2022 Scientific Consensus Statement

Question 1.1 What are the socio-ecological, cultural, economic, and intrinsic values of the Great Barrier Reef?

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Explanatory Notes for readers of the 2022 SCS Syntheses of Evidence

These explanatory notes were produced by the SCS Coordination Team and apply to all evidence syntheses in the 2022 SCS.

What is the Scientific Consensus Statement?

The Scientific Consensus Statement (SCS) on land use impacts on Great Barrier Reef (GBR) water quality and ecosystem condition brings together scientific evidence to understand how land-based activities can influence water quality in the GBR, and how these influences can be managed. The SCS is used as a key evidence-based document by policymakers when they are making decisions about managing GBR water quality. In particular, the SCS provides supporting information for the design, delivery and implementation of the Reef 2050 Water Quality Improvement Plan (Reef 2050 WQIP) which is a joint commitment of the Australian and Queensland governments. The Reef 2050 WQIP describes actions for improving the quality of the water that enters the GBR from the adjacent catchments. The SCS is updated periodically with the latest peer reviewed science.

C_2O Consulting was contracted by the Australian and Queensland governments to coordinate and deliver the 2022 SCS. The team at C_2O Consulting has many years of experience working on the water quality of the GBR and its catchment area and has been involved in the coordination and production of multiple iterations of the SCS since 2008.

The 2022 SCS addresses 30 priority questions that examine the influence of land-based runoff on the water quality of the GBR. The questions were developed in consultation with scientific experts, policy and management teams and other key stakeholders (e.g., representatives from agricultural, tourism, conservation, research and Traditional Owner groups). Authors were then appointed to each question via a formal Expression of Interest and a rigorous selection process. The 30 questions are organised into eight themes: values and threats, sediments and particulate nutrients, dissolved nutrients, pesticides, other pollutants, human dimensions, and future directions, that cover topics ranging from ecological processes, delivery and source, through to management options. Some questions are closely related, and as such Readers are directed to Section 1.3 (Links to other questions) in this synthesis of evidence which identifies other 2022 SCS questions that might be of interest.

The geographic scope of interest is the GBR and its adjacent catchment area which contains 35 major river basins and six Natural Resource Management regions. The GBR ecosystems included in the scope of the reviews include coral reefs, seagrass meadows, pelagic, benthic and plankton communities, estuaries, mangroves, saltmarshes, freshwater wetlands and floodplain wetlands. In terms of marine extent, while the greatest areas of influence of land-based runoff are largely in the inshore and to a lesser extent, the midshelf areas of the GBR, the reviews have not been spatially constrained and scientific evidence from anywhere in the GBR is included where relevant for answering the question.

Method used to address the 2022 SCS Questions

Formal evidence review and synthesis methodologies are increasingly being used where science is needed to inform decision making, and have become a recognised international standard for accessing, appraising and synthesising scientific information. More specifically, 'evidence synthesis' is the process of identifying, compiling and combining relevant knowledge from multiple sources so it is readily available for decision makers[1]. The world's highest standard of evidence synthesis is a Systematic Review, which uses a highly prescriptive methodology to define the question and evidence needs, search for and appraise the quality of the evidence, and draw conclusions from the synthesis of this evidence.

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[1] Pullin A, Frampton G, Jongman R, Kohl C, Livoreil B, Lux A, ... & Wittmer, H. (2016). Selecting appropriate methods of knowledge synthesis to inform biodiversity policy. *Biodiversity and Conservation*, 25: 1285-1300. https://doi.org/10.1007/s10531-016-1131-9

In recent years there has been an emergence of evidence synthesis methods that involve some modifications of Systematic Reviews so that they can be conducted in a more timely and cost-effective manner. This suite of evidence synthesis products are referred to as **'Rapid Reviews'**[2]. These methods typically involve a reduced number of steps such as constraining the search effort, adjusting the extent of the quality assessment, and/or modifying the detail for data extraction, while still applying methods to minimise author bias in the searches, evidence appraisal and synthesis methods.

To accommodate the needs of GBR water quality policy and management, tailormade methods based on Rapid Review approaches were developed for the 2022 SCS by an independent expert in evidence-based syntheses for decision-making. The methods were initially reviewed by a small expert group with experience in GBR water quality science, then externally peer reviewed by three independent evidence synthesis experts.

Two methods were developed for the 2022 SCS:

- The **SCS Evidence Review** was used for questions that policy and management indicated were high priority and needed the highest confidence in the conclusions drawn from the evidence. The method includes an assessment of the reliability of all individual evidence items as an additional quality assurance step.
- The **SCS Evidence Summary** was used for all other questions, and while still providing a high level of confidence in the conclusions drawn, the method involves a less comprehensive quality assessment of individual evidence items.

Authors were asked to follow the methods, complete a standard template (this 'Synthesis of Evidence'), and extract data from literature in a standardised way to maximise transparency and ensure that a consistent approach was applied to all questions. Authors were provided with a Methods document, *'2022 Scientific Consensus Statement: Methods for the synthesis of evidence'*[3], containing detailed guidance and requirements for every step of the synthesis process. This was complemented by support from the SCS Coordination Team (led by C_2O Consulting) and the evidence synthesis expert to provide guidance throughout the drafting process including provision of step-by-step online training sessions for Authors, regular meetings to coordinate Authors within the Themes, and fortnightly or monthly question and answer sessions to clarify methods, discuss and address common issues.

The major steps of the Method are described below to assist Readers in understanding the process used, structure and outputs of the synthesis of evidence:

1. **Describe the final interpretation of the question.** A description of the interpretation of the scope and intent of the question, including consultation with policy and management representatives where necessary, to ensure alignment with policy intentions. The description is supported by a conceptual diagram representing the major relationships relevant to the question, and definitions.
2. **Develop a search strategy**. The Method recommended that Authors used a S/PICO framework (Subject/Population, Exposure/Intervention, Comparator, Outcome), which could be used to break down the different elements of the question and helps to define and refine the search process. The S/PICO structure is the most commonly used structure in formal evidence synthesis methods[4].

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[2] Collins A, Coughlin D, Miller J, & Kirk S (2015) The production of quick scoping reviews and rapid evidence assessments: A how to guide. UK Government. https://www.gov.uk/government/publications/the-production-of-quick-scoping-reviews-and-rapid-evidence-assessments

[3] Richards R, Pineda MC, Sambrook K, Waterhouse J (2023) 2022 Scientific Consensus Statement: Methods for the synthesis of evidence. C_2O Consulting, Townsville, pp. 59.

[4] https://libguides.jcu.edu.au/systematic-review/define

3. **Define the criteria for the eligibility of evidence for the synthesis and conduct searches.** Authors were asked to establish **inclusion and exclusion criteria to define the eligibility of evidence** prior to starting the literature search. The Method recommended conducting a **systematic literature search** in at least **two online academic databases**. Searches were typically restricted to 1990 onwards (unless specified otherwise) following a review of the evidence for the previous (2017) SCS which indicated that this would encompass the majority of the evidence base, and due to available resources. In addition, the geographic **scope of the search for evidence** depended on the nature of the question. For some questions, it was more appropriate only to focus on studies derived from the GBR region (e.g., the GBR context was essential to answer the question); for other questions, it was important to search for studies outside of the GBR (e.g., the question related to a research theme where there was little information available from the GBR). Authors were asked to provide a rationale for that decision in the synthesis. Results from the literature searches were screened against **inclusion and exclusion** criteria at the title and abstract review stage (**initial screening**). Literature that passed this initial screening was then read in full to determine the eligibility for use in the synthesis of evidence (**second screening**). Importantly, all literature had to be **peer reviewed and publicly available.** As well as journal articles, this meant that grey literature (e.g., technical reports) that had been externally peer reviewed (e.g., outside of organisation) and was publicly available, could be assessed as part of the synthesis of evidence.
4. **Extract data and information from the literature**. To compile the data and information that were used to address the question, **Authors were asked to complete a standard data extraction and appraisal spreadsheet**. Authors were assisted in tailoring this spreadsheet to meet the needs of their specific question.
5. **Undertake systematic appraisal of the evidence base**. Appraisal of the evidence is an important aspect of the synthesis of evidence as it provides the reader and/or decision-makers with valuable insights about the underlying evidence base. Each evidence item was assessed for its spatial, temporal and overall relevance to the question being addressed, and allocated a relative score. The body of evidence was then evaluated for overall relevance, the size of the evidence base (i.e., is it a well-researched topic or not), the diversity of studies (e.g., does it contain a mix of experimental, observational, reviews and modelling studies), and consistency of the findings (e.g., is there agreement or debate within the scientific literature). Collectively, these assessments were used to obtain an overall measure of the level of confidence of the evidence base, specifically using the overall relevance and consistency ratings. For example, a high confidence rating was allocated where there was high overall relevance and high consistency in the findings across a range of study types (e.g., modelling, observational and experimental). Questions using the **SCS Evidence Review Method** had an **additional quality assurance step**, through the assessment of reliability of all individual studies. This allowed Authors to identify where potential biases in the study design or the process used to draw conclusions might exist and offer insight into how reliable the scientific findings are for answering the priority SCS questions. This assessment considered the reliability of the study itself and enabled authors to place more or less emphasis on selected studies.
6. **Undertake a synthesis of the evidence and complete the evidence synthesis template** to address the question. Based on the previous steps, a narrative synthesis approach was used by authors to derive and summarise findings from the evidence.

Guidance for using the synthesis of evidence

Each synthesis of evidence contains three different levels of detail to present the process used and the findings of the evidence:

1. **Executive Summary**: This section brings together the evidence and findings reported in the main body of the document to provide a high-level overview of the question.
2. **Synthesis of Evidence:** This section contains the detailed identification, extraction and examination of evidence used to address the question.

- ***Background***: Provides the context about why this question is important and explains how the Lead Author interpreted the question.
- ***Method:*** Outlines the search terms used by Authors to find relevant literature (evidence items), which databases were used, and the inclusion and exclusion criteria.
- ***Search Results:*** Contains details about the number of evidence items identified, sources, screening and the final number of evidence items used in the synthesis of evidence.
- ***Key Findings:*** The **main body of the synthesis**. It includes a summary of the study characteristics (e.g., how many, when, where, how), a deep dive into the body of evidence covering key findings, trends or patterns, consistency of findings among studies, uncertainties and limitations of the evidence, significance of the findings to policy, practice and research, knowledge gaps, Indigenous engagement, conclusions and the evidence appraisal.

3. **Evidence Statement:** Provides a succinct, high-level overview of the main findings for the question with supporting points. The Evidence Statement for each Question was provided as input to the 2022 Scientific Consensus Statement Summary and Conclusions.

While the Executive Summary and Evidence Statement provide a high-level overview of the question, it is **critical that any policy or management decisions are based on consideration of the full synthesis of evidence.** The GBR and its catchment area is large, with many different land uses, climates and habitats which result in considerable heterogeneity across its extent. Regional differences can be significant, and from a management perspective will therefore often need to be treated as separate entities to make the most effective decisions to support and protect GBR ecosystems. Evidence from this spatial variability is captured in the reviews as much as possible to enable this level of management decision to occur. Areas where there is high agreement or disagreement of findings in the body of evidence are also highlighted by authors in describing the consistency of the evidence. In many cases authors also offer an explanation for this consistency.

Peer Review and Quality Assurance

Each synthesis of evidence was peer reviewed, following a similar process to indexed scientific journals. An Editorial Board, endorsed by the Australian Chief Scientist, managed the process. The Australian Chief Scientist also provided oversight and assurance about the design of the peer review process. The Editorial Board consisted of an Editor-in-Chief and six Editors with editorial expertise in indexed scientific journals. Each question had a Lead and Second Editor. Reviewers were approached based on skills and knowledge relevant to each question and appointed following a strict conflict of interest process. Each question had a minimum of two reviewers, one with GBR-relevant expertise, and a second 'external' reviewer (i.e., international or from elsewhere in Australia). Reviewers completed a peer review template which included a series of standard questions about the quality, rigour and content of the synthesis, and provided a recommendation (i.e., accept, minor revisions, major revisions). Authors were required to respond to all comments made by reviewers and Editors, revise the synthesis and provide evidence of changes. The Lead and Second Editors had the authority to endorse the synthesis following peer review or request further review/iterations.

Contents

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Executive Summary

Question

Question 1.1 What are the socio-ecological, cultural, economic, and intrinsic values of the Great Barrier Reef?

Background

The Great Barrier Reef (GBR) embodies a diverse array of values, ranging from tangible commercial benefits like tourism and fishing, to cultural aspects, including Indigenous heritage and identity. Many benefits are enjoyed directly, including recreational activities such as snorkelling, diving, and boating, enriching people's sense of wellbeing and lifestyle. The GBR also generates a range of indirect benefits, including aesthetic, lifestyle, protection, educational and research outcomes. The 'outstanding universal value' of the GBR was formally recognised globally for its ecological, geomorphic and oceanographic values through its declaration as a UNESCO World Heritage Area in 1981.

The recognition and measurement of benefits is typically done by assessing values, to inform policy, financial investments, regulatory instruments, and management decisions. How the GBR generates benefits and attributes involves multifaceted values that are intertwined, making measurement complex, and assessment involving multiple factors, different sets of stakeholders, and varying motivations and uses. The extent and complexity of values differs across geographical and spatial zones of the GBR, as well as by the different uses, populations and benefits being assessed.

This question reviews the current evidence of the socio-ecological, cultural, economic, and intrinsic values of the GBR. This provides the critical context for understanding the importance of the current evidence presented in the 2022 Scientific Consensus Statement (SCS) including the distribution, impact and management of land-based pollutants that influence water quality in the GBR.

Methods

- A formal Rapid Review approach was used for the 2022 Scientific Consensus Statement (SCS) synthesis of evidence. Rapid reviews are a systematic review with a simplification or omission of some steps to accommodate the time and resources available[5]. For the SCS, this applies to the search effort, quality appraisal of evidence and the amount of data extracted. The process has well-defined steps enabling fit-for-purpose evidence to be searched, retrieved, assessed and synthesised into final products to inform policy. For this question, an Evidence Summary method was used.
- Search locations included Web of Science, Scopus, Google Scholar, and Reef protection agencies eLibraries.
- The primary source of evidence for this question was from publications of direct relevance to the GBR. While external evidence offered some insights, the contextual applicability to this question was considerably limited.
- The search process for relevant evidence resulted in the identification of 1,729 potentially eligible items. After primary and secondary screening, 85 evidence items were used in this synthesis.

[5] Cook CN, Nichols SJ, Webb JA, Fuller RA, Richards RM (2017) Simplifying the selection of evidence synthesis methods to inform environmental decisions: A guide for decision makers and scientists. *Biological Conservation* 213: 135-145. https://doi.org/10.1016/j.biocon.2017.07.004

Method limitations and caveats to using this Evidence Summary

For this Evidence Summary, the following caveats or limitations should be noted when applying the findings for policy or management purposes:

- Only studies written in English were included.
- Predominantly GBR studies were included, with some additional relevant literature outside of the GBR.
- Only studies published from 1990 to the present were included.
- Limited search scope: the search scope was restricted to peer reviewed and publicly available publications. This included grey literature from the major government organisations and programs associated with the GBR.

Key Findings

Summary of evidence to 2022

An initial comprehensive search of the literature on the GBR values yielded 1,729 studies. However, after rigorous screening through titles, abstracts, and full texts, and applying specific inclusion criteria, this was refined to 85 relevant studies. (including 6 global studies relevant to the topic). The majority of articles concentrated on economic or intrinsic values within the GBR region, but there is a noticeable emergence in research addressing indirect socio-relational, intrinsic, and aesthetic values, highlighting their importance in the overall valuation of the GBR. The main conclusions from the synthesis are:

- The values of the GBR can be categorised into multidimensions of ecological (including biological), social, economic and cultural (including Indigenous and non-Indigenous) heritage, which are interconnected, making the definition of values complex.
- The GBR is a complex and diverse ecosystem that supports a vast array of marine life, including fish, corals, turtles, dugong, whales, and many other lifeforms. It encompasses 70 ‘bioregions’ (30 reef bioregions and 40 non-reefal bioregions) and it is home to thousands of species, including many endangered and threatened species, making it important for biodiversity. The GBR also provides many ecosystem services (in areas both within and adjacent to the GBR), and related livelihoods for GBR communities.
- The GBR generates a range of indirect and non-use benefits, including the intrinsic value of its existence, aesthetic, lifestyle, protection, educational and research outcomes. Australians, even those who do not use it directly, place great value on the GBR, and broadly support efforts to ensure the maintenance and continuation of its existence, aesthetic and other intrinsic benefits. Further loss of values may affect public trust in the government's ability to effectively manage the GBR.
- Previous (pre-pandemic) economic analyses show that the GBR generates billions of dollars annually through tourism, fishing, research and recreational activities. It supports approximately 64,000 direct and indirect jobs and attracts over two million visitors each year who contribute to the local and national economy through spending on accommodation, trips to the reef, and other services. However, there is a need for updated economic information that considers the economic, social and cultural implication of bleaching events and the economic effects of the COVID-19 pandemic on a larger scale.
- Cultural heritage values, particularly the Indigenous values of Aboriginal and Torres Strait Islander peoples and their connection with traditional lands and waters are important. The GBR has deep spiritual, cultural, and historical significance to these communities, having been at the heart of their culture and way of life for thousands of years, supplying sustenance, cultural practices, and connections to ancestral lands.
- The low level of Indigenous participation in studies on GBR values is identified as a gap, and there is a need for further research into methodologies that incorporate Indigenous values

into established economic models. Different conceptual frameworks are available to depict the complex relationships between ecological and human systems which categorise the flow of uses, benefits and services in different ways, informing concepts of value. The Total Economic Value framework and Ecosystem Services framework are two of the main approaches that have been applied. More recent approaches place greater emphasis on the relationships between people and ecosystems and how the condition and perceptions of the GBR can impact on those.

