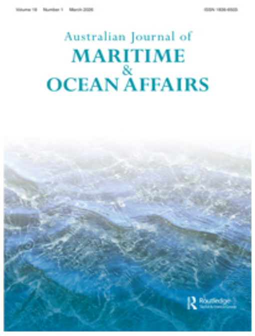

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Integrated ocean management: national science and governance priorities for Australia's marine estate

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ABSTRACT

Integrated Ocean Management (IOM) is an approach that links planning, decision-making and management arrangements across sectors in a unified framework, to enable a more comprehensive view of sustainability and the consideration of cumulative effects and trade-offs. As pressures on marine systems intensify, implementing effective IOM becomes increasingly critical for ensuring Australia's increasingly crowded marine estate remains healthy and productive for future generations. For Australia to successfully utilise IOM it must overcome many challenges associated with the scale of its marine ecosystems, which are highly interconnected, multifaceted (multi-species, multi-use, multi-stakeholder) and multi-jurisdictional. This is not an insurmountable task, but it does requires sustained commitment to coordination and integration; additional research to inform policy, including better tools for evaluating complex allocations, trade-offs and cumulative effects; effectively engaging stakeholders at scale; stronger legal and institutional frameworks for coordination; building capacity for implementation; robust monitoring systems to assess outcomes and enable adaptive management; and adaptive approaches that can respond to new information and changing conditions. In this paper we lay out the pathway to IOM in Australia, including priority milestones to 2030.

KEYWORDS

Integrated ocean management; Australia; marine estate; priorities

Introduction

Australia's marine estate is defined by the world's third-largest marine territory, spanning tropical to Antarctic waters, with multiple jurisdictions and many separately managed

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sectors. These waters support all manner of marine activities that together generated $229 billion economic output in 2022–2023 (approximately 9.1% of Australia's GDP), supporting over 712,000 jobs (AIMS 2025). The value is more than monetary however, as Australia's marine waters are culturally significant for Australia's First Nations and wider communities.

Similar to many marine regions, Australia's marine estate is under mounting pressure from existing and emerging activities (Laubenstein et al. 2022), compounded by climate change impacts (Commonwealth of Australia 2024), and the need to conserve biodiversity and maintain ecosystem functionality to ensure that the ocean continues to provide the many benefits it provides to society. The identification of threats in Australian waters has increased over time, with the identification and evaluation of 'threats from use and extraction' rising most rapidly over the last decade (Laubenstein et al. 2022).

Traditional ocean management approaches have operated amid a lack of knowledge of ecosystem function, complexities of overlapping jurisdictions, inconsistent governance and/or differing resource use policies and allocation of resources within sector-specific frameworks (Stephenson et al. 2023) with a lack of integrated governance across portfolios/sectors and jurisdictions. There are currently over 200 pieces of legislation relevant to Australia's marine activities, but the current siloed approach to ocean is inadequate to address the rapid growth in ocean uses and the complex interplay between human activities and marine ecosystems (Stephenson et al. 2019). This is because this approach to ocean management lacks mechanisms for coordination or to achieve balanced outcomes across the many diverse objectives of the actors involved (Winther et al. 2020).

Integrated Ocean Management (IOM) is a comprehensive approach that brings together multiple sources of knowledge and aims to balance multiple stakeholder interests and values to ensure sustainable use of marine ecosystems (Stephenson et al. 2019). It links planning, decision-making and management arrangements across sectors in a unified framework to address cumulative effects, protect biodiversity, support economic development, and maintain ecosystem services. Effective integration seeks to align or reconcile competing objectives at multiple scales and levels (e.g. Thebaud and Boschetti 2024; Stephenson and Hobday 2024). This includes recognising trade-offs and reconciling the different social, economic, cultural and environmental goals and objectives of ocean users or sectors (normative integration), the regulatory or practical management arrangements for individual sectors or stakeholders (applied integration), and the integration of scientific data or knowledges (empirical integration) (Vince et al. 2024). Adopting IOM in Australia is essential to achieving ecologically sustainable use and conservation of Australia's marine ecosystems amid their escalating and cumulative human pressures, climate change, and competing sectoral interests.

The following sections synthesise information on the IOM approach, set IOM within an Australian context, identifies critical needs for successfully delivery and lays out a pathway to implementation, including priority milestones over the next two decades.

Dimensions of integration

Delivering IOM requires coordination and partnership leading to integration in a number of dimensions:

1. Integrating values, norms and objectives

Successfully and equitably addressing competing interests – including stakeholder preferences relating to resource allocation, economic development and long-term environmental sustainability – remains a fundamental hurdle for management (Haugen et al. 2024). Effective IOM processes seek to create a foundation of shared values and objectives that ground decision-making, exploring where and why conflicts might occur (Stephenson and Hobday 2024) and thereby reducing them by involving those who will be affected in developing solutions and alternatives. This requires robust stakeholder and Traditional Custodian engagement, partnerships and co-management processes from the outset and throughout IOM processes (Brooks et al. 2020).

