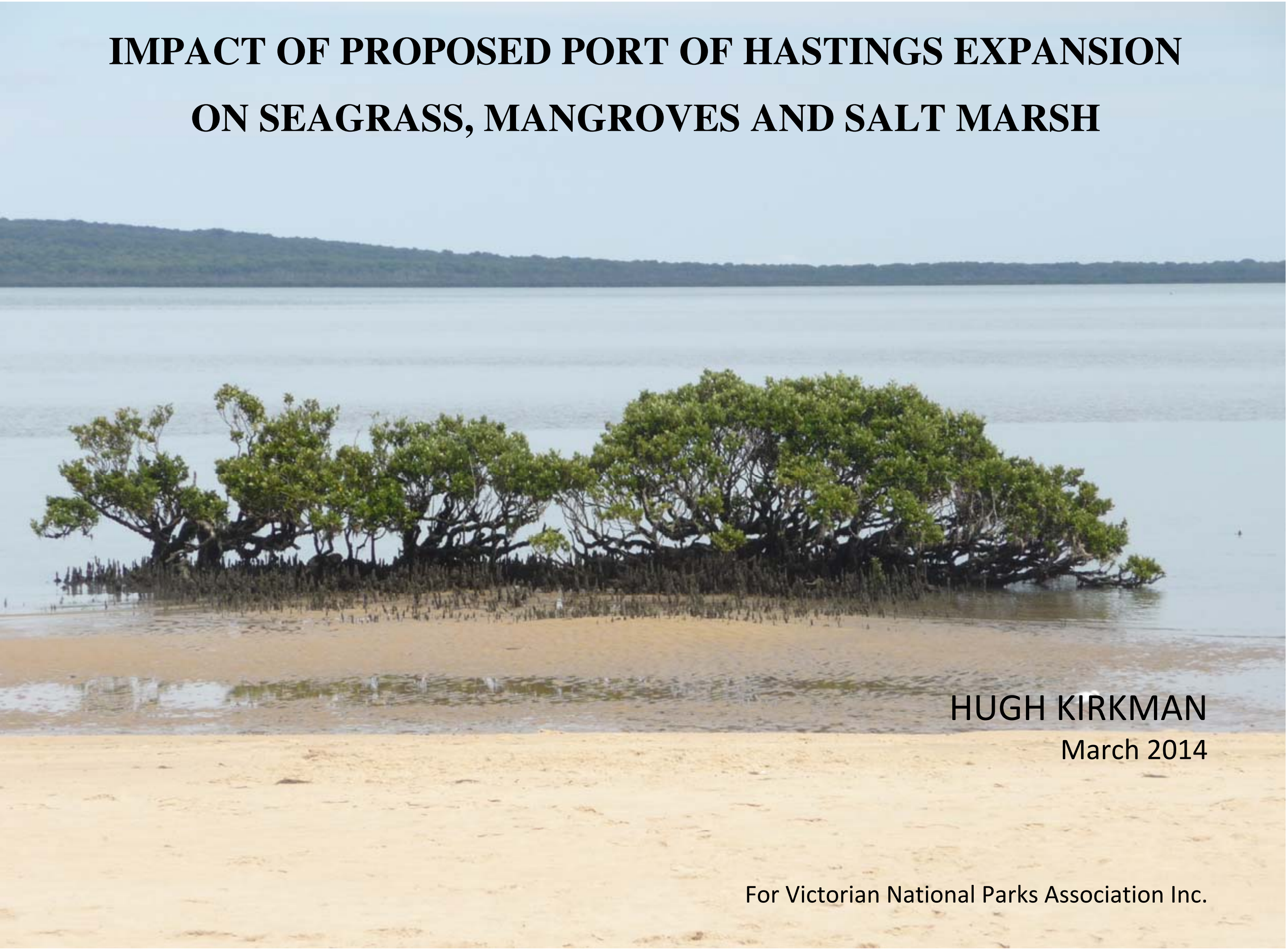
IMPACT OF PROPOSED PORT OF HASTINGS EXPANSION ON SEAGRASS, MANGROVES AND SALT MARSH



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March 2014

For Victorian National Parks Association Inc.

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Contents

Executive Summary

The Victorian Government is planning to extend the Port of Hastings to provide for container ships as the population of Melbourne increases to about 6.5 million in 2050. It is located within Western Port, a designated Ramsar site. Western Port is recognised world-wide for its seagrass, mangrove and salt marsh communities. These form ideal habitats for a wide range of animals, birds, insects, fish and marine invertebrates. The waters cover 680 km^2, including 270 km^2 of exposed mud flats at low tide. Over 3,500 ha of coastal land are zoned for port related uses. The Victorian National Parks Association Inc. has commissioned this report to briefly describe the impacts of the proposed expansion of the Port of Hastings on seagrass, mangroves and salt marsh. The report considers the following: a description of the seagrass/mangroves/salt marsh species found in Western Port, and why these species are environmentally significant; the distribution of seagrass mangrove and salt marsh in Western Port; the main threats facing these habitats and the likely impact on them of three different oil spill scenarios.

The distribution of *Zostera muelleri* in the intertidal and *Heterozostera nigricaulis* in the subtidal is described. *Halophila australis* is not extensive while *Amphibolis antarctica* grows at the entrances to Western Port. *H. nigricaulis* and *Z. muelleri* beds have declined in area since they were first mapped in 1974. The mangrove, *Avicennia marina* grows along much of the shoreline particularly in the north of Western Port. Nine vegetation complexes of salt marsh were identified on the basis of floristic and structural criteria.

The plant habitats of Western Port are under continual threat. Anthropogenic impacts from runoff, dredging, nutrient addition, and changed hydrology are reinforced by climate change and natural disturbance to put Western Port in a vulnerable position. For seagrass the main threat is turbidity from eroding edges, runoff and disturbance of areas already denuded of seagrass. For mangrove the main threat is clearing them and possible oil spills. Salt marsh is vulnerable to clearing and a lack of respect for its value.

The development and use of the port at Hastings will bring further potential disturbance to the natural resources of Western Port. A comprehensive risk assessment of oil spills from shipping was used to identify where the three habitats would be most vulnerable to oil spills and the likelihood of particular shores being impacted. The footprint of the new port and facilities was mainly on seagrass beds. Vessel generated waves could disturb the various habitats by increasing turbidity or by erosion.

A series of maps of the salt marsh and mangrove of Western Port and extracts on the risk assessment of three oil spill scenarios are attached as Appendix I and Appendix II, respectively.

Key Concepts:

1. Western Port has great conservation value.
2. Western Port is a complex system with tidal currents, vigorous weather conditions, input from urban and rural areas all impacting on environmental habitats.
3. Diesel and Heavy Crude Oil were used in three scenarios of a possible oil spill in Western Port.
4. An oil spill in Western Port would damage large areas of seagrass, mangrove and salt marsh depending on tidal and weather conditions.
5. Investigation on the physics of disturbance by vessels and knowledge of the effects on different ecosystems should be carried out.
6. Mangrove, salt marsh and seagrass will be affected by development of the Port of Hastings.
7. After development there will be more large ships entering Western Port and their wakes can cause some damage to seagrass, mangrove and saltmarsh.
8. These plants are difficult or even impossible to restore after any disturbance.
9. Strategic monitoring before and after the development is essential.
10. An economic valuation of environmental goods and services is recommended.

Background

The Victorian Government is planning to extend the Port of Hastings to provide for container ships as the population of Melbourne increases to about 6.5 million in 2050 http://www.dpcd.vic.gov.au/home/publications-and-research/urban-and-regional-research/census-2011/victoria. The Port of Hastings is located within Western Port, a designated Ramsar site (Fig.1). It is recognised world-wide for its seagrass, mangrove and salt marsh communities. These form ideal habitats for a wide range of animals, birds, insects, fish and marine invertebrates. The waters cover 680 km^2, including 270 km^2 of exposed mud flats at low tide. The whole of Western Port is protected under the Convention on Wetlands of International Importance, called the Ramsar Convention. This is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resource. The boundaries of the Ramsar site are shown in Fig 1.

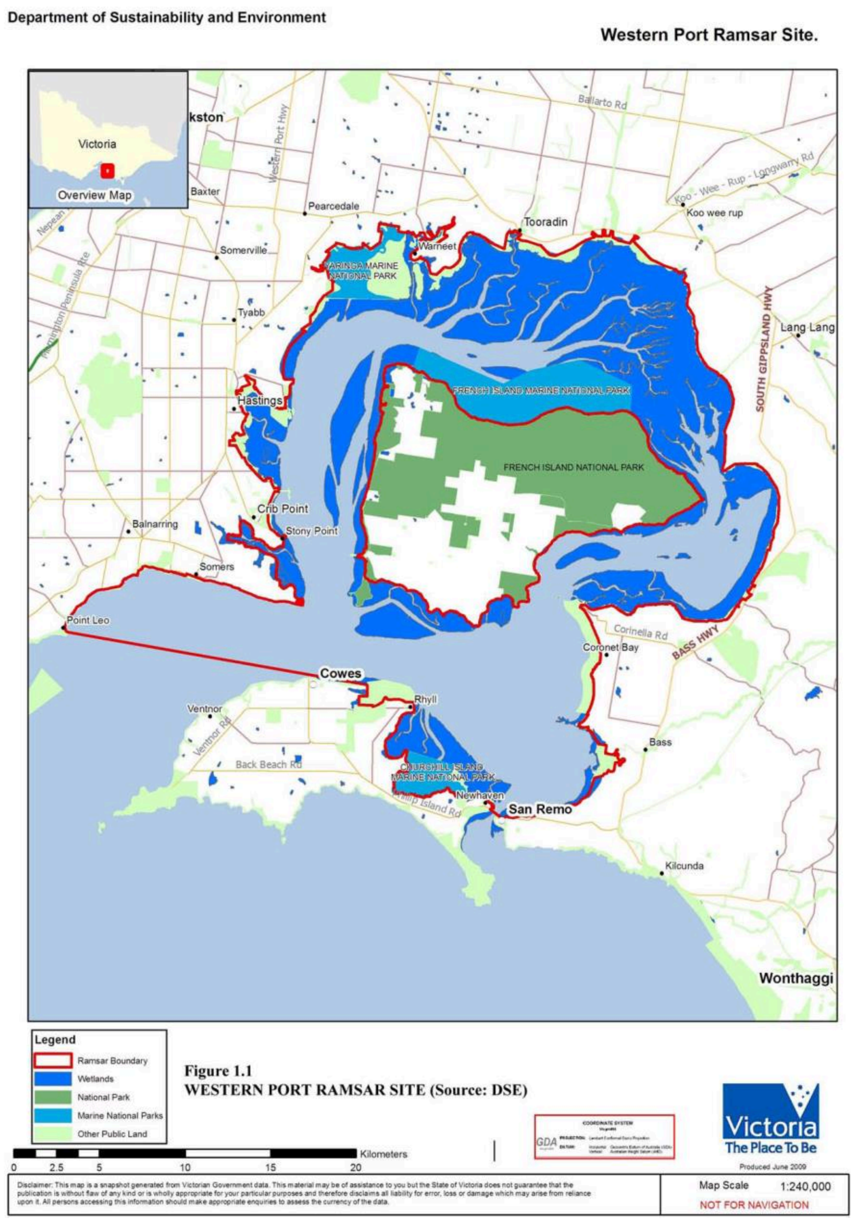

Figure 1. Western Port Ramsar site.

The Port of Hastings serves major international and domestic shipping movements that include import and export of oil, LPG, ULP and steel, general cargo, project cargo, ship to ship transfer, pipe laying operations and the lay up/repair of oil rigs/floating platforms. The naturally deep shipping channel is 16 nautical miles long with 13.6 km^2 additional anchorage up to 21 metres deep north of Phillip Island and has been dredged for maintenance and to accommodate existing traffic. Over 3,500 ha of coastal land are zoned for port related uses. Some of this land is already used by BlueScope Steel and the Esso-BHP Billiton facilities. The port comprises of jetties and land within Western Port and these are situated along a shoreline of approximately 8 km. These facilities include: Stony Point jetty and depot, Crib Point liquid berths 1 and 2, Long Island Point liquid berth and BlueScope Steel jetty. The facilities at Stony Point are also used by passenger ferries (to Cowes and a public transport passenger ferry to French Island), the Royal Australian Navy (training vessel), fishing industry, oil exploration vessels and small commercial vessels, Harbour tugs and the Harbour service vessel.

The Victorian National Parks Association Inc. has commissioned this report to briefly describe the impacts of the proposed expansion of the Port of Hastings on seagrass, mangroves and salt marsh. The report considers the following questions:

1. What are the seagrass/mangroves/salt marsh species found in Western Port, and why are these species environmentally significant?

2. What is the current extent of these species in Western Port?

3. What are the major threats facing these species?

4. What would be the likely impact on Western Port's seagrass/mangroves/salt marsh caused by:

a. An oil spill along the lines of each of three scenarios outlined below?

i. A 200 Metric Tonne (MT) spill of Heavy Fuel Oil (HFO) at Long Island Point Jetty, involving an initial release of 100 MT over the first 12 hours with the remaining volume leaking over the next 60 hours (total spill duration of 72 hours).

ii. A 200 MT spill of HFO at McHaffie's Reef, also involving an initial release of 100 MT over the first 12 hours with the remaining volume leaking over the next 60 hours (total spill duration of 72 hours).

iii. An 80 m^3 (66 MT) spill of diesel occurring over less than 20 minutes at Long Island Point Jetty.

b. Land reclamation and dredging works as described above in their immediate impacts and via the plume created by dredging?

c. Wash from the increase in vessel use of Western Port?

