

A. BOEREMA, K. VAN DER BIEST AND P. MEIRE

TOWARDS SUSTAINABLE PORT DEVELOPMENT

ABSTRACT

This article aims to contribute to the positive sustainability outcomes of port development projects by means of enhancing port activities (Prosperity) and benefiting the broader society (People) and the ecosystem (Planet). Many marine infrastructure works are taking place in environmentally sensitive areas. A more objective evaluation of the benefits and potential negative effects of port development for our Prosperity, People and Planet would assist with assessing the sustainability of a port development project.

The concept of ecosystem services (ES) has become increasingly important as a tool for integral evaluation of project effects – whether benefits or impacts – and achieving broad public support. Taking an ecosystem services perspective will not always give a conclusive answer whether a project is overall beneficial or not (in case there are both positive and negative effects), but has an important added value by identifying all effects and by putting them together in a single assessment.

The Ecosystem Management Research Group (ECOBE) in the Department of Biology of the University of Antwerp in Belgium and the International Association of Dredging

Companies (IADC) have joined forces to explore the subject of ecosystem services assessments in regards to sustainable dredging and marine infrastructure works. This article demonstrates that a more integrated evaluation of the Prosperity, People and Planet outcomes of port development can be achieved through the use of ES. To illustrate this approach, the ES assessment for the port expansion project in Botany Bay in Australia is shown. The ability to identify and evaluate a broad range of effects of port development for society is the first step towards sustainable port development projects.

The target audience of this article consists of personnel within IADC member companies, particularly those who are in the position to further operationalise the ES concept within their own organisations. The article is meant to help them familiarise themselves with the concept and identify opportunities for sustainability in different stages of port development projects. The article can also be used to inspire and streamline discussions with third parties involved with decision-making on port development projects.

Above: A bird's eye perspective of Port Botany's expanded container terminal and Penrhyn estuary situated adjacent to the reclaimed area. Photo courtesy of AECOM

INTRODUCTION

Sustainable Port Development: Needs and Challenges

The ongoing need for navigation in the context of a growing world population and global world trade as well as climate change challenges are major drivers of the dredging sector. Consequently, there is a permanent need for marine infrastructure projects due to growth and this is especially so for people living in low-lying delta areas. However, nowadays, development companies are operating in an increasingly complex world – not only are projects getting more complicated from a technical point of view but there is also a growing environmental awareness amongst project proponents, legislators and contractors. Companies are taking ownership of their responsibilities – environmental awareness in this case – by promoting the design and implementation of more sustainable solutions. But alone, developing and designing solutions are not good enough. To enable broad implementation and ensure effective realisation, these solutions should be widely accepted by clients, project financiers and other stakeholders. The benefits of these solutions or approaches should be taken into account in the evaluation method being utilised. This is where the concept of

ecosystem services (ES) comes into play. To enable the design of more sustainable dredging and marine infrastructure works and their efficient, safe implementation and realisation in environmentally sensitive areas, the concept of ES has become increasingly important as a tool for integral evaluation of project effects – whether benefits or negative impacts - and achieving broad public support.

Port Expands into Botany Bay

To illustrate how the concept of ES can help in the transition towards sustainable port development, an ES analysis is demonstrated in this article for the Port Botany container terminal expansion project in Botany Bay, Australia. Most information about the project is taken from the environmental impact statement [1], Port Botany Expansion overview brochure [2] and Annual Environmental Management Report of 2009 [3].

Sydney Ports (Sydney, Australia; Figure 1A) expanded Port Botany to ensure sufficient port capacity – availability of berths and terminal land – to meet the forecasted growth in New South Wales (NSW) container trade after 2010. The project was approved in 2005 and completed in 2011. It extended the existing Patrick Stevedores container terminal with 1,850 metres of additional wharf face – approximately 550 metres west and 1,300 metres north – which facilitates five extra shipping berths adjacent to the existing berths (see Figure 1). An additional 63 hectares of

terminal area was created and an area of two hectares adjacent to the tug berth facility was reclaimed to create a new public boat ramp and car park with direct access to Foreshore Road [1] (see Figure 1C).

The extra terminal area and berths have a capacity of about 1.6 million TEUs per year. This brings the total capacity at Port Botany to more than 3 million TEUs per year for the next 25 years and beyond. The depth of the port basin – up to 16.5 metres – allows large container ships with a capacity of up to 8,000 TEUs. Dredging of approximately 7.8 million cubic metres of fill material was necessary to deepen shipping channels and berth boxes (see Figure 1B). The total cost of the Port Botany Expansion amounts to AUD 1 billion. Economic benefits result from improving the efficiency of cargo handling, making exports more competitive and avoiding congestion costs. Furthermore, the project's construction and the expanded terminal's operation generate many direct and indirect jobs.

The Botany Bay port area has been subject to many changes related to previous human activities including the creation and removal of habitats, contamination of water and sediment from industrial activities, introduced species, fishing activities and shipping operations. Land uses surrounding the site comprise primarily open space, industrial, residential and transport-related uses with associated support services. Residential areas

are located in the vicinity of the site to the north and northeast. The industrial-slash-residential suburb of Banksmeadow lies to the north of the site. The residential area of Botany is located approximately 0.5-1 kilometres to the northeast of the site. A relatively large residential area consisting of Hillsdale, Matraville and Maroubra is located to the east of the site.

The key developments in the region that result in significant impacts are the existing port facilities, Sydney Airport and the Green Square redevelopment in Alexandria. Sydney Airport - the major aviation gateway to Australia and a major focus of economic activity – is located approximately 1.5 kilometres west of the site. Used for rail transport of freight to and from Port Botany, the Botany Freight Rail Line occupies a corridor to the north and northeast of the site. At the port end of the freight line sits Botany Yard which facilitates shunting activities and the breaking up of trains prior to entering the port terminals. The increase in aviation, train and shipping traffic – independent of the Botany Bay expansion – already caused a lot of effects in the area.