2. Integrating sectoral and stakeholder management arrangements

IOM is generally focused on producing a policy outcome that balances resource allocation and access across multiple sectors, stakeholders or rightsholder groups and interests (Figure 1). Key management approaches used in IOM include marine zoning and protected areas, establishing and coordinating access rights, licensing frameworks and regulatory controls, and supporting monitoring and knowledge sharing programs. Established processes like Marine Spatial Planning (Douvere 2008) and Integrated Coastal Zone Management (Olsen 2003) are examples of practical tools used to implement IOM (Stephenson et al. 2021). Practicality and flexibility will need to have primacy when applying

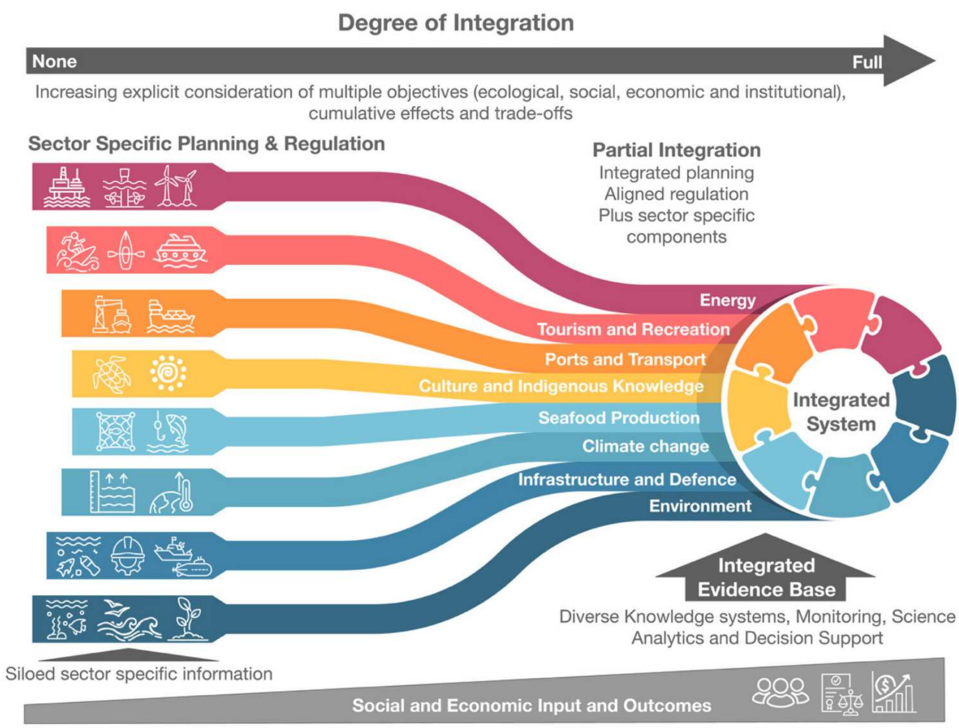

Figure 1. Integrated Ocean Management seeks to harmonise use of ocean spaces across multiple sectors. The fundamental challenges for the successful implementation of IOM lie in optimising resource allocation across various competing interests, recognising potential immediate economic gains while ensuring long-term environmental sustainability.

IOM in Australia, where the marine estate spans the tropics to the poles and needs to accommodate activities regulated in multiple jurisdictions (Vince et al. 2024).

3. Integrating data, knowledge and information

The implementation of IOM relies on evidence-based decision-making supported by various tools and mechanisms that drive adaptive management (Stephenson et al. 2021; Vince et al. 2024; Figure 1). This involves collecting and analysing data on marine ecosystems, resource usage patterns, and socioeconomic outcomes and impacts to inform policy development and management strategies (Heenan et al. 2016). Care needs to be taken to avoid privileging specific data sources, which can marginalise specific disciplines, as well as social and cultural values (Fischer et al. 2022; McKinley et al. 2022). Instead, approaches used should make coordinated and collaborative use of all available knowledge to inform the applied policy development and management strategies (Brooks et al. 2020). Where there is absence of sufficient knowledge, application of the Precautionary Principle is warranted (Kriebel et al. 2001).

Current stakeholder engagement may occur through established partnerships and co-management arrangements between management agencies, industry, and community groups, formal consultation processes, and community and industry-based monitoring programs (Cvitanovic et al. 2015a). However, engagement levels vary significantly across regions and sectors and can also be transitory if connected to time-bound projects. Engagement could be substantially improved through the development of more structured and sustained linking mechanisms and governance across portfolios/sectors and jurisdictions (Lockwood et al. 2010). Such links facilitate knowledge exchange throughout the engagement process (Cvitanovic et al. 2015a).

Indigenous perspectives are included in several ways in current marine management initiatives, such as via formal consultation (Hill et al. 2012), co-management processes (Yunupingu and Muller 2009; Rist et al. 2019), traditional knowledge incorporation into management frameworks (Nursey-Bray et al. 2019), through to Indigenous-led and implemented marine management (Hill et al. 2012). Examples include the Traditional Use of Marine Resources Agreements (TUMRAs), Indigenous Protected Areas (IPAs), and Sea Country Plans (Rist et al. 2019). The stepped Three-category approach, which provides a framework for understanding and respecting the different levels of engagement (Australian Government 2022), and the 'Our Knowledge, Our Way' resources (Woodward et al. 2020), offer valuable information on cultural protocols, Indigenous knowledge, and best practices for engaging with Indigenous communities in research projects. However, there is recognition that partnerships and deeper links with Indigenous knowledge systems are essential for ensuring inclusive management that recognises multiple values and rights (Tengö et al. 2017). The mixed success and penetration of existing undertakings highlights that significant co-ordinated effort is still required in this space for successful and consistent outcomes nationally.