1. Flora of Western Port

Seagrasses

There are four species of seagrass growing in Western Port. At the western mouth, in wave driven and vigorous water flow, *Amphibolis antarctica* forms beds in subtidal water on sand or near rocks. It propagates by releasing small seedlings with an anchoring device that can attach to rocks, seaweed or its own uncovered rhizomes. *Heterozostera nigricaulis* is a subtidal seagrass that grows on muddy sand, sand or mud. It cannot tolerate exposure to heat or sunlight. Growing next to *H. nigricaulis* is *Zostera muelleri* but in the intertidal areas of Western Port. *Z. muelleri* is the most visible seagrass in Western Port and probably occupies the largest area. Its leaves are very similar to those of *H. nigricaulis* but the plant lacks the fibrous black stems of *H. nigricaulis*. The other seagrass species in Western Port although of minor importance is *Halophila australis*. This plant grows amongst the others in small communities of less than one metre square.

Swans feed on *Z. muelleri* rhizomes and many invertebrates live on all the seagrass species' leaves and in the substrate in which the plants live (Edgar et al., 1994). They found 33 species in intertidal seagrass sediments in a 150 mm diameter corer and 15 species on unvegetated intertidal sediments. Above ground fauna include shrimps, juvenile fish and prawns of commercial use and snails, bivalves, starfish and ascidians. Living on the leaves are snails, hydroids, anemones and bivalves. Some of these are the grazers of algal epiphytes but few animals eat the seagrass leaves directly.

Apart from their nursery role to juvenile commercially and recreationally taken fish and prawns (Jenkins et al., 1993), seagrass stabilises the sediment, is a collection site for organic detritus eaten by detritivores and is a nutrient sink for inorganic nitrogen and phosphorus. The main threat to seagrass in Western Port is reduction of light to plants by increased sediment loads in the water, phytoplankton blooms and excessive growth of epiphytes.

Mangroves

In Victoria, mangroves grow at their southernmost global limit and only one species exists, the grey or white mangrove *Avicennia marina*. The var. *australasica,* which is the only variety found in Western Port Bay, is described as a tree or shrub to 10 m high (Duke, 1991) but in Western Port it commonly grows only to around 1.5 to 4 m tall (Harty, 2010). This 'dwarfing' of the species is most likely due to its proximity to its southernmost geographical limit and is probably related to lower temperatures and the increasing occurrence of frosts (Farrell & Ashton 1974).

Mangroves are found only in a few locations in Victoria, generally where they are protected from the high energy waves of Bass Strait, including Barwon Heads, Port Phillip Bay and Wilson's Promontory, with the largest population growing along the shores of Western Port (Boon et al., 2010). The reproductive periodicity of mangroves in Western Port is every 2–3 years rather than one year in more northerly areas. These mangrove populations are considered to be ecologically stressed and extremely sensitive to disturbance and other impacts (EPA, 1996).

Avicennia marina fringes a large proportion of Western Port Bay. The species has a wide tolerance to salinity, intertidal position and temperature and is able to occupy rocky and sandy sheltered embayments and offshore lagoons (Duke 1991). Common to all *Avicennia* species (and many other mangrove species) is their viviparous fruit which germinates while still attached to the parent plant. Another distinguishing feature of these plants is their pneumatophores which are specialised root structures allowing gas exchange functions for root respiration in waterlogged soils (Hutchings & Saenger, 1987). Mangroves respond to and assist with sedimentation processes. The pneumatophores, the mangrove's root system, trap and retain sediment and, while facilitating sediment deposition, protect shorelines from erosion by wave action. They do this in four ways;

- fine mats of surface roots bind sediment;
- pneumatophores decrease current velocities and encourage deposition of fine particles;

- the plants add organic matter to sediments via primary production and thus contribute to surface elevation; and
- the dense plant roots help reduce burrowing invertebrates from reworking sediments.

There has been little research on the natural recruitment characteristics of mangroves in Western Port Bay with the most comprehensive study undertaken as part of the Western Port Bay Environmental Study in 1974 (Shapiro, 1975). This study examined the factors contributing to the growth and establishment of *A. marina* in Western Port Bay (Farrell & Ashton, 1974). A later comprehensive study by Boon et al. (2011) provided an excellent review and description of mangroves and salt marsh in Western Port (http://www.ozcoasts.gov.au/geom_geol/vic/index.jsp)

Salt marsh

"Salt marshes occur around much of the coast of Western Port, generally between the mangrove fringe on the seaward side and more terrestrial vegetation, such as Swamp Paperbarks and Manna Gum woodlands, on the landward side. There are about 1 000 ha of salt marsh in Western Port, which is about the same area as there is of mangroves. A number of the larger salt marshes in Western Port occur in protected areas, such as the Yaringa (980 ha), French Island (2 800 ha) and Churchill Island (670 ha) Marine National Parks. Salt marshes in Western Port are likely to be very vulnerable to sea-level rise and other consequences of climate change, especially rising air and water temperatures. Salt marshes have been progressively lost already, due mostly to development for agriculture and industry, around the western and northern shores of Western Port" (taken from Boon, 2011).

Boon (2011) goes on to list the salt marsh habitats as: behind the most seaward zone of *Avicennia marina.* Nine vegetation complexes were identified on the basis of floristic and structural criteria:

• introduced *Spartina*

• extensive *Salicornia* (now *Sarcocornia*) –dominated zone

• extensive Arthrocnemum (now *Tecticornia*) –dominated zone

• *Suaeda* complex

• *Puccinellia* complex

• *Juncus* complex

• *Stipa* (now *Austrostipa*) complex

• *Schoenus-Cotula* complex

• *Melaleuca* zone

Within these complexes *Lawrencia spitica* and *Limonium australe* are listed as rare in Victoria (DSE, 2003). Salt marsh has value as a nursery area for fish but is not as important as previously thought for detrital food webs and productivity (see Boon, 2011 for a comprehensive review of ecological and economic value of salt marsh.)

2. Extent of flora of Western Port

Seagrass

Seagrass cover in Western Port has declined since it was first measured by Shapiro (1975). It had 250 km^2 of seagrass then but this area fell to 72 km^2 in 1984 (Shepherd et al., 1989). The area fluctuated to 59 km^2 in 1983–84 and then to 93 km^2 in 1994. This area increased in 1999–2000 to 130 km^2 (Blake and Ball, 2001) and Melbourne water measured 150 km^2 in 2011.

Amphibolis antarctica grows near the western entrance to Western Port. It prefers strong water movement and sandy substrate. Its range is from Sealers Cove to Richardson Point on Phillip Island and a small amount at Homestead Point, Munuka Point, Woody Point and opposite on the mainland coast. From the western entrance it extends to Sandy Point and to French Island at Tortoise Head.

Heterozostera tasmanica and *Zostera muelleri* were not separated in the maps of Blake and Ball (2001). Usually the *Heterozostera* is subtidal and the *Zostera* intertidal but the two may grow together. The *Heterozostera/Zostera* complex grows from Sandy Point to Chinaman Island on the western mudflats and along the western and northern shores of French Island. Watson Inlet and Yaringa have extensive beds but then the seagrass follows inlets and reduces in extent to a line from Moodys Inlet to Palmer Point on French Island. There are extensive beds from Tenby Point to Settlement Point and seagrass beds follow the coast to San Remo where there is a large expanse of *Heterozostera/Zostera*, further beds from Woody Point to Fisherman Point at Rhyll and Rhyll Inlet complete the seagrass beds of Western Port (see the maps of Blake and Ball, 2001).

Mangroves

There are 1,823 hectares (18 km^2) of mangroves in Western Port. At Grantville mangroves occur as a scattering of trees with more extensive coverage at Pioneer Bay to the north. At these locations a sandy beach remains intact. Shorelines around Grantville, with a healthy mangrove fringe, have less evidence of erosion. A comprehensive study by Boon et al. (2011) provided maps of mangroves in Western Port (http://www.ozcoasts.gov.au/geom_geol/vic/index.jsp)

With respect to climate change, mangroves are vulnerable to sea level rise and will migrate landwards as an adaptive response. Human development can prevent mangroves adapting to increase sea levels by preventing them from migrating landwards, so that they will suffer from "coastal squeeze". Mangroves have the ability to adapt to rising sea levels such as those associated with climate change.

Salt marsh

With a combined area of just over 1000 ha (10 km^2) there is nearly as much salt marsh around Western Port as there is mangroves. An extent of salt marsh has been preserved in Western Port (ca 85%), notwithstanding some substantial losses around the Hastings foreshore and marina, and industrial development at nearby Long Point and at The Inlets. The Inlets are part of Koo Wee Rup swamp, and their surrounding Swamp Paperbark-dominated Swamp Scrub and Estuarine Scrub has been almost entirely cleared for agriculture (Roberts, 1985). A comprehensive study by Boon et al. (2011) provided the most up-to-date maps of salt marsh in Western Port (http://www.ozcoasts.gov.au/geom_geol/vic/index.jsp) See Appendix I.

3. Threats to flora of Western Port

Seagrass

The human impacts on seagrasses are well discussed in Ralph et al. (2007). Runoff from land clearing in preparation for housing construction may be the largest impact on offshore seagrass meadows. The problem is that the land is cleared for building and sometimes heavy rains wash off the topsoil because it is no longer held by vegetation. New roads and cuttings for roads are another source of sediment run-off.

Development of the coast by building causeways and shoreline armouring may divert water and generally destabilize beaches and shorelines. Rivers are often diverted or changed to enable the extraction of freshwater and this may have an effect on seagrass beds by favouring one species that prefers seawater (*H. tasmanica*) over *Z. muelleri* that has adapted to changed salinity conditions.

Physical damage to seagrass beds can occur when marinas, jetties and boat ramps are built on or adjacent to seagrass beds or these structures may change the hydrology (water circulation patterns) of the area, reducing on-shore drift and water flow. Mining or oil and gas extraction from under seagrass beds are potentially damaging to seagrass beds when considering freshwater flows, oil spills and mining accidents that cause collapse of mined areas.

Human occupation of the coastal zone is accompanied by the dangers of pollution. Industrial chemicals from factories, including heavy metals, petrochemicals and toxic compounds are a danger to seagrass ecosystems. Heavy metals, petrochemicals and nutrients enter the sea from runoff and stormwater drains. Agricultural runoff containing herbicides and insecticides can damage seagrass beds and their associated fauna.

By far the most damaging pollutant in seagrass beds is nutrients. These nutrients promote epiphyte growth that smothers seagrass. Eutrophication occurs when high nutrient loads, particularly inorganic nitrogen, are taken up by opportunistic macroalgae growing on seagrass leaves. Growth of epiphytic algae blocks light to the seagrass blades, preventing photosynthesis, and eventually smothers the seagrass. The epiphytes and dead seagrass leaves fall to the substrate beneath, are broken down by bacteria that use up oxygen, and this anoxic sediment gives off hydrogen sulphide that kills the benthic flora and the whole seagrass ecosystem may be lost.

Another way that seagrass plants are prevented from photosynthesising is by increasing the turbidity of the surrounding water. As mentioned above, this occurs when runoff containing sediment flows across the seagrass bed. Dredging near seagrass beds increases turbidity and there may be a smothering effect as well if silt screens are not used. If the sediment load is very high, the effect of seagrass leaves slowing the surrounding water will cause the sediment to drop out of the water column and smother plants.

The effects of overfishing on seagrass beds can be quite devastating. A top-down trophic cascade can occur when the top level predators are removed. The decline in large predators brought about by fishing causes an increase in small fish predators which deplete populations of mollusc and crustacean grazers that keep down epiphyte loads. Increasing epiphytes leads to a gradual loss of seagrass as explained above (Heck and Valentine, 2007). The threat of a trophic cascade caused by recreational and commercial fishing should always be kept in mind. N.B. only long-lining is permitted for commercial fishing in Western Port.

Disease in seagrass in Australia has not been identified as a major threat. However, loss of seagrass due to exposure to strong sunlight or heat has been shown to damage seagrass beds in South Australia (Seddon et al., 2000). Diligent monitoring of seagrass beds will alert managers of disease and poor condition of seagrass meadows.

Invasive species are a problem in seagrass meadows in other parts of the world and of particular note in seagrass beds is the damage done by *Caulerpa taxifolia* in *Posidonia oceanica* beds in the Mediterranean (Meinesz, et al., 1993). Some consideration should be given to other invasive species that may arrive, e.g. *Undaria* and *Asterias,* when considering the vulnerability of seagrass to marine pests (Glasby and Creese, 2007).

The full extent of climate change has not yet been demonstrated or predicted in Western Port nor have the forecast extremes eventuated yet. However, temperature rises greatly exceeding average rates of change over the last 20,000 years are predicted. Climate change affects ocean temperature, salinity, acidification and aragonite saturation, sea level, circulation, productivity and exposure to damaging UV light (Fine and Franklin, 2007).