- Quantifying the benefits of the GBR is complex given the large number of factors involved and diversity of stakeholders. Financial investments, regulatory instruments, policy and management decisions are typically informed through the assessment of values, and these values can vary across the GBR region depending on location, demographics and the benefits being assessed.
- There are knowledge gaps in the understanding of value concepts, particularly how scientists and researchers define 'value.' The evidence suggests that the development of a typology of GBR values that considers different perspectives and cultures would be helpful to define those values.
- A number of threats to the values of the GBR have been identified, though climate change is recognised as the most significant. The health of the Great Barrier Reef has an important impact on people's economic security and sense of wellbeing, and the connection between value, health and wellbeing is critically important, particularly in the context of the threats impacting its outstanding universal value.

Recent findings 2016-2022

Since 2017, measured approaches to integrating Traditional Knowledge into western science and GBR management decision making processes has increased, including the *Strong Peoples – Strong Country (2019)* Indigenous heritage monitoring program, which is grounded in Indigenous values, connecting the health of the GBR and its catchment to the quality of life enjoyed by Traditional Owners[6]. Providing a Traditional Owner-led approach, the program reflects a worldview underpinned by the symbiosis of land and sea Country.

The distribution of the articles across two time periods, 1990-2016 and 2017-2022, reveals interesting trends in the research focus. During the earlier period of 1990-2016, 49 articles were published, accounting for approximately 58% of the total reviewed articles. Between 2017 and 2022, a further 36 articles, constituting approximately 42% of the total reviewed, of which 35 were published on the GBR. The surge in research in the second period, which spans for only 5 years, reflects an escalating interest in the GBR's values. Moreover, the period 2017-2022 saw increased government investment in conservation efforts, advancements in coral reef restoration science, and the rise of citizen science initiatives.

Significance for policy, practice and research

The GBR generates a wide range of benefits to multiple stakeholders, including those in regional, national and international locations. Direct use values for tourism, recreation and commercial fishing are important, and provide major economic flow-on benefits at the regional, state and national levels. However, it is likely that the indirect and protection (non-use) values of the Australian population are even more significant, consistent with the GBR being a nationally and internationally iconic asset, as per its outstanding universal value as a World Heritage Area. The extent of recognition and values for the GBR means that Australians and the international community are sensitive to potential threats and losses, with evidence of high values for ongoing protection.

[6] Strong People – Strong Country Indigenous Heritage Monitoring Framework Summary Report

This synthesis reveals that a more comprehensive approach to identifying and valuing benefits of the GBR, one that extends beyond economic considerations, would greatly benefit policymakers. The potential impact of the COVID-19 pandemic on GBR benefits and values is also noted, indicating the need to update data on the aesthetic, social, ecological, and intrinsic values at both local and broader GBR levels.

The loss of ecological and cultural values may have severe consequences for Indigenous communities, generating requirements for further work on ways of integrating Traditional Knowledge systems and cultural heritage to build both resilience and better inform adaptive governance models. Addressing deficits in socio-ecological and economic information to build trust in management processes is important. Finally, the synthesis emphasises the connection between the values of the GBR and Australia's identity, suggesting that further loss of values may affect public trust in the government's ability to effectively manage the GBR.

For practitioners and researchers, this synthesis of evidence reveals the diverse values of the GBR including ecological, economic, cultural, and social dimensions. The review identifies a key knowledge gap in integrating Indigenous perspectives into management practices, research and decision support systems.

Key uncertainties and/or limitations

The review underscores the insufficient attention given to Indigenous values in studies on the GBR, highlighting a significant gap in understanding the cultural and socio-ecological significance of the GBR. The absence of Indigenous perspectives may result in an incomplete portrayal of human relationships with the GBR, neglecting valuable insights from traditional ecological knowledge. The result suggests a need for research methodologies integrating Indigenous values into economic models and as the synthesis identifies, there are a limited number of projects addressing sustainable values in 2023.

Additionally, many studies are dated, indicating a need for more research to update with present-day values and conservation efforts for the GBR. The reliance on 2016 data for estimations of economic use values is highlighted, emphasising the need for updated information that considers bleaching events and the effects of the COVID-19 pandemic on a larger scale. Despite a surge in publications related to assessment, evaluation or review of GBR values post-2017, economic studies continue to dominate relative to studies from other disciplines that are focused more strongly on relational factors.

Evidence appraisal

The synthesis of the evidence for **Question 1.1** was based on 85 studies, primarily undertaken in the GBR and published between 1990 and 2023, including a High diversity of study types (62% observational, 11% modelled, 5% experimental, 3% theoretical/conceptual and 19% reviews), and with a High confidence rating (based on High consistency and High overall relevance of studies). This rating indicates that most of the articles were highly relevant in addressing the question and provided substantial insights into the socio-ecological, cultural, economic, and intrinsic values of the GBR.

The relevance of the evidence items to the research question was rated High for 49 studies, Moderate for 30, and Low for 6 studies. This large number of highly relevant studies underscores the importance and depth of the research conducted on the values of the GBR. The spatial relevance was predominantly High (2.5/3.0), indicating broad coverage of the GBR, while the temporal relevance was Moderate (1.9/3.0). The high confidence rating, based on high overall relevance and consistency, demonstrates the robustness and quality of the body of evidence used to answer the primary question. The high confidence level supports the findings and conclusions drawn from the evidence synthesis, providing a strong foundation for informing policy, and management decision making.

1. Background

The Great Barrier Reef (GBR) embodies a diverse array of values, ranging from tangible commercial benefits like tourism and fishing, to cultural aspects, including Indigenous heritage and identity. Many benefits are enjoyed directly, including recreational activities such as snorkelling, diving, and boating, enriching people's wellbeing and lifestyle. The GBR also generates a range of indirect and non-use benefits, including aesthetic, lifestyle, protection, educational and research outcomes. The 'outstanding universal value' of the GBR was formally recognised globally through the inclusion on the UNESCO World Heritage List in 1981. The GBR meets all four World Heritage natural criteria: natural phenomena and exceptional natural beauty; representing major stages of Earth's history; significant ongoing ecological and biological processes; and contain the most important and significant habitats for conservation of biodiversity (GBRMPA, 2019). However, the World Heritage Committee has expressed some concerns on the current threats to the outstanding universal value of the GBR World Heritage Area, which triggered a Reactive Monitoring Mission in March 2022, and the preparation of a report (May 2023) with a series of recommendations for the Australian and Queensland governments to address the key pressures on the reef, including climate change, water quality and fisheries[7].

The recognition and measurement of benefits is typically done by assessing values, to inform policy, financial investments, regulatory instruments, and management decisions. How the GBR generates benefits and attributes involves multifaceted values that are intertwined, making measurement complex, and assessment involving multiple factors, different sets of stakeholders, and varying motivations and uses. The extent and complexity of values differs across geographical and spatial zones of the GBR, as well as by the different uses, populations and benefits being assessed.

The complexity of the GBR means that it is simplistic to summarise the benefits and values to a singular social understanding, a uniform cultural interpretation, or a single economic value. One approach is to treat the system as a dichotomy between broad scientific systems of ecological value (Hoegh-Guldberg et al., 2017; Hughes et al., 2018), and social or human systems (Curnock & Marshall, 2019); and the ways the two systems interact are relational and interconnected (Chan et al., 2016).

Defining the 'value' of the GBR has long been debated. As early as 1893, Saville-Kent's book '*The Great Barrier Reef: Its Products and Potentialities'* recognised links between economics, aesthetics, and marine ecology. In 1905, a journalist writing about the GBR noted the values are "practically unknown; yet its values economically, apart from its value in beauty, makes it one of the greatest assets in Australia"; and in the 1920s, extrapolating economic and scientific value was an idea championed by the Royal Geographical Society of Australasia and later adopted by the Great Barrier Reef Committee where "scientific and economic resources of the GBR's products, their associated industries and their markets, were imperative and formed an essential agenda of the society" (Lloyd, 2022).

This question aims to capture **the socio-ecological, cultural, economic, and intrinsic values of the GBR,** which requires an understanding of the complexity of GBR values. This involves recognition of the diverse elements of the system that are valued by people, and acknowledgement of the inherent trade-offs between individual preferences and the broader needs of ecological and socio-ecological systems. As Stoeckl et al. (2014) notes, 'value' is a subjective term and varies from person to person. It also shifts depending on the interplay among different sets or categories of values. This review therefore includes a synthesis of the different ways of interpreting values, the main considerations for identifying values, and how values of the GBR are both relational to one another including the human dimension, the ecological systems, and the other value systems. This provides the critical

[7] https://www.dcceew.gov.au/parks-heritage/great-barrier-reef/world-heritage

context for understanding the importance of the current evidence presented in the 2022 Scientific Consensus Statement (SCS) including the distribution, impact and management of land-based pollutants that influence water quality in the GBR.

1.1 Question

Primary question	What are the socio-ecological, cultural, economic, and intrinsic values of the Great Barrier Reef?

The 'outstanding universal value' of the GBR was formally recognised globally through the inclusion on the UNESCO World Heritage List in 1981. The GBR meets all four World Heritage natural criteria: natural phenomena and exceptional natural beauty; representing major stages of Earth's history; significant ongoing ecological and biological processes; and contain the most important and significant habitats for conservation of biodiversity (GBRMPA, 2019; Lucas et al., 1997).

The multidimensional value of the GBR from ecological, social, socio-ecological, cultural, and economic perspectives cannot be reduced to a handful of metrics, without emphasising the interconnections between social, human, and ecological systems. Interpreting the 'values' of the GBR requires an understanding of the way beliefs and cultural perceptions of sea and landscapes, management resources and institutional arrangements contribute to effective ecosystem services and socio-ecosystem development (Carpenter, 2006).

Socio-ecological systems (SES) are described as interconnected relational elements, emphasising the complex interactions between ecological and social systems at different scales. Socio-ecological, in this context refers to the socio-ecological systems (SES) framework (Berkes & Folke, 1994; Ostrom, 2009), a concept used in environmental and social sciences to describe the complex interactions and interdependencies between social and ecological systems.

Ecological and linked social values: The GBR is a complex and diverse ecosystem that supports a vast array of marine life, including fish, corals, turtles, dugong, whales, and many others. It provides habitat and is home to many thousands of species including endangered and threatened species, making it important for biodiversity. The GBR also plays an important role in storing carbon, and the overall health of the world's oceans, as it serves as a breeding ground for nomadic and other marine species that then migrate to regional and global parts of the ocean.

Socio-ecological systems can be characterised as a set of interconnected elements, including ecological components (e.g., flora, fauna, and abiotic factors such as climate and soil), social components (e.g., people, institutions, culture, and knowledge systems), and their interactions over time. These interactions can occur across different scales, ranging from local to global, such as the interaction between commercial, government, science, and other sectors such as fishers, shipping, tourism, coastal communities, ports, extraction industries, supply chains, and others.

Understanding socio-ecological values is crucial for comprehending the drivers of human interaction with the GBR and improving governance outcomes (Cinner et al., 2016). By incorporating insights from social science research, policy and stakeholders can develop more effective and targeted strategies that account for the diverse values, motivations, and behaviours of individuals and communities interacting with the GBR (Stoeckl et al., 2014). For example, Marshall et al. (2019a) found that various coastal resource users may have different perceptions of the GBR's ecological value, which in turn can influence their behaviours and the effectiveness of management practices. Recognising these differences and addressing potential conflicts between stakeholder groups can lead to more inclusive and collaborative decision-making processes.

Links between ecology and society extend to non-users, such as people living in distant locations (Chan et al., 2016; Van Riper & Kyle, 2014). Those non-users may hold values and interests in the GBR's wellbeing, and often underpin concerns for intergenerational equity and global importance of

the GBR, as suggested in the 2017 CSIRO led Social and Economic Long-Term Monitoring Program (SELTMP) study (2017). Integrating social scientific research into management approaches is proposed to improve public understanding, communication strategies, educational programs, and community engagement initiatives.

Cultural values: The SELTMP identifies cultural and heritage values as a major value set. This includes the incorporation of 18 cultural services, including but not limited to categories that measure the economic value the GBR as an asset for the economy; the value of the GBR from supporting a variety of life; the aesthetic beauty, the sense of interconnectedness and pride in World Heritage status; and visitation including the number of international visitors it attracts. These values vary widely for user groups and communities.

Values held by Aboriginal and Torres Strait Islanders are important, as their holistic approach represents a symbiosis between ecological systems and peoples. The GBR has deep spiritual, cultural, and historical significance to these communities, having been at the heart of their culture and way of life for thousands of years, supplying sustenance, cultural practices, and connections to ancestral lands. However, evaluating Indigenous peoples' knowledge and values is difficult as there is an underrepresentation of their perspectives in environmental and economic assessment models (Sangha et al., 2018).

Traditional Owners feel that they have carried out their cultural obligations and responsibilities in looking after land and sea Country and its heritage for tens of thousands of years (Jarvis et al., 2017; Stoeckl et al.,2021). Biocultural relationships are also at the heart of Aboriginal and Torres Strait Islanders peoples' decision making emerging from intimate causal relationships between biodiversity and culture at local levels (Maffi & Woodley, 2010; cited in Bock et al., 2021). The Reef 2050 Long Term Sustainability Plan (Reef 2050 Plan) contains an objective to "Develop, implement and coordinate a protocol and knowledge management system for: recording, storing, protecting, and where appropriate, sharing of knowledge; innovations and practices; conserving and cultural use of biocultural diversity; and use in decision making" (Commonwealth of Australia, 2021a). The knowledge, innovations and practices of Traditional Owners relevant for conservation and cultural use of biocultural diversity need to be preserved and maintained.

Economic and intrinsic values: Economic concepts of value encompass the various dimensions in which society derives benefits from the GBR, including from direct use, indirect use and non-use. Direct uses include recreation, tourism and fishing, with some of those benefits reflected in market prices, while indirect uses include ecosystem services such as coastal protection. Many Australians have large non-use values for the GBR despite having never visited or snorkeled to see coral reefs (Rolfe & De Valck, 2021). Those non-use values include the existence, bequest and option values that people hold to ensure that the GBR continues to be in good condition without necessarily being used by humans.

Intrinsic values are important in environmental ethics and conservation biology, as they provide a basis for valuing and protecting natural entities for their own sake, rather than solely for their usefulness to humans. In environmental ethics and conservation biology, intrinsic value suggests that the GBR has value simply by virtue of its existence, its natural beauty, and the ecological processes it supports. This perspective aligns with a broader environmental ethic that seeks to maintain the integrity and diversity of natural ecosystems for the wellbeing of the planet and future generations.

There are some overlaps between the economic concepts of non-use values and concepts of intrinsic values, as both are focused on the importance of ecological assets independent from direct use. However, the economic concept has a pragmatic basis in that it assesses those non-use or protection values from a human perspective and thus allows them to be quantified, whereas intrinsic value concepts are independent of humans and thus cannot be directly measured.

Review approach

This review adopted a staged approach. The first stage was to identify four value dimensions in line with the discussion above: ecological, social, cultural and economic. Concepts of values vary across these dimensions from recognition that ecological assets are important to people through to precise measures of benefit streams.

The second stage was to identify where the four values interconnect within a complex system (see Figure 1). The overarching message is that value dimensions are interrelated. It is notable that having a healthy GBR is important to people in multiple ways, including Australia's identity, sense of place and wellbeing, the economic systems dependent on the ecological system, and the intrinsic value of the GBR. Hence, the focus of this review is more on the linked socio-ecological system with less emphasis on documentation of the ecological values which are comprehensively captured elsewhere, e.g., Great Barrier Reef 2019 Outlook Report (GBRMPA, 2019).

It is equally important to note the Great Barrier Reef Marine Park and the World Heritage Area cover vast areas, and a detailed breakdown of the various cultural, social, economic and intrinsic values within those areas and the associated catchments is beyond the scope of this study.