How is Australia progressing IOM?

Australia has strong foundations in traditional marine management, particularly in single-sector approaches (Smith et al. 2017) and marine protected area management (Day et al.

2019). Australia has historically also been a leader in the concept of IOM (Vince et al. 2015). Recent work has shown that IOM, and associated tools such as Integrated Ecosystem Assessments, have been partially implemented in Australia (Smith, Fulton, and Boxshall 2022; Stephenson et al. 2023). National and State governments have both made steps towards IOM (e.g. NSW's Marine Estate,[1] or Victoria's marine Spatial Planning framework[2]), completing engagement, scoping and some risk assessments. However, in each case the process has either failed to be comprehensive (including only some groups and industries), has stopped short of evaluating cumulative effects, or has not progressed through to truly integrated management outcomes. In practice, planning initiatives have focused primarily on marine spatial planning, or remained constrained by existing siloed governance arrangements, often due to limited legislative mandate or insecure funding.

As competition for access to marine spaces grows, interest has renewed in IOM as a possible solution. Nationally, the draft Sustainable Ocean Plan[3] recognises IOM as one way to achieve improved outcomes for ocean stakeholders.

Australia is not alone in looking to IOM. Full implementation of IOM is an aspiration for several other nations – such as Norway (Olsen et al. 2014), the Netherlands (de Vrees 2021) and Canada (Fisheries and Oceans Canada 2002; Auditor General of Canada 2025) – but these nations also face the challenges described here (e.g. Vince et al. 2015). Progress requires advancing cross-jurisdictional frameworks, real-time data integration, and tools to balance competing interests in dynamic environments (Winther et al. 2020; Vince et al. 2015, 2024). Effective IOM also depends on improved governance, stakeholder engagement, technological innovation to facilitate data collection, reporting, communication and engagement at continental scales, and better coordination across research, management, and policy sectors (Cvitanovic et al. 2015b; Brodie Rudolph et al. 2020; Voyer et al. 2021; Vince et al. 2024). Increased and sustained investment and collaboration will be key to achieving comprehensive and sustainable outcomes.

The pathway to IOM

IOM, and through that sound resource allocation, in Australia should balance the benefits to multiple end users including the responsible agencies, individual commercial sectors, as well as recreational users, Traditional Owners, coastal communities and conservation organisations (Hill et al. 2012; Cvitanovic et al. 2015b). Indirect beneficiaries include the broader Australian public through improved environmental outcomes and sustainable resource management with transparent conflict resolution mechanisms.

The degree of success of taking an IOM approach can be characterised in terms of sustainable resource use, reduced user conflicts and enhanced social outcomes due to inclusive decision-making processes, improved ecological outcomes through better management of cumulative effects, enhanced economic outcomes across sectors (through coordinated planning) and more effective governance through coordinated institutional arrangements (Stephenson et al. 2019).

While it is possible to identify metrics of IOM success (further elaborated below), understanding and addressing key science gaps, needs, and challenges in implementing IOM requires a strategic approach that encompasses both fundamental research and applied science. Achieving scientific progress at the necessary pace demands overcoming roadblocks such as funding limitations, technological constraints, and time-sensitive pressures (e.g. pre-development surveys). In the following three sections, we set out the needs for science, infrastructure and capability, and the dependencies that set the stage for success. Together the broad set of dependencies highlights the need for sustained investment in both technological infrastructure and human capability development across multiple scales within and beyond Australia.

Science needs – research requirements

The multidimensional nature of IOM creates numerous science gaps and challenges. Bridging these gaps requires advances of knowledge and information, infrastructure and capability (Figure 2).

Key amongst the information and knowledge needs is (Figure 2, top left panel) improved understanding of marine socioecological system thresholds, tipping points and recovery potential (particularly at multi-year to decadal scales), and quantification of cumulative effects across pressures and sectors (Smith, Fulton, and Boxshall 2022). This enables evaluation of trade-offs but also a shift to a new perspective that looks for mutually beneficial outcomes rather than competitive framing of ocean use. Achieving these advances requires improved understanding of cross-scale connectivity and socioecological system function, which will support identification of the most informative social, economic and cultural indicators that can then be tracked through time (past, present and into the future).

