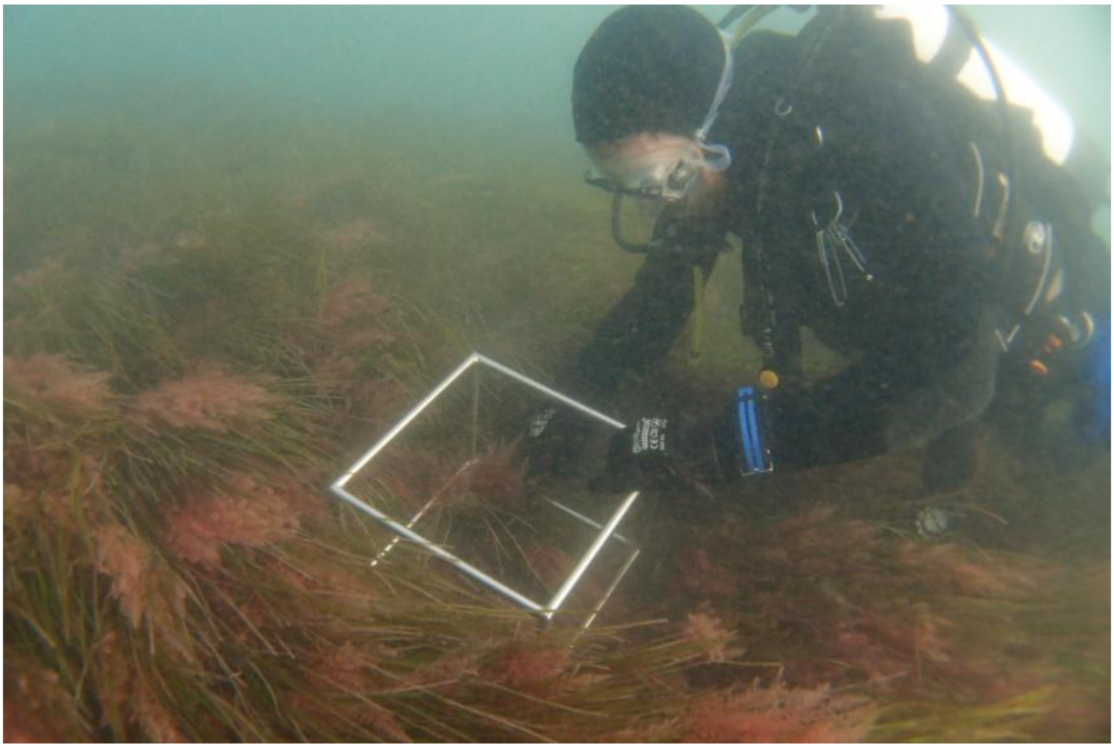
Report to: Port of Hastings Development Authority/AECOM+GHD JV

Port of Hastings Development Project



Seagrass Desktop Review and Study Design

AGH-CEP0-EV-REP19

December 2014

CEE

Environmental Scientists and Engineers

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In May 2016 the Special Minister of State asked Infrastructure Victoria to provide advice on the future capacity of Victoria's commercial ports. Specifically, the Minister has asked for advice on when the need for a second container port is likely to arise and which variables may alter this timeline. The Minister has also asked for advice on where a second container port would ideally be located and under what conditions, including the suitability of, and barriers to investing in, sites at the Port of Hastings and the Bay West location.

In undertaking this task, Infrastructure Victoria reviewed work that was completed as part of the Port of Hastings development project before it was cancelled in 2014. This document forms part of the initial work undertaken for the proposed port development at Hastings. Infrastructure Victoria considers that much of the previous Hastings work, although preliminary in nature, is relevant and suitable for informing a strategic assessment. Therefore, Infrastructure Victoria has made the reports previously commissioned for the development project part of the evidence base on which Infrastructure Victoria will use in providing the Minister with advice.

The opinions, conclusions and any recommendations in this document are based on conditions encountered and information reviewed at the date of preparation of the document and for the purposes of the Port of Hastings Development Project.

Infrastructure Victoria and its consultants have used the information contained in these reports as an input but have not wholly relied on all the information presented in these reports.

Port of Hastings Development Project
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Port of Hastings Development Proposal: Key Questions for Seagrass Studies DRAFT

1 INTRODUCTION

The Victorian Government has identified the Port of Hastings as a key area for port expansion. An expanded Port of Hastings will increase capacity and competition in the container ports sector servicing Melbourne and Victoria helping to manage the expected growth in container trade.

The Port of Hastings Development Authority (the Authority) and its board were established in January 2012 under the *Transport Integration Act 2010*. The primary objectives of the Authority are to:

- manage and operate the Port of Hastings.
- facilitate the development of the Port of Hastings as a viable alternative to the Port of Melbourne as a container port to increase capacity and competition in the container ports sector to accommodate future growth in trade, consistent with the vision statement and the transport system objectives.

Over the next three to four years, the Authority will be working to develop a business case for an expanded Port of Hastings and undertake comprehensive environmental assessment. This business case will include:

- preferred project design/scope (including transport connections).
- necessary environmental approvals (including impact assessment).
- preferred governance and delivery strategy.

In May 2014, the Port of Hastings Development Project was declared a 'Major Transport Project' under the *Major Transport Project Facilitation Act 2009* (MTPF Act). In July 2014, the then Minister for Ports, Mr David Hodgett, formally appointed the Authority as the Project Proponent under the MTPF Act.

1.1 Environmental and social studies

The overall design methodology for the Project involves an iterative design process which has commenced and will continue for around two years. The design process will cycle and re-cycle the evolving design through an evaluation process that allows design options to be tested and evaluated against economic, environmental, social and other objectives and associated criteria. Performance requirements will be developed as an integral part of the design process to clearly define the environmental and social outcomes that the Project must achieve in its implementation phases. The preliminary design will demonstrate the way in which the Authority considers the Project could be developed so as to achieve the performance requirements.

Environmental and social studies are required for the Project to inform the design development process and to assess the Project in accordance with the Approvals Strategy previously adopted by the Authority. An overview of the framework for the environmental and social studies and their relationship with the design process is shown in Figure 1.

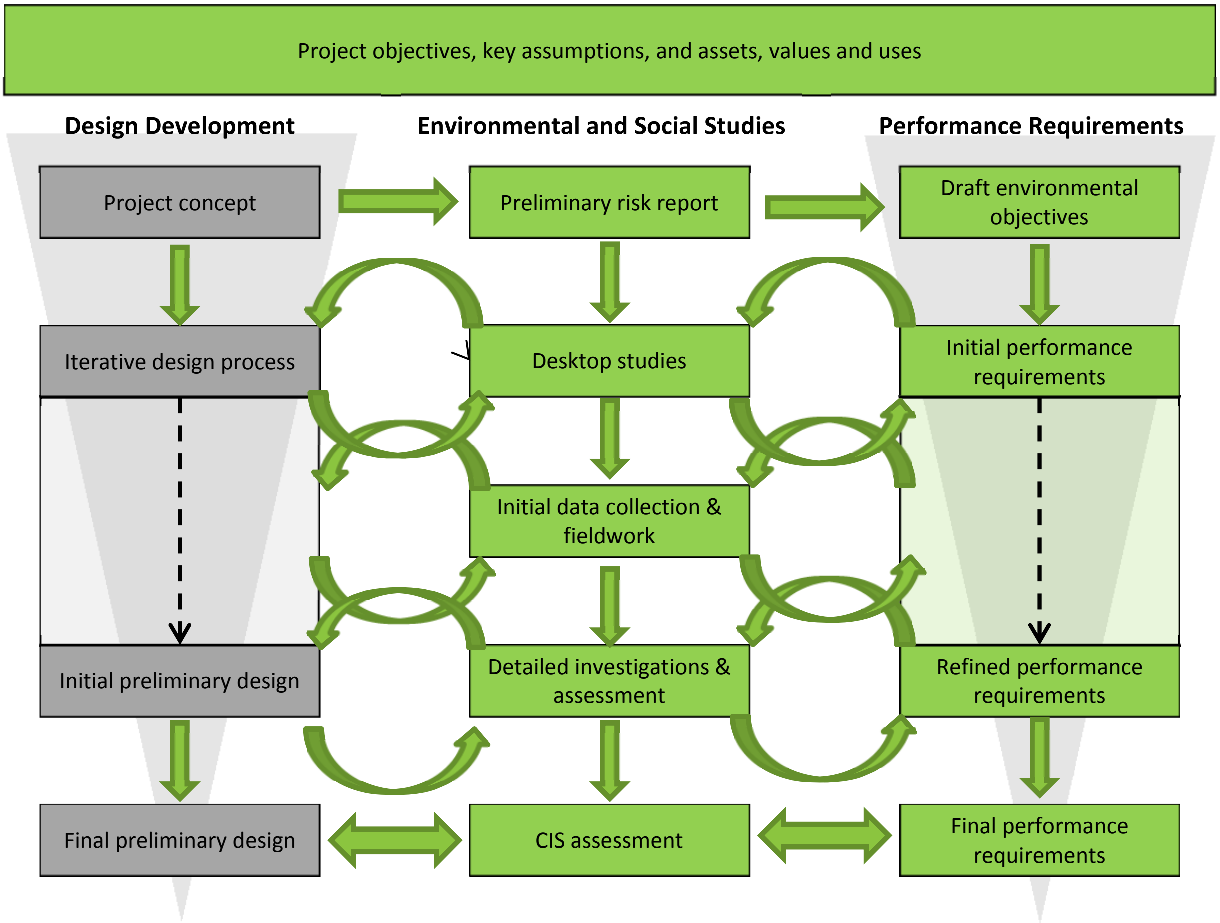

Figure 1 Framework for environmental and social studies

As shown in Figure 1, a stepwise approach is being employed to implement the environmental and social studies for the Project. This reflects both the iterative relationship between the studies and the design development process and their ultimate purpose of informing assessment under the *Major Transport Projects Facilitation Act 2009* (MTPF Act) and the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The key steps in the implementation of the environmental and social studies are:

- Undertake an initial assessment of need using an issues screening process to identify priorities for studies.
- Initiate environmental and social investigations required to support the design development process.
- Undertake desktop reviews to complete the assessment of the adequacy of existing information and confirm methodology for any further existing conditions investigations, including field work (where required).
- At the relevant stage of project definition and taking into account emerging performance requirements, undertake field and other investigations to characterise existing conditions.
- Following the issue of the preliminary design, undertake risk and impact assessments to support preparation of the Comprehensive Impact Statement (CIS).

1.2 Purpose and Scope

The purpose of this report is to present a desktop review of the adequacy of existing information and confirm methodology for any further investigations including field work (where required) on the existing condition of seagrass.

The scope of this report includes:

- Identifying the key questions to be addressed by a seagrass baseline study to support investigations being completed for the Project.
- Review of existing background information and historical data to identify its suitability to define existing seagrass conditions in support of design decision making, impact assessment, identification of relevant management and mitigation measures and development of performance requirements, and approvals requirements.
- Identifying gaps in existing data or information which should be addressed to adequately inform design decisions, impact assessment, performance requirements and approvals.
- Defining seagrass study methods to address any identified information requirements.

1.3 Limitations

The contents of this document reflect CEE's current position on the subject matter of this document. It is provided for discussion or information purposes and is intended to be a guide only. The contents of this document should not be relied upon as representing CEE's final position on the subject matter, except where stated otherwise. Any views expressed by CEE in this document may change as a consequence of CEE finalising formal technical studies or specifications, or legislative, or procedure and regulatory developments. Any figures provided are indicative only, are subject to change and are dependent upon a number of factors.

1.4 Seagrasses in Western Port

Seagrasses are found in all parts of Western Port. Substantial beds of seagrass are distributed within and close to the proposed marine and landside port development in the lower North Arm of Western Port.

Seagrasses are identified as a key component of the marine environment of Western Port (Shapiro, 1975, EPA 2001, Melbourne Water 2011). Four species are present, *Zostera nigricaulis, Z. muelleri, Halophila australis* and *Amphibolis antarctica*, of which the most abundant is *Z. nigricaulis*. Western Port lacks significant areas of reef, so seagrasses and other biogenic habitats provide the only complex habitat to support other species, such as fish and invertebrates. Seagrasses are understood to be the most extensive of these biogenic habitats, covering almost 25% of Western Port (Blake and Ball, 2001). The Ramsar listing of Western Port identifies its value as “a natural wetland marine embayment with extensive intertidal flats, mangroves, saltmarsh, seagrass beds within the South East Coastal Plain”. Seagrass meadows are a critical ecosystem component of the ecological character description in the Ramsar listing.