Storms stir up sediment in shallow seas and hence reduce light to seagrass. The light required by seagrass to live in winter is often very low and plants are at a compensation level. Increased storm frequency means that there will be increased turbidity and this may reduce light to lower than compensation levels for marginal meadows at the deeper edge. Increased frequency of storms may also disturb seed beds that normally lie in the sediment, e.g. *Halophila australis* and *Halodule uninervis* were lost from Hervey Bay, Queensland when two very large storms followed each other, the first destroying the seagrass and the second destroying newly germinated seedlings (Preen et al., 1995). *Halophila australis* grows in Western Port in small areas.

Storm intensity may also increase the disturbance to seagrass meadows. It has been estimated that a one in a hundred year storm can remove seagrass from its substrate. More intense storms will also increase erosion of edges.

Warmer temperatures and ice cap melting are expected to raise sea levels. For seagrasses this will bring their habitats shoreward. Those seagrasses growing at the deeper edge of their habitat may be lost while the shallower margins will gain coverage. The problem is if development has used those shallower edges and the seagrass can move no further up the shore, large areas will be lost. The building of sea walls, coastal roads, housing to the edge of the sea and other development must be carefully managed with sea level rise in mind.

Little is known about the effect of seawater temperature rising, but shifts in distribution are expected. Seagrass plants cannot move as can some invertebrates and fish as the water temperature increases. The success of a slow distributional shift will depend upon the suitability of a new habitat being available.

As carbon dioxide rises in the atmosphere more is dissolved in seawater leading to ocean acidification. In seagrass ecosystems, calcareous epiphytes will be the main victims. The response of calcareous epibionts to a fall in pH to 7.7 in aquaria was a loss of all calcareous algae and the only calcifers were bryozoans at pH 7.7 (Martin et al., 2008). This result may have dramatic effects on biogeochemical cycling of carbon and carbonate in coastal ecosystems dominated by seagrass beds.

Mangrove

Early settlers and developers generally considered mangroves as wastelands—places to be filled in and put to “better” use. Thousands of hectares were buried under rubbish or converted to pasture, roads, industrial sites, playing fields and other developments. The most widespread destruction of mangroves and salt marshes has resulted from land filling to create sites for industrial areas, harbour facilities, waterfront housing, dumps and sports fields. This landfill can modify patterns of tidal inundation. Once the landfill area is in use, other environmental problems usually follow. Stormwater runoff, acid sulphate soils, accidental spills of pollutants and discharge of treated or untreated effluent cause environmental problems in remaining mangrove forests.

Elevated nutrient levels from sewage and stormwater discharges could also affect mangrove ecosystems adjacent to outfalls. In shallow sheltered areas, large drifts of *Ulva* (together with dead seagrass), prevent or retard the establishment and growth of young mangrove seedlings, and also choke established trees by smothering and eventually killing the aerial roots or pneumatophores (Edyvane, 1991; Connolly, 1986).

Acid sulphate soil is the common name given to naturally occurring soil and sediment containing iron sulphides, principally the mineral iron pyrite, or containing acidic products of the oxidation of sulphides. Mangrove soils contain iron sulphides and when these are exposed to air, oxidation takes place and sulphuric acid is ultimately produced when the soil’s capacity to neutralise the acidity is exceeded. As long as the sulphide soils remain under the water table, oxidation cannot occur and the soils are quite harmless and can remain so indefinitely.

Straightening meandering tidal channels causes changed tidal levels and reduced nutrient uptake for the remaining mangroves. Mangrove ecosystems remove nutrients from runoff and river deltas by having meandering streams that slowly release water to the sea. If these meanders are straightened out, for example for boating channels or drainage, the water passes quickly to the sea with little chance for nutrients and organic matter to be retained and used in the mangroves. Bund walls and estuarine dredging may be for flood mitigation but environmental impacts include destruction of habitat in the dredged area and alteration of channels causing erosion. Hydrodynamic changes to the mangrove habitat have multi-faceted impacts. *Avicennia marina* can survive in conditions that may be two or three times the salinity of seawater. However, it shows signs of stress and much reduced growth rate at these high salinities. Any changes in the freshwater drainage patterns through a mangrove swamp are likely to have a serious effect on its condition. Reduction in oxygen in the immediate environment of roots when land immediately behind a mangrove stand is drained or roadways cut through mangrove swamps without the provision of drainage pathways, will damage mangroves. These stresses on mangroves in Western Port are especially important as the plants are already stressed by growing at their southernmost limit.

Carbon dioxide assimilation interacts in complex ways with aspects of mangrove physiology. At higher levels of atmospheric carbon dioxide levels stomatal conductance is reduced and water loss falls while CO_2 uptake levels are maintained. The result is an increase in water-use efficiency. The trade off between water use and CO_2 acquisition means the mangrove response to high atmospheric CO_2 may combine increased water use efficiency with varying effects on transpiration rate and growth depending on other circumstances. Given the range of temperatures that mangroves experience in their daily lives it seems unlikely that the rises predicted will make much difference to mangrove productivity. Geographic range may be affected depending on topography. This also applies to the effects of sea level rise (Hogarth, 2007).

Salt marsh

Salt marshes have been impacted by development in Western Port and are more likely to be impacted in the future (Connolly & Lee, 2007). As for mangroves and other low-lying coastal habitats, early settlers and developers generally considered salt marshes as wastelands and put to "better" use after they were "reclaimed". Thousands of hectares were thus converted to pasture, buried under rubbish tips or used for roads, industrial sites, playing fields, housing, car parks and other developments. The most widespread destruction of salt marshes has resulted from filling to create dryland sites for coastal land uses by humans. This landfill can modify the local tidal range and thus patterns of inundation in any remnants that persist. Thus, much of the remaining salt marshes are poorly connected to Western Port or otherwise suffering from disturbed hydrology. As for mangroves, once the landfilled area is in use, other environmental problems usually follow. Stormwater runoff, accidental spills of pollutants, and discharges of treated or untreated effluent cause environmental problems in remnant salt marshes. Elevated nutrient levels, from sewage and stormwater discharges also affect salt marsh ecosystems adjacent to outfalls or urban centres. Salt marshes to the north of Western Port and mangroves were burnt and the ash used for the production of soap. Salt marsh was impacted with bund walls to limit tidal inundation. Many of these salt marshes do not receive anything like the natural degree of infrequent interchange of seawater at high tides. Through a lack of inundation, salt marsh sediments may suffer from acid sulphate soil syndrome.

Housing projects can destroy large areas of salt marshes, and straightening of meandering tidal channels causes changed tidal levels and reduced inundation and hence nutrient uptake for the remaining salt marshes. Salt marsh ecosystems remove nutrients from runoff by having large areas that are occasionally flooded and drained by meandering streams that slowly release water to the sea. If these meanders are straightened, for example, for boating channels, the water passes more quickly to the sea and many salt marshes will not be flooded as frequently with little chance for nutrients and organic matter to be retained and used in the salt marshes. Bund walls are useful for flood mitigation but their environmental impacts include limiting the upward rise of flooding king tides and thus result in disconnection and destruction of habitat in the area beyond the bunds. Hydrodynamic changes to salt marsh habitats thus have multi-faceted and extreme impacts.

In many areas salt marshes are grazed by kangaroos at levels beyond their natural use. Stock, moving along pathways, alters drainage lines and these paths act as shallow channels that often remove water very quickly from flooded areas. Stock damage *Tecticornia* bushes and soils are loosened and can then be eroded in salt marshes. Similar subtle changes to topography resulting in altered drainage also come from use of off-road vehicles or attempts at mosquito control via runnelling. Even a single vehicle pass can produce changes that can last decades, either removing (crushing) vegetation or creating lower paths that alter drainage lines and rates. Such damage can be readily seen across any salt marsh surface so impacted.

A number of weedy species of plants are found in salt marshes close to urban land or otherwise impacted, e.g. from nutrient-rich runoff. There are few species, however, because most land plants cannot tolerate saturated soils and many aquatic species cannot tolerate hypersaline soils. Invasive species e.g. *Spartina* and *Juncus acutus* are also of concern in Western Port.

Carbon dioxide assimilation interacts in complex ways with aspects of salt marsh physiology. Some salt marsh plants have C4 or CAM metabolic pathways and these may do better under higher temperatures and increased CO_2 levels than C3 plants. Given that salt marsh plants are already "on the edge" in regards to their water relations, increases in water-use efficiency may not be possible. The general trade off between water use and CO_2 acquisition means the salt marsh response to high atmospheric CO_2 may not be easy to predict. Also salt marshes naturally reach their zenith at mid-latitudes (Saintilan, 2009) and so a general rise in temperatures may not favour many species and probably not over the grey mangrove. The most likely effects of sea level rise will be to further squeeze salt marshes into a narrowing space between the sea and human habitation and other structures (Saintilan, 2009).

4. Impact of Port of Hastings on flora of Western Port

a. Oil Spill

An oil spill close to Western Port was on Hebe Reef in northern Tasmania. The grounding of the *Iron Baron* released about 350 tonnes of Bunker C fuel oil. Edgar and Barrett (2000) found that the release of fuel oil did not appear to have substantially affected populations of subtidal reef associated animals. The most significant damage to reef fauna and flora was the physical abrasion done by the ship's hull and the death of 10–20,000 little penguins (*Eudyptula minor*) (Goldsworthy et al., 2000).

The *Exxon Valdez* oil tanker oil spill occurred in Prince William Sound, Alaska, on March 24, 1989, when the *Exxon Valdez* struck Prince William Sound's Bligh Reef and spilled 42,000 m^3 of crude oil. I investigated the near shore area of Prince William Sound in September, 1989 and found that the intertidal algae and invertebrates on sand or beaches were damaged either by the oil, or the clean up, very little dispersant was used. The seagrass *Zostera marina*, which was growing sub-tidally, was little affected (pers. observation). Later it was reported that seagrass recovered from any damage within one year (Dean et al., 1998). *By 1991, in the lower and middle intertidal zones, algal coverage and invertebrate abundances on oiled rocky shores had returned to conditions similar to those observed in unoiled areas. However, large fluctuations in the algal coverage in the oiled areas in the upper intertidal caused a subsequent alteration in community structure. The Fucus canopy was initially eliminated in most of the areas that underwent extensive cleaning, thereby removing the protection provided by this alga to intertidal organisms from predation, desiccation and abrasion. This early eradication of Fucus led to instability of this alga's subsequent populations because the single-aged stands present after recolonization of the habitat were susceptible to large synchronous die-offs. Until a broader distribution of mixed-aged stands is established, this cycle may continue for many generations. Meanwhile, full recovery of Fucus is crucial for the recovery of intertidal communities at oiled sites, because many intertidal organisms depend on the shelter this seaweed provides.*

By 1997, Fucus had not fully recovered in the upper intertidal zone on shores oriented towards direct sunlight, but in many locations, recovery of intertidal communities had been substantial. Studies on the effects of clean-up activities on oiled and washed beaches showed some invertebrates, like molluscs and annelid worms were still much less abundant than on comparable unoiled beaches through 1997 http://www.evostc.state.ak.us/recovery/status_intertidal.cfm.

The macroalga *Fucus* that grew along the intertidal reef fringe was greatly affected and died all along the impacted coast: it later recovered (Dean et al., 1998). In temperate Australia this seaweed is replaced by *Hormosira banksii* on any fringing reefs but affords a similar habitat to *Fucus*. It is expected that *H. banksia* would be affected by an oil spill in a similar way to *Fucus* on rocky reefs.

The findings of Wilson and Ralph (2010) are that non-dispersed oil, in general, leads to less photosynthetic stress to *Zostera capricorni* and *Halophila australis* compared with the stress caused by the addition of a chemical dispersant. When the addition of a chemical dispersant is deemed necessary to protect other resources in the area, the seagrass may still recover depending on the dispersant used. Oil spills will immediately kill mangrove seedlings and, pneumatophores covered in oil will cause mangrove trees to die (Eddyvane, 1991). An oil spill from the "Era" in mangroves near Port Pirie in South Australia, in 1992, resulted in 3.2 ha of mangrove trees being completely defoliated and not recovering four years after the spill. In lightly oiled areas mangroves lost leaves until 1993 then recovered. No clean up in the mangroves was feasible. This will probably be the case if an oil spill occurs in Western Port (Wardrop et al., 1996). It should be considered that, as mangroves are on the limit of their southern range, they are already under stress and an oil spill could have serious consequences.

The Amoco Cadiz oil spill in 1978 was of 220 thousand metric tons of crude oil and bunker fuel and polluted some 384 km of the Brittany coast (Grigalunas et al., 1986). They reported on the estimated economic cost of the spill including loss to oyster and mussel beds. The loss to shellfish was conservatively estimated at $US 28.6 million 1978 value. The total cost of economic goods and services was $US195–284 million in 1978 value.

The damage done by the Torrey Canyon oil spill in 1967 on the coast of Cornwall was compounded by the use of dispersants. Southward and Southward (1978) reported that the oil and dispersant affected the herbivores more than the plants and there was some shift in community to a sheltered shore condition of low species richness and greater biomass. The sequence of succession started with green algae and took more than ten years.