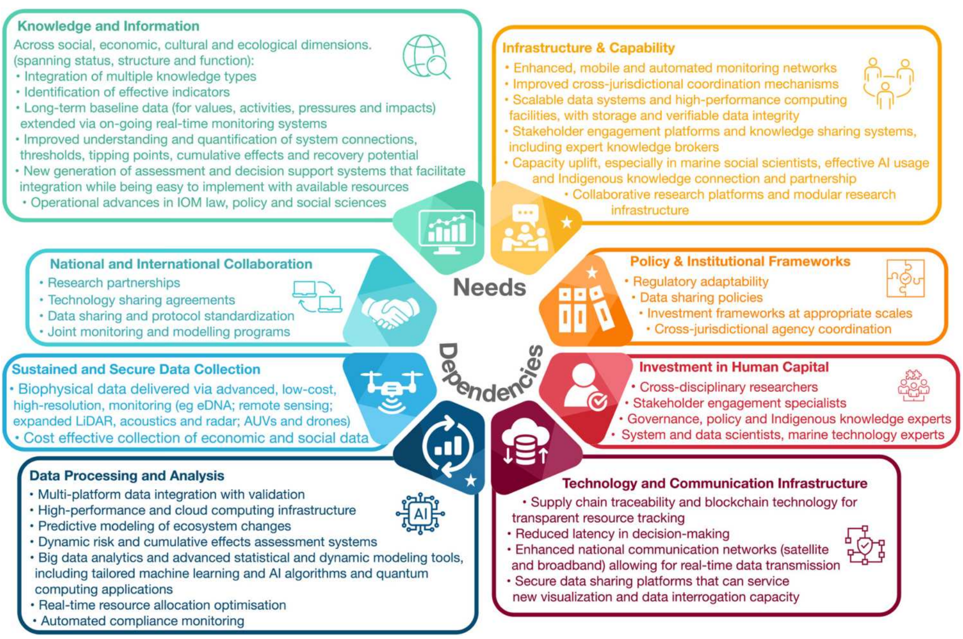

Figure 2. National science and infrastructure needs to advance Integrated Ocean Management (upper half) must be supported by collaboration, policy frameworks, human capital, technology, data processing and analytics, and advanced data collection (lower half). White stars in inner circle indicate domains with major foreseeable capacity gaps.

Providing system scale insights and predictive capacity in support of IOM requires long-term baseline environmental and socioeconomic impact data, resource use patterns, cultural and heritage value mapping, and scenarios of future change (Stephenson et al. 2019; Smith, Fulton, and Boxshall 2022). Analytical innovation is also required to find and explore connections across these properties more effectively. For this knowledge to be captured in a meaningful way for end users, a new generation of integrated decision support systems are required, incorporating real-time monitoring dashboards, predictive modelling platforms, spatial planning tools, risk assessment frameworks and stakeholder engagement platforms that can function at the scales needed (from fine scale around specific features to much larger regional to national scale assessments).

For the maximum benefit of any technical and analytical requirements to be realised, research on the 'how to' of IOM is necessary (Winther et al. 2020; Rölfer et al. 2021). Law and policy development is required (Vince et al. 2024) alongside research on stakeholder behaviour analysis, apposite forms of governance, social impact assessment methods and appropriate cultural value mapping techniques (including their facilitation into ecosystem service valuations) (Voyer et al. 2021; Partelow et al. 2023; Vince et al. 2024). Success necessitates advances in underpinning disciplinary, interdisciplinary, and transdisciplinary approaches, including research on integrating diverse values held across different groups (Tengö et al. 2017; Rölfer et al. 2021), securing reliable evidence bases and translating that plethora of information into operational management and governance (Stephenson et al. 2021; Karcher et al. 2024). Together this requires marine social sciences and humanities working with marine and computational scientists in interdisciplinary teams, furthering research and assisting action in the IOM governance and policy space, without waiting for all research gaps to be filled.

Infrastructure and capability needs

Success in the widespread implementation of IOM requires sustained investment in physical infrastructure and human capability development (Figure 2, top right). It will be necessary to build and maintain the strong and reliable connections needed between science, stakeholders and management systems that is the foundation of IOM, which will involve technological and methodological advances. While effort and investment are required in all segments shown in Figure 2, foreseeable capacity gaps centre on integrated data systems, cross-jurisdictional coordination, advanced modelling capabilities and end user capacity (domains marked with a star in Figure 2**)**.

Institutionally, effective delivery of IOM into decision-making and public good (especially cross-jurisdictionally) entails, at a minimum, improved coordination mechanisms and unimpeded exchange of information (Haas et al. 2022). Ideally, there is also explicit supporting policy, planning and management coordination, conflict resolution and underpinning legal and institutional arrangements (Stephenson et al. 2019). This requires clear governance, to provide an authorising environment, as well as more effective stakeholder engagement platforms and knowledge sharing systems (especially at scale) (Stephenson et al. 2019; Haas et al. 2022). In turn, this engenders expanded capacity needs in these areas, with transdisciplinary research (Kelly et al. 2019) and stakeholder inputs across data collection, knowledge generation and decision support critical for successful IOM.

Technologically, the mismatch in system understanding versus IOM needs translates into key infrastructure needs around enhanced (and automated) monitoring networks, associated equipment and data visualisation tools, data storage, high-performance computing facilities, collaborative research platforms and accessible information delivery platforms that allow stakeholder exploration of connections, interactions and trade-offs between alternative uses or management interventions. This may require modular research infrastructure, increased investment in mobile monitoring capabilities and scalable data systems (Jones et al., in review). There are also substantial needs in terms of human resources capable of using these technologies, including more people with appropriate engineering or analytical skills (e.g. modelling, data analytics, Artificial Intelligence (AI) and Machine Learning), marine social scientists, Indigenous knowledge integration experts, knowledge brokers and cross-disciplinary expertise (especially in marine science, economics, and policy) – see the papers in this Special Issue on enabling science.

The new decision support systems needed by IOM end users will come with expanded security and capacity needs, requiring investment in new data integrity checks (e.g. via blockchain), evolving security measures and an AI capacity lift, including specialised training programs or other forms of technical capability-building within agencies. Beyond quantitative analytical skills, effective and powerful communications/strategies and people to broker those connections are also essential. Societal trust in the processes and underlying information needs to be an embedded feature for IOM to be effective in practical terms (Francis et al., in review).