Ecosystem Services Assessment

Ecosystem services (ES) are the benefits humans derive from nature [4, 5]. The ES framework forms the bridge between ecosystems and human well-being, often referred to as the socio-cultural context. This

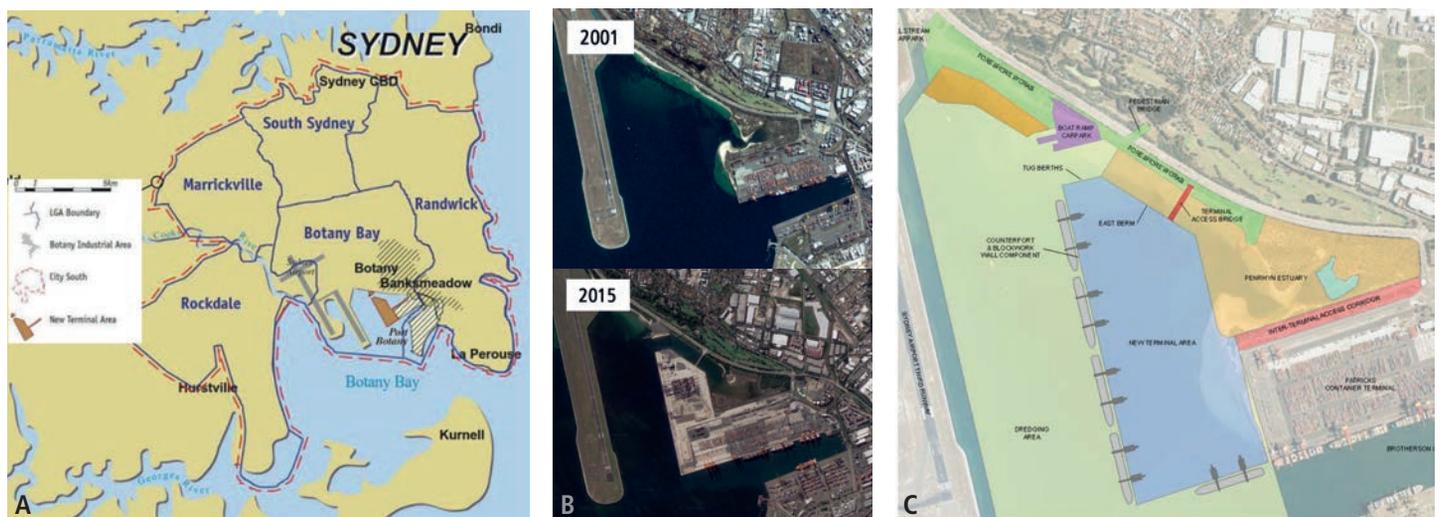


Figure 1. A: Location of the new terminal area for the Port Botany expansion, Botany Bay, Sydney, Australia [1]. B: Project area before (2001) and after (2015) the port expansion. Image courtesy of Google Earth C: Project layout: New terminal area, boat ramp, Penrhyn estuary, foreshore, dredging area [3].



ANNELIES BOEREMA

is a postdoctoral researcher at the Research Group Ecosystem Management of the University of Antwerp in Belgium. Her research focuses on biophysical and economic evaluation of ecosystem services to assess the impact of ecosystem management with an emphasis on estuaries. She obtained her master's degree in business engineering and also acquired master's and doctoral degrees in environmental science from the University of Antwerp.



KATRIEN VAN DER BIEST

is a doctoral researcher at the Research Group Ecosystem Management of the University of Antwerp in Belgium. She obtained a Master's degree in physical geography from the University of Ghent in Belgium and another Master's degree in oceanography from the University of Liège in Belgium. Her current research focuses on quantifying and mapping ecosystem services as a supportive tool in environmental management, both in terrestrial and marine ecosystems.



PATRICK MEIRE

is a professor in biology and head of the research group Ecosystem Management (ECOBE) at the University of Antwerp in Belgium. His research focuses on the environmental impact of human activities on aquatic and wetland systems, and these insights are used to develop concepts for integrated water and ecosystem management. He coordinates the OMES project, monitoring the environmental impact of the Sigmaplan, an undertaking which promotes safety against flooding as well as leisure, nature and navigation resources within the Scheldt estuary in Flanders. He obtained a PhD in biology from the University of Ghent in Belgium.

shows how humans depend on ecosystems and ES to explain these relationships. The concept of ES aims at classifying, describing and assessing the value of natural resources and ES in terms of benefits for society such as security, basic material for good life, health, good social relations. Relevant ES in the

context of port development are provisioning services such as food provisioning from fish, wood production and transportation, regulating services like climate, water quality air quality regulation, flood protection and sedimentation and erosion regulation, and cultural services including recreation and cultural heritage [6-10]. Although not considered ES, biodiversity is part of this assessment exercise because of the strict nature regulation targets worldwide.

Though these benefits are always delivered, project stakeholders – including developers, financiers, governments – do not always perceive them as a full 'economic good'. An ES assessment can provide quantifiable information and data that can be included in a traditional cost-benefit analysis of projects. Thus, monetary valuation of ES can be utilised to make a full environmental cost-benefit analysis and weigh the investment cost with not only technical profits, but also environmental and socio-economic benefits. An ES assessment also allows for a better comparison between project alternatives – not just scenarios that mitigate negative effects but also the ones that positively contribute to the environment. Furthermore, qualitative assessment can be done for ES when monetary valuation is not possible in a straightforward manner. In this way, other considerations can be added to the evaluation such as habitat and biodiversity targets.

ES ASSESSMENT OF BOTANY BAY PORT EXPANSION PROJECT

The ES assessment is conducted following four steps. In Step 1, the different types of habitats affected by the project are identified. Habitat types that might be relevant for port development projects range from offshore to shore and estuarine to terrestrial habitats (see Table I). In Step 2, ES delivered within these habitat types are identified and the relevant ES for the specific project selected (see Table I). Each ES as well as the underlying mechanisms driving the delivery are described in Step 3. Table I gives an overview of the main ES that are delivered by the listed habitat types. This overview is based on an ES analysis of five case studies of dredging and marine infrastructure projects of which the Port Botany Expansion project is one case study [11]. Finally in Step 4, all ES are assessed

first in a qualitative review and a quantitative and monetary assessment is added as much as possible depending on available data.

The assessment consists always of the comparison of alternatives: either comparing the situation with or without a project, or the comparison of other scenarios. For the quantitative assessment, each service has its own unit which is most relevant for that service. For example, carbon sequestration is expressed in tonnes of carbon sequestered per hectare per year; wood production is expressed in cubic metres of wood volume increase per hectare per year. For the monetary valuation, each of the quantitative units is translated into euros per hectare per year, forming a basis for comparison of scenarios. The methodologies used to quantify and value the different ES are explained in more detail for the case study.

