FINAL REPORT

Project 1.9

November 2022

Quantifying the ecosystem services of the Great Southern Reef

Centre for Marine Science & Innovation, School of Biological, Earth & Environmental Sciences, UNSW Sydney

Institute for Marine and Antarctic Studies, University of Tasmania

Centre for Environmental Economics and Policy, UWA School of Agriculture and Environment, The University of Western Australia

UWA Oceans Institute, School of Biological Sciences, The University of Western Australia

Global Ocean Accounts Partnership, UNSW Sydney, Faculty of Law

Milestone number: 6

Research Plan number: RP2021

Please address inquiries to Aaron Eger, aaron.eger@unsw.edu.au

Preferred citation

Eger, A.M, Bennett, S., Zimmerhackel, J., Rogers, A., Burton, M., Filbee-Dexter, K., Wernberg, T., Gacutan, J., Milligan, B., Vergés, A. (2022) Quantifying the ecosystem services of the Great Southern Reef. Report to the National Environmental Science Program. University of New South Wales.

Copyright

Acknowledgement

This work was undertaken for the Marine and Coastal Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Program (NESP).

NESP Marine and Coastal Hub partners

The Australian Institute of Marine Science, Bioplatforms Australia, Bureau of Meteorology, Charles Darwin University, Central Queensland University, CSIRO, Deakin University, Edith Cowan University, Flinders University, Geoscience Australia, Griffith University, Integrated Marine Observing System, James Cook University, Macquarie University, Murdoch University, Museums Victoria, NSW Department of Planning and Environment (Environment, Energy and Science Group), NSW Department of Primary Industries, South Australian Research and Development Institute, The University of Adelaide, University of Melbourne, The University of Queensland, University of New South Wales, University of Tasmania, University of Technology Sydney, The University of Sydney, University of Western Australia, The University of Wollongong

Disclaimer

Cover images: The Great Southern Reef is home to endangered giant kelp forests in Tasmania: © Stefan Andrews

This report is available on the NESP Marine and Coastal Hub website:

www.nespmarinecoastal.edu.au

Contents

List of figures

List of tables

Executive summary

Ecosystems provide numerous services and benefits to society. While historically overlooked, these services are increasingly recognized and are now being mapped and accounted for. There are several approaches to mapping and evaluating these ecosystem services. In this report, we use two increasingly common approaches, Ocean Accounting and Welfare Economics, to evaluate ecosystem services for the Great Southern Reef.

The Great Southern Reef is a network of rocky reefs dominated by temperate algal forests known as kelp. It spans over 8,000 km of coastline and two thirds of the Australian population live alongside it. Despite its presumed importance, there has been little work quantifying the extent and value of the ecosystem services provided by the Great Southern Reef.

Through a systematic review we assessed the current state of knowledge of the ecosystem services provided by the Great Southern Reef. Using the Common International Classification of Ecosystem Services (CICES) framework, we created an overview of the ecosystem services (provisioning, regulating, and cultural) provided by the Great Southern Reef in New South Wales, Victoria, Tasmania, South Australia, and Western Australia. We then created metrics to quantify how these services benefit coastal societies in these five states.

Highlight summaries include over 17 million Australians who live within 50 km of the reef, 26 wild seaweed harvest companies, 115 tourism SCUBA operators, 1436 mapped dive sites, 18 million tourist visits each year, 16 temperate marine biology university programs, 43 books and films, key medical products, 23 tons of harvested seaweed, 1116 grams of carbon per m^2 used for growth each year, 2,361 peer-reviewed scientific publications from 1976 to 2022, 186 marine protected areas, 2.16 million recreational fishers, and over 28 commercial fisheries with 20,000 tons of biomass taken each year. We also show that there is 163,936 km^2 of unmapped habitat in the Great Southern Reef.

We then conducted economic evaluations using these biophysical values and the available information. Using a variety of approaches, we found that the total economic value of the Great Southern Reef was $11.56 billion each year. Individually the values were as follows, commercial fishing (producer surplus - $33.2 million), carbon sequestration (avoided damages - $37.8 million), nutrient cycling (avoided damages - $6,484 million), recreational fishing (consumer surplus - $1,668 million), diving and snorkelling (consumer surplus - $403 million), other recreational activities (consumer surplus $1,836 million), and the existence value (consumer surplus - $1,096 million).

Acknowledging that the total economic values figures are based on an ‘all-or-nothing’ scenario of the Great Southern Reef continuing to provide all ecosystem services, we also evaluated a scenario to estimate the cumulative total economic value associated with a 20% loss of Great Southern Reef ecosystem services over the next 20 years. The proposed 20% loss is a hypothetical but clearly plausible scenario, and the analysis is more appropriately grounded in economic theory than the ‘all-or-nothing’ evaluation. These losses accumulated over 20 years amount to the following values: commercial fishing ($65 million), carbon sequestration ($74 million), nutrient cycling ($12,726 million), recreational fishing ($3,274 million), diving and snorkelling ($791 million), other recreation ($3,603 million) and existence value ($8,830 million). The cumulative total economic value of $29.4 billion illustrates the potential benefits that we stand to lose should the Great Southern Reef continue to be adversely affected by climate change and other anthropogenic pressures and a 20% loss of services over the next 20 years is actually realised.

We evaluated how these values may be combined to create a national ocean account for kelp forests and the Great Southern Reef. The main barrier to such an account is the lack of comprehensive habitat mapping for kelp forests and other biotic habitats across the reef. Further, very little of the ecosystem services were spatially explicit and higher resolution data is needed to create an ocean account.

This project brings together a first order approximation of the ecosystem services provided by the Great Southern Reef and their economic value. While tabulating these values at such a large scale is a considerable accomplishment, there remain numerous data gaps and data quality improvements to be made. As such, these values should be considered as one step in an iterative process and will be updated as more and higher quality data becomes available.

1. Introduction

1.1 Great Southern Reef and its defining kelp forests: importance and knowledge gaps

The Great Southern Reef (Great Southern Reef) is an interconnected system of temperate rocky reefs that span over 8,000 km along the southern half of the Australian continent, from northern NSW (~28.5°S) to Kalbarri in Western Australia (27.7°S; Bennett et al. 2016; Map Figure 4). These rocky reefs are largely defined by the distribution of golden kelp (*Ecklonia radiata*, order Laminariales*;* hereafter 'Ecklonia'*)*, which dominates shallow reefs throughout temperate Australia, New Zealand and south-eastern Africa (Wernberg et al. 2019b).

Ecklonia occurs on hard substrates from the shallow subtidal to mesophotic reefs up to 60 m depth in Australia. While *Ecklonia* forms monospecific forests throughout much of Australia, it can also be found interspersed with other large canopy-forming fucoid seaweeds (e.g., *Phyllospora comosa*, *Cystophora spp*. *Durvillaea potatorum, Sargassum spp*.; order Fucales). In the south-eastern Australia *Ecklonia* is also often found adjacent to other large laminarian kelp species such as giant kelp (*Macrocystis pyrifera*), and *Lessonia corrugata*.

Here, we quantify the ecosystem services of Australia's Great Southern Reef by including all shallow (0-30 m) rocky reefs and the shallow margin of mesophotic reefs to depths of 50 m, including *Ecklonia* as well as other canopy-forming fucoids and laminarian species. Where possible, we estimate services for the reef area as a connected set of ecosystems, failing that, we estimate services for "kelp forests" from the orders Laminariales and Fucales, and failing that, we estimate services for the regionally dominant kelp, *Ecklonia radiata.*

It is important to note that these kelp forests are found within a mosaic of other shallow coastal habitats including seagrass meadows, sandflats, mudflats, saltmarshes, mangrove forests, oyster reefs and sponge gardens. There is high connectivity between these other habitats and kelp forests, as well as with deeper habitats along the continental shelf. Most of Australia's kelp forests lie within the 'coastal zone' and are therefore under state jurisdiction (i.e., within 3 nautical miles or 5.5 km from shore). They are managed independently by the five states in which they occur: Western Australia, South Australia, Tasmania, Victoria and New South Wales (Figure 4).

The Great Southern Reef was first described as an ecological entity in 2016 to raise awareness about the importance of kelp forests as a valuable and interconnected system that is shared by millions of Australians who live right alongside it (Bennett et al. 2016). The Great Southern Reef is thus not only interconnected through oceanographic, ecological and evolutionary processes but also by providing highly valuable social, cultural, environmental and economic benefits to 70% of Australia's human population, who live within 50 km of this ecosystem (Bennett et al. 2016).

From an ecological perspective, the Great Southern Reef is particularly remarkable because of its high productivity (Kirkman 1984) and as a global biodiversity and endemism hotspot for multiple taxa including seaweeds, sponges, crustaceans, chordates, bryozoans, echinoderms and molluscs (Bennett et al. 2016). Many of these species are found nowhere else on the planet. The rate of endemism among fish and mobile invertebrates on the Great Southern Reef is 77% (Bennett et al. 2016). By contrast, fish and mobile invertebrate endemicity on the Great Barrier Reef is about 7% (Graham Edgar, pers comm).

A major concern is that kelp forests of the Great Southern Reef are rapidly diminishing in many regions due to ocean warming, marine heatwaves and pollution (Wernberg et al. 2011, Layton et al. 2020). In 2011 alone, 96,300 hectares of kelp forest were lost in Western Australia (Wernberg et al. 2016). Giant kelp (*Macrocystis pyrifera*) forests of South-east Australian ecological community are also listed as a threatened ecological community under the EPBC Act, following losses in Tasmania of 95% in area over the last few decades (Butler et al. 2020). Warm-affinity species are moving south and transforming reefs, with major implications to local ecosystems. For example, long-spined sea-urchins have already caused the collapse of 15% of reefs in Tasmania and are projected to cause the degradation of 50% of reefs by 2030 at current rates (Ling & Keane 2018). At the warm edge of their distribution, kelp forests are also threatened by the range expansions and growing populations of tropical herbivorous fishes, which can either overgraze kelp or prevent its re-establishment following impacts from warming (Bennett et al. 2015b, Vergés et al. 2016, Zarco-Perello et al. 2017, Smith et al. 2021). Further, human population growth along the Great Southern Reef is increasing pressure on fish stocks, causing coastal runoff and eutrophication of reefs (Evans et al. 2017).

Evidence-based management of Australia's declining kelp forests is hindered without accurate estimates of their contribution to society and the economy. Knowledge and data gaps about the extent and benefits of our kelp forests hinder monitoring and evaluation. We are losing our kelp forests without fully understanding the benefits they provide. In this project, we have systematically compiled and synthesised existing data on the extent and benefits provided by the kelp forests of the Great Southern Reef, including market and non-market values and highlighted specific knowledge gaps. We have aligned the available biophysical data with existing accounting standards to ensure compatibility with ongoing and future efforts, to facilitate management and policy targets and to ultimately support evidence-based decision making.

Quantifying and assessing the benefits of Australia's kelp forests is relevant in the context of the UN Decade of Ocean Sciences, achieving the UN Sustainable Development Goals, the growing the field of ocean accounting, and developing cost-benefit analyses to inform restoration efforts linked to the UN Decade on Restoration.

1.2 Ecosystem measurement, valuation and links with economy and society

The last decade has seen growing optimism for oceans as a solution for food and energy security (Stuchtey et al. 2020), and a source of economic growth and prosperity (Organisation for Economic Co-operation and Development 2011). There is an increasing recognition that economic sectors, human wellbeing and prosperity are contingent on the health of ecosystems and the goods and services they provide (Liquete et al. 2013).

The concept of 'capital' as a stock that produces goods and services has long been applied to the natural environment (Ekins et al. 2003). 'Natural capital' (e.g., an ecosystem) is responsible for the yield of certain goods and services ('ecosystem services') that in turn contribute to human well-being, not only in providing food and raw materials but also in maintaining a habitable environment and satisfying intangible needs (Bennett et al. 2015a). The use of natural capital and ecosystem service concepts provides a means to identify and measure feedbacks between the environment, society, and the economy, where natural capital and ecosystem services assessments have become central in communicating the consequences of ecosystem change on human and societal wellbeing (Luisetti et al. 2014).

Natural Capital Accounting (NCA) is an umbrella term that covers accounting frameworks to measure the stocks of natural capital and its flows to economy and society. A NCA approach recognises the importance of the environment as an asset that needs to be properly managed and conserved, so that its contributions (through services) may continue to benefit people. There are several NCA approaches, including the internationally accepted standard UN System of Environmental-Economic Accounting (SEEA). The SEEA provides guidance towards the measurement of natural resources (water, energy, air emissions) and emissions (wastes, air emissions), in addition to measuring the extent, condition and services provided by ecosystems. This standard advances environmental accounting by providing a format to present information in both physical units (e.g., litres, hectares and tons) alongside their monetary value. A critique common to NCA approaches, however, is the domain of values captured within accounting tables, which tend to focus on market goods and quantified instrumental values, relevant to ocean-based economic growth and material aspects of human wellbeing. As such, intangible and non-material values that are equally important to human wellbeing are under-represented.

A complementary approach for evaluating the contribution of ecosystem services to people is Welfare Analysis. Embedded in the economic consumer demand theory, Welfare Analysis approach environmental evaluations using the framework for Total Economic Value. Importantly, this framework includes the capacity to integrate intangible or non-material values, termed 'non-market values', in ways that make them commensurate with other market-based values, explained further in Section 1.5. Different to NCA, which is focussed on understanding whether there are changes occurring in stocks and flows, Welfare Analysis is aimed at evaluating whether or not a policy, project or program is worthwhile doing. For example, if a change is recognised in an ecosystem service account, and managers are considering intervening in some way, a Welfare Analysis can identify whether there is an aggregate net benefit of undertaking such an intervention, or it can rank and prioritise how investment should occur among a set of possible management actions. It also provides us with a measured understanding of the loss in value that will be incurred by a community if we allow a habitat and its associated ecosystem services to decline by a certain extent over time.

Here, we present the best available knowledge and data that could be compiled into an accounting structure in support of Natural Ocean Capital Accounts. Further, we separately estimate the range of market and non-market benefits associated with the Great Southern Reef that are appropriate for inclusion in Welfare Analyses.

1.3 Overview of this report

This project has 6 key objectives:

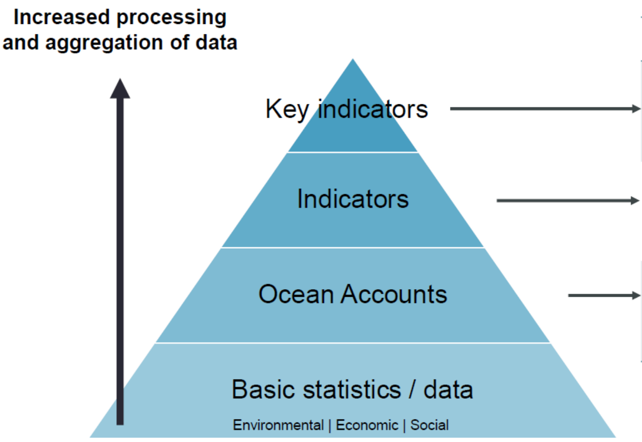
- Provide an overview of the ecosystem services provided by the Great Southern Reef with a focus on kelp forests and the dominant, habitat forming *Ecklonia radiata*.
- Describe and assess the feasibility of the different evaluation approaches for valuing these services.
- Use available information to enumerate the biophysical values of the ecosystem services provided by the Great Southern Reef.
- Provide economic evaluation estimates of these services.

- Highlight the current limitations preventing full evaluations of these services.
- Provide recommendations for conducting a comprehensive evaluation country wide.

1.4 What is ocean accounting?

Effective and justifiable policy relies on a diverse array of information, proper implementation, and public support across Australian society (National Marine Science Committee 2015). This often involves balancing social, economic, and environmental considerations (‘triple bottom line’), which are further framed within the context of sustainability. Traditional approaches to measure the ocean environment and its links with society and the economy have largely been *ad hoc*, with limited coherence between datasets and a fragmentation of information between institutions.

The SEEA provides an approach to standardise and collate information into a ‘common set of facts’, achieved through an internationally agreed upon set of definitions and classifications. It stipulates a set of principles and processes to organise social, economic, and environmental data, and ensures the information is spatially and temporally comparable. Ocean Accounting, as an extension of SEEA and national accounting, seeks to identify and measure links between the ocean, society, and the economy. The information produced is aligned with other sets of information, such as national accounts, making them of relevance to a wide audience including managers, policy-makers, and the public (Figure 1). In other words, ocean accounts are integrated records of economic activity (e.g., sale of fish), social conditions (e.g., coastal employment and poverty), and environmental conditions (e.g., extent / condition of kelp) that are compiled on a regular basis (e.g., annually) and are compatible with international statistical standards.



Role	Audience
Support broad communication	Public, high-level policy makers, law makers
Support decision- making, policies	Government officials, policy analysts, managers, stakeholders
Support in-depth analysis	Policy analysts, researchers, statisticians

Modified from UNECE 2017 & TG (v0.9)

Figure 1 Aggregation of data from basic statistics and data to indicators, through an accounting framework. The related table identifies the role played in communication and expected audience.

An accounting framework (Figure 2) structures ocean ecosystems into assets of a particular size (i.e., extent) and type (e.g., kelp, seagrass, mussel bed) of a condition, based on reference conditions or other indicators. These ecosystems are responsible for the production of goods and services (henceforth 'ecosystem services', such as raw materials, protecting coastlines, a place for recreation), that benefit human health and wellbeing, through their use by individuals, businesses, government, household, or community.

Therefore, decision makers may monitor policies and management interventions, which may impact the extent of ecosystems and the flow of services. For services that are not easily (or should not be) valued in monetary terms, accounts may be presented in both physical (e.g., litres, hectares) while other, more easily monetized services are represented in monetary units (Figure 3). A set of accounts, maintained over time, may then be used to monitor the condition and sustainable of the ecosystem over time, allowing for informed management and evidence-based decision making (Figure 2).

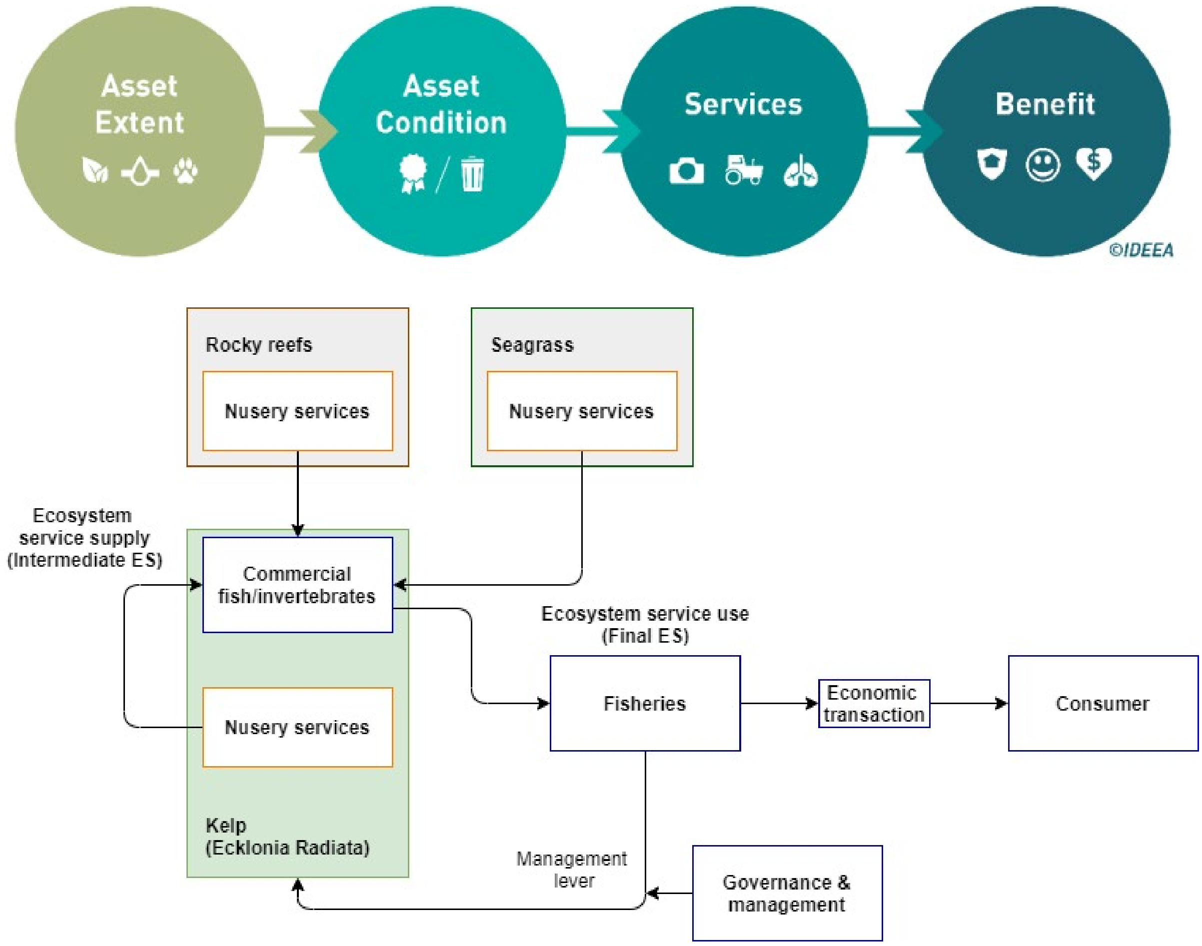


Figure 2 Core ecosystem accounting framework, adapted from Eigenraam and Obst, (2018) and IDEEA group (2020).

