National Environmental Science Program

Integrated data requirements for natural resource management

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Cover photograph

Albany, Western Australia. Photo: Lucy Commander.

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Acknowledgement of Country

We acknowledge the Traditional Owners of Country throughout Australia and their continuing connection to and stewardship of land, sea and community. We pay our respects to them and their cultures and to their Ancestors, Elders and future leaders.

Our Indigenous research partnerships are a valued and respected component of National Environmental Science Program research.

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Acknowledgements

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1. Executive summary

1.1 What problem were we trying to solve?

We do not have sufficient data to adequately describe the integrated socio-ecological systems that support us. It is prohibitively expensive to collect enough data to describe all, so it is important to think strategically about how to (i) use the information we do have and (ii) prioritise the collection of new data.

We aim to help by finding efficient ways of improving the information that is available for policy-makers to generate better human–nature outcomes.

1.2 What did we do?

We used insights from frameworks developed within a broad range of disciplines and literatures to identify and describe the 'ideal' dataset required to adequately support natural resource managers in different situations. The frameworks focused on relationships between nature and people (both good and bad) and are differentially relevant to different problems (e.g. highlighting the 'value' of nature, encouraging pro-environmental behaviours). Collectively, the frameworks highlighted the broad range of data required to adequately support resource managers (a *wish list* of data requirements). We used the *wish list* as a guide/template – searching for relevant Australian data to fill the template where possible. We compared the *wish list* with our compilation (the *reality check),* identifying data gaps. We note that not all frameworks are relevant to all practical/policy problems, so data gaps are differentially relevant to different problems. We outlined ways of using our existing dataset and designed a conceptual model explaining our pathway to producing our *wish list* dataset and how it can facilitate improved environmental policy outcomes (see Figure 1-1).

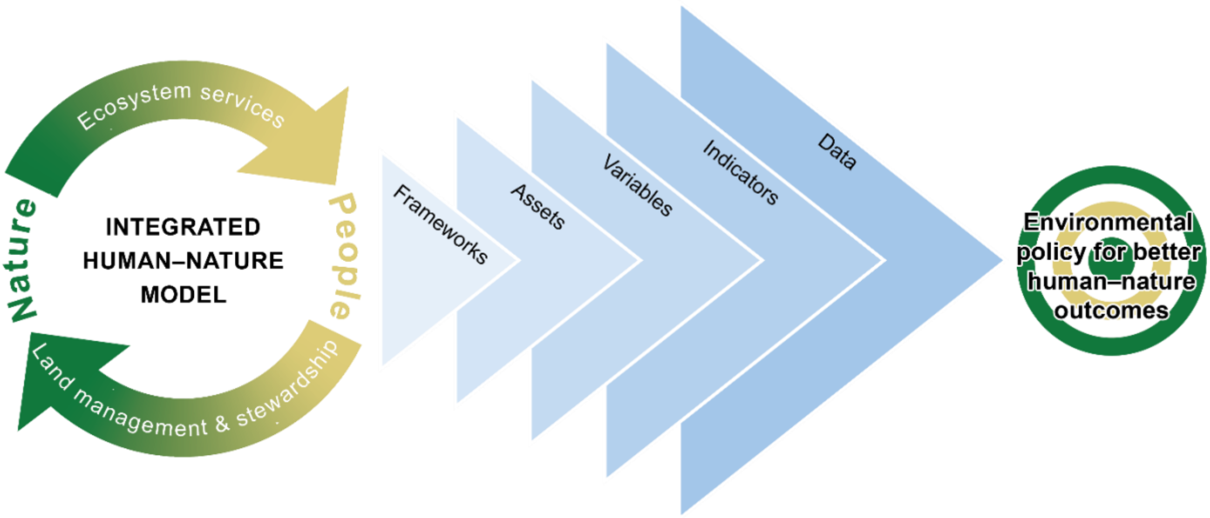

Figure 1-1. Integrated human–nature model. An integrated human–nature model helps us to derive insights from frameworks to determine the selection of indicators to guide environmental policy for better human and nature outcomes. The integrated model shows net flows – noting that some of the things that people do for and to nature are good and some are bad; so too are some of the things that nature does for and to people. Examples include poor stewardship or land management and ecosystem (dis)services that are harmful to people.

1.3 What did we find?

Our discussion of various frameworks highlighted that **when considering**

- **what nature does for or to humans,** it is important to consider multiple categories of ecosystem services and to also consider who is benefiting from flows if wanting to value or describe the benefits. One may also need to consider the mediating factors that enable, or prevent, people from reaping the benefits of nature.
- **what humans do to or for nature,** one does not just need to count or describe the sociodemographic or economic characteristics of the population and its organisations (including businesses); or to consider people's intentions to undertake pro-environmental behaviours. One also needs to account for the numerous internal and external factors (personal, psychological, social, institutional) that have a bearing on final outcomes. This includes the intentions/goals/priorities of people and organisations and any mediating factors (including, but not limited to governance systems) that enable or prevent them from translating their intentions into actions that benefit nature.
- **the reciprocal and connected human–nature system,** one needs to explicitly account for the fact that changes in one part of the system will impact other parts. This requires one to consider feedbacks and inter-relationships at various scales (local, regional, national). It is also important to account for decision-making processes and different world views.

Our subsequent discussion of data requirements further highlights that

- most decision-makers who seek to improve human–nature outcomes will need data that describes a broad range of 'capitals' (e.g. human, social/institutional, financial/built and nature) and the interactions between them. Not every decision-maker will require information on every capital, but most will need to select variables that describe at least some aspects of both the natural and the human system.
- many frameworks describe both the extent and the status/condition of capitals (e.g. the number of people, their age, and their income; the types of forests, their extent and their health). It is also important to include other measures that describe broader contextual factors (e.g. the social and economic environment in which people live; the climatic conditions in which forests live). But it is not enough to simply describe the current state of the system (or part thereof). One also needs to consider processes of change and interventions that have the potential to create positive, or mitigate negative, changes. It may, therefore, be necessary to include variables that are able to serve as indicators of change (to various capitals) or predictors of outcomes of management interventions. This helps explain the difficulty – and the complexity – of developing and/or undertaking fully integrated models, environmental assessments and of plans. Thankfully, it is not always necessary to do so.

Our compilation of data highlighted significant data gaps – in particular, the relative paucity of data describing core human and social/institutional capitals (compared to data describing financial/built and natural capitals). Detailed data requirements will vary by context, including the particulars of the problem to be addressed, the scale at which a problem is to be addressed (backyard, small community, large region?) and the stakeholders involved.

1.4 Of what practical use is this work?

To achieve the best outcomes (such as knowledge gains and ultimately, protection of ecosystems and biodiversity), funds allocated to research, planning and on-ground environmental action must be spent cost-effectively. This means being able to translate knowledge across regions in sensible ways to use the available evidence to build the most impactful environmental programs. Our integrated dataset, which provides contextual descriptors of 4 capitals across all of Australia, lays the foundations for doing just that. It consistently describes areas across Australia using metrics that can be compared and analysed to identify regions that share similar attributes. It thus provides resource managers with useful *contextual* social, economic and biophysical background across Australia.

Specifically, our dataset and the supporting information within this report provides a platform that can be used in subsequent investigations with significant value-add:

1. **Identifying the *right plan* for the *right place*.** There are many different types of regional plans, some of which may be relatively easy to implement and some of which are not. Before developing potentially expensive regional plans, it is thus important to determine what type of planning is needed – the goal should be to ensure that plans are sufficient, but not superfluous, to manage the problem at hand. Requirements for planning depend on context. Our regional-planning decision tree (Figure 6-1) can be used in conjunction with our dataset to help scope planning needs.

2. **Identifying *places* where insights from a research project undertaken at a specific *study site* might be transferred to (potential *Transfer sites*).** Our dataset can be analysed to identify regions that are contextually similar, so it may help research dollars (and findings) stretch further. When transferring insights from studies undertaken in one place, to another, we need to ensure the places are similar for meaningful results. It makes little sense to transfer the findings of research undertaken in one ecosystem to a vastly different ecosystem; neither does it make sense to transfer findings between places that share similar biophysical characteristics but have different social, economic, and cultural characteristics. Our dataset can be analysed to identify regions that are *contextually* similar (across 4 different capitals – human, social/institutional, financial/built and natural), so it may help research dollars (and findings) stretch further.

3. **Prioritising activities to fill identified data gaps.** We have identified clear data gaps across multiple capitals. There is, for example, generally much less readily available information to describe human and social/institutional capital than to describe financial/built or natural capital. But it would be prohibitively costly to fill all gaps – and may not be necessary to do so since data requirements depend critically on context. We have discussed broad types of data needed to address broad problems, explaining *why* that data is required for management decision-making. And we have outlined a process for working with local stakeholders to clearly determine which data gaps need filling to address specific problems in specific contexts and to co-design a system for doing so.