1.2 Conceptual diagram

The conceptual diagram (Figure 1) illustrates the ecological, social, economic, and cultural value sets of the GBR, highlighting the dynamic interplay between the natural state of the GBR and collective human actions and perceptions. The figure shows that at the core of the GBR's values are four distinct but interconnected categories incorporating socio-ecological and intrinsic values**.**

Figure 1 situates these values within a broader framework of change, indicated by circular arrows, showing how shifts in perceptions, governance, and management strategies influence and are influenced by the GBR's socio-ecological systems. These systems are described in terms of demographic, technological, economic, and cultural drivers of marine resource use, highlighting the human activities that affect the ocean. The marine ecosystem section reflects on the natural variations in the drivers of ecosystem change in coastal seas and world oceans, suggesting an ongoing interaction between the GBR's inherent ecological processes and external factors. Adjacent to these foundational elements, the diagram indicates the relationship of this Question 1.1 with other sections of the 2022 SCS, including ecosystem condition and drivers (Q1.2/1.3/2.1, McKenzie et al.; Q2.2, Fabricius et al.; and Q2.3, Lewis et al.), management options for reduction of land-based pollutants (Themes 3 to 5), human dimensions (Theme 7), co-benefits (Q8.1, Gordon et al.) and innovative frameworks for monitoring and evaluation (Q8.2, Devlin & Wenger).

Following the initial peer review of this question, Figure 1 was adjusted to incorporate the thinking of Chan et al. (2016) on relational values and adapted to the GBR. This is presented in Figure 12 as part of this review.

The frameworks inform the structure of this review and represent key considerations for understanding the multidimensional complexity of the values of the GBR.

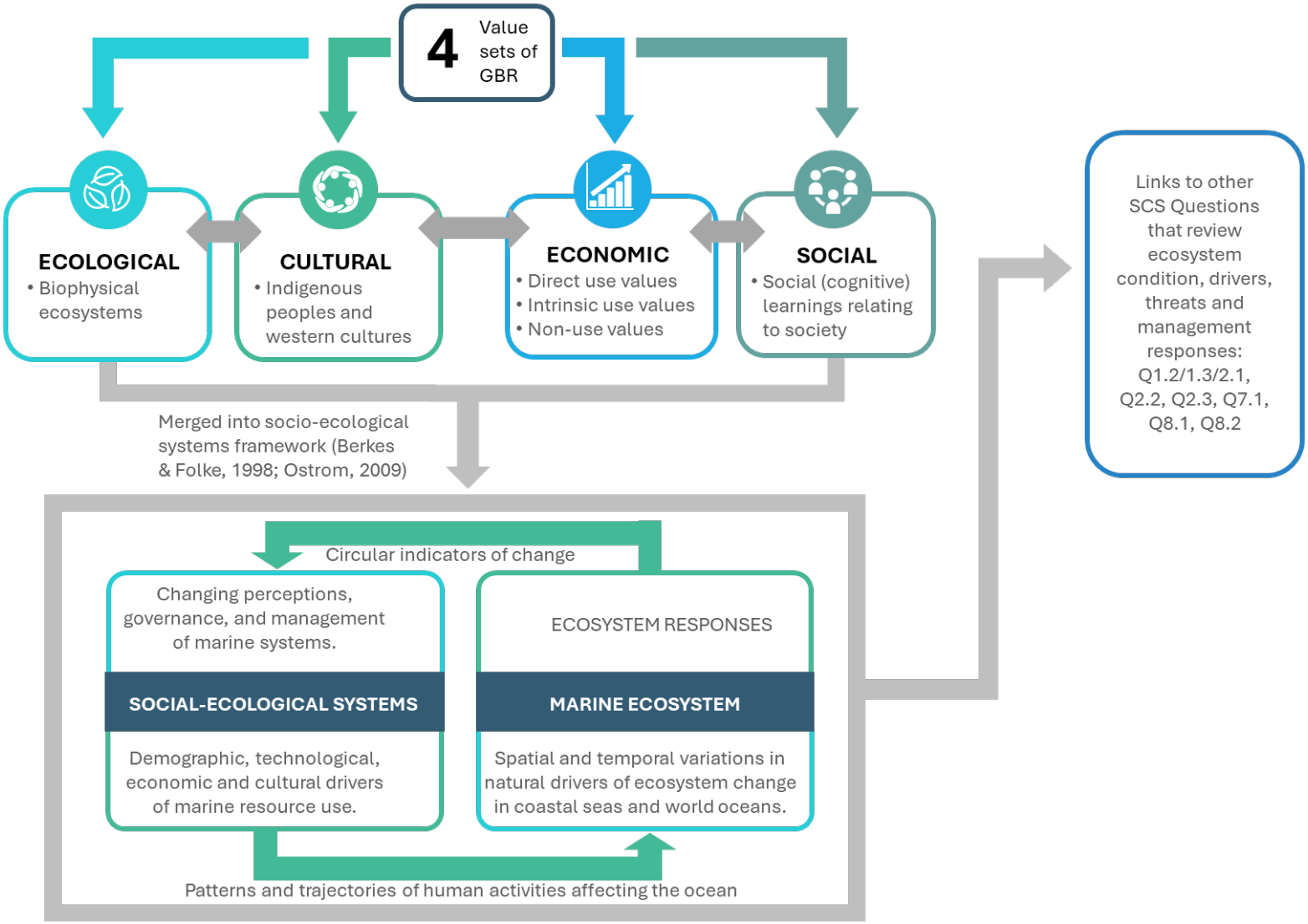


Figure 1. Initial conceptual diagram in relation to Q1.1 that sets out the four groups of values and their relationship to socio-ecological and marine ecological systems. The box on the right indicates how these values inform and relate to other questions in the 2022 SCS.

1.3 Links to other questions

This synthesis of evidence addresses one of 30 questions that are being addressed as part of the 2022 SCS. The questions are organised into eight themes: values and threats, sediments and particulate nutrients, dissolved nutrients, pesticides, other pollutants, human dimensions, and future directions, that cover topics ranging from ecological processes, delivery and source, through to management options. As a result, many questions are closely linked, and the evidence presented may be directly relevant to parts of other questions. The relevant linkages for this question are identified in the text where applicable. The broad nature of this question links it to many other questions within the SCS but the primary question linkages are listed below.

Links to other related questions	**Q1.2/1.3/2.1** What is the extent and condition of Great Barrier Reef ecosystems, and what are the primary threats to their health? **Q2.2** What are the current and predicted impacts of climate change on Great Barrier Reef ecosystems (including spatial and temporal distribution of impacts)? **Q2.3** What evidence is there for changes in land-based runoff from pre-development estimates in the Great Barrier Reef? (Covers how land use is changing over time.) **Q7.1** What is the mix of programs and instruments (collectively and individually) used in the GBR catchments to drive improved land management actions for Great Barrier Reef water quality benefits and how effective are they? **Q8.1** What are the co-benefits e.g., biodiversity, carbon, productivity, climate change, and drought resilience, of land management to improve water quality outcomes for the Great Barrier Reef? **Q8.2** What are the key attributes of successful monitoring and evaluation programs to support coastal and marine water quality management, and what examples are there of innovative monitoring and evaluation frameworks, methods and approaches that are applicable to the Great Barrier Reef?

2. Method

A formal Rapid Review approach was used for the 2022 Scientific Consensus Statement (SCS) synthesis of evidence. Rapid Reviews are a systematic review with a simplification or omission of some steps to accommodate the time and resources available[8]. For the SCS, this applies to the search effort, quality appraisal of evidence and the amount of data extracted. The process has well-defined steps enabling fit-for-purpose evidence to be searched, retrieved, assessed and synthesised into final products to inform policy. For this question, an Evidence Summary method was used.

2.1 Primary question elements and description

The primary question is: ***What are the socio-ecological, cultural, economic, and intrinsic values of the Great Barrier Reef?***

S/PICO frameworks (Subject/Population, Exposure/Intervention, Comparator, Outcome) can be used to break down the different elements of a question and help to define and refine the search process. The S/PICO structure is the most commonly used structure in formal evidence synthesis methods[9] but other variations are also available.

- **Subject/Population:** Who or what is being studied or what is the problem?
- **Intervention/exposure:** Proposed management regime, policy, action or the environmental variable to which the subject populations are exposed.
- **Comparator**: What is the intervention/exposure compared to (e.g., other interventions, no intervention, etc.)? This could also include a time comparator as in 'before or after' treatment or exposure. If no comparison was applicable, this component did not need to be addressed.
- **Outcome:** What are the outcomes relevant to the question resulting from the intervention or exposure?

Table 1. Description of primary question elements for Question 1.1.

Question S/PICO elements	Question term	Description
Subject/ Population	Value Great Barrier Reef	Value is recognition and measurement of the importance of assets and services. The concept varies across discipline areas. For example, the Outstanding Universal Value (OUV) of the GBR that is recognised internationally through World Heritage listing is mostly focused on the importance of ecological assets in addition to heritage values, whereas values assessed in economic terms reflect the tradeoffs that people will make between money and the use and/or protection of the GBR.
Intervention, exposure & qualifiers		**Ecological:** biodiversity and living things. **Social:** e.g., societal influence and systems. **Economic:** includes use, non-use, social and cultural values. **Cultural:** includes Indigenous, Aboriginal and Torres Strait Islander peoples, and non-Indigenous, Aboriginal and Torres

[8] Cook CN, Nichols SJ, Webb JA, Fuller RA, Richards RM (2017) Simplifying the selection of evidence synthesis methods to inform environmental decisions: A guide for decision makers and scientists. *Biological Conservation* 213: 135-145 https://doi.org/10.1016/j.biocon.2017.07.004

[9] https://libguides.jcu.edu.au/systematic-review/define and https://guides.library.cornell.edu/evidence-synthesis/research-question

Question S/PICO elements	Question term	Description
		Strait Islander people, and the ecosystem services that form different interpretations of value around the GBR, both domestically and internationally. This links to the OUV and the global icon status of the GBR.
Comparator	none	(Not relevant)
Outcome & outcome qualifiers	Socio-ecologic	Socio-ecologic: a framework that recognises that there is no point in separating ecosystems from people when addressing their study or management since changes in one will necessarily affect the other, positively or negatively.
	Intrinsic value	Environmental entities have intrinsic value in virtue of having a good of their own or interests that people (value) ought to care about (Sterba, 2001). All living organisms have a good of their own.
	Cultural	Indigenous culture and associated terms: First Nations, living maritime culture including sea Country, bio-cultural, spirituality, cultural identity, native title and other terms.
	Economic	Culture (non-economic but may be duplicated in intrinsic values): includes heritage, place and even shipwrecks.
		Direct use: benefits enjoyed directly by people that can often be valued through market prices.
		Indirect use: ecosystem services, valued with replacement cost and other techniques.
		Non-use values: benefits realised without having to use the GBR, assessed with non-market valuation techniques.

Table 2. Definition of terms used in Question 1.1. Adapted from Marshall et al. (2016) taxonomy of cultural values.

Definitions	
Aesthetic Appreciation	Describes the aesthetic value that an individual attributes to aspects of an ecosystem; aesthetic responses are linked to both the characteristics of an environment and culturally or personally derived preferences (Klain et al., 2014; Marshall et al., 2018; MEA, 2005; Pike et al., 2011; Pocock, 2002;).
Appreciation of biodiversity	Describes how people are emotionally inspired by biodiversity and other measures of ecosystem integrity at a particular place (Marshall et al., 2016; 2018).
Attachment to place ("Place")	The emotional and physical bond between person and place, which is influenced by experiences, emotions, memories, and interpretations; it often provides a reason for people to live in a specific area (Marshall et al., 2018).
Cultural (Indigenous)	Refers to Indigenous culture, sea Country, spirituality and song lines both on land and in the rivers and marine environment.

Definitions	
Cultural (services)	Connecting provisioning and regulating services.
Direct value	Outputs/ services that can be consumed directly (Rolfe & De Valck, 2021).
Great Barrier Reef	In the context of the 2022 SCS, it refers to the Great Barrier Reef World Heritage Area.
Identity	The feeling of belonging to a place or social group with its own distinct culture and common social values and beliefs (Adger et al., 2011; Marshall et al., 2012; 2018).
Lifestyle	The expression of "visible" culture that has evolved around a natural resource or ecosystem; describes the extent to which the lives of people revolve around a natural resource and how people interact with it for recreation (Marshall et al., 2016; 2018; MEA 2005).
Scientific value	The value that people associates with learning opportunities in the past, present, and future; the legacy and appreciation of ecosystems and natural resources that have been inherited from the past and their sense of continuity across time (Barbier, 2012; Klain et al., 2014; Marshall et al., 2018).
Socio-ecological values	The interlinked connections between humans and ecosystems. A framework that recognises there is no point in separating ecosystems from people when addressing their study or management since changes in one will necessarily affect the other, positively, or negatively.
Wellbeing	The extent to which individuals are concerned for their own wellbeing if the health of the natural resource were to decline (MEA, 2005), i.e., concept of 'solastalgia' literature (Albrecht, 2020) and the 'sense of place' literature (Marshall et al., 2018).

2.2 Search and eligibility

The Method includes a systematic literature search with well-defined inclusion and exclusion criteria.

Identifying eligible literature for use in the synthesis was a two-step process:

1. Results from the literature searches were screened against strict inclusion and exclusion criteria at the title and abstract review stage (initial screening). Literature that passed this initial screening step were then read in full to determine their eligibility for use in the synthesis of evidence.
2. Information was extracted from each of the eligible papers using a data extraction spreadsheet template. This included information that would enable the relevance (including spatial and temporal), consistency, quantity, and diversity of the studies to be assessed.

a) Search locations

Searches were performed in:

- Academic databases: Scopus, Web of Science.
- Google Scholar.
- Great Barrier Reef Marine Park Authority (GBRMPA) eLibrary.
- Queensland Government database (especially the Department of Environment and Science (QDES) and the Department of Agriculture and Fisheries (QDAF) databases.
- Great Barrier Reef Foundation website and publications.

- Federal and State Government agency websites/ document databases.

b) Search terms

Table 3 shows a list of the search terms used to conduct the online searches.

Table 3. Search terms for S/PICO elements of Question 1.1.

Question element	Search terms
Subject/Population	Values, GBR
Exposure or Intervention	Social, cultural
Comparator	(Not relevant)
Outcome	socio-ecological, cultural, economic, and intrinsic

c) Search strings

Table 4 shows a list of the search strings used to conduct the online searches.

Table 4. Search strings used for electronic searches. The grey lines are the additional searches carried out following the first round of peer review.

Search strings
"great barrier reef" AND value*
"great barrier reef" AND value* AND Intrinsic OR economic OR social OR environmental OR ecosystem
"great barrier reef" AND value* AND Indigenous
"great barrier reef" AND value* AND (cult* w/3 (recreation OR aesthetics OR heritage OR shipwrecks))
"great barrier reef" AND (value* AND w/3 (economic OR dollar* OR Worth OR Eco*))
"great barrier reef" AND economic OR “willingness to pay
"great barrier reef" AND economic OR “non-market”
"great barrier reef" AND nonmarket OR “non market” OR existence

d) Inclusion and exclusion criteria

Table 5 shows a list of the inclusion and exclusion criteria used for accepting or rejecting evidence items.

Table 5. Inclusion and exclusion criteria for Question 1.1 applied to the search returns.

Question element	Inclusion	Exclusion
Subject/Population	GBR studies conducted within the GBR* region. GBR catchment. GBR World Heritage Area (GBRWHA). Studies conducted within Queensland Marine Parks. Values – economic models and studies.	Studies not connected to the GBR, but connected to water quality. Studies outside of the GBR catchment area, GBRWHA. Studies outside of the Queensland Marine Parks.

Question element	Inclusion	Exclusion
	Economic studies on Indigenous engagement.	
Exposure or Intervention *Social factors* *Cultural*	Studies with a focus on human dimensions/human geography, social sciences – Anthropocene and anthropogenic impacts. Adaptation/ mitigation/ commercial and recreational fisheries/ intrinsic values. Ecosystem services/ tourism. Human dimension monitoring data. Stewardship. Citizen science. Engagement (public and private). Indigenous, Aboriginal and Torres Strait Islander peoples. Non-Indigenous, Aboriginal and Torres Strait Islander people, and the ecosystem services that form a cultural value around the GBR, both domestically and internationally.	Pure biophysical (e.g., no human interaction). Studies outside of the GBR region (if possible). Non-peer reviewed, e.g., newspaper articles; magazines; blogs; media or social media text or images, including LinkedIn posts; self-published literature; grey literature not peer reviewed e.g., Annual reports. Non-peer reviewed evidence from Traditional Owners and Indigenous peoples, to be evaluated on a case-by case basis in conjunction with Indigenous scholars and the SCS team.
Outcome	Socio-ecological, cultural, economic, and intrinsic.	
Socio-ecological	Socio-ecological frameworks – qualitative and quantitative studies. Socio-ecological evaluations and monitoring programs including qualitative datasets. Socio-ecological uses and benefits. Regulating services. Provisioning services. Indigenous culture and associated terms, in particular: First Nations. Living maritime culture. Sea Country. Bio-cultural. Spirituality. Cultural identity. Native title/ land rights.	Non-socio-ecological. Non-social/ biophysical only. Lab based data/ quantitative datasets. Pure science on GBR ecosystems.
Economic	Goods and services. Populations. Households. Tourism. Value added.	