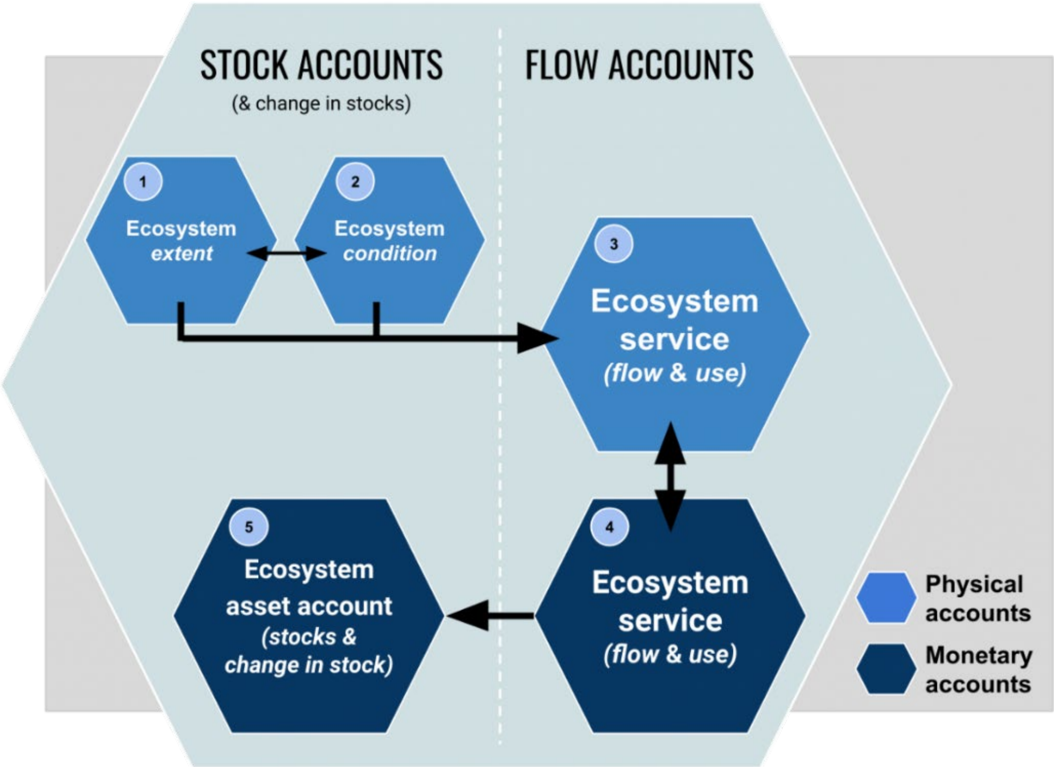


Figure 3 Ecosystem accounting framework (from SEEA-EA, 2012). Note that the accounts stem from physical measures of the environment.

1.4.1 Ocean accounting within Australia

The need for OA has been endorsed internationally by national statistical offices and international institutions. Currently, 16 Heads of State, as members of the High-Level Panel for a Sustainable Ocean Economy ('Ocean panel'), have committed to 100% sustainable management of national waters. Australia, as a member of the Ocean Panel, has committed to the compilation of national Ocean Accounts by 2025. In support of this commitment, a partnership between the Department of Water, Agriculture, and the Environment (DAWE) and the Australian Bureau of Statistics (ABS) have begun the scoping and development of Ocean accounts (specifically ecosystem accounts, after SEEA-EA) for seagrass and mangroves, with the intention to extend to other ocean ecosystems and deliver preliminary accounts by 2023.

Several pilot accounts have been compiled within Australia, including Geographe Bay Marine Park, Western Australia and Lake Illawarra, NSW, to test and extend accounting concepts to the Australian context. The Geographe Bay Ocean Accounts pilot identified the utility of accounts to monitor the 'State of the Environment', by providing a standardised means of assessing ecosystems and their services over time. The development of Ocean accounts, both within Australia and Internationally, are supported by the Global Ocean Accounts Partnership (GOAP), as a multi-institutional collaboration mechanism to share experiences and lessons learnt between countries within the growing community of practice.

1.5 What is welfare economics?

Economic valuation measures the change in utility, or welfare, that people experience as a result of a change in the supply of a good or service. Monetary values are used as the common metric to compare changes in utility associated with changes in different goods and services. When these values, including the positive values (benefits) and the negative values (costs) are integrated into an economic assessment, such as a benefit-cost analysis of an environmental project or policy, we are able to quantify (in dollars) what the aggregate change in welfare is for the affected human population. Equating all values into monetary terms has the advantage of making all things commensurate, so that we can directly compare financial, social, and environmental values.

Different categories of values are considered in economic valuation, which collectively sum to the Total Economic Value. The values include 'use values', which encompass direct use of the environment, such as the provisioning services provided by the Great Southern Reef and some cultural services such as recreational use, and indirect use values which includes some regulating services (e.g., carbon sequestration). Importantly, 'non-use values' are also encapsulated in the Total Economic Value framework. These relate to the values associated with the knowledge that something is being maintained or protected, even if someone does not (plan to) interact with that thing directly. Such existence values are often particularly relevant for threatened species, or habitats that support them.

There are two elements that make up the economic value of a good or service. Using a consumptive product such as fish bought in the market as an example: First, the 'producer surplus' measures the value to the producer (supplier) for selling the product (Hanley et al. 2009). This is effectively the profit to the producer, in other words, the revenue less their expenses. Second, the 'consumer surplus' measures the benefit to the consumer that they gain from purchasing the fish, above and beyond the price they actually paid for the fish (if the enjoyment they gained from consuming the fish was not worth more than the cost of the fish, they would be indifferent about the fish, and consumer surplus would be zero). The consumer surplus plus producer surplus is the total economic value of the good or service that has been provided. If there are changes in the provision of a good or service, then it is the change in total economic value that is the appropriate measure for this change from a Welfare Analysis perspective.

It is important, when aggregating the components of total economic value, to avoid duplication or double counting (Wallace & Jago 2017). Double counting is where (at least some component of) the same underlying value is measured and aggregated more than once. This can occur for example, if one is to measure the value of a regulating service like pollutant removal (which is a process, or, a means to an end), and then also measure the cultural services such as the existence value of a healthy habitat and the direct use value of a high-quality recreation experience (both of which could be outcomes of, and the end point from having removed pollutants).

Ideally, we want to measure consumer and producer surplus when conducting an economic valuation, as this gives the true reflection of total economic value. However, we are often limited by the way in which data is reported or made publicly available, such that we might only have access to measures of revenue as a proxy for producer surplus, or expenditure as a proxy for consumer surplus. When deferring to these proxy measures, we need to interpret values carefully. For example, we might note an industry has a high revenue simply because it is large, but this does not necessarily mean it is highly profitable (i.e., economically valuable). In addition, the aggregation of consumer and producer surplus to measure total economic value involves aggregation of values that are measuring something similar, conceptually. Aggregation (or even comparison) of profit for some industries and revenue for others would not be meaningful.

Further, while we can extract market data (prices) for tangible ecosystem services such as commercial products and tourism, we know that a substantial element of the value provided by the Great Southern Reef will be in the provision of intangible ecosystem services, such as the existence value of Great Southern Reef habitat, and the recreation benefits for fishers, divers, and other beach users. These non-market values can be measured through economic non-market valuation approaches.

A commonly used Non-market valuation approach aims to estimate how much people are willing to pay for a change in the quality or quantity of the service provided (Champ et al. 2003). Because people are not actually having to pay for the service, when they indicate their willingness to pay it is the equivalent to measuring their consumer surplus (i.e., there is no expenditure to subtract). Producer surplus is generally not relevant for these non-market services, because they are 'public goods' and their supply is not dependent on a private producer. However, there may be cases where provision of recreational services involves private services (e.g., bait/fuel in recreation services), while the benefits enjoyed by users are non-market. In this case producer surplus from the provision of intermediate inputs may also need to be inferred.

A suite of non-market valuation approaches have been widely applied to the environment and other areas of public policy (Rogers et al. 2015). They include 'revealed preference' methods where we can, for example, observe the frequency with which people visit a popular dive site, and their travel costs to get there, to reveal how much they are willing to pay for the recreational trip (e.g., Zimmerhackel et al., 2018).These methods are particularly useful to measure use values. There are also a range of survey-based approaches known as 'stated preference' methods, which are able to measure both use and non-use values. In these surveys respondents are asked to consider the trade-offs they are prepared to make to achieve particular outcomes that result from a new policy or management action, and how much they would be prepared to pay for that given their disposable income (McCartney 2006, Rogers 2013). The hypothetical nature of the choice scenarios presented to respondents enables the practitioner to move beyond thinking about current use of our natural resources, and towards understanding how values will be affected, for example, if we were to implement a new conservation program relative to continuing business as usual.

The business-as-usual case, or the 'counterfactual', is an important element of any economic valuation. In economic theory, people's values for goods and services change depending on how much of something we already have. For example, if we have a scarce resource, such as a critically endangered ecosystem, the value of including an additional hectare of the core habitat in the marine reserve system is probably quite large. On the other hand, if we have an ecosystem that occurs in abundance, the value of including an additional hectare in the reserve system will be relatively much smaller. This is referred to as diminishing marginal value (Rogers et al. 2019). For this reason, in any welfare analysis, it is important to clearly define the outcomes of the counterfactual – which refers to what the quality and/or quantity is of the services to be valued if we do not intervene with the current expected trajectory – and to define how we expect these outcomes to change depending on proposed policy or management actions. In this sense, the margin of change is clearly defined, and the valuation is placed in a meaningful context.

2. Methodology

2.1 Mapping ecosystem extent of the Great Southern Reef

Kelp forests are the dominant habitat formers along the Great Southern Reef. Here, we used the distribution of shallow rocky reefs (< 30 m) and the shallow margin of mesophotic reefs to depths of 50 m, where *Ecklonia* and other kelp grow (i.e. avoiding sand and soft sediment), and the distribution of *Ecklonia*, the dominant kelp in Australia (Wernberg et al. 2019a) to define the extent of the Great Southern Reef. This distribution equates to a rough extent of -27.61° to -43.743° and 113.39° to 153.69° (Supporting data 1) and follows the 50 m depth contour discussed above.

2.1.1 Kelp extent

2.1.1.1 SeaMap Australia

The most comprehensive benthic habitat map for Coastal Australia is represented in the SeaMap project (Butler et al. 2017) which relies on the Coastal Marine and Ecological Classification Standard. This standard has three relevant levels: aquatic (coastal or marine), substratum (hard or soft), and biota (present or absent). Within Australia, only the aquatic and substratum levels are well developed as comprehensive spatial layers.

For the context of the Great Southern Reef and kelp, the aquatic classification specifies that is 1) marine and 2) nearshore. With substratum, the classification is made as 1) hard substrata 2) consolidated hard substrata and 3) mixed consolidated substrata. The biota component only records information at the group level (e.g., macroalgae instead of *Ecklonia*). These classifications are not standardised across the country but similar groups are applied in other data sets e.g. National Inter/ Subtidal Benthic habitat classification scheme (NISB) (Mount et al. 2007), and other state level and regional assessments. Generally, potential *Ecklonia* habitat can be considered as some fraction of either the hard substrata or mixed substrata.

The database consists of a combination of survey efforts which were conducted using a combination of aerial imagery, in-water surveys, remote operated vehicles, and towed video surveys. The extent of habitat type by mapping method is presented in Table 1**.** As a result, our estimate of kelp forest area is a composite and may be subject to the different biases with each survey method (discussed below).

We used the available data from SeaMap Australia to quantify the mapped extent of habitat that fell within the Great Southern Reef zone (Supporting Data 1). The SeaMap Australia dataset contains 36 habitat classifications, as defined by the National Habitat Classification system (see below). The following six classified habitats were selected as areas of interest for the Great Southern Reef and tabulated their mapped area.

- Mixed hard substrata
- Macroalgae
- Consolidated hard substrata
- Hard substrata
- Mixed macrophytes
- Urchin barren

Table 1: Habitat type by mapping method

Habitat	Area Ha
Consolidated Hard Substrata	11576.5
Acoustic	184.6
Acoustic, aerial photography	126.6
Aerial photography, single beam	4860.4
Unknown	6404.8
Hard Substrata	5825.9
Acoustic, aerial photography	5080.7
Aerial photography	15.1
Aerial photography, topographic maps	351.2
Multibeam	206.1
TBA	172.9
Macroalgae	29395.9
Acoustic	993.8
Acoustic, aerial photography	17346.0
Aerial photography, single beam	318.7
Multibeam	3606.2
TBA	843.4
Unknown	6287.8
Mixed Hard Substrata	2.3
Aerial photography, sidescan sonar	2.3
Mixed Macrophytes	1238.3
Multibeam	1238.3
Urchin Barren	0.8
Multibeam	0.8
Grand Total	48039.7

2.1.1.2 Pros and Cons of Survey Methods

As to understand the potential biases in the SeaMap database, we provide a brief overview of the pros and cons of the different methods used to map kelp forest habitat (Table 2).

Aerial imagery, by satellite, plane, or drone is a good method for mapping rocky reefs over a large scale but is limited to mapping shallow water kelp. The range of *Ecklonia* is entirely subtidal and thus aerial imagery ecosystem mapping is limited by the habitat depth, water conditions, and air conditions on the day the imagery is captured (Kenny et al. 2003). In Australia, *Ecklonia* occurs up to 60 m depth (Marzinelli et al. 2015), well past the detection depth for aerial imagery. However, substantial parts of the *Ecklonia* range are less than 15 m depth (Wernberg et al. 2019a) and thus aerial imagery may help capture some useful information. Satellite imagery may pass over a given area repeatedly over time and help to generate time series data. Plane or drone mapping only has this advantage if new data collection trips are petitioned.

Table 2: Overview of the techniques used to record the extent and condition of kelp forests.

Measurement technique	Units	Pros	Cons	Reference
Aerial imagery	Area (m^2, Ha, Km^2)	Covers large spatial scale	Cannot detect deep water kelp. Potentially low spatial resolution No associated biodiversity or kelp density data High expertise required to process	(Moro-Sota et al. 2020)
In water surveys (SCUBA/snorkel)	Area, percent cover, density	Highly accurate Can obtain biodiversity and density data. Low training to process	Covers small area. Slow	(Edgar & Stuart-Smith 2014)
Automated Underwater Vehicles (AUVs) and underwater videos (towed)	Area, percent cover, density	Covers significant area. Can obtain biodiversity and density data	High processing time Expensive	(Marzinelli et al. 2015)

In-person surveys to monitor marine ecosystems are technologically simple and relatively affordable, they are however, extremely limited in the spatial extent they can cover, as well as the surveyable depth (typically 20 m with scientific SCUBA divers). Surveys are conducted using belt transects, quadrats, presence-absence, diver operated videos. These data then need to be transposed onto a map to generate extent lines for the monitored habitat. In situ surveys generate accurate, high-quality data for habitat mapping, but given that *Ecklonia* occurs across ~8000 km of coastline in Australia, it is not feasible to map the whole range this way. In-person surveys are most valuable in areas with high visitation such as recreational areas or scientific study sites. Here, data points maybe collected over an extended period and help generate important time series data.

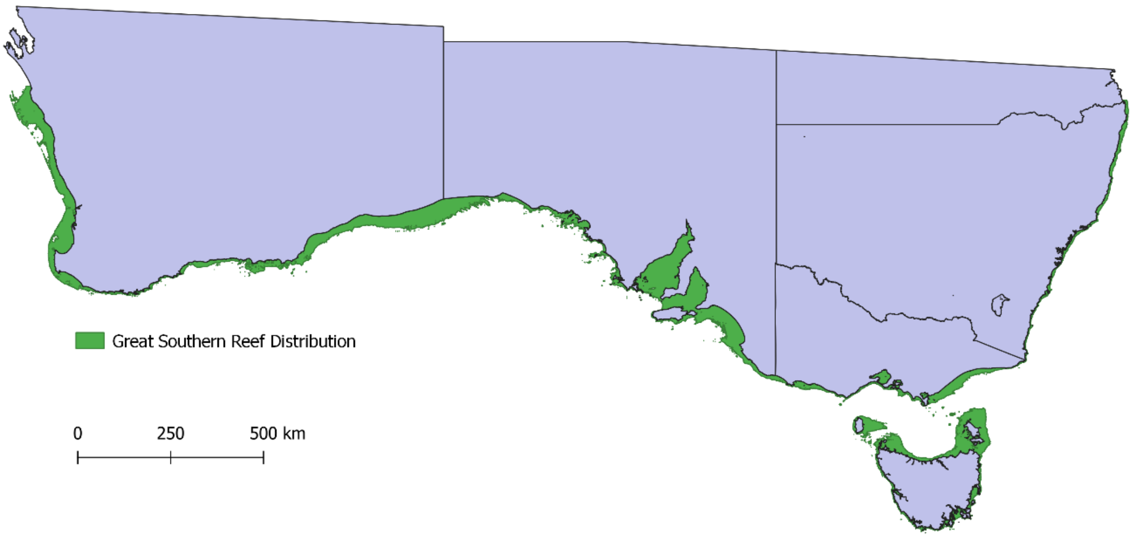


Figure 4 Footprint of the Great Southern Reef out to the 50 m depth limit.

2.1.2 Kelp condition

Ecosystem condition is a general term that can be used to indicate the state of an ecosystem, and it can be represented in differing ways (O'Brien et al. 2016). Generally, condition is considered using physical, chemical, or biological indicators, each with varying units. Physical indicators are related to substrate composition, primary habitat indicators (density, height, biomass), proximity to disturbance factors, or environmental variables (e.g., temperature, current). Chemical indicators are measured by contaminant levels, nutrient loads, primary production (chlorophyll), or physiochemical measures. Lastly, biological indicators are measured by looking at the biodiversity in the ecosystem, either at the community, individual, or population level (O'Brien et al. 2016).

Percent cover is a common way to estimate ecosystem condition in kelp forest ecosystems (Krumhansl et al. 2016). Cover is easy to estimate through visual surveys, does not require destructive sampling, may be assessed post-survey using imagery, and is low cost (Table 1). We used kelp percent cover as the best available measure of ecosystem condition for the Great Southern Reef. These data were compiled from a citizen science program, Reef Life Survey and were collected using underwater transects and photo quadrats across 159 sites in Australia (Edgar & Stuart-Smith 2014). For more details on the survey method, see ReefLifeSurvey.com.

Additional data on percent cover is available on the Squidle platform (https://squidle.org/) which hosts thousands of AUV imagery from the Integrated Marine Observing System (IMOS). The imagery spans all 5 states included in the Great Southern Reef but is not yet classified.

2.1.3 Human population

We mapped the human population that lives within 50 km of the coastline along the Great Southern Reef. First, we obtained the Australian population grid (resolution 1 km^2), for the whole of Australia for the year 2011 (Australian Bureau of Statistics 2014). We then obtained a 1:100,000 map of the Australian coastline (GEODATA 2004), clipped it to the extent of the Great Southern Reef, and created a 50 km buffer. We then extracted the sum population of people living within that 50 km buffer zone.

2.2 Identifying the ecosystem services provided by the Great Southern Reef

Ecosystem services extend from the biophysical conditions of an ecosystem. Here, we focus on the services that provide benefit to humans (Table 3). Kelp forests are home to thousands of different species of algae, fish, and invertebrates. Many of these species are directly harvested in Australia. The rock lobster and wild abalone industries on the Great Southern Reef report revenues of hundreds of millions of dollars per annum and both of these species are heavily reliant on kelp (Mayfield et al. 2012, Penn et al. 2015, Steven et al. 2021). Many other species spend time in kelp forests before migrating to other habitats and contributing value there (Olson et al. 2019). The direct harvest of wild kelp is relatively low in Australia compared to other countries such as Japan, France, Chile (Fujita 2011, Buschmann et al. 2014, Frangoudes & Garineaud 2015), but still exists to a small extent (Kelly 2020). Because kelp forests are three dimensional structures, there is some evidence that they dampen wave energy and help prevent coastal erosion, though this is not well demonstrated in Australia. As kelp species grow, they withdraw carbon, nitrogen, and phosphorus from the water. The removal of these elements helps lower the carbon dioxide levels and reduces nutrient pollution in surrounding waters (Marinho et al. 2015, Filbee-Dexter & Wernberg 2020).

2.2.1 Kelp ecosystem services use and benefits

All human activities within the ocean space are dependent on ecosystem assets (i.e., natural capital) and the ecosystem services provided to develop and function. The human activities which could be considered partially dependent on kelp habitat and its services are identified in Table 2.

The average provision of services (explored in Section 2.1) from kelp habitats provides an understanding of the flows that could be accessed by human activities. A measure of the ‘utilisation’ of these flows, however, requires an understanding of the spatial distribution and intensity of activities, in both monetary and physical measures. In addition, these activities may be reliant on services supplied by a combination of ecosystems, and the extent to which they are dependent on kelp ecosystems should be estimated.

Several ecosystem service classifications have been developed and adapted, according to policy and project aims. Previous ecosystem accounting by the Australian Bureau of Statistics for the Great Barrier Reef (2017) referenced the Common International Classification of Ecosystem Services (CICES). Standardisation and harmonization of ecosystem services and their indicators should be a priority to ensure integration and continuity of accounts.

Here we present our data using the CICES framework (Table 4) within the context of how it can be applied to kelp forest ecosystems. Each CICES category has an associated example for how that category applies to kelp forest ecosystems in Australia. We have focused on the biotic services which are provided by habitats such as kelp forests.

