which seagrasses do you have experience working with (please tick appropriate boxes)?

   Posidonia angustifolia ☐

   Posidonia sinuosa ☐

   Other *Posidonia* species ☐

   Other seagrass species ☐

Part 2 – Perceptions of *Posidonia* Ecosystem Health

1. What factors do you think are important in shaping the perceptions of seagrass ecosystem health?

……………………………………………………………………..

……………………………………………………………………..

……………………………………………………………………..

……………………………………………………………………..

……………………………………………………………………..

2. Which of the following variables would you consider to be the most important in formulating a perception about the health of a seagrass ecosystem (Please don't modify your answer to question 1)?

0 – Not important
1 – Some importance
2 – Important
3 – Very important
4 – Extremely important

Variable	0	1	2	3	4
Biomass – above					
Biomass – below					
Productivity					
Epiphyte biomass					
Epiphyte composition					
Shoot density					
% Canopy Cover					
Shoot width					
Shoot length					
Lacunal gas area					
Nitrogen in leaf					
Other (please specify)					
....					
....					

3. From the 1st questionnaire, the following sites were chosen as unhealthy:
Mangles Bay, James Point and Woodman Point.
For the purpose of this project, I would like to know whether the basis of the perceptions of health is the same for all three sites.
In relation to these sites, which variables do you think were most influential in creating the perception that they were 'unhealthy'?

A - Mangles Bay

0 – not influential
1 – partially influential
2 – influential
3 – very influential
4 – extremely influential

Variable	0	1	2	3	4
Biomass – above					
Biomass – below					
Productivity					
Epiphyte biomass					
Epiphyte composition					
Shoot density					
% Canopy Cover					
Shoot width					
Shoot length					
Lacunal gas area					
Nitrogen in leaf					
Other (please specify)					
....					
....					

B – James Point

Variable	0	1	2	3	4
Biomass – above					
Biomass – below					
Productivity					
Epiphyte biomass					
Epiphyte composition					
Shoot density					
% Canopy Cover					
Shoot width					
Shoot length					
Lacunal gas area					
Nitrogen in leaf					
Other (please specify) ………………………					
………………………					
………………………					

C – Woodman Point

Variable	0	1	2	3	4
Biomass – above					
Biomass – below					
Productivity					
Epiphyte biomass					
Epiphyte composition					
Shoot density					
% Canopy Cover					
Shoot width					
Shoot length					
Lacunal gas area					
Nitrogen in leaf					
Other (please specify) ………………………					
………………………					
………………………					

4. The concept of ecosystem health is difficult to define. This makes it extremely difficult to monitor ecosystems such as seagrass meadows in terms of health. Do you have any comments on the concept of ecosystem health as it applies to use in monitoring?

....

....

....

....

....

Thank you for your assistance.

Appendix C

Full Responses of Respondents to Question 4 of Questionnaire 2 – Do you have any comments on the concept of ecosystem health as it applies to monitoring?

Respondent 1

Ensure it embodies a range of indicators and is multidimensional.

It is complex and must integrate range of factors that define it.

- Physical measurements
- Epiphytes
- Spatial
- Infauna
- Above-below ground biomass
- Physiological

Respondent 2

A number of parameters are used to give indications of ecosystem health in seagrass meadows, different species of seagrass behave differently, e.g. 'Posidonia' vs 'Ruppia', therefore I think it is important to have measures or indicators of health for groups of species which have similar habits, phenology. I think some indicators can be useful when used in context of the system, i.e. need to know variations in the system to interpret the ecosystem health indicators.

Respondent 3

Bullshit Term – Jargon – and irrelevant. On top of that seagrasses are only components of an ecosystem and due to their longevity are not good early warning indicators of change in an ecosystem.

Respondent 4

The number of "health" variables that can be monitored realistically is very limited. The variables to choose are the ones that measure the important or valued aspects of the ecosystem, e.g. in some areas sediment stability may be most important and diversity or productivity in other areas.

Respondent 5

Yes. Read the thingy by deLeo and Levin on the web. I'm thinking of health in the sense of integrity. Integrity implies that all the components are intact. As a system degrades, the components (i.e. the trophic structure and the species) change or disappear completely.

Respondent 6

Monitoring needs to address management questions, issues and objectives. They need to be defined first in order to set up a useful monitoring program, i.e. ecosystem health may or may not be an objective.

Respondent 7

If indicative factors such as water quality, light attenuation etc suggest a threat to seagrass health then the monitoring of the health of the habitat is essential despite its being difficult or expensive. In addition as more information is gathered as a result of monitoring programmes it may be possible to refine and focus the assessment of seagrass health criteria.