STEP 1: HABITAT CHANGES RELATED TO THE BOTANY BAY PROJECT

Different zones and habitat types are affected by the project (see Table II). In the shore zone, the relevant habitat types are the bay, seagrass and mangroves. Along the north and northwest boundary of the new terminal (Figure 1B, C), the inner Penrhyn estuary is located with subtidal shallow water, intertidal flats and marshes. The hard substrata of the new terminal and berths is considered as a separate category referred to as 'artificial habitat'. The last part is terrestrial, with planted shrubland. The description of habitat changes is mainly based on following references: Port Botany Expansion Environmental Impact Statement [1], Penrhyn estuary Habitat Enhancement Plan [12], Port Botany Post Construction Environmental Monitoring: Seagrass Summary Report, April 2015 [13].

STEPS 2 AND 3: ECOSYSTEM SERVICES OF THE BOTANY BAY PROJECT

The main target of the studied project, the Botany Bay Container Terminal, was to increase port capacity using the existing navigation function of Botany Bay. The aim of this article is to assess whether the project generated other benefits beyond the main economic target. Depending on the available data, the calculation of these effects – in

Table I. Description of the different habitat types impacted by dredging and marine infrastructure projects and identification of ecosystem services potentially delivered by the different habitat types. This overview is based on an ES analysis of five case studies of dredging and marine infrastructure projects [11].

Category	Habitat type	Description	Provisioning					Regulating					Cultural			
			Fish production	Agricultural production	Wood production	Water production for potable water	Water provisioning for transportation	Climate regulation	Water quality regulation	Air quality regulation	Flood protection	Sedimentation and erosion regulation	Recreation	Heritage	Cognitive development Heritage	Biodiversity
Offshore	Shallow, soft substrate	Soft substrate of shallow offshore waters (~6 to 10 m below sea level); e.g. sand banks	x					x			x	x			x	
	Open water	Water column in the entire offshore zone	x									x			x	
Shore	Foreshore	Seaward extension of beach, subtidal zone between low water mark and depth at which seafloor is no longer stirred by waves	x						x						x	x
	Beach	Between low tide and springtide				x					x			x	x	x
	Lagoon, bay	Water body along the shoreline, separated from the sea by a barrier, connected to the sea by restricted inlets; e.g. lagoon of the sand engine between the sand supplementation and the beach	x						x	x		x		x		x
	Sea grass	Submerged aquatic vegetation in shallow zones	x						x	x		x	x			x
	Mangroves	Inundated forest area	x		x				x	x	x	x				x
Estuary	Subtidal deep habitat	>5 m beneath mean low water (MLW); e.g. gully	x						x				x			x
	Subtidal moderately deep habitat	Between 2 m and 5 m beneath mean low water (MLW)														
	subtidal shallow habitat	Between mean low water (MLW) and 2 m beneath MLW	x													x
	Bare tidal flat	Between mean high water (MHW) and mean low water (MLW)	x						x	x	x	x	x	x	x	x
	Low tidal marsh	Above mean high water (MHW); e.g pioneer vegetation		x					x	x	x	x	x	x		x
	High tidal marsh	e.g. willow shrub		x					x	x	x	x	x	x		x
Fresh	Freshwater rivers	Creeks that flow into Penrhyn Estuary (Botany Bay)	x													
hard substrate	Artificial reefs at all depth	Concrete, manmade structures; e.g. quay wall, groynes, dykes, jetty	x	x				x	x	x	x	x	x	x	x	x
Terrestrial	Dunes	Above springtide along sandy shores				x			x	x	x	x	x	x	x	x
	Dune lake	Water body in sandy sediments close to the sea but without connection to the sea, rain or groundwater fed													x	x
	Cropland	Corn, vegetables, ...		x					x	x	x	x		x		x
	Grassland	Natural grassland, pasture		x					x	x	x	x	x	x		x
	Forest	Coniferous, deciduous, marsh forest			x				x	x	x	x		x		x
	Wetland	e.g. Reed		x	x				x	x	x	x	x	x		

Table II. Summary of habitat changes.

Habitat		Change (projected completed in 2011)	Area (ha)
Shore	Beach, foreshore beach	<i>Restored and enhanced</i>	
	Lagoon, bay	- 57 ha reclaimed (ship berths up to 16.5 m depth) - 2 ha adjacent to the tug berth facility for the new boat facility <i>Small channel developed in the inner estuary</i>	-59
	Seagrass	2001: 10 ha; 2008: 0.03 ha (=300 m ²); 2015: 40 m ² (=0.004 ha) à Planned: 6 ha new = + 6 ha	+6
	Mangroves	Project: - 1 ha	-1
Inner estuary	Subtidal shallow	<i>Loss of a previously dredged hole and some areas of shallow subtidal sand habitat Will partly develop to seagrass and intertidal flat</i>	
	Intertidal flat	Initial: 3.4 ha; Project: -1.7 ha à Planned: 10 ha new = + 8.3 ha	+8.3
	Marsh	Initial: 1.4 ha; Project: -0.4 ha à Planned: 2.4 ha new = + 2 ha	+2
Outer estuary			
Hard substrata	Ship berths	- 57 ha reclaimed (ship berths up to 16.5 m depth)	
	Rock rubble	+ 1,850 m of wharf face + 500 m of seawall adjacent to seagrass habitat within the access channel and Penrhyn estuary + 1,000 m rock wall adjacent to intertidal habitat + 500 m of seawall used for the tug berths and recreational boat ramp ----- + subtidal rock wall between the tug berth area and the downstream end of the estuary channel (average height of 5.5 m) + 4.5 m subtidal rock wall as an extension of the boat ramp rock revetment	+ 3850 m = 19250 m ² (average 5 m height) = 1.9 ha
Terrestrial	Dune, planted shrubland	Project: - 0.6 ha and - 10.5 ha Retained: 4.5 ha	-11.1
	Surrounding area (road, residential, industry)		
Freshwater habitat	Drains		

biophysical and monetary terms – are illustrated which can be used to include in a cost-benefit analysis. However, making a full cost-benefit analysis for the example project is not the aim of this article.

Provisioning Services

Food Production: Fish and Shellfish

Fish production is directly related to the amount of fish available from open water, from sea floor species such as crabs, shrimp and flatfish to hard substrata species present in the sea, estuary and harbour such as oysters and mussels. The potential for fish production is indirectly regulated by several other ecosystem functions and services such as the amount of food available for fish to feed on as well as biomass production, water quality regulation, nursery function and biodiversity.