A petroleum product leakage and subsequent fire outbreak caused a high degree of biological damage to the impacted mangrove ecosystem near Lagos in Nigeria. At most of the impacted stations almost all macrobenthic and plant species in the area were completely destroyed by the petrol leakage and fire outbreak. A significantly high population of the early dominant species were observed about three months after the rehabilitation of the impacted area. This high population influx coincided with a significant decrease in the total hydrocarbon content in the sediment (Otitoloju et al., 2007). The observed rapid recovery of some populations within such a short period may be attributed to their ability to emigrate quickly into the deeper parts of the surrounding waterbody during the inferno or rapid migration of other populations of the animals back into the impacted area post rehabilitation activities (Otitoloju et al., 2007).

According to Yamamoto *et al.* (2003), rapid recovery of a snail and a limpet following a 'heavy-oil' spill incident in the rocky coast of Imago-Ura Cove, Japan was largely related to their greater movement ability and relatively shorter generation time. The rapid recovery and colonization of the impacted area in Nigeria, by a hermit crab may also be related to the observation that populations of this crab had higher tolerance to petroleum products than a population of the same species inhabiting an unpolluted reference station (Otitoloju and Are, 2003). According to Yamamota et al. (2003), it took about two years for the diversity and three years for the abundance of animals to recover to the original level after the heavy-oil spill in Japan. Such long period of recovery following crude oil spill was also reported by Southward and Southward (1978).

Less is known about the effects of oil on salt marsh but the "Deepwater Horizon" oil spill in the Gulf of Mexico will add to the knowledge of resilience and vulnerability of salt marsh. Two years after this spill there was rapid recovery (high resilience) but also permanent marsh area loss. The salt marsh loss came about because, after heavy oiling leading to plant mortality, oil-driven plant death on the edges of these marshes more than doubled rates of shoreline erosion. The poor condition of the salt marsh amplified this erosion and thereby set limits to the recovery of otherwise resilient vegetation (Silliman, 2012).

When spilled, the various types of oil can affect the environment differently. They also differ in how difficult they are to clean up. Only two types are discussed in the Western Port context—diesel (Type 2) and heavy crude oil (Type 4). Spill responders group oil into four basic types:

Type 1: Very Light Oils (Jet Fuels, Gasoline) (an example of a spill of this type of oil—Otitoloju et al. 2007)

- Highly volatile (should evaporate within 1-2 days).
- High concentrations of toxic (soluble) compounds.
- Localized, severe impacts to water column and intertidal resources.
- No cleanup necessary but containment at once would be necessary in Western Port.
- No dispersant necessary.

Type 2: Light Oils (Diesel, No. 2 Fuel Oil, Light Crudes) (Edgar and Barrett, 2000)

- Moderately volatile; leaves residue (up to one-third of spill amount) after a few days.
- Moderate concentrations of toxic (soluble) compounds.
- Will "oil" intertidal resources with long-term contamination potential.
- Has potential for subtidal impacts (dissolution, mixing, sorption onto suspended sediments).
- No dispersion necessary.
- Cleanup can be very effective as long as containment of the spill is quickly carried out.

Type 3: Medium Oils (Most Crude Oils) (Dean et al., 1998)

- About one-third will evaporate within 24 hours.
- Maximum water soluble fraction 10–100 ppm.
- Oil contamination of intertidal areas can be severe and long-term.
- Oil impacts to waterbirds and fur-bearing mammals can be severe.
- Chemical dispersion is an option within 1–2 days.
- Cleanup most effective if conducted quickly.

Type 4: Heavy Oils (Heavy Crude Oils, No. 6 Fuel Oil, Bunker C)

- Little or no evaporation or dissolution.
- Maximum water soluble fraction is less than 10 ppm.
- Heavy contamination of intertidal areas likely.

- Severe impacts to waterbirds and fur-bearing mammals (coating and ingestion).
- Long-term contamination of sediments possible.
- Weathers very slowly.
- Chemical dispersion seldom effective.
- Shoreline cleanup difficult under all conditions.

The threats of an oil spill in Western Port may be from a collision, grounding, a spill from refuelling vessels or from delivering oil to the port. Asia Pacific ASA used diesel (Type 2) and heavy Fuel Oil (Type 4) in its scenarios. Three scenarios were presented by Asia Pacific ASA (2013):

1. A 200 Metric Tonne (MT) spill of Heavy Fuel Oil (HFO) at Long Island Point Jetty, involving an initial release of 100 MT over the first 12 hours with the remaining volume leaking over the next 60 hours (total spill duration of 72 hours).
2. A 200 MT spill of HFO at McHaffie's Reef, also involving an initial release of 100 MT over the first 12 hours with the remaining volume leaking over the next 60 hours (total spill duration of 72 hours).
3. An 80 m^3 (66 MT) spill of diesel occurring over less than 20 minutes at Long Island.

Spill 1 and 2 are conservative volumes of fuel oil that might result from a ship grounding or collision with another ship or part of the port. The volumes are low compared with those of many spills in Australian waters. The first scenario represents the initially fast loss as the head of pressure in fuel tanks reduces while the second scenario is to represent ongoing leakage at a reduced rate. The third scenario covers fuel leakage from smaller support craft such as tugs and crew boats (Asia Pacific ASA, 2013).

The oil spill modelling in Western Port is described in Asia Pacific ASA (2013) and results from replicated simulations which were then statistically analysed and mapped to define contours of risk around the release point. The effect of oil on seagrass, mangroves and salt marsh ecosystems depends on an involved complex of physical, biological, chemical and climatological factors and on the type and amount of oil spilled. The potential for damage to seagrass, salt marsh and mangrove ecosystems can be broken into two broad categories: susceptibility and vulnerability. Susceptibility is taken to be the potential for damage to plants and associated communities due to contact with oil, breakdown products or cleanup chemicals. Vulnerability is largely a positional effect, reflecting the proximity of a particular ecosystem to a potential hazard (Zieman et al., 1984). Concentrations of oil that will damage seagrass, saltmarsh and mangroves are not given here because any oil will have deleterious effects on these plants.

Oil spills effect plant ecosystems in a number of ways:

- Direct mortality of organisms due to smothering, fouling, and asphyxiation; poisoning due to direct contact with oil (especially with fresh oil); absorption of toxic fractions from the water column.

- Indirect mortality due to the death of food sources or the destruction or removal of habitat.
- Destruction of sensitive juvenile forms, especially those using the ecosystem as a nursery ground.
- Incorporation of sublethal amounts of petroleum fractions into body tissues, potentially lowering tolerance to other stresses.
- Reduction or destruction of the food or market value of recreational fish due to the tainting of flavor by absorption of hydrocarbons even though the amounts are sublethal.
- Incorporation of potentially carcinogenic or mutagenic substances into the food chain.

The amount of oil reaching plants and the length of time spilled oil remains near the plants are key variables in determining the severity of effect.

The comments below should be read with the Asia Pacific, ASA (2013) document: pages 54 (sites of national parks and marine reserves) 55, 56, 57, 65, and 74. The references to places are found on page 10 of the document (Appendix 1).

The first scenario of Asia Pacific, ASA (2013): a 200 Metric Tonne (MT) spill of Heavy Fuel Oil at Long Island Point Jetty. Concentrations given here are not those that effect the various habitats, rather they are the levels used in the model of Asia Pacific ASA (2013). The simulation, in summer, shows the oil going to Lower North Arm at concentrations greater than 10 g/m^2 and with a probability of 30% of oil going to Northern North Arm. There is a greater than 30% probability of stranding from the Port of Hastings to Yaringa Marine Park (Quail Island Marine Reserve) at concentrations greater than 25 g/m^2. The intertidal seagrass from Hastings to Yaringa is particularly susceptible if the oil lies on it for a low tide. Deeper seagrass, i.e. *Heterozstera tasmanica* is not so vulnerable because the oil will flow over it. Affected seagrass will probably recover. There is a greater than 10% probability of oil at concentrations greater than 25 g/m^2 moving north around Quail Island which has large expanses of seagrass. Mangroves here will be badly impacted while salt marsh is relatively safe, protected by mangroves unless there is a large southerly or south easterly storm driving oil contaminated water inland. Churchill Island Marine National Park and Phillip Island Nature Park are at low risk. There is also a low risk in summer for both entrances to Western Port.

In winter there is still a more than 10% chance that oil will go into the Northern North Arm and a 30% chance it will impinge on the seagrass and mangrove along the western edge of the North Arm. There is a higher probability than summer for oil to impinge on the western coast of French Island and the highest likelihood around Tortoise Head where there are some seagrass and mangroves.

Oil will adhere to seagrass, which will quickly lose oiled blades. Plants have the capacity to grow new leaves unless the sediments are heavily oiled. Oil commonly passes over seagrass beds with minimal impacts. However, organisms living on the seagrass blades or using the beds as nurseries are highly sensitive to oil on the seagrass and sediments.

Mangroves are highly susceptible to oil exposure; oiling may kill them within a few weeks to several months. Lighter oils are more acutely toxic to mangroves than are heavier oils. Increased weathering generally lowers oil toxicity. Oil-impacted mangroves may suffer yellowed leaves, defoliation, and tree death. More subtle responses include branching of pneumatophores, germination failure, decreased canopy cover, increased rate of mutation, and increased sensitivity to other stresses. Response techniques that reduce oil contact with mangroves, such as chemical dispersants, reduce the resultant toxicity. Tradeoffs include potential increased toxicity to adjacent communities, and increased penetration of dispersed oil to mangrove sediments. Mangrove-associated invertebrates and plants recover more quickly from oiling than do the mangroves themselves, because of the longer time for mangroves to reach maturity.

Mangroves are generally more vulnerable to oil spills than salt marshes because oil on the partially submerged roots of mangroves interferes with respiratory activity. The degree of oil impact also depends on various factors, such as the type and amount of oil, the extent of oil coverage, the plant species, the season of the spill, the soil composition, and the flushing rate.

The second scenario of Asia Pacific, ASA (2013): a 200 Metric Tonne (MT) spill of Heavy Fuel Oil at McHaffie's Reef. The oil will drift from McHaffie's Reef along the Western Entrance channel and spread into the Western Entrance Segment. There is a 30–40% probability of oil with a greater concentration than 25 g/m^2 going through the Confluence Zone (Fig. 2.1 Appendix II) and entering North Arm and East Arm impinging on Tortoise Head where there are some seagrass flats and mangroves on the eastern side. There is a 10% probability that the oil will pass through the western entrance out to sea. *Amphibolis antarctica* is unlikely to be affected as this grows subtidally and water movement will move oil away more rapidly than in the North Arm. There is little chance of the seagrass beds along Phillip Island being affected. There may be a high oil accumulation but the probability is low. In winter, the probability that the oil will impinge on McHaffie's Reef is 50% and about 30% that it will go to the northern coast of Phillip Island. Concentrations of more than 25 g/m^2 have a 10% probability of leaving the bay and 5% of entering Northern Arm and the Rhyll Segment. North Arm and East Arm are relatively safe.

The third scenario of Asia Pacific ASA (2013): An 80 m^3 (66 MT) spill of diesel occurring over less than 20 minutes at Long Island. In summer the diesel will be constrained to North Arm at levels greater than 25 g/m^2 along four to five km around Long Island Jetty. The seagrass and mangrove at French Island Marine National Park will be most likely to be affected by this diesel. In winter there is a higher probability of diesel drifting south or south east (30%) into the Confluence Zone. French Island National park and Phillip Island Nature Park have the highest probability of exposure to surface films.

b. Land claim from and dredging in Western Port

The Port Land Use and Transport Strategy (PLUTS) was presented in 2009 by the then Minister for Roads and Ports. It focussed on future development on the Long Island precinct, northeast of Hastings around Long Island Point. The marine infrastructure and construction activities are: infilling parts of the existing shoreline, intertidal area and nearshore subtidal area, dredging the seabed in the shipping basin adjacent to the wharf area and in the channel leading to the shipping basin and depositing dredge spoil either in Western Port or in Bass Strait outside Western Port. The area where dredge spoil will be deposited, if it is in Western Port is about 100 ha and about three million tons of material. Substantial areas of subtidal seagrass will be removed along the western shore of the lower North Arm in Stages 2 and 3 of the development. These seagrass areas are important for juvenile fish habitat and may have orders of magnitude more benthic invertebrates than bare areas. Before the claiming of the seagrass area takes place an area where turfs or sods from this claimed section should chosen to re-establish the seagrass removed in a new suitable place.

As mentioned earlier many of the threats to seagrass will be increased by the development. Runoff from the larger catchment area of container holding bays, roads and buildings will not be absorbed slowly into salt marsh and mangrove but will pour into the bay unless controlled. This runoff, particularly from bare soil during development combined with sediment loosened from the dredge sites and the plume, if dredge spoil is deposited in the bay, will reduce light to benthic habitats. For seagrass the dredging is better timed in winter (Kirkman et al., 2012). This release of sediment may also cause smothering of seagrass as described in Erftemeijer and Lewis (2006). Care should be taken in choosing the spoil ground for its position in Western Port and its damage to underlying substrate.

Further north of the development site, disturbing potential acid sulphate soils may be a problem if mangrove substrate is moved or mangroves are destroyed. This should be kept in mind with mangrove and salt marsh clearing. Acid sulphate soils can cause fish kills and prevent recolonisation of shore plants.