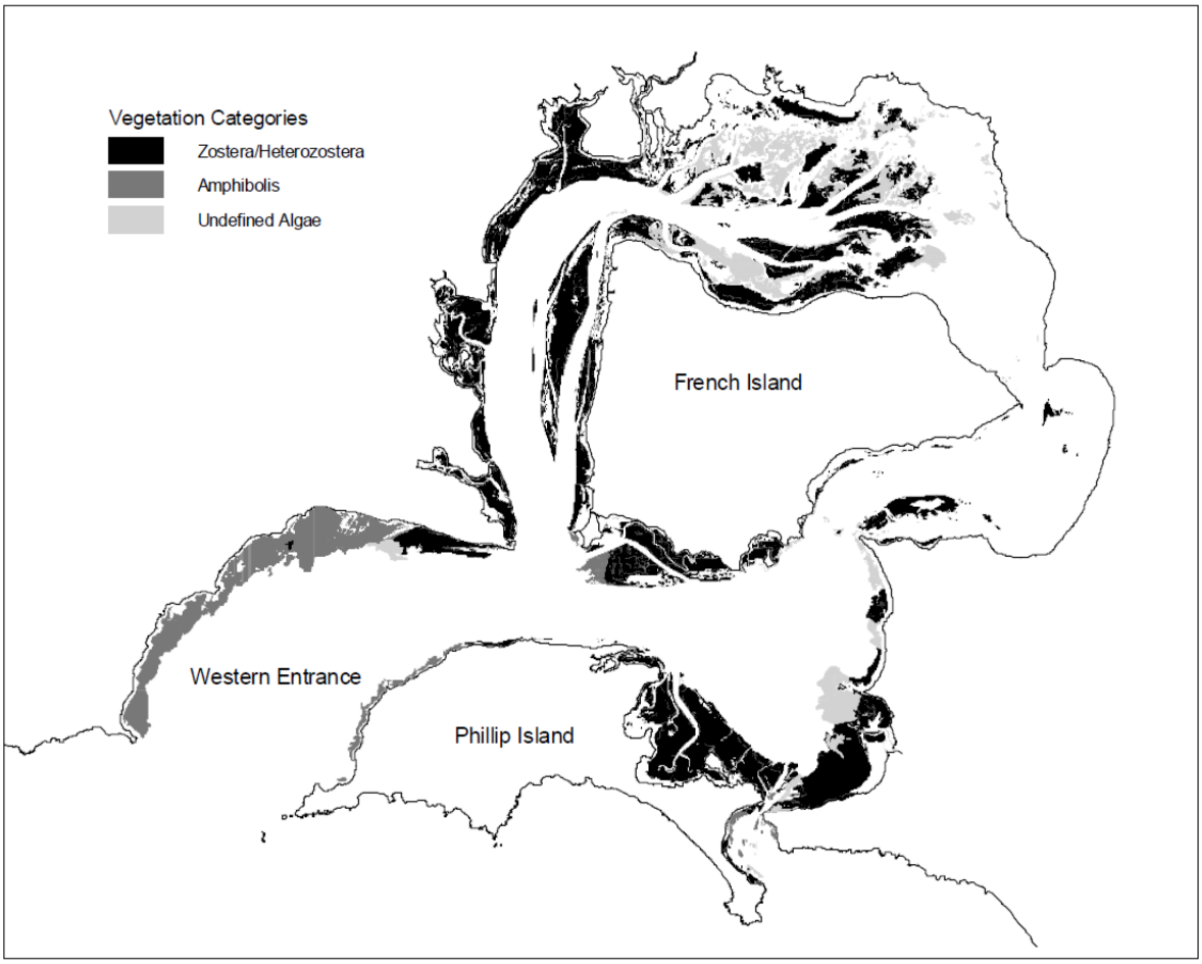

Figure 2 Extent of seagrass and macroalgae in 1999 (Blake and Ball, 2001)

They are a fundamentally important component of the Western Port marine ecosystem today despite enormous losses of intertidal seagrasses in the late 1970s and early 1980s (Blake and Ball, 2001). The extent and density of seagrass changed dramatically at this time, but some recovery has occurred. The macroalga *Caulerpa cactoides* also forms large beds of habitat in mainly eastern areas of Western Port that have a similar habitat function to seagrass (Jenkins, 2013).

Seagrasses can be the key primary producer in bays. Seagrass carbon production per unit area is typically five times greater than phytoplankton alone (Mateo *et al* 2006). It was considered based on the "*area covered by seagrasses and benthic algae* (in the late 1970s) *that Westernport Bay ranked amongst the most productive estuarine ecosystems in Australia*" (Clough and Attiwill1980).

Seagrasses on mudflats, sandspits and on the banks of channels provide a habitat for marine biota in an area that would otherwise offer little refuge for small fish and invertebrates, or permanent attachment for small marine algae, invertebrates and microscopic plants.

Few animals feed directly on seagrasses in Western Port, except for swans, some fish (garfish) and some invertebrates (Watson *et al* 1984). However, the organic debris produced by seagrass provides an important source of nutrients and carbon for microbiota (bacteria and fungi), which in turn are food for a range of invertebrate detritovores which ingest seagrass material to digest the attached microbiota (Watson *et al* 1984). Microscopic plants and animals are attached to the living leaves of seagrasses. These microscopic plants such as diatoms are grazed by small animals including snails and crustaceans (Daly 1979, Howard 1976), which become food for larger animals living among the leaves.

Hence, the seagrasses in Western Port create complex habitat for a wide variety of epibiota such as the algae and invertebrates that live on or among their leaves and infauna that live within the sediments bound by the roots of the seagrasses (Watson *et al* 1984, Edgar and Shaw 1995b). These invertebrates are food for small fish species and the juveniles of larger fish, which are the prey of a range of larger fish (Robertson 1984, Edgar and Shaw 1995a, c, Hindell *et al* 2000a, b, Smith 2009).

Seagrasses can protect sediments below their leaves from the actions of waves and tidal currents, resulting in accumulation of fine sediments beneath the canopy of seagrass leaves (Marsden et al 1979). Other mechanisms of fine sediment accumulation in seagrass beds include filtering of particulates by the microbiota on the seagrass leaves and adherence of material directly on the leaves (Marba *et al* 2006). On the other hand, some seagrasses can mechanically brush the seabed below the canopy resulting in only coarse sediments remaining (Koch *et al* 2006). The loss of intertidal seagrasses from parts of the upper North Arm of Western Port in the early 1980s was observed to result in the exposure of surface sediments to wave action, resuspension of fine sediments and increase in turbidity of water over the mudflats and in the tidal channels draining the mudflats (Bulthuis *et al* 1984).

The condition of Western Port seagrass is vital to Western Port's international status as a wetland and its national and local recognition as a unique and important marine ecosystem.

2 KEY QUESTIONS

A number of key questions need to be addressed to gauge the potential impacts of the Project on seagrass in Western Port. Those that are particularly important to this early stage of the development are listed below.

How much seagrass is in Western Port?

Information on the amount of seagrass in Western Port overall is required to understand the relative importance of seagrass that may be impacted by the Project.

- Area (including past changes leading to present area)?
- Species (including *Caulerpa cactoides*)?
- How does it compare with other bays, inlets in southern Australia?
- Environmental requirements?

How much do they vary naturally?

- How much does their area vary over time?
- How does their condition (various measures of abundance and health) vary between seasons and years?
- What environmental factors influence natural variation?

Where and how much seagrass would be lost due to port development?

- Removed due to infrastructure?
- Lost due to light reduction, sedimentation, smothering, erosion?
- Temporary and permanent loss (in context of previous losses and recovery)?
- Intertidal versus subtidal losses?

Flow on effects of seagrass loss?

- How would other species (fish, birds, invertebrates) be affected?
- How would water quality (resuspension) be affected?
- For how long?

What is the recovery potential for seagrass?

- Lessons from historical loss and recovery of seagrass in Western Port and elsewhere
- How long would it take?

To answer these questions requires an integrated multidisciplinary program linking biological information and biological process understanding with information on the physical processes that may be affected by the development. Integration of biological and physical process models will be required to provide clear but sophisticated answers to the questions with a prescribed level of certainty.

Available information on seagrass in Western Port and relevant information on seagrasses elsewhere is reviewed and summarised below, information gaps are identified and studies proposed to provide information to answer these questions. These studies will be prioritised and addressed in an iterative process, as shown in Figure 1, in parallel with development of the preliminary design and development of performance requirements.

3 INFORMATION REQUIREMENTS

Table 1 Existing and required information for answering key questions

Key Question	Existing Information	Information Requirements
How much seagrass is in Western Port?	There is a large volume of information on the extent of seagrass species in Western Port compiled up to 1999. There is information on the extent of seagrass in other Victorian embayments from the late 1990s and early 2000s. The extent of intertidal and shallow subtidal seagrass in Western Port was last mapped in 1999 from aerial photographs and ground-truthing.	It is 15 years since the last estimates of the extent of seagrass in Western Port were made in 1999. The area of seagrass showed large variations over the 20 years prior to the last comprehensive survey. Hence, the present extent and condition of Western Port seagrass species is unknown. The present distribution boundaries, abundance and health of intertidal and subtidal seagrass needs to be mapped and the condition established. Mapping is fundamental to assessing the significance of loss of seagrass as a proportion of the total area in Western Port. This will form a key piece of information to set the limit of acceptable change in accordance with the ecological character description.
How much natural variation in seagrass extent and condition is there?	There are a limited number of studies that have examined seasonal variability in *Zostera* seagrasses in Western Port – mostly conducted in the 1980s (Bulthuis & Woelkerling, 1983b) with some in the early 2000s (Campbell & Miller, 2002). There has been some long term monitoring of changes in *Zostera* seagrass extent at a small number of sites in Western Port (Ball et al, 2010, Ball et al, 2010) – though no sites have been monitored in the area directly affected by the Project (North Arm).	There is uncertainty about seagrass seasonal dynamics, seagrass environmental requirements (light, seabed type, hydrodynamics, nutrients) and seagrass productivity. Existing information on natural variability in seagrasses can provide guidance for structuring monitoring and investigations specific to Project impact assessment. Monitoring of natural variation in extent and condition indicators of seagrass health/condition is required to determine their environmental requirements with regards to light, hydrodynamics, seabed type and sedimentation. Understanding the degree of natural variation (cyclic seasonal, random short-term, interannual, long term) would define the baseline from which predicted impacts must be assessed. This will also inform the ecological character description.

Key Question	Existing Information	Information Requirements
How could seagrasses be lost due to port development?	The processes that can lead to seagrass loss due to port development include permanent removal of seagrass habitat, temporary impacts on water quality leading to reduced light availability and permanent changes to hydrodynamics and water quality that make previously suitable seagrass habitats unsuitable for their persistence. Vast areas of intertidal seagrass were lost from the North Arm of Western Port in the late 1970s and early 1980s. Identification of the cause of the loss in Western Port has been inconclusive. The subsequent partial recovery of seagrass in parts of North Arm indicates that conditions may now be suitable for seagrasses compared to previous conditions. However, the rate of recovery has not been documented since 1999. Few studies have attempted to define seagrass requirements for Western Port *Zostera* seagrass (e.g. Holland et al, 2013, Bulthuis 1983). The results are informative at a general level but are not sufficiently project specific to enable assessment of likely impacts from the Project. Impacts from port development processes can be divided into direct (removal of seagrass habitat) and indirect (changes to water quality and hydrodynamics) impacts.	Direct impacts can be readily predicted from the Project 'footprint' (when known) and the extent of seagrasses in Western Port (when known). Prediction of other pathways of impact requires an understanding of seagrass habitat requirements (light, hydrodynamics, sedimentation), project specifications (dredge volumes, duration of program) and hydrodynamic and particle transport modelling of dredge plumes. Project specific investigations and monitoring programs are required to define the habitat requirements for the four Western Port seagrass species, in particular *Z. nigricaulis* – the species likely to be subject to the greatest impacts. Information on seagrasses is required in a form that would be directly linked with predictive hydrodynamic and water quality models to predict indirect impacts on seagrass, refine predictions and inform dredge planning. Models would require accurate data on seagrass habitat requirements and water quality, in particular data on the tolerance of seagrasses to sub-optimal habitat conditions (ie. how long Western Port seagrasses can survive under reduced irradiance), and how this tolerance may change from season to season.