Dependencies

All the advances and science needs outlined above come with strong interconnected dependencies (the bottom 6 panels of Figure 2). Successfully delivering to the many science needs will require coordinated advancement across multiple scientific and technological domains, supported by appropriate policy and governance frameworks and strong leadership. The rate of progress will be significantly influenced by breakthroughs in key enabling technologies and the successful integration of these innovations into existing management frameworks, but also by investment in human capital and capacity uplift.

Six broad classes of critical dependencies exist: (1) Sustained and secure data collection and monitoring; (2) Data processing and analysis; (3) Technology and Communication systems; (4) Policy and institutional frameworks; (5) Investment in human capital; and (6) National and international collaboration.

The dynamic nature of marine socioecological systems, and the fact they are moving into novel combinations that may invalidate past understanding, means that the IOM must be underpinned by real-time data at appropriate scales. Ongoing advances in validated remote monitoring remain the most-cost effective means of covering Australia's vast EEZ (Evans et al. 2026). Other knowledge holders and citizen scientists have substantial roles in providing on-water understanding and monitoring of a range of system properties, such as biodiversity, beach and coastal condition, marine debris, species distributions and shifts, and water quality (Aceves-Bueno et al. 2015; Pecl et al. 2019). Nonetheless, these approaches are insufficient in isolation and there is no escaping the importance of nationally coordinated ecosystem monitoring and sustained observing programs. This means there are strong dependencies on the development of advanced sensor technologies for real-time monitoring (Vitousek et al. 2023). These include hyper-spectral imaging capabilities and expanded LiDAR systems for marine mapping (Smart et al. 2026), autonomous underwater vehicles (AUVs) and drones (Yuan et al. 2023), eDNA sampling and analysis capabilities (especially at sea capability and an expanded set of molecular markers for species identification) (Jiang et al. 2025), advanced acoustic monitoring systems (Mooney et al. 2020), integrated coastal radar systems and multi-platform data integration, and satellite technologies that provide for both broad-scale monitoring and readily available low-cost high-resolution satellite imaging. All these require research and appropriate validation to ensure accurate interpretation and representativeness of remotely collected data (Murray et al. 2018).

The required data and analyses will not be confined to biophysical systems. In terms of economics, cost–benefit analysis frameworks for multi-use scenarios are already in demand, as are Blue Economy opportunity assessments, ecosystem accounting and non-market valuation (required for both historical market oversight and new markets) (Milligan et al., in review). Integration of human population data, values and needs, and details of institutional arrangements for decision-making into analyses will require standards allowing for social and economic datasets to be joined with other 'big data' in new ways informative to IOM. Social and governance sciences, finance, economics and even less traditionally associated disciplines (e.g. psychology) will also have an increased role to play in IOM and in the integrated research teams required to service it.

To maximise the benefit possible from different knowledge bases, Australia needs to invest in the innovative use of new analytical approaches. This creates infrastructure dependencies, such as high-performance and cloud computing infrastructure, as well as disciplinary dependencies – especially increasing demand for expertise in statistical and Bayesian inference, Machine Learning and AI algorithms (and related fields such as neuro-computing methods), and advanced statistical and dynamic/hybrid ensemble modelling tools (Jones et al., in review; Friedman and Shafi in review). As techniques evolve there is also the potential for a need to pivot to new technologies as breakthroughs occur (e.g. in quantum computing applications) (Figure 2**)**.

A swath of dependencies in realising secondary service-oriented delivery also exist, including leveraging AI and Machine Learning to deliver automated relevant pattern recognition for broader sets of ecological data, improved predictive modelling of ecosystem changes (with assessment of the efficacy of predictions), real-time resource allocation optimisation (e.g. in-season catch adjustment, or changes in spatial use), automated compliance monitoring, and dynamic risk assessment systems. Expanded datasets and automated biotechnological processing would see needs around effective genetic tracking of marine populations, bioinformatics tools for ecosystem analysis and rapid reliable biodiversity assessment methods. The growth in familiarity with digital twins (i.e. models), and the pressure to develop them for marine systems (Tzachor, Hendel, and Richards 2023), requires the technical know-how to build such models (requiring breakthroughs in connection of physical and socioecological systems from local to global scales), but also in terms of their delivery and ethical use (Tzachor, Hendel, and Richards 2023; Hazeleger et al. 2024).

The speed and magnitude of delivery required is dependent on advances in engineering and computational technologies (such as AI), automating monitoring and analytical workflows, while accelerating assessment and information sharing, delivering near real-time simulation capabilities, knowledge processing and provision, broader scenario testing platforms, interactive visualisation tools, and simultaneously more powerful and increasingly user-friendly, predictive management systems. Realisation of this new computing capacity will be dependent on investment in the development of analytical capacity, adherence to standard operating procedures,[4] and FAIR data standards, such as standardised metadata protocols, interoperable databases, rigorous quality assurance frameworks (as recognised by IMOS[5]). Maximal benefit will only be realised from cross-jurisdictional data sharing agreements and, where-ever possible, open-source software (Figure 2). In parallel, enhanced data security and necessary regulatory controls are needed to address knowledge access and security concerns.