1.5 Where to next?

We have already begun to focus on points (1) and (2), working with partners until end 2022 to add additional variables to our dataset that relate to climate, water, aquatic biodiversity and threatened species. We will then analyse the data to identify groups of regions that share similar social, economic, and biophysical characteristics and/or regions that similar locational characteristics (e.g. priority places, protected areas); and to identify regions that have characteristics most suited to particular planning approaches (that focus on conservation/ecological systems). Our process for identifying which data gaps need to be filled to address specific management projects could be used in a wide variety of future projects, helping to ensure that the information available is both necessary and sufficient to support environmental policy-makers improve human–nature outcomes.

2. Introduction

People and nature live in a connected, integrated, socio-ecological system. The agencies and organisations who deal with issues relevant to biodiversity and natural resource management face increased pressure to consider the social and economic dimensions of resource management, in addition to biophysical dimensions. We do not have sufficient data to adequately describe the integrated socio-ecological systems that support us. It is prohibitively expensive to collect enough data to describe all aspects in detail, so it is important to think strategically about how to most effectively (i) use the information we do have and (ii) prioritise the collection of new data. We aim to help do that by finding efficient ways of improving the information that is available for policy-makers to generate better human–nature outcomes.

We use frameworks to help us concentrate on conceptual models that have been developed to describe relationships between humans and nature in a connected human–nature system. The primarily focus is on frameworks that integrate social, economic and ecological concerns on an equal footing. We took this approach as these frameworks are critically important when aiming to promote resilient landscapes and/or protect threatened species and places in terrestrial, wetland/aquatic and marine environments. The compilation of frameworks that we discuss is not intended to be complete or comprehensive. Rather, it is intended to help readers understand how knowledge about the relationship between nature and people has grown over time. Our compilation of frameworks also aims to highlight core insights provided by comparing different types of frameworks and the diversity of data/knowledge needed to describe the complex human–nature system.

We note that some frameworks for thinking about the relationship between nature and people focus on a one-way flow of benefits from nature to people. This expression of benefits should be thought of as 'net benefits', since flows from nature to people are not always positive. Nature supports people, but nature can also produce negative impacts for humans – for example, when damage is done to life and infrastructure by natural disasters. Similarly, some methods for evaluating or thinking about the success or failure of management or conservation actions focus on the one-way flow of services (or disservices if a damaging relationship) from people to nature. Other frameworks and models, such as those that describe complex adaptive systems, acknowledge the existence of dual flows (from nature to people and from people to nature) and the dynamics and inter-relationships between parts of the system across time and place.

Conceptualising relationships between people and nature as an integrated people ⇔ nature model (Figure 1-1) thus makes explicit the notion that various parts of the system influence environmental outcomes. Critically, this conceptualisation helps to identify factors that need consideration if aiming to design policy or influence behaviours to benefit the environment – and thus provides a foundation from which to identify critical data gaps to support decision-makers for improved nature-human outcomes.

We used insights from the conceptual frameworks to identify and describe the 'ideal' dataset required to adequately support natural resource managers in different situations (the 'wish list'). This highlights the broad range of data required to adequately support resource managers. We used the wish list as a guide/template, searching for relevant Australian data to fill the template where possible. We compared the wish list with our compilation (the 'reality check'*)*, identifying data gaps*.* Not all frameworks are relevant to all practical or policy problems, so data gaps are differentially relevant to different problems (e.g. highlighting the 'value' of nature, encouraging pro-environmental behaviours). We discuss appropriate ways in which to use the existing compilation to support current decision-makers: identifying the right plan for the right place; assessing the likely transferability of research findings from one (study) location to another location; and prioritising data gaps to support specific management problems. The structure of our report is given below:

Introduction: **What problem are we trying to solve?**

- We do not have sufficient data to adequately describe the integrated socio-ecological systems that support us. It is prohibitively expensive to collect enough data to describe all, so it is important to think strategically about how to most effectively (i) use the information we do have and (ii) prioritise the collection of new data.

Methods: **How did we try to solve the problem?**

- We review frameworks that focus on the nature-human system to identify data requirements (section 3).
- We consider what data are required, and why (section 4).
- We develop a generic list of variables relevant to integrated human-nature systems and compile data where readily available (section 5).

Discussion: **How does our work help solve the problem?**

- It can help to identify the right plan for the right place (section 6.1).
- It can help identify places that are contextually similar to facilitate knowledge transfer (section 6.2).
- It can help prioritise data gaps that need 'filling' to support managers addressing specific problems (section 6.3).

3. Frameworks that help us understand socio-ecological systems

Here we discuss the emergence and development of conceptual frameworks that help us understand both sides of the people ⇔ nature circle and the contextual factors that mediate the flows between them. We do so in 3 parts. First, we provide an overview of conceptual frameworks that help us to think about what nature does for and to people (section 3.1); second, we consider the behavioural, organisational and planning frameworks that help us to think about what people (including businesses/organisations), do for and to nature (section 3.2); and finally, we consider complex circular frameworks that look at the system in its entirety (section 3.3).

A more detailed explanation of a subset of key frameworks is provided in the appendices. We again note that our compilation is not intended to be complete or comprehensive. Rather, it is intended to help readers understand how knowledge about the relationship between nature and people has grown over time. The compilation presented in this section is intended to highlight core insights provided by different types of frameworks and the diversity of data needed to describe the human–nature system in its entirety. Figure 3-1 summarises the key insight offered by each framework discussed and the context and timeline of their development.

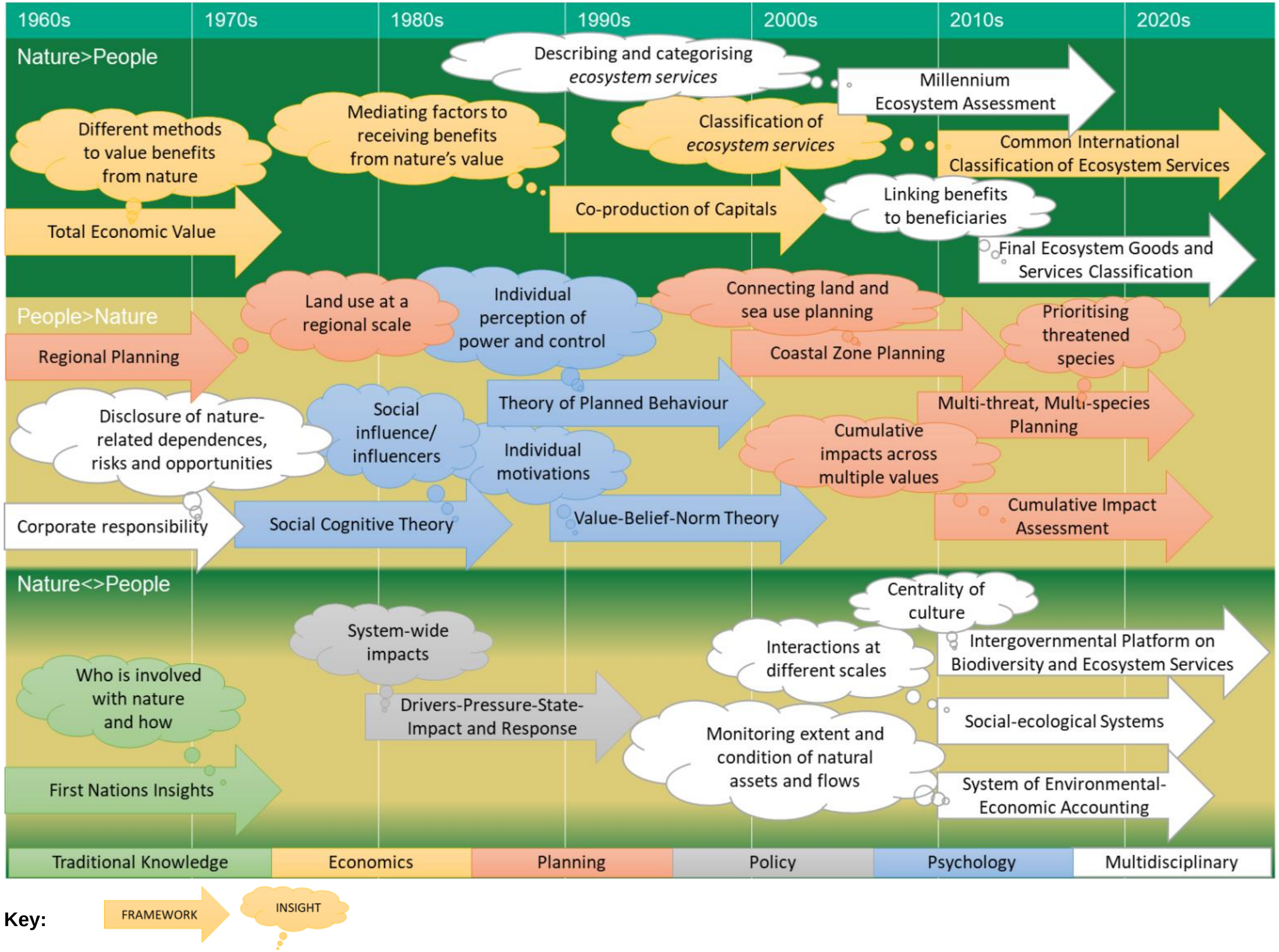

Figure 3-1. Timeline and context for development of frameworks and key insights offered.