Key Question	Existing Information	Information Requirements
Where and how much seagrass would be lost?	The area over which seagrasses are directly impacted by port development depends on the ‘footprint’ of the port and how much seagrass habitat it covers. Other pathways of direct impact depend on their exposure to temporary dredge plumes and the magnitude of permanent changes to water quality and hydrodynamics. Permanent changes to water quality and hydrodynamics are likely to affect a larger area than temporary changes to water quality. How much seagrass is lost ultimately depends on how much habitat becomes unsuitable for seagrass due to port construction activities. Intertidal and subtidal seagrasses occupy distinctly different habitats and are subject to different degrees of variation in light and temperature – habitat requirements of intertidal versus subtidal seagrasses appear to be distinct, but are as yet undefined.	The present area and distribution of seagrass condition is needed as a baseline for any future assessment of extent of effect of the project. Estimates of the magnitude of direct losses can only be made when design details of port development options are available. Estimates of the magnitude and significance of seagrass losses would require the following information: • The current extent of seagrasses and their environmental requirements in Western Port • Quantification of the tolerances of seagrasses to reductions in water quality (particularly light) at spatial and temporal scales relevant to the Project activities, activity schedules and spatial process scales. • Modelling of turbid plumes and changes to hydrodynamics • Integration of seagrass tolerances and turbid plume predictive models. Mitigation options and monitoring strategies would require the following information: • The tolerance and resilience of seagrasses to reductions in water quality (light and sedimentation) including seasonally variable tolerance • Details of dredge volumes, material characteristics and dredging and disposal options. Any predictions of both seagrass loss and recovery would need to be cognisant of factors unrelated to the project that may also affect seagrass in Western Port, i.e. temperature.

Key Question	Existing Information	Information Requirements
What are the flow-on effects of seagrass loss?	Information from Western Port, the Australian region and globally shows that a wide range of flora and fauna are associated with or dependent on seagrass habitats, and that seagrass habitats support a complex food web of multiple trophic levels and temporal variability in productivity and habitat use. Losses of seagrass habitat could lead to a series of indirect impacts to other ecological values through impacts on water quality and sediment stability (primarily through mobilisation of sediments and nutrients), primary productivity (of seagrasses and associated micro and macroalgae), habitat loss (algae, invertebrates, fish) and carbon emissions (sequestered carbon would be released as beds degrade).	Flow-on effects of seagrass loss are likely to be complex due to the large number of trophic levels and feedbacks involved. General flow-on effects of seagrass loss are likely to be expressed in terms of impacts on primary productivity and area of habitat character affected. The subsequent effects on dependent ecosystem components may have to be assessed in terms of (1) key species and (2) percentage reduction in ecological community groups. Understanding the degree of natural variation in seagrass habitat (cyclic seasonal, random short-term, interannual, long term) would define the baseline from which predicted impacts must be assessed.
Would seagrass recover?	Historically there has been loss and partial recovery of seagrasses in Western Port. Vast areas of intertidal seagrass were lost from the North Arm in the late 1970s and early 1980s. Efforts to identify the cause of this loss have been inconclusive. The subsequent partial recovery indicates that conditions may now be suitable for seagrasses compared to previous conditions. However, the rate of recovery has not been documented since 1999. The ability of seagrass to recover from deleterious impacts depends on the nature of seagrass loss, the future suitability of habitat, the health of remaining populations (plants or seed bank) and the availability of recruits from outside the impacted area. • Habitat suitability would determine the likelihood of recovery • The type of seagrass ‘loss’ is important – if loss is only partial (e.g. loss of stems and leaves only may allow recovery from rhizomes and roots below ground) or total (above and below ground material lost). • The supply of propagules (seeds, seedlings and vegetative propagules) from adjacent areas would influence the speed of recovery.	Assessment and documentation of seagrass condition along existing water quality gradients would be required into areas that previously provided habitat for seagrass but are now bare. This observational information would be used to develop a correlation matrix of seagrass condition and environmental condition. Correlations (positive and negative) would be used to inform the potential for a predictive model and the scope of investigations to develop a recovery model. Any predictions of both seagrass loss and recovery would need to be cognisant of factors unrelated to the project that may also affect seagrass in Western Port. Predicting recovery of seagrass beds requires a thorough understanding of post-dredging hydrodynamics and water quality, the scale and pattern of seagrass loss and the reproductive capacity of remaining populations

4 PROPOSED STUDY METHODS

The review has identified the key uncertainties with regard to the present extent and condition of Western Port seagrass habitat, and further uncertainties that affect the ability to predict likely impacts of dredging and/or seagrass recovery. Seagrass monitoring and targeted trials should be used to understand inherent spatial and temporal variability in seagrasses and link these to variations with natural factors (i.e. light) and particularly those that may also be affected by the development processes (light, suspended solids concentrations, hydrodynamics). This would support development of integrated predictive models of effects of the Project on seagrasses and dependent ecosystem components.

Methods and indicators should be selected from well-established and proven techniques, with appropriateness for studying seagrasses in the Western Port environment to be assessed at an early stage. The approach to the studies therefore would be staged and iterative.

The list of main studies required to answer the main questions identified in the beginning of this report are:

1. **Seagrass present spatial extent and variation**
    - Intertidal areas to be mapped and remapped over time
    - Subtidal areas to be mapped and remapped over time
2. **Seagrass present condition including spatial and temporal variation**
    - Comparison of seagrass metrics and indicators for ongoing monitoring and investigations
    - Relationship with natural environmental factors in Western Port
        - Light, suspended solids, sediment loads, temperature
    - Monitor physico chemical conditions
        - Monitor ambient light and temperature at depths and locations in Western Port
        - Monitor suspended solids concentrations
        - Monitor turbidity
        - Monitor sedimentation rates
    - Monitor productivity
    - Predictive model development
3. **Seagrass tolerance**
    - Light requirement
    - Smothering (sedimentation of leaves)
    - Burial (sedimentation burying plant parts)
    - Predictive model development
4. **Seagrass recovery**
    - Recovery pathways (clonal growth vs. recruitment from seed or fragments)
    - Predictive model development
    - Mitigation opportunities
5. **Ecosystem dependencies**
6. **Integrated predictive models**
    - Hydrodynamic, water quality, seagrass response, ecosystem dependency

A staged approach would be taken to carrying out the studies to enable information to be progressively collected and used to refine the scope and focus of subsequent studies. The first two studies on the list should be commenced as soon as possible as they would inform the scope and design of the subsequent studies. These observational studies are the basis for developing predictive model frameworks and informing design, procedures and expected outcomes for all subsequent studies and assessments related to seagrass.

4.1 Extent of seagrass beds in Western Port

Establishing the current extent and condition of seagrasses in Western Port is required to answer the following key questions:

- **How important is seagrass to Western Port?**
    - o by establishing its current extent and condition
- **How much seagrass will be lost due to port development?**
    - o by identifying how much seagrass is present within affected areas
- **Where in Western Port will seagrass be lost or temporarily affected?**
    - o by identifying where seagrass is present within affected areas

Mapping the existing extent of seagrass in Western Port is fundamental to assessing Project impacts on seagrass as it is a critical ecosystem component of Ramsar wetlands. This information is critical to understanding and defining the limits of acceptable change. The area of seagrass can then be compared with other communities in the region (Port Phillip, Corner Inlet) to provide international and statewide context for the assessment of impacts on seagrass as a habitat.

4.1.1 Use of information

Information from this investigation would also be essential to understanding the relationships between seagrass distribution and environmental variables (light availability, hydrodynamics) and as inputs to environmental modelling (hydrodynamics, water quality, ecology).

4.1.2 Coordination

Mapping exercises should be undertaken by suitably experienced personnel and take account of the range of habitat forming seagrass (*Zostera nigricaulis*, *Z. muelleri, Halophila australis, Amphibolis antarctica*) and algae species (*Caulerpa cactoides*). Other habitat boundaries (mangroves, saltmarsh) or visible features (sediment colour, texture) should also be mapped and or explained. The mapping exercise would require coordination between areas of experience including:

- Remote sensing
- Groundtruthing
- Ecology
- GIS.

4.1.3 Spatial coverage

Mapping of seagrass should cover the whole of Western Port. Mapping of seagrass boundaries (presence/absence) should be undertaken at the same or higher spatial resolution as previous studies to enable comparison (Blake and Ball (2001) used 1:10,000 scale remote imagery). Mapping should aim to achieve ± 1 m resolution for particular areas of interest, such as specific monitoring locations. This would require ground level mapping.

Documentation of the condition (abundance and health) of seagrasses at different monitoring locations within the mapped areas and depths is required to describe the potential range of seagrass community characteristics in North Arm (see Section 4.2). This may include higher resolution Assessment of impacts to seagrass will be required to predict the significance of impacts to the ecological character of the Ramsar site. The characteristics of seagrasses in North Arm will need to be compared with other locations in Western Port that are less likely to be affected by the Development during assessment of impacts, to provide reference conditions for impact management during construction and provide information for proof of concept of predictive models on completion of construction stages.

4.1.4 Timing

Repeat mapping surveys would be required to establish natural variation in the extent of seagrass over time including short term cyclic variations (seasons), random short term variations ('noise'), interannual variations and long term trends. Past aerial images would be examined to show the trajectory to the present condition. This would contribute to understanding historic factors resulting in the present 'baseline' conditions and understanding the possible uncertainties in the natural stability of the baseline. .

4.1.5 Methods

There are well established methods for mapping of intertidal seagrasses using remote imagery, assisted by ground truthing (i.e. Blake and Ball, 2001). Personnel experienced in these methods are currently available in Victoria. Recent observations of intertidal habitats shows that an extensive ground truthing of habitats would be required to distinguish the species within remotely identified 'beds', which could comprise a range of vegetation types.

4.1.6 Outputs

GIS mapping of seagrass extent and condition.

4.2 Seagrass present condition and spatial and temporal variation in Western Port

Defining baseline spatial and temporal variation in seagrass biomass, condition and other key indicators is an essential part of defining their tolerance to changed environmental conditions and predicting the impact of changed environmental conditions.

4.2.1 Purpose

Investigations of seagrass condition are required to answer the following key questions:

- **Will seagrass be lost due to port development, if so how much and how would seagrass be lost?**
- **Would seagrasses recover and how?**

Documentation of seagrass condition along existing water quality gradients into areas that previously provided habitat for seagrass but are now bare would be used to develop a correlation matrix of seagrass condition and environmental condition. Correlations (positive and negative) would be used to inform the potential and scope for a predictive model and the scope of investigations to develop a recovery model.

4.2.2 Coordination

This task should be coordinated with:

- Mapping
- Other ecological studies
- Seagrass response models
- Hydrodynamic studies
- Water quality studies
- The design process
- Integrated modelling

4.2.3 Spatial coverage

These investigations require monitoring at a range of sites and times representative of Western Port seagrass distributions and temporal dynamics. A range of seagrass condition indicators and environmental variables would be monitored. This phase of investigations would establish relationships between indicators and environmental variables and identify parameters with the best cost:benefit ratio for use in further investigations.

Some monitoring sites were established in mid-2014. Further monitoring sites will be established for the ongoing monitoring program such that all major Western Port seagrass habitats are monitored. Suggested sites are shown in Table 2. These sites have been proposed on the basis of preliminary discussions with team members in other disciplines, but will be finalised during an integrated workshop when the study proposals have been approved.

Table 2 Recommended sites for seagrass monitoring

Location	Depth	Position data WGS 84/MGA 94 Zone 55H		Segment	Dominant Seagrass	Type
		Suggested monitoring sites				
Inside Channel	**Intertidal***	357358	5761020	UNA	*Zostera*	Project
	Subtidal*	357287	5760874	UNA	*Zostera*	Project
Yaringa	**Intertidal***	346389	5763611	NA	*Zostera*	Project
	Shallow subtidal	346869	5763454	NA	*Zostera*	Project
	Subtidal	347078	5763397	NA	*Zostera*	Project
The Bluff	Intertidal	345215	5761883	NA	*Zostera*	Project
The Bluff	Shallow subtidal	345454	5761802	NA	*Zostera*	Project
The Bluff	Subtidal	345716	5761745	NA	*Zostera*	Project
Stony Pt	**Intertidal**	344553	5752358	LNA	*Zostera*	Project
	Shallow subtidal	344627	5752356	LNA	*Zostera*	Project
Tea Tree Pt	**Shallow subtidal**	348649	5749473	LNA	*Zostera*	Project
Corinella	Intertidal	362126	5748195	C	*Zostera*	Ref
Corinella	Shallow subtidal	361845	5748602	C	*Zostera*	Ref
Mosquito Creek	Subtidal	360117	5750307	C	*Zostera*	Ref
Rhyll	Shallow subtidal	352433	5742253	EA	*Zostera*	Ref
Balnarring	Subtidal	336974	5748646	WE	*Amphibolis*	Ref
Tortoise Head	Subtidal	349628	5746323	CZ	*Amphibolis*	Ref

Sites in **bold** were originally established in mid-2014.
*Denotes previously established site that has been repositioned in a more appropriate location
Shallow subtidal sites: 1.5 m below MSL to 2.5 m below MSL, Subtidal sites: >2.5 m below MSL