Walls, port facilities and causeways are all structures that can impede hydrological flows causing erosion of seagrass beds, shorelines, mangroves and salt marsh. Tidal flows may be impeded and there may be stagnant areas left by these structures.

c. Wash from vessels

Wash from ships' wakes will affect plant communities either side of the channel. They induce a variety of hydrodynamic changes and physical forces having impacts on the surrounding flow, banks and sediments. In Torpedo Bay, Auckland, vessel generated waves (VGW) reached maximum heights in excess of 0.85 m, had an average height of about 0.3 m and periods of 2–6 s on the foreshore (Osbourne and Boak, 1999). The grouping and nonlinear form of these large VGWs made them capable of entraining and suspending significant quantities of bottom sediment (concentrations reaching 10–100 g/l) resulting in sustained increases of turbidity in the near shore region. Sand resuspension events under non-linear (asymmetric and skewed) shoaling and breaking VGWs exhibited a distinctive temporal structure. This structure was characterised by a marked instantaneous response to sharp accelerations, high velocities and intense turbulence under the crests of asymmetric breaking waves and also by a gradual accumulation and decay of suspended sediment in the water column. The former feature led to net onshore transport while the latter feature led to a distinctive phase lag between the largest VGW and the event maximum suspended sediment concentration and to the enhancement of turbidity in the near shore. Despite short term fluctuations in bed elevation of up to +/- 10 cm in response to large VGWs and relatively high gross sediment transport, the net effect of VGWs on the sediment transport and foreshore response at Torpedo Bay appeared to be insignificant (Osbourne and Boak, 1999). In an experiment at Hillsborough in Florida, Schoellhamer (1996) found that some resuspended sediments remain in suspension for at least eight hours. A secondary impact of VGWs is that sediments that are resuspended and newly deposited are more susceptible to resuspension by tidal currents than undisturbed sediments.

In Western Port intertidal seagrass will be the worst affected but subtidal *Heterozostera* may also receive the impact at very low tides or if the beds have been damaged by earlier storms. The erosion effect at Cribb Point, western French Island and the western entrance channel on Phillip Island will be the main places of impact. All seagrass will be affected by increased turbidity generated by the wakes then, later, resuspended sediment. Resuspended and disturbed sediment may, if enough is disturbed, smother seagrass as well as reduce light availability. The accumulated time that will occur with many passages of ships and their wakes will incrementally reduce light to seagrass and this will be deleterious at compensation levels.

Currently, only little information is available on the magnitude of this anthropogenic impact on the mangrove ecosystems. Investigation on the physics of vessel impacts and knowledge of the mangrove and other ecosystems should be carried out. Complemented by a number of monitoring and measurement campaigns, the aim should be to describe the quantitative relationship between passing ships and coastal erosion. Currently, very little information is available on the magnitude of this anthropogenic impact on the mangrove ecosystems of Western Port. The vessels may range from pleasure craft, yachts and cruise ships to container vessels and tankers.

Farrell & Ashton (1974) found that wave action can damage young mangrove seedlings that are exposed on the seaward edge of the mangrove fringe. Wave exposure can also lead to seedlings becoming clogged with detritus such as seagrass, although seagrass can also provide some protection for a seedling attempting to establish in sandy soils.

Salt marsh in Western Port will not be greatly affected by VGWs although sediment resuspension and transport in response to wakes generated by supercritical pilot boats and subcritical container ships at the mouth of the Savannah River in Georgia was found to increase with the turbulent kinetic energy of the supercritical pilot boat wake (Houser, 2011). The amount of sediment resuspended depended on the available supply of sediment on the upper-foreshore. Whereas sediment is transported landward by the individual waves of these vessels, net transport is offshore in response to a low-frequency oscillation similar to a second-order group-forced current. In some cases, the direction of net transport was reinforced or reversed depending on the timing of the pilot boat wake with the seiche or standing wave, forced by a passing container ship. In contrast to the pilot boats, sediment transport by subcritical container ships tended to be landward, but could also be weakly offshore depending on the timing of the wave group with the low-frequency drawdown and surge (Houser, 2011).

Conclusion and Discussion

A planned port may be built at Hastings in Western Port near Melbourne. It will impact many of the natural resources of Western Port. Seagrass and mangroves are renowned for their inability to be regrown and restoration efforts have had limited success (Kirkman and Boon, 2012).

An established coastal plant monitoring programme to examine the short and longer-term impacts of an oil spill event is recommended for Western Port immediately. Results for potentially impacted seagrass, mangrove and salt marsh areas can be compared with existing monitoring data and with control plant ecosystems located outside the oil spill area. Taylor and Rasheed (2011) demonstrated the value of long-term monitoring of critical habitats in high risk areas to effectively assess impacts of an oil spill in Gladstone Harbour.

Western Port is a complex system as far as tidal currents and inputs from drains, rivers and creeks is concerned. Precautions should be taken to realise the full implications to this system when changes are made. Its conservation value for migratory and water birds and fish should also be compared to gains from the development. A full goods and services economic analysis and valuation for natural resources should be carried out in Western Port.

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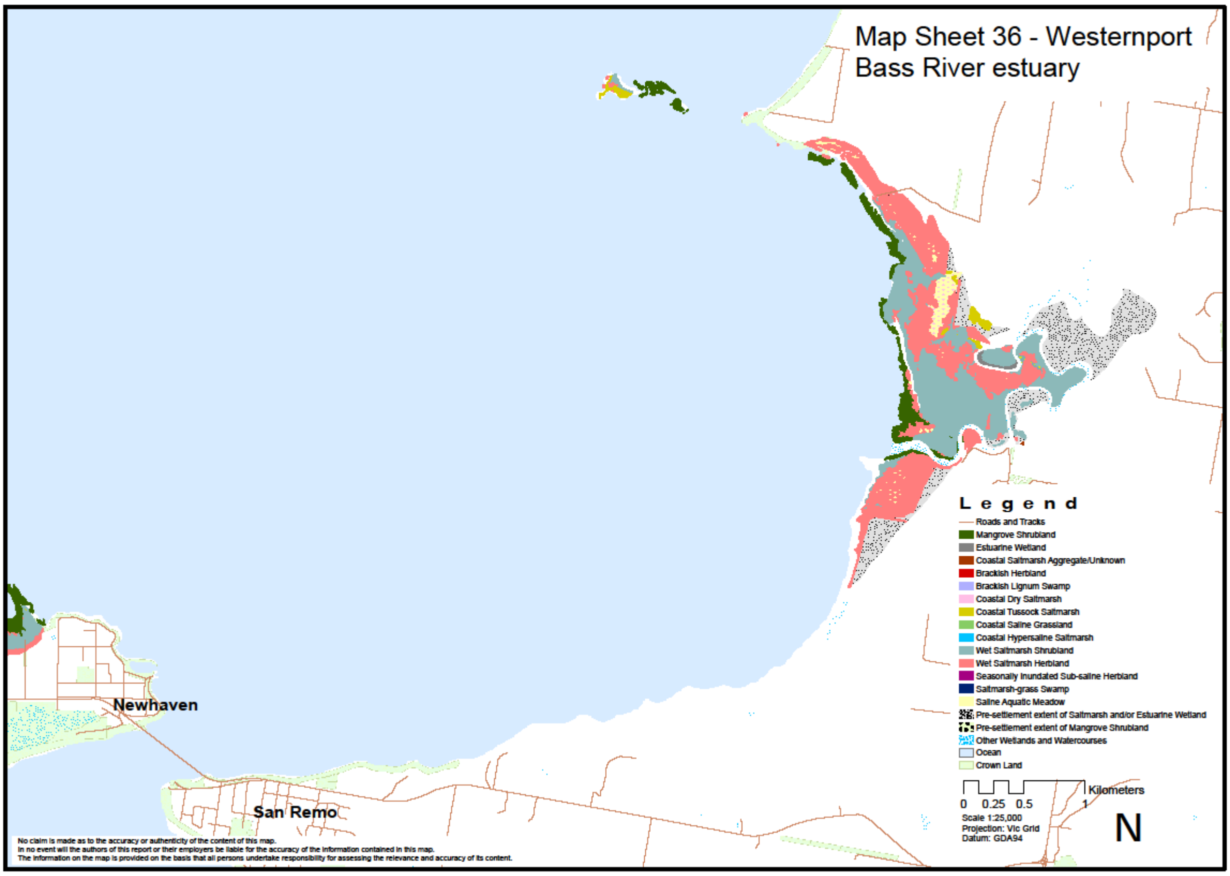
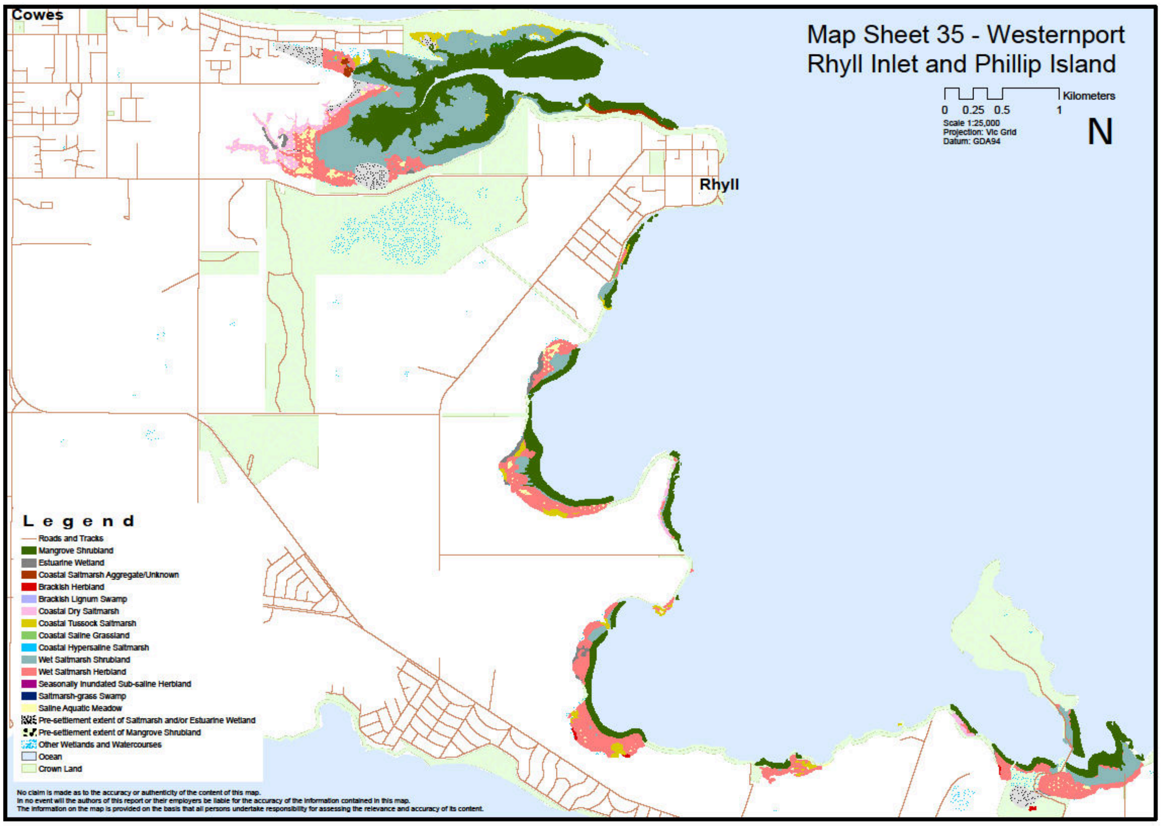
Appendix I. Salt marsh and Mangrove Maps of Western Port.