*Table 3: Kelp ecosystem services and their indicators. *Estimated by authors.*

Ecosystem service	Indicators	Units	Refs	Difficulty in ecosystem service assessment*
Food provisioning	- Fish biomass - Invertebrate biomass - Kelp harvest - Nursery function - Food web provisioning	Biomass, density, production	(Bennett et al. 2016, Wernberg et al. 2019a)	Low
Mass stabilisation and erosion control	- Wave power attenuated by kelp forests. - Costs avoided from erosion damage.	Size of wave height, volume of erosion, dollars	(Morris et al. 2020)	Moderate
Nutrient removal (e.g., phosphorus and nitrogen)	- Nutrients removed by kelp forests. - Costs avoided from water treatment	Mass removed per area per unit time	(Neveux et al. 2018)	Moderate
Water purification and filtering	- Pollutants removed by kelp forests. - Costs avoided from water treatment	Mass removed per area per unit time	(Kim et al. 2015)	Moderate
Carbon sequestration	- Carbon captured per year. - Carbon sequestered by year.	Mass removed per area per unit time	(Filbee-Dexter & Wernberg 2020)	Low
Recreation	- Boat /Diving / trips - Coastal tourism revenue	Trips, dollars, time spent	(Hasler 2016)	High
Cultural heritage	- Documents, paintings - Cultural practices	Number of experiences, intangible	(Thurstan et al. 2018)	Very high

Table 4: CICES Framework and kelp specific example goods and benefits.

Section	Group	Class	Code	Example Service	Example Goods and Benefits
Provisioning (Biotic)	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown for nutritional purposes	1.1.2.1	*Harvestable surplus of seaweed biomass in situ*	*Vitamin supplement*
	Cultivated aquatic plants for nutrition, materials or energy	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	*Harvestable surplus of seaweed biomass in situ*	*Seaweed as an insulating material*
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1	*Harvestable volume of wild berries or wild mushrooms, Or*	*kelp wrack for food*
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	*Harvestable volume of reeds Or Macroalgae used for thickening*	*Roofing material*
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1	*Harvestable surplus of cod population, or deer population*	*fisheries*
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2	*Reindeer skins Or Zooplankton – jellyfish used to*	*shells*
	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	*Seeds or spores that we can harvest*	*Wild plant seed for commercial sale*
	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	*Population of plant algae or fungi species used to in breeding programmes*	*Plant, algae or fungi species with novel characteristics that*
	Medicinal	Medicinal	1.3.1	*Materials used for medicinal purposes*	*Food supplements*
Regulation & Maintenance (Biotic)	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1	*Bio-remediation of industrial wastes by disposal on agricultural land Or*	*Reduction in toxic elements*
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	*Dust filtration by urban trees Or Macrophytes, for example salt marsh*	*Reduction in nutrient pollution*
	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	*The capacity of vegetation to prevent or reduce the incidence of soil erosion Or*	*Reduction of damage (and associated costs) of sediment*
	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	2.2.1.2	*The capacity of forest cover to prevent or mitigate the extent and force of snow avalanche*	*Shoreline protection*
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*The capacity of vegetation to retain water and release it slowly, Or*	*Regulation of sediment flows*
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*The capacity of vegetation to retain water and release it slowly, Or*	*Sediment trapping on reef*
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*The capacity of vegetation to retain water and release it slowly, Or*	*Coastal erosion*
	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	2.2.2.3	*Important nursery habitats include estuaries, seagrass, kelp forest, wetlands, soft sediment, hard bottom,*	*Sustainable populations of useful or iconic species that*
	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	Fish communities that regulate the resilience and resistance of coral reefs to eutrophication	*Increased dissolved oxygen*
	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	Fish communities that regulate the resilience and resistance of coral reefs to eutrophication	*Increased water clarity*
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*Sequestration of carbon*	*Climate regulation resulting in avoided damage costs*
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*Sequestration of carbon*	*Mitigation of impacts of ocean acidification*
Cultural (Biotic)	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or	3.1.1.1	*Ecological qualities of woodland that make it attractive to hiker; private gardens*	*Diving/snorkel*
	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational	3.1.1.2	*Mix of species in a woodland of interest to birdwatchers Or*	*Diving/snorkel*
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	*Site of special scientific interest, Natura 2000 site*	*Knowledge about the environment and nature*
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	3.1.2.2	*Site used for voluntary conservation activities*	*Research sites*
	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*Sherwood Forest*	*Tourism, local identify*
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	*Area of Outstanding Natural Beauty; panorama site*	*Artistic inspiration*
	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	*Abalone*	*Social cohesion, cultural icon*
	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	3.2.1.2	*Totemic species, such as the turtle*	*Mental well-being*
	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	3.2.1.3	*Archive records or collections*	*Nature films*
	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	3.2.2.1	*Areas designated as wilderness*	*Mental/Moral well-being*
	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	*Endangered species or habitat*	*Moral well-being*

2.2.2 Presence and absence of ecosystem services

Because many of the services identified are reported or managed by state-level entities, we conducted 5 literature searches per service, each targeting one of the 5 states which border the Great Southern Reef (New South Wales, Victoria, Tasmania, South Australia, Western Australia). The name of each state was paired with a service search term (Appendix 1) and the first 50 Google results were reviewed. The search was then repeated using Google Scholar to identify academic publications.

If we found widespread evidence that a service was present in a state, we recorded that service as "present", if we found one to two examples of that service, we recorded it as "present to a small extent", if the service was plausibly found in that state but had no documented evidence , we recorded it as "likely present but not accounted for", and if we found no evidence of the service in that state after both searches, we recorded that service as "absent".

2.3 Quantifying services in the Great Southern Reef

2.3.1 Metrics used to quantify each service

There are multiple ways to record the biophysical units associated with each CICES services category. For instance, the recreational value of a kelp forest could be measured by hours spent SCUBA diving or by ocean swimming in the ecosystem. We selected one or two indicator values for each service, which aimed to be representative of the service as a whole and obtainable without further data collection.

2.3.2 Data collection process

As before, we created search terms for each service and paired them with each state, but the structure of the search term varied substantially by category. Unless specified otherwise, the search process was as follows: we conducted 5 literature searches per service, each targeting one of the 5 states which border the Great Southern Reef (New South Wales, Victoria, Tasmania, South Australia, Western Australia). The name of each state was paired with a service search term (Appendix 1) and the first 50 Google results were reviewed. The search was then repeated using Google Scholar to identify academic publications. If no information was found in these two searches, we did not quantify that service. Certain services (fisheries landings, media produced) had specific search criteria as described further in the methods.

2.3.2.1 Cultivated aquatic plants for nutrition, materials, or energy

We quantified the number of business operations that culture kelp species for nutrition, material goods, or energy end uses. The information on the amount of cultured kelp species was not readily available.

2.3.2.2 Reared aquatic animals for nutrition, materials, or energy

There was no evidence of reared aquatic animals being reared for nutritional, material, or energy purposes in any state. Therefore, we did not try to quantify this service.

2.3.2.3 Wild plants (terrestrial and aquatic) for nutrition, materials or energy

The information on the amount of collected kelp species was not readily available. Rather we collected aggregate data from the Fisheries and Agriculture organization (FAO) which reported the wild harvest landings of all brown seaweeds (Class: Phaeophyceae) in Australia. We also quantified the number of business operations that collect wild kelp species for nutrition, material goods, or energy end uses.

2.3.2.4 Wild animals (terrestrial and aquatic) for nutrition, materials or energy

We used government reports to quantify the number of species involved in commercial fisheries as well as the biomass extracted per year per fishery (Steven et al. 2021). We collected values for the year 2019 as the most data was available for this year and it represents standard catches, as the years 2020 and 2021 were impacted by the COVID-19 closures.

For a country wide assessment of recreational fishing, we looked at reports which contained surveys about the number of persons per year and hours per year spent recreational fishing in each state (Campbell & Murphy 2005). We also included state specific reports which detailed the biomass landed or percent of the total recreational catch, though these reports did not disaggregate catch by specific habitat type, only ocean versus estuary versus freshwater (Giri & Hall 2015, West et al. 2015, Lyle et al. 2019, Ryan et al. 2019, Ernst & Young 2020).

2.3.2.5 Genetic material from plants, algae or fungi

We quantified the number of business operations that provide kelp seed stock for sale. The information on the sales quantity was not readily available.

2.3.2.6 Genetic material from animals

There was no evidence of the sale or use of the genetic materials (i.e., stock) of aquatic animals associated with kelp forests. Therefore, we did not try to quantify this service.

2.3.2.7 Medicinal

We focused our search for the number of published papers describing medicinal or bio-pharmaceutical compounds derived from the most common kelp, *Ecklonia radiata*. Specifically, we queried the number of scientific articles available on Web of Science using the key words “Ecklonia radiata AND bioact* OR pharma OR medic*”.

We further quantified the number of business operations that sold medicinal, health, or food supplements made wholly or partially from kelp materials. The sales values for these products were not readily available.

2.3.2.8 Mediation of wastes or toxic substances of anthropogenic origin by living processes

We searched for studies that quantified the reduction of toxic substances by kelp. Ideally this value would be reported in the uptake of the substance per unit area of kelp (e.g., grams) per time period (e.g., days).

We also used the net primary production and elemental composition of *Ecklonia* in Australia to estimate how much nitrogen was taken up from one square-meter of kelp forest per year.

2.3.2.9 Mediation of nuisances of anthropogenic origin

There was no evidence that kelp ecosystems mediated nuisances of anthropogenic origins. Therefore, we did not try to quantify this service.

2.3.2.10 Regulation of baseline flows and extreme events

We searched for studies that quantified the reduction in wave height, shore erosion, sediment flow, sediment deposition in areas with kelp forests and without. Ideally these values would be reported in units of distance (e.g., wave height reduction), weight (e.g., sediment load), or ratios (e.g., amount of beach eroded with and without kelp).

2.3.2.11 Lifecycle maintenance, habitat and gene pool protection

We provided a brief summary of the available evidence for the nursery function of kelp forests in Australia. We did not find evidence that kelp forests were associated with pollination or seed dispersal services and did not attempt to quantify those services.

2.3.2.12 Pest and disease control

There was no evidence that kelp ecosystems are associated with pest or disease control services. Therefore, we did not try to quantify these services.

2.3.2.13 Water conditions

We searched for studies that quantified the increase in water clarity with and without kelp forests.

2.3.2.14 Atmospheric composition and conditions

We quantified the amount of net primary production (grams dry biomass) of kelp forest ecosystems per year as well as what amount of the production was carbon, nitrogen, and phosphorus. We also searched for studies that reported the change in water pH with and without kelp forests.

2.3.2.15 Physical and experiential interactions with natural environment

We quantified the number of businesses offering dive and or snorkel experiences. We also quantified the number of mapped dive sites related to kelp forests.

We collected data on the number of coastal tourists visits per year across Australia from 2008 to 2015 using Australia's State of the Environment report 2015 (Clark & Johnston 2017). These values were divided into domestic day, domestic overnight, and international visitor categories as well as by which proportion of these groups partook in various activities during those visits (visit National Park, Bushwalking, visit botanical garden, visit zoo, snorkelling, whale or dolphin watching, and scuba diving). The values were not reported at the state level, so we approximated what percentage of these values pertained to the Great Southern Reef by collecting information on the total number domestic and international tourists in each state and assuming those proportions were the same for coastal tourist visits. This is a fair assumption for all states except Western Australia, as half the state's coastline is not covered by the Great Southern Reef. However, tourist values for Western Australia were relatively small and this assumption would have little effect on the total tourism numbers.

2.3.2.16 Intellectual and representative interactions with natural environment

We queried the number of scientific articles available on Web of Science using the key words “kelp* OR macroalga* OR Laminariales OR Fucales OR Desmarestiales”. We then considered how many of those articles were associated with Australian institutions compared to international institutions. We quantified the number of university programs that offer degrees in marine biology as well as the number of sites surveyed by the citizen science program Reef Life Survey.

2.3.2.17 Spiritual, symbolic and other interactions with natural environment

We quantified the number of books, films, and other media created about kelp forest ecosystems. This search was conducted using the WorldCat© library catalogue. We contacted the culture and heritage department of each state to quantify how many coastal shell middens are documented. We also summarized the available information about the cultural and spiritual value of kelp forests but were unable to find any further quantifiable information.

2.3.2.18 Other biotic characteristics that have a non-use value

We used the Collaborative Australian Protected Areas database (Commonwealth of Australia 2021) to quantify the number, size, and protection level of managed areas within the Great Southern Reef 50 meter depth contour. This database includes state and federally managed protected areas, with most federal areas occurring offshore and state managed zones occurring nearshore or coastal. The protection levels are detailed below (International Union for the Conservation of Nature 2022).

Ia Strict Nature Reserve: Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/geomorphical features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values.

Ib Wilderness Area: Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.

II National Park: Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible, spiritual, scientific, educational, recreational, and visitor opportunities.

III Natural Monument or Feature: Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine cavern, geological feature such as a cave or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.

IV Habitat/Species Management Area: Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many Category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.

V Protected Landscape/ Seascape: A protected area where the interaction of people and nature over time has produced an area of distinct character with significant, ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.

VI Protected area with sustainable use of natural resources: Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.

2.3.3 Uncertainty assessment

We assigned scores of low, medium, high to assess the certainty of the spatial coverage, quality, and quantity of the data collected. These scores were assigned as follows.

Spatial coverage of information

- Low: Information available from within none or one state bordering the Great Southern Reef
- Medium: Information available from 2 - 4 states bordering the Great Southern Reef
- High: Information available from all states bordering the Great Southern Reef

Quality of information

- Low: Indirect evidence or modelling suggestive of service including unpublished proxy for service. No direct, empirical evidence available that is published in peer-review literature or official report
- Medium: Combination of some "*direct empirical evidence of service published in peer-review literature or official report*" and some "*indirect evidence or modelling suggestive of service including unpublished proxy for service*" required to attain estimate of service.
- High: Direct empirical evidence of service, published in peer-review literature or official report

Quantity of information

- Low: Information available from none to one report/study
- Medium: Information available from >1 and <10 report/studies
- High: Information available from >10 reports/studies

2.4 Assigning economic value to ecosystem services

The building blocks of the economic assessment of ecosystem services are as follows:

- Quantity of product or service: e.g., fisheries landings, the number of recreational trips, or the amount of sequestered carbon from the atmosphere.

- Value of unit: Either value for the commercial enterprise (producer surplus) or for the “consumer” (consumer surplus), where consumer is defined broadly as the benefiting private person from an ecosystem service
- Aggregation over relevant quantity: Over the quantity of product or service, a geographic area and/or the relevant human population
- Other adjustments: Purchasing power parity, inflation, discount rates, currencies
- Uncertainties: Sensitivity analyses

We collected economic information from published data and literature such as journal articles, university and government department report and databases. In scope are ecosystem services that have direct and measurable benefits. As we did not engage in any primary data collection, data availability limited the possibility of quantifying services.

We assessed the following services:

- Provisioning services: Commercial fisheries and direct kelp harvest
- Cultural services: Recreation and tourism
- Regulative services: Nutrient cycling and carbon sequestration
- Habitat services: Existence values for kelp ecosystem

Ecosystem services can generate indirect benefits e.g., when kelp increases net primary production with flow-on effects on final services such as fisheries catches and/or recreational experiences. While we recognize that these ‘intermediate services’ could have substantial value, the complex relationship between services and their associated values are rarely understood. Furthermore, to the extent that these values are captured in an assessment of the value of the final service, one has to be wary of double counting. For this reason, intermediate services are excluded from this analysis. Moreover, we excluded ecosystem services that generate values that are not sufficiently understood such as spiritual, religious, and symbolic meaning. Moreover, ecosystem services that have numerous substitutes such as the provision of education are not in scope of this economic valuation. The following sections give details on the economic assessment for each ecosystem service.

2.4.2 Provisioning services

2.4.2.1 Commercial fisheries

Revenues

There are several alternative proxies for identifying the value of commercial fisheries. We obtained information on annual landings and gross value of production (GVP) for the years 1998 to 2020 from Australian fisheries and aquaculture statistics (Steven et al. 2021). For Western Australian fisheries, the catch and associated GVP outside the Great Southern Reef (Great Southern Reef) boundaries were excluded. For each fishery, we extracted the minimum, maximum, average and latest year (2019-2020) landings and GVP. All GVP were inflation adjusted to 2020 Australian dollar (AUD).

The economic value of commercial fisheries attributable to kelp forests underlies the rationale of the counterfactual case: What economic value would be lost if kelp forests were reduced or even lost. Hence, the economic value attributable of fisheries to kelp forests depends on the level of dependency of the target species on kelp. For this reason, fisheries were classified according to the level of kelp dependency of target species using the definitions below. We adjusted the GVP of each fishery by the fractions as defined by the kelp dependency classes. A full list of target species and their dependency on the Great Southern Reef can be found in Appendix 2.

- High (100%): target species directly dependent on kelp for survival
- Moderate (50%): target species dependent on rocky reef and benefit from kelp but can survive without
- Low (15%): Observations around reefs but no immediate dependence for food or habitat
- None/unclear (0%): Little or no association with rocky reefs or kelp

Surplus measures

To estimate the producer surplus of commercial fisheries, we did a literature search using the fisheries target species, the Australian states that lie within the Great Southern Reef, and the terms ‘profit’ and ‘economic performance’ as search terms. For those fisheries that are managed through individually transferable quotas (ITQs), we expect the total value of fishing licenses and quotas to indicate the discounted flow of profits. Therefore, we used the value of the licenses and quotas as a proxy for the surplus value of the fishery (Pascoe et al. 2016). The obtained values were inflation adjusted to 2020 AUD.

2.4.2.2 Direct kelp harvest

We did a literature search using the search terms ‘seaweed’, 'kelp harvest’, ‘Australia’, ‘economic value’. Due to a low return on information on the quantity and value of Australian kelp harvest, we described the findings qualitatively.

2.4.3 Cultural services

The analysis of cultural services focused on recreational and touristic coastal activities. We identified a range of activities that have distinct levels of dependency on the biota of the Great Southern Reef. The levels were identified by using the counterfactual case: What would be the loss in welfare of each coastal activity if kelp forests were reduced or lost. Based on this rationale, we defined the following classification of recreational activities in their reef relatedness and adjusted the associated values of each activity according to their level of relatedness (Table 5).

Table 5: Great Southern Reef relatedness of recreational activities.

Class	Description	Value adjustment	Activities
High	Activity directly dependent on reef biota for aesthetic or extractive purposes	100%	Recreational fishing, snorkelling, scuba diving
Moderate	Activity occurs *on* the reef and interactions with reef biota improves the quality of the experience but are not primary motivation	50%	Ocean swimming, surfing
Low	Activity occurs *on* or next to the water, reef biota only influences quality of activity marginally	15%	Beach walking, beach combing
None/unclear	Activity does not interact with reefs or influence on the quality of the experience is unclear	0%	Going to shops near the beach, boating, personal watercraft

2.4.3.1 Recreational fisheries

Expenditure

Recreational fishing directly targets species that at least partially depend on the Great Southern Reef. Hence, we classified this activity as highly related to the reef biota. We obtained the most recent economic data on recreational fishing activities within the boundaries of the Great Southern Reef:

- Victoria: The economic value of recreational fishing in Victoria (Ernst & Young 2020)
- Western Australia: Economic dimension of recreational fishing in Western Australia (McLeod & Lindner 2018)
- All other States: The 2000-01 national recreational fishing survey (Campbell & Murphy 2005)

We extracted the number of recreational fishing participants, the number of fishing trips and the associated expenditures on fishing trips per year. For Western Australia, we included only those trips inside the Great Southern Reef boundaries (West and South Coast fishing regions). As the years of data collection varied greatly between the single studies, we normalized all numbers to 2020 population using population growth statistics (Australian Bureau of Statistics 2022).

Moreover, we obtained information on the species composition of recreational fishing catches per State (Giri & Hall 2015, West et al. 2015, Lyle et al. 2019, Ryan et al. 2019, Ernst & Young 2020). For each State, we calculated that fraction of the catch that is attributable to kelp by the product of the percentage each species was caught and its kelp dependency class (Appendix 3). Under the assumption that the expenditures are directly proportional to that fraction of the trips that recreational fishers target kelp dependent species, we adjusted expenditures according to these classes.

Surplus measures

Additionally, we estimated the consumer surplus from recreational fishers for participating in this activity. Western Australia was the only State for which a consumer surplus was estimated (McLeod & Lindner 2018) (McLeod et al, 2018). However, this estimate was also based on a benefit transfer, so we did not apply the value to the other States. Instead, we used the Recreation Use Value Database that contains economic valuation studies that estimated the willingness to pay for recreation activities in the U.S. and Canada from 1958 to 2015 (Rosenberger 2016). The database allows the user to extract values according to different activity types, locations, target species, and resource type (among others). Values that fulfilled the following criteria were included:

- Primary activity: saltwater fishing
- Species: saltwater species
- Publication type: Journal papers, books or book chapters, Government Agency or university reports, consulting reports, PhD dissertations
- Location: States that have kelp forests

All resulting values were converted into 2020 AUD and adjusted for purchasing power parity (PPP). We aggregated the average consumer surplus from these results over the number of recreational fishing trips per Australian State. For Western Australia, we used the consumer surplus estimates from McLeod et al (2018) and adjusted them to the Great Southern Reef region of WA using the fraction of the effort from recreational fishers in the West and South Coast fishing regions. Under the assumption that the surplus is directly proportional to that fraction of the trips that recreational fishers target kelp dependent species, we adjusted the consumer surplus according to the fraction of the catch attributable to kelp (Appendix 3).