Question element	Inclusion	Exclusion
	Industry (ports, agriculture etc.). Research. Intrinsic value. Indirect values. Economic OR “willingness to pay”. “non-market” OR nonmarket OR “non market” OR existence.	
Cultural (Indigenous)	As above.	Non-public literature.
Cultural (non-Indigenous)	Ecosystem services frameworks. Fisheries/ food. Culture. Spirituality. Sea Country.	
Language	English only.	Non-English text.
Study type	Qualitative and quantitative.	Pure science.

3. Search Results

A comprehensive search of online databases, including Scopus, Web of Science, and Google Scholar, yielded 1,711 studies (644 from Scopus, 1,034 from Web of Science, and an additional 33 from Google Scholar). After initial screening, which involved reviewing titles and abstracts and removing 404 duplicates, 348 studies were selected for full-text assessment from the online searches, accounting for 95.1% of the total relevant literature. Additionally, 18 studies, or 4.9% of the total evidence, were manually obtained through expert consultations and personal collections. In total, 366 studies were selected for full-text assessment. The final screening process resulted in 85 evidence items eligible for inclusion in the evidence synthesis (Table 6, Figure 2).

During the search process, certain search strings proved to be more effective in identifying relevant literature, which contributed to the efficiency and comprehensiveness of the search. Moreover, the combination of database searches and manual identification of studies through expert contact and personal collections ensured that a broad range of relevant research was considered. The multi-step screening process, starting with the initial screening of titles and abstracts, followed by a thorough full-text assessment (i.e., second screening), allowed for a rigorous evaluation of each study's relevance to the research question, ultimately leading to a robust and reliable body of evidence for the synthesis.

Table 6. Search results table, separated by A) Academic databases, B) Search engines and C) Manual searches.

Date	Search strings	Sources	
A) Academic databases		Scopus	Web of Science
Jan 23	*Search string 1:* “great barrier reef” and value*	642	1,034
Jan 23	*Search string 2:* "great barrier reef" AND value* AND Intrinsic OR economic OR social OR environmental OR ecosystem	333	482
Jan 23	*Search string 3:* "great barrier reef” AND value* AND w/3 (water OR Quality) AND (Socio OR Eco* AND culture)))	0	4
Jan 23	*Search string 4:* "great barrier reef " AND value* W/3 indigenous OR bio AND cultural OR sea AND country OR native AND title	0	0
Jan 23	*Search string 5:* "great barrier reef” AND value* AND Indigenous	14	21
Jan 23	*Search string 6:* "great barrier reef" AND value* AND culture	11	28
Jan 23	*Search string 7:* "great barrier reef" AND value* AND cult*	57	82
Jan 23	*Search string 8:* "great barrier reef" AND value* AND cult* w/3 recreation OR aesthetics OR heritage OR shipwrecks	6	15
Jan 23	*Search string 9:* "great barrier reef" AND value* AND eco* (economic, ecosystem, ecological)	289	23
Jan 23	*Search string 10:* "great barrier reef" AND value* W/3 indirect OR intrinsic OR eco*	62	440
Jan 23	*Search string 11:* "great barrier reef" AND value* W/3 economic OR dollar* OR worth OR eco*	58	440

Date	Search strings	Sources	
Jan 23	*Search string 12:* "great barrier reef" AND value* W/3 environmental OR account*	29	2
	Total	***1,501***	***2,571***
	Total after removing duplicates	***644***	***1,034***
B) Search engines (Google Scholar)			
Feb 23	*Search string 1:* "great barrier reef" and value*	33 (first 250)	
	Total items online searches	***348 (1,711) (95.1 %)***	
C) Manual search			
Date	Source	Number of items added	
Feb 23	Great Barrier Reef Marine Park Authority (GBRMPA) eLibrary	7	
Feb 23	Great Barrier Reef Foundation-website and publications	3	
Feb 23	Queensland Government (especially the Department of Environment and Science (QDES) and the Department of Agriculture and Fisheries (QDAF)	8	
	Total items manual searches	***18 (4.9%)***	

Following the initial peer review, the search strings were also reviewed with consideration of additional terms including more restricted, discipline-specific search strings. These searches did not yield additional papers that were missed by the broader search query, as "great barrier reef" AND (value* AND w/3 (economic OR "willingness to pay" OR "non-market" OR nonmarket OR "non market" OR existence)) is a form of subset of "great barrier reef" AND "value*". The results showed little to no change in the output. The primary search query ("great barrier reef" AND "value*") was comprehensive, capturing both general and specialised literature relevant to the study objectives.

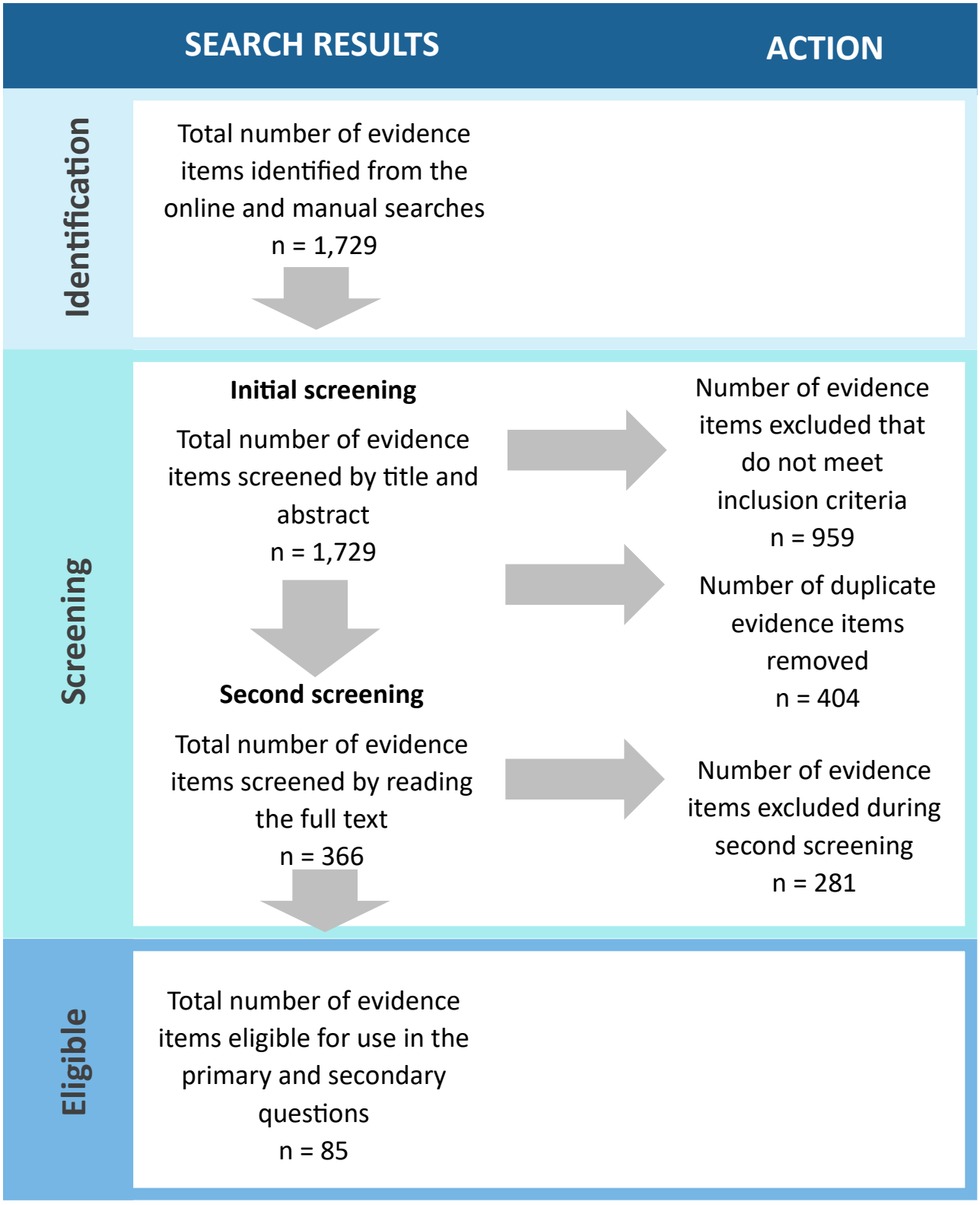


Figure 2. Flow chart of results of screening and assessing all search results for Question 1.1.

4. Key Findings

4.1 Narrative synthesis

4.1.0 Summary of study characteristics

There were 85 studies that provide the lines of evidence used to answer the primary question. Most studies were GBR-wide including the catchment and marine landscapes, with a handful covering specific spatial zones. In accordance with the inclusion and exclusion criteria, studies focusing on ecological and socio-ecological studies were included. The majority of studies were peer reviewed international journal articles published since 1994. More recent literature (after 2017) were predominantly peer reviewed technical reports. Excluded items included conference papers, technical and methodology reviews not containing original data or reinterpretation of secondary data, and some books. Where a technical report was superseded by a later journal publication, the report was excluded from the review.

Temporal distribution of studies

There has been a steady increase in the number of publications over the years, reflecting a growing interest in the GBR. During the 1990s, there was emerging literature focusing on the GBR as a tourist destination, and the increasing influence of global environmental governance to address global warming. Between 2005 and 2007, there was a noticeable increase in publications, with nine studies in 2005 and eight studies in 2007. This may be linked to the implementation of rezoning of the entire GBR Marine Park in 2004. The most substantial increase in publications occurred between 2009 and 2017, peaking at 30 studies in 2017 (Figure 3). This period saw an average of around 18 studies published per year. Post-2017, the number of publications was still relatively high, with 20 or more studies published each year between 2018 and 2022. These trends suggest that research on the GBR continues to be important, with the scientific community striving to better understand and protect the values of this unique ecosystem (Figure 3).

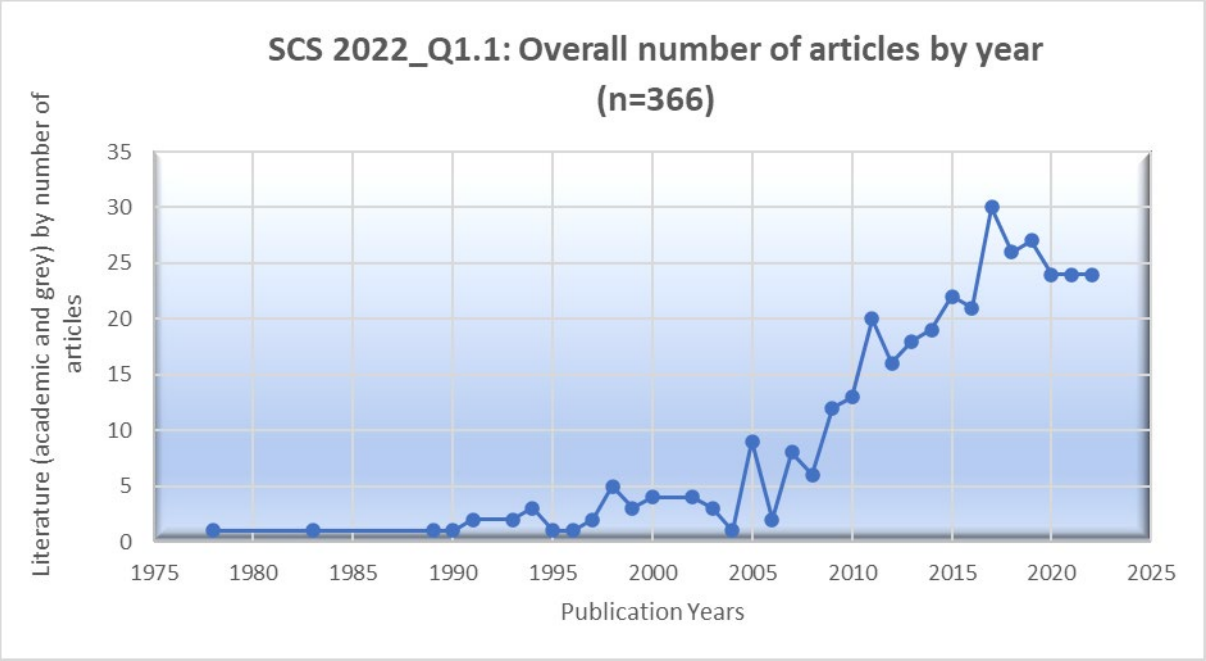


Figure 3. Temporal distribution of the 366 articles included for full text reading and second screening on the values of the GBR.

After excluding 281 studies that did not meet the inclusion criteria on second screening, the remaining 85 studies show a varied distribution across the years (Figure 4). Starting around 1994, the number of studies remained relatively low until the early 2000s, with only a few studies published

each year. From 2002 onwards, there was a gradual increase in the number of studies, with a noticeable growth between 2012 and 2014, when an average of six studies per year were published. A spike in publications was evident in 2017 and again in 2019, with 11 studies from these years (Figure 4).

Figure 4. Temporal distribution of the 85 articles included for data extraction for evidence on the values of the GBR.

Study type

In the 85 studies reviewed, various study types were represented, reflecting the multifaceted nature of research on values of the GBR. The majority were observational studies (53), focusing on empirical data collection and analysis, as well as conceptual studies (3), and experimental studies (4) that tested specific hypotheses under controlled conditions, determining causal relationships and informing management and conservation efforts. Modeling studies (9) used computational techniques to simulate ecological processes, predict future scenarios, or evaluate management strategies, while review studies (16) synthesised existing research to draw broader conclusions, identify knowledge gaps, and guide future research and actions. The diverse study designs contribute to a comprehensive understanding of the values of the GBR, informing effective conservation and management efforts.

Locations of studies

The majority of the studies (55) relate to the GBR as a whole (including some global studies indirectly related to GBR values (6)), while the remaining studies were concentrated on specific sections of the GBR, such as the northern GBR (14), central GBR (6), southern GBR (5), and the Great Barrier Reef World Heritage Area (GBRWHA) (5).

This distribution highlights the diverse spatial research interests and values within the GBR ecosystem, including larger-scale issues like climate change and conservation strategies (GBR-wide), as well as region-specific values and concerns.

4.1.1 Summary of evidence to 2022

4.1.1.1 Measuring values and frameworks for assessing GBR values

To provide further background to the approach to addressing the question, a review of the main frameworks that are used to identify and measure GBR values was conducted. This involved a review of early methods employed to measure the values of the GBR and consideration of various

conceptual frameworks used for valuing the GBR's multidimensional aspects. The Total Economic Value (TEV) framework and Ecosystem Services (ES) framework are discussed, capturing both direct and indirect values associated with the GBR. The socio-cultural perspective is enriched through frameworks like First Nations Peoples (FNP), emphasising spiritual and identity values. Instrumental, relational, and intrinsic values, and how they contribute to a comprehensive understanding of the GBR's significance, are also introduced. Specific frameworks were also considered, emphasising the need for a holistic approach that considers the full spectrum of values associated with the GBR, integrating diverse stakeholder perspectives. Additionally, newer frameworks such as the extended ecosystem accounting framework that aim to provide a more inclusive and comprehensive valuation of ecosystem services, considering both market and non-market values, were reviewed.

Prior to 2003, the focus of studies largely rested on assessing the size of the tourism, recreation and fishing industries (Rolfe & De Valck, 2021). However, a few studies investigated specific aspects, such as the value of prawns harvested from healthy seagrass beds (Watson et al., 1993), and Knapman and Stoeckl's (1995) employment of the Travel Cost Method (TCM) to assess recreational demand on Hinchinbrook Island. Subsequent influential studies expanded the scope of economic evaluation. For example, Kragt et al. (2009) applied a contingent behaviour model to gauge how tourists might respond to deteriorating coral reefs in the Port Douglas region. A similar approach, combining TCM and contingent behaviour models, was used by Prayaga et al. (2010) to evaluate the value of recreational fishing along the southern part of the GBR and the Capricornia coast. Rolfe and Windle (2011) reported the use of choice experiments to assess community values for reducing agricultural emissions to improve water quality and protect coral health.

Stoeckl et al. (2011) described the GBR as a complex system of non-linear, interdependent components, with a nexus of varied values encompassing ecological, economic, and socio-cultural dimensions. Its multidimensional nature sparks a broad spectrum of valuations drawn from different value concepts and worldviews, often articulated through diverse approaches and frameworks. The TEV framework, for instance, encapsulates the GBR's direct use values, indirect use values, option values, and non-use values, providing a monetised valuation lens (Costanza et al., 1997). From an ecological perspective, the Millennium Ecosystem Assessment's Ecosystem Services framework elucidates the GBR provisioning, regulating, cultural, and supporting services, offering a perspective grounded in ecological functionality and human benefits (MEA, 2005). Socio-cultural models such as the First Nations Peoples (FNP) framework further enrich this valuation setting by recognising the sociocultural, spiritual, and identity values associated with the GBR, often resonating with the lived experiences and traditional knowledge of local communities (Nursey-Bray, 2009).