From: http://www.ozcoasts.gov.au/geom_geol/vic/Salt marsh/PortPhillip.jsp#




Map Sheet 35 - Westernport
Rhyll Inlet and Phillip Island
Cowes
Rhyll
Kilometers
0 0.25 0.5 1
Scale 1:25,000
Projection: Vic Grid
Datum: GDA94
N
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Crown Land
No claim is made as to the accuracy or authenticity of the content of this map.
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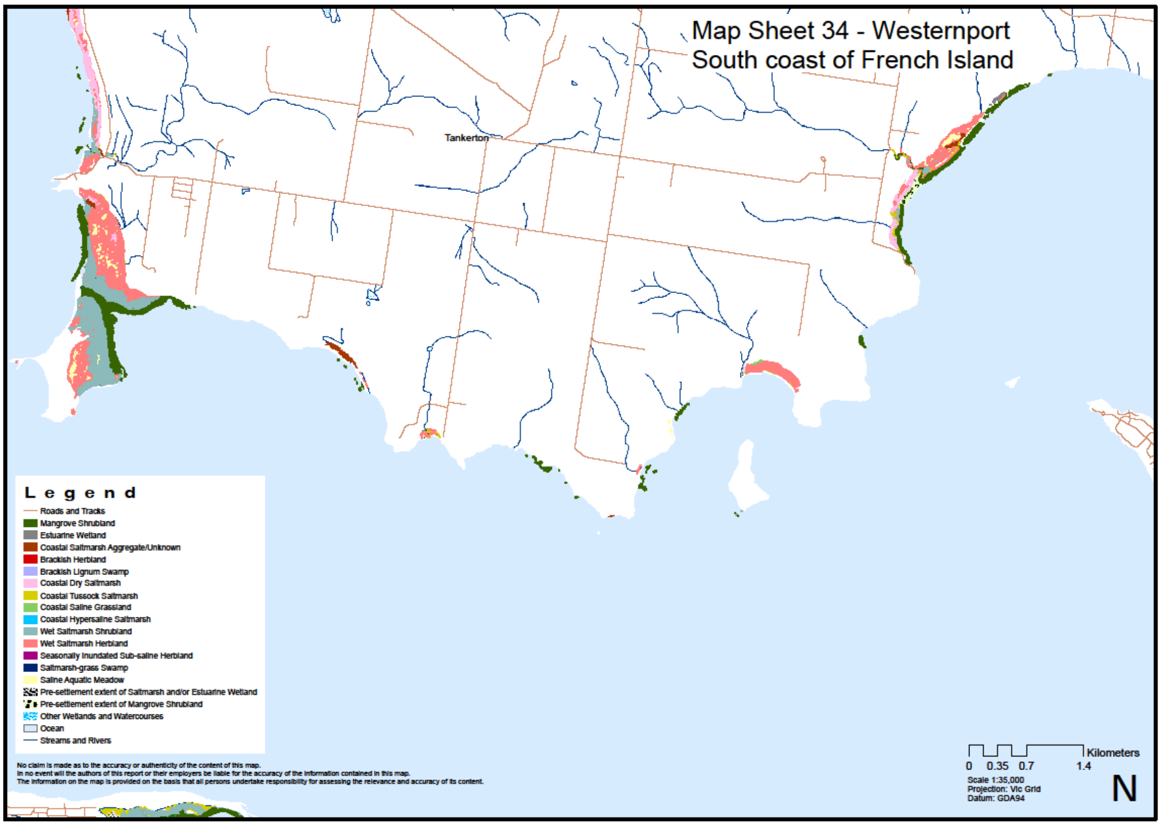
Map Sheet 34 - Westernport
South coast of French Island
Tankerton
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
No claim is made as to the accuracy or authenticity of the content of this map.
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Kilometers
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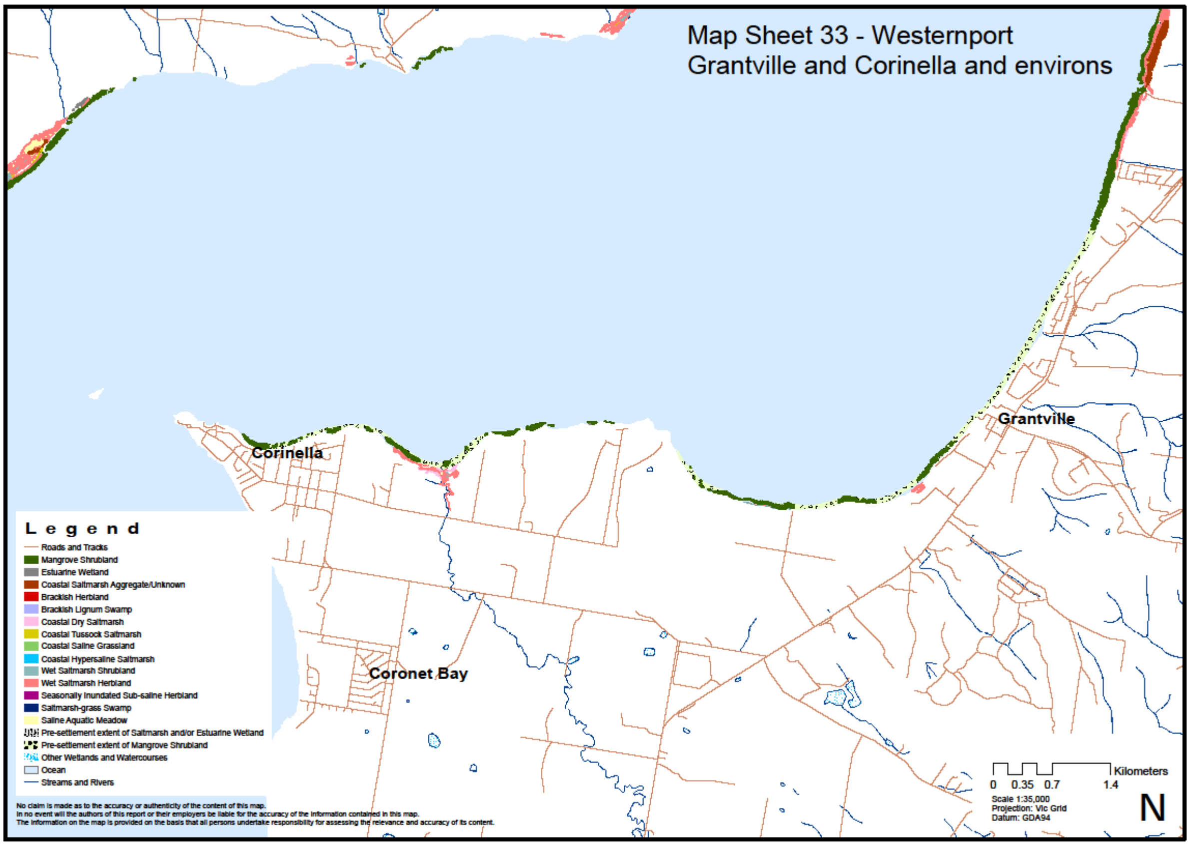
Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
N