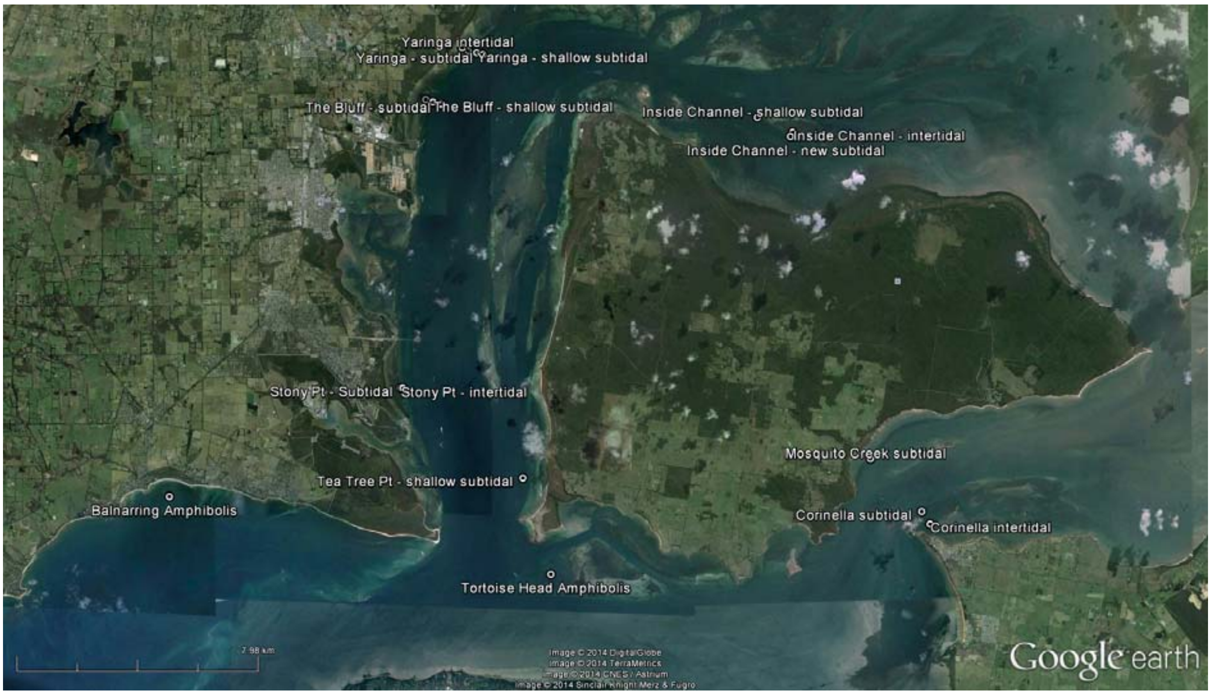

Figure 3 Map of Western Port showing proposed study sites

4.2.4 Timing

The timing of surveys need to be planned according to the known or likely scales of variability in the seagrass characteristics being measured and the relevance of the natural variations to the prediction of potential project impacts. Previous work by Bulthuis & Woelkerling (1983b) and Campbell & Miller (2002) will provide guidance on timing surveys.

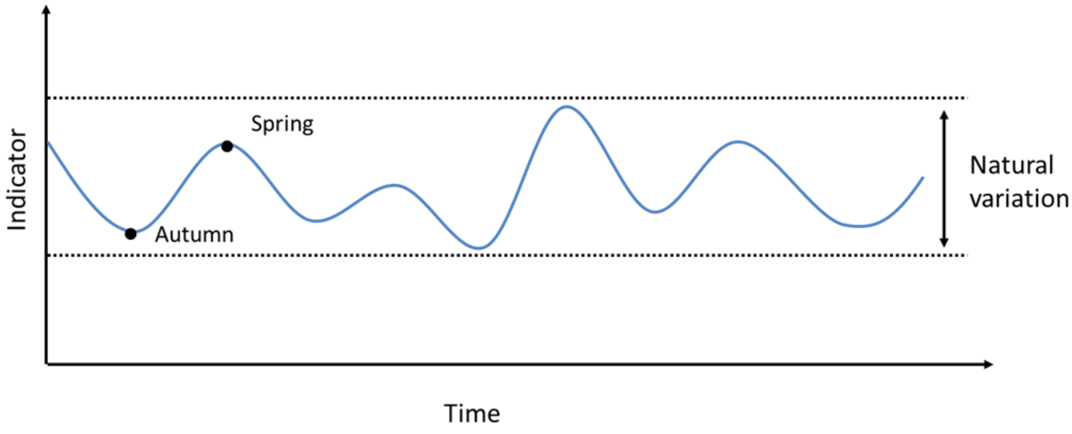

Figure 4 Conceptual model of possible natural variation in a seagrass condition indicator

Initially, surveys would be conducted 5 times per year at sites within North Arm segments (Figure 5, Table 2), and twice per year (at times of max and minimum biomass) at other sites.

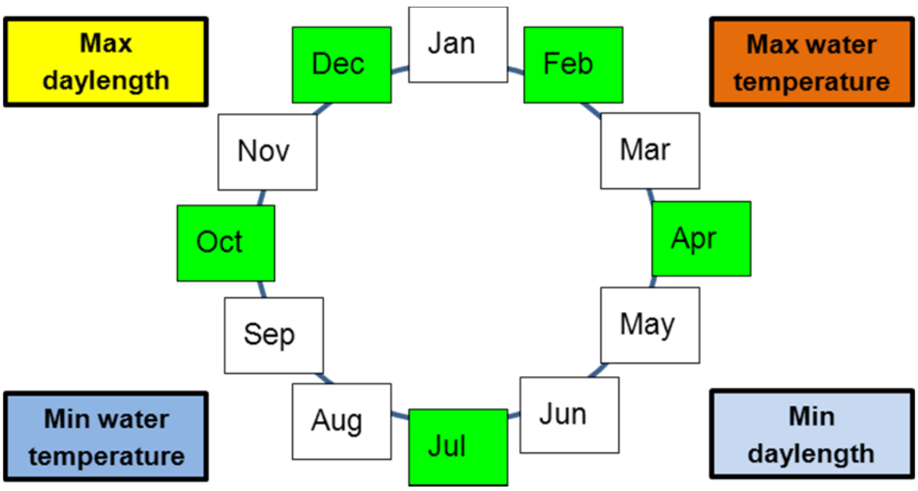

Figure 5 Schedule for monitoring surveys (green denotes survey month)

A minimum of two years of comprehensive baseline data is required to document the strength of seasonal and spatial variability, with a longer period desirable to determine the range of interannual variability. Interannual variability may be determined from a reduced number of monitoring sites.

4.2.5 Seagrass indicators

Seagrass condition can change in response to short and long term environmental changes. Some indicators provide an ‘early warning’ of change in seagrass condition, while other indicators provide information on longer term changes in seagrass (McMahon *et al,* 2013). Relevant indicators of both types will be investigated as part of the monitoring program. Review of available literature on indicators of seagrass condition that are likely to respond to predicted impacts (light, sedimentation) have been selected based on their utility, cost and practicality for use with Western Port seagrasses (Table 3). These indicators are:

- Above ground biomass;
- Dimensions of seagrass stems and leaves (e.g. stem length, leaf length, leaves per shoot, leaf clusters);
- Non-structural carbohydrates in above and below ground seagrass tissues;
- Carbon stable isotopes ($\delta^{13}C$) in seagrass leaves;
- Productivity: this may be assessed using conventional benthic chambers, or via lacunal gas discharge, fluorometry, oxygen evolution or acoustic methods.
- Sedimentation: determining background sediment accretion rates and levels of adherence to seagrass leaves will be important to predicting impacts of sedimentation resulting from dredging activities.

The list of indicators would be refined based on the results of early monitoring surveys – with a view to continuing to monitor only those indicators that provide good quality information at a reasonable cost.

4.2.6 Methods

Methods of monitoring these indicators are presented and assessed in Table 3. The methods would be developed via an iterative process. Results would be continually assessed for suitability, efficiency and application in predictive modelling or impact assessment.

4.2.7 Outputs

The first six months of results would inform development of predictive impact assessment models and tools, and provide the basis for design of trails to quantify impact response. The results of the first year or two would provide the basis of detailed description of existing conditions with respect to seagrass biology relevant to impact assessment for the Project.

Table 3 Summary of seagrass indicators, utility, practicality, economics

Indicator	Utility	Practicality and time requirements	Economics	Level of use
Mapping	Measure of seagrass extent and composition, over long term (years) will indicate whether seagrass habitat expanding or contracting	Commonly achieved using aerial images in intertidal/shallow subtidal areas. Requires *in-situ* assessment in deeper water.	Time and resource demands relatively high	High
Biomass	Measure of biomass and productivity of seagrass, can indicate changes to seagrass health in response to environmental factors over weeks to years	Requires destructive sampling but time and processing requirements relatively low	Low time requirements and simple processing makes this an economical option	Moderate
Shoot density	Indirect measure of seagrass biomass/abundance. Predictable short term response to light availability.	Can be measured non-destructively, but is relatively time consuming	High time requirements lead to high cost:benefit ratio.	Moderate
Plant morphology	Can be used as a measure of seagrass health. Predictable short term responses to environmental factors, particularly light.	Time consuming, most easily achieved through destructive sampling	High time requirements lead to high cost:benefit ratio.	Low
Photosynthetic efficiency, rates.	Indicator of seagrass health and productivity. Responds predictably and quickly. Can be used to define seagrass light requirements.	Time consuming non-destructive sampling. Best suited to laboratory studies.	High time requirements lead to high cost:benefit ratio.	Low
Non-structural carbohydrates	Measure of seagrass productivity and health. Responds predictably and quickly to light availability. Can be used to define seagrass light requirements.	Simple destructive sampling and laboratory analysis of samples. Laboratory costs thought to be cost-effective.	Low time requirements leads to low cost, high volumes of samples may reduce laboratory costs	Low
$\delta^{13}C$	Can be used as an indicator of light limitation in seagrasses, as the lighter isotope is more easily taken up by the plant, in low light less ^{13}C is accumulated relative to ^{12}C.	Simple destructive sampling and laboratory analysis of samples. Relatively low laboratory costs.	Low time requirements leads to low cost, high volumes of samples may reduce laboratory costs	Low
Lacunal gas discharge	Discharge of gas from cut rhizomes can be used to measure plant productivity under different light regimes	Simple destructive sampling and relatively simple laboratory techniques.	Low time requirements for sampling though laboratory procedures may be time consuming	Low
C:N ratio	Measure of seagrass access to nutrients and/or productivity. Responds to changes in both nutrient and light levels – cause:effect may be hard to assign to either factor.	Simple destructive sampling and laboratory analysis of samples. Laboratory costs of around $20 per sample?	Low time requirements leads to low cost, high volumes of samples may reduce laboratory costs	Low
Molecular techniques (genomics and proteomics)	Studies have shown responses of seagrass genes and proteins to environmental factors. Remains a relatively new area for seagrass science.	Few genetic or protein indicators have been developed for seagrass. Large amount of preliminary work would be required to identify molecular responses. Response time scale may be too long.	Molecular analysis costs are falling rapidly. However, costs of establishing this method for Western Port seagrass species and environment may be high.	Nil