3.1 Frameworks for thinking about what nature does for and to people

Here we provide a brief overview of frameworks that consider the numerous ways in which nature benefits people – not just financially, but in other ways, e.g. by enhancing wellbeing. The discussion highlights the need to consider multiple categories of ecosystem services to also consider who is benefiting from flows if wanting to value or describe the benefits. It also highlights that one may need to consider the mediating factors that enable, or prevent, people from reaping the benefits of nature.

Environmental economists started thinking about the value of environmental goods and services, even when devoid of price, as early as the 1930s (for a historical review related to Cost–Benefit Analysis, see Hanley and Spash (1993)). Over the last 100 years a range of methodological approaches measuring different types of values in dollar terms identified new ways of thinking about the different types of benefits that flow from nature to people (Stoeckl et al., 2018). These values are often categorised by economists using the Total Economic Value (TEV) framework (see Appendix 1. Total Economic Value), which describes the benefits that flow from nature to humans by distinguishing between what are termed 'direct-use values' (e.g. fishing, recreation), 'indirect-use values' (e.g. climate regulation) and 'non-use values' (e.g. just knowing an area exists for its own sake). TEV cannot be estimated by adding direct use, indirect use and non-use values unless numerous restrictive assumptions hold (Stoeckl et al., 2014). However, the categories are unlikely to be mutually exclusive, so the TEV framework is best thought of as a tool that helps identify which of numerous non-market valuation techniques are best suited for a particular valuation task (e.g. hedonic pricing for aesthetic values, travel cost for recreational values, contingent valuation of choice modelling for non-use values). This is important when trying to learn more about the way in which nature benefits humans, since the TEV helps identify the best way to 'value' (or highlight) different types of benefit.

Each non-market valuation technique identified by the TEV requires different types of information as input (e.g. characteristics of houses and the views of each, number and nature of recreational trips taken by people, values and preferences). Irrespective of differences, all require the description and characterisation of: (i) the environment or natural asset, (ii) the people who are associated with that natural asset, and (iii) the way those people interact with the asset. The level of detail required to adequately do so is often substantive, a key point being that it can be expensive to conduct be-spoke valuation studies. This has contributed to the growing popularity of benefit transfer studies, whereby values estimated in one region are transferred to another. There are publicly available compilations of estimates from valuation studies (e.g. Van der Ploeg and De Groot (2010); Lantz and Slaney (2005)) which further facilitate the use of benefit transfer (Richardson et al., 2015).

In the early 2000s, in response to the Millennium Ecosystem Assessment (MA), the idea of valuing the benefits that flow from nature to people became popularised outside that (relatively) small group of environmental economists. Publication of the MA (see Appendix 2. Millennium Ecosystem Assessment) popularised the term 'ecosystem services', a new term used to describe those flows (MEA, 2005a). These ecosystem services were categorised as provisioning, regulating, cultural and supporting services. These categories differ from those used in the TEV but there are similarities (Stoeckl et al., 2011) – the MA reinforcing earlier messages about there being a wide variety of ways in which nature benefits humans, in this case by contributing to wellbeing.

The framing and valuation of ecosystem services was intended to increase public awareness of beneficial ecosystem functions and the need for biodiversity conservation, and improve environmental policies, management and decision-making (Westman, 1977, Ehrlich and Ehrlich, 1981). Ecosystem services make nature's value visible and create a common language and understanding of the relationship between ecosystems and human wellbeing. The MA framework thus helps us to understand how nature produces ecosystem services and explicitly considers how those services create wellbeing. Those using the MA to frame thinking about human–nature relationships thus need information about each of the ecosystem services that benefit humans differing contextually, for example, the services provided by mangroves will differ from those provided by deserts or coral reefs. Although not a required part of MA, some researchers step beyond that model using non-market techniques developed through the TEV framework (above) to estimate the dollar value of those services (Tallis et al., 2008).

The extent the ecosystem services concept has proven useful to decision-makers is evidenced by its adoption for use in various policy forums and settings. There are now internationally recognised systems for classifying ecosystem services. For example, the Common International Classification of Ecosystem Services (CICES; see Appendix 3. Common International Classification of Ecosystem Services) (Haines-Young and Potschin-Young, 2018), provides input into the development of the experimental ecosystem accounts within the System of Environmental-Economic Accounting (SEEA) process (UNCEEA, 2021) (see Appendix 4. System of Environmental-Economic Accounting). There are also local systems developed by national governments. For example, in Australia there is an Aquatic Systems Toolkit (Aquatic Ecosystems Task Group, 2012) outlining a process for undertaking consistent biophysical assessments of aquatic ecosystems at a regional and landscape scale and there is a national framework to assess the ecological character (components, processes and services) of Ramsar Convention (potential or actual) wetlands (Department of the Environment, 2008).

These classification systems help decision-makers identify areas with important ecosystem services considered valuable natural assets that may thus warrant investments in protection measures and need to invoke significant offsets if they are degraded (Maynard et al., 2010). In addition, the ecosystem-services framework can enable decision-makers to manage ecosystems to maintain or enhance current levels of services, anticipate losses in services due to development activities or evaluate trade-offs between alternative ecosystem management regimes that impact the natural environment (for good or bad), thus affecting ecosystem services.

Others have found ways of adding supplementary information to ecosystem service classification systems that focus on the type of service and seek to identify the different types of beneficiaries of the various ecosystem services. For example, the US Environmental Protection Agency's Final Ecosystem Goods and Services (FEGS) classification system (see Appendix 5. Final Ecosystem Goods and Services) makes explicit the association between the landscape where ecosystem services occur and the people that interact with the services (Landers and Nahlik, 2013, Ringold et al., 2013, Nahlik et al., 2012).

Notably, the mere existence of a good or product, does not guarantee that people are able to benefit from it. Hicks and Cinner (2014) note that numerous social, institutional and knowledge mechanisms can enable or prevent different groups of people from accessing flows of benefits from nature. So, it may be important to distinguish between the services that are 'supplied' (or generated) and those that people are able to benefit from. Costanza et al. (2014, 2021a) highlight that the actual value of ecosystem services flowing from nature (natural capital) to generate wellbeing depends on the interaction of other capitals (social, human, built) (see Appendix 6. Co-production of capitals models).

3.2 Frameworks for thinking about what people do for and to nature

There is a long, and diverse literature – including insights from accountants, economists, planners, environmental scientists and social scientists – that has developed frameworks for considering the way in which people both benefit from and impact nature.

In this section, we discuss that literature in 3 separate sub-sections; (i) first focusing on frameworks relevant to individuals, (ii) next focusing on frameworks relevant to businesses and other organisations, and (iii) last considering frameworks that address larger-scale interactions involving multiple people and organisations at a regional scale, under the broad label planning approaches. Our core insight from examining these frameworks is that to understand, monitor, or influence environmental behaviours and thus improve the value (or quality) of services that flow from people to nature, one does not just need to count or describe the sociodemographic or economic characteristics of the population and its organisations; or to consider people's intentions to undertake pro-environmental behaviours. Numerous internal and external factors (personal, psychological, social, institutional) have a bearing on final outcomes. Therefore, one needs to consider the intentions of people and organisations; in addition, we also need to consider the mediating factors that enable or prevent people and organisations from translating their intentions into actions that benefit nature.

3.2.1 Individuals

A core learning from the literature is that factors which drive pro-environmental behaviours (or other behaviours that promote the public good) are often different from factors that drive behaviours associated with personal gain. Therefore, those seeking to promote behaviours that improve the flow of positive services from humans to nature may need to engage different levers than those seeking to promote other behaviours (Gneezy et al., 2011). For example, de Groot and Steg (2009) propose that pro-environmental behaviours might be enhanced by strengthening the saliency of altruistic and bio spheric values or by creating compatibility between acting on egoistic values and acting on altruistic and bio spheric values.

At an individual level, social scientists have sought to understand factors that influence individual behaviours. Information on individuals' behavioural influences is critical if we seek to understand and change the way people interact with nature. Here we discuss a number of models that seek to understand factors that influence people's environmental behaviours, e.g. reducing water use or participating in Clean Up Australia Day.