Different models and frameworks have been developed and applied to understand the multifaceted values of the GBR. Among these, Thomas and Brodie (2015) built on the foundational works of Barbier et al. (2011) (refer to Figure 5) and earlier insights from the National Research Council (NRC, 2005), to offer a comprehensive exploration of the intricate relationships between ecosystems and their multifaceted values to society in the Cape York Peninsula coastal and marine region of the GBR.

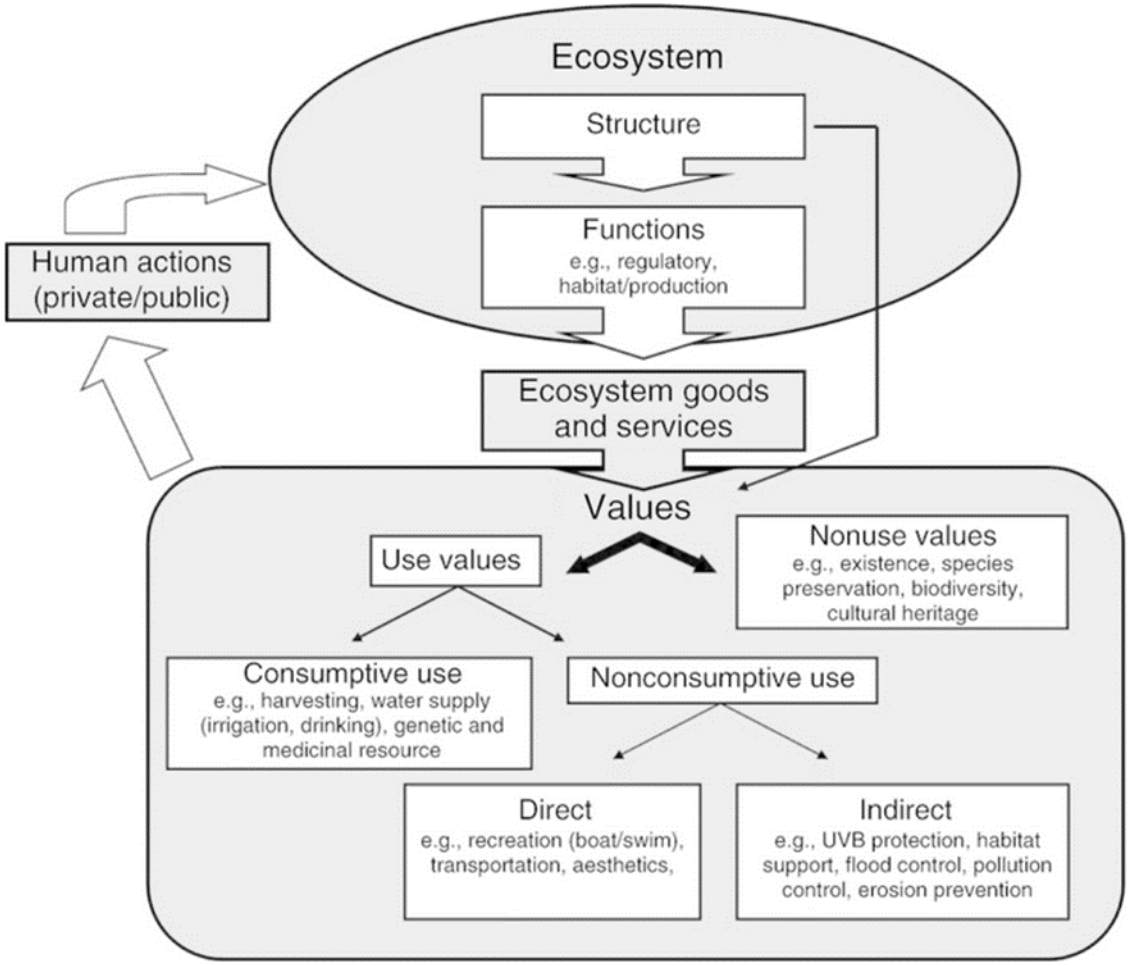


Figure 5. The classification of environmental values presented in Barbier et al. (2011) which identifies the relationship between the ecosystem (structure and functions) and the generation of ecosystem goods and services, and how these influence use and non-use values. Note UVB is ultraviolet-B radiation from sunlight which can cause skin cancer.

Barbier et al. (2011) (Figure 5) recognises the different ways in which humans benefit from, or value, ecosystem goods and services, and categorically breaks down the economic values into use values, non-use values, and option values, each with its unique components and implications. The direct use values, emanating from tangible interactions with the ecosystem, are contrasted with the indirect use values, which are derived from the ecosystem's supportive and protective roles, highlighting the complexity and the often-overlooked dimensions of ecosystem services. The non-use values, encompassing existence and bequest values, reflect the intrinsic worth and the intergenerational equity considerations of ecosystem conservation. The option value, representing the societal preference for preserving future interaction possibilities with the ecosystem, underscores the need for a precautionary approach in ecosystem management. This framework underpins the review and synthesis of values conducted by Rolfe and De Valck (2021).

In the comprehensive review conducted by Stoeckl et al. (2011), the authors highlighted the intricate values of the GBR, adopting a multifaceted approach to understand and quantify the ecosystem services it provides. They assessed not only the economic value of the GBR but also highlighted the interconnectedness of the marine system with adjacent ecosystems, emphasising the need for a holistic valuation that encompasses a wide array of services. Their approach to valuation is inclusive, considering not just the direct economic benefits from tourism and fishing, but also the less tangible cultural and ecological values.

Stoeckl et al. (2011)'s framework uniquely combines the MEA ecosystem services and the TEV framework, and methods employed range from conventional economic valuation techniques to more innovative conceptual models, illustrating the flow of benefits from various ecosystem services (Figure 6). Stoeckl et al. (2011) concluded by underscoring the critical need for further research, particularly terrestrial-based investigations, to fill the existing knowledge gaps and provide a more complete understanding of the GBR's value.

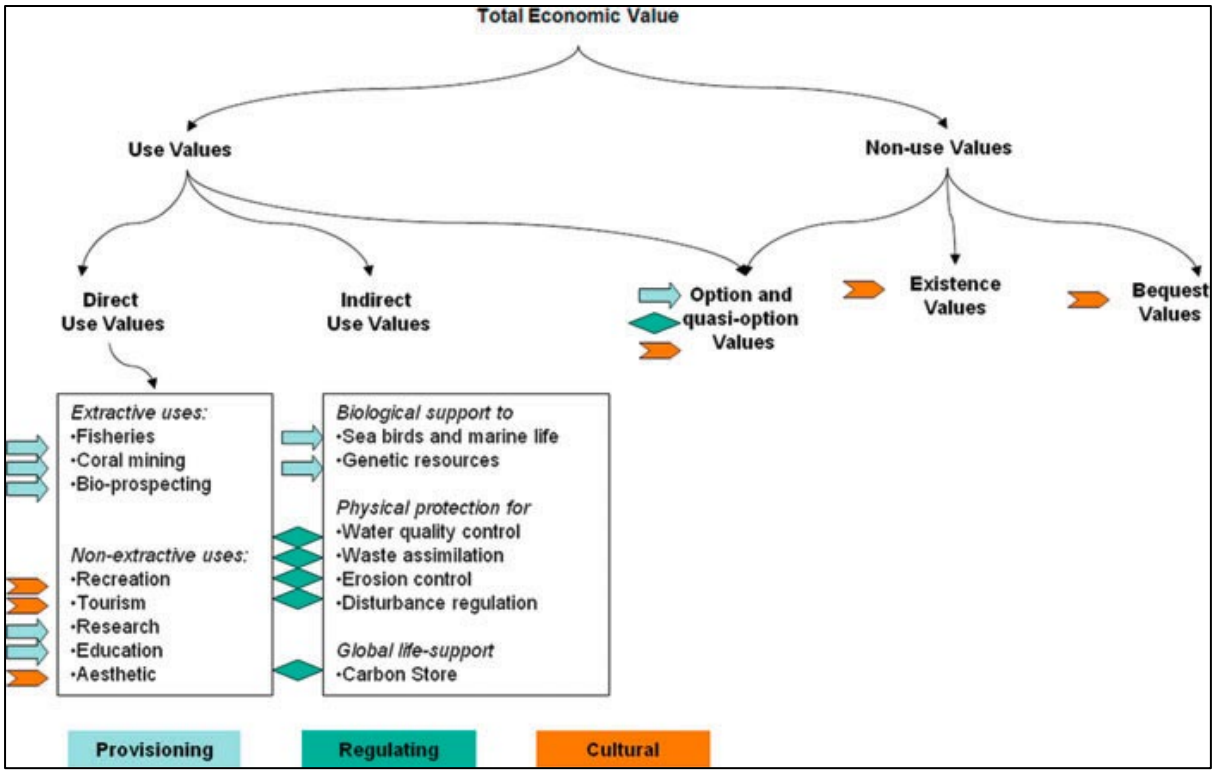


Figure 6. MEA ecosystem services and the TEV framework. Source: Stoeckl et al. (2011).

Building on Stoeckl et al. (2011), Stoeckl et al. (2014) challenged the conventional TEV framework and introduced a 'whole ecosystem' approach to valuing the GBR, addressing the complexities and interdependencies inherent in ecosystem services. The authors critique the TEV framework for the potential to double-count values due to assumptions of separability and additivity of ecosystem services. To overcome these limitations, they proposed a novel method grounded in life satisfaction, using data from over 1,500 GBR catchment area residents. This approach aims to capture the entire value of the ecosystem, considering the overlapping and interdependent nature of ecosystem services, and incorporating both direct use and non-use values (Figure 7).

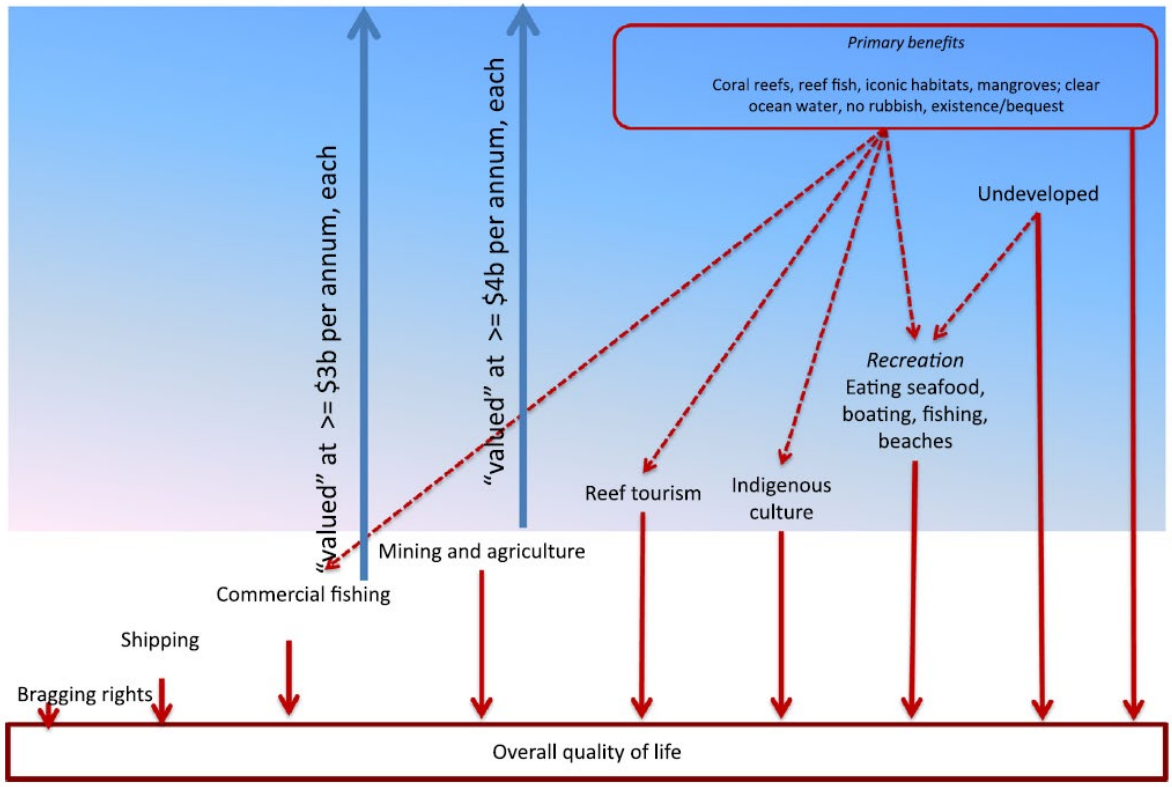


Figure 7. Diagrammatic representation of the way in which various community defined benefits contribute to the overall quality of life of residents in the GBR catchment area, presented in Stoeckl et al. (2014).

Despite acknowledging the limitations of their data and methods, Stoeckl et al. (2014) argue that their approach provides a more holistic understanding of ecosystem values and could serve as a viable alternative to additive valuation methods. However, the reliance on self-reported data and the complexity of the GBR ecosystem present challenges in accurately capturing and valuing all relevant services.

In their seminal work, De Valck and Rolfe (2018) presented a nuanced conceptual framework aimed at valuing the direct use benefits to society ensuing from fluctuations in water quality within the GBR, following a causal chain from environmental stressors to requisite remedial actions. This framework stands out for its holistic integration of various critical components, including the identification of environmental change drivers, assessment of the current ecosystem state, categorisation of ecosystem services, evaluation of impacts on human wellbeing, economic valuation of ecosystem service changes, and the proposition of policy responses. The authors justify this comprehensive approach by underscoring its necessity for crafting effective management strategies and policies vital for the GBR's conservation, drawing on established methodologies and previous studies to bolster its robustness.

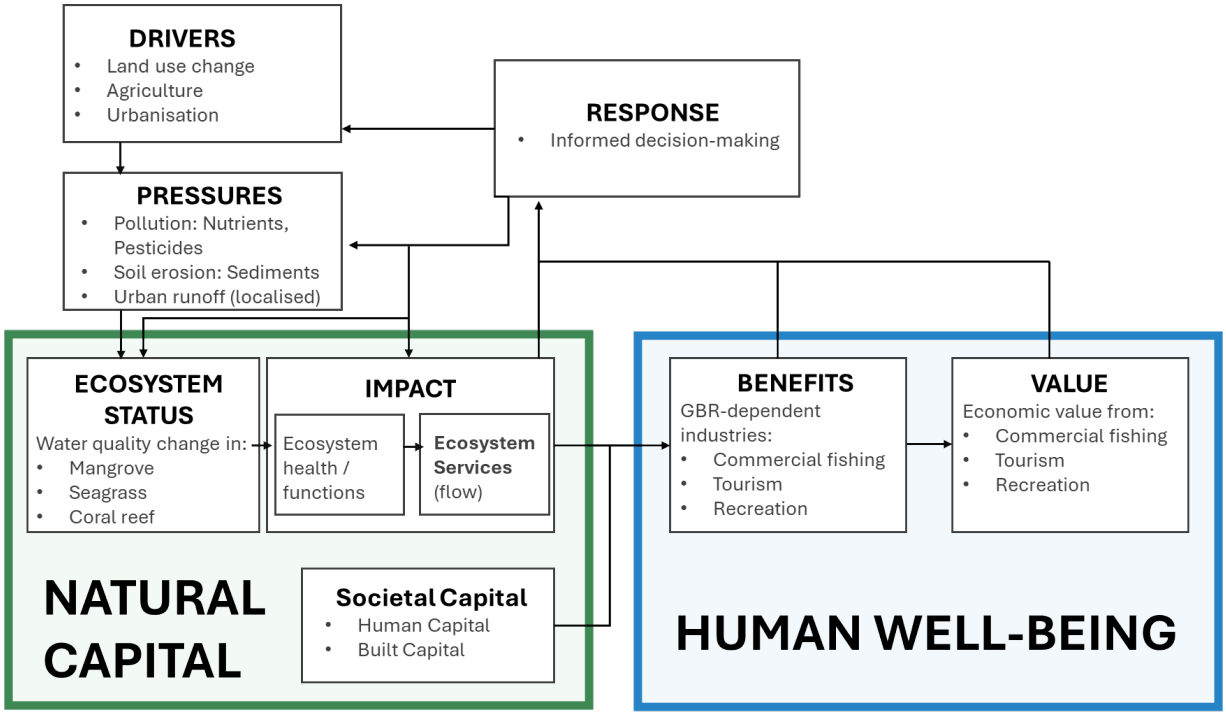


Figure 8. Conceptual framework for linking changes in water quality to changes in benefits associated with ecosystem service provision in the GBR presented in De Valck and Rolfe (2018).