5 CRITICAL REVIEW OF AVAILABLE INFORMATION ON SEAGRASS – A3 TABLE

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
General	Shapiro, M.A (1975) A Preliminary Report on the Western Port Bay Study, Ministry of Conservation, Melbourne.	Presents findings of a two year multidisciplinary study into the Western Port environment. Established existing conditions such as distribution of key ecological features (mangroves, seagrass, mudflats, feeding areas for birds), water quality, hydrodynamics, estimates of productivity. Provided advice on management strategies for the ecosystem	**High**	Information is now outdated	How much seagrass is in Western Port?
Distribution	Stephens, A. (1995). The distribution of seagrass in Western Port, Victoria. Australia. Environment Protection Authority, No. 490. Victoria, Australia.	*Zostera/Heterozostera* distribution in Western Port was mapped aerially. Total seagrass area in 1994 was 93 km^2 (excluding Western Entrance segment). The largest area of seagrass was in the Upper North Arm (43 km^2), followed by Lower North Arm (24 km^2) and the Rhyll segment (11 km^2). The least amount of seagrass was at Corinella segment (5 km^2). Comparisons with past surveys indicated that seagrass in 1994 increased by 26 km^2 from 1983/84 (lowest at 67 km^2) but was still well below that in 1973/74 (highest at 197 km^2).	**High** – seagrass distribution data specific to Western Port	Information is now outdated	How much seagrass is in Western Port?
Distribution	Roob, R. and D. Ball (1997). Gippsland Lakes Seagrass Mapping. Victorian Marine Habitat Database. Queenscliff. Marine and Freshwater Resources Institute.	Seagrass distribution in Gippsland Lakes and Lake Tylers was mapped aerially Total seagrass area was 43 km^2. *Zostera/Heterozostera* was the dominant seagrass (43 km^2) while *Ruppia spiralis* was a very minor component (0.6 km^2). The depth distribution of seagrass within the Lakes system was generally 0-2 m. Comparisons with past surveys indicated seagrass here somewhat followed that at Western Port, with high cover prior in the 1960s, lowest cover in the mid 1980s and peaking again in 1997.	**Moderate** – demonstrates seagrass abundance in other Victorian habitats	Information is now outdated	How much seagrass is in Western Port?
Distribution	Roob, R., P. Morris, et al. (1998). Corner Inlet and Nooramunga Seagrass Mapping. Victorian Marine Habitat Database. Queenscliff, Marine and Freshwater Resources Institute.	Seagrass distribution in Corner Inlet and Nooramunga was mapped aerially Total seagrass area was 149 km^2. *Zostera/Heterozostera* was the dominant seagrass (110 km^2). *Posidonia australis* is prevalent but is found in lesser amounts (32 km^2). *Halophila* was only a minor component of the seagrasses (0.2 km^2). The depth distribution of seagrass within Corner Inlet and Nooramunga was generally between 0-4 m. Comparisons with past surveys indicated that like Western Port, seagrass distribution fluctuated markedly through time; but was lowest in the early 1970s, and highest in late 1970s and 1998.	**Moderate** – demonstrates seagrass abundance in other Victorian habitats	Information is now outdated	How much seagrass is in Western Port?
Distribution	Blake, S., Roob, R., et al. (2000). Seagrass Mapping of Victoria's Minor Inlets. Queenscliff, Marine and Freshwater Resources Institute.	Seagrass distribution in the 6 minor inlets of Victoria was mapped aerially. Total seagrass area was 21 km^2. The dominant seagrass was *Zostera/Heterozostera* (14 km^2), while *Ruppia* sp. was a minor component (2 km^2). Comparisons with past surveys across 4 inlets indicated that seagrass distribution varied at broad scales through time even though the inlets were independent of each other. Lowest seagrass densities were generally observed in the 1970s, while densities were highest in the 1990s.	**Moderate** – demonstrates seagrass abundance in other Victorian habitats	Information is now outdated	How much seagrass is in Western Port?
Distribution	Blake, S. and D. Ball (2001). Victorian Marine Habitat Database: Seagrass Mapping of Port Philip Bay. Queenscliff, Marine and Freshwater Resources Institute.	Seagrass distribution in Port Philip Bay was mapped aerially. Total seagrass area was 68 km^2, making up 40% of the vegetated area in the bay. *Zostera/Heterozostera* was the dominant seagrass (59 km^2), followed by *Amphibolis* (2 km^2) and *Halophila* (1.4 km^2). *Amphibolis* was dominant in the Heads where wave energy was high and sediments were coarse. The depth distribution of *Zostera/Heterozostera* was between 0-5 m. Comparisons with past surveys indicated that unlike Western Port, seagrass distribution in the Port Philip Bay had remained relatively constant from 1957 to 2000, although there were significant fluctuations over time at the scale of sites.	**Moderate** – demonstrates seagrass abundance in other Victorian habitats	Information is now outdated	How much seagrass is in Western Port?
Distribution	Blake, S. and D. Ball (2001). Victorian Marine Habitat Database: Seagrass Mapping of Western Port. Queenscliff, Marine and Freshwater Resources Institute.	Aerially mapped distribution of seagrass. Found that in 1999 84% of total vegetated area was seagrass or seagrass with macroalgae. Dense *Zostera/Heterozostera* with algae was dominant category. *Amphibolis* dominant in Western Entrance and present in Eastern Entrance. *Zostera*/*Heterozostera* begins at entrance of North Arm (as Amphibolis declines) and becomes dominant from the lower North Arm. *Zostera*/*Heterozostera* decreases in upper North Arm. Starts appearing after east of French Island and becomes dense from Bass River to San Remo.	**High** – seagrass distribution data specific to Western Port	Information is now outdated	How much do they vary naturally? How much do they vary naturally?

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Distribution	Miller, C. J, S. J. Campbell and S., Scudds (2005). "Spatial variation of *Zostera tasmanica* morphology and structure across an environmental gradient". Marine Ecology Progress Series, 304: 45-53.	3 regions North (Upper North Arm- Charring Cross), Mid (Lower North Arm- Stony Point), South (between Rhyll & San Remo). Patchy cover in northern region (20-50%). Slightly patchy cover in middle region (80-100%). Thick and consistent cover in the southern region (~100%).	**Moderate** – assesses spatial variation of seagrass in Western Port	Assessments made on a small scale	How much do they vary naturally?
Distribution	Ball, D., Parry, G. et al. (2010). "Victorian Multi-regional Seagrass Health Assessment 2004-07". Fisheries Victoria Technical Report Series No. 66. Queenscliff, Marine and Freshwater Resources Institute.	Aerial mapping showed total seagrass cover at Woolleys Beach (~86%), Rhyll (96-98%) and Scrub Point (~97%) relatively stable from 1999 to 2007. Cover at Tankerton increased (70% to 88%). Fine-scale studies found *H. nigricaulis* percent cover varied significantly though time and space (Rhyll 45-85%; Chicory Lane 15-90%; Woolleys Beach 50-100%) with large decline in 2006.	**High –** shows ongoing variability in seagrass extent demonstrating need for up-to date assessment	No sites within Project area	How much do they vary naturally?
Ecology	Bulthuis, D. A. and Woelkerling, Wm. J. (1981). "Effects of in situ nitrogen and phosphorus enrichment of the sediments on the seagrass *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog in Western Port, Victoria, Australia". Journal of Experimental Marine Biology and Ecology, 53: 193-207.	Leaf growth, density and biomass generally were lowest in winter and peak in summer. There was a 20% increase in leaf growth rate when enriched with ammonium, but no change in leaf standing crop or shoot density. Lower concentrations of total nitrogen of leaves and rhizomes suggests that *H. tasmanica* on intertidal mudflats in northern region may be nitrogen limited (only in spring and early summer when time of maximum growth).	**High –** shows seasonal and nutrient related variation in *Zostera*.	Nutrients do not appear to be a key issue in Western Port, may be a minor issue for the Project.	How much do they vary naturally?
Ecology	Bulthuis, D. A. (1983). "Effects of in situ light reduction on density and growth of the seagrass *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog in Western Port, Victoria, Australia". *Journal of* Experimental Marine Biology and Ecology, 67: 91-103.	Effect of light reduction on leaf cluster density related to degree of light availability and timing. *H. tasmanica* requires min. ~5-13% of surface irradiance (SI) to establish and survive. When SI ≤4.5%, plants died within 14 months (within 2 months at 1% SI). Light reduction resulted in decline in leaf cluster density and leaf length but growth is maintained due to less self-shading. Rate of decline was quicker in summer than winter due to increased light compensation point during warmer months.	**High –** demonstrates different responses of seagrass to shading depending on time of year	Shading took place in intertidal areas only, some uncertainty about minimum light requirements calculated here.	How much do they vary naturally?
Ecology	Bulthuis, D. A. and Woelkerling, Wm. J. (1983). "Biomass accumulation and shading effects of epiphytes on leaves of the seagrass, *Heterozostera tasmanica*, in Victoria, Australia". Aquatic Botany, 16: 137-148.	Higher rates of epiphyte biomass accumulation at San Remo than at Charing Cross likely due to low grazing pressure by gastropods at San Remo. Highest epiphyte biomass accumulation occurred during summer months and on older leaves. Epiphyte accumulation during 'bloom' periods can adversely affect net photosynthesis.	**High –** demonstrates regional differences in epiphyte accumulation		How much do they vary naturally? Flow on effects of seagrass loss?
Ecology	Bulthuis, D. A., Brand, G. W. and Mobley. M. C. (1984). "Suspended sediments and nutrients in water ebbing from seagrass-covered and denuded tidal mudflats in a southern Australian embayment". Aquatic Botany, 20: 257-266.	Water flowing from seagrass-covered intertidal mudflat in summer contained significantly less suspended solids, phosphorus and silicate than water from an ungrassed mudflat. Loss of seagrass on intertidal mudflat likely to increase movement of materials from sediments to overlying water.	**High –** demonstrates flow on effects of seagrass loss (increased turbidity)		Flow on effects of seagrass loss?
Ecology	Edgar, G. J. And Shaw, C. (1995). "The production and trophic ecology of shallow-water fish assemblages in southern Australia I. Species richness, size-structure and production of fishes in Western Port, Victoria". Journal of Experimental Marine Biology and Ecology, 194: 53-81.	Sampled fish assemblages in seagrass and unvegetated habitats in Western Port over 1 year. 3% of all fish caught during the study were commercially important of which consisted of 23% of all species. Seagrass habitats did not support much higher densities of large fish than unvegetated habitats. Seagrass habitats supported greater abundance and production of the small sized fishes compared to unvegetated habitat, but these were mostly non-commercially valuable species. However, small-sized commercially important fish that were caught were more abundant in seagrass habitats. Fish density and production in seagrass habitats varied markedly through time following seasonal changes in seagrass biomass (high in summer months, low in autumn and winter months).	**High –** demonstrates differences in utilisation of Western Port seagrass (and other) habitats by fish.	Data around 20 years old	Flow on effects of seagrass loss?
Ecology	Edgar, G. J. And Shaw, C. (1995). "The production and trophic ecology of shallow-water fish assemblages in southern Australia II. Diets of fishes and trophic relationships between fishes and benthos at Western Port, Victoria". Journal of Experimental Marine Biology and Ecology, 194: 83-106.	Crustaceans were the dominant dietary component for majority of fish species in Western Port (69%). Seagrass was only ingested in large amounts by the southern garfish. Similar trophic pathways were found; major linkage was from benthic microalgae and detritus to epifaunal crustaceans to smaller fishes. Condition of seagrass-associated fish declined and mortality rates increased during the autumn months when total fish consumption could not be supported by crustacean production when seagrass declined.	**High –** Provides information on how seagrass habitat primary productivity enters the foodweb	Data around 20 years old	Flow on effects of seagrass loss?