Modelling intentions can help predict actual behaviour. However, the models have inherent uncertainty because intention has a suboptimal predictive power for actual behaviour. The separation between intended and actual behaviour has yet to be fully explained in any predictive behavioural model. However, practitioners advocate that with the correct application of theory and robust study design, the predictive power of models can be improved, helping us to better understand the factors that influence actual behaviour (DiClemente and Prochaska, 1982, Ajzen, 2015).

Behavioural models focusing on individuals each reveal subtly different factors that should be considered in understanding and influencing environmental behaviours. Norm Activation Theory (Schwartz, 1977) proposes that individuals will only act to prevent harm to others (i.e. act pro-socially) if they are aware of the potential for harm to others (or to others and oneself) and believe that they have a personal responsibility to act. This theory has been used to explain pro-environmental behaviour, including recycling and travel mode choice (Valle et al., 2005, Wall et al., 2007). The Value–Belief–Norm Theory proposed by Stern (2000) presents 3 types of values explaining pro-environmental behaviour: egoistic (i.e. self-enhancement or pro-self), altruistic (i.e. self-transcendent or prosocial) and biospheric (i.e. ecocentric). People with an egoistic value orientation will consider the personal costs and benefits of pro-environmental behaviour; when the perceived benefits exceed the perceived costs, they will behave pro-environmentally and vice versa. This type of value is the most frequently targeted by current management options, i.e. through incentives and other financial instruments. People with altruistic values will base their decision to behave pro-environmentally (or not) on perceived costs and benefits for other people. Some community-based initiatives target this type of value. Finally, people with a biospheric value orientation will mainly base their decision to act pro-environmentally (or not) on the perceived costs and benefits for the ecosystem and biosphere (targeted by large international non-governmental organisations [NGOs] 'save the whales' type of drives).

Social Cognitive Theory (see Appendix 7. Social Cognitive Theory) highlights the need to consider other factors, emphasising that individuals do not make decisions in a vacuum, their behaviours are fundamentally learned from and influenced by other people (Bandura, 1986). Therefore, as well as studying individuals, one also needs to understand social context and how people interact and influence each other and behave in group settings (described in many models as the construct of social influence). These understandings can help to guide the development of policies or interventions designed to alter behaviours (e.g. persuasive communication, identification, and promotion of positive role models). The Theory of Planned Behaviour (see Appendix 8. Theory of Planned Behaviour), includes insights from Norm Activation and Value–Belief–Norm theories, highlights the need to consider not only subjective social norms (i.e. social influence) but also the extent an individual feels their behaviours and actions will have an actual impact (perceived power) and that they are capable of taking action (perceived behavioural control) (Ajzen, 1991). It is apparent that describing individuals and their social context (e.g. counting the number of people within a region and documenting their social networks) is inadequate to explain environmental behaviour, one also needs to understand the deeper psychological motivations and drivers. To provide a relevant example here: if people feel disempowered and/or inadequate, they are unlikely to undertake actions that someone else believes will benefit the environment.

Individual and socio-contextual factors interact to mediate environmental outcomes, influencing what people do to or for nature. For example, Sher et al. (2020) and Primack et al. (2021) found that both individual and broader social/contextual factors were important in influencing the success of restoration programs (e.g. how many agencies were involved, the relative priority of particular goals, how intensive monitoring was, what type of degree the manager had). Similarly, in their review of studies seeking to understand the factors that influence landowners' decisions to set aside areas for perpetual conservation, Kemink et al. (2021) found a broad range of variables, including those related to the social, psychological or economic characteristics of individual decision-makers (landowners) and to the broader socio-ecological context in which the landowners live. Few studies considered these critically important broader contextual factors, however it is clear that they can, and do, matter. The literature indicates contextual factors often interact with individual factors to jointly determine outcomes.

Laws, regulations, and rules cause behaviour change via mandates and prohibitions. Market-based price tools such as taxes and subsidies induce economically rational behaviour change by manipulating costs and benefits. A rational agent would respond to these incentives. However, for behaviours that deviate from rational predictions and cannot be (adequately) addressed by these, we need other approaches; one that is evidence-based and increasingly popular is nudging.

First introduced in the book 'Nudge' by Nobel laureate Richard Thaler and Cass Sunstein (Thaler and Sunstein, 2008). A nudge policy is one where the decision context is designed based on behavioural science insights to gently steer people's behaviour in a particular direction. In terms of implementation, nudges are lighter in touch compared with policies which mandate or prohibit and lower in cost compared to price-based tools such as subsidies. Nudges do not force or remove choice – instead, they appeal to people's psychology (their cognitive processes, heuristics, biases) by making it easier and more attractive for people to adopt the recommended behaviour. To nudge effectively requires policy-makers to be aware of how people actually behave and the psychology underlying that behaviour, as opposed to how people are assumed to behave as a rational response to traditional policy tools. For example, some fishers may not renew their fishing licences because present bias has caused them to procrastinate. As people tend to stick to the status quo (status quo bias), a nudge can leverage this insight to address this problem by changing the default, so licences are automatically renewed unless fishers opt out. The nudge makes renewal of licences easier, but fishers still retain choice as they can opt out if they want to. Changing the default is cheaper to implement than monitoring compliance.

As nudges retain choice, they are suited for situations where there is a gap between intended and actual behaviour. Nudges help people close that gap. In the above example, the nudge will be suitable for those fishers who intend to renew their licences but have somehow been prevented by their psychology (e.g. procrastination) from doing so. However, it will not be suitable for those fishers who have made a calculated decision not to have a valid licence and have no intention to renew. A heavier hand of formalised mandates and penalties is needed for such situations.

3.2.2 Organisations

It is not only the actions of people, acting as individuals, that impact nature, for good or for bad, the actions of organisations must also be considered (be they private businesses, financial institutions or not-for profit organisations including, but not limited to volunteer groups, government funded service providers in health and education, local government associations).

Private firms are often assumed to have as their sole objective, that of maximising profits. Their activities often impose costs on the environment or society and, historically, policy-makers have attempted to control these external costs through regulation. Market based incentives (MBIs) are now also commonly used to improve environmental outcomes in a variety of settings – e.g. subsidies to encourage agricultural stewardship, carbon markets to reduce carbon emissions, taxes to reduce pollution). There is also growing recognition of the important role that consumers play; the poor environmental performance of firms in some situations can prompt action from consumers (Stoeckl, 2004).There is nowadays a substantive body of literature focusing on corporate social responsibility (a term first coined in 1953 Bowen (2013)) and popularised several decades later (Carroll, 1991), which highlights the importance of company disclosures.

Essentially, Carroll outlines 4 areas essential in a company's corporate social responsibility and organises them in order of importance into what is now known as the Pyramid of Corporate Social Responsibility. The first and most vital level of the pyramid is a company's economic responsibilities. As a fundamental condition for its existence, a company must be profitable. If this requirement is not met, the business cannot survive, and as a result, the company will not be able to move on to the other levels of the pyramid. After satisfying its economic responsibilities, companies must ensure that their business operations are within the confines of the law. At this level, organisations must fulfill their legal requirements (such as competition or health and safety laws). Like the economic requirements, if legal requirements are not met the company's survival may be at stake, preventing them from moving on to other levels of the pyramid. The next level of the pyramid is the company's ethical responsibilities. In this stage, the company goes beyond legal requirements by acting morally and ethically. In other words, the company makes a conscious decision to 'do the right thing' (i.e. introduce recycling targets). Once the economic, legal, and ethical foundations of the pyramid have been built, the company can move on to the final level of the pyramid, philanthropic responsibilities. At this level, the company goes beyond its ethic responsibilities by actively giving back and making a positive impact on society, either via financial donations or donations of employee time and expertise.

Accountability experts seek to ensure that organisations (including, but not limited to private-sector firms) 'disclose' actions/activities that impact the environment or society more broadly, in measurable and comparable ways. The Taskforce on Nature-related Financial Disclosures (TNFD, 2022), which leverages concepts relating to ecosystem services, is one example of a framework that systematises disclosures[1]. This taskforce has developed a framework, based on SEEA Ecosystem Accounting (SEEA-EA) principles, which is intended to support financial corporations to assess, value and manage their impacts on nature. This formally recognises the impact that corporations have on the quality and resilience of ecosystem services, services on which they are dependant for their business processes (e.g. clean and regular water supply). The impact on these dependencies creates medium- and long-term risk for these organisations which they have a duty to disclose and act upon. Other financial organisations, such as the Global Impact Investing Network (Bass et al., 2020), use SEEA-EA's concepts of stocks and flows (ecosystem services) to measure the impact of investments on social and environmental issues, comparing performance across the market and to the United Nations' Sustainable Development Goals (United Nations, 2020).