The increased computational demand associated with many of the technologies listed above creates dependencies in terms of real-time data processing, edge- and distributed-computing networks, and mobile processing capabilities. Additional infrastructure dependencies come from researcher and user group expectations around the necessary speed of access to and transfer of information. The shape of communication is changing quickly, with dependencies both in terms of the physical infrastructure and delivery mechanisms (e.g. enhanced satellite communication networks, national broadband 5G/6G network infrastructure and capacity, Internet of Things (IoT) integration), but also the service side – such as real-time data transmission systems and visualisation and data interrogation capacity. Delivering these infrastructure requirements will be physically dependent on addressing energy needs through renewable sources, an area where there is considerable scope for Australian research contributions.

Dependencies go beyond physical infrastructure and computational methods to include human capital. Research technical expertise will be required to develop and use the methods (e.g. skilled data scientists, marine technology experts, systems integration specialists, Indigenous knowledge experts and cross-disciplinary researchers). In addition, expertise will be needed pertaining to stakeholder engagement, governance, policy development, community support, effective communication and supporting/facilitating Indigenous, industry and agency partnerships. Moreover, these differing research domains will need to come together to build a shared understanding of what the given IOM need is for a particular issue or region (e.g. Alexander et al. 2018). Without a pipeline of multidisciplinary researchers, the workforce needed to support IOM will not be available (Blythe and Cvitanovic 2020).

Nationally, for the full potential of the technologies and societal needs to be realised, supporting policy and institutional frameworks pertaining to regulatory adaptability, cross-jurisdictional and agency coordination, data sharing policies and investment frameworks at appropriate spatiotemporal scales will need to be implemented. For ultimate success, however, Australia will need to invest in building the capacity of its people to understand and utilise all these advances. Investment in communications and social learning within educational institutions, and more broadly in terms of society's ocean literacy, will be fundamental to ensuring the maximum possible benefit from all knowledge bases (Francis et al., in review; Blythe and Cvitanovic 2020). For IOM to succeed, high levels of ocean literacy and accessibility of evidence to those involved is required (Kelly et al. 2025). Otherwise, decision makers will be required to prioritise some forms of knowledge over others (e.g. science versus local observational/anecdotal data), which can cause many conflicts, and limit the ability for ongoing constructive engagement across stakeholder groups after decisions are made.

Finally, there is a dependency on collaboration. Collaboration herein is defined as the intentional, synergistic process of multiple organisations, individuals, and entities working collectively with a shared mindset to achieve the IOM goal. Australia can only bridge the gaps, address the dependencies and deliver IOM via partnership and enhanced levels of sustained investment from a diversity of sources, public and private. Collaboration is essential at every step, from appropriate long-term collaborations that can support sustained coordinated monitoring and assessment programs (and overcome fragmented data collection and complex jurisdictional arrangements) through to end-user delivery (IMOS 2025). Engaging the broader set of ocean uses in the development, but especially the use of data collection technologies, would have immense benefit (e.g. Lago et al. 2025). Imagine the radical step change in observational extent, knowledge and capabilities if Australia's entire maritime infrastructure and fleet were instrumented for environmental data collection. Critical partnerships in delivering IOM not only involve industry close research-industry-agency partnerships (e.g. with technology providers), but also connection across jurisdictions and with Traditional Owner organisations. Programs such as the Global Archive (Harvey et al. 2021) and NESP standard operating procedures (Przeslawski et al. 2019) provide starting points.

International collaboration remains essential despite geopolitical shifts requiring some self-reliance (e.g. in technological developments and analytics), Australia's limited resources versus the size of its maritime jurisdiction (third largest globally) necessitates leveraging international efforts through technology sharing agreements, research partnerships, data sharing (of actual data but also in alignments of data protocols and standards), and joint monitoring and modelling programs.

Priority milestones

Achieving this level of change in the governance system and supporting research agenda benefits from clear timelines and objectives. Priority milestones (described briefly below and outlined in Figure 3) are directed by what can be leveraged from the capability and momentum built over the past 10–20 years of marine social-ecological research investment in Australia and what will be needed to keep pace with societal needs and climate change impacts over the next 20–30 years. These priorities reflect the science, infrastructure and dependencies discussed above. Staging of these priorities allows funding and delivery pathways to be developed, and for changes in future years if circumstances change.

5-Year Milestones (2025-2030):

1. **Standard Operating Procedures for IOM endorsed in one or more regions.**[6]

a. Governance systems for empowered and improved participation across sectors and jurisdictions for decision-making (vs single issue constituent groups), also for aligning policies and actions across sectors to reduce conflict and enhance synergy.
b. Methods for cumulative effects assessment and evaluation of impacts are agreed by government agencies and are fit for purpose given available data and decisions that are needed in IOM regions.
c. Performance metrics are defined and available for IOM, spanning species, habitats, legal, social, economic, governance and cultural activities.

Figure 3. Indicative timeline for the outcomes needed to achieve Integrated Ocean Management.

d. Standard operating procedures and survey design are agreed on to maximise downstream data use.
e. Principles for data sovereignty and inclusion of Indigenous and local knowledge systems into IOM (the Canadian Integrated Ocean Observing System can be looked

to as an example of the application of digital data standards and CARE[7] and FAIR[8] principles).