Respondent 8

My feeling is that 'health' is near impossible to define, but is conveyed by a sort of mass mentality in Perth. An area seems to develop a reputation for being 'unhealthy' and this is more often than not related to the water quality of the area, rather than any real measurements of the seagrass. In this respect it seems to reflect a 'potential' for stress to the seagrass rather than a measured change. My own experience also suggests that the variability in seagrass ecosystem variables is so enormous that attempting to use univariate statistical designs to show difference in parameters that relate to health is almost doomed to fail.

Respondent 9

I think health is a term made up (or should be made up) of a number of factors as long as it is a sum I am happy with it being used (and explained) in fact I believe a consistent use of a "number"/"health" is possibly the one way to compare systems.

Respondent 10

Much depends on the impact you are monitoring for. If turbidity impacts are being considered (eg due to dredging, stirring of sediment due to shipping movements, or discharge of turbid water), then light attenuation and seagrass biomass/production/shoot density are suitable. If nutrient impacts are being considered, then there is a whole suite of things you can look at, including seagrass biomass/production/shoot density/epiphyte load etc as per above. Nitrogen content of epiphyte might be useful to consider in cases of eutrophication. The type and amount of periphyton growth on plastic seagrass could be very useful for providing a standardised measure of conditions that might lead to deteriorating seagrass health.

Some care has to be exercised in the case of nutrient enrichment, for example proximity to a reef can create some level of natural eutrophication responses in seagrass meadows, simply because there is a lot of particulate material floating around. And extreme care must be taken to relate measurements in your area of study to seagrasses in areas of similar depth, hydrodynamic conditions, sediment type, proximity to the shore (especially if there is appreciable groundwater discharge in the area) and/or reefs, etc. Taking into account natural seasonal variations is also pretty obvious. It is also vital to know what level of change you want to detect in your monitoring programme, so that you can make sure you have sufficient statistical power to detect that level of change.

Respondent 11

Ecosystem health probably does not apply to seagrass meadows or other habitats. Indicators of habitat health will be most useful if we find some emergent properties that only apply at the level of the total habitat. Otherwise, the concept of habitat health may be useful as a conceptual framework to be used in explaining why we monitor, how we will do it and what the results mean.

Respondent 12

Seagrass ecosystems can be deceptive in appearance, in that they may be quite dynamic. Consequently monitoring programmes should take this into account (e.g. the seagrasses of Success Bank have been observed to be very dynamic in their distribution and abundance, both over short time scales and longer periods, up to decades). Clearly there is a variety of seagrass ecosystems out there, and therefore the concept of "pioneer" and "climax" communities can be a tricky one to apply, with attendant consequences for defining systems as healthy or not. For example, natural deep basins in Owen Anchorage and Warnbro Sound have thriving *Halophila* communities within them. *Halophila* is considered to be a "pioneer" species, and these communities might therefore be considered to be "unhealthy" or "disturbed" when in fact the environment cannot sustain the larger "climax" species (generally in terms of light availability). While some might argue that this is an indication of "unhealthy" conditions for seagrass growth, it may be perfectly suitable for species such as *Halophila*, and therefore I would class it as "healthy" in that respect. I suggest that definitions of ecosystem health should include some way of determining actual disturbance to the system, and this should be incorporated into any monitoring scheme. Care should be taken to avoid confusing naturally unsuitable systems with disturbed systems when establishing monitoring schemes.

Respondent 13

There is an obvious need for people to bite the bullet when asked to make management decisions on the condition of a habitat or ecosystem they are studying. Failure to be able to do this at least to some degree is not really acceptable and will lead to a lack of faith from decision makers in the work they are doing.

However the term health does seem to be causing some contention and perhaps the word status could be used to describe the sum of the measurements you are making. How do we know what the status quo of the meadow is or was at some time in the past. I think though that we can gauge changes over time and comment on the status and how that has changed since measurements were made.

There is also a need to distinguish between anthropogenic disturbances and natural variability. This is not an easy task given the number of variables acting on the seagrass meadows, but can be ironed out over long-term sampling. I think you should check out the meadows in the most remote and undisturbed places possible i.e. Shark Bay, East of Esperance, Southern Ningaloo Reef etc.

Respondent 14

When considering seagrass ecosystems or any marine systems, it is imperative to look at the whole picture. When monitoring these systems though, obviously everything can't be monitored. So, yes I agree that indicators are really the only alternative for this sort of monitoring.

Respondent 15

A whole range of measurements could be used for monitoring seagrass ecosystems. In the past, shoot density, epiphytes, biomass and productivity have all shown to respond nutrient enrichment. I guess the amount of time that is able to be spent on monitoring a range of meadows is the key issue here though. If we are being practical, a cost effective monitoring schedule needs to be developed.

NB: - Only 15 out of 17 respondents answered this question.