Commercial fishing was not directly affected by the port expansion because this activity was already prohibited within Botany Bay. There is, however, commercial fishing at the entrance to the Bay and within adjacent coastal waters. Based on modelling of hydrology and coastal processes, it is highly unlikely that the proposed port expansion would affect the physical nature of fishing activities outside the Bay. Given that many species of fish and invertebrates utilise the Bay waters as juveniles and then migrate into coastal waters, a possible concern is that there would be some effect on fish stocks as a result of the proposal. Under the proposal, there would be an overall increase in the amount of seagrass present in the core study area, hence it is expected there would be no net loss to fishery productivity and potentially a small increase.

Currently, aquaculture (including oyster farming) occurs on the southern side of Botany Bay. Since the changes to Botany Bay outside the study area are considered negligible, no effects are expected. There are no plans to introduce aquaculture to Botany Bay's northern section, particularly within the study area. However, in some areas of the shore, there are oysters on the mud flats. [1]

Overall, the port expansion project results in more fish productivity thanks to an increase in nursery area. Fish sampling in the existing brackish portion of the Penrhyn estuary indicates usage by a variety of fishes such as sea mullet (*Mugil cephalus*), sand mullet (*Myxus elongatus*), flat-tail mullet (*Liza argentea*), yellowfin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*) and silver biddies (*Gerres subfasciatus*). These

Table III. Calculation of the impact on climate regulation (carbon burial).

Habitat		Area effect Botany project (ha)	C burial (ton C/ha/y)	References data C burial	Impact (ton C/y)
Shore	Lagoon, bay	-59	0.068	[11]	- 4
	Seagrass	+6	1.38	[18]	8-12
	Mangroves	-1	0.83 – 3	[19-22]	- 0.83-3
Inner estuary	Intertidal flat	+8.3	0.55-2.46	[18, 21, 23-25]	4-20
	Marsh	+2	0.55-2.46		1-5
Hard substrata	Rock rubble	+1.9			
Terrestrial	Dune, planted shrubland	-11.1	6.8	[26]	-75
Total impact in tonC/y (average values)					-56
Monetary value in €/y (220 €/ton C)					-12,320

species would use the estuary for a variety of functions, including shelter and feeding. Currently, access to the inner estuary is restricted to a narrow shallow channel at low tide, but with unrestricted access at high tide. Fish passage in the water column is important to enable fish and invertebrates access to spawning sites, nursery habitat and feeding grounds, and fish passage would generally not be altered under the proposed port expansion. The access channel parallel to Foreshore beach would be sufficiently deep (1.5 metres at low tide) to enable access by fish [1]. It is possible that fish could be affected by any powerful lights shining on the channel at night. It would therefore be preferable to have strong lights facing away from the channel [1].

Subtidally, dredging and reclamation would replace a large area of shallow sandy habitat with deeper soft sediments. The dredging would cause a temporary loss of benthic productivity whilst the reclamation would cause a permanent loss of productivity within the terminal footprint. Colonisation of the dredge holes would be rapid (timescale of months), but 'recovery' to a condition that could be considered representative of this type of deep habitat could take in excess of two years [1]. Furthermore, fish assemblages in the dredge hole would differ to the shallows [1].

Unvegetated soft sediments provide habitat for mainly invertebrate animals (polychaete worms, amphipods and molluscs), which in turn are a supply of prey for wading birds and

food for fish in deeper water. Shallow, soft sediment habitats provide habitat for transient fish species of commercial value – tailor (*Pomatomus saltatrix*), southern herring (*Herklotsichthys castelnaui*), sand mullet, flat-tailed mullet and sea mullet – and non-commercial species including bait fish, gobies (*Gobiidae*), hardyheads (*Atherinidae*), perchlets (*Ambassidae*), sprats (*Sprattus*) and toad fish [1].

To the east of the boat ramp, the beach would be adjacent to the new terminal and be very sheltered from waves. Under these conditions, the pattern of erosion and accretion would cease at the eastern portion of the beach and be largely unchanged for the western portion. Given that the western beach would have a similar aspect to the present condition, it is to be expected that

similar types of benthic assemblages would be present following construction of the new terminal. Assemblages colonising the beach adjacent to the terminal and in the Penrhyn estuary would be likely to reflect a more sheltered, estuarine habitat. Surveys of benthic invertebrates in the intertidal zone indicate a relatively diverse assemblage of organisms, particularly in sheltered locations around the Penrhyn estuary. [1]

Seagrass provides food and habitat for fish and invertebrates and provides 'nursery habitats' for recreationally and commercially important species of fish and invertebrates such as prawns and crabs [1]. From a study on fish communities inhabiting separate meadows of the seagrasses *Zostera capricorni* and *Posidonia australis* in Botany Bay, it was concluded that about 50 per cent of the



Figure 2. A container vessel berthed at Port Botany. Photo courtesy of AECOM

dominant fish species associated with each seagrass habitat were of some economic importance [14]. Such species were usually residents or transients and made up most of the biomass in each habitat. Adults of these dominant economically important species were most abundant in both seagrass habitats during summer.

Hence, an increase in seagrass habitat is beneficial by attracting additional fish and marine life. The extent to which fish can use the seagrass lagoons depends on their depth. Anything greater than about one metre in depth can be used by a variety of large and small fish. The design of the seagrass habitat takes this into account as it would be submerged during low tide and water would be able to drain into the access channel to prevent any stranding of larger fish [1]. The loss of one hectare of mangroves results in a foregone opportunity for fish, shellfish and molluscs (539 kg/y) and for shrimps (146 kg/y), with an economic value for fisheries of 23,613 US\$/y.