2.4.3.2 Other recreational activities

Data on recreation and tourism were obtained from Tourism Research Australia (Tourism Research Australia 2022). The data detailed the number of recreational visits, duration of stay and the average expenditures per visitor for domestic day visits as well as domestic and international overnight stays for the 50 most visited destinations in Australia. We excluded all destinations that do not have direct access to the Great Southern Reef. Moreover, we only included coastal activities that were classified with a 'high' or 'moderate' reef relatedness, namely snorkelling, scuba diving, surfing and ocean swimming (Table 4).

We estimated the annual number of trips for each activity as the product of the State population, the fraction of users on each activity per State population and the average number of days participants spent on each activity based on survey data for domestic day trips (Surf Life Saving Australia 2021) and international and domestic overnight stays (Clark & Johnston 2017). As the survey sample of domestic trips included domestic residents older than 16 years old, we aggregated the values for domestic trips over the State population 17 years and older that lives along the Great Southern Reef (Bennett et al. 2016). We applied the fraction of trip days on each activity to total GVA to estimate the GVA from each activity. Here, we assumed that visitors have the same expenditure independent of the coastal activity they engage in.

We estimated the consumer surplus of coastal activities using the benefit transfer approach using the following sources:

- Pascoe, 2019: Applied a travel cost approach to estimate the willingness to pay for several recreational beach uses including surfing, ocean swimming, and walking.
- Leon et al., 2022: Conference paper on the willingness to pay for surfing in Noosa, South Queensland.

Consumer surplus values were aggregated over the number of trips (in days) of each activity. All dollar values were adjusted to their Great Southern Reef relatedness class and were inflation adjusted to 2020 AUD.

2.4.4 Regulating services

2.4.4.1 Nutrient cycling

We estimated the value of nutrient uptake by kelp forests as the avoided costs of water treatment plans removing nitrogen from the environment before it reaches the ocean. The uptake of nitrogen from kelp is beneficial to humans only where kelp is preventing nutrient excess. Therefore, we limited the value to areas with reported excess nutrient (nitrogen and phosphorus) levels. We first estimated what area of Australian waters had excess nutrient loading using reported hypoxic or eutrophic regions along the Great Southern Reef (Diaz & Selman 2008). We created coastal buffer zones around those points. Estuaries were given buffer zones of 1 km in each direction (2 km of coastline) while smaller outflows were given buffer zones of 100 m in each direction (200 m of coastline), which conservatively captures the scale of the different regions with excess nutrients. We then estimated the area of kelp forest along that stretch of coastline using the average ratio of reef area to coastline length reported for the Great Southern Reef (Filbee-Dexter & Wernberg 2020) of 500 Ha of kelp forest per 1km of coastline.

We estimated the amount of total nitrogen taken up by a kelp forest within these ' hypoxic or eutrophic' areas using average net primary production values (g biomass per area per year) and an average kelp nitrogen content of kelp tissue of 1.6%. We applied the abatement costs of AUD $7,236/kg nitrogen for 20 years given by the ‘Melbourne stormwater offset program’ (Productivity Comission 2020). This generates AUD $581/kg of removed nitrogen per year at a 5% real discount rate. The abatement costs were multiplied with the annual amount of nitrogen absorbed by the kelp forests within nutrient excess areas.

2.4.4.2 Carbon sequestration

The social cost of carbon (SCC) was created to monetize the damage of CO_2 emissions and is defined as the externalities (value of damages) associated with one additional ton of CO_2 emissions (Dietz 2012). We applied estimates of SCC from the Interagency Working Group (National Academies of Sciences and Medicine and Engineering 2017) and from a global meta-analysis of SCC (Wang et al. 2019) at different discount rates (Table 6). SCC was converted to the price of carbon which is absorbed in kelp tissues. We adjusted these values for inflation and currency to 2020 AUD.

Table 6: Social cost of carbon at different discount rates used in this study.

SCC (2007 USD/t CO_2)	Discount rate (%)	Source
30.78	3 %	Wang et al. 2019
13	5 %	Interagency Working Group 2016
43	3 %	Interagency Working Group 2016
64	2.5 %	Interagency Working Group 2016

The price of carbon was multiplied by the amount of carbon that is absorbed from kelp forests and stored long-term in the ocean. For that purpose, we estimated the area of kelp cover in the Great Southern Reef using the fractions of kelp cover from photo quadrats in the Reef Life Survey dataset for 'macroalgae' and 'rocky reef' habitat (section 2.1.2).

The amount of exported carbon was estimated as the mean export of Net Primary Production (NPP) at 15.29% (SD 8.6). We estimated carbon sequestration using transport potential of detrital kelp material to deep ocean along the Great Southern Reef using models of coastal residence time (CRT) (Liu et al. 2019). Coastal residence time was defined as the elapsed time in days for a parcel of source water in the coastal domain (e.g., reef) to exit to the open ocean (beyond the 200-m isobath). This CRT model was run using the NOAA Modular Ocean Model (MOM6), the highest available resolution global current model (Griffies et al. 2020), which tracked parcels of coastal water bodies in 3 dimensions from at 0.125º resolution, and then calculated an average CRT for each starting point from 1998 to 2007. We cropped these CRT models to the coastline using 50 m depth cut off, which captures the typical lower limit of kelp forests. We estimated export potential of 23% (13 SD) of detrital production using a weighted range of decomposition rates for brown algae species (k values, Pedersen et al. Unpublished data) and average CRT in days to the coastal shelf edge. We excluded all areas with bottom currents less than 0.045 m/s, which is the minimum for bedload transport of seaweed (Filbee-Dexter et al. unpublished data). We estimated that 67% of NPP was exported as detritus (Krumhansl & Scheibling 2012).

2.4.5 Habitat services

Surplus measures

Kelp forests in the Great Southern Reef provide habitat to many species. Both the habitat as well as the species can be valued purely for their existence. These non-use/existence values are measured with non-market valuation methods and are expressed as consumer surplus. We did a literature search using the terms 'Australia,' 'economic value,' 'kelp,' 'non-market value' and 'consumer surplus.'

The search yielded one study from Tasmania that measured the consumer surplus for different kelp restoration measures from residents using a Discrete Choice Experiment (Grover et al. 2021). Results were given as consumer surplus per restored area and household. Values were inflation adjusted to 2020 AUD and aggregated over the households that live within 50km of the Great Southern Reef coastline as well as the total area of macroalgae and rocky reef habitat in the Great Southern Reef.

2.4.6 Certainty assessment

The economic valuation of ecosystem services using secondary data is often characterised by different types of uncertainties. To create transparent results, we scored the degree of certainty about different ecosystem service values from unusable to high using six criteria (Table 7) depending on whether the study provided the economic value as follows:

1. evaluated the specific ecosystem service in question
2. evaluated a similar ecosystem value (for example measuring existence value of seagrass rather than kelp forests)
3. is high in quality by meeting best disciplinary practice
4. primary data source is based within the boundaries of the Great Southern Reef
5. study captures full geographic scope of the Great Southern Reef, and/or an equivalent quantity of the ES as is present in the Great Southern Reef (i.e. no extrapolation
6. study sample captures all relevant populations for the ES and geographic scope of Great Southern Reef (i.e. no extrapolation to other populations required) relevant populations refer to the users and non-users (where relevant) of the ES in the Great Southern Reef, and might include the WA, SA, TAS, VIC and NSW communities.

Table 7: Criteria used to assess the certainty score.

Degree of certainty in economic data:	Evaluates specific ES in question	Evaluates similar ES to that in question	High quality econ study	Study is based on the Great Southern Reef	Full geographic scope or an equivalent quantity of the ES	Relevant populations & geographic scope of Great Southern Reef
High	x		x	x	x	x
Medium	x		x	x	x	
Medium	x		x	x		x
Medium		x	x	x	x	x
Low	x		x	x		
Low	x			x	x	x
Low		x	x	x	x	
Low		x	x	x		x
Very poor	x			x		
Very poor	x				x	
Very poor	x					x
Very poor		x	x	x		
Unusable	x					
Unusable		x		x	x	x

3. Results

3.1 Habitat extent in the Great Southern Reef

3.1.1 Great Southern Reef and kelp distribution

We found 30,029 km^2 of mapped area with the boundaries of the Great Southern Reef. Of this area, 2,940 km^2 were classified as macroalgae, 1,158 km^2 as consolidated hard susbstrata, 583 km^2 as hard substrata, 124 km^2 as mixed macrophytes, and less than 1 km^2 as mixed hard substrate or urchin barren (Table 8). These values do not reflect the proportion of distribution of habitats, for instance, there is greater than 1 km^2 of urchin barren habitat (Ling et al. 2009), it has just not been systematically surveyed and extent mapped.

Table 8: Mapped habitat distribution by state

Habitat	Area km^2
Consolidated Hard Substrata	1157.6
SA	12.7
TAS	486.0
WA	658.9
Hard Substrata	582.6
NSW	543.2
VIC	37.9
WA	1.5
Macroalgae	2939.6
SA	1734.6
TAS	31.9
VIC	445.0
WA	728.2
Mixed Hard Substrata	0.2
WA	0.2
Mixed Macrophytes	123.8
VIC	123.8
Urchin Barren	0.1
VIC	0.1
Total	4804.0

3.1.2 Kelp condition

We found 159 sites with kelp present in the Reef Life Survey dataset that covered all five states containing kelp. The average kelp cover at sites containing kelp was 20.8% while the average cover across all rocky sites was 11.44% (293 sites).

Losses of kelp forests have been documented across specific regions within the Great Southern Reef. In Western Australia kelp cover declined by 43% after the 2011 marine heatwave, with a total areal loss of 97,438 hectares, and 310 – 949 tons of carbon (Wernberg et al. 2016). In South Australia coastal pollution is impacting kelps in metropolitan areas with a 20 Km stretch of coastline that lost 60% of kelp cover (Connell et al. 2008). In

Victoria, there has been an estimated 86% decline over 17,665 hectares due to a combination of warming and increased salinity over the past half century (Carnell & Keough 2019). In Tasmania, sea urchins are expanding their range southwards and have overgrazed 4,861 hectares of kelp since 2001, resulting is a carbon stock loss of 15,513 tons C. In New South Wales surveys across 25 km of coastline along the Solitary Islands Marine Park region showed that warming and increased herbivory caused an 88.7% decline across that area (Vergés et al. 2016).

Under future ocean temperatures, temperate seaweeds along much of Australia's Great Southern Reef are predicted to decline and conditions push past their upper thermal limits. By 2100 species distribution models show that RCP2.6 scenario could result in 49% loss of temperate seaweeds or loss of 34,981 hectares (Martínez et al. 2018).

3.1.3 Human population

There were 15.02 million people living within 50 km of the Great Southern Reef in 2011. This value represents ~67% of the 22.34 million people living in Australia in 2011. If we apply this proportion to the number of people living in Australia in 2022 (25.87 million), there are 17.33 million people living within 50 km on the Great Southern Reef today.

3.1.4 Data gaps

There are large areas where the ocean substrate has not been mapped, notably in the Great Australian bight in Southern Australia, the west coast of Tasmania, and the majority of the coast of SW Western Australia. The Great Southern Reef to 50 meters, has a footprint of 193,966 km^2 and there is thus 163,936 km^2 of unmapped area.

The SeaMap database contained only ~3,000 km^2 of area that has been classified and attributed as kelp habitat. The true value will be considerably higher, other estimates suggested *Ecklonia* alone covered 5,000 Km^2 (Eger et al. 2021) and all kelp forests covered ~32,000 km^2 (Filbee-Dexter & Wernberg 2020). In terms of total spatial cover, almost no large scale data on kelp cover, density, or biomass is publicly available. There is therefore a need for greater kelp extent mapping as well as condition assessments.

3.2 Services present in the Great Southern Reef

3.2.1 Provisioning

Wild animals used for nutritional purposes (i.e., fisheries) was the only provisioning service that was found across all five states. The collection of shells and wild kelp materials were the second most common services but were sometimes absent or only present to a small extent in some states. Aquaculture of kelp plants was found in all states but Western Australia, but this service was only present to a small extent (Table 9).

3.2.2 Regulation and maintenance

Carbon production and nursery habitat were the two regulating services that were present across all five states. We found evidence that kelp forests regulate baseline water flows and extreme events in Tasmania, where Giant Kelp Forests are present, but these findings were not readily available for other states, namely South Australia and Western Australia as there was some evidence for these services in New South Wales and Victoria (Table 10).

3.2.3 Cultural

Cultural services were consistently document across all five states. Certain services, such as "elements of living systems that have sacred or religious meaning" were not documented in New South Wales or Victoria but are likely present in these states (Table 11).

3.2.4 Habitat

Kelp forests across all five states supported species richness, endemism, and charismatic species. While there were ~15,000 species assessed that were associated with kelp forests, there were no IUCN red-listed species that were strongly associated with kelp forests on the Great Southern Reef. There are however six species of handfish (genera: *Brachionichthys, Thymichthys, Brachiopsilus, Pezichthys*) which occupy reef habitat that are critically endangered or endangered.

3.2.5 Data gaps

We found 19 services that were not present across the Great Southern Reef. This finding may reflect that the services do not exist for this ecosystem or that they have not been developed and may exist in the future (Table 12).

Kelp forests are likely to provide many of the regulating services, mediation of toxic substances, regulations of baseline flows, water conditions, and atmospheric conditions in Southern Australia, but there is little evidence demonstrating these services. Future research will need to determine if these services exist in the specified regions and then work to quantify them (see section 3.3.2).

Further, as the Australian aquaculture industry grows, it is likely that other services such as cultivated kelp for energy (i.e., biofuel) or aqua-cultured animals from kelp forests and their associated genetic code will be used by humans in the near future.

Table 9: Presence and absence of provisioning services across the states bordering the Great Southern Reef

						NSW	Victoria	Tasmania	South Australia	Western Australia
Section	**Group**	**Class**	**Code**	**Example Service**	**Example Goods and Benefits**	**Presence/Absence**				
Provisioning (Biotic)	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown for nutritional purposes	1.1.2.1	*Harvestable surplus of seaweed biomass in situ*	*Vitamin supplement*	Present to small extent	Likely present but unknown	Present to small extent	Present to small extent	Not-present
	Cultivated aquatic plants for nutrition, materials or energy	Fibres and other materials from in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.2.2	*Harvestable surplus of seaweed biomass in situ*	*Seaweed as an insulating material*	Not-present	Not-present	Likely present but unknown	Not-present	Not-present
	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown as an energy source	1.1.2.3	*Harvestable surplus of seaweed biomass in situ*	*Seaweed as a source of energy*	Not-present	Not-present	Not-present	Not-present	Not-present
	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	*Harvestable stock of bivalves*	*Seafood (e.g. mussels)*	Not-present	Not-present	Not-present	Not-present	Not-present
	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.4.2	*Harvestable pearls produced by oyster beds*	*Pearls used for adornment*	Not-present	Not-present	Not-present	Not-present	Not-present
	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source	1.1.4.3	*Biogas from aquaculture waste*	*Energy production*	Not-present	Not-present	Not-present	Not-present	Not-present
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition	1.1.5.1	*Harvestable volume of wild berries or wild mushrooms, Or*	*kelp wrack for food*	Present to small extent	Likely present but unknown	Present	Present	Not-present
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)	1.1.5.2	*Harvestable volume of reeds Or Macroalgae used for thickening*	*Roofing material*	Not-present	Present to small extent	Present to small extent	Present	Present to small extent
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3	*Volume of harvested wood*	*Fuel wood*	Not-present	Not-present	Not-present	Not-present	Not-present
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes	1.1.6.1	*Harvestable surplus of cod population, or deer population*	*fisheries*	Present	Present	Present	Present	Present
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)	1.1.6.2	*Reindeer skins Or Zooplankton – jellyfish used to*	*shells*	Present to small extent	Present to small extent	Present to small extent	Present to small extent	Present
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3	*Seal blubber used by traditional cultures in lamps Or*	*biofuel*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population	1.2.1.1	*Seeds or spores that we can harvest*	*Wild plant seed for commercial sale*	Present to small extent	Not-present	Present to small extent	Not-present	Not-present
	Genetic material from plants, algae or fungi	Higher and lower plants (whole organisms) used to breed new strains or varieties	1.2.1.2	*Population of plant algae or fungi species used to in breeding programmes*	*Plant, algae or fungi species with novel characteristics that*	Not-present	Not-present	Present to small extent	Not-present	Not-present
	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	*Harvestable share of population of plant species used to extract genes*	*Creation of artificial gene products*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	*Spat for fish and shellfish farms*	*Reduced costs of production*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties	1.2.2.2	*Population of animals used in breeding programmes*	*Animals with novel characteristics that increase yields or*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	*Harvestable share of population of a given species used to extract genes*	*Creation of a novel micro-organism to help produce a*	Not-present	Not-present	Not-present	Not-present	Not-present
	Medicinal	Medicinal	1.3.1	*Materials used for medicinal purposes*	*Food supplements*	Present to small extent	Likely present but unknown	Present to small extent	Not-present	Not-present
	Other	Other	1.3.X.X			Not-present	Not-present	Not-present	Not-present	Not-present

Table 10: Presence and absence of regulating services across the states bordering the Great Southern Reef.

						NSW	Victoria	Tasmania	South Australia	Western Australia
Section	**Group**	**Class**	**Code**	**Example Service**	**Example Goods and Benefits**	**Presence/Absence**				
Regulation & Maintenanc e (Biotic)	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Bio-remediation by micro-organisms, algae, plants, and animals	2.1.1.1	*Bio-remediation of industrial wastes by disposal on agricultural land Or*	*Reduction in toxic elements*	Present	Likely present but unknown	Likely present but unknown	Likely present but unknown	Likely present but unknown
	Mediation of wastes or toxic substances of anthropogenic origin by living processes	Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	2.1.1.2	*Dust filtration by urban trees Or Macrophytes, for example salt marsh*	*Reduction in nutrient pollution*	Likely present but unknown	Likely present but unknown	Present	Present to small extent	Likely present but unknown
	Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	*Shelter belts that filter particulates that carry odours Or*	*Reduction in nuisance effect of smells from animal lots*	Not-present	Not-present	Not-present	Not-present	Not-present
	Mediation of nuisances of anthropogenic origin	Visual screening	2.1.2.3	*Shelter belts around industrial structures*	*Visual amenity*	Not-present	Not-present	Not-present	Not-present	Not-present
	Regulation of baseline flows and extreme events	Control of erosion rates	2.2.1.1	*The capacity of vegetation to prevent or reduce the incidence of soil erosion Or*	*Reduction of damage (and associated costs) of sediment*	Likely present but unknown	Present	Present to small extent	Likely present but unknown	Likely present but unknown
	Regulation of baseline flows and extreme events	Buffering and attenuation of mass movement	2.2.1.2	*The capacity of forest cover to prevent or mitigate the extent and force of snow avalanche*	*Shoreline protection*	Likely present but unknown	Present	Present to small extent	Likely present but unknown	Likely present but unknown
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*The capacity of vegetation to retain water and release it slowly, Or*	*Regulation of sediment flows*	Likely present but unknown	Likely present but unknown	Present	Likely present but unknown	Likely present but unknown
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*The capacity of vegetation to retain water and release it slowly, Or*	*Sediment trapping on reef*	Present	Likely present but unknown	Present	Likely present but unknown	Likely present but unknown
	Regulation of baseline flows and extreme events	Hydrological cycle and water flow regulation (Including flood control, and coastal protection)	2.2.1.3	*The capacity of vegetation to retain water and release it slowly, Or*	*Coastal erosion*	Present	Present	Present	Likely present but unknown	Likely present but unknown
	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	*Providing a habitat for native pollinators Or*	*Contribution to yield of fruit crops*	Not-present	Not-present	Not-present	Not-present	Not-present
	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	*Acorn dispersal by Eurasian Jays*	*Tree regeneration in parkland*	Not-present	Not-present	Not-present	Not-present	Not-present
	Lifecycle maintenance, habitat and gene pool protection	Maintaining nursery populations and habitats (Including gene pool protection)	2.2.2.3	*Important nursery habitats include estuaries, seagrass, kelp forest, wetlands, soft sediment, hard bottom,*	*Sustainable populations of useful or iconic species that*	Present	Present	Present	Likely present but unknown	Present
	Pest and disease control	Pest control (including invasive species)	2.2.3.1	*Providing a habitat for native pest control agents Or*	*Reduction in pest damage to cultivated crop*	Not-present	Not-present	Not-present	Not-present	Not-present
	Pest and disease control	Disease control	2.2.3.2	*Presence of native disease control agents such as microbial antagonists for the control of postharvest diseases*	*Reduction in disease damage due to harvested fruit or*	Not-present	Not-present	Not-present	Not-present	Not-present
	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	Fish communities that regulate the resilience and resistance of coral reefs to eutrophication	*Increased dissolved oxygen*	Likely present but unknown	Likely present but unknown	Present	Likely present but unknown	Likely present but unknown
	Water conditions	Regulation of the chemical condition of salt waters by living processes	2.2.5.2	Fish communities that regulate the resilience and resistance of coral reefs to eutrophication	*Increased water clarity*	Likely present but unknown	Likely present but unknown	Likely present but unknown	Likely present but unknown	Likely present but unknown
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*Sequestration of carbon*	*Climate regulation resulting in avoided damage costs*	Present	Present	Present	Present	Present
	Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	*Sequestration of carbon*	*Mitigation of impacts of ocean acidification*	Likely present but unknown	Present to small extent	Present	Likely present but unknown	Likely present but unknown
	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*Evaporative cooling provided by urban trees*	*Increased thermal comfort in cities*	Not-present	Not-present	Not-present	Not-present	Not-present

Table 11: Presence and absence of cultural services across the states bordering the Great Southern Reef.