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Ecology	Edgar, G. J. And Shaw, C. (1995). "The production and trophic ecology of shallow-water fish assemblages in southern Australia III. General relationships between sediments, seagrasses, invertebrates and fishes". Journal of Experimental Marine Biology and Ecology, 194: 107-131.	Conducted over large geographic scale from WA, TAS, VIC to NSW. Multiple regression showed that fish production was highly correlated with crustacean production and seagrass biomass, and was negatively correlated with wave exposure. The estimated crustacean production was highly correlated with the biomass of seagrass material and also proportion of particle <63um.	**Low –** general ecological study with low relevance to Project		Flow on effects of seagrass loss?
Ecology	Miller, C. J, Campbell, S. J. and Scudds, S. (2005). "Spatial variation of *Zostera tasmanica* morphology and structure across an environmental gradient". Marine Ecology Progress Series, 304: 45-53.	Environmental gradient in water quality shapes seagrass form and meadow structure. Northern regions characterised by low leaf numbers, low shoot weights, low shoot densities and few internodes. Mid to southern regions have more and longer leaves, more nodes and longer internode lengths as well as having higher shoot densities and greater seagrass cover.	**High** – provides information on existing conditions in seagrass beds	Small number of sites and did not provide information on subtidal *Zostera*	How much do they vary naturally?
Ecology	Morris, L., Jenkins, G., Hatton, D. And Smith, T. (2007). "Effects of nutrient additions on intertidal seagrass (*Zostera muelleri*) habitat in Western Port, Victoria, Australia". Marine and Freshwater Research, 58: 666-674.	Nutrient addition to *Z. muelleri* in Western Port increased leaf dry weight and loose algae at 2 out of 3 sites, but did not affect number of seagrass leaves, epiphyte biomass.	**Low** – study primarily concerned with nutrients, results equivocal.	Does not demonstrate light responses	How much do they vary naturally?
Ecology	Hutchinson, N., Jenkins, G. P., Brown, A. and Smith, T. M. (2013). "Variation with Depth in Temperate Seagrass-Associated Fish Assemblages in Southern Victoria, Australia". Estuaries and Coasts, 37: 801-814.	Sampling fish in shallow (<1 m) and deep (2-8 m) *Z. nigricaulis* meadows in Port Philip Bay over 3 years. Species richness was higher in shallow beds than deep beds. There was a positive relationship between seagrass biomass/length and total abundance/species richness. Total abundance of fish was generally significantly higher in shallow beds than in deep beds. Both seagrass habitats had distinctive assemblage structure between the two depths, with small schooling fish dominating shallow beds.	**Moderate –** demonstrates depth related differences in fish associated with seagrass.	Not assessed in Western Port	How much do they vary naturally?
Bioindicators	Atkinson, M. J. (1983). "C:N:P ratios of benthic marine plants." Limnology and Oceanography 28(3): 568-574.	Establishes C:N:P ratio for benthic marine macroalgae and seagrasses as 550:30:1. benthic marine plants require lower amount of nutrients to support a particular level of net production than phytoplankton. Benthic plants growing with highly elevated N levels approach Redfield C:N:P - this suggested as a limit rather than central tendency of their ratio.	**Moderate**		
Bioindicators	Dennison, W. C. (1987). "Effects of light on seagrass photosynthesis, growth and depth distribution." Aquatic Botany 27: 15-26.	Studies effects of light on *Z. marina* photosynthesis, growth and depth distribution. Gross photosynthesis peaked in late-summer but net photosynthesis peaked in spring due to high respiration at summer temperatures. Depth limit related to depth distribution of compensation irradiance and minimum annual average compensation irradiance of 12.3 h/d found. Even though longest days are at summer solstice, Hcomp and Hsat were longest in northern spring (April) - temperature affects Hcomp and Hsat as they are based on net photosynthesis.	**Moderate –** establishes general light requirements and measures of 'light dose' for seagrass, establishes interactive effect of light and temperature on photosynthesis.		How much do they vary naturally?
Bioindicators	Duarte, C. M. (1990). "Seagrass nutrient content." Marine Ecology Progress Series 67: 201-207.	Examine nutrient content of 27 seagrass species from 30 locations (literature based). Suggested stable C:N and C:P ratios of 12 and 200 (somewhat higher than redfield ratio). Median values of N and P content were 1.8 and 0.2 percent DW - values below this might indicate nutrient limitation. Structural carbon in seagrass contributes to higher C:N:P ratios compared with phytoplankton. Did not examine effects of light.	**Moderate –** Establishes generalised C:N:P ratios for seagrasses	General relevance only: species studied not found in Western Port.	
Bioindicators	Abal, E. G., N. Loneragan, et al. (1994). "Physiological and morphological responses of the seagrass *Zostera capricorni* Aschers to light intensity." Journal of Experimental Marine Biology and Ecology 178(1): 113-129.	Study response of *Z. capricorni* to changes in light intensity. High light led to smaller shoots, higher biomass and productivity, less negative 13C values, lower leaf N content, less chlorophyll and more photoprotection than low light plants.	**Moderate** – demonstrates response of related *Zostera* species to light availability	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Bioindicators	Kraemer, G. P. and R. S. Alberte (1995). "Impact of daily photosynthetic period on protein synthesis and carbohydrate stores in *Zostera marina* L. (eelgrass) roots: implications for survival in light-limited environments." Journal of Experimental Marine Biology and Ecology 185(2): 191-202.	Examines effect of reduction in Hsat period on rhizome metabolism. Found protein synthesis in rhizomes could continue anaerobically given sufficient C stores. Plants quickly switch to anaerobic metabolism in rhizomes when photosynthesis ceases. *Z. marina* rhizomes could withstand 10-14 day anoxic periods (2 hr Hsat period). Seagrass more resilient to reduced Hsat if they had good C stores to begin with.	**Moderate** – demonstrates effects of light availability on carbohydrates and proteins in *Zostera*	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Burke, M. K., W. C. Dennison, et al. (1996). "Non-structural carbohydrate reserves of eelgrass *Zostera marina*." Marine Ecology Progress Series 137(1-3): 195-201.	Studies NSC dynamics in *Z. marina*. Found seasonal variation in sugar, but not starch. Most NSC stores in rhizomes, most starch in roots. Shading reduced NSC reserve storage, spring an important time for both growth and NSC accumulation. NSC reserves depleted throughout remainder of year.	**Moderate** – demonstrates effects of light availability on carbohydrates stores in *Zostera.*	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Grice, A., N. Loneragan, et al. (1996). "Light intensity and the interactions between physiology, morphology and stable isotope ratios in five species of seagrass." Journal of Experimental Marine Biology and Ecology 195(1): 91-110.	Examined effects of light on stable isotope ratios, physiology, morphology on five species of seagrass. Less negative delta 13C values, higher productivities, higher C:N ratio under full sun. Seagrass productivity positively correlated with delta 13 C. Discuss increased root biomass at higher productivity - perhaps used to acquire more N from sediments to boost depleted N stores. Seagrasses discriminate less against 13C at higher irradiances.	**Moderate** – demonstrates effects of light availability on *Zostera* bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Fourqurean, J. W., T. O. Moore, et al. (1997). "Spatial and temporal variation in C:N:P ratios, S15N and S13C of eelgrass *Zostera marina* as indicators of ecosystem processes, Tomales Bay, California, USA " Marine Ecology Progress Series 157: 147-157.	Examine C:N:P and stable isotopes in *Z. marina* in response to temporal and spatial variation in nutrient availability. Strong positive relationship between C:N ratio and distance from nutrient source (seasonal upwelling).	**Moderate** – demonstrates effects of light availability on *Zostera* bioindicators	General relevance only: species studied not found in Western Port.	
Bioindicators	Longstaff, B. J. and W. C. Dennison (1999). "Seagrass survival during pulsed turbidity events: the effects of light deprivation on the seagrasses *Halodule pinifolia* and *Halophila ovalis*." Aquatic Botany 65(1-4): 105-121.	Examined responses of natural light gradients and experimental light starvation in two seagrass species. Showed 38-78 day tolerance of *H. pinnifolia* to light deprivation, death at 90-100 days. *H. ovalis* dead after 38 days darkness. Increase in amino acid content of *H. pinnifolia* due light deprivation. Early indicators of light stress in *H. pinnifolia* were increased amino acid content, decrease in Chl-a/b ratio, decrease in 13C values.	**Moderate** – demonstrates effects of light availability on seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Longstaff, B. J., N. R. Loneragan, et al. (1999). "Effects of light deprivation on the survival and recovery of the seagrass *Halophila ovalis* (RBr) Hook." Journal of Experimental Marine Biology and Ecology 234(1): 1-27.	Used light deprivation experiments to examine mortality of *Halophila ovalis*. Biomass declined after 3-6 days of darkness, death after 30d. Sugar concentrations declined rapidly for first 2 days of deprivation, stabilised, then rapidly increased in recovery period. Starch concentrations did not change during light deprivation (inhibition of utilisation due anaerobiosis). Also examined photosynthesis, C isotope, pigments.	**Moderate** – demonstrates effects of light availability on seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Cabello-Pasini, A., C. Lara-Turrent, et al. (2002). "Effect of storms on photosynthesis, carbohydrate content and survival of eelgrass populations from a coastal lagoon and the adjacent open ocean." Aquatic Botany 74(2): 149-164.	Examined response of *Z. marina* to reduced light levels associated with storms. Storms reduced light availability to nearly zero for nearly three weeks on open coast. 85% decline in leaf sugar and starch content after three weeks, and shoots died off. Seedlings re-appeared after storm season ended and light availability increased.	**Moderate** – demonstrates effects of light availability on seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development? What is the recovery potential for seagrass?
Bioindicators	Peralta, G., J. Perez-Llorens, et al. (2004). "Effects of light availability on growth, architecture and nutrient content of the seagrass *Zostera noltii* Hornem." Journal of Experimental Marine Biology and Ecology 269(1): 9-26.	Examine response of *Z. noltii* to shading over 14 days. Find that growth parameters, C:N, NSC are negatively affected by light reduction.	**Moderate** – demonstrates effects of light availability on seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Brun, F. G., I. Hernandez, et al. (2003). "Growth, carbon allocation and proteolytic activity in the seagrass *Zostera noltii* shaded by *Ulva* canopies." Functional Plant Biology 30(5): 551-560.	Tested effect of shading on *Z. noltiicarbon* allocation and proteolytic activity. Shaded plants had negative net growth and starch mobilised in above and below ground tissue. Sucrose declined in below ground parts, accumulated in above ground parts. Severe shading led to low activity of enzymes associated with sucrose formation, but increased C 'sink strength' indicated by high activity of sucrose synthase.	**Moderate** – demonstrates effects of light availability on seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Bioindicators	Baird, M. E. and J. H. Middleton (2004). "On relating physical limits to the carbon:nitrogen ratio of unicellular algae and benthic plants." Journal of Marine Systems 49: 169-175.	Examine physical reasons for higher C:N:P ratios in benthic algae and seagrasses compared with phytoplankton. Find that potential light absorption is higher for benthic plants than phytoplankton, which may explain why they require around 4 times as much light per unit N compared to unicellular algae. This may explain higher C:N:P ratios and nitrogen limitation in benthic plants.	**Low** - Provides general information only on algae versus seagrass C:N:P	Provides general information only on	
Bioindicators	Hackney, J. W. and M. J. Durako (2004). "Size-frequency patterns in morphometric characteristics of the seagrass *Thalassia testudinum* reflect environmental variability." Ecological Indicators 4: 55-71.	Examined variability in structural characteristics of *Thalassia testudinum* in Florida Bay, USA. Shoot morphometrics showed significant inter-annual differences in size-frequency distributions, but only leaf number per shoot showed difference in mean. There were larger differences between basins within Florida Bay than between years.	**Low** – demonstrates regional differences in seagrass shoot dimensions related to water quality/habitat.	General relevance only: species studied not found in Western Port.	
Bioindicators	Ibarra-Obando, S., K. Heck, et al. (2004). "Effects of simultaneous changes in light, nutrients, and herbivory levels, on the structure and function of a subtropical turtlegrass meadow." Journal of Experimental Marine Biology and Ecology 301(2): 193-224.	Studied effects of nutrient addition, herbivory and light on seagrass response variables. All variables negatively responded to light reduction except below-ground biomass, shoot density and leaf length.	**Low** – demonstrates effects of light availability on seagrass bioindicators	General relevance only: species studied not found in Western Port.	
Bioindicators	Ransbotyn, V. and T. B. G. Reusch (2006). "Housekeeping gene selection for quantitative real-time PCR assays in the seagrass *Zostera marina* subjected to heat stress." Limnology and Oceanography: Methods 4: 367-373.	Study where authors attempted to identify *Z. marina* 'house keeping genes' whose expression (or degree of expression) could be used to study response to heat stress. Authors found only a small number of 'stable' house keeping genes (3). Their response (in terms of expression) of these genes to changes in temperature were not investigated.	**Low** – demonstrates effects of heat on seagrass genetics	Study shows current utility of genetic/molecular techniques limited	
Bioindicators	Hoffmann, A. A. and P. J. Daborn (2007). "Towards genetic markers in animal populations as biomonitors for human-induced environmental change." Ecology Letters 10: 63-76.	Propose genetic 'markers' as potentially sensitive indicators of changes in environmental conditions. Review documented genetic changes in animal (mostly small arthropods) genetics in response to toxins and temperature. Such changes in genetics ('evolution') in response to contemporary changes in environment are happening in species with short generation times (multiple times per year) - which is not the case for seagrasses.	**Low** – shows genetic response to environment	Uses examples of animals with very short generation times	
Bioindicators	McKenzie, L. J., J. Mellors, et al. (2007). Great Barrier Reef Water Quality Protection Plan - Marine Monitoring Program: Intertidal Seagrass. Great Barrier Reef Water Quality Protection Plan - Marine Monitoring Program. Townsville, Great Barrier Reef Marine Park Authority.	Large scale monitoring program. Included monitoring of C:N and C:P ratios in 2005/2006 - both were able to differentiate between coastal and reef habitat types, inferring a distinction between low light, and comparatively higher light environments (C:N and C:P ratios are lower in low light, high nutrient environments).	**Moderate** – shows utility of C:N and C:P monitoring for assessing seagrass condition	Unable to distinguish between nutrient and light availability effects	Where and how much seagrass would be lost due to port development?
Bioindicators	Procaccini, G., J. L. Olsen, et al. (2007). "Contribution of genetics and genomics to seagrass biology and conservation." Journal of Experimental Marine Biology and Ecology 350(1-2): 234-259.	Outlines applications for different types of molecular analyses in seagrasses, including 'genetic' monitoring. Applications discussed appear to be mostly applicable to impacts on the scale of years to decades. Does not provide information on whether monitoring 'gene expression' is currently feasible in seagrasses.	**Low** – shows genetic response to environment	Uses examples of changes over scale of years to decades	
Bioindicators	Schwartz, M. K., G. Luikart, et al. (2007). "Genetic monitoring as a promising tool for conservation and management." Trends in Ecology and Evolution 22(1): 9.	Examine uses of genetic monitoring for tracking changes in population size, connectivity, gene flow, genetic diversity.	**Low** – shows genetic response to environment	Uses examples of changes over scale of years to decades	