The freshwater habitats of the drains are limited in size, restricted in diversity and polluted. They are also subject to very rapid flushing due to the highly cleared catchment. Few fish would access the drains – for example eels, mosquito fish, gudgeons and mullet – and fish passage in and out of the drains is not likely to be a major issue. Fish sampling in the existing brackish portion of the Penrhyn estuary indicates usage by a variety of fishes such as sea mullet, sand mullet, flat-tail mullet, yellowfin bream,

tarwhine and silver biddies. These species would use the estuary for a variety of functions, including shelter and feeding. [1]

Some fish species in NSW travel to and from freshwater bodies and barriers can cause extinctions to local populations. In the Penrhyn estuary, access needs to be considered in relation to movement between the estuary and Botany Bay, and the movement between Springvale and Floodvale Drains and the estuary and into Botany Bay. [1]

The structure associated with the proposed port expansion would generally be made of rock which could provide habitat for a variety of invertebrates and fish fauna. Limited information is available on the ecology of hard-substrata communities within the Bay, although much is known about the ecology of rocky intertidal and subtidal habitats at the entrance to the Bay (Cape Banks). Species lists available for these habitats suggest that communities on artificial surfaces are similar to those on natural rocky reefs, but often differ in the structure of the assemblage. [1]

Benthic algae are attached on some of the seawalls, on rubble and derelict pylons at the old Government Pier near the Penrhyn estuary. Most of this would be removed as a result of the proposed expansion (except for the Government Pier), but would colonise the new solid structures associated with the new terminal. [1]

Aquatic species that are considered critically endangered and endangered in the vicinity of

the site are the Loggerhead Turtle, Grey Nurse Shark, Murray Hardyhead, Eastern Freshwater Cod, Trout Cod, Oxleyan Pygmy Perch, River Snail, Green Sawfish, Blue Whale and Southern Right Whale.

Wood Production

Given the potential of mangroves for wood production, the loss of one hectare of mangroves results in a forgone opportunity for timber production (5976 kg/y) and fuel wood (5,140 kg/y) with a monetary value for forestry of 38,115 US\$/y. Data is taken from a meta-analysis on mangrove forests [15]. However, due to the very small mangrove area in the project bounds, this service is considered too small to be beneficial for potential harvesting of timber and firewood.

Water Provisioning for Transportation

Port development projects do not directly affect the abiotic conditions of the system to increase water provisioning for transportation, but it increases the facility to gain more from the existing presence of the service water provisioning for transportation. The extra terminal area and berths have a capacity of about 1.6 million TEUs per year (see Figure 2).

Regulating Services

Climate Regulation Through Carbon Burial

Due to the habitat changes and the carbon burial capacity of each habitat type, it was estimated that the port expansion project results in a small negative effect (see Table III). Although the newly created habitat contributes positively to carbon burial, it does not compensate for the forgone carbon burial

Table IV. Calculation of the impact on water quality regulation (denitrification, nitrogen and phosphorous burial).

Habitat		ha	Denitrification (kgN/ha/y)	N-burial (kgN/ha/y)	P-burial (kgP/ha/y)
Shore	Lagoon, bay	-59	61-63 [30, 31]	Negligible	Negligible
	Seagrass	+6	29.45 [32, 33]	134 [34]	20.1 [34]
	Mangroves	-1	No data	No data	No data
Inner estuary	Intertidal flat	+8.3	0-437 [35, 36]	56.9 – 252 [35-37]	3.64 – 40 [36, 38-42]
	Marsh	+2	0-437 [35, 36]	14.2 – 252 (see references intertidal flat)	0.91 – 40 (see references intertidal flat)
Hard substrata	Rock rubble	+1.9	21.9 [43]	0.7-0.8 [43]	0.10 [43]
Terrestrial	Dune, planted shrubland	-11.1	No data	277 [26, 44]	20 [26, 44]
Total impact in kg N or P/y (average values)			-1,500	-723	+120
Monetary value in €/y (40 €/kgN, 55 €/kgP)			-60,000	-28,920	+6,643

in lost habitats, predominantly shrubland. The monetary value of climate regulation through carbon sequestration which is calculated as the avoided reduction cost, i.e. the costs for emission reduction measures that can be avoided in other areas to reach the environmental targets such as the worldwide maximum 2 degrees Celsius temperature increase relative to the pre-industrial level of 1780. Data is based on a meta-analysis of several climate model studies [16]. A monetary value of 220 €/ton C or 60 €/ton CO₂-equivalent was used to calculate the economic value of carbon sequestration [17].

Water Quality Regulation

Predicted impacts on the Penrhyn estuary include a small increase in siltation, small changes in temperature and dissolved oxygen, and an increase in nutrients and faecal coliforms. Such impacts would place pressures on the Penrhyn estuary’s ability to provide viable habitat for shorebirds, although the direct and indirect impacts on shorebirds and their Penrhyn estuary habitats with a reduction in tidal flushing and water quality is difficult to predict. [1]

As a consequence of the dredging and reclamation, the Environmental Impact Statement predicted there would be greater turbidity at the discharge location and dredging in clay areas was expected to lead to extended turbidity [27]. Decreasing water clarity is particularly critical to protect the remaining seagrass from potential damage [1]. Turbidity associated with dredging was

generally lower than predicted. Modelling predicted up to 20 mg/L, however monitoring indicates less than 5 mg/L outside the silt curtain. Total suspended solids (TSS) throughout the dredging and reclamation period has not exceeded 50 mg/L, and only reached a maximum of 23 mg/L on one occasion [3].

While some water quality indicators have varied from pre-construction averages, overall water quality outcomes in the Penrhyn estuary are suitable to support the habitats enhanced by the Penrhyn estuary Habitat Enhancement Plan, with no indication to date of potential for the formation of eutrophic conditions. Total levels of nitrogen (N) and phosphorous (P) did not change post-construction. [28]

Based on the habitat changes, an overall small negative effect on water quality regulation is estimated for the area (see Table IV). Although the newly created habitat contributes positively to nutrient removal from the water, it does not compensate for the forgone nutrient removal in the lost habitats and shrubland in particular. For the bay area, no effect for N and P burial is included since sedimentation rates are considered limited. For the monetary value, the shadow price for nitrogen and phosphorous removal (€/kg N, €/kg P) is used which is the cost for an equal removal of nitrogen using (other) technical investments. For nitrogen removal, a monetary value of 40 €/kg(N) was used, this is the average from the range found in literature (5 – 74 €/kg(N), [29]. For phosphorous

removal, a monetary value of 55 €/kg(P) was used, this is the average from the range found in literature (8 - 103 €/kg(N), [29]).

Air Quality Regulation

Air quality is expected to be affected by dust emissions during the Port Botany Expansion’s construction. Dispersion modelling of construction emissions showed dust concentrations and deposition rates comply with EPA criteria and would not result in significant impacts on surrounding land uses [45]. Monitoring in 2011 did not record PM10 exceedances compared to the PM10 dust goal of 50 µg/m³ [27]. Changes in habitat types decreased the potential for fine dust capture in the area by reducing the presence of above ground vegetation (see Table V). Loss of 11.1 hectares planted shrubland and one hectare of mangroves is replaced by only two hectares of marshes which is the only habitat type with a potential to capture fine dust. The monetary value of air quality regulation through fine dust removal is calculated as the avoided damage to human health (€/kg PM10). This is based on studies on the damage to human health due to fine dust emission, with an average of 54 €/kg [29].