Map Sheet 33 - Westernport
Grantville and Corinella and environs
Corinella
Grantville
Coronet Bay
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
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0 0.35 0.7 1.4 Kilometers
Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
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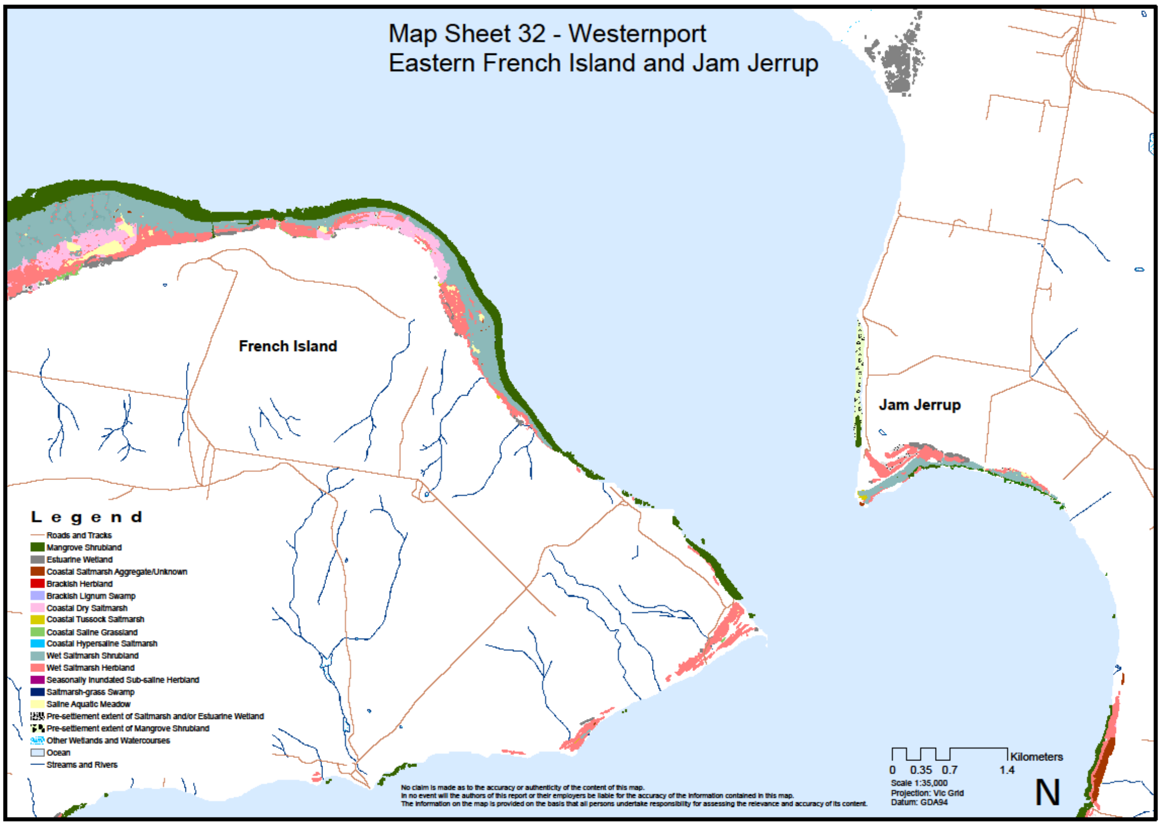
Map Sheet 32 - Westernport
Eastern French Island and Jam Jerrup
French Island
Jam Jerrup
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
0 0.35 0.7 1.4 Kilometers
Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
N
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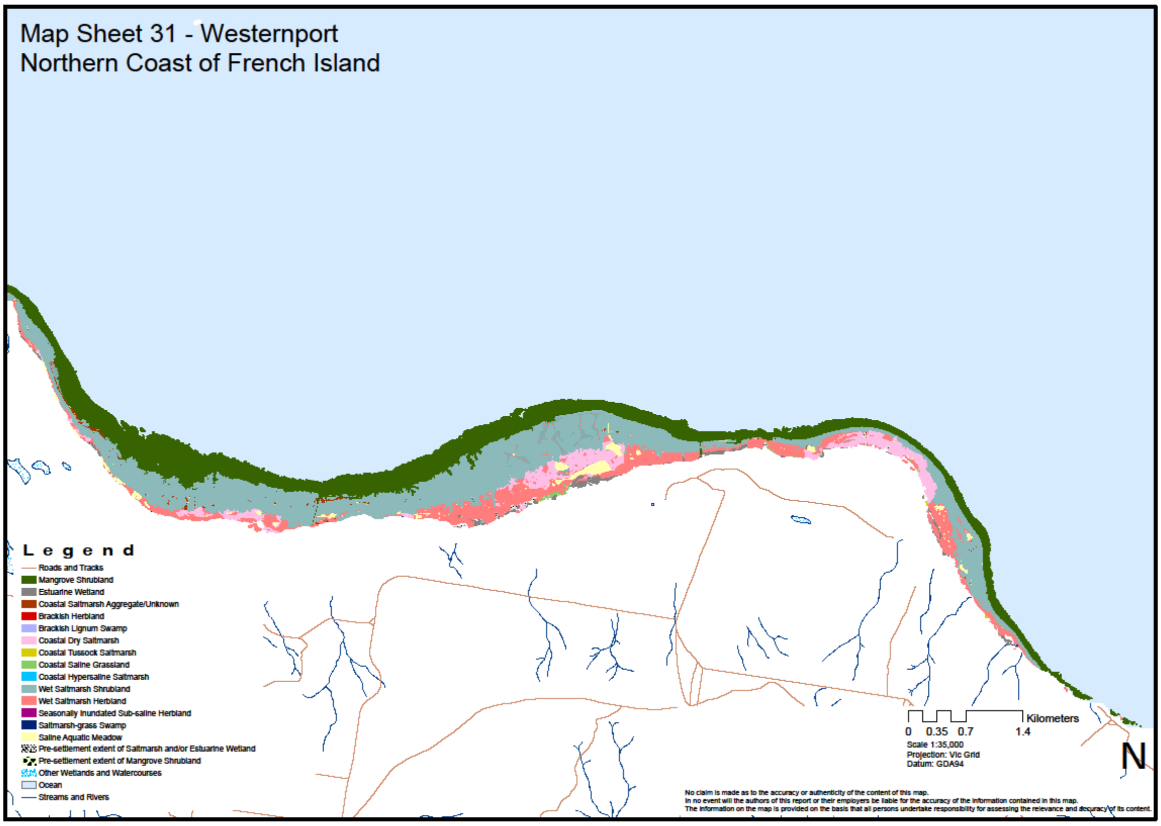
Map Sheet 31 - Westernport
Northern Coast of French Island
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
0 0.35 0.7 1.4 Kilometers
Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
N
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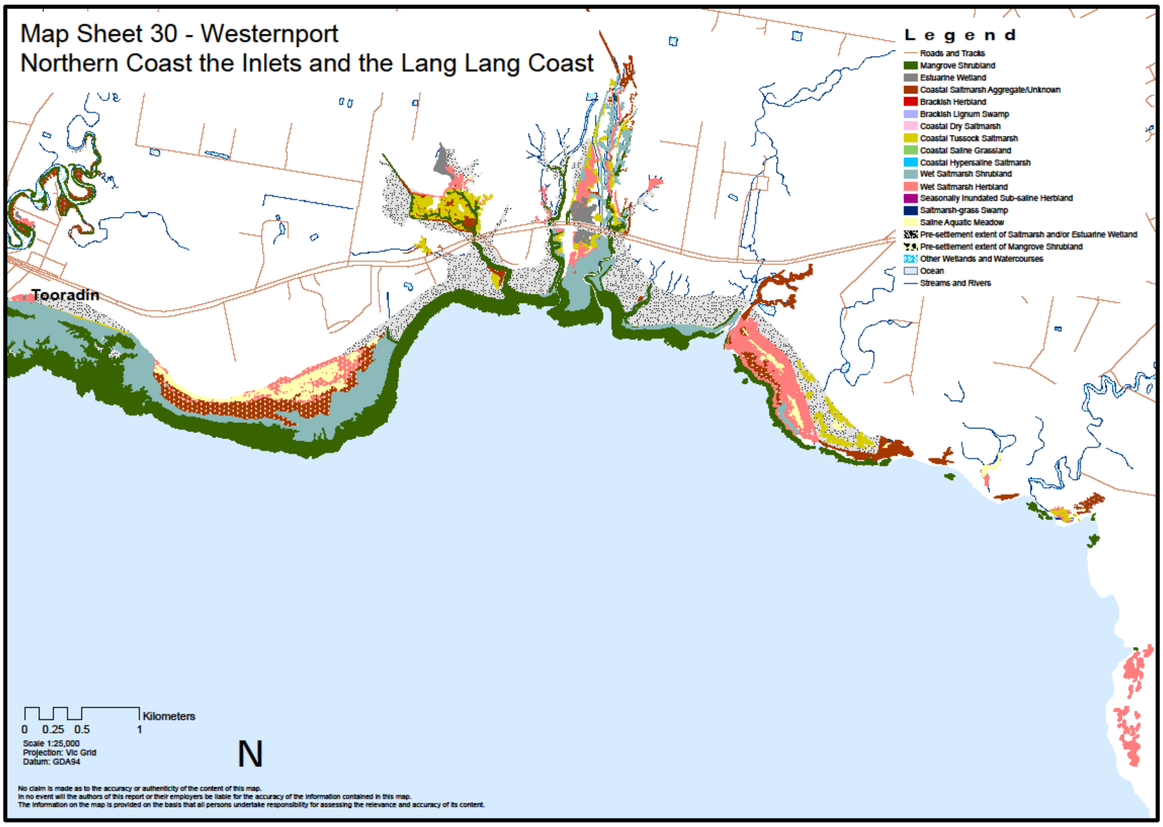
Map Sheet 30 - Westernport
Northern Coast the Inlets and the Lang Lang Coast
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
Tooradin
Kilometers
0 0.25 0.5 1
Scale 1:25,000
Projection: Vic Grid
Datum: GDA94
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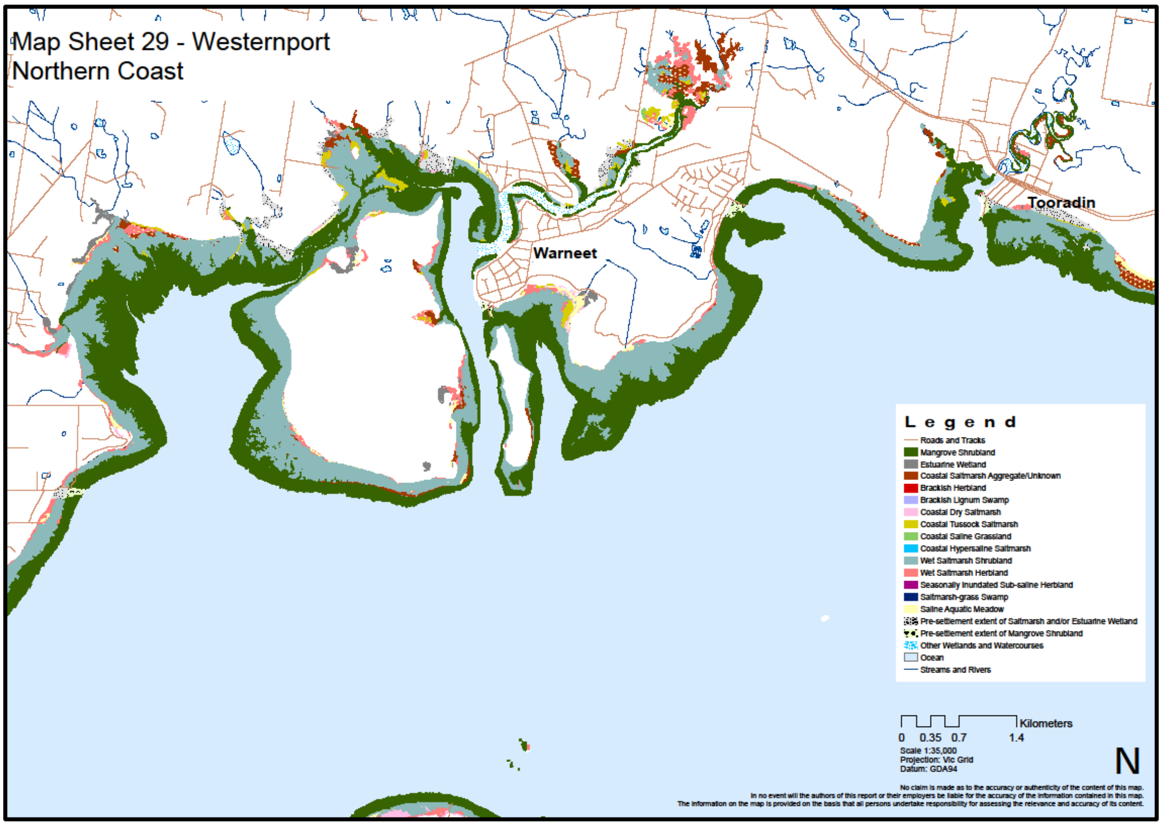
Map Sheet 29 - Westernport
Northern Coast
Warneet
Tooradin
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
Kilometers
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Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
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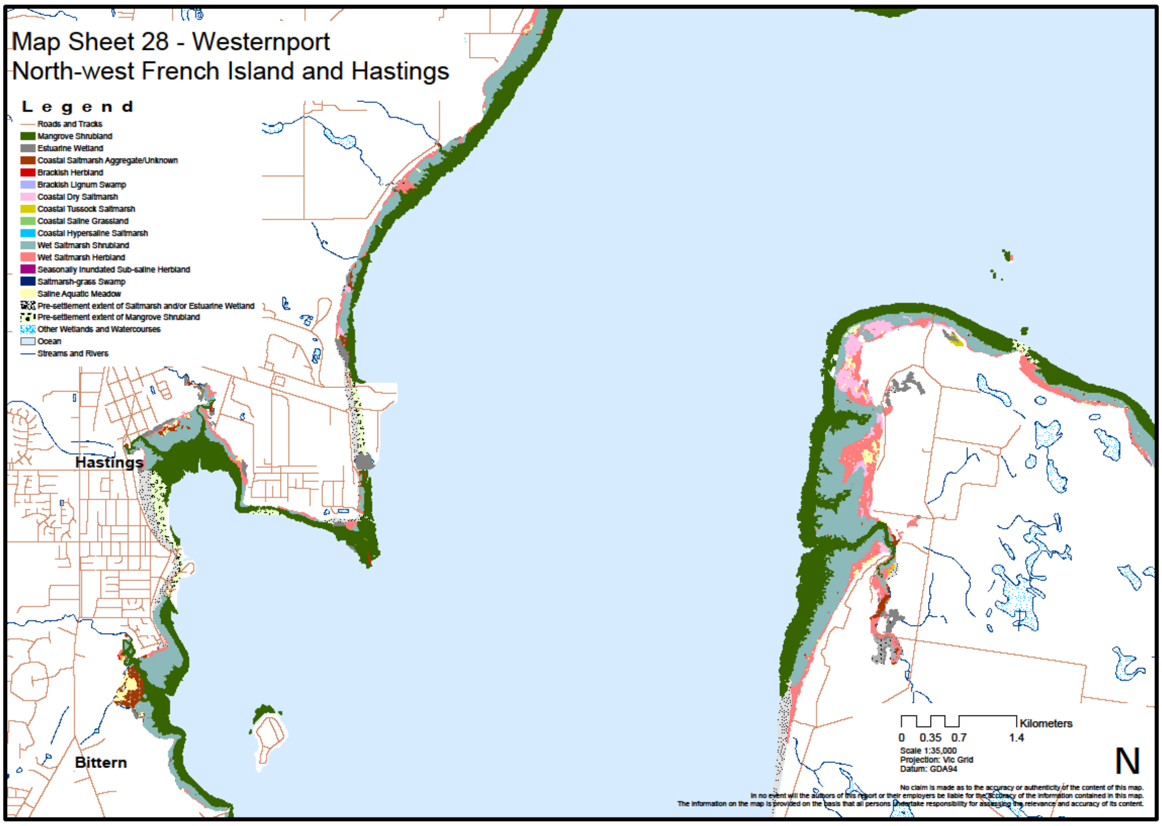
Map Sheet 28 - Westernport
North-west French Island and Hastings
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
Hastings
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Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
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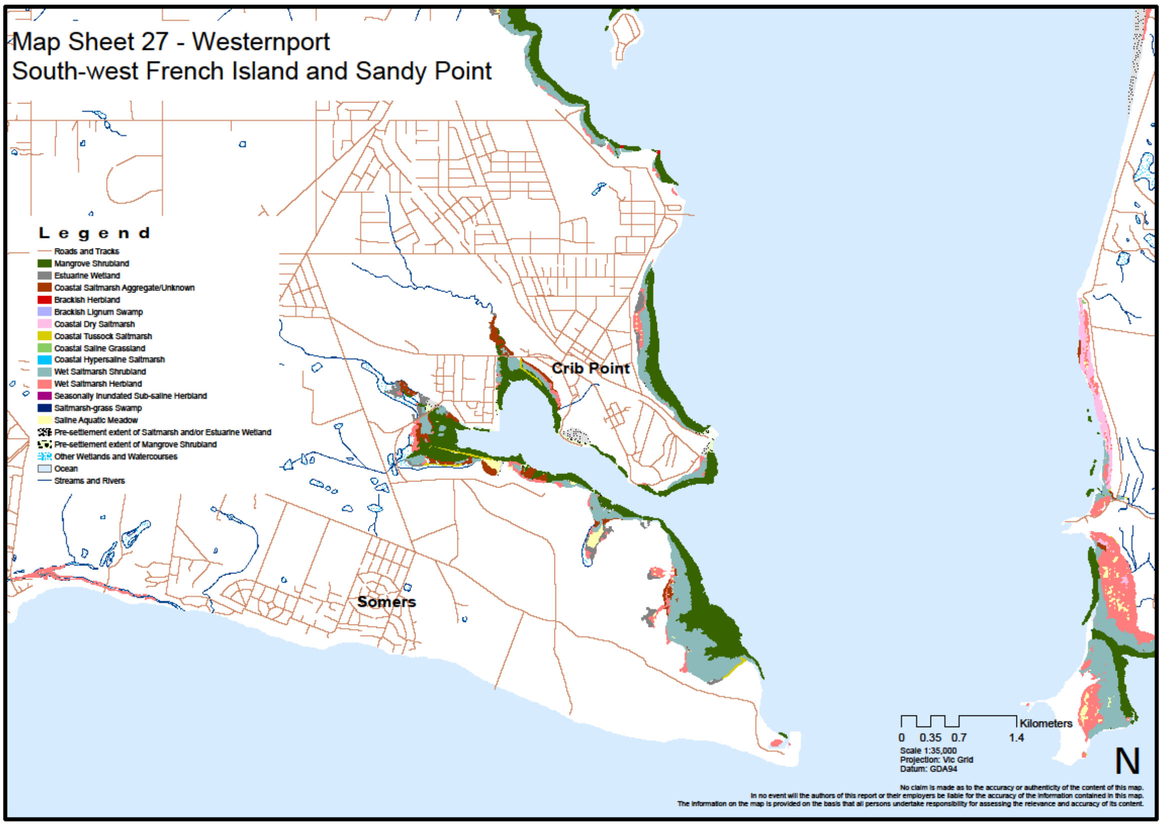
Map Sheet 27 - Westernport
South-west French Island and Sandy Point
Legend
Roads and Tracks
Mangrove Shrubland
Estuarine Wetland
Coastal Saltmarsh Aggregate/Unknown
Brackish Herbland
Brackish Lignum Swamp
Coastal Dry Saltmarsh
Coastal Tussock Saltmarsh
Coastal Saline Grassland
Coastal Hypersaline Saltmarsh
Wet Saltmarsh Shrubland
Wet Saltmarsh Herbland
Seasonally Inundated Sub-saline Herbland
Saltmarsh-grass Swamp
Saline Aquatic Meadow
Pre-settlement extent of Saltmarsh and/or Estuarine Wetland
Pre-settlement extent of Mangrove Shrubland
Other Wetlands and Watercourses
Ocean
Streams and Rivers
Crib Point
Somers
0 0.35 0.7 1.4 Kilometers
Scale 1:35,000
Projection: Vic Grid
Datum: GDA94
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Appendix II. Extracts from Asia Pacific, ASA (2013)