3.2.3 Communities and regions

The collective impact, on nature, of the activities of individuals and organisations, is mediated through institutional arrangements, developed by society, which guide and govern behaviours. Societies generally develop a prevailing social norm that states what is acceptable and what is not. Prevailing social norms differ from society to society and within the same society over time. Various institutional arrangements form to implement and safeguard such norms. In addition to informal institutional arrangements (such as customs, socially acceptable behaviours, and lore; captured in the behavioural models described above), societal responses to changes in the natural world are also guided by a range of formal institutional arrangements. Formal institutional arrangements include governance frameworks devised in response to prevailing societal concerns, from standards such as the Open Standards for the Practice of Conservation (Conservation Standards) which assist conservation practitioners with the conservation project design, management and monitoring (Conservation Measures Partnership, 2020), to legislative frameworks which set statutory obligations for a range of planning tools and implementation mechanisms, including incentives and subsidies. Of particular relevance to this report are regional-planning approaches, with a specific focus on regional spatial planning, coastal-zone planning, cumulative impact assessment and regional threat-abatement and species-protection plans. These are discussed in more detail in section 6.1.

3.3 Frameworks and ways of thinking about the system in its entirety

In this section, we discuss the numerous and diverse whole-of-system multidisciplinary frameworks encompassing ecological, social, economic and policy sciences that consider relationships between human activity and the environment. Each focuses on different aspects of the system, generally conceptualising relationships between nature and people as a complex circular system. These models are non-linear, include feedbacks often as an interlinked cause–effect chain, and explicitly acknowledge a multitude of actors (stakeholders) and their differing and potentially contesting values and world views. Simplifying, they effectively consider both what nature does for and to people and what

[1] See also TASKFORCE ON CLIMATE RELATED FINANCIAL DISCLOSURES 2021. Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures, ibid.

people do for and to nature, blending insights from all the models discussed above and adding new and different ideas. The most relevant additional insights brought by these frameworks are that one needs to explicitly account for feedbacks, inter-relationships, scale, decision-making processes and different world views. Numerous complex integrated models, assessment and planning tools are able to do this – although complexity is not always required (as when a problem can be solved with simpler methods – see section 6.1).

The Drivers–Pressure–State–Impact and Response (DPSIR) framework (see Appendix 9. Drivers–Pressure–State–Impact and Response) gained popularity in the early 1990s after its adoption by the Organisation for Economic Co-operation and Development for their environmental reporting (OECD, 1993). It is a policy-oriented framework that allows one to organise and think about problems along a cause-effect chain (Patrício et al., 2016). It has been used globally to assess, address and communicate environmental issues and to evaluate relationships between human activity and the environment (EEA, 1999, Pirrone et al., 2005); it is the framework of choice for several environmental agencies (e.g. the US Environmental Protection Agency, United Nations Environmental Program, European Union). The components of the model underscore the importance of obtaining data on a broad range of factors that describe the state of core attributes within the system (e.g. natural, economic, social, or political assets), the drivers and pressures that impact those assets (some of which may be external), and potential responses to impacts (which could be biophysical, economic, social, institutional, or other). Evidently, it is not enough to simply describe the current state of a system, one also needs to consider processes of change around it and plan interventions that have the potential to create positive, or mitigate negative, changes.

The Sustainable Development Goals (SDGs) are also widely used. The SDGs form the centrepiece of the UN's 2030 Agenda for Sustainable Development, adopted by all UN member states in 2015 as a 'blueprint to achieve a better and more sustainable future for all' (United Nations, 2020). Each of the 17 SDGs focus on a different dimension of the human–nature system, and incorporate factors drawn from the economic, social, and environmental domains of life. The 17 goals are underpinned by 169 specific targets, each of which is underpinned by multiple indicators. The SDGs thus provide a useful monitoring and management system at individual indicator level over time within a particular country/region. That said, it is difficult to use SDGs to compare regions/countries primarily because different countries collect and report on different sub-sets of indicators. This is further complicated by differences in the methods used to collect and measure indicators across countries. We note that one potential solution, which is currently the focus of attention by the UN and others, is to link the SDGs with the SEEA frameworks (UNEP-WCMC & UNSD, 2019).

In 2007, Elinor Ostrom challenged the presumption that scholars can make simple, predictive models of social-ecological systems (SESs) and deduce universal solutions ('panaceas') to problems of overuse or destruction of resources. Instead, she argued that a serious study of complex, multivariable, non-linear, cross-scale and changing systems is required (Ostrom, 2007) and proposed a new framework for thinking about this complex system (see Appendix 10. Socio-ecological System). Like the DPSIR framework, Ostrom's SES model highlights the need to consider factors (and thus capture data) across a broad range of domains. Two (of many) fundamentally important insights that her work added to that of previous scholars were (i) the need to consider variables at different scales and (ii) to explicitly recognise the critical role of actors. Fundamental to the role of actors was her observation that humans can make conscious choices as individuals or as members of collaborative groups (including corporations and governments) and that outcomes could vary markedly depending upon whether choices were made individually or collaboratively (McGinnis and Ostrom, 2014). To understand the importance of this, consider a fisher faced with reduced stocks. A fisher may sensibly adapt by fishing more frequently but if every fisher responds accordingly, the stock is further depleted. In this case, individuals are making choices that are good (‘optimal’) for themselves but their individually optimal adaptations generate collective maladaptation (Barnett and O'Neill, 2012). One does not only need to consider (and collect data about) multiple states and multiple pressures but also the processes by which decisions are made when determining how best to respond to change/impacts.

Many of the core insights from the frameworks discussed above are incorporated within the framework developed by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; see Appendix 11. Intergovernmental Platform on Biodiversity and Ecosystem Services) (Díaz et al., 2015), acknowledging the critical importance of different world views, knowledge systems and stakeholders (Kadykalo et al., 2019). In short, the IPBES adds ‘culture’ to the list of factors that need to be considered when thinking about people, nature, and environmental policy. It also introduces new terminology, namely, the concepts of nature’s contribution to people and people’s contribution to nature, incorporating an inclusive set of perspectives and stakeholders to address human–nature relationships and placing culture at the centre of all links (Díaz et al., 2015).

A pro-active and forward-looking type of impact assessment that explicitly takes many of these factors into consideration is: Integrated Environmental Assessment (IEA) (Boileau et al., 2019). IEAs have been part of the environmental management since the 1972 United Nations Conference on The Human Environment in Stockholm and have grown to become a major and common feature of environmental management conducted by various stakeholders. The most notable outcome of the introduction of the IEA is The Global Environment Outlook (GEO), which reports on the state, trends and outlooks of the environment. Importantly, it does not only provide an independent assessment of the state of the environment but also of the effectiveness of the policy responses. The IEA and GEO processes inform environmental decision-making for governments (in Australia, through both state and federal State of the Environment (SoE) reports) but also for various stakeholders such as the agricultural businesses or women (for example, via Global Gender and Environment Outlook GGEO).

Critically, the insight that different cultures have different world views (see Appendix 12. Insights from First Nations People) underscores the notion that a single size does not fit all. All frameworks for thinking about problems, be they about nature–people relations or others, need to be contextualised before use in situ. In Australia, for example, Indigenous people depend on an intimate connection between nature, health and wellbeing – a total connectedness/integration of physical and spiritual life (Salmón, 2000). Indigenous communities view social–economic and ecological aspects as a unified system, unlike the ecosystem-services framework, which sees nature and people contributing to each other (positively or negatively) as separate objects (Stoeckl et al., 2021, Sangha et al., 2015). The wellbeing of Indigenous communities is thus embedded within and inseparable from ‘Country’

(Sangha et al., 2015) and the way that Country is looked after. Not only is it important to consider (and account for) the flows of benefits from nature to people, and from people to nature, and to account for who benefits from nature's flows, there is also a clear need to account for how activities (caring for Country, restoration, or other activities to improve the environment) are undertaken and by whom. When activities are undertaken the right way (with caring, sharing and respect for Country), the flow of benefits to both people and Country is enhanced (Stoeckl et al., 2021). This approach is practically embodied in Bush Heritage Australia's 'right-way' science which brings together different knowledge systems for thinking, planning and acting for the benefit of people and Country based on the principles of respect, sharing knowledge, listening and learning (Bush Heritage Australia, 2022).

In sum: the interconnected human–nature system in which we live is exceedingly complex. It would be prohibitively resource intensive to develop models, assessment and/or planning tools that adequately capture all nuanced details – and critically – it is not always necessary to do so. Different types of integrated models and assessment methods tend to concentrate on different parts of the system, the focus rightfully determined by the core management/policy/planning question at hand (Hardy et al. (2021b), Stoeckl et al. (2016)). Section 6.1 provides an illustrative example of the way in which one can start with the core priorities of managers and use core descriptors of a region to help select an appropriately complex planning approach.