Flood Protection

Hydrologic modelling – to determine surface water flow rates under design rainfall conditions – and hydraulic modelling – to determine the flood water levels – before and after the proposed development showed the Port Botany Expansion would not have an adverse impact on local flood behaviour in the catchments surrounding the port or cause an increase in flood levels within the Penrhyn estuary [45]. Modelling concluded there would be very little change in the tidal prism of the bay due to the expansion. Tide heights in the Penrhyn estuary are – and would remain – the same as in the rest of Botany Bay. Since these heights are unchanged, the tidal penetrations in Springvale and Floodvale Drains would also remain the same [1].

The purpose of the subtidal rock walls – constructed between the tug berth area and the downstream end of the estuary channel and as an extension of the boat ramp rock revetment – is to dissipate energy arising from tug vessel operations, which will reduce potential for scour of the estuary channel and

Table V. Calculation of the impact on air quality regulation (fine dust capture by vegetation).

Habitat		Ha	Fine dust capture (kg/ha/y) [46]
Shore	Lagoon, bay	-59	0
	Seagrass	+6	0
	Mangroves	-1	44-88
Inner estuary	Intertidal flat	+8.3	0
	Marsh	+2	18-36
Hard substrata	Rock rubble	+1.9	0
Terrestrial	Dune, planted shrubland	-11.1	18-36
Total change fine dust capture in kg/y (average values)			-312
Monetary value €/y (54 €/kg)			-16,848

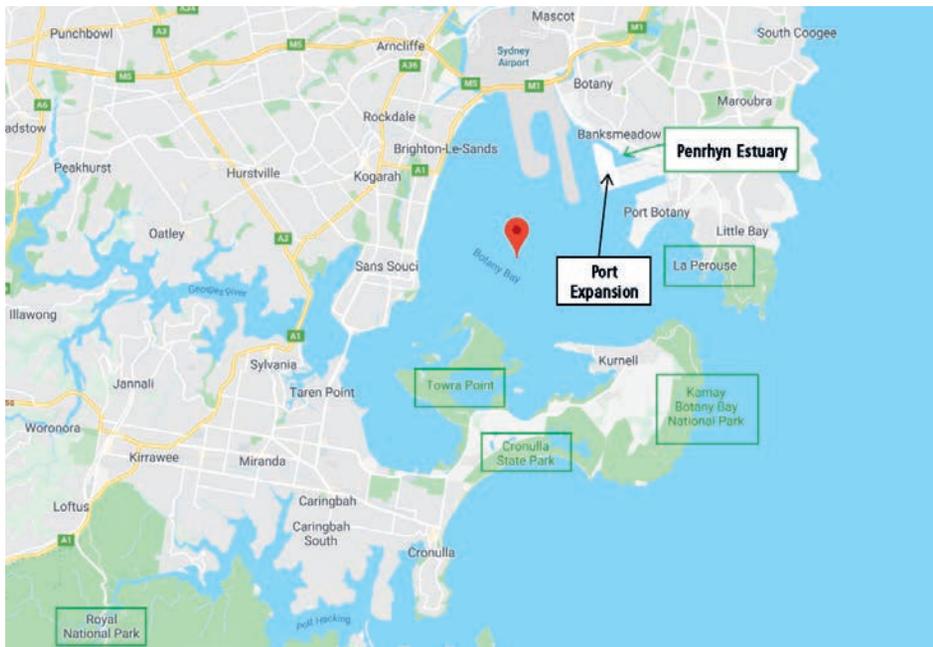


Figure 3. National parks in the vicinity of Botany Bay. Image courtesy of Google Maps

protect recreational boat users from tug vessel wash [12]. In the long term, the new terminal would cause a small reduction in wave energy in some parts of the study area and have no effects in other parts. Importantly, there would be no increase in wave height in areas where seagrass would be retained [1].

The loss of mangrove areas is considered to be negative for coastal protection (Lee et al. 2014). However, in the case of the Botany Bay port expansion, this seems of low importance and the area is too small to present any significant impacts for the protection of the city Sydney.

Sedimentation and Erosion Regulation

Different habitat types contribute differently to sedimentation and erosion regulation, and this depends on local conditions such as water currents and sediment type. Monitoring sedimentation and erosion rates before and after the project is necessary to get a good idea of the impact. Physical disturbances to seagrass patches were not observed. Sedimentation was different at each location and was generally below 20 mm/y [3] and later generally below 25 mm/y [27]. Due to a lack of comparable pre-construction data, it was not possible to compare this to pre-construction conditions. Increased deposition was observed in March 2011, however this returned to normal levels the

following month. The increased deposition was associated with observed beach erosion along Foreshore Beach, and the disturbance was likely due to the removal of the seagrass silt curtain. A subsequent increase and decrease to sediment deposition at the various stations over time indicates sand movement in the retained seagrass area. However, sand deposition has remained low across the retained seagrass area.

In the estuary's intertidal flat and marsh areas, there is a trend towards deposition. Due to a lack of comparable pre-construction data, it was not possible to determine if the observed rate of deposition to date is within the normal pre-construction range. Sediment deposition does not appear to be related to dredging or other project related activities. The predicted average deposition rate was 20 mm/y, and the recorded average sediment deposition rate varied between years: 11 mm/y [3] and 23.7 mm/y [27]. While this exceeds the 20 mm/y annual deposition limit set in the Minister's Conditions of Approval (MCOA), it remains below the annual siltation rate of 26 mm/y predicted by modelling carried out for the Environmental Impact Statement. [27].

Overall, sediment deposition in the area will be enhanced with the project which is positive for nutrient and carbon burial. However, this

could result in a complete silting up of the Penrhyn estuary since the area cannot further expand with the presence of the surrounding walls and road. For the survival of seagrass, deposition rates should not be excessive.

Cultural Services

Opportunities for Recreation

The habitat enhancement plan and recreation plan developed alongside the port expansion project enhances recreation possibilities in the area. Part of the habitat enhancement design for Penrhyn estuary habitat is, on the one hand, to provide controlled public access and, on the other hand, to minimise disturbances within the estuary [12]. A number of facilities are integrated with the project to benefit the local community. A pedestrian and cycle path, large car park and amenity buildings should improve the access to the area in a controlled way. An elevated viewing platform and native landscaping near the mouth of the Mill Stream are developed to enjoy the enhanced natural features of the area – such as reinstatement of foreshore dune areas, intertidal sand and mudflats, salt marsh and seagrass habitats without disturbing the nature area. A specially designed bird watching platform and seating accessed from a boardwalk was developed to enjoy the migratory shorebirds for which the encompassing Penrhyn estuary is an important ecological habitat [1].