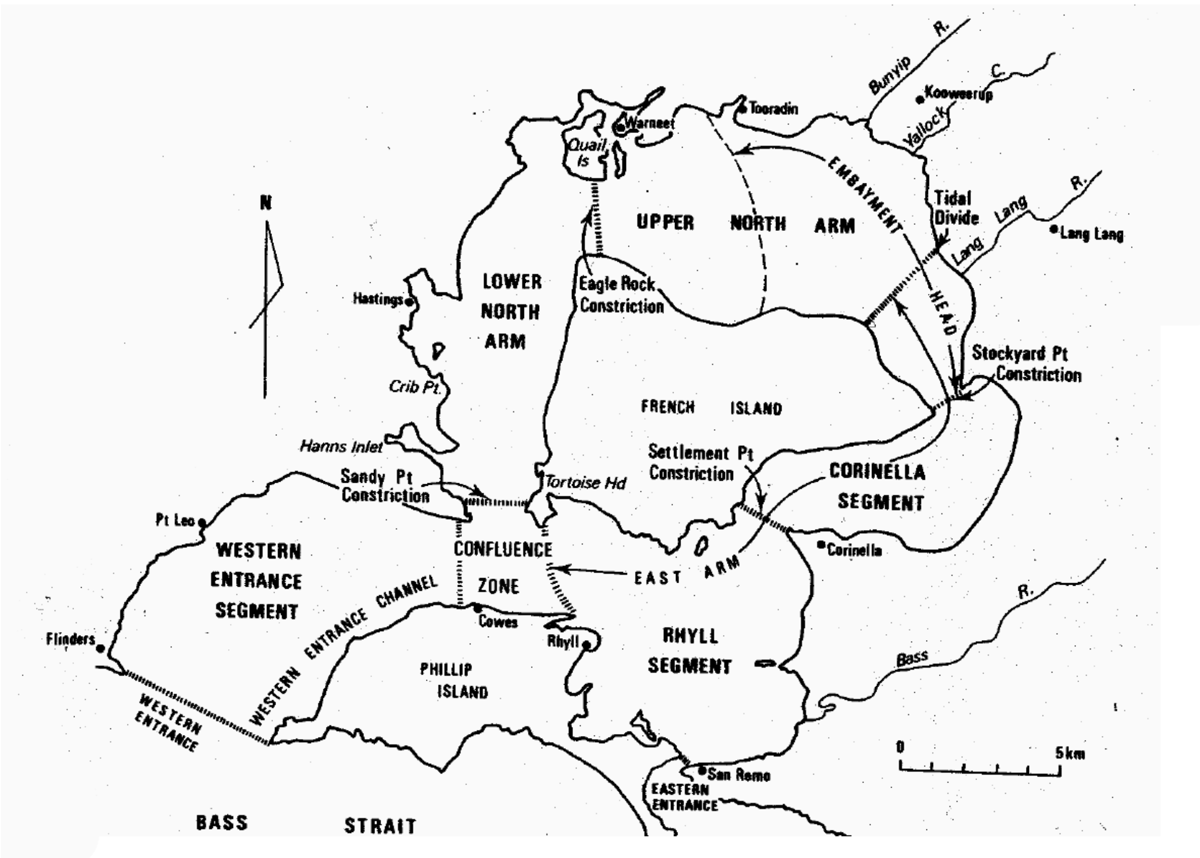

Fig. 2.1 Regional Distinctions of Western Port Bay

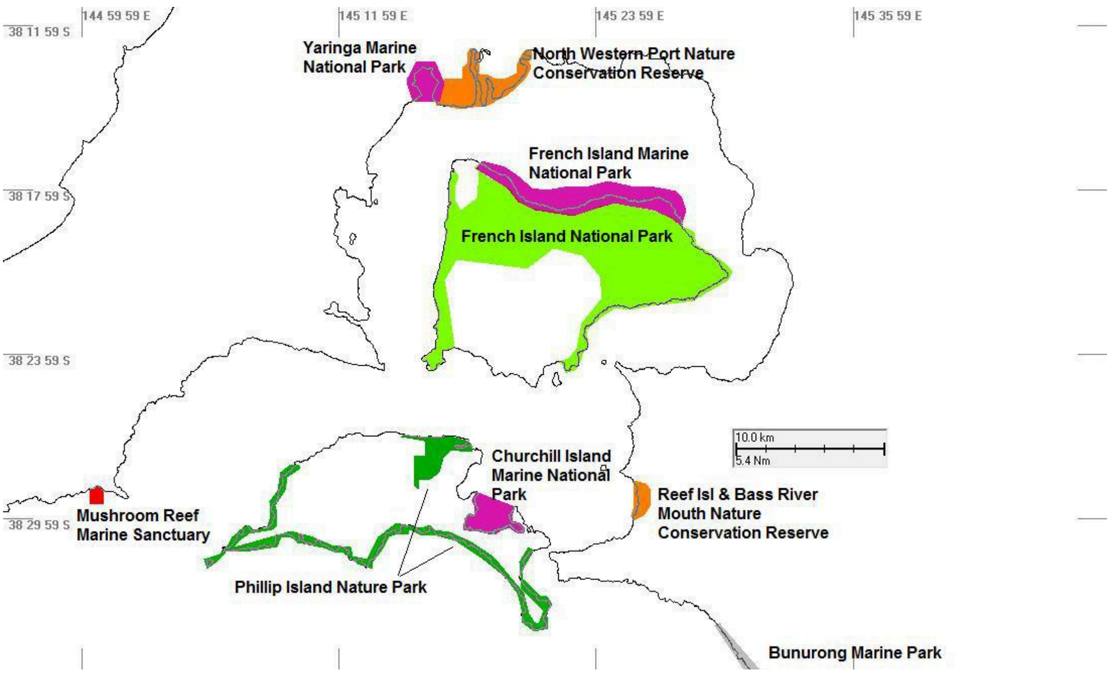

Figure 4-2: Distribution of national parks and marine reserves that have been established in Western Port Bay.

4.2 Simulation of a 200 Metric Tonne HFO spill at Long Point Jetty

This scenario investigated risks of contact for surrounding shorelines from a 200 MT spill of HFO over 3 days at Long Point Jetty.

Simulations of this spill scenario indicated that a high proportion of the oil mass would likely strand on shorelines at some point. Estimates as high as 85-90% of the volume were reported by the model, with this exposure occurring over a large part of the bay in a high proportion of cases.

The exposure probability contours calculated for this spill scenario commencing in summer indicate that floating oil is most likely to occur at concentrations > 10 g/m^2 within Lower North Arm but with the probability exceeding 30% of oil drifting into Northern North Arm. Probabilities of oil > 10 g/m^2 decrease to < 10% towards the Embayment Head and through the confluence zone between the Western Entrance Segment and the Rhyll Segment. The highest probability of contact (>50%) is forecasted along the tidal axis within 4 km of the jetty in both the ebb and flood direction. It is notable that the contours calculated for > 1 g/m^2 and > 10 g/m^2 are very similar for this spill scenario due to the forecast that the oil type will not spread but will be present as relatively thick layers of viscous oil.

Risks of contact with shorelines are indicated to be highest along the western shoreline, with > 30% probability of stranding indicated for the section of coastline extending from the Port of Hastings to Yaringa Marine Park (Quail Island Marine Reserve), at concentrations > 25 g/m^2. Probability of contact with North Western Port Nature Conservation Reserve are also indicated at > 30 % for concentrations > 25 g/m^2. The minimum time forecasted for floating oil to reach these locations is 6 to 7 hours – which would correspond with a single flood tide period. The potential concentrations of oil that could accumulate on any part of the shorelines in these areas was estimated at greater than 17 kg/m^2 (as oil, not inclusive of the mass of water in emulsified form) under the worst case simulation but averaged just over 1 kg/m^2 among the replicate simulations. Sections of shoreline along French Island National Park were forecasted to have > 20% probability of exposure at > 25 g/m^2 with extreme concentrations also forecasted to exceed 17 kg/m^2 and with similar durations (~ 8 hrs) required before exposure might occur. Churchill Island Marine National Park and Phillip Island nature park are forecasted to have relatively low risk of contact for this scenario in this season (~ 2%) with minimum drift times before exposure calculated at about 3 days.

The simulations indicated a low risk that oil would drift as far as the eastern or western entrances if the spill occurred in summer.

The exposure probability contours generated for spill simulations under winter conditions varied markedly from those calculated for spills in summer. While the contours still indicated > 10% probability that floating oil would occur at > 25 g/m^2 within Northern North Arm and Quail Island Marine Reserve, and > 30% probability of impinging on the western coastline of North Arm, the contours indicate a higher probability that floating oil at this concentration or greater would drift onto the western coastline of French Island, with the highest likelihood around Tortoise Island and into the confluence zone north of Phillip Island. The contours for winter indicate >20% probability that oil > 25 g/m^2 would extend across the Rhyll Segment and into the Churchill Island Marine National Park as well as along the Western Entrance

Channel. At least 5% probability is indicated that concentrations > 25 g/m^2 would drift through the Eastern Entrance Channel to potentially affect shorelines along Cape Woolamai State Faunal Reserve and shorelines flanking the eastern side of this entrance.

The shoreline of French Island National Park is forecasted to have > 50% probability of contact at > 25 g/m^2, with the potential for over 17 kg/m^2 to occur under the worst case conditions. The shortest drift time to this shoreline indicated at ~ 6 hrs under winter conditions. Phillip Island Nature Park is forecasted to have 25% probability of exposure at > 25 g/m^2 with a similar potential concentration forecasted for the worst case but requiring about 1 day as a minimum elapsed duration. North Western Port Nature Conservation Reserve is forecasted to have 8% probability of exposure to oil > 25 g/m^2, with the potential for oil to arrive within 12 hours and accumulate to > 17 kg/m^2.

4.3 Simulation of a 200 Metric Tonne HFO spill at McHaffie's Reef

This scenario investigated risks of contact for surrounding shorelines from a 200 MT spill of HFO over 3 days at McHaffie's Reef, which lies along the shipping route to Port Hastings.

Repeated simulations of this spill scenario also indicated that a high proportion of the spill volume would eventually run aground, although this proportion is likely to be reduced compared to the same spill scenario at Long Point Jetty (~ 50-60%), with higher proportions likely during summer because a higher proportion is likely to be driven out to sea with offshore winds that are more frequent during winter.

Risk contours calculated from simulation of this spill scenario during summer indicated the highest probability that oil would drift along the Western Entrance Channel and spread over the Western Entrance Segment. The probability that concentrations > 25 g/m^2 would drift through the Confluence Zone and enter North Arm and East Arm is forecasted at 30-40%, with this contour impinging on Tortoise Point. The 30% probability contour is also forecasted to impinge on the northern coastline of Phillips Island. There is > 10% probability that concentrations of floating oil > 25 g/m^2 would drift out of the Western Entrance to potentially affect the southern coastline of Phillip Island and open coastlines to the east of the bay.

French Island National Park is forecasted to have > 35% probability of exposure at > 25 g/m^2 for this spill scenario in summer, with the minimum exposure time forecasted at ~ 6 hours and the potential for significant accumulation (> 17 kg/m^2) indicated. Phillip Island Nature Park is also forecasted as a potential site of high oil accumulation, but at a lower probability.

Probability contours generated from spill simulations under winter conditions indicate a markedly higher probability that floating oil > 25 g/m^2 would be constrained to oscillate through the Western Entrance Channel with the highest probability for oil to impinge onto McHaffie's Reef (>50%) and the northern coastline of Phillip Island.(> 30%). Oil concentrations > 25 g/m^2 are indicate to have > 10% probability of migrating from the bay at > 25 g/m^2. Oil concentrations > 25 g/m^2 are also indicated to have > 5% probability of entering Northern Arm and the Ryll Segment but relatively low probability of drifting further along North Arm and East Arm

4.4 Simulation of an 80 m^3 diesel spill at Long Point Jetty

This scenario investigated risks of contact for surrounding shorelines from a 80 m^3 spill of diesel fuel at Long Point Jetty.

Risk contours calculated for spills of floating diesel during summer show similar seasonal trends to the HFO spill scenario but indicate that floating slicks will most likely be constrained within North Arm at > 25 g/m^2 but could extend to the mudflats in the Northern sector of North Arm at > 5% at > 1 g/m^2. Similar minimum concentrations are forecasted to potentially migrate south into the Confluence Zone but at low probability (1%). The highest probability of exposure (> 50%) over open water is indicated for a distance of 4-5 km along the tidal axis around Long Point Jetty and > 30% probability of exposure to shorelines on both the western and eastern coastline of North Arm is indicated.

Summary tables for the quantification of exposure risk for sensitive resources indicates a marked decrease in exposure probability at increasing concentration thresholds, which is attributed to the high spreading rate, the evaporation rate of volatile components and the tendency for diesel to entrain (hence reducing surface concentrations). High probabilities (>70%) of exposure are indicated for a number of the resources at the low threshold but probabilities of contact are forecasted at < 20% at > 25 g/m^2. Similar minimum drift times are indicated for oil to reach sensitive resources, compared to the HFO scenario from this location. The highest potential concentrations on shorelines are forecasted at > 12 kg/m^2, for French Island Marine National Park.

In contrast to the HFO scenarios, simulation of the diesel spills indicate that concentrations > 100 ppb have a high probability (> 50%) of occurring over a wide part of North Arm, with > 30% probability of exposure along the eastern and western shorelines of this arm. The mudflats in the north-east section of the bay have > 5% probability at > 100 ppb. Highest short term concentrations of entrained oil forecasted for any of the sensitive resource areas is around 3 ppm.

Exposure probability contours calculated from simulation of the diesel spill under winter conditions indicated a higher probability that diesel would drift south or south-east, with thin sheens (>1 g/m^2) forecasted to have > 30% probability of drifting into the confluence zone. A low probability is indicated for surface films to persist at > 25 g/m^2 in this area. French Island National Park and Phillip Island Nature Park are indicated to have the highest probability of exposure for surface films.

Exposure contours forecasted for physically entrained diesel indicate that concentrations > 500 ppb could occur throughout North Arm, with higher probabilities (> 20%) to the south of Long Point Island Jetty. Concentrations > 100 ppb are indicated to potentially occur into the Northern sector of North Arm, and through the Eastern Channel and Rhyll segment. French Island National Park is forecasted to have the highest probability of exposure (19% at > 500 ppb) and highest potential concentration (> 23 ppm).