2. **Data for IOM are accessible and useable** by decision makers, researchers, and stakeholders in IOM processes, and support management and evaluation (as highlighted in the draft Sustainable Ocean Plan).

a. IOM should seek to utilise existing data sets, which may need to be federated
b. Data custodians should seek to adhere to CARE and FAIR principles and establish standardised cross-jurisdictional data sharing protocols (e.g. by agencies).
c. Data analysis and mechanisms for exchange must be resourced alongside data collection.

3. **Declaration of an IOM testbed** to accelerate experience in implementing IOM, as understanding and supporting the transition in test bed locations provides lessons for broader implementation.

a. Select a small number of candidate regions for developing IOM testbeds. This will likely require an authorising process to declare regions (e.g. akin to the Blue Economy Zone in Bass Strait) where IOM can be tested.
b. Candidate regions should span jurisdictions both horizontally and vertically and be selected and evaluated in terms of present governance, science and data frameworks, and how these would need to change to achieve IOM (an ideal candidate would have several IOM elements already in place, such as a recognition of the need for IOM, a governance structure that is amenable to new arrangements and either existing resources or a clear pathway to necessary funding). This will require looking across both those sites with extant partial implementation and 'greenfield' sites where there is a desire to move to IOM. Example regions include Bass Strait, southern Queensland and GBR, southwest Western Australia, and across different levels of government from the Commonwealth to States and Local Councils.

4. **Real-time integrated monitoring networks** established in regions proposed for IOM that are sustained and will support management and evaluation. This takes the standards of Milestone 1 and leverages broader data streams from Milestone 2 and concepts/advances from Milestone 5 but involves dedicated investment in monitoring in the specific region(s) identified under Milestone 3.

a. Establish monitoring priorities for each region encompassing species, habitats, social, economic and cultural activities that build on efforts to date where possible.
b. Identify what would be needed to ensure implementation of the monitoring networks once priorities have been identified, including: what is needed to integrate current monitoring systems and how to transition to delivery of real-time data/information

5. User-friendly decision support for all stages of IOM.

a. Creation of collaborative and transdisciplinary stakeholder engagement and partnership platforms to address research questions (e.g. Reef Knowledge Platform; RPN coordination group for fisheries); Summit approach (DEECA); code-designers with participatory approaches; Communities of Practice and Networks aimed at acknowledging and combining local knowledge.
b. Initiation of a growing set of AI-supported analytical and decision support systems.
c. Technology transfer and capacity development enabling locally appropriate data collection and full participation in subsequent activities.

Building on these and other formative activities already under way sees the fruition of several technologies on the decadal time horizon, such that the **10-Year Milestones (2030-2035) include**:

1. Technological advances and innovation
- Complete national coverage of automated monitoring networks
- Data exchange systems in place
- Full deployment of AI-driven decision support systems
- Implementation of advanced predictive modelling capabilities
2. IOM testbed in place with expansion to new regions planned.
3. Development of cross-sector (and ideally cross-jurisdictional) and integrated management frameworks.
4. Establishment of comprehensive IOM oriented ecosystem valuation systems.

Given the potential degree of global change by mid-century and beyond the **20–30 Year Milestones (2035-2055)** for resource allocation and IOM are:

1. Complete cross-jurisdictional coordination (all levels) in Australia.
2. Fully integrated adaptive management systems.
3. Comprehensive sustainable resource allocation frameworks.
4. Advanced monitoring and prediction systems operating in real time.
5. Advanced climate change response capabilities (e.g. chronic climate change and extreme event strategic response plans that include operational climate interventions that are triggered by predetermined trigger points) that simultaneously build resilience to undesirable change.

Improving connectivity and communication will be key to delivering on these priorities for resource allocation and IOM, and would be assisted by: the development of an easily accessible and real-time national marine information and management network (underlain by standardised data sharing platforms) facilitation of seamless data access and regular knowledge exchange programs; cross-sector forums and workshops; enhanced digital collaboration tools; integrated stakeholder communication systems; standardised reporting frameworks across jurisdictions and national guidelines on relevant topics and protocols (such as climate responses, and integrated or regional strategic assessments).

IOM as a unifying thread across Australia's ocean research domains

IOM draws on diverse knowledge, requires inter-, multi- and transdisciplinary input and, in its most developed form, has substantial data collection and computational needs (Stephenson et al. 2021; Vince et al. 2024; and as discussed above). Simpler forms of IOM can be shaped to match the available resources and should still yield significant benefit (Vince et al. 2024). IOM links domains covered in all the white papers contributing to Australia's National Marine Science Strategy 2026–36: Building Blue Futures[9] (see other papers in this special issue). It provides the governance, data integration, and decision-support systems necessary for sustainable delivery of the Blue Economy, biodiversity conservation, climate adaptation, and cultural heritage management. It also supports and benefits from Indigenous leadership, education, and national security and is reliant on each of the enabling disciplines and technologies.

Progress and impact measurement

Science delivery in support of IOM resulting in equitable resource allocation spans direct stakeholder engagement through digital platforms, regular reporting, policy briefings, online decision support tools, industry-specific guidance documents and public awareness campaigns. Outputs will be evident in the form of formal management plans and strategies, decision support tools used by agencies, industries and other decision makers, monitoring reports and research publications. Key indicators of success include maintaining biodiversity, stable or increasing fish stocks, improved biosecurity, preservation of cultural values and sustainable industry growth.