Improvements to Foreshore Beach would enhance access arrangements and public recreation opportunities, especially along the foreshore and connections with Sir Joseph Banks Park. In the northern part, the development of a beach was not considered viable as the slope was too steep, therefore, a rock wall was constructed to discourage swimming in the estuary channel. This offers further benefits such as better protection for seagrass habitat from disturbance as well as discouragement from entering Penrhyn estuary outside of the designated access path [12]. To improve the land-water connection, a new four-lane boat launching ramp was developed. With the port expansion, there would be a loss of about 1.5 per cent of bay waters for recreational fishing [1]. As seagrass is an important habitat for the fish communities, enhanced seagrass habitat is expected to improve the occurrence,

abundance and biomass in the area [14]. An enclosed fish cleaning facility is foreseen to prevent birds from being attracted to the area, an important feature due to its proximity to the airport [2].

The loss of mangroves is negative for recreation but is expected to be compensated for through the newly created areas adding opportunities for recreational fishing and attracting birds.

The presence of marine mammals could be affected by the port expansion. Effects are mainly expected for the Southern Right Whales which are sensitive to sounds [12], possibly reducing opportunities for whale watching in the area.

Although several large national parks are present around Botany Bay's southern side, the presence of the Foreshore Beach and Penrhyn estuary could add an important recreational benefit to the inhabitants (see Figure 3).

Cultural Heritage

In the context of this research, heritage comprises both cultural and natural aspects. The Millennium Ecosystem Assessment defines cultural heritage as 'memories' in the landscape from past cultural ties. There are two features of notice in the study area which are not affected by the project: Government Pier and Aboriginal heritage. The significance of the pier lies in its association with the Government's first attempt at fostering trade and creating port infrastructure within Botany Bay [45]. Historic remains of Government Pier are present in the study area but will not be disturbed as part of the works while no Aboriginal sites or artefacts have been found [27].

Biodiversity

Biodiversity is not considered an ecosystem service in itself but there is a strong positive feedback mechanism between biodiversity and service delivery. For example, biodiversity will be higher under good water quality conditions, and a higher biodiversity may increase removal of excessive nutrients as a result of niche partitioning within a certain habitat. Other services however may have negative feedback mechanisms with biodiversity. Recreation may result in a decline

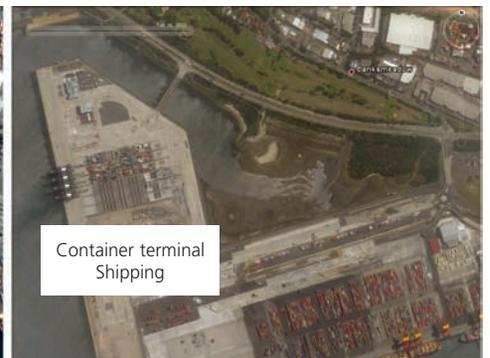


Figure 4. Photographed on 22 July 2006, a Southern Right Whale (*Eubalaena australis*) seen in Botany Bay (left) and an Australian Fur Seal (*Arctocephalus pusillus doriferus*) spotted off Botany Bay's Molineaux Point. Photos DEC [12]

of species richness due to trampling or repeated disturbance, but on the other hand, recreational attraction may be higher if a higher diversity of species is present. Although the relationships between biodiversity and ecosystem services are complex and service dependent, it is believed the creation of habitats which are new – such as artificial reefs and sand engines – or more natural – depoldering – habitat increases both biodiversity and service delivery for each of the habitat types.

The port expansion project is expected to have a positive impact on birds –mainly shorebirds – but more time is needed to see the full impact. There are seven key species of interest in this area: the Bartailed Godwit, Red-necked Stint, Double-banded Plover, Curlew Sandpiper, Red Knot, Pacific Golden Plover, and Sharp-tailed Sandpiper. Feeding and roosting areas could be disturbed from changes such as lighting regime, increased movement, noise from construction and operation of the port [1]. This might be

ES	Total effect
Fish production	+
Agricultural production	
Wood production	
Water production for potable water	
Water provision for transportation	+
Climate regulation	-
Water quality regulation	-
Air quality regulation	-
Flood protection	
Sedimentation and erosion regulation	+/-
Recreation	+
Heritage	
Cognitive development	
Biodiversity	+



Bay -59ha

- Fish production
- Climate regulation
- Water quality regulation
- Recreation
- Biodiversity

Mangroves -1ha

- Fish production
- Nursery function
- Water quality regulation
- Climate regulation
- Air quality regulation
- Biodiversity

Shrubland -11ha

- Climate regulation
- Water quality regulation
- Air quality regulation
- Biodiversity

Seagrass +6ha

- Fish production
- Nursery function
- Water quality regulation
- Climate regulation
- Biodiversity

Intertidal flats +8ha

- Fish production
- Nursery function
- Water quality regulation
- Climate regulation
- Biodiversity

Marshes +6ha

- Water quality regulation
- Climate regulation
- Air quality regulation
- Biodiversity

Shore +8ha

- Recreation
- Heritage

Figure 5. Summary of the ES effects of the Botany Bay project. The main benefit for the container sector (in black: shipping) is the main project benefit considered in the initial project evaluation. All additional ecosystem services effects are indicated in green (if positive) or red (if negative).

problematic since the Penrhyn estuary is a significant habitat for migratory shorebirds listed under international treaties or as threatened species under both Commonwealth and NSW legislation [12].

A habitat enhancement plan developed along with the Port Botany expansion has a central aim to improve shorebird feeding and roosting habitat as this area – and especially Penrhyn estuary – is an important spot for migratory shorebirds. Planted shrubland (10.5 ha) and mangroves (1 ha) are removed and converted to intertidal flats (11 ha), saltmarsh habitat (5 ha) and seagrass habitat (8 ha) [1]. Three islands have been included in the estuary design to provide secure roosting sites for shorebirds [12].

Benthos is an important feeding source for birds therefore benthic assemblages were studied in Botany Bay to determine the short- and the long-term consequences of dredging in marine sedimentary environments [47]. Monitoring in the study area revealed a positive trend with increasing benthos abundance and biomass [3].