Section	Group	Class	Code	Example Service	Example Goods and Benefits	NSW	Victoria	Tasmania	South Australia	Western Australia
						Presence/Absence				
Cultural (Biotic)	Physical and experiential interactions with natural environment	Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or	3.1.1.1	*Ecological qualities of woodland that make it attractive to hiker; private gardens*	*Diving/snorkel*	Present	Present	Present	Present	Present
	Physical and experiential interactions with natural environment	Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational	3.1.1.2	*Mix of species in a woodland of interest to birdwatchers Or*	*Diving/snorkel*	Present	Present	Present	Present	Present
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge	3.1.2.1	*Site of special scientific interest, Natura 2000 site*	*Knowledge about the environment and nature*	Present	Present	Present	Present	Present
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable education and training	3.1.2.2	*Site used for voluntary conservation activities*	*Research sites*	Present	Present	Present	Present	Present
	Intellectual and representative interactions with natural environment	Characteristics of living systems that are resonant in terms of culture or heritage	3.1.2.3	*Sherwood Forest*	*Tourism, local identify*	Present	Present	Present	Present	Present
	Intellectual and representative interactions with natural environment	Characteristics of living systems that enable aesthetic experiences	3.1.2.4	*Area of Outstanding Natural Beauty; panorama site*	*Artistic inspiration*	Likely present but unknown	Likely present but unknown	Present	Present	Present
	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning	3.2.1.1	*Abalone*	*Social cohesion, cultural icon*	Present	Present	Present to small extent	Present	Present
	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have sacred or religious meaning	3.2.1.2	*Totemic species, such as the turtle*	*Mental well-being*	Likely present but unknown	Likely present but unknown	Present to small extent	Present	Present
	Spiritual, symbolic and other interactions with natural environment	Elements of living systems used for entertainment or representation	3.2.1.3	*Archive records or collections*	*Nature films*	Present	Present	Likely present but unknown	Present	Present to small extent
	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an existence value	3.2.2.1	*Areas designated as wilderness*	*Mental/Moral well-being*	Present	Present	Present	Present	Present
	Other biotic characteristics that have a non-use value	Characteristics or features of living systems that have an option or bequest value	3.2.2.2	*Endangered species or habitat*	*Moral well-being*	Present	Present	Present	Present to small extent	Present

Table 12: Ecosystem services which did return results in our literature search.

						NSW	Victoria	Tasmania	South Australia	Western Australia
Section	**Group**	**Class**	**Code**	**Example Service**	**Example Goods and Benefits**	**Presence/Absence**				
	Cultivated aquatic plants for nutrition, materials or energy	Plants cultivated by in- situ aquaculture grown as an energy source	1.1.2.3	*Harvestable surplus of seaweed biomass in situ*	*Seaweed as a source of energy*	Not-present	Not-present	Not-present	Not-present	Not-present
	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture for nutritional purposes	1.1.4.1	*Harvestable stock of bivalves*	*Seafood (e.g. mussels)*	Not-present	Not-present	Not-present	Not-present	Not-present
	Reared aquatic animals for nutrition, materials or energy	Fibres and other materials from animals grown by in-situ aquaculture for direct use or processing (excluding genetic materials)	1.1.4.2	*Harvestable pearls produced by oyster beds*	*Pearls used for adornment*	Not-present	Not-present	Not-present	Not-present	Not-present
	Reared aquatic animals for nutrition, materials or energy	Animals reared by in-situ aquaculture as an energy source	1.1.4.3	*Biogas from aquaculture waste*	*Energy production*	Not-present	Not-present	Not-present	Not-present	Not-present
	Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Wild plants (terrestrial and aquatic, including fungi, algae) used as a source of energy	1.1.5.3	*Volume of harvested wood*	*Fuel wood*	Not-present	Not-present	Not-present	Not-present	Not-present
	Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used as a source of energy	1.1.6.3	*Seal blubber used by traditional cultures in lamps Or*	*biofuel*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from plants, algae or fungi	Individual genes extracted from higher and lower plants for the design and construction of new biological entities	1.2.1.3	*Harvestable share of population of plant species used to extract genes*	*Creation of artificial gene products*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from animals	Animal material collected for the purposes of maintaining or establishing a population	1.2.2.1	*Spat for fish and shellfish farms*	*Reduced costs of production*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from animals	Wild animals (whole organisms) used to breed new strains or varieties	1.2.2.2	*Population of animals used in breeding programmes*	*Animals with novel characteristics that increase yields or*	Not-present	Not-present	Not-present	Not-present	Not-present
	Genetic material from organisms	Individual genes extracted from organisms for the design and construction of new biological entities	1.2.2.3	*Harvestable share of population of a given species used to extract genes*	*Creation of a novel micro-organism to help produce a*	Not-present	Not-present	Not-present	Not-present	Not-present
	Other	Other	1.3.X.X			Not-present	Not-present	Not-present	Not-present	Not-present
	Mediation of nuisances of anthropogenic origin	Smell reduction	2.1.2.1	*Shelter belts that filter particulates that carry odours Or*	*Reduction in nuisance effect of smells from animal lots*	Not-present	Not-present	Not-present	Not-present	Not-present
	Mediation of nuisances of anthropogenic origin	Visual screening	2.1.2.3	*Shelter belts around industrial structures*	*Visual amenity*	Not-present	Not-present	Not-present	Not-present	Not-present
	Lifecycle maintenance, habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)	2.2.2.1	*Providing a habitat for native pollinators Or*	*Contribution to yield of fruit crops*	Not-present	Not-present	Not-present	Not-present	Not-present
	Lifecycle maintenance, habitat and gene pool protection	Seed dispersal	2.2.2.2	*Acorn dispersal by Eurasian Jays*	*Tree regeneration in parkland*	Not-present	Not-present	Not-present	Not-present	Not-present
	Pest and disease control	Pest control (including invasive species)	2.2.3.1	*Providing a habitat for native pest control agents Or*	*Reduction in pest damage to cultivated crop*	Not-present	Not-present	Not-present	Not-present	Not-present
	Pest and disease control	Disease control	2.2.3.2	*Presence of native disease control agents such as microbial antagonists for the control of postharvest diseases*	*Reduction in disease damage due to harvested fruit or*	Not-present	Not-present	Not-present	Not-present	Not-present
	Atmospheric composition and conditions	Regulation of temperature and humidity, including ventilation and transpiration	2.2.6.2	*Evaporative cooling provided by urban trees*	*Increased thermal comfort in cities*	Not-present	Not-present	Not-present	Not-present	Not-present

3.3 Extent of services present in the Great Southern Reef

A number of ecosystem services are provided by the Great Southern Reef, and these are outlined in the following sections, and summarised in Figure 5.

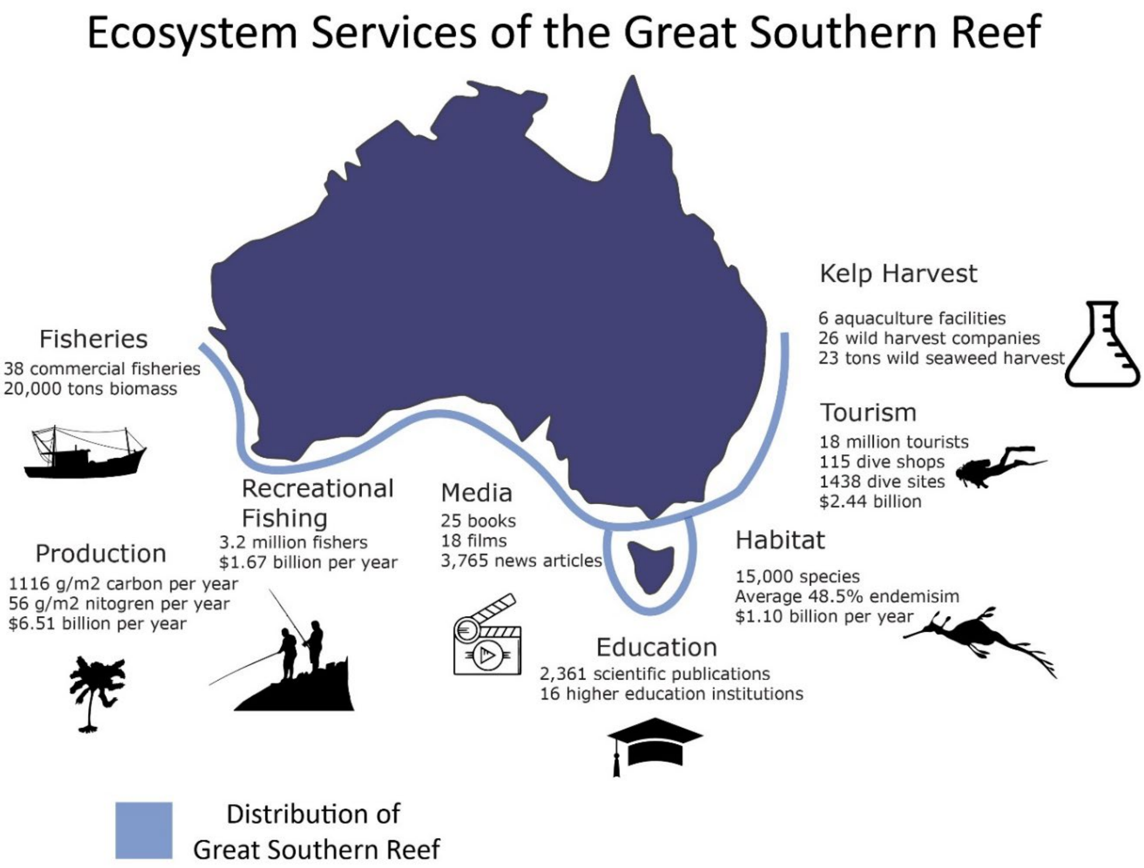


Figure 5 Summary numbers of the biophysical and economic benefits provided by the Great Southern Reef.

3.3.1 Provisioning

3.3.1.1 Aquaculture for nutritional purposes

Only New South Wales and Tasmania currently have businesses which support kelp aquaculture for nutritional purposes. These are Venus Shell Systems (Bomaderry, NSW), Sea Health Products (Tilba, NSW), PhycoHealth (Huskisson, NSW), Aquatopia (Lady Barron, Tasmania), and Ocean Treasure (Hobart, Tasmania). These operations are involved in culturing *Ecklonia* species, while Ocean Treasure also cultures *Macrocystis* and *Lessonia*. Raw data are presented in SI 1.

3.3.1.2 Wild harvest of kelp materials

We counted 26 businesses involved in selling materials derived from wild kelp harvest, primarily *Durvillea* (19/26). These businesses are relatively spread across the country, 7 in New South Wales, 6 in Victoria, 6 in Tasmania, 1 in South Australia, 1 in Western Australia, 1 in Canberra, and 4 in Queensland. Raw data are presented in SI 2. The Food and Agriculture organization reported that 23 tons of wild “brown seaweeds” were harvested in 2019.

3.3.1.3 Wild harvest of animals associated with kelp

We found extensive evidence of recreational and commercial fisheries supported by the Great Southern Reef. There were at least 38 species fished commercially across the five states. Of these fisheries (66 total), 20 were located in New South Wales, 9 in South Australia, 14 in Tasmania, 8 in Victoria, and 15 in Western Australia.

These commercial fisheries amounted to 19,915 tons of biomass. The largest state level fisheries by biomass landed were *Panilurus* – Western Australia (6231 tons), *Mugil cephalus* – Tasmania (2,737 tons), *Jasus spp.* – South Australia (1,539 tons), *Sardinops sagax* – Western Australia (1,092 tons), and *Jasus edwardsii* – Tasmania (1,010 tons).

The five largest fisheries at the national level are *Panilurus spp.* (6,231 tons), *Mugil cephalus* (2,932 tons), *Jasus spp.* (1,998 tons), *Haliotis rubra* (1,919 tons), and *Sardinops sagax* (1,092 tons).

Raw data are presented in SI 3.

A nationwide assessment by Henry and Lyle 2003 estimated that 2.16 million Australians partook in recreational fishing each year, spending an estimated 6.03 million days on the activity. While a systematic update has not been conducted, a compilation of other estimates suggests this number is 3.2 million in 2022 (see section 3.4.3).

We recorded no businesses associated with the sale of animals harvested from kelp forests for non-consumption purposes.

3.3.1.5 Sale of materials derived from wild plants

We recorded only one business, Sea Health Products in Tilba, New South Wales that sells kelp materials as stock material. Raw data are presented in SI 4.

3.3.1.6 Kelp materials used for medicinal purposes

We recorded businesses using kelp materials in medicinal products and supplements in all states but Western Australia, eight in total. These businesses sold products made from *Ecklonia, Undaria, Alaria,* and *Durvillaea.* Raw data are presented in SI 5.

We found 10 papers that reported medicinal or pharmaceutical uses for derivatives of *Ecklonia radiata*. The most common derivative was phlorotannin, which has been shown to have anti-diabetic, anti-cancer, anti-oxidation, antibacterial, radioprotective, and anti-HIV properties, though *in vivo* demonstration of these effects is limited (Selfati et al. 2018). The other main derivative was Fucoidan which has anticoagulant, antitumor, antithrombosis, antivirus, antioxidation, and immunomodulating properties (Shen et al. 2018). Lastly, there was evidence that derivatives from *E. radiata* were useful as probiotics and increased the production of beneficial gut bacteria (Zheng et al. 2020). Raw data are presented in SI 6.

3.3.2 Regulation and maintenance

3.3.2.1 Carbon and nitrogen cycling

The average carbon production of *Ecklonia* forests across Australia was 1,116 grams of carbon per m^2. Raw data are presented in SI 7. We estimated that 67% of NPP was exported away from these reefs as detritus (Krumhansl & Scheibling 2012). Our work estimated (see section 3.2.2) an average export of kelp NPP of 15.29% (SD 8.6) into deep ocean sinks, which represents a coarse estimate of potential sequestration. Note this does not include any burial on continental shelves or in other blue carbon habitats.

We recorded only one measure of nitrogen content, 1.6%, which would equate to 55.8 grams of nitrogen per m^2. We found no measures of phosphorus content of *Ecklonia*.

3.3.2.2 Sediment transport

Three studies quantified the impact of kelp forests on water and sediment flow. Together they found that *Ecklonia radiata* can reduce wave height (Morris et al. 2020) and reduce sediment flow and deposition across the benthos (Layton et al. 2019b), while a modelling study for “kelp” found a reduction in erosion and shoreline retreat (Van Rooijen & Winter 2019). Raw data are presented in SI 9.

3.3.2.3 Habitat provisioning

We found limited studies quantifying the nursery effect of kelp forests (i.e., juvenile density or performance inside and outside of a kelp forest). There is however, substantial evidence for this service in more studied kelp forest ecosystems (Dayton 1985, Steneck et al. 2002, Miller et al. 2018) and some species-specific evidence for the importance of kelp forests as nursery habitat for ostracods, important prey species (Yassini et al. 1995), and various reef fishes (Kingsford & Carlson 2010). Further, juvenile abalone and lobster species have been found to have higher survival and growth rates in kelp forests than outside (Hinojosa et al. 2014, Marzinelli et al. 2014). Raw data are presented in SI 10.

We found evidence of nearly 15,000 species which live in the Great Southern Reef. The most populous group was sponges (Porifera – 4463 species), followed by invertebrates (4100 species), seaweeds (Rhodophyta – 565 species, Phaeophyta – 219 species, Chlorophyta – 124 species), Mollusca (757 species), Fishes (731 species), Isopoda (541 species), Bryozoa (546 species), Decapoda (390 species), Echinodermata (115 species), Brittle stars (Ophiuroidea – 235 species). The average endemism rate for these groups was 48.5% with a low of 22% (brittle stars) and a high of 77% (Rhodophyta). Raw data are presented in SI 11.

3.3.2.4 Regulation of water quality

The only evidence for kelp forests regulating water quality was from a study that showed the *Macrocystis* forests around aquaculture facilities reduced chlorophyll a concentration by 8.5 – 12.5%. Raw data are presented in SI 12.

Three studies from Tasmania showed that *Ecklonia* forests can increase local pH levels by 0.05 – 0.13 units (Noisette & Hurd 2018, Layton et al. 2019a, Ling et al. 2020). Raw data are presented in SI 13.

3.3.3 Cultural

3.3.3.1 Elements promoting health, recuperation, or enjoyment

Direct measures that accurately reflect the cultural significance of kelp and temperate reefs across southern Australia are either currently not available or in many instances have gone to sleep. For instance, over the past 65,000 years, kelp forests have played an important role for Indigenous peoples across the southern half of the continent, where an estimated 46 Indigenous nations border onto the Great Southern Reef. Within these nations, evidence of the importance of reefs is illustrated by the abundance of midden areas around the coastline. In NSW and Tasmania, for instance, there are 7570 and 4098 shell midden sites reported. The number of comparable sites in Victoria, South Australia and Western Australia is unknown. Raw data are presented in SI 14.

The diversity of seaweeds and the diversity of Indigenous cultures across temperate Australia make it likely that seaweeds were important for a range of traditional uses and cultural practices. While much of this traditional knowledge is not available from published sources, some uses have been recorded related to ceremonial activities, medicine, clothing, diet/cooking, fishing, and shelter/domestic use (Thurstan et al. 2018). In Tasmania, for example, Aboriginal women used kelp to assist them to dive and catch crayfish (Backhouse 1843). Tasmanian Aboriginals traditionally used the thick leathery fronds of Bull kelp (*Durvillea potatorum)* to make water carriers, baskets, and shoes (Thurstan et al. 2018). While some of these cultural practices are maintained today, the extent of reliance on kelps historically has not been documented.

In contemporary Australian culture, temperate reefs and kelp also play an important role for many Australians from major cities, to regional towns across the nation (Bennett et al. 2016). Kelp forests form a tacit part of the environment and coastal experience for millions of Australians who directly or indirectly, have an association with kelp forests through recreation, leisure and/or enterprise. Many of these past times are documented

3.3.3.1 Dive shops

We recorded 115 dive shops across all five Southern states. The most shops were in New South Wales (45), followed by Western Australia (23), Victoria (20), South Australia (17), and Tasmania (10). Raw data are presented in SI 15.

We also recorded 1436 marked and named dive sites across the five states. The most dive sites were in Tasmania (452), New South Wales (344), South Australia (285), Victoria (188), and then Western Australia (167). Raw data are presented in SI 16.

3.3.3.2 Tourism – visits

There were an average 18.01 million people who partook in tourist activities along the coastline of the Great Southern Reef between 2008 and 2015. Of these, most people visited coastal national or state parks (11.59 million), visited aquariums or zoos (4.29 million), went snorkelling (0.95 million), whale watching (0.83 million), or went Scuba diving (0.38 million). These values include visits to Northern Western Australia which is not part of the Great Southern Reef but all of Western Australia was only a small percentage of the total tourism values (see below).

There are more specific activity values available domestically. In 2020, 11.1 million Australians visited the coast, on average 3.3 times a month. Together, there were over 500 million visits to the coast by Australians in this year. Of those people, 5.33 million were swimming, 1.67 were boating, 1.44 were fishing from the shore, 1 million were snorkelling, 0.89 million used non-motorized crafts (e.g., kayaks, stand up paddle boards), 0.67 million were surfing, 0.56 million were rock fishing, 0.44 million were using PWC, and 0.22 million went scuba diving. Raw data are presented in SI 17.

3.3.3.3 Recreational fishing

The best available nationwide estimate of recreational fishing along the Great Southern Reef is from Henry and Lyle in 2003. They estimated that 2.16 million Australian participated in recreational fishing each year. The greatest participations rates were in Tasmania (29%), Western Australia (28.5%), South Australia (24.1%), New South Wales (17.1%), and Victoria (12.7%). Raw data are presented in SI 18.

Within New South Wales, an estimated 2.01 million fish were caught by recreational fishers in the ocean in 2019-2020 (Murphy et al. 2022). These numbers are not disaggregated by habitat type. The most commonly caught species over this period were sand flathead (*Platycephalidae*, ~335,000), snapper (*Chrysophrys auratus,* ~264,000), yellowfin and black bream (*Acanthopagrus spp*. ,~184,000), yellowtail scad (*Trachurus novaezelandiae*, ~173,000), and blue mackerel (*Scomber australasicus* ,~154,000).

In Victoria, the most commonly caught fish in recreational fishing were King George whiting (19% of total catch), Flathead – other than dusky (33%), and squids (15%).

In South Australia, the most commonly caught fish in recreational fishing were blue swimmer crabs (21% - 2,456,336), King George whiting (17% - 2,001,937), and Australian herring (10% - 1,167,774).

In Tasmania, the most commonly caught fish in recreational fishing were flathead (49.6% - 1,426,115), bivalves (27% - 804,675), and scallops (4.4% - 129,670).

In Western Australia, the most commonly caught fish in recreational fishing were school whiting (11%), Australian herring (5%), and Western Australian dhufish (3%).

All raw data for recreational fishing are presented in SI 18.

3.3.3.4 Elements enabling learning

We found 22,664 scientific publications related to kelp forests listed on Web of Science. Of these, 2,361 were from published from Australia between 1976 and 2022. This number represented 10.4% of all publications and was the second highest result, behind the United States of America (5,263 publications or 23.22%). Raw data are presented in SI 19.