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Bioindicators	Touchette, B. W. and J. M. Burkholder (2007). "Carbon and nitrogen metabolism in the seagrass, *Zostera marina* L.: Environmental control of enzymes involved in carbon allocation and nitrogen assimilation." Journal of Experimental Marine Biology and Ecology 350(1/2): 216-233.	Carbon and Nitrogen metabolism in *Z. marina* strongly influence by prevailing environmental conditions, especially temperature, salinity and environmental nutrient levels. *Z. marina* characterised as adapted to N limitation, and able to maximise nitrate uptake during infrequent nitrate pulses (by re-allocating carbohydrates to reducing nitrate and forming amino acids). Low carbohydrate reserves generally lead to low nitrate reductase activity, but NR activity usually up regulated when Nitrate available, may cause internal carbon limitation. Glutamine synthetase activity closely linked to inorganic N levels (up-regulated at increase N levels) and temperature (up-regulated at optimum temperature)	**Low** – study primarily concerned with nutrients	Does not demonstrate light responses	
Bioindicators	Vichkovitten, T., M. Holmer, et al. (2007). "Spatial and temporal changes in non-structural carbohydrate reserves in eelgrass (*Zostera marina* L.) in Danish coastal waters." Botanica Marina 50(2): 75-87.	Examine spatial and seasonal changes of non-structural carbohydrates in *Z. marina*. Rhizomes major storage organ, sucrose major storage, starch <15% total reserves. Plants with lower light had more reserves, nutrient availability did not affect reserves. More starch was accumulated over winter.	**Moderate** – demonstrates carbohydrate dynamics in *Zostera*	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Collier, C., P. S. Lavery, et al. (2008). "Physiological characteristics of the seagrass *Posidonia sinuosa* along a depth-related gradient of light availability." Marine Ecology Progress Series 353: 65-79.	Examined physiology of *P. sinuosa* along a depth-related gradient of light availability. RLC, pigments, nutrient and carbohydrate concentrations showed few differences among depths but some adjustment between seasons. C:N ratio was lower in winter (low light) than summer.	**Moderate** – demonstrates light related dynamics in *Posidonia* bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Collier, C. J., P. S. Lavery, et al. (2009). "Shade-induced response and recovery of the seagrass *Posidonia sinuosa*." Journal of Experimental Marine Biology and Ecology 370(1–2): 89-103.	Document changes in shoot density, rhizome sugars, leaf morphology, S13C, photosynthesis, %N in response to light reduction.	**Moderate** – demonstrates light related dynamics in *Posidonia* bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	McKenzie, L. J. and R. L. Yoshida (2009). Coastal Canaries. Seagrass-Watch. Cairns, Seagrass Watch.	Decreasing C:N and C:P ratios in seagrass leaves at GBR sites indicated reduced light availability (or nutrient enrichment?). Shift from N-limited to P-limited conditions, 2005-2006.	**Moderate** – demonstrates light and nutrient related dynamics in seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Collier, C. J., P. Prado, et al. (2010). "Carbon and nitrogen translocation in response to shading of the seagrass *Posidonia sinuosa*." Aquatic Botany 93(1): 47-54.	Examined translocation of C and N in *P. sinuosa* in response to shading (ambient vs below limiting light, 10 days). Found mature leaves could translocate N to growing leaves under shade conditions, enhancing light harvesting efficiency.	**Moderate** – demonstrates light related dynamics in *Posidonia* bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Niedringhaus, T. P., D. Milanova, et al. (2011). "Landscape of Next-Generation Sequencing Technologies." Analytical Chemistry 83(12): 4327-4341.	Examines applicability of next-generation molecular techniques (genetics)	**Low**		
Bioindicators	Cabacao, S. and R. Santos (2012). "Ecological Indicators." Seagrass reproductive effort as an ecological indicator of disturbance 23: 116-122.	Review changes in seagrass reproductive effort in response to disturbances and seagrass traits. RE increased with disturbance in 72% cases, 25% decreased. Seagrass RE increased 4-fold with disturbance. Mechanical and sedimentary/hydrodynamics disturbances caused greatest RE increase. Responses to decreased light availability equivocal, but generally RE falls when light drops.	**Moderate** – demonstrates effects of disturbance on seagrass reproductive effort	General relevance only: species studied not found in Western Port.	What is the recovery potential for seagrass?
Bioindicators	Durako, M. J. (2012). "Using PAM fluorometry for landscape-level assessment of *Thalassia testudinum*: Can diurnal variation in photochemical efficiency be used as an ecoindicator of seagrass health?" Ecological Indicators 18: 243-251.	Used diurnal (rather than once per day) PAM measurement of effective quantum yield (deltaF/Fm' as an indicator of seagrass response to interannual variability in light availability. Regressions of effective quantum yield versus PAR showed strong linear relationships in each year. Comparison of slopes between years showed strong statistically significant differences - related to light availability/water clarity).	**Low** – demonstrates light related dynamics in *Thallasia* photophysiology	General relevance only: species studied not found in Western Port.	

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Bioindicators	Gacia, E., N. Marba, et al. (2012). "Thresholds of irradiance for seagrass *Posidonia oceanica* meadow metabolism." Marine Ecology Progress Series 466: 69-79.	Describe 3 week shading experiment to determine compensation irradiance for *P. oceanica* and recovery. Intensive shading depleted rhizome carbohydrate stores and led to elevated sediment sulfide levels. Ic threshold varied 2-fold. Sucrose content showed typical seasonal patterns in all treatments except 12% incident (stable sucrose) and 2% incident (decrease in sucrose) over the study. Recovery in these treatments did not occur at 8 days post-shading.	**Moderate** – demonstrates light related dynamics in *Posidonia* bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	McKenzie, L. J., C. Collier, et al. (2012). Monitoring inshore seagrasses of the GBR and responses to water quality. 12th International Coral Reef Symposium. Cairns.	Increasing tissue leaf nutrient concentrations since 2006. Decline in C:N ratios (<20) since 2005, could be result of N loading and/or reduced light availability.	**Moderate** – demonstrates light and nutrient related dynamics in seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Sherman, C. D. H., A. M. Stanley, et al. (2012). "Development of twenty-three novel microsatellite markers for the seagrass, *Zostera muelleri* from Australia." Conservation Genetics Resources 4(3): 689-693.	Describes development of 'Microsatellite primers' for *Z. muelleri* which can be used to examine population connectivity, genetic diversity and the relative importance of asexual versus sexual reproduction.	**Moderate** – provides means of assessing genetics of *Z. muelleri* populations	*Z. muelleri* a minor component of Western Port seagrass	
Bioindicators	Holland, D., P. Cook, et al. (2013). Preliminary assessment of water quality requirements of seagrasses in Western Port. Melbourne, Melbourne Water, Monash University, Water Studies Centre.	Study to identify factors that control the present day seagrass distribution in order to identify water quality requirements for seagrass growth in Western Port. Found that high seagrass density was found in areas with highest nutrient concentrations (eutrophication discarded as factor in seagrass loss). Stable isotope analysis suggested seagrasses in WP light limited in relatively shallow water compared to PPB. TSS strong predictor of seagrass distribution. TSS thresholds for seagrass presence in subtidal were 0.007 mg/L (dense), 0.012 mg/L (medium), 0.019 mg/L (sparse), threshold for intertidal seagrass was around 0.0.1 mg/L (but very limited subtidal sampling).	**High –** attempts to model distribution of seagrass based on light, sediments, wave energy and currents	Seagrass species to which the study relates not specified. Some relationships are relatively weak and study was not focussed on questions relevant to the Project.	How much seagrass is in Western Port? Where and how much seagrass would be lost due to port development?
Bioindicators	Marba, N., D. Krause-Jensen, et al. (2013). "Diversity of European seagrass indicators: patterns within and across regions." Hydrobiologia 704(1): 265-278.	Review indicators used to monitor seagrass in Europe. Found 49 indicators in 42 different monitoring programs, 51 metrics in use overall, including distribution, abundance, shoot characteristics, growth, molecular/chemical and associated species	**Low** – provides general review of indicators in use in Europe.	general article, does not provide recommendations useful for the project	
Bioindicators	Mazzuca, S., M. Bjork, et al. (2013). "Establishing research strategies, methodologies and technologies to link genomics and proteomics to seagrass productivity, community metabolism, and ecosystem carbon fluxes." Frontiers in Plant Proteomics In Press.	Report on methods used to study molecular, physiological and metabolic differences of *P. oceanica* over a depth profile: Genomics, Proteomics, PAM fluorometry, Oxygen evolution.	**Moderate** – shows genetic response to environment	Methods are mostly speculative	
Bioindicators	McMahon, K., C. Collier, et al. (2013). "Identifying robust bioindicators of light stress in seagrasses: A meta-analysis." Ecological Indicators 30: 7-15.	Review article examining utility of different bioindicators form monitoring seagrass responses to light stress. Consistent and robust bioindicators were described for different scales of impact: early and sublethal indicators, later and meadow-scale indicators. They were also classified according to costs and effort. Recommend 19 indicators ready for use without further development.	**High**		
Bioindicators	Silva, J., I. Barrote, et al. (2013). "Physiological Responses of *Zostera marina* and *Cymodocea nodosa* to Light-Limitation Stress." PLoS ONE 8(11): 1-9.	Examined light limitation stress response in *Z. marina* and *C. nodosa.* Both had similar amounts of carbohydrate in the leaves, which declined with shading. *C. nodosa* had more carbohydrate stores in rhizomes, which did not change with shading levels used (understorey species). Also examined pigments, photosynthesis, proteins.	**Low** – shows response of carbohydrates to light availability in a canopy forming and understory seagrass species	General relevance only: species studied not found in Western Port.	

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Bioindicators	Smith, T. M., P. H. York, et al. (2013). "Microsatellite primer development for the seagrass *Zostera nigricaulis* (*Zosteraceae*)." Conservation Genetics Resources 5: 607-610.	Describes development of 'Microsatellite primers' for *Z. nigricaulis* which can be used to examine population connectivity, genetic diversity and the relative importance of asexual versus sexual reproduction.	**High** – provides means of assessing genetics of *Z. nigricaulis* populations	Costs and relevance of methods for Project unclear	
Bioindicators	Warry, F. Y., P. Reich, et al. (2013). Using leaf chemistry to better understand the ecology of seagrass in the Gippsland Lakes. D. o. S. a. Environment. Heidelberg, Victoria, Arthur Rylah Institute for Environmental Research.	Study on *Ruppia* and *Zostera* leaf chemistry in Gippsland lakes (and other parameters). For *Zostera* found % N range (min-max) of 2.09-5.21, % P range of 0.15-0.35, % C range of 39-44, C:N of 7.5-20, N:P of 7-19.	**Low**	General relevance only – study not conducted in Western port	
Bioindicators	Zhijian, J., H. Xiaoping, et al. (2013). "Dynamics of nonstructural carbohydrates in seagrass *Thalassia hemprichi*i and its response to shading." Acta oceanologica Sinica 32(8): 61-67.	Examine dynamics of NSC in *Thalassia hemprichii* and response to shading. Found more carbohydrate stores in below ground parts, mostly soluble sugars as storage, starch minor component but measurably higher in low intertidal compared to high intertidal areas.	**Moderate** – demonstrates light related dynamics in seagrass carbohydrate stores	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?
Bioindicators	Dattolo, E., M. Ruocco, et al. (2014). "Response of the seagrass *Posidonia oceanica* to different light environments: Insights from a combined molecular and photo-physiological study." Marine Environmental Research In Press.	Investigated gene-expression response to seasonal and depth related light availability differences. Demonstrated up-regulation of a number of genes, and down regulation of others in response to 'high' light. High light plants showed narrow range of gene expression (genes for photoprotection and regeneration of membrane proteins switched on), while low light plants had more variable gene expression.	**Moderate** – shows genetic response to environment	Time scale for genetic response unclear (spatial study, not temporal)	
Bioindicators	Falkenberg, L. J. and C. A. Styan (2014). "Too much data is never enough: A review of the mismatch between scales of water quality data collection and reporting from recent marine dredging programmes." Ecological Indicators 45: 529-537.	Cautions against data kleptomania in water quality monitoring.	**Low**		
Bioindicators	Govers, L. L., W. Suykeruyk, et al. (2014). "Rhizome starch as indicator for temperate seagrass winter survival." Ecological Indicators 49: 53-60.	Study of *Zostera noltii* transplant survival. Low autumn rhizome starch concentrations usually resulted in unsuccessful transplants. Removing seagrass leaves (clipping) over winter did not affect rhizome starch concentration or seagrass biomass in June (Summer). Autumn rhizome starch concentrations were found to be a good indicator of next year's growth success. Shoot density and winter leaves were bad indicators of growth success. Suggest timing of disturbance at start of growing season (late spring) as at this time seagrasses are not completely reliant on their carbohydrate reserves.	**Low**	Provides some information on re-establishment strategies for seagrass.	What is the recovery potential for seagrass?
Bioindicators	Kilminster, K., V. Forbes, et al. (2014). "Development of 'sediment-stress' functional level indicator for the seagrass *Halophila ovalis*." Ecological Indicators 36: 280-289.	Study relating seagrass productivity with sediment sulfur dynamics. Primarily considers impacts of eutrophication on sulfur in sediments.	**Low**	Considers nutrients rather than light impacts	
Bioindicators	Macreadie, P. I., M. T. Schliep, et al. (2014). "Molecular indicators of chronic seagrass stress: A new era in the management of seagrass ecosystems?" Ecological Indicators 38: 279-281.	Review article examining molecular (genetic) techniques for examining seagrass responses to chronic stressors. Monitoring 'gene expression' or specific protein production may have application for dredging related impacts. Suggests such techniques may become feasible coming years. Unclear how much work and cost involved in developing gene expression methods for monitoring responses to acute stressors, such as dredging.	**High**	Methods discussed are unproven and likely costly at this point	
Bioindicators	Roca, G., J. Romero, et al. (2014). "Detecting the impacts of harbour construction on a seagrass habitat and its subsequent recovery." Ecological Indicators 45: 9-17.	Harbour construction caused increase in sediment organic matter, sediment (fine sand) deposition and decreased light availability over 5-15 months. Shoot density showed response, light reduction caused decline in carbohydrate content. No response seen in N or P content, morphological (shoot biomass) and community (epiphytes) indicators. Heavy metal and carbohydrate content were much better in detecting recovery over short term. "Shoot density and indicators directly related to light availability (starch, sucrose, total carbohydrates) and metal pollution responded most to disturbance".	**High –** Directly assessed the impact of a dredging project on seagrass bioindicators	General relevance only: species studied not found in Western Port.	Where and how much seagrass would be lost due to port development?