A positive link is expected between the benthic community and shorebirds, but it is too early to test properly. It is expected that at least a five year period is needed for the benthic community to fully colonise the newly

created area. Nevertheless, many shorebird species have been observed at Penrhyn estuary: 16 species after the first monitoring period with 11 migratory and five non-migratory shorebird species [3] and a total of 22 species after the second monitoring period with 16 migratory and 6 non-migratory species [27]. Bar-tailed Godwits, Black-winged Stilts, Masked Lapwing, Pacific Golden Plover and Red-capped Plovers have been the most numerous, with other shorebird species being observed occasionally or rarely.

Between 2009 and 2011, a reduction in the number of migratory birds has been observed [27]. For the resident shorebirds, there has been a shift in the species of birds observed in the estuary with a reduction in black winged stilts, but an increase in red capped plovers and masked lapwings. It is difficult to make conclusions as to what has caused this shift in resident species and reduction in migratory species – it is likely from a combination of factors that may not be directly attributable to construction activities. Further monitoring is required to see the real impact of both the port expansion and the habitat enhancement plan.

The impact for marine mammals is also considered (see Figure 4) since Botany Bay and its surrounding waters are visited by the Southern Right Whale (*Eubalaena australis*)

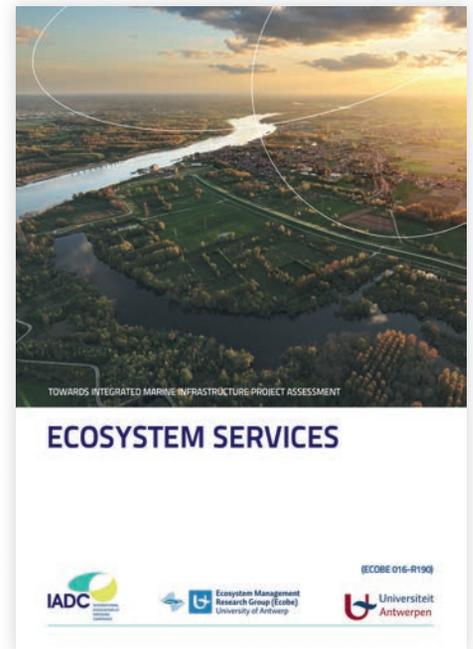


Figure 6. To help dredging industry professionals, especially those who are in the position to further the ecosystem services concept within their own organisations as well as project stakeholders gain an understanding of the value of the ecosystem services approach, the IADC commissioned a study which was carried out by the Ecosystem Management Research Group (ECOBIE) of the University of Antwerp. Download the free report *Ecosystem services: towards integrated marine infrastructure project assessment* at <https://www.iadc-dredging.com/ul/cms/fck-uploaded/documents/report-ecosystem-services-low-res.pdf>

Table VI. Summary of the impact of the port expansion project in Botany Bay on ES.

ES	Overall effect	Summary main effects
Food production: fish	+	increase nursery area
Wood production		not relevant since the area is too small to be beneficial for potential harvesting of timber and fire wood from mangroves
Water provision for transportation	++	Project target: Increased possibilities to use this service (economic benefit)
Climate regulation	-	Positive effect of newly created habitat is smaller than the negative effect of the lost habitat
Water quality regulation	-	Positive effect of newly created habitat is smaller than the negative effect of the lost habitat
Air quality regulation	-	Due to a loss of above ground vegetation
Flood protection		not relevant, small area
Sedimentation and erosion regulation	+/-	sediment deposition: positive and negative for other functions
Recreation	+	enhanced with the recreation plan
Heritage		no impact; remains are integrated in the design
Biodiversity: shorebirds, marine mammals	+	positive impact on shorebirds was expected, but more time is needed to see the full impact

and the Humpback Whale (*Megaptera novaeangliae*). Occasional visitors can include the Bottlenose Dolphin (*Tursiops truncatus*), Common Dolphin (*Delphinus delphis*), Pygmy Sperm Whale (*Kogia breviceps*), Australian Fur Seal (*Arctocephalus pusillus doriferus*) and Leopard Seal (*Hydrurga leptonyx*). Visiting more regularly in deeper parts of the Bay, Southern Right Whales may be affected by the port expansion due to sources of lower frequency noises and slower moving commercial shipping vessels [12].

To be enhanced with the port expansion, commercial shipping could potentially bring 'introduced species' with it. Toxic and pest species as well as exotics could affect the fauna and flora local community. This risk already existed in the area with the port facilities, but could be increased with the expansion. As for introduced species previously brought to Botany Bay, there is some risk of changes caused by the dredging of settled sediment containing toxic dinoflagellates present as cysts as well as *Caulerpa taxifolia* presently occurring along Foreshore Beach which could threaten the seagrass habitat [1].

STEP 4: EVALUATION

The conversion of a part of the bay, shrubland and mangroves for the port's expansion including the habitat enhancement of the Penrhyn estuary generates both positive and negative effects on ecosystem services (see Figure 5 and Table VI).

The habitat enhancement plan is developed for biodiversity – shorebirds mainly – and recreation, and presents positive impacts for fish production by the development of more nursery area. However, the large areas of habitat converted into terminal area results in net negative effects for the regulation of climate, water quality and air quality. Since the main benefits to recreation and biodiversity are among the most difficult ES to assign monetary values, a monetary assessment of this project does not contribute to an objective project evaluation.

The negative effects should be evaluated in a broader management plan for the area in relation to factors such as water quality and climate.

CONCLUSIONS

An ES assessment can help in the implementation of sustainable port development projects. It provides a framework to evaluate the societal benefits and negative impacts of existing and planned projects. Furthermore it can be used to evaluate and compare different alternatives of project's design as well as location to inform decisions based on project targets (Prosperity and People) but also on a broad range of societal benefits (Plants and People). This enables a better comparison between project alternatives, taking into account subtle differences to the environment. It will also depict the alternatives which properly contribute to the environment and not just compensate negative effects.

By targeting a variety of ecosystem services from the conceptualisation phase of a project and optimising its design for additional benefits, innovation efforts shift away from 'avoiding damage' to 'creating opportunities'. Taking ecosystem services into account from the design phase of a project allows a comprehensive and more objective evaluation of the potential benefits and impacts of port development projects covering Prosperity, People and the Planet. It can add value to a project which might otherwise be missed out on while creating awareness and receiving support from different stakeholders.

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