We recorded 16 higher education institutions offering marine biology programs in all five states. Nearly the majority (7) of institutions were in New South Wales, while 4 were in Western Australia, 2 in Victoria, 2 in South Australia, and 1 in Tasmania. Raw data are presented in SI 20.

We also recorded 1436 citizen science survey sites led by the Reef Life Survey project. These sites were split across the states as follow: New South Wales (233), Victoria (188), Tasmania (452), Western Australia (167), and South Australia (285). Together, these comprised 61% of the reef life survey sites in the country (total, 2358). Raw data are presented in SI 21.

3.3.3.5 Elements that have symbolic, sacred, or religious meaning

While shell middens are likely present in all states, we only found accessible records for New South Wales and Tasmania, which recorded 7,570 and 4,098 coastal middens respectively. Raw data are presented in SI 14.

3.3.3.6 Elements used for entertainment or representation

We found 43 media outputs that featured kelp forests, 25 of which were books and 18 of which were films or videos. Raw data are presented in SI 22. Kelp forests were mentioned in 3765 news articles across 14 local, state, and federal news outlets in Australia. Raw data are presented in SI 23.

3.3.3.7 Elements which have existence value

We recorded 161 unique marine managed areas with the Great Southern Reef 50m contour, totalling an area of 50,710 km^2. Of these, there are 1,964 km^2 in New South Wales, 25,327 km^2 in South Australia, 189 km^2 in Tasmania, 697 km^2 in Victoria, and 4,345 km^2 in Western Australia, and 18,188 km^2 under commonwealth jurisdiction. These areas varied by size and management level and are summarized in Table 13. These Raw data are presented in SI 24.

Table 13: Marine managed areas in the Great Southern Reef. Data are split by protection type and state. NSW (New South Wales), Tas (Tasmania), WA (Western Australia), SA (South Australia), Vic (Victoria), Com (Commonwealth).

IUCN Classification	Area (km^2)
Commonwealth	18,188
II	2,759
IV	21
VI	15,408
New South Wales	1,964
II	326
IV	1,027
VI	612
South Australia	25,327
Ia	2,794
II	3,600
III	6
IV	11,512
VI	7,414
Tasmania	189
Ia	0
II	66
IV	8
V	19
VI	95
Victoria	697
II	367
III	1
VI	329
Western Australia	4,345
Ia	30
II	860
IV	2,180
VI	1,275
Total	**50,710**

3.3.4 Data gaps

3.3.4.1 Provisioning

We identified the following values as important data gaps for understanding the value of Australian kelp ecosystems and the Great Southern Reef as a whole.

- Reports on the amount of kelp or seaweed that is cultured per year, specified by species would help understand the amount of kelp or seaweed that is produced by aquaculture.
- There was no information on the use or take of animals that are associated with kelp forests outside of fisheries. Abalone shells, for instance, are a popular decorative and art item but information is needed on how many shells are collected and sold each year for this purpose.
- We identified a number of businesses that sold nutritional and supplemental products containing kelp, but we recommend that the amount of kelp material that is used in this production process be specified.

3.3.4.2 Regulating and maintenance

There is evidence elsewhere in the world for the bioaccumulation functions of seaweeds and kelp species. This question has not been studied in Australia and we recommend that the uptake rates of various pollutants and toxins by important habitat species such as *Ecklonia* and *Phyllospora* be tested in different geographies across Australia.

There were very few studies which investigated how much kelp forests attenuated wave height in marine systems across Australia. Future research should work to determine how the presence of a kelp forest impacts wave height in various locations around Australia.

There was only one study which quantified the amount of erosion prevented by a kelp forest. This data point is insufficient to sufficiently determine the extent that this service is provided in Australia. Future research will need to quantify the length (m) of shoreline retreat per year that is prevented by 1) the presence of a kelp forest and 2) differing densities of kelp forests.

We found point studies that described the ways in which various species used kelp forest as nursery habitat. We did not find any work that quantified the value of kelp forest habitat compared to an alternative habitat. Further research will need to quantify how survival and growth of juveniles is impacted by the presence and absence of a kelp forest.

Only one studied modelled the impact of kelp forests on water clarity. Further empirical work is needed to determine how water clarity varies inside of a kelp forest compared to outside or with and without a kelp forest.

All the studies which examined the role of kelp forests in modulating pH looked at *Ecklonia* in Tasmania. Future work will need to expand on these locations and consideration how different geographies and genera impact the results.

Many species reside in or transit through a kelp forest. There is however little information about the dependency of these species on kelp forests, i.e., what would happen to that species if the kelp was not there. Future work will need to determine how much of a species life cycle is truly dependent on kelp forests and how much can be substituted for other habitats. Important species such as lobster and abalone should be prioritized, followed by other commercially and recreationally important species.

There are no kelp-affiliated species on the IUCN red list. This absence likely reflects a lack of information as opposed to a lack of risk. Future work should look to assess the population trends of animals living in the Great Southern Reef.

3.3.4.3 Cultural

An achievable next step for understanding the value of recreation and tourism on the Great Southern Reef is to quantify the number of dive trips and days. These values include the number of tank fills, number of gear hires, number of boat trips, and persons employed in retail and guiding. Said values could likely be obtained from interviews with the relevant dive shops highlighted in section 3.3.3.

It will be important for future work to quantify how many students are enrolled in university and TAFE programs related to the Great Southern Reef.

It will be important for future work to quantify how many people are engaged in citizen science activities such as Reef Life Survey across Southern Australia.

3.3.6 Available data

We identified a number of datasets which address some of the noted data gaps but are not publicly available or are not processed.

Squidle data platform

Australia

- Benthic imaging from AUVs across the Australian coast

New South Wales – DPI Fisheries Research

- Kelp distribution across the Greater Sydney coastline (Newcastle to Shellharbour).
- Fish assemblages from state-wide Baited Remote Underwater Vehicle program which could be useful in the context of separate kelp datasets.
- Kelp density from towed video transects at 22 sites along the NSW coast from Tweed Heads to Eden. There is also biomass data from quadrats collected at 6 locations across the same geographic range.
- Estimations of the total biomass of kelp along the NSW coast using key drivers (habitat availability, light and *in situ* temperatures) of kelp occurrence and cover (Davis et al. 2021).

3.3.7 Certainty assessment

We provided an assessment of how much certainty can be placed on the biophysical estimates, given the availability of data, how much of the Great Southern Reef it covered, and the quantity of the data (Table 14).

Table 14: Qualitative confidence score based on Spatial coverage, Quality and Quantity of information informing bio-physical measurements.

Ecosystem Service	Spatial coverage	Quality	Quantity
Commercial fisheries	High	High	High
Recreational fishing	High	Medium	Medium
Existence value	Low	High	Low
Carbon sequestration	High	Medium	Low
Diving and snorkelling	High	Medium	Low
Nutrient cycling	Medium	Low	Low
Other Recreation	High	Medium	Low

3.4 Economic value of services provided by the Great Southern Reef

3.4.1 Total economic value of the Great Southern Reef

In total, we estimate the total economic value from the Great Southern Reef at AUD $11,558 million per year. Table 15 shows the economic value of the ecosystem services in the Great Southern Reef. Surplus values are equivalent and can be directly compared. We obtained surplus values from commercial fisheries, recreational and tourism activities and habitat services. Moreover, the social cost of carbon as well as the avoided abatement costs for nutrients are net values that are considered comparable to surplus values. Table 15 also shows how much certainty can be placed on the economic value estimates. The criteria used for the certainty assessment are detailed in section 2.4.6.

Table 15: Estimated total economic value of ecosystem services provided by the Great Southern Reef.

Ecosystem Service	Main Beneficiary	Value (M AUD/year)	Value measure	Certainty score
Provisioning Services				
Commercial fisheries*	Commercial fisheries	$33.2	Producer surplus	Medium
Regulating Services				
Carbon sequestration	General public	$37.8	Social cost of carbon	Medium
Nutrient cycling	General public	$6,484	Avoided abatement costs	Medium
Cultural Services				
Recreational fisheries	Recreational fishers	$1,668	Consumer surplus	Medium
Diving and snorkelling	Divers and snorkelers	$403	Consumer surplus	Very poor
Other recreation	Other reef visitors	$1,836	Consumer surplus	Low
Habitat Services				
Existence value for kelp ecosystem	General public	$1,096	Consumer surplus	Low
Total		**$11,558**		

* Surplus value only for rock lobster fishery.

The scenario above is effectively based on an evaluation of having *all* of the Great Southern Reef, or having *none* of it: it is measuring the value of all ecosystem service provision from the reef. However, as identified in Section 1.5, Welfare Analysis should be a marginal analysis. We recognise that people's values for a unit of an ecosystem service will change depending on how many units of the ecosystem service we have to begin with. Thus, for an evaluation to be meaningful, it should be defined in terms of a potential change in the number of units available, relative to how much we have now: we need to define the marginal change, as opposed to an all-or-nothing situation which, when dealing with a major ecosystem such as the Great Southern Reef, is non-marginal.

In addition, the data sources used for the economic valuation are based on current extents of the ecosystem services that are being valued. This means that when extrapolating these values per unit, we can be reasonably confident that the values per unit are consistent for small changes in the amount of the service provided relative to current extent (such as a 10 or 20% change in provision), but highly unreliable if we start to assume the values per unit will hold as we try to measure large changes (such as the difference between all-or-nothing).

Recognising that the annual economic value reported is unstable due to the non-marginal counterfactual on which it is based, we present here an alternative estimation that evaluates a marginal change.

In Table 16, we report the *potential loss of total economic value that we would experience if, over the next 20 years, we were to lose 20% of the ecosystem services provided by the Great Southern Reef*. While this scenario is hypothetical, it is plausible to consider that we may lose such a proportion of the Great Southern Reef's services in 20 years' time due to climate change and other anthropogenic pressures given model projections of expected changes in distribution (Martínez et al. 2018).

In this scenario we assume there is a uniform 20% loss across all services, and across the spatial extent of the Great Southern Reef. We assume that the loss occurs gradually and linearly over the 20 years, such that we have 100% of the ecosystem service benefits occurring in Year 0, and only 80% of the benefits remaining in Year 20, according to the following equation where T represents the timeframe in years:

$$Benefit\ (year\ t) = \frac{(annualised\ benefit)t}{T}$$

The annualised benefits are the 'values per year' from Table 15. We measure the value associated with the change that occurs; that is, the proportion of benefit that is lost each year, up to the full 20% that is lost by Year 20. We then discount the future years' values to a present value, using the following equation:

$$Present\ value = \sum_{t=0}^{T} \frac{x_t}{(1+r)^t}$$

Where *X* is the value of the future benefit, and *r* is the discount rate at time *t.* The Australian Government currently recommends using a discount rate of 7%, but to conduct a sensitivity analysis using lower and higher rates. Accordingly, we apply discount rates of 3%, 7% and 10% to the estimation.

The total economic value of the (hypothetical) 20% loss of Great Southern Reef ecosystem services over 20 years is estimated to be between $30.5 and $28.6 billion AUD, depending on the discount rate (Table 16). Notwithstanding the issues around data certainty as reported in Table 15, the figure of $29.36 billion AUD (7% discount rate) aligns to the basic principles of total economic valuation and provides a meaningful estimate of the value that we could stand to lose from the Great Southern Reef if we continue with business-as-usual management.

Table 16: The total economic value of a 20% loss of Great Southern Reef ecosystem services over 20 years, reported in millions of AUD.

	Discount rate		
Ecosystem Service	3%	7%	10%
Provisioning Services			
Commercial fisheries*	$67.69	$65.16	$63.38
Regulating Services			
Carbon sequestration	$77.07	$74.19	$72.16
Nutrient cycling	$13,219.81	$12,725.61	$12,378.55
Cultural Services			
Recreational fisheries	$3,400.78	$3,273.64	$3,184.36
Diving and snorkelling	$821.65	$790.93	$769.36
Other recreation	$3,743.30	$3,603.36	$3,505.09
Habitat Services			
Existence value for kelp ecosystem	$9,172.72	$8,829.81	$8,589.00
Total	**$30,503.01**	**$29,362.71**	**$28,561.91**

3.4.1.1 Additional economic measures

We obtained smaller economic outputs using other various economic measures for different services (Table 17). For provisioning services, we found gross value product (GVP), whereas for recreation and tourism, values were available in gross value added (GVA – which is the gross product minus intermediate inputs). These value measures are not compatible with surplus values and are not considered to represent the true value of the resource. However, they are often used as proxy measures where surplus values are not available.

Table 17: Estimated additional economic measures of ecosystem services provided by the Great Southern Reef.

Ecosystem Service	Main Beneficiary	Value (M AUD/year)	Value measure
Provisioning Services			
Commercial fisheries *	Commercial fisheries enterprises	$843	GVP
Direct kelp harvest	Commercial fisheries enterprises	$3	GVP
Cultural Services			
Recreational fisheries	Commercial enterprises	$1,668	Expenditure

Details on the values of each ecosystem service are given in the following sections. Also, further details on all analyses and calculus are available.

3.4.2 Provisioning

Commercial fisheries

We estimate the total GVP generated from commercial fisheries that depend on the Great Southern Reef at an average of AUD $840 million. In 2019-2020, the GVP was AUD $633 million (Table 18). GVP is mainly driven by the Rock Lobster and the Abalone fisheries with $504 million AUD and $118 million AUD, respectively. We identified 29 other fisheries that target species that depend on kelp moderately or on a low level with a combined value of $10 million AUD within the Great Southern Reef. Western Australia generates the highest GVP, followed by South Australia and Tasmania.

Table 18: GVP from fisheries per target species and Australian State in 2020 M AUD.

	Min	Max	Average	Latest (2019-20)
Species				
Rock Lobster	$377	$933	$600	$504
Abalone	$109	$427	$229	$118
Others	$6	$17	$10	$11
State				
NSW	$11	$45	$23	$22
SA	$110	$210	$158	$145
VIC	$39	$145	$74	$51
WA*	$209	$661	$383	$280
TAS	$123	$316	$202	$135
Total			**$840**	**$633**

* Area outside Great Southern Reef boundaries (north of Geraldton) excluded

The GVP of rock lobster fishery fluctuated between AUD $377 million in 2010-2011 and AUD $933 million in 1999-2000 (Figure 6). The GVP of abalone fisheries shows a declining trend since the early 2000s.

There is a decreasing production value in 2019-2020 (particularly of rock lobster) which can be explained by a lower demand for exports due to the COVID-19 pandemic.

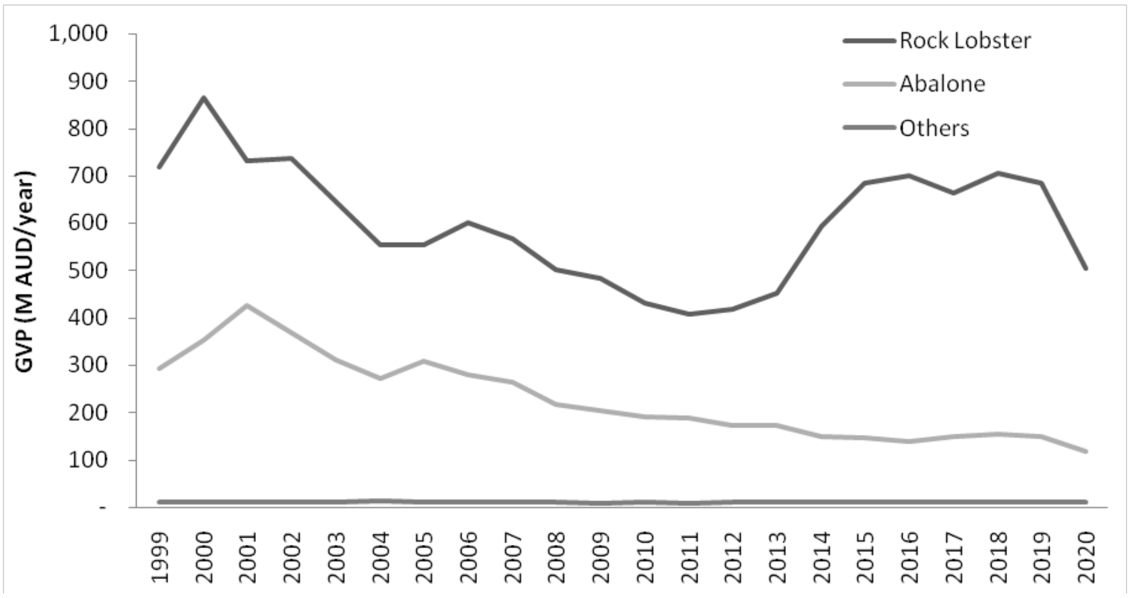


Figure 6 Historic trend of the GVP from Great Southern Reef dependent fisheries (Steven et al. 2021).

Data on the economic performance from commercial fisheries (i.e., the profit earned component of GVP) is commercially sensitive information and was therefore difficult to obtain for the majority of commercial fisheries. We found the value from fishing licenses for the South Australian Southern Zone rock lobster fishery from 2016 to 2020 (BDO EconSeatch 2021). The license value ranged from AUD $5.4 million in 2017-18 to AUD $6.2 million in 2019-20 (Figure 7). On average, the profit was 5.52% from the GVP of this fishery. Under the assumption that the economic performance between the rock lobster fisheries in Australia is constant, we estimated that the profit from all rock lobster fisheries combined is AUD $33.1 million per year.

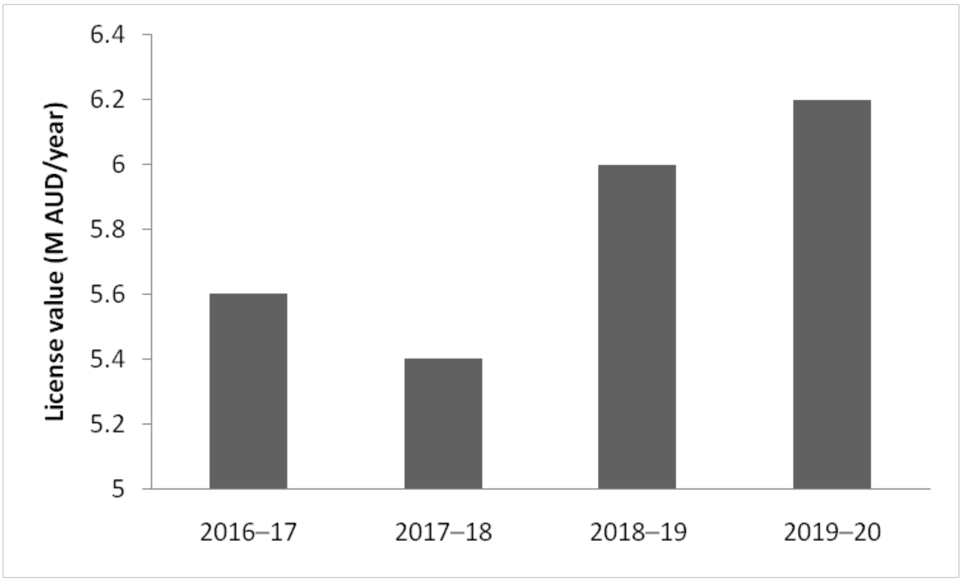


Figure 7 License value of the South Australian Southern Zone rock lobster fishery (BDO EconSeatch 2021).

Direct kelp harvest

The seaweed industry in Australia has a small production of 1923 tonnes of wet weight through farmed and wild harvest which makes up 0.01% of the worlds production (Fisheries and Agriculture Organization 2021). The wild harvest is valued at approximately AUD $3 million GVP (Kelly 2020), all of which can be attributed to the Great Southern Reef. The industry is based on small scale operations in Tasmania, New South Wales and Victoria and focuses mainly on beach cast collection of *Durvillea potatorum*, *Ecklonia radiata* and species of *Undaria* (Kelly 2020).

Seaweed exports from Australia are estimated at AUD $1.5 million (ABS, 2020). About 20 full time equivalents (FTE) are directly employed in commercial seaweed harvest in the Great Southern Reef (Kelly 2020). However, it is expected that the Australian seaweed industry will significantly increase GVP and employment in the next years (Kelly 2020).

3.4.3 Regulation and maintenance

3.4.2.1 Carbon sequestration

The area of habitat mapped and classified as 'macroalgae' in the Great Southern Reef (see 3.1.1) is approximately 2,940 km^2. With a carbon sequestration of 1,116 g/m^2, we estimate the carbon content of kelp in the Great Southern Reef at 1,116 t/ Km^2. Based on 15.29% (SD 8.6) of carbon that is exported across the shelf, a total of 501,671 t (+/- 282,169) of carbon that stems from kelp in the Great Southern Reef is stored in the long term.

We estimate the value of carbon sequestration based on the SCC from the Interagency working group and a 'central' discount rate of 3%, at AUD $37.85 million. The value ranges between AUD $11.4 million and AUD $56.33 million, depending on the SCC and the discount rate applied. Table 19 shows the value of carbon sequestration of the Great Southern Reef based on the different SCC.

However, it is important to note that current SCC estimates do not account for several of the climate change impacts that were identified by the Intergovernmental Panel on Climate Change (IPCC). Further, considering the substantial data gaps identified (3.1.4) the area of kelp forest or macroalgae in the Great Southern Reef is likely much higher . Hence, our results are likely underestimated and represent a lower bound value.

Table 19: Value of carbon sequestration under different SCC estimates and discount rates.