4. Using frameworks to identify data requirements

In this section, we structure our discussion around 4 broad types of capital: natural, human, social/institutional and financial/built (physical). We explain why it is important to have information about these capitals when aiming to make decisions or set policy and give examples of the type of data that can be used to describe the different types of capital. Table 4-1. Overview of the key use and output from each framework and the capitals considered.

(next page), provides a visual overview of the breadth of capitals considered by different frameworks – the core message being that, in almost all situations, it will be important to select variables that describe both the natural and the human system. Many frameworks either explicitly or implicitly suggest that one should describe both the extent and the status/condition of each capital (e.g. the number of people, their age, and their income; the types of forests, their extent and their health) in addition to broader contextual factors (e.g. the social and economic environment in which people live; the climatic conditions in which forests live). The frameworks also identify the importance of considering variables that could serve as indicators of change or predictors of outcomes of management interventions.

The conceptual frameworks described above use different terminology and group variables into different clusters. However, there is considerable overlap and agreement about the need to consider variables/information that describes different parts of the system. Different bodies of literature use different language to describe component parts – for example 'capitals' (in the terminology of Costanza et al.) or 'assets' (to use SEEA terminology). Hereafter, we use the term 'capital', noting also that different people refer to different numbers of and types of 'capital'. For example, some authors consider 4 capitals (human, social, built, natural); others identify 5, or 6 (human, social, institutional, built, financial, natural). We contend that there is no single correct way to categorise capitals, our key point being that the frameworks described above clearly show that natural resource managers need information and data about a cross-section of 'capitals', however named.

We note that many of the variables and indicators we discuss (the data) cannot be neatly categorised as describing just one capital. Household income, for example, is an indicator relevant to both human and financial/built capital. Similarly, areas of land dedicated to agricultural production might be viewed as an indicator of both natural and financial/built capital. Our grouping should therefore be considered as indicative only. Readers should always keep in mind that although these are discussed separately, capitals affect and are affected by each other, interactively and dynamically determining pathways, trajectories and outcomes (Costanza et al., 2021). Any individual part of the connected system we are seeking to understand will interact with, and be affected by the broader ecological, socioeconomic and political settings (Ostrom, 2007, 2009). The critical role that interactions and context/setting play in determining environmental outcomes should not be underestimated. Further detail on the capitals and flows covered, the types of data required and the contextual issues considered by each framework is provided in the appendices in a more detailed version of Table 4-1. Overview of the key use and output from each framework and the capitals considered.

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Table 4-1. Overview of the key use and output from each framework and the capitals considered.

Flows key:  Nature to people  People to nature  Both nature to people and people to nature

Framework Listed by flow category then in order of emergence	Managerial context/use	Outputs	Capitals considered:				
			Natural capital	Human capital	Social/ institutional capital	Financial/ built capital	Flows
Total Economic Value	A way of thinking about the different ways natural assets benefit people – helps identify an appropriate non-market valuation 'tool'	Estimates of the monetary value of a natural asset, highlight its 'worth' even if it is not something that generates wealth or income	✓	✓			
Co-production of capitals	A way to understand how ecosystem services can be 'produced' without necessarily benefitting people	Helps to understand factors that may enable or prevent people from benefiting from ecosystem services	✓	✓	✓	✓	
Millennium Ecosystem Assessment and Common International Classification of Ecosystem Services	A way of thinking about the different ways natural assets enhance human wellbeing by providing ecosystem services	Helps to understand the way an ecosystem contributes to human wellbeing – and how degradation of the ecosystem might degrade services, impacting wellbeing (some researchers extend to generate monetary estimates of those values)	✓	✓			
Final Ecosystem Goods and Services	A way of explicitly identifying and accounting for the beneficiaries of ecosystem services	Helps to understand the way an ecosystem contributes to human wellbeing and the people/stakeholders who benefit from it	✓	✓			
Social Cognitive Theory	A way of understanding the social context in which one is operating (the 'movers and shakers')	Identifies key influences (and influencers) of people's behaviours		✓	✓		
Theory of Planned Behaviour	A way of understanding the likely extent to which people will 'engage' (e.g. in a plan to improve the environment)	Highlights individual and social norms that influence behaviours – and the extent to which people feel their behaviours can make a 'real' difference	✓	✓	✓	✓	

Framework Listed by flow category then in order of emergence	**Managerial context/use**	**Outputs**	**Capitals considered:**				
			Natural capital	**Human capital**	**Social/ institutional capital**	**Financial/ built capital**	**Flows**
Value–Belief–Norm Theory	Another way of understanding core 'values' that motivate a person	Helps identify the best types of social–psychological 'levers' to encourage different behaviours		✓			
Norm Activation Theory	A way of understanding core 'values' that motivate a person	Helps to identify the best types of social–psychological 'levers' to encourage different behaviours (e.g. money in some cases, medals in others)		✓			
Corporate responsibility, e.g. Taskforce on Nature-related Financial Disclosures	SEEA-EA system adapted for corporations and financial institutions	Identifies the need to consider disclosure of nature-related risks	✓	✓	✓	✓	
Planning and Regional Plans	Wide variety of approaches, intended to plan for and influence actions and behaviours that impact environmental outcomes at broad regional scale	Helps develop regional-scale plans for multiple stakeholders – most are spatially explicit (see section 6.1 for details)	Some or all of these may be included (depending on type of plan)				
First Nations insights	Incorporating First Nations' views Increasingly used as managers increase their appreciation of diverse insights and knowledge systems	Expands other knowledges and knowledge systems to greatly improve understandings – critically important in connected human–nature systems	People and nature are holistic and inseparable; spirituality is paramount. It is not only important to consider components of the system and flows, but also who is involved (undertaking stewardship activities or benefiting from nature/people) and how that involvement is occurring (in a respectful way)				
Drivers–Pressure–State–Impact and Response	A way to assess and evaluate relationships between human activity and the environment Commonly used to by environmental agencies to organise and support thinking about environmental issues	Highlights the way external drivers or pressures can change the state of a system and flags the importance of considering responses and feedbacks	✓	✓	✓		
Socio-ecological Systems	Describes the way human–nature systems interact at different scales	Improves understanding of interactions between humans and nature and helps identify critical points of interaction that	✓	✓	✓	✓	

Framework Listed by flow category then in order of emergence	**Managerial context/use**	**Outputs**	**Capitals considered:**				
			Natural capital	**Human capital**	**Social/ institutional capital**	**Financial/ built capital**	**Flows**
	Influential in academic circles, has also created a paradigm shift in management situations	need attention (since to focus on only one sub-system may be to overlook core parts that drive or prevent good 'outcomes' for both nature and society					
Intergovernmental Platform on Biodiversity and Ecosystem Services	Describes the way human–nature systems interact at different scales Influential in academic circles, has also created a paradigm shift in management situations	Helps decision-makers think about the 'scale(s)' (e.g. local, regional) at which problems and potential solutions arise, so that resources can be appropriately focused	✓	✓			
System of Environmental-Economic Accounting	Provides a system to account for and monitor the state of assets and flows between them. Increasingly influential in management situations, in particular as support tool for development of datasets suitable for long-term monitoring, at different scales (from regional to national and global) yet comparable	Has multiple different accounts relating to different assets and flows – allowing one to monitor changes over time.	✓	✓	✓	✓	

4.1 Natural capital

The TEV framework encouraged people to think about how people benefited from the environment directly, indirectly, or vicariously, but it is a people-centric model and thus does not systematically categorise environmental assets. In contrast, ecosystem services classifications (MEA, 2005a) require one to first consider the environment (ecosystem) and then consider the flow of services that the ecosystem generates. The MA thus concentrates on flows (of ecosystem services) from nature to people, grouped into supporting, provisioning, regulating and cultural services. CICES differentiates between services that flow from biotic (ecosystems) and those associated with the natural environment from abiotic systems (excluding things such as minerals). The flow of ecosystem services from abiotic systems can either be non-depletable (e.g. the asset of solar radiation and the flow of renewable energy it creates) or depletable (e.g. the asset of fossil fuels and the flow of fertilisers it creates). When reporting on ecosystem services, the natural assets that generate those services are sometimes referred to as 'biomes' or (natural) 'assets'. These assets are grouped in SEEA, making it possible to describe their extent, structure, and condition (e.g. of forests, woodlands, oceans, lakes, rivers, coasts, wetlands, grasslands, croplands, heathlands, and urban parks). Making this distinction allows one to explicitly account for the fact that the ecosystem services generated from biomes that are in good condition are likely to generate more wellbeing (or 'value') than those in poor condition. This accounting aligns with much environmental economics research (linked to TEV), which 'values' environmental flows, often contingent upon the asset's extent, structure, and condition. Within SEEA and elsewhere, changes in the condition and health of ecosystems and biodiversity are considered critical factors affecting the value of ecosystem services over time. The value of ecosystem service flows is assessed by considering the extent to which the services contribute to the economy, social wellbeing and jobs and livelihoods.