While De Valck and Rolfe (2018) stands as a pivotal contribution to the literature, particularly in its comprehensiveness and policy relevance, the framework is not without its challenges. These include the inherent complexity of the relationships it seeks to elucidate, potential data limitations, and a scope that may underestimate the GBR's overall value by concentrating estimates predominantly on use values related to tourism, recreation, and fishing.

Building on De Valck and Rolfe (2018), De Valck and Rolfe (2019) explore different approaches to valuing biodiversity in the context of the GBR, emphasising the need for sustainable policymaking in light of the threats posed by climate change, water quality degradation, and coastal development (Figure 9). The authors review the TEV framework and an ecosystem services approach, assessing their suitability for biodiversity valuation in the GBR.

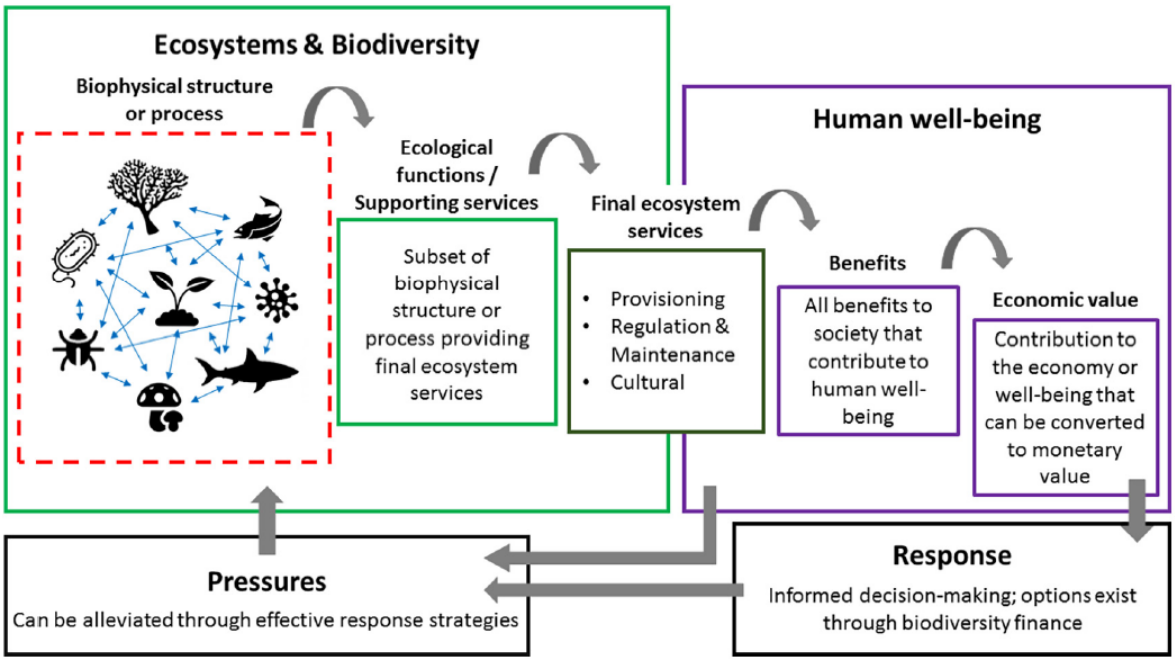


Figure 9. Framework linking biodiversity, ecosystem services and human wellbeing presented in De Valck, and Rolfe (2019).

De Valck and Rolfe (2019) discussed the components of the TEV framework, including direct use, indirect use, and non-use values, and highlight the challenges and limitations of applying this framework to biodiversity valuation. They argue that the TEV framework needs to be extended beyond its traditional boundaries to encompass spatial and temporal dimensions that are crucial for a comprehensive biodiversity valuation. Highlighting the links between biodiversity and ecosystem services, the authors emphasised the role of biodiversity in supporting key ecosystem processes and contributing to human wellbeing. De Valck and Rolfe's work highlights the necessity of a holistic and inclusive valuation approach, one that acknowledges the multifarious values of biodiversity and ensures the sustainable stewardship of the GBR. Their recommendations paved the way for future research trajectories, emphasising the need to integrate diverse stakeholder perspectives.

Interestingly, Chan et al. (2016) present an alternative perspective on valuing natural entities such as the GBR, diverging from the conventional instrumental and intrinsic values to introduce relational values (Figure 10). Relational values encompass the preferences, principles, and virtues associated with relationships between humans, and between humans and nature. They argue that traditional approaches focusing solely on instrumental or intrinsic values may not fully resonate with diverse worldviews, highlighting the potential for commodification and the undermining of genuine conservation efforts.

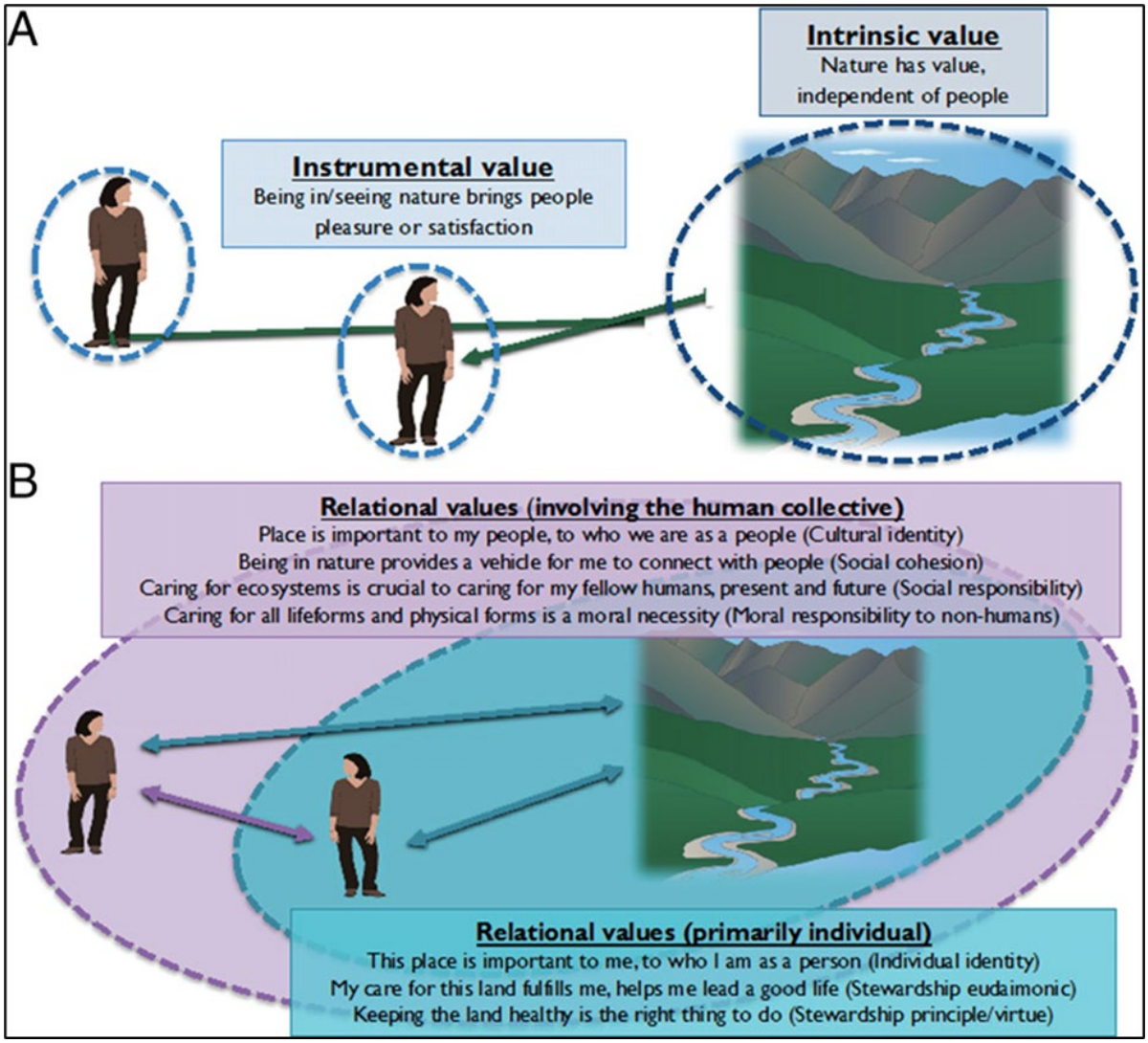


Figure 10. The difference between the instrumental and intrinsic value framings that dominate environmental literature and relational values presented in Chan et al. (2016).

Chan et al. (2016) advocate for a more holistic approach that integrates relational values, drawing on various philosophies and worldviews, including Indigenous, feminist, and Eastern philosophies, to enrich the discourse on environmental protection. By doing so, they underscore the potential of relational values to address overlooked aspects of cultural ecosystem services, ultimately contributing to more effective and legitimate environmental policies and initiatives. This work presents a nuanced and innovative framework for assessing the value of the GBR, emphasising the importance of relationships and community engagement in conservation efforts.

More recently, De Valck et al. (2023) offered an extended ecosystem accounting framework for valuing ecosystem services in complex coastal systems, with a specific focus on the GBR (Figure 11). The authors critique and integrate three major valuation frameworks: the Ecosystem Services framework operationalised by the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA-EA), the TEV framework, and First Nations Peoples (FNP) frameworks. They highlight the strengths and weaknesses of each, proposing an extended SEEA-EA valuation framework tailored for complex coastal settings. The TEV framework is recognised for its focus on different streams of economic values obtained from environmental assets, but it is critiqued for potentially overlooking non-market and cultural values. The FNP frameworks are appreciated for their ability to capture values from FNPs' perspectives, addressing the holistic and intangible nature of their values.

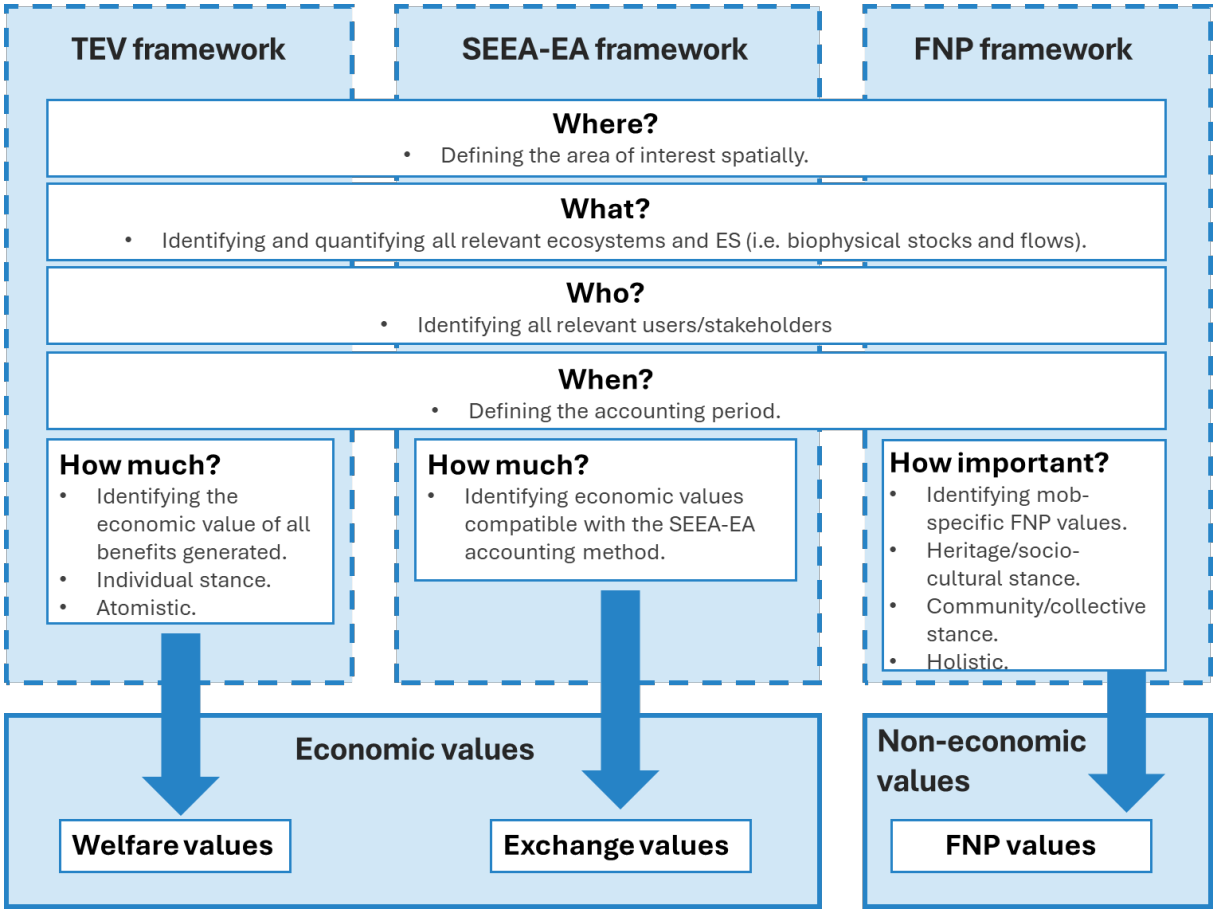


Figure 11. Stepwise ecosystem accounting process following the extended SEEA-EA methodology presented in De Valck et al. (2023).

De Valck et al. (2023) justify their integrated approach by emphasising the need for a comprehensive understanding of the full range of benefits from all coastal and marine uses and users. They argue that assessments considering multiple values from diverse frameworks are more likely to yield sustainable management outcomes. The extended SEEA-EA framework proposed aims to integrate non-market and FNP values into the traditional market-based valuation approach, ensuring a more inclusive and holistic valuation of ecosystem services. While its exclusion of non-use values may present a limitation, the extended SEEA-EA framework is laudable for its ability to provide a consistent system of measurement across time and space, promoting comparability and detailed assessment of all beneficiaries of ecosystem services.

4.1.1.2 Characterising the values of the GBR

The conceptual figure below (Figure 12), adapted from the conceptual frameworks discussed above, presents a comprehensive view of the multidimensional complexity of GBR values. Figure 12 offers a multi-layered perspective on the values associated with the GBR. It illustrates how different value sets are identified, transformed, and integrated within the context of the GBR's ecological, cultural, social, and economic dimensions. At the heart of the framework is the GBR itself, represented symbolically by a coral reef, indicating the natural unit where ecological, cultural, economic, and social factors converge. This central motif is encircled by arrows that signify the cyclical and interconnected nature of these factors, which are continuously influencing and shaping the values derived from the GBR. The four pillars or corners of the central diagram correspond to the four areas of focus in the study, with arrows depicting how values are defined and gates representing the stages values pass through before becoming relational values.

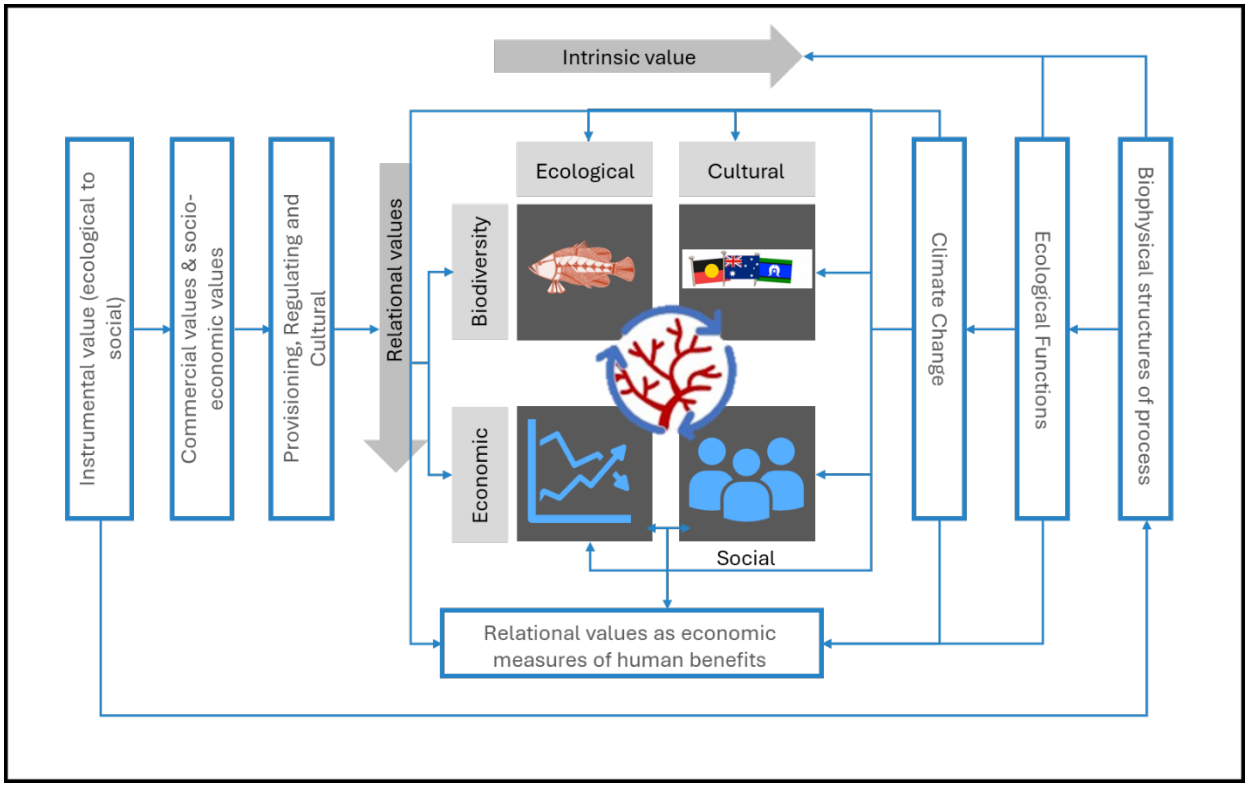


Figure 12. Conceptual framework adapted to represent a better understanding of the ways of valuing the GBR for Question 1.1. The figure represents what to consider when working to understand the multidimensional complexity of GBR values. From left to right – shows how our instrumental value- that is the value people gain from the GBR ecosystem, and the ways that being in and witnessing nature brings people pleasure. The symbol in the middle identifies the GBR through a coral reef and the cyclical ways in which the four components of ecological, cultural, economic and social values are integrated. Reading from the right the biophysical system, and intrinsic value pertains to the value of the inherent object, where natural values are independent of people. The addition of climate change in the biophysical columns shows that climate change impacts on the foundational components and how the values of those components interact to work with and against each other.