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
Bioindicators	Ruocco, M., E. Dattolo, et al. (2014). Daily variation of gene-expression along a depth-related gradient of light availability in *Posidonia oceanica*. Seagrasses in Europe: Threats, Responses and Management. Olhao, Portugal.	Reports on results of *P. oceanica* study of Mazzuca et al, 2013. Find different gene expression between shallow (5 m) and deep (20 m) plants.	**Moderate** – shows genetic response to environment	Time scale for genetic response unclear (spatial study, not temporal)	
Reproduction	Marbà, N. and Walker, D., I. (1999). "Growth, flowering, and population dynamics of temperate Western Australian seagrasses". Marine Ecology Progress Series, 184: 105-118.	Studied reproduction characteristics of 8 seagrass species in Western Australia. Growth patterns varied markedly between seagrass species but clonal growth (via rhizome elongation) was main mechanism for providing shoots for all species. Large differences in flowering capacity indicate that sexual production may be important for population maintenance for some species. *H. tasmanica* meadow was maintained mainly by fast recruitment rates of shoots via rhizome growth.	**Moderate**	General relevance only – study not conducted in Western port	What is the recovery potential for seagrass?
Reproduction	Parry, G. D., Heislers, S., Chan, K., Cleaver, J., Werner, G. F. (2005). Seasonality of flowering and fruiting of the seagrass *Zostera muelleri* and *Zostera* (formerly *Heterozostera*) *tasmanica*. Industries Research Victoria: Marine and Freshwater Systems. Report No. 5.	Sampled 7 sites in Western Port. Seasonal patterns of flowering and seed development were consistent at all sites. Number of male flowers from Z. muelleri peaked in November and developing seeds were found between November and March. Immature seeds were found from November to March, but were most abundant between early December and mid-January. Mean density of *Z. muelleri* seeds on plants was 540-840/m^2 and 280/m^2 in sediments. The fruiting and flowering season of *Z. tasmanica* occurred between September and January with peak production of male flowers occurring earlier than November. Developing seeds were abundant between November and mid January. No spadices were found during February or March. *Z. tasmanica* mean density on plants was 490/m^2 and 88-890/m^2 in sediments.	**High –** shows seasonality of *Zostera nigricaulis* and *Z. muelleri* in Western Port.	Unclear how important seeds are to seagrass growth/colonisation	What is the recovery potential for seagrass?
Reproduction	Parry, G. D. (2007). Feasibility of restoration of seagrass beds using seeds. Primary Industries Research Victoria: Marine and Freshwater Systems. Report No. 21.	Review of restoration projects using rhizome and seeds in the USA. Highlighted the complexities involved in establishment of new seagrass beds (such as seeding techniques, dormancy and germination triggers, planting density). Focus on Western Port was on distribution dynamics.	**Moderate** – demonstrates difficulties involved with seagrass restoration efforts		What is the recovery potential for seagrass?
Reproduction	Cabacao, S. and Santos, R. (2012). "Seagrass reproductive effort as an ecological indicator of disturbance". Ecological Indicators, 23: 116-122.	Meta-analysis of reproductive effort of several seagrass species worldwide in response to disturbances. Seagrasses show a general trend of increase reproductive effort with disturbance. This response was significantly correlated with rhizome diameter, suggesting that species with higher storage capacity have greater capacity of investing in flowering in unfavourable conditions.	**Moderate** – demonstrates effects of disturbance on seagrass reproductive effort	General relevance only: species studied not found in Western Port.	What is the recovery potential for seagrass?
Reproduction	Thompson, A. C. G., York, P. H., Smith, T., Sherman, C. D. H., Booth, D. J., Keough, M. J., Ross, D. J., Macreadie, P. I. (2014). "Seagrass Viviparous Propagules as a Potential Long-Distance Dispersal Mechanism. Estuaries and Coasts". (In press)	Field and lab-based study on vivaparous shoots of *Z. nigricaulis* meadows in Port Philip Bay. Vivaparous shoot density was higher at sites with high wind and water currents than sheltered sites. There is potential for vivaparous shoots to act as long-distance dispersal vector as they are able to remain buoyant and healthy for >85 days. However, successful establishment and/or survivorship is rare and will depend on many factors (e.g. location of establishment, seasonal and sediment conditions).	**High** – demonstrates modes of reproduction and establishment of new *Zostera* beds in Victoria		What is the recovery potential for seagrass?
Reproduction	Macreadie, P. I., York, P. H., Sherman, C. D. H. (2014). "Resilience of *Zostera muelleri* seagrass to small-scale disturbances: the relative importance of asexual versus sexual recovery". Ecology and Evolution, 4: 450-461.	Studied recovery of *Z. muelleri* in NSW. At small scales (cms), recovery was driven mainly via asexual rhizome growth. Recovery took 35 weeks via shoot regrowth and 65 weeks via asexual rhizome regrowth. Seed propagules did not contribute to recovery. Genotypic diversity did not appear to influence recovery.	**High** – demonstrates modes of reproduction and establishment of new *Zostera* beds in SE Australia		What is the recovery potential for seagrass?
Dredging monitoring	Westera, M. and R. Babcock (2007). Post-dredging recovery of seagrasses in the Geraldton region, year 3 report. Floreat Park, CSIRO.	Post-dredging monitoring of seagrass impact and reference sites in the Geraldton region. Impacts were greatest closest to source of turbid plumes. Recover was seen in most areas, except in areas nearest the channel and marina where dredging occurred. Impacts were consistent with extent of dredge plumes. Recommend future programs start by mapping benthic primary producer habitats to identify sites for more intensive monitoring, and use of	**High** – direct assessment of actual dredging project impacts on seagrass, provides		What is the recovery potential for seagrass? Where and how much seagrass

Category	Bibliographic details	Summary	Relevance	Limitations	Related key question
		appropriate bioindicators.	recommendations for future projects		would be lost due to port development?
Dredging monitoring	Mulligan (2009). 'Applying the learning': The Geraldton Port dredging project 2002-03. Paper to the Freight and Logistics Council of WA and Ports WA.	Examines 'lessons learnt' from the Geraldton Port dredging project 2002-03. Found that baseline monitoring (seagrass and water quality) was insufficient and was inadequate to inform hydrodynamic modelling. Impact predictions from research on 'unknowns' could not be made accurately prior to the project - studies after the fact identified early indicators of stress.	**High** – direct assessment of actual dredging project impacts on seagrass, provides recommendations for future projects		Where and how much seagrass would be lost due to port development?
Dredging monitoring	Chartrand, K. M., P. J. Ralph, et al. (2012). Development of a Light-Based Seagrass Management Approach for the Gladstone Western Basin Dredging Program. DAFF Publication. Cairns, Fisheries Queensland.	Used shading study, PAR monitoring and laboratory studies to derived light-based triggers for management of dredge plume impacts on seagrasses. Monitored PAR, temperature, seagrass cover and biomass, shoot densities, below ground carbohydrates. Found Z. capricorni required between 4.5 and 12 mol quanta m-2 d-1 for minimum period of two weeks in the growing season to maintain or increase cover/biomass. Light reductions in the senescent season had no effect on biomass or cover. Intertidal seagrasses were stressed when emmersed and net photosynthesis declined. Carbohydrate stores declined through the senescent season, in the growing season they remained stable (low-med shading) or decreased (high shading) and increased in all treatments when shades were removed. Interestingly control plots did not increase stores for first 4 weeks. Found lower light requirement in laboratory studies (3.5 mol quanta m-2 d-1)	**High** – derives trigger values for regulating water quality around seagrass beds	Only considered intertidal seagrasses. Unclear exactly how trigger values were derived	Where and how much seagrass would be lost due to port development?
Dredging monitoring	CQG Consulting (2013). Port of Gladstone Western Basin Dredging and Disposal Project, Queensland: Annual Environmental Performance Report. Report to Gladstone Ports Corporation. Gladstone, CQG Consulting.	Annual review of monitoring. Found that seagrass and water quality not adversely affected by dredging overall.	**Low**	Routine monitoring report only	
Dredging monitoring	McCormack, C., M. A. Rasheed, et al. (2013). Long Term Seagrass Monitoring in the Port Curtis Western Basin: Quarterly Seagrass Assessments & Permanent Transect Monitoring Progress Report November 2009 to November 2012. Townsville, TropWater/JCU.	Used 'Seagrass Watch' methods to monitor seagrasses for Gladstone dredging project 2009-2012. Monitored multiple parameters (cover, biomass, C:N:P, flowering, seeds, shoot density, leaf and rhizome growth, productivity) - the most informative of which appear to have been cover and biomass (showing clear seasonal and longer-term trends). Growth and productivity estimates showed seasonal patterns but not longer term patterns. Used literature values to estimate light requirements for seagrasses in mol m-2 d-1 (not minimum light requirements). Found relationship between seagrass cover and biomass with light availability 2 weeks and 3 months before sampling.	**High** – derives trigger values for regulating water quality around seagrass beds	Only considered intertidal seagrasses. Unclear exactly how trigger values were derived	Where and how much seagrass would be lost due to port development?
Dredging monitoring	Environment, V. (2013). Western Basin Duplication and Dredging: Water Quality Monitoring (Final Project Report). Report to Gladstone Ports. Gladstone, Vision Environment.	Reports on results of Gladstone water quality monitoring 2009-2013: Turbidity, nutrients, Chl-a, Metals, PAR. Mean monthly PAR consistently above trigger value (6 mol photons m-2 d-1) at all sites - occasional instances where close to or less than 6 at one site (TC1). PAR sensors were telemetered, and moored on seabed 1.5-2 m below LAT.	**Low**	Routine monitoring report only	
Dredging monitoring	York, P. H. and T. Smith (2013). Research, monitoring and management of seagrass ecosystems adjacent to port developments in central Queensland: Literature Review and Gap analysis. Waurn Ponds, Deakin University.	Reviews research on managing dredging impacts on seagrass. Find that none of the physiological parameters measured PAM fluorometry, CO2 flux or pigments showed sub-lethal effects any faster than morphological measures (leaf size, density). Work on gene expression still underway by Rasheed. Stress that new genetic techniques may be used to detect chronic stress impacts on seagrass genetic diversity.	**High –** Assesses effectiveness of seagrass monitoring and management strategies during Gladstone project	Still unclear how trigger values for Gladstone project derived.	Where and how much seagrass would be lost due to port development?

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APPENDIX - CRAWFISH ROCK SPECIAL MANAGEMENT AREA

Crawfish Rock is an isolated rocky outcrop in the north of North Arm. It is the major natural hard seabed habitat in the north of Western Port, is regarded by many marine scientists as a significant location and is a *Special Management Area*.

The flora and fauna of Crawfish Rock has shown detectable change that is likely due to changes in water quality over the past 30 years (Shepherd et al 2009).

Purpose

There is potential for the Project to further affect the flora and fauna characteristics at Crawfish Rock. Hence low effort monitoring of the existing conditions at Crawfish Rock is recommended to document medium term variation and inform prediction of impacts of the development on the ecological community.

Coordination

This task would require coordination with:

- Mapping
- Hydrodynamic studies
- Water quality studies
- The design process

Spatial coverage

Crawfish Rock marine community would be monitored along two vertical transects at positions that are accessible and sheltered from tidal currents.

Timing

Crawfish Rock flora and fauna should initially be monitored twice per year for the first two years.

Methods

The diversity and abundance of the marine community would be monitored at depth/sites along two vertical transects using quantitative photographic techniques.

Outputs

The results will inform development of predictive impact assessment models. The results of the first year or two will provide the basis of detailed description of existing conditions with respect to seagrass biology relevant to impact assessment for the Project.