Source	Discount rate (%)	SCC (2020 AUD/Kg C)	Aggregated value (2020 M AUD/year)
Wang et al. 2019	3	$0.17	$85.28
IWG 2016	5	$0.09	$45.15
IWG 2016	3	$0.30	$150.50
IWG 2016	2.5	$0.44	$220.73

3.4.2.2 Nutrient cycling

We assessed the value of the uptake of nitrogen from kelp in areas with reported excess nutrient levels. We estimate the kelp area in hypoxic or eutrophic regions along the Great Southern Reef at 200 Km^2. With a nitrogen content of 55.8 g/m2 of kelp, 11,160 t of nitrogen per year is being absorbed by kelp within the area of nutrient excess.

We applied the costs for avoiding one Kg of nitrogen to enter the marine system of AUD $581/Kg of removed nitrogen per year at a 5% real discount rate. We estimate that the value of kelp providing nutrient cycling is AUD $32.4 million per Km^2 and AUD $6,484 million for the entire Great Southern Reef.

Our results are high compared to other studies (Bayley et al. 2021, Eger et al. 2021). This difference can be mainly explained by the relatively high abatement costs per Kg of nitrogen in Victoria compared to AUD $193/Kg in Sweden (Cole & Moksnes 2016), AUD $31/Kg in Spain (Molinos-Senante et al. 2010) or AUD $9/Kg in the United States of America (Pollack et al. 2013).

The nitrogen absorption in this study is based on one nitrogen content value only. However, distinct types of nitrogen are being absorbed at different rates which would influence the monetary value of this service. Moreover, we applied the value for nutrient cycling to 100% of absorbed nitrogen within the nutrient excess areas. However, kelp would still store a certain amount of nutrients if nitrogen levels were reduced to healthy levels. Therefore, our value might be overestimated.

On the other hand, we have estimated the size of nutrient excess areas conservatively at 1 Km around reported locations. In the Great Barrier Reef, effects of nutrient excess were measured commonly 15 to 20 Km off the coast, but were detected even hundreds of kilometres offshore (Furnas et al. 2005, Prange et al. 2009). If the areas of nutrient excess in the Great Southern Reef were substantially larger than estimated here, our values could be significantly underestimated. A better understanding of affected areas in the Great Southern Reef, the proportion of nutrients that are above healthy levels, as well as the types of nitrogen in the system are needed to improve the accuracy of value estimates.

To the best of our knowledge, there is no information on the absorption or abatement costs of phosphorus.

3.4.4 Cultural

3.4.3.1 Recreational fishing

We estimate that 3.2 million people participated in recreational fishing activities in the Great Southern Reef per year. These recreational fishers make 10.1 million fishing trips in the Great Southern Reef per year. Recreational fishers from Western Australian and South Australia are more avid, doing more fishing trips per participant compared to other States. The total expenditure associated with kelp dependent species is AUD $1,668 million annually (Table 20).

The search in the recreation used value database resulted in 34 consumer surplus values that were relevant to our search criteria. We estimate the consumer surplus of a daily recreational fishing trip at an average real value of AUD $276 (± 161 SD) per person. The value of all fishing trips that can be attributed to kelp dependent species is estimated to be AUD $1,115 million per year. Table 20 shows the aggregated expenditure and consumer surplus per State.

Table 20: Participants, coastal fishing days, expenditure and consumer surplus related to recreational fishing activities per Australian State. All values are given in real 2020 AUD.

State	Participants ('000/ year)	Great Southern Reef fishing trips ('000 days/ year)	Kelp associated catch (%)	Expenditure (M 2020 AUD)	Consumer surplus (M 2020 AUD)
New South Wales	1,244.2	2,093.4	22.7	$164.4	$130.9
Victoria	1,169.2	502.7	16.8	$31.0	$138.5
Tasmania	142.4	484.9	14.7	$9.2	$19.6
South Australia	37.8	1,643.8	37.1	$68.2	$167.6
Western Australia	629	5,400	40.0	$1,395.3	$657.9
Total	**3,222.4**	**10,124.5**	**26.3**	**$1,668.2**	**$1,114.6**

3.4.3.2 Diving and snorkelling

We estimate that about 13.8 million domestic and international day and overnight holiday visitors engaged in diving and/or snorkelling activities on the Great Southern Reef. Under the assumption that expenditure is directly proportional to the trip duration and does not vary with holiday activities, visitors spent AUD $3,417 million for diving and snorkelling in the Great Southern Reef in 2019 (Tables 21 and 22). Information on the producer surplus associated with these expenditures could not be obtained.

We used the benefit transfer approach to assess the welfare of divers and snorkelers in the Great Southern Reef. We identified one study on the value of diving within Great Southern Reef boundaries. Harvey et al. (2021) estimated the consumer surplus for diving on marine infrastructure such as shipwrecks and the Busselton Jetty in Geographe Bay, Western Australia. Based on the midpoint consumer surplus (AUD $20.4/person and day), we estimate that divers and snorkelers perceive a benefit of AUD $403 million/year from the Great Southern Reef.

We could not obtain a value associated with natural reef. The consumer surplus (CS) is low compared to CS from diving in GBR at AUD $185/trip (Kragt et al. 2009) which is to be expected due to the reputation of the GBR as well as a larger proportion of international tourists diving on the reef. A non-market value study on diving and snorkelling on the Great Southern Reef or at least a more suitable value to transfer would generate a more accurate result.

Table 21: Day trips from domestic travellers spent on snorkelling and diving in 2019.

State	Coastal day trips (000/year)	Expenditure (2020 M AUD/year)	CS (2020 M AUD/year)
NSW	2,983	$317	$61
SA	2,235	$262	$46
TAS	1,631	$227	$33
VIC	1,477	$307	$30
WA	2,433	$545	$50
Total	**10,760**	**$1,659**	**$220**

Table 22: Domestic and international overnight holiday trips spent on snorkelling and diving in 2019.

State	Coastal Visitors (000/year)	Nights (000/year)	Expenditure (2020 M AUD/year)	CS (2020 M AUD/year)
NSW	481	2,254	$403	$46
SA	757	2,421	$461	$49
TAS	686	2,111	$411	$43
VIC	501	1,012	$223	$21
WA	633	1,182	$260	$24
Total	**3,059**	**8,980**	**$1,758**	**$183**

3.4.3.3 Other recreational activities

Surfing and ocean swimming were classified as moderately dependent on the Great Southern Reef because the activities could be pursued without reef biota, however, is expected to increase the quality of these activities. Therefore, values for these activities were adjusted by a factor of 50%.

The literature search yielded two CS values associated with surfing with a mean CS of AUD $23/trip. Aggregating this individual CS over $36.4 million surfing trips per year (Surf Life Saving Australia 2021) results in an annual CS of AUD $425.5 million. Pascoe et al 2019 estimated the consumer surplus for ocean swimming at AUD $10.4/trip. Aggregated over 281 million swimming trips per year, we estimate the value of ocean swimming at AUD $1,411 million.

These values of recreational activities are likely underestimates because they do not include the costs that residents pay to live closer to the locations where they participate in coastal activities (Scorse et al. 2015). Moreover, other activities that might be associated with the reef such as visits to National Parks and walking were not included due to data deficiency. For example, the quality of beach walks might be influenced by species that depend on the Great Southern Reef such as shells that wash up on the shore. Pascoe et al. (2019) found a CS associated with beach walking. However, we could not disentangle to what extent this value could be attributed to the biota of the Great Southern Reef. Boating and other watercrafts were not included to avoid double counting because often, they are used as a way of transport to engage in other activities such as diving or recreational fishing which is already accounted for. We could not obtain information on the profit of tour operators.

3.4.5 Habitat

We identified one study from Tasmania that was deemed suitable for benefit transfer: Grover et al. (2021) estimated the willingness to pay for the restoration of kelp forests within the East Coast Stock Rebuilding Zone through three different management options: (i) Extension of marine reserves, (ii) Invasive species control through the culling of sea urchins, the reintroduction of rock lobsters or subsidising sea urchin farms and (iii) Provision of habitat through replanting of kelp or artificial kelp beds. Respondents were willing to pay AUD $8.07 for the replanting of kelp within the East Tasmanian Stock Rebuilding Zone per household and year (Grover et al. 2021).

Under the assumption that kelp is distributed equally across the Great Southern Reef, we estimated that there is 360.3 km^2 of kelp forest within the Stock Rebuilding Zone. Moreover, Ling and Keane (2018) found that in Tasmania, sea urchin barrens had expanded by 15.2% in the last 15 years and predict that by 2030, about 50% of kelp cover could be damaged. Hence, we estimated the kelp area valued by respondents to be between 54.8 Km^2 and 180.1 km^2 which results in a consumer surplus between AUD $0.05 and AUD $0.15 per household, year and km^2 of replanted kelp. Under the assumption that respondents' value applies for healthy kelp forests (irrespective of whether it is being maintained or restored), we scaled up to the part of the Great Southern Reef that is classified as containing significant kelp forest (macroalgae and rocky reef habitat), which covers 4,003 km^2. At an estimated 6.1 million households that live along the Great Southern Reef coast, the aggregated consumer surplus is between AUD $1,096 and $3,605 million/ year for the entire Great Southern Reef.

Economic theory shows that usually, marginal values are diminishing with increasing supply. Our analysis assumed a constant marginal value due to a lack of data. Therefore, we might have overestimated the value by scaling up the CS over the Great Southern Reef area and our value should be seen as the upper bound value.

However, we scaled the value only over the mapped area of the Great Southern Reef, while about 163,936 km^2 of the 193,966 km^2 of the Great Southern Reef is unmapped. Moreover, previous non-market valuation studies have shown that people are risk averse, meaning there is a greater benefit gained from avoiding losses (i.e. to maintain) than for creating gains (i.e. to restore) (Cleland et al. 2015). Therefore, it is likely that our estimates are rather conservative.

Finally, kelp forests are the basis for the Great Southern Reef ecosystems. Hence, maintaining or restoring healthy kelp forests would most likely have positive effects on all other associated ecosystem services.

3.4.6 Certainty assessment

We provided an assessment of how much certainty can be placed on the economic estimates, given the availability of data, and how much extrapolation was required to estimate values over the whole of the Great Southern Reef (Table 23). Overall, the certainty of economic values is medium for extractive activities such as commercial and recreational fishing and regulating services, Other cultural services and habitat services only scored low or very poor.

Table 23: Certainty scores for assessed ecosystem services.

Degree of certainty in economic data:	Evaluates specific ES in question	Evaluates similar ES to that in question	High quality econ study	Study is based on the Great Southern Reef	Geographic scope or an equivalent quantity	Samples relevant populations	Certainty score
Provisioning services							
Commercial fisheries	x		x	x	x		Medium
Regulating services							
Nutrient cycling	x		x	x		n/a	Medium
Carbon sequestration	x		x	x		n/a	Medium
Cultural services							
Recreational fisheries	x		x	x	x		Medium
Diving and snorkeling		x	x	x			Very poor
Other recreation	x		x	x			Low
Habitat services							
Existence value for kelp ecosystem	x		x	x			Low

3.4.7 Gaps

There are multiple gaps in the economic valuation of kelp ecosystem services. In addition to the knowledge and data gaps described for each ecosystem service, we also identified several gaps that completely prevented the valuation of surplus values as outlined in Table 24. Mostly, values could not be assessed due to a complete lack of economic data, while for some certain economic measures were available, but no surplus data. Moreover, certain values could not be included because they could result in double counting issues. For example, valuing the profit from food supplements derived by kelp would be wrong if the profit for harvesting that same kelp was already accounted for.

We also acknowledge a challenge that is not unique to the Great Southern Reef, but to the formation of environmental accounts and environmental Welfare Analysis nationally: current applications of these frameworks are limited in their ability to adequately integrate the cultural values held by First Nations communities. Some of the challenges relevant to embedding Indigenous-held non-market values in Welfare Analysis are outlined in Manero et al. (2022), and include:

- It can be difficult to access large enough sample sizes that are required for adequate statistical analyses.
- There is a lack of resourcing of, and familiarity with, the correct engagement approaches for researchers working with Indigenous communities, and this engagement is particularly important for correctly defining the environmental resources to be evaluated in ways that resonate with local, traditional knowledge.
- Any application that monetises environmental and cultural values without explicit inclusion of non-use (existence) values is likely to misrepresent values held by Indigenous Australians, as economic frameworks are built on the concept of utility maximisation (i.e. that people seek to take more of the things they like). As custodians of country, Indigenous Australians may not take more than they really need because they value the existence of country.
- There is a broader need (than just for economic frameworks) to investigate how to reconcile Indigenous and non-Indigenous ontologies in decision making.

Table 24: Complete data gaps for ecosystem services not valuated in this work.

Service	Reason for gap		
	Biophysical measure	**Economic value**	**Other**
Provisioning Services			
Direct kelp harvest	Limited data	No surplus measure	
Food supplements	Limited data	No data	Possibly double counting as already covered in aquaculture and/or direct kelp harvest
Aquaculture	Limited data	No data	
Animal parts harvested (shells)	Limited data	No data	
Medical purpose	Limited data	No data	Possibly double counting as already covered in aquaculture and/or direct kelp harvest
Genetic material	Limited data	No data	Possibly double counting as already covered in aquaculture and/or direct kelp harvest
Regulating services			
Erosion and sediment flow	Limited data	No data	Possibly double counting if effects on direct use values are covered
Nursery	Limited data	No data	Possibly double counting if effects on direct use values are covered
Water clarity	Limited data	No data	Possibly double counting if effects on direct use values are covered
Change of pH of water	Limited data	No data	Possibly double counting if effects on direct use values are covered
Cultural services			
Knowledge generation	Limited data	No surplus measure	Uncertainty due to a large amount of substitutes available
Symbolic/spiritual identity	Limited data	No data	

4. Ocean Accounting

4.1 Scoping of Ocean Accounts for the Great Southern Reef

Ocean accounts provide several approaches to better identify and measure (i) the extent and condition of ecosystems, (ii) the services they provide and (iii) their use (and thus dependencies) within economic sectors and other human activities. There are several entry points to apply ocean accounts to the Great Southern Reef, however these are currently limited in application to kelp due to the lack of biophysical data (and time-series), which underlies the robustness of accounts and subsequent valuation activities. The data inventory here presented provides a baseline for future compilation of ocean accounts (SI 1 – 22).

4.2 Ecosystem extent and condition

At present, there is no empirical data for the extent of kelp cover across the Great Southern Reef. There are limited surveys of benthic macrophytes that include kelp (e.g., Reef Life Survey, SeaMap), with modelled estimates produced through habitat distribution models. Other studies have inferred the cover of kelp on rocky reefs, although substantial ground truthing would be needed to determine the accuracy of such assumptions. The reliance on modelling outputs within accounting is still under consideration. Condition indicators for kelp systems (listed in Table 25), whilst known in principle, also have limited supporting data at scales required to monitor habitats across the Great Southern Reef.

Table 25: Proposed indicators for condition on kelp forest ecosystems.

Condition	Environmental indicators
State	Percent cover / Density
	Measures of biomass
	Biodiversity
	Growth rate
	Sea surface temperature
	Sea surface salinity
	Turbidity
	Chlorophyll a
Pressures	Harvest pressure
	Eutrophication indicators (nutrient levels)
	Fishing pressure (lobster)
	Urchin barren cover

4.3 Ecosystem Services

As an extension of environmental-economic and national accounting standards, the definitions and concepts used within Ocean Accounting constrain the use of data and its treatment. For example, ecosystem services are only measured when there is a beneficiary or user within economic sectors, government, or households (i.e., society). For instance, the uptake of nitrogen and phosphorus is not considered a service unless there are excess levels of those nutrients in the system (i.e., eutrophication).

An estimation of services requires an understanding of both ecosystem extent and condition, as the supply of ecosystem services is rarely linear with extent and modified by several factors encapsulated within condition. Data also needs to be compiled for the 'users' of ecosystem services, such as economic sectors (e.g., fisheries, tourism activities) within an accounting area.

4.4 Future directions for kelp accounts

Accounting for kelp systems presents a challenge that should only be attempted once a robust foundation of biophysical and economic data has been compiled. Ocean Accounting is spatially explicit and considers the stocks and flows between the environment, society and the economy. The first steps, therefore are:

- Investment into empirical mapping of kelp extent
- Monitoring programs of kelp condition across kelp habitats
- Research into dependencies between kelp and economic activities

Carbon sequestration and storage, as a kelp ecosystem service, is of interest to ongoing projects within the Department of Agriculture, Water, and the Environment (DAWE) and the Australian Bureau of Statistics (ABS). Robust estimates of sequestration into biomass require intensive efforts in mapping kelp extent. Further, carbon storage is complex within kelp systems, relative to other ecosystems that may be considered 'blue carbon'. Further research should be undertaken to better understand carbon exports from kelp forests to long term storage habitats (e.g., deep sea), whilst also accounting for net carbon production that may occur within kelp habitats.

Another key service considered within kelp systems are fisheries, where kelp provide a 'nursery service' to enhance commercial fish catch. From an environmental-economic accounting perspective, fish landed cannot be used to measure the service because it is unclear how much of those landings were dependent on the ecosystem. Efforts should be made to understand the enhancement directly attributable to kelp systems (whether through direct consumption of provisioning of habitat).

5. Conclusion

This study is the first step forward in properly enumerating the values of the Great Southern Reef, a biological entity that covers half of coastal Australia. Using available information, we showed that the Great Southern Reef supports at least 32 ecosystem services from kelp aquaculture to carbon cycling, spiritual ties, commercial fisheries and coastal tourism. A preliminary economic analysis of these values suggests that they contribute $11.05 billion AUD each year, a number similar to previous, less rigorous estimates (Bennett et al. 2015).

Considering a plausible decision making scenario in which we would consider whether to invest resources in management: if we were to lose 20% of the Great Southern Reef's ecosystem services over the next 20 years due the various pressures affecting it, there would be a loss of $29.36 billion AUD of benefits to the Australian community. These values are distributed across 5 Australian states and affect the two thirds of the Australian population, who live within 50 km of the Great Southern Reef.

While this quantified value of the Great Southern Reef is high, there still remains substantial work to properly understand the true value of this ecosystem to society. Many services present in kelp forests in other regions around the world are poorly understood in Australia and require further validation and quantification. There is also limited data about the extent and condition of kelp forests, a gap which precludes the creation of an ocean account. Addressing this gap and creating this account are key next steps for the management of the Great Southern Reef. While we captured snapshots of the magnitude and value of the ecosystem services provided by the reef, much of the information had to be extrapolated for a country wide analysis. Further research is needed to better quantify and value these services locally.

5.1 Key recommendations

Based on the findings from this report, we suggest the following priority actions.

1. Map the extent of kelp forests and other ecosystems in the Great Southern Reef
2. Increase the number and geographic spread of survey locations that record ecosystem condition.
3. Increase the number and geographic spread of survey locations of ecosystem services with a focus on regulating services (e.g., water purification, carbon cycling, wave attenuation).
4. Increase the investigation of the cultural and recreational services provided by the Great Southern Reef.
5. Disaggregate which services are provided by different habitats and ecosystems within the Great Southern Reef.
6. Model predicted changes that are likely to occur to the Great Southern Reef with and without potential management interventions.

7. Fund the collation of the needed economic information as to provide a more robust economic estimate and prepare a Welfare Analysis to inform management investment decisions on the basis of the predicted changes.
8. Begin developing an ocean account of the Great Southern Reef.

6 References

Australian Bureau of Statistics (2014) Australia Population Grid, 2011.

Australian Bureau of Statistics (2022) Population. https://www.abs.gov.au/statistics/people/population

Backhouse J (1843) A Narrative of a Visit to the Australian Colonies. London: Hamilton, Adams.

Bayley D, Brickle P, Brewin P, Golding N, Pelembe T (2021) Valuation of kelp forest ecosystem services in the Falkland Islands: A case study integrating blue carbon sequestration potential. One Ecosyst 6:e62811.

BDO EconSeatch (2021) Economic and Social Indicators for the South Australian Southern Zone Rock Lobster Fishery, 2019/20.

Bennett E, Cramer W, Begossi A, Cundill G, Díaz S, Egoh BN, Geijzendorffer IR, Krug CB, Lavorel S, Lazos E (2015a) Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr Opin Environ Sustain 14:76–85.

Bennett S, Wernberg T, Connell SD, Hobday AJ, Johnson CR, Poloczanska ES (2016) The 'Great Southern Reef': social, ecological and economic value of Australia's neglected kelp forests. Mar Freshw Res 67:47–56.

Bennett S, Wernberg T, Harvey ES, Santana-Garcon J, Saunders BJ (2015b) Tropical herbivores provide resilience to a climate-mediated phase shift on temperate reefs. Ecol Lett 18:714–723.

Buschmann AH, Prescott S, Potin P, Faugeron S, Vasquez JA, Camus C, Infante J, Hernández-González MC, Gutierrez A, Varela DA (2014) The status of kelp exploitation and marine agronomy, with emphasis on Macrocystis pyrifera, in Chile. In: *Advances in Botanical Research*. Bourgougnon N (ed) Elsevier, p 161–188

Butler C, Lucieer V, Walsh P, Flukes E, Johnson CR (2017) Seamap Australia [Version 1.0] the development of a national benthic marine classification scheme for the Australian continental shelf.

Butler C, Lucieer VL, Wotherspoon SJ, Johnson CR (2020) Multi-decadal decline in cover of giant kelp Macrocystis pyrifera at the southern limit of its Australian range. Mar Ecol Prog Ser 653:1–18.

Campbell D, Murphy JJ (2005) The 2000-01 National Recreational Fishing Survey Economic Report.