Ostrom uses a somewhat different classification, dividing natural resources into resource systems and resources units (Ostrom, 2009). The 'resource system' sub-classification goes beyond the sectors (i.e. forest, pasture) to include more salient characteristics of the systems, such as dynamics, location and clarity of boundaries. 'Resource units' are also not concerned only with the existence and number of units (flows) and their economic value. When considering resource units through the lens of Ostrom, one should also explore issues such as growth and the replacement rate of the resource and interaction among resource units. In both classifications, as ecosystem assets or resource systems, land use and management become vital parameters to be considered as part of natural capital assessment.

Common to the study of natural capital is the assumption that ecosystem services are positive, i.e. they contribute to wellbeing. However, nature can also negatively impact humans through natural disasters or the emergence of pests and diseases. For example, a forest creates many positive ecosystem services (flows) but can also result in a bushfire. Therefore, the history of extreme events should also be recorded as part of the natural capital inventory.

A key contextual aspect of natural capital relates to climate and weather which impacts capitals within both the 'natural' and the 'human' sub-stems. Some impacts are direct (as when extreme events damage natural and physical infrastructures). Others are indirect – as when climate operates through economic, social, psychological and physiological mechanisms to impact human wellbeing (Parker, 1995). Weather refers to short-term atmospheric changes, while climate refers to what the weather is like in a specific area over a long period of time (NCEI, 2018); thus, the impacts of weather may be relatively transient when compared with those of the climate. The impact on human wellbeing of changes in climate have been documented in various studies (see Lignier et al. (2022) for a review). Variations in temperature, rainfall or windiness can all impact wellbeing. For example, harsh climatic conditions such as cold winters and high summer humidity can adversely impact wellbeing (Frijters and Van Praag, 1998), while rainfall in temperate regions can have a positive impact (Brereton et al., 2008). Further, extreme climate events such as drought (Carroll et al., 2009), floods (Fernandez et al., 2019) and hurricanes (Calvo et al., 2015) impact wellbeing in both tangible and intangible ways. Importantly, the climate we face today, plus the anticipated changes to climate in the future, need to be recognised within our analysis of the interlinked nature–human systems.

4.2 Human capital

Human capital is often considered to describe people and their productivity: their experience, education, training, skills, health, and abilities. Thus, education levels, population density and various measures of population composition are commonly used variables. Also common are demographic variables such as age and gender. When seeking to describe human capital some literature also includes variables that describe consumer awareness/behaviour, stakeholder pressure and specialised human resources available for eco-innovation and participation in ‘green’ economies as potentially relevant contributors to environmental outcomes (González-Benito and González-Benito, 2006, Ortega-Lapiedra et al., 2019, ten Brink et al., 2011, BIO Intelligence Service, 2011).

A wide range of economic, demographic, and psychological variables (that describe human capital) have been reported in the literature as ***potential*** predictors of human relationships with nature. However, commonly used variables such as age, gender and education, often demonstrate little predictive power in models that attempt to explain environmental behaviour – compared to variables that capture subjective and social norms, ideologies and political orientation (see, for example, Hornsey et al. (2016), a meta-study synthesising 25 polls and 171 academic studies across 56 countries). At the individual level, people’s contribution to nature includes both the act of changing to less damaging behaviours such as using public transport or purchasing energy-saving appliances and acts of direct contribution to the environment such as participating in forestation or control of invasive species (noting that participation can be direct, or indirect via financial contribution).

It may be necessary to differentiate between different ethnic communities and people from different cultural backgrounds as they are strong determinants of environmental behaviours (Ghazali et al., 2019); while belief in a controlling God (Eom et al., 2021) and conservative voting (Inkpen and Baily, 2020, Poortinga et al., 2011) were reported as resulting in less environmental concern. Values and beliefs (psychological variables) are not very good predictors of the extent to which people are willing to act upon their intentions (Steg and

Vlek, 2009, Stern, 2000) and indicators for cultural norms and beliefs are often not readily available, so data on acted behaviours are often used as proxy indicators.

4.3 Social/institutional capital

Environmental behaviour was broadly defined by Stern (2000) as all types of behaviour that change the availability of materials or energy from the environment or alter the structure and dynamics of ecosystems or the biosphere. Pro-environmental behaviour then refers to behaviour that harms the environment as little as possible or benefits the environment (Steg and Vlek, 2009). The aim here is to capture pro-environmental behaviours, that is, actions (contribution) rather than intent (to contribute), at individual, society and institutional levels that have the potential to influence conservation outcomes.

Solving environmental problems requires a collective effort, including adopting pro-environmental behaviours (Bodin, 2017). The components of influence over behaviour in the Theory of Planned Behaviour (section 3.2) can be meaningfully used as variables relevant to environmental outcomes. Frequently researched thus are social networks, an aspect of social capital that impacts subjective norms. Being embedded in a social context where others do not approve of pro-environmental behaviour can be a significant barrier to adopting such behaviours (Amel et al., 2017). Social networks are seen as an important avenue for distribution of influence (such as peer pressure and subjective norms discussed above) and also for new information (e.g. on scientific breakthroughs, pro-environmental technologies, potential catastrophic impacts of climate change) (Yletyinen et al., 2021). Levels of trust in sources of information and more general trust towards others in society and in particular towards government or other regulators are also important.

Also evident from section 3.2, is the critical need to consider social context and social composition. Economically and culturally diverse societies are likely to form ‘in-groups’ with beliefs and values that are very different from those of ‘out-groups’ within the same society (Spears, 2011). Different groups are then likely to voice their preferences and fight for dominance of their ideas by, for example, supporting different political parties and other interest groups. Therefore, variables such as cultural background and political party preferences need to be included in assessments. The existence, or desire for the existence, of alternative institutional arrangements and governance systems should also be noted (Addison et al., 2019).

Some believe that large-scale change in human values and associated behaviour is the ultimate solution to achieving global biodiversity conservation (Manfredo et al., 2016). The key argument here is that positive environmental and conservation outcomes are true social challenges and thus can only be effective in the long term through the active support of society, particularly landowners and sectors of the economy engaged in potentially destructive activities (de Snoo, 2013). Financial incentives such as payments for ecosystem services or carbon credits, legal instruments, regulation and similar ‘outside’ drivers are only temporary motivators, argues Pretty (2003). Only once new social norms, such as pro-environmental behaviours, have been embedded within the peer group is there a chance that desired behaviours will last for generations (Fielding et al., 2008, Primmer and Karppinen, 2010).

Effective governance and trust in governing institutions are important contributors to environmental outcomes. Specific to Australia is a large area of land and seas managed by Traditional Owners. Therefore, indicators of governance systems need to include not only government and institutions but also governance systems of organisations (private businesses and not-for profits) and of Indigenous people, community groups and NGOs. These aspects are particularly important, having in mind a report by the International Union for Conservation of Nature (Hockings, 2006) that identified inadequate funding, inadequate monitoring, lack of political support, lack of community support and insufficient outreach and partnerships as the most significant barriers to effective management.

Policy-making and planning-environmental laws, regulations and standards for the business sector, particularly building, manufacturing, agriculture and mining, can contribute to environmentally positive change (OECD, 2019). National-level policies, such as energy, land use or conservation policies, and ensuing plans, can also make significant contributions (ten Brink et al., 2011), with numerous studies reporting examples of dedicated conservation efforts producing considerable ecological gains (de Snoo, 2013). Environmental outcomes of some planning activities are noticeable at local and regional levels, while some aim at national and global outcomes.

In addition to creating a positive regulatory and policy environment through developing and passing pro-environmental policies and planning instruments, funding for implementation is essential. Ward and Lassen (2018) estimate Australia’s annual conservation finance gap to be approximately AUD 10 billion per annum (to put this in perspective, this represented less than 0.5% of total annual institutional investment in Australia at the time of study publication). They argue that, with some 77% of Australia’s land area managed by private landholders (including Indigenous people), expanding finance approaches to broaden the role of private land conservation, in conjunction with increasing Australia’s protected area network and other efforts, is a priority issue. Stoeckl et al. (2015) suggest that identifying pro-environmental objectives that are complementary (co-benefits) rather than competing with market objectives (trade-offs) may lower the cost of conservation to land managers. National budgets and tax policy cover 57% of conservation costs worldwide, compared, for example, to 2% from philanthropy and conservation NGOs; hence, the role of government policy, planning and financing mechanisms should not be underestimated (Deutz et al., 2020).