The left side of the diagram identifies a spectrum of values ranging from instrumental to intrinsic. The arrows flowing from these values towards the centre indicate the process of integration and the transformation of these values into relational ones, which can be seen as economic measures of human benefits. This reflects a deeper understanding of value that goes beyond monetary terms to include the relational aspects that people have with the GBR. The right side of the diagram introduces the intrinsic value and biophysical structures or processes, including climate change. The diagram's framing of the GBR's values within the context of climate change underscores the urgency of understanding and mitigating its impacts. It also suggests that the values ascribed to the GBR are not static; they evolve as the natural system changes and as societal values and economic systems adapt.

In recognition of this framework, the description of GBR values provided below captures the themes and characteristics by grouping to frame a discussion on the relational integration between ecological, economic, social and cultural values to describe the values of the GBR. As recognised in Figure 12, social values are also integrated within each grouping.

Ecological values

From an ecological perspective, the concept of value relates to the diversity and quantity of biodiversity in the GBR, including[10]:

- 70 'bioregions' comprising 30 reef bioregions and 40 non-reefal bioregions.
- 450 types of hard corals.
- At least 1,000 species of soft corals and sea pens.
- More than 100 species of jellyfish.
- Over 6,000 varieties of molluscs.
- More than 1,000 species of worms.
- 1,625 types of fish.
- 14 types of sea snakes.
- 6 species of marine turtles.
- 20 nesting species of seabirds.
- 41 species of shorebirds.
- Over 1,300 species of crustaceans.
- 630 species of echinoderms.
- At least 2,500 species of sponges.
- 136 varieties of sharks and rays.
- More than 30 species of whales and dolphins.

The GBR is a complex and diverse ecosystem that not only supports a vast array of marine life, including endangered and threatened species, but it also provides a vast array of ecosystem services, and related livelihoods for GBR communities. However, the GBR ecological value can be impacted by stressors and pressures, including from climate change (Question 2.2, Fabricius et al., this SCS), poor water quality including sediments and particulate nutrients (Question 3.2, Collier et al., this SCS), dissolved nutrients (Question 4.2, Diaz-Pulido et al., this SCS), pesticides (Question 5.1, Negri et al., this SCS) and other pollutants (Question 6.1, Chariton & Hejl, this SCS) and the coral-eating crown-of-thorns starfish (Question 4.3, Caballes et al., this SCS). Threats to the GBR include climate change, coastal degradation, loss of functionality and processes, and poor water quality which affect various habitats among a range of direct uses which can be important at local scales (Question 1.2/1.3/2.1, McKenzie et al., this SCS).

Economic values

From an economic perspective, the concept of value relates to what people will trade off to directly or indirectly enjoy services provided by the GBR, or to maintain its non-use values. Some of the direct use values can be assessed from market prices and estimates of use (e.g., visitation data). Rolfe and De Valck (2021) provide a comprehensive review and synthesis of over 40 economic valuation studies conducted in the GBR since 1985. They note that measures of value are not always in the same terms, with 23 studies assessing consumer surplus estimates, six studies assessing producer surplus and 15 studies that estimated gross financial values or other measures of industry size and activity. For example, the gross financial value of tourism, recreational activities and commercial fishing combined within the Marine Park (plus tourism in the adjoining catchment area) has been previously estimated to exceed AU$5.4 billion per annum and generate some 66,000 jobs (Deloitte Access Economics, 2017).

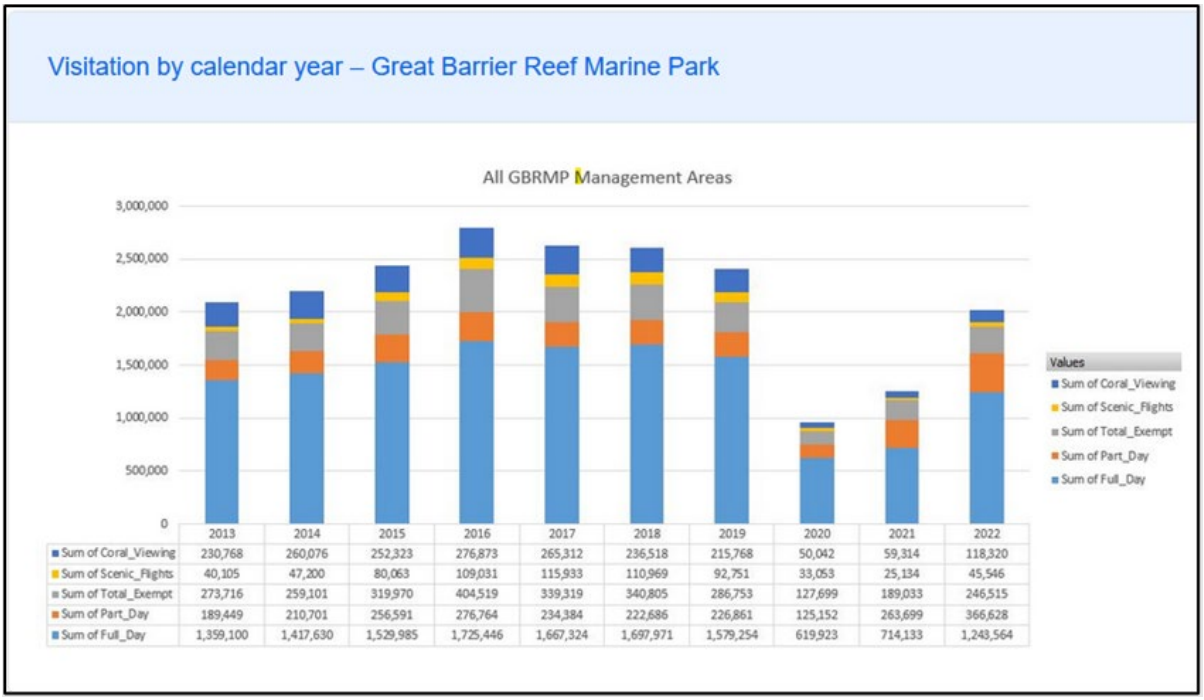
Estimates of total expenditures

Total annual expenditures on tourism were estimated by Rolfe and De Valck (2021) from 10 studies at an average of $4.3 billion per annum. At the time of the 2017 SCS (Deloitte Access Economics, 2017;

[10] See https://www2.gbrmpa.gov.au/learn/reef-facts

Eberhard et al., 2017), the annual level of commercial activity related to the GBR was estimated at $2.9 billion in the GBR regions and $6.4 billion in Australia overall, driven largely by tourism, and the economic value of agricultural production in the GBR catchment was about half of that (Deloitte Access Economics, 2017). However, the back-to-back bleaching events of 2016 and 2017 and the COVID-19 health pandemic have had an effect on tourism and the economic values of the GBR through reduced visitation rates.

In 2022, visits by tourists across the entire GBR Marine Park were reported at approximately two million total visitor days (2,020,573), an improvement in 2020 and 2021, but below the peak visitation rate of 2016 (Figure 13). The location and intensity of "on-reef" tourism mapped in Spalding et al. (2017) also corresponded to findings from GBRMPA that over 80% of tourism to the GBR took place in only 7% of the region (near Cairns and Whitsunday) (GBRMPA, 2023; Spalding et al., 2017).



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Sum of Coral_Viewing	230,768	260,076	252,323	276,873	265,312	236,518	215,768	50,042	59,314	118,320
Sum of Scenic_Flights	40,105	47,200	80,063	109,031	115,933	110,969	92,751	33,053	25,134	45,546
Sum of Total_Exempt	273,716	259,101	319,970	404,519	339,319	340,805	286,753	127,699	189,033	246,515
Sum of Part_Day	189,449	210,701	256,591	276,764	234,384	222,686	226,861	125,152	263,699	366,628
Sum of Full_Day	1,359,100	1,417,630	1,529,985	1,725,446	1,667,324	1,697,971	1,579,254	619,923	714,133	1,243,564

Figure 13. GBR Marine Park data on number of visitors to view coral reefs on the GBR; scenic flight tourists in 2022. Source GBRMPA Tourism Visitation Data[11].

Other total expenditure estimates reported by Rolfe and De Valck (2021) included commercial fishing at $200 M yr^{-1}, recreation at $370 M yr^{-1}, and scientific research at $72.5 M yr^{-1} (all in 2019 dollar equivalents).

Economic surplus values

In contrast to the studies that measure gross values of economic activity by industry in the GBR, other studies have assessed economic surpluses, such as consumer surplus and producer surplus, which are suitable for economic evaluation and cost benefit assessments (Rolfe & De Valck, 2021).

Rolfe and De Valck (2021) identified 11 studies that valued recreation in the GBR, with consumer surplus per trip ranging from $25 to $1,312, although studies with very high estimates were often based on poorer quality data. There was some evidence that recreation was sensitive to environmental conditions, with trip values decreasing with factors such as crowding or poor water

[11] Tourism Visitation Data

quality. Producer surplus values were identified from eight studies, with average producer surpluses for the tourism sector ($247.1M) being 6.6 times higher than the average estimate for the recreation sector ($37.2M) and 19 times higher than for the commercial fishing sector ($12.9M).

Rolfe and De Valck (2021) report that very few studies have attempted to assess the indirect use values related to the GBR, and that it is difficult to reconcile values between studies. For example, Stoeckl et al. (2014) used a life satisfaction approach to assess benefits across 18 community-defined ecosystem service categories at $22.3 billion per year across the GBR, while De Valck and Rolfe (2018) generated an annual value of $3.6 billion by summing estimates of consumer and producer surplus generated by coral reefs, seagrass and mangrove ecosystems in the commercial fishing, tourism and recreation sectors.

A large number of studies that assess non-use values were identified by Rolfe and De Valck (2021), with the earliest conducted in 1987. The most relevant are a series of discrete choice valuation exercises asking Australian households for their willingness to pay to maintain the GBR in good condition. Rolfe and De Valck (2021) summarise the average Australian household would be willing to pay $30.15 yr^{-1} for each 1% improvement in reef condition.

Cultural-Biocultural and Indigenous Heritage values

The 2017 SCS recognised the importance of Indigenous values and benefits to communities and management agencies (Waterhouse et al., 2017). Traditional Owners have long had a continuing relationship with the GBR and its catchment stretching back over 65,000 years. The 2022 State of the Environment Report recognises the role of Indigenous peoples in better managing the GBR and enhancing the values of Traditional Owners who care for their sea Country and benefit from the use of the GBR's resources and places of cultural significance (Commonwealth of Australia, 2021b).

More than 70 Traditional Owner clan groups keep connection to sea Country within the World Heritage Area (GBRMPA, 2019). Traditional use of marine resource agreements (TUMRA) is broad and includes undertaking lawful activities, as part of Aboriginal and Torres Strait Islander peoples' customs or traditions to satisfy personal, domestic or communal needs. Traditional use of marine resources is important to Traditional Owners and continues long-established Indigenous heritage traditions. It includes fishing, collecting (for example, shellfish), hunting (or harvesting), and looking after Indigenous heritage places. Many Aboriginal and Torres Strait Islanders undertake traditional use of marine resources to practice 'living maritime culture', provide traditional food for families and educate younger generations about traditional rules and protocols (GBRMPA, 2019).

Connections to place, identity and sense of place is at the heart of Indigenous culture. Connectivity within a broader Aboriginal and Torres Strait Islanders relationship to nature, including transcendental values, is often poorly addressed in environmental assessments and planning processes, to the exclusion of Indigenous knowledge (Hernández-Blanco et al., 2022).

Being on Country goes beyond a static view of 'nature' in understanding the biophysical elements of sense of place, to engage with how dynamic ecosystems influence place meaning and attachment. Only by being in the GBR catchment area, and on Country will there be understanding of connectivity and spiritual connection with Country, where people "Connect to ancestors through Country" and "Do a lot of thinking and reflection when on Country" (Stoeckl et al., 2021).

Social and place based values

Relational values include the relationships between people and nature, as well as relationships that are between people but involve nature. Examples of individual relational values include sense of place, where the place is important to the person (individual identity) and looking after the place gives a sense of worth and good life for the person. The CSIRO-led Social Economic Long-Term Monitoring Program (SELTMP) project found that more than two thirds of people surveyed identified

a sense of wellbeing from their experience of physically connecting with the GBR. The data found that:

- 64% felt an intrinsic value when connecting with people to interact and share the wonderful experience of the reef with was the main benefit.
- 57% enjoyment for leisure purposes.
- 45% focus on aesthetics, by enjoying the beauty of the natural marine environment.
- 30% of tourism operators gained educational value by 'contributing to the education of people that you takeout' (30%).
- 23% of tourism operators found 'satisfaction in running an exciting and fun business professionally' (Biggs et al., 2012; Curnock et al., 2023).

However, when values are challenged, such as through a bleaching event that can impact GBR habitats such as coral reefs, tourists 'protective sentiment' is "heightened after a notable climate impact, while their sense of self-efficacy diminished" (Curnock & Marshall, 2019). A person's value sets, how they value the world, can be heightened if a person's sense or desire for pleasure is disrupted.

Responses can range from 'Reef grief' -associated emotive responses (sadness, anger, and fear) that tourists express empathy for the icon through increased ratings of place values, identity, and protective sentiment (Curnock & Marshall, 2019). Values for protection and sentiment can also transfer to support for global environmental protection, often a narrative which underpins the World Heritage system (Davey & Gillespie, 2014).

The 'sense of place' concept has the potential to bridge the gap between the science of ecosystems and their management by recognising that people are part of the ecosystem and vice versa (Larson et al., 2013b), and this can be heightened with local knowledge and lived experience (Goldman & Pabari, 2021; Reed et al., 2018; Reed & Rudman, 2022). 'Sense of place' involves an "emotional bond that people have with a specific place" (van Putten et al., 2018), and refers to individual identity – a key component of the GBR more broadly with 73% of Australian residents claiming the GBR belongs to their Australian identity (Commonwealth of Australia, 2021b). Although further work is required to identify any GBR specific connections between local knowledge and the concept of sense of place.

4.1.2 Recent findings 2016-2022 (since the 2017 SCS)

The distribution of the articles across two time periods, 1990-2016 and 2017-2022, reveals interesting trends in the research focus. During the earlier period of 1990-2016, 49 articles were published, accounting for approximately 58% of the total reviewed articles. Between 2017 and 2022, a further 36 articles, constituting approximately 42% of the total reviewed, were published. The surge in research in the period 2017-2022, which spans five years only, reflects an escalating interest in the GBR's values. This trend was likely spurred by the unprecedented back-to-back bleaching events (2016/17), heightened research into water quality (i.e., SCS 2017) and sustainable farming, an increase in socio-ecological studies, and a growing public consciousness about environmental issues and climate change impacts. Moreover, the period 2017-2022 saw augmented government investment in conservation efforts, advancements in coral reef restoration science, and the rise of citizen science initiatives.

These data suggest that the back-to-back bleaching events (2016/17), increasing impacts from climate change and local stressors, and associated implications for the outstanding universal value of the GBR as a World Heritage Area (Pocock, 2021), may have led to more articles and reports investigating the economic, but also the cultural and intrinsic values of the GBR. New terms have emerged such as 'Reef Grief', a concept that identifies the emotional response to the well-documented and publicised degradation of the GBR (Marshall et al., 2019b). However, there still remains a low level of output that directly address Indigenous value systems and the GBR, and that is an omission that requires urgent action.