Carnell PE, Keough MJ (2019) Reconstructing historical marine populations reveals major decline of a kelp forest ecosystem in Australia. Estuaries and coasts 42:765–778.

Champ PA, Boyle KJ, Brown TC, Peterson LG (2003) A primer on nonmarket valuation. Springer.

Clark GF, Johnston EL (2017) Australia state of the environment 2016: coasts.

Cleland JA, Rogers AA, Burton MP (2015) Investigating stakeholder reactions to a bold salinity policy using a choice experiment. Land use policy 42:718–728.

Cole SG, Moksnes P-O (2016) Valuing Multiple Eelgrass Ecosystem Services in Sweden: Fish Production and Uptake of Carbon and Nitrogen. Front Mar Sci 2:121.

Commonwealth of Australia (2021) Collaborative Australian Protected Areas Database (CAPAD) 2020.

Connell SD, Russell BD, Turner DJ, Shepherd SA, Kildea T, Miller DC, Airoldi L, Cheshire A (2008) Recovering a lost baseline: missing kelp forests from a metropolitan coast. Mar Ecol Prog Ser 360:63–72.

Davis TR, Champion C, Coleman MA (2021) Climate refugia for kelp within an ocean warming hotspot revealed by stacked species distribution modelling. Mar Environ Res 166.

Dayton PK (1985) Ecology of kelp communities. Annu Rev Ecol Syst 16:215–245.

Diaz R, Selman M (2008) Coastal Eutrophic and Hypoxic Areas of Australia and Oceania. https://www.wri.org/data/coastal-eutrophic-and-hypoxic-areas-australia-and-oceania

Dietz S (2012) The treatment of risk and uncertainty in the US social cost of carbon for regulatory impact analysis. Economics 6.

Edgar GJ, Stuart-Smith RD (2014) Systematic global assessment of reef fish communities by the Reef Life Survey program. Sci Data 1:1–8.

Eger AM, Marzinelli E, Baes R, Blain C, Blamey L, Carnell P, Choi CG, Hessing-Lewis M, Kim KY, Lorda J, Moore PJ, Nakamura Y, Perez-Matus A, Pontier O, Smale DA, Steinberg PD, Verges A (2021) The economic value of fisheries, blue carbon, and nutrient cycling in global marine forests.

Ekins P, Simon S, Deutsch L, Folke C, De Groot R (2003) A framework for the practical application of the concepts of critical natural capital and strong sustainability. Ecol Econ 44:165–185.

Ernst, Young (2020) The economic value of recreational fishing in Victoria.

Evans K, Bax N, Smith DC (2017) Australia state of the environment 2016: marine environment, independent report to the Australian Government Minister for the Environment and Energy. Aust Gov Dep Environ Energy, Canberra.

Filbee-Dexter K, Wernberg T (2020) Substantial blue carbon in overlooked Australian kelp forests. Sci Rep 10:1–6.

Frangoudes K, Garineaud C (2015) Governability of kelp forest small-scale harvesting in Iroise Sea, France. In: *Interactive governance for small-scale fisheries*. Springer, p 101–115

Fujita D (2011) Management of kelp ecosystem in Japan. CBM-Cahiers Biol Mar 52:499.

Furnas M, Mitchell A, Skuza M, Brodie J (2005) In the other 90%: phytoplankton responses to enhanced nutrient availability in the Great Barrier Reef Lagoon. Mar Pollut Bull 51:253–265.

GEODATA (2004) GEODATA COAST 100K 2004.

Giri K, Hall K (2015) South Australian Recreational Fishing Survey 2013/14.

Griffies SM, Adcroft A, Hallberg RW (2020) A primer on the vertical lagrangian-remap method in ocean models based on finite volume generalized vertical coordinates. J Adv Model Earth Syst 12:e2019MS001954.

Grover IM, Tocock MS, Tinch DR, MacDonald DH (2021) Investigating public preferences for the management of native and invasive species in the context of kelp restoration. Mar Policy 132:104680.

Hanley N, Barbier EB, Barbier E (2009) Pricing nature: cost-benefit analysis and environmental policy. Edward Elgar Publishing.

Hasler B (2016) Marine ecosystem services: Marine ecosystem services in Nordic marine waters and the Baltic sea-possibilities for valuation. Nordic Council of Ministers.

Hinojosa IA, Green BS, Gardner C, Jeffs A (2014) Settlement and early survival of southern rock lobster, Jasus edwardsii, under climate-driven decline of kelp habitats. ICES J Mar Sci 72:i59–i68.

International Union for the Conservation of Nature (2022) Protected Area Categories. https://www.iucn.org/theme/protected-areas/about/protected-area-categories

Kelly J (2020) Australian Seaweed Industry Blueprint.

Kenny AJ, Cato I, Desprez M, Fader G, Schüttenhelm RTE, Side J (2003) An overview of seabed-mapping technologies in the context of marine habitat classification. ICES J Mar Sci 60:411–418.

Kim JK, Kraemer GP, Yarish C (2015) Use of sugar kelp aquaculture in Long Island Sound and the Bronx River Estuary for nutrient extraction. Mar Ecol Prog Ser 531:155–166.

Kingsford MJ, Carlson IJ (2010) Patterns of distribution and movement of fishes, Ophthalmolepis lineolatus and Hypoplectrodes maccullochi, on temperate rocky reefs of south eastern Australia. Environ Biol Fishes 88:105–118.

Kirkman H (1984) Standing stock and production of Ecklonia radiata (C. Ag.): J. Agardh. J Exp Mar Bio Ecol 76:119–130.

Kragt ME, Roebeling PC, Ruijs A (2009) Effects of Great Barrier Reef degradation on recreational reef-trip demand: a contingent behaviour approach. Aust J Agric Resour Econ 53:213–229.

Krumhansl KA, Okamoto DK, Rassweiler A, Novak M, Bolton JJ, Cavanaugh KC, Connell SD, Johnson CR, Konar B, Ling SD, Micheli F, Norderhaug KM, Pérez-Matus A, Sousa-Pinto I, Reed DC, Salomon AK, Shears NT, Wernberg T, Anderson RJ, Barrett NS, Buschmann AH, Carr MH, Caselle JE, Derrien-Courtel S, Edgar GJ, Edwards M, Estes JA, Goodwin C, Kenner MC, Kushner DJ, Moy FE, Nunn J, Steneck RS, Vásquez J, Watson J, Witman JD, Byrnes JEK (2016) Global patterns of kelp forest change over the past half-century. Proc Natl Acad Sci 113:13785–13790.

Krumhansl KA, Scheibling RE (2012) Production and fate of kelp detritus. Mar Ecol Prog Ser 467:281–302.

Layton C, Cameron MJ, Shelamoff V, Fernández PA, Britton D, Hurd CL, Wright JT, Johnson CR (2019a) Chemical microenvironments within macroalgal assemblages:

Implications for the inhibition of kelp recruitment by turf algae. Limnol Oceanogr 64:1600–1613.

Layton C, Coleman MA, Marzinelli EM, Steinberg PD, Swearer SE, Vergés A, Wernberg T, Johnson CR (2020) Kelp forest restoration in Australia. Front Mar Sci 7.

Layton C, Shelamoff V, Cameron MJ, Tatsumi M, Wright JT, Johnson CR (2019b) Resilience and stability of kelp forests: The importance of patch dynamics and environment-engineer feedbacks. PLoS One 14:e0210220.

Leon J, Lazarow N, Spencer-Cotton A, Pearce T (2022) Surfing Economics: a novel application of the travel cost method to the Noosa World Surfing reserve. In: *Australian Agriculture and Resource Economics Society Conference*. p 17

Ling S, Keane J (2018) Resurvey of the Longspined Sea Urchin (Centrostephanus rodgersii) and associated barren reef in Tasmania. Hobart, Tasmania.

Ling SD, Cornwall CE, Tilbrook B, Hurd CL (2020) Remnant kelp bed refugia and future phase-shifts under ocean acidification. PLoS One 15:e0239136.

Ling SD, Johnson CR, Frusher SD, Ridgway KR (2009) Overfishing reduces resilience of kelp beds to climate-driven catastrophic phase shift. Proc Natl Acad Sci U S A 106:22341–5.

Liquete C, Piroddi C, Drakou EG, Gurney L, Katsanevakis S, Charef A, Egoh B (2013) Current status and future prospects for the assessment of marine and coastal ecosystem services: a systematic review. PLoS One 8.

Liu X, Dunne JP, Stock CA, Harrison MJ, Adcroft A, Resplandy L (2019) Simulating water residence time in the coastal ocean: A global perspective. Geophys Res Lett 46:13910–13919.

Luisetti T, Turner RK, Jickells T, Andrews J, Elliott M, Schaafsma M, Beaumont N, Malcolm S, Burdon D, Adams C (2014) Coastal zone ecosystem services: from science to values and decision making; a case study. Sci Total Environ 493:682–693.

Lyle J, Stark K, Ewing GP, Tracey SR (2019) 2017-18 Survey of Recreational Fishing in Tasmania.

Manero A, Taylor K, Nikolakis W, Adamowicz W, Marshall V, Spencer-Cotton A, Nguyen M, Grafton RQ (2022) A systematic literature review of non-market valuation of Indigenous peoples' values: Current knowledge, best-practice and framing questions for future research. Ecosyst Serv 54:101417.

Marinho GS, Holdt SL, Birkeland MJ, Angelidaki I (2015) Commercial cultivation and bioremediation potential of sugar kelp, Saccharina latissima, in Danish waters. J Appl Phycol 27:1963–1973.

Martínez B, Radford B, Thomsen MS, Connell SD, Carreño F, Bradshaw CJA, Fordham DA, Russell BD, Gurgel CFD, Wernberg T (2018) Distribution models predict large contractions of habitat-forming seaweeds in response to ocean warming. Divers Distrib 24:1350–1366.

Marzinelli EM, Campbell AH, Vergés A, Coleman MA, Kelaher BP, Steinberg PD (2014) Restoring seaweeds: does the declining fucoid Phyllospora comosa support different biodiversity than other habitats? J Appl Phycol 26:1089–1096.

Marzinelli EM, Williams SB, Babcock RC, Barrett NS, Johnson CR, Jordan A, Kendrick GA, Pizarro OR, Smale DA, Steinberg PD (2015) Large-Scale Geographic Variation in Distribution and Abundance of Australian Deep-Water Kelp Forests. PLoS One 10:e0118390.

Mayfield S, Mundy C, Gorfine H, Hart AM, Worthington D (2012) Fifty years of sustained production from the Australian abalone fisheries. Rev Fish Sci 20:220–250.

McCartney A (2006) The social value of seascapes in the Jurien Bay Marine Park: an assessment of positive and negative preferences for change. J Agric Econ 57:577–594.

McLeod P, Lindner R (2018) Economic Dimensions of Recreational Fishing in Western Australia.

Miller RJ, Lafferty KD, Lamy T, Kui L, Rassweiler A, Reed DC (2018) Giant kelp, Macrocystis pyrifera, increases faunal diversity through physical engineering. Proc R Soc B Biol Sci 285:20172571.

Molinos-Senante M, Hernández-Sancho F, Sala-Garrido R (2010) Economic feasibility study for wastewater treatment: A cost-benefit analysis. Sci Total Environ 408:4396–4402.

Moro-Sota A, Palacios M, Macaya EC, Gómez I, Huovinen P, Pérez-Matus A, Young M, Golding N, Toro M, Yaqub M, Macias-Faruai M (2020) A High-Resolution Global Map of Giant Kelp (Macrocystis pyrifera) Forests and Intertidal Green Algae (Ulvophyceae) with Sentinel-2 Imagery. Remote Sens 12.

Morris RL, Graham TDJ, Kelvin J, Ghisalberti M, Swearer SE (2020) Kelp beds as coastal protection: wave attenuation of Ecklonia radiata in a shallow coastal bay. Ann Bot 125:235–246.

Mount RE, Bricher PK, Newton JB (2007) National/Intertidal/Subtidal Benthic (NISB) Habitat Classification Scheme Version 1.0 October 2007.

Murphy JJ, Ochwada-Doyle FA, West LD, Stark KE, Hughes JM, Taylor MD (2022) Survey of recreational fishing in NSW, 2019/20–Key Results.

National Academies of Sciences and Medicine and Engineering (2017) Valuing climate damages: updating estimation of the social cost of carbon dioxide. National Academies Press.

National Marine Science Committee (2015) National marine science plan 2015-2025: driving the development of Australia's blue economy. National Marine Science Committee.

Neveux N, Bolton JJ, Bruhn A, Roberts DA, Ras M (2018) The bioremediation potential of seaweeds: recycling nitrogen, phosphorus, and other waste products. Blue Biotechnol Prod Use Mar Mol:217–241.

Noisette F, Hurd C (2018) Abiotic and biotic interactions in the diffusive boundary layer of kelp blades create a potential refuge from ocean acidification. Funct Ecol 32:1329–1342.

O'Brien A, Townsend K, Hale R, Sharley D, Pettigrove V (2016) How is ecosystem health defined and measured? A critical review of freshwater and estuarine studies. Ecol Indic 69:722–729.

Olson AM, Hessing-Lewis M, Haggarty D, Juanes F (2019) Nearshore seascape connectivity enhances seagrass meadow nursery function. Ecol Appl:e01897.

Organisation for Economic Co-operation and Development (2011) Doing Better for Families.

Pascoe S (2019) Recreational beach use values with multiple activities. Ecol Econ 160:137–144.

Penn JW, Caputi N, de Lestang S (2015) A review of lobster fishery management: the Western Australian fishery for Panulirus cygnus, a case study in the development and implementation of input and output-based management systems. ICES J Mar Sci 72:i22–i34.

Pollack JB, Yoskowitz D, Kim H-C, Montagna PA (2013) Role and value of nitrogen regulation provided by oysters (Crassostrea virginica) in the Mission-Aransas Estuary, Texas, USA. PLoS One 8:e65314.

Prange GB, Jannink MJ, Groothuis-Oudshoorn CG, Hermens HJ, IJzerman MJ (2009) Systematic review of the effect of robot-aided therapy on recovery of the hemiparetic arm after stroke.

Productivity Comission (2020) Integrated Urban Water Management — Why a good idea seems hard to implement. Canberra, Australia.

Rogers AA (2013) Public and expert preference divergence: evidence from a choice experiment of marine reserves in Australia. Land Econ 89:346–370.

Rogers AA, Dempster FL, Hawkins JI, Johnston RJ, Boxall PC, Rolfe J, Kragt ME, Burton MP, Pannell DJ (2019) Valuing non-market economic impacts from natural hazards. Nat Hazards 99:1131–1161.

Rogers AA, Kragt ME, Gibson FL, Burton MP, Petersen EH, Pannell DJ (2015) Non-market valuation: usage and impacts in environmental policy and management in A ustralia. Aust J Agric Resour Econ 59:1–15.

Van Rooijen A, Winter G (2019) Modelling the effect of kelp on sand dune erosion. In: *Australasian Coasts and Ports 2019 Conference: Future directions from 40 [degrees] S and beyond, Hobart, 10-13 September 2019*. Engineers Australia Hobart, p 1186–1191

Rosenberger RS (2016) Recreation Use Values Database–Summary.

Ryan KL, Hall NG, Lai EK, Smallwood CB, Tate A, Taylor SM (2019) Statewide survey of boat-based recreational fishing in Western Australia 2017/18. Fisheries Research Report No. 297.

Scorse J, Reynolds III F, Sackett A (2015) Impact of surf breaks on home prices in Santa Cruz, CA. Tour Econ 21:409–418.

Selfati M, El Ouamari N, Lenfant P, Fontcuberta A, Lecaillon G, Mesfioui A, Boissery P, Bazairi H (2018) Promoting restoration of fish communities using artificial habitats in coastal marinas. Biol Conserv 219:89–95.

Shen P, Yin Z, Qu G, Wang C (2018) 11 - Fucoidan and Its Health Benefits.Qin YBT-BS for FA (ed) Academic Press, p 223–238

Smith SM, Malcolm HA, Marzinelli EM, Schultz AL, Steinberg PD, Vergés A (2021)

Tropicalization and kelp loss shift trophic composition and lead to more winners than losers in fish communities. Glob Chang Biol 27:2537–2548.

Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA, Tegner MJ (2002) Kelp forest ecosystems: biodiversity, stability, resilience and future. Environ Conserv 29:436–459.

Steven A, Dylewski M, Curtotti R (2021) Australian fisheries and aquaculture statistics 2020. Canberra, Australia.

Stuchtey M, Vincent A, Merkl A, Bucher M, Haugan PM, Lubchenco J, Pangestu ME (2020) Ocean solutions that benefit people, nature and the economy. Washington, DC World Resour Inst.

Surf Life Saving Australia (2021) National Coastal Safety Report 2021.

Thurstan RH, Brittain Z, Jones DS, Cameron E, Dearnaley J, Bellgrove A (2018) Aboriginal uses of seaweeds in temperate Australia: an archival assessment. J Appl Phycol 30:1821–1832.

Tourism Research Australia (2022) National Visitor Survey results September 2021

Vergés A, Doropoulos C, Malcolm HA, Skye M, Garcia-Piza M, Marzinelli EM, Campbell AH, Ballesteros E, Hoey AS, Vila-Concejo A, Bozec Y-M, Steinberg PD, Vergés A, Doropoulos C, Malcolm HA, Skye M, Garcia-Pizá M, Marzinelli EM, Campbell AH, Ballesteros E, Hoey AS, Vila-Concejo A, Bozec Y-M, Steinberg PD (2016) Long-term empirical evidence of ocean warming leading to tropicalization of fish communities, increased herbivory, and loss of kelp. Proc Natl Acad Sci U S A 113:13791–13796.

Wallace KJ, Jago M (2017) Category mistakes: A barrier to effective environmental management. J Environ Manage 199:13–20.

Wang P, Deng X, Zhou H, Yu S (2019) Estimates of the social cost of carbon: A review based on meta-analysis. J Clean Prod 209:1494–1507.

Wernberg T, Bennett S, Babcock RC, De Bettignies T, Cure K, Depczynski M, Dufois F, Fromont J, Fulton CJ, Hovey RK (2016) Climate-driven regime shift of a temperate marine ecosystem. Science (80-) 353:169–172.

Wernberg T, Coleman MA, Babcock RC, Bell SY, Bolton JJ, Connell SD, Hurd CL, Johnson CR, Marzinelli EM, Shears NT (2019a) Biology and ecology of the globally significant kelp Ecklonia radiata. Oceanogr Mar Biol.

Wernberg T, Krumhansl K, Filbee-Dexter K, Pedersen MF (2019b) Status and trends for the world's kelp forests. In: *World seas: An environmental evaluation*. Sheppard C (ed) Elsevier, p 57–78

Wernberg T, Russell BD, Moore PJ, Ling SD, Smale DA, Campbell A, Coleman MA, Steinberg PD, Kendrick GA, Connell SD (2011) Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. J Exp Mar Bio Ecol 400:7–16.

West L, Stark K, Murphy J, Lyle J, Ochwada-Doyle F (2015) Survey of Recreational Fishing in New South Wales and the ACT, 2013/14.

Yassini I, Jones BG, King RJ, Ayress M, Dewi KT (1995) Ostracod fauna associated with sublittoral kelp forest vegetation at Windang Island, New South Wales, Australia. Mar Freshw Res 46:1181–1194.

Zarco-Perello S, Wernberg T, Langlois TJ, Vanderklift MA (2017) Tropicalization strengthens consumer pressure on habitat-forming seaweeds. Sci Rep 7:1–8.

Zheng L-X, Chen X-Q, Cheong K-L (2020) Current trends in marine algae polysaccharides: The digestive tract, microbial catabolism, and prebiotic potential. Int J Biol Macromol 151:344–354.

Zimmerhackel JS, Rogers AA, Meekan MG, Ali K, Pannell DJ, Kragt ME (2018) How shark conservation in the Maldives affects demand for dive tourism. Tour Manag 69:263–271.

Glossary

SEEA: System of Environmental Economic Accounting

Great Southern Reef: Great Southern Reef – a network of connected rocky reef marine habitat across southern Australia. Dominated by macroalgae kelp forests to 30m depth and sessile invertebrates (e.g., sponges, soft corals) below 30m.

IDEEA: Institute for Development of Environmental-Economic Accounting.

Kelp: Marine habitat formers from the macroalgae orders Laminariales and Fucales.

Ecosystem services: The benefits provided to humans by ecosystems and the natural environment.

Producer surplus: The difference between how much a person would be willing to accept for a given quantity of a good versus how much they can receive by selling the good at the market price.

Consumer surplus: The difference between the price a consumer pays for an item and the price they would be willing to pay rather than do without it.

Non-market valuation: The valuation of goods and services that are not directly defined by market prices.

GVA: Gross value added, productivity metric which is the value of goods and services that have been produced in a country, minus the cost of all inputs and raw materials that are directly attributable to that production.

GVP: Gross value of production, the value placed on production at the wholesale prices realised in the marketplace.

TEV: Total Economic Values, the benefits derived by people when an ecosystem is present compared to when it is not.

NISB: National Inter/ Subtidal Benthic habitat classification scheme.

SCC: Social Cost of Carbon, an estimated cost which represent the costs and damages from emitting one additional ton of carbon dioxide into the atmosphere.

CRT: Coastal Residence Time, the elapsed time since a parcel of source water enters the coastal domain before it exits into the open ocean.

CONTACT

Name: Aaron Eger

Email: aaron.eger@unsw.edu.au

This project is supported with funding from the Australian Government under the National Environmental Science Program.