Progress around delivery of IOM can be measured through integration of IOM concepts and materials into established reporting mechanisms such as: resource (e.g. fisheries) and marine park management; State of the Environment reports; Environmental Impact Assessments and other forms of environmental assessment (including the establishment of new cumulative or broad scale strategic assessments); National Environmental Economic Accounts; SDG reporting, particularly Goals 14 (Life Below Water) and 13 (Climate Action); Economic performance metrics across marine sectors (reported via AIMS Marine Index and Australian Bureau of Statistics and the Australian Bureau of Agricultural and Resource Economics and Sciences); and other established reporting mechanisms, including commercial reporting requirements (e.g. Environmental, Social and Governance (ESG) reporting, climate and nature related financial disclosures) and international reporting mechanisms such as those associated with Nationally Determined Contributions (NDCs) and National Biodiversity Strategies and Action Plans (NBSAPs).

Tracking progress and impact becomes increasingly problematic as IOM dimensions grow (Stephenson et al. 2021; Stephenson and Hobday 2024). In addition, the increasingly non-stationary nature of marine systems (in terms of judging resource status and allocations) creates challenges. Nonetheless, indicators for measuring the impact of IOM remain viable across the quadruple bottom line – i.e. of ecological condition, economic performance, social/cultural outcomes and governance effectiveness (Haugen et al. 2024). A list of illustrative examples are provided in Table 1. Combined with the milestones in Figure 3, the progress and performance of IOM could be evaluated using a suite of these indicators. Specific indicators and desired end states would be determined through the IOM processes itself, as IOM requires input from stakeholders and rightsholders as a foundational part of the process.

In selecting indicators is not only important to settle on indicators that capture system state, but also structure and function. Where possible, these should be leading, rather than lagging indicators. Without a breadth of indicators, there cannot be confidence that all dimensions are being understood through time and over larger spatial areas. The performance of indicators can be tested in simulation models to understand leading/lagging performance, and sensitivity to system change. While consistency of concept is important, the specific indicators may need to be updated over longer

Table 1. Example indicators and strategic metrics for tracking the progress of IOM.

Indicator metrics	Strategic progress metrics
• marine ecosystem health (e.g. the status of representative or indicator species, or species of special cultural or ecological importance – such as habitat forming species, hub species or keystone species) • ecosystem structure and function (e.g. network indices or derivatives such as the 'Green Band' or ETI) • economic performance across sectors • resource utilisation efficiency • stakeholder and First Nations community participation and satisfaction rates • degree of implementation of management recommendations • levels of social license and trust in the process • community ocean literacy and behavioural change • cross-sector collaboration effectiveness • levels of conflict (or harmony/cooperation) • esearch outputs and citations	• achievement of implementation milestones • adoption rates of management tools • ecosystem recovery • stakeholder and rights holder engagement levels • cross-jurisdictional coordination effectiveness • technology and assessment method adoption rates • data sharing, data usage, knowledge access and integration metrics • extent and magnitude of ecosystem and ocean accounts

periods as climate change (and other pressures) reshape species mixes, potentially in novel ways.

Tracking the selected indicators of the socioecological system of interest will be important for IOM, but they are insufficient in isolation. As noted under the strategic progress metrics, and as illustrated in Figure 3, important aspects of IOM implementation require establishment of the technological, knowledge and policy infrastructure to support at-scale, sustainable approaches. While there are benefits to the ocean from development of individual component parts, such as the data collection, interoperability, technological advances, and improved assessment methods, the greatest benefits (and the biggest cumulative savings in terms of avoidance of undesirable ocean system states and minimisation of social and economic losses) can only be realised if true collaboration and coordination is achieved.

Conclusions

The size and complexity of the challenges facing those responsible for management of Australia's marine estate requires a move beyond historical approaches. The importance of these marine ecosystems to Australian cultures and economy intensifies the need. IOM presents a unified framework that can address the system complexities (interconnections, feedback processes, trade-offs, etc) while simultaneously reducing the complicated nature of cumulative incrementally developed single-jurisdiction/single-sector policies. Supporting such a shift while not suspending maritime operations necessitates addressing specific national science and infrastructure needs (Figure 2) and tracking progress again the priority milestones of standardising operating procedures, increasing data accessibility and usability under CARE and FAIR principles, undertaking (and learning from) IOM testbeds that demonstrate all associated steps – from policy to planning, ongoing real-time integrated monitoring networks, advanced predictive modelling capabilities, decision support and response capabilities. IOM provides Australian governance, and its supporting research community with real opportunities to achieve a sustainable, valued, equitable and thriving ocean future.

Notes

1. https://www.marine.nsw.gov.au/
2. https://www.marineandcoasts.vic.gov.au/marine/marine-spatial-planning
3. https://www.dcceew.gov.au/environment/marine/sustainable-ocean-plan#draft-sustainable-ocean-plan
4. E.g., https://marine-sampling-field-manual.github.io/
5. https://imos.org.au/data/about-the-australian-ocean-data-network/data-management-standards-and-policies/quality-assurance-and-quality-control
6. These regions may be jurisdictional or bioregional. The exact scale remains flexible as the initial application processes are developed and implemented.
7. https://ardc.edu.au/resource/the-care-principles/
8. https://ardc.edu.au/resource-hub/making-data-fair/
9. https://www.marinescience.net.au/white-papers/

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