4.1.3 Key conclusions

The GBR embodies a diverse array of values including ecological (including biological), social, economic and cultural (including Indigenous and non-Indigenous) heritage values, as recognised by its outstanding universal value as a World Heritage Area. The values and benefits generated by the GBR are multifaceted and intertwined. Values range from tangible commercial benefits like tourism, recreation and commercial fishing, to cultural aspects, including Indigenous heritage and identity. Many benefits are enjoyed directly, including recreational activities such as snorkelling, diving, and boating, that enrich people's wellbeing and lifestyle. The GBR also generates a range of indirect and non-use benefits, including the intrinsic value of its existence, aesthetic, lifestyle, protection, educational and research outcomes.

Quantifying the benefits of the GBR is complex given the large number of factors involved and diversity of stakeholders. Financial investments, regulatory instruments, policy and management decisions are typically informed through the assessment of values, and these values can vary across the GBR region depending on location, demographics and the benefits being assessed. A number of threats to the values of the Great Barrier Reef have been identified, though climate change is recognised as the most significant. This question reviewed the current evidence of the ecological, social, economic and cultural values of the GBR and the underlying associated intrinsic values. Information on these values provides critical context for understanding the importance of the evidence presented in the 2022 SCS including the distribution, impact and management of land-based pollutants that influence water quality in the GBR.

4.1.4 Significance of findings for policy, management, and practice

The GBR generates a wide range of attributes to multiple stakeholders, including those from regional, national and international locations. Direct use values for tourism, recreation and commercial fishing are important, and provide major economic flow-on benefits at the regional, state and national levels. However, it is likely that the indirect and protection (non-use) values of the Australian and Global population are even more significant, consistent with the GBR being a nationally and internationally iconic asset, as per its outstanding universal value as a World Heritage Area. The extent of recognition and values for the GBR mean that Australians and the international community are sensitive to potential threats and losses, with evidence of high values for ongoing protection.

This synthesis has revealed that a more comprehensive approach to identifying and valuing the benefits of the GBR, one that extends beyond economic considerations, would greatly benefit policymakers. The potential impact of the COVID-19 pandemic on GBR benefits and values is also noted, indicating the need to update data on the aesthetic, social, ecological, and intrinsic values at both local and broader GBR levels.

The loss of ecological and cultural values may have severe consequences, particularly for Indigenous communities, generating requirements for further work on ways to integrate Traditional Knowledge systems and cultural heritage that will build both resilience and better inform governance models. Addressing deficits in socio-ecological and economic information to build trust in management processes is important. Finally, the synthesis emphasises the connection between the values of the GBR and Australia's identity, suggesting that further loss of values may affect public trust in the government's ability to effectively manage the GBR.

For practitioners and researchers, this synthesis of evidence reveals the diverse values of the GBR including ecological, economic, cultural, and social dimensions. The review identifies a key knowledge gap in integrating Indigenous perspectives into management practices, research and decision support systems.

4.1.5 Uncertainties and/or limitations of the evidence

There has been limited attention given to Indigenous values in studies on the GBR, highlighting a significant gap in understanding the cultural and socio-ecological significance of the GBR. The literature emphasises the deep connections Indigenous communities have with the GBR, encompassing cultural, spiritual, and historical dimensions. The absence of Indigenous perspectives may result in an incomplete portrayal of human relationships with the GBR, neglecting valuable insights from traditional ecological knowledge.

An additional issue is that many studies assessing uses, benefits and values are now dated, indicating the need for more updated research to align with present-day values and conservation efforts for the GBR. The reliance on 2016 data for estimations of economic use values is highlighted, emphasising the need for updated information that considers post-bleaching events and the effects of the COVID-19 pandemic on a larger scale. Despite a surge in publications related to assessment, evaluation or review of GBR values post-2017, economic studies continue to dominate, further emphasising the need for a more diverse approach that is inclusive and considers the relationships between GBR value sets.

4.2 Contextual variables influencing outcomes

The values of the GBR are influenced by a very wide range of factors, some of which are captured in the synthesis above, therefore, contextual variables were difficult to characterise for this question. Relevant contextual variables include environmental factors, including climate change; social, political; and economic factors such as global markets. These variables also operate across a range of scales from individuals to communities, to industries and global scales for factors such as climate change, pandemics and markets. Table 7 identifies potential variables associated with climate change as examples.

Table 7. Examples of contextual variables for Question 1.1.

Contextual variables	Influence on question outcome or relationships
Climate change	Perceived values could alter when the GBR has more media attention, often following an event such as bleaching or election cycles (Konkes & Foxwell-Norton, 2021; Newlands et al., 2021).
Climate change	Values and public understanding can be amplified during certain periods. (Ridd, 2020; Tranter & Foxwell-Norton, 2021).
Dramatic changes to the ecological system	Changes in ecological values due to climate change impacts could have impacts on cultural, social and economic values.

4.3 Evidence appraisal

Relevance

The evidence appraisal of the literature on GBR values, identified an overall relevance rating of High (7 out of 9). This rating indicates that most of the articles were highly relevant in addressing the question and provided substantial insights into the socio-ecological, cultural, economic, and intrinsic values of the GBR.

The relevance of the body of evidence to the question was rated High for 49 studies, Moderate for 30, and Low for 6 study. This large number of highly relevant studies underscores the importance and depth of the research conducted on the values of the GBR. The spatial relevance was predominantly High (2.5/3.0), indicating broad coverage of the GBR. However, the temporal relevance of the body of evidence was lower (rated Moderate) (1.9/3.0).

Consistency, Quantity and Diversity

The body of evidence consisted of 85 studies, which is considered to be a High number of studies in addressing the question on the values of the GBR.

The consistency of the body of evidence is considered to be High, particularly within the economic and ecological domains.

The diversity of study designs is considered to be High, including observational (62%), theoretical (3%), experimental (5%), modelling (11%), and review studies (19%), contributing to an assured understanding of GBR values.

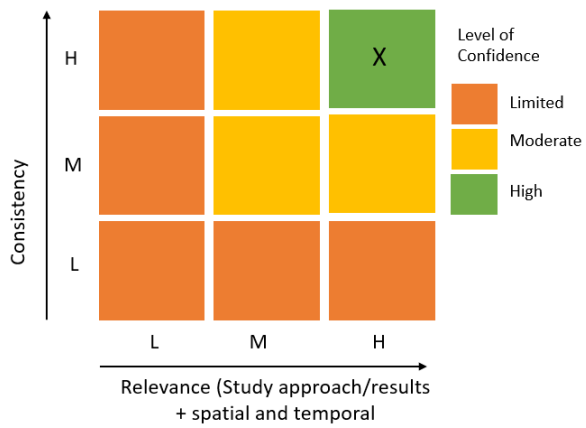
Confidence

The overall confidence in the body of evidence used to answer the primary question about the ecological, social, economic and cultural values of the GBR is High. This high confidence rating is based on the evidence appraisal results, which consider relevance and consistency, and are supported by characteristics of the quantity, and diversity of evidence. The ratings for relevance indicate that a majority of the articles were highly relevant to the question, while the spatial and temporal relevance ratings demonstrate the applicability of the findings to the GBR context.

The consistency of the evidence, particularly in the economic and ecological domains, supports the overall confidence in the body of evidence. The quantity of articles provides a representative sample of the available research. The diversity of evidence, encompassing a range of study designs, contributes to a comprehensive understanding of the GBR's values.

Considering the evidence appraisal results, the High confidence rating in the confidence matrix (Table 8) reflects the robustness and quality of the body of evidence used to answer the question. This high confidence level supports the findings and conclusions drawn from the evidence synthesis and provides a strong basis for informing policy, management, and future research on the values of the GBR.

Table 8. Summary of results for the evidence appraisal of the whole body of evidence in addressing Question 1.1. The overall measure of Confidence (i.e., Limited, Moderate and High) is represented by a matrix encompassing overall relevance and consistency.

Indicator	Rating	Overall measure of Confidence
Relevance (overall)	High	
-To the Question	High	
-Spatial	High	
-Temporal	Moderate	
Consistency	High	
Quantity	High (85 studies)	
Diversity	High (62% observational, 3% theoretical, 5% experimental, 11% modelling and 19% review studies	

4.4 Indigenous engagement/participation within the body of evidence

Of the 85 studies included in the body of evidence, 23 included some acknowledgement of Indigenous values or participation. Since 2017, measured approaches to integrating Traditional Knowledge into western science and GBR management decision making processes has increased, including the *Strong Peoples – Strong Country (2019) Indigenous monitoring program,* which takes steps to improve the consideration of Indigenous values, connecting the health of the GBR and its catchment to the quality of life enjoyed by Traditional Owners[12]. Providing a Traditional Owner led approach, the program reflects a worldview underpinned by the symbiosis of land and sea Country. However, the available literature acknowledges that more work and methodologies are needed to improve our understanding of Indigenous values, while it also acknowledges the limitations in existing valuation methods for assessing biocultural values. This suggests that further research and development of valuation methods are needed to better understand and incorporate Indigenous and cultural values in the management of the GBR.

4.5 Knowledge gaps

A summary of knowledge gaps for Question 1.1 is presented in Table 9.

Table 9. Summary of knowledge gaps for Question 1.1.

Gap in knowledge (based on what is presented in Section 4.1)	Possible research or Monitoring & Evaluation (M&E) question to be addressed	Potential outcome or Impact for management if addressed
Greater understanding of values across different groups, communities, and management plans	What are the alternative methods to measure biodiversity and socio-ecological values of the GBR and its catchments (e.g., biodiversity credits, Nature credits and others for net zero results)?	Policy makers can make better informed decisions based on up-to-date data.
How climate change impacts affect people's values.	Inclusion of values and climate change impacts into biophysical and non-biophysical studies.	Adaptive governance and management practices.
How Indigenous values can be 'measured' in a way to be more reflective of Traditional environmental practices.	Work with Traditional Owners and elders to identify ways to share knowledge with dignity.	Great weaving together of knowledge systems.
Understanding of value concepts on people's economic security and sense of wellbeing, particularly in the context of climate change impacts.	Further research with qualitative and quantitively data.	A common understanding of GBR values.
How scientists, researchers and managers define 'value'. In many ways, the definition is often too narrow, focusing on economic value only.	A typology of the term 'value' and the GBR and a program to reach consensus from all major GBR stakeholders.	An agreed typology of 'value' for the GBR across sectors that includes many of the categories in

[12] Strong People – Strong Country Indigenous Heritage Monitoring Framework Summary Report

Gap in knowledge (based on what is presented in Section 4.1)	Possible research or Monitoring & Evaluation (M&E) question to be addressed	Potential outcome or Impact for management if addressed
		SELTMP and the literature presented here.
The impact of the COVID-19 pandemic on peoples' values of the GBR - especially aesthetics	What are the impacts of the pandemic on GBR values (biocultural and economic value)?	Further research beyond SELTMP through the Reef 2050 Integrated Monitoring and Reporting Program (RIMReP) and other programs to evaluate the impact of the pandemic and lessons learnt for future pandemics.
A lack of integration of Indigenous values into water quality, policy development, inclusion and equity decision making process, resources, functionality and process.	How can we better integrate Traditional environmental knowledge into GBR management and governance to ensure equity and inclusivity?	Collaborative, integrated research between Traditional environmental knowledge and existing scientific data to monitor and evaluate more ways of integration into GBR management.
Peer reviewed academic social science articles. GBR publications on value spiked in 2017 (13), which mainly consisted of grey literature, and the prominence of economics continues to rise.	How can we increase our socio-ecological knowledge, in the face of climate change, to help communities to adapt?	More data on values will better help prepare governments and non-government organisations to plan for the oncoming impacts of climate change.
Greater research is needed to find methodologies that map sustainable values and benefits.	How can biocultural relationship be protected?	See above

5. Evidence Statement

The synthesis of the evidence for **Question 1.1** was based on 85 studies undertaken predominantly within the Great Barrier Reef region and published between 1990 and 2023. The synthesis includes a *High* diversity of study types (62% observational, 11% modelled, 5% experimental, 3% theoretical and 19% reviews), and has a *High* confidence rating (based on *High* consistency and *High* overall relevance of studies).

Summary of findings relevant to policy or management action

The Great Barrier Reef embodies a diverse array of values including ecological (including biological), social, economic and cultural (including Indigenous and non-Indigenous) heritage values. Its outstanding universal value is formally recognised through the declaration of the Great Barrier Reef as a World Heritage Area in 1981. The values and benefits generated by the Great Barrier Reef are multifaceted and intertwined. Values range from tangible commercial benefits like tourism, recreation and commercial fishing, to cultural aspects, including Indigenous heritage and identity. Many benefits are enjoyed directly, including recreational activities such as snorkelling, diving, and boating, that enrich people's wellbeing and lifestyle. The Great Barrier Reef also generates a range of indirect and non-use benefits, including the intrinsic value of its existence, aesthetic, lifestyle, protection, educational and research outcomes. Quantifying the benefits of the Great Barrier Reef is complex given the large number of factors involved and diversity of stakeholders. Financial investments, regulatory instruments, policy and management decisions are typically informed through the assessment of values, and these values can vary across the Great Barrier Reef region depending on location, demographics and the benefits being assessed. A number of threats to the values of the Great Barrier Reef have been identified, though climate change is recognised as the most significant.

Supporting points

- The Great Barrier Reef is a complex and diverse ecosystem that supports a vast array of marine life including fish, corals, turtles, dugong, whales, and many other life forms. It encompasses 70 ‘bioregions’ (30 reef bioregions and 40 non-reefal bioregions) and it is home to thousands of species, including many endangered and threatened species, making it important for ecosystem biodiversity. The Great Barrier Reef and its catchment area also provides many ecosystem services and related livelihoods for Great Barrier Reef communities.
- Different conceptual frameworks are available to depict the complex relationships between ecological and human systems which categorise the flow of uses, benefits and services in different ways, informing concepts of value. The Total Economic Value framework and Ecosystem Services framework are two of the main approaches that have been applied. More recent approaches place greater emphasis on the relationships between people and ecosystems and how the condition and perceptions of the Great Barrier Reef can impact on those.
- Previous (pre-pandemic) economic analyses show that the Great Barrier Reef generates billions of dollars annually through tourism, fishing, research and recreational activities. It supports approximately 64,000 direct and indirect jobs and attracts over two million visitors each year who contribute to the local and national economies through spending on accommodation, trips to the reef, and other services. However, there is a need for updated economic information that considers the economic, social and cultural implication of bleaching events and the economic effects of the COVID-19 pandemic on a larger scale.
- Australians, even those who do not use it directly, place great value on the Great Barrier Reef, and broadly support efforts to ensure the maintenance and continuation of its existence,

aesthetic and other intrinsic benefits. Further loss of values may affect public trust in the government's ability to effectively manage the Great Barrier Reef.

- Cultural heritage values, particularly the Indigenous values of Aboriginal and Torres Strait Islander peoples and their connection with traditional lands and waters are significantly important. The Great Barrier Reef has deep spiritual, cultural, and historical significance to these communities, having been at the heart of their culture and way of life for thousands of years, supplying sustenance, cultural practices, and connections to ancestral lands.
- The low level of Indigenous participation in studies on the values of the Great Barrier Reef is identified as a gap, and there is a need for further research into methodologies that incorporate Indigenous values into established models.
- There are knowledge gaps in the understanding of value concepts, particularly how scientists and researchers define 'value.' The evidence suggests that the development of a typology of Great Barrier Reef values that considers different perspectives and cultures would be helpful to define those values.
- The health of the Great Barrier Reef has an important impact on people's economic security and sense of wellbeing, and the connection between value, health and wellbeing is critically important, particularly in the context of the threats impacting its outstanding universal value.

6. References

The 'Body of Evidence' reference list contains all the references that met the eligibility criteria and were counted in the total number of evidence items included in the review, although in some cases, not all of them were explicitly cited in the synthesis. In some instances, additional references were included by the authors, either as background or to provide context, and those are included in the 'Supporting References' list.

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Appendix 1: 2022 Scientific Consensus Statement author contributions to Question 1.1

Themes 1 and 2: Values, condition and drivers of health of the Great Barrier Reef

Question 1.1 What are the socio-ecological, cultural, economic, and intrinsic values of the Great Barrier Reef?

Author team

Name	Organisation	Expertise	Role in addressing the Question	Sections/Topics involved
1. Maxine Newlands	James Cook University	Environmental social science; policy; Reef social science	Lead author for Q1.1	All sections.
2. Oluwatosin Olayioye	James Cook University	Environmental scientist; governance	Second author for Q1.1	All figures and tables, data extraction sheet, part of writing up, editing, data analysis, evidence appraisal and all other sections.