Variables for institutional assets emphasised by SEEA are those related to progress towards targeted conservation efforts, expenditures, and the development of economic instruments on nature conservation, estimation of a nation’s wealth, including natural capital and economic potential once the state of nature is considered, and assessment of government performance on sustainable development.

4.4 Financial/built capital

Economic activity clearly impacts the environment – the expectation being that different sectors affect the environment differently. Core variables that are regularly used to describe economic activity when focused on environmental policy thus include things such as the percent of workforce in various sectors of the economy; the percent of workforce in the ‘blue’ or ‘green’ economy (including eco-innovation and eco-design); economic participation and specifically, economic participation of the Indigenous population; responsible business conduct and requirements for best business practice or best-available techniques; and investment in environmental research and development, by companies as well as government (Ortega-Lapiedra et al., 2019, OECD, 2019, Scarpellini et al., 2018). Some of the later variables also describe governance and are thus also relevant to earlier discussion around social/institutional capital. Noted earlier, it is a rare variable that is relevant to only one type of capital.

Strong financial markets and access to finance are essential for economic development, growth, and poverty reduction. However, for such growth to be sustainable, financial institutions should embrace sound environmental and social management systems to underpin their financial investment and thereby enhance the productive role of domestic capital and financial markets (OECD, 2019). Governments need to put in place policy measures – such as tax breaks, de-risking guarantees and regulatory requirements, if the private sector is to be induced to invest (Deutz et al., 2020). Therefore, indicators related to financial capital and its relevance to the environment, could represent individual/family finance, productive capital finance and environmental regulations linked to the finance sector. Financial instruments that support environmental incentives are also relevant (de Snoo, 2013).

Innovative financial instruments and vehicles have been developed internationally to channel finance towards investments that support the transition to a low-carbon economy, improve the efficient use of natural resources and reduce environmental impacts (OECD, 2019). For instance, corporates, national and sub-national governments, and development banks have increasingly issued green bonds to attract private finance for green projects. However, it is also important to note that the provision of financial incentives is not without potential drawbacks (de Snoo, 2013). The economisation of nature has been an important shift in environmental management in the 1990s (Goldman, 1998, Katz, 1998); however, evidence is emerging that offering financial incentives for performing pro-environmental behaviours can lead to previously intrinsically motivated behaviours becoming financially motivated (Deci et al., 1999).

In addition to the economic system in place, economic context is largely determined by the most profitable sectors of the economy and those providing significant employment. Economic dependence on a resource system, or a high value attached to the sustainability of the resource, determines the importance of the system to its users (Ostrom, 2009, Berkes and Folke, 1998). In an economic context, social–ecological systems that are heavily dependent on resource extraction will face different challenges from a system dependent on nature-based tourism (Stoeckl et al., 2011). Thus, economic context variables that might be relevant to environmental outcomes include the contribution of different sectors to gross domestic product and the percentage of the workforce in various sectors of the economy. The economic diversity of the society should also be noted where relevant as it contributes (as noted above) to the creation of ‘in groups’ and ‘out groups’. In this respect, economic participation and, specifically, the economic participation of the Indigenous population is relevant (Taylor et al., 2011).

Infrastructure is also critically important: it sits at the centre of development pathways and is linked to economic growth, environmental outcomes and wellbeing. Decisions on the location, type, design and timing of infrastructure developments can have profound implications for the environment, with poor-quality infrastructure contributing to air pollution, climate change, water quality and quantity changes, biodiversity loss and the degradation of ecosystems (OECD, 2019). Some infrastructure investments, such as investment in public transport infrastructure, can bring positive environmental outcomes. Other infrastructure development, such as roads, ports, housing, and factories, will bring predominantly negative outcomes. However, addressing the sustainability of such investments can decrease negative environmental outcomes by recycling materials and reducing air and water pollution (OECD, 2019). An infrastructure development might also create both positive and negative outcomes; for example, the existence of a road will increase air pollution but will also be fundamentally beneficial in accessing and extinguishing a wildfire.

5. Developing a generic list of variables relevant to integrated human–nature systems

In this section, we summarise Australian data we have been able to find that are available across the continent and that describe each of the capitals discussed above (Table 5-1). This helps identify data gaps. We note, in particular, the paucity of data relating to human and social/institutional capital, compared to data relating to natural and financial/built capital. We leverage insights from the literature and the data compilation to suggest a generic list of variables wish list that could assist in future assessments of integrated systems where the intent is to inform decisions relevant to our marine and terrestrial environments (Table 5-2).

Still a work in progress, Table 5-1 provides a rough count of the number of datasets we have thus far been able to obtain and compile within an integrated geographic database by type of capital. The numbers reported in that table corroborate findings from other researchers, who note an insufficiency of data to describe integrated systems and considerable knowledge gaps (BIO Intelligence Service, 2011, Hardy et al., 2021a, TEEB, 2010). For example, Larson and Alexandridis (2009) compared a 'wish list' of variables developed at the start of their project with variables that they were able to populate with readily available data, noting the following significant problems: in some cases no data or only potentially unreliable data were available; in many cases data were available but out of date; in numerous cases data were available but not at a useable geographic scale or data were available for some regions but not others.

Data relating to some forms of human, social and institutional capital are particularly difficult to obtain (BIO Intelligence Service, 2011, Hardy et al., 2021a, Brooks et al., 2006, Larson and Alexandridis, 2009). Looking at the descriptors within the human/social and institutional categories in Table 5-1, it is evident that data on more tangible elements of human society such as financial support for particular programs or the location of cultural sites are more readily available than data on, for example, subjective norms, perceptions or values. Similarly, for descriptors aligned with human capital the Australian Bureau of Statistics (ABS) collects much data that describe the general demographic characteristics of the population at each census or the number of years of education for people within a region. However, to the best of our knowledge, there are no nation-wide datasets reporting on the quality of the education or whether people understand natural systems. Data relevant to some forms of institutional capital is particularly difficult to find – there are broad indicators that describe land tenure or political incumbents, but we have yet to identify nation-wide datasets that describe critically important informal institutional arrangements and social norms. Moreover, for each type of capital, some specific data types are much more readily available than others, which is in line with reports in the literature (BIO Intelligence Service, 2011, TEEB, 2010, Brooks et al., 2006).

Table 5-1. Number of nationwide datasets compiled by type of capital, with general description.

Capital and description of type of data	Number of indicators obtained (count of datasets)
Natural capital	**41**
Climate	4
Extreme events	2
Land suitability	1
Geographic boundaries (IBRA)	2
Land use – conservation and natural environments	4
Plant distribution	1
Land use – production from relatively natural environments	3
Land use – water	7
Major vegetation groups	3
Significant ecological communities	1
Significant ecological communities and species	1
Significant species	1
Surface water – presence	1
Ecosystem service values – cultural	3
Ecosystem service values – regulating	6
Human capital	**23**
Demographics – households	8
Demographics – individuals	1
Demographics – Indigenous	1
Unemployment	1
Population count	2
Population count – Indigenous	2
Population density	1
Education	6
Social/institutional capital	**30**
Length of tenure	1
Institutional boundaries	4
Average block size	1
Places on the Commonwealth Heritage List (Indigenous, natural, historic)	1
Places on the National Heritage List (Indigenous, natural, historic)	1
Land concentration	1
Land tenure	1
Number of individual landholders	1
Protected areas	1
Political indicators	10
Cultural Background	2
Religion	1
Volunteering	1
Stewardship	1
ILSC Land Acquisitions and Grants	1
Indigenous – IPAs	1
Indigenous – Native Title	1

Capital and description of type of data	Number of indicators obtained (count of datasets)
Financial and built (physical) capital	**55**
Ecosystem service values – provisioning	2
Land use – intensive	3
Land use – manufacturing and industrial	1
Land use – mining	1
Land use – residential and farm infrastructure	1
Land use – services	1
Production from dryland agriculture and plantations	7
Production from irrigated agriculture and plantations	7
Land-use Transport	1
Land use – Utilities	1
Land use – Waste treatment and disposal	1
Indigenous Businesses	3
Mines – Location and status	1
ARIA Remoteness index (distance to major centres and services)	1
Employment	2
Sector of employment	7
Family/household income	3
Home ownership	3
Financial stress – mortgages	1
Financial stress – rent	1
Infrastructure – housing and public utilities 'at risk' from biosecurity pests	1
Internet	1
Housing	3
Vehicular ownership	1
Transport	1
Grand total	**149**

Our integrated dataset is not specific enough to populate the frameworks discussed or inform specific management issues; however, it provides contextual background that is critically important to all. Recognising the need to also take steps to develop bespoke datasets, we used insights from our in-progress compilation and insights from the literature to create a generic list of potential indicators and variables that could assist in future assessments. The main utility of such a list is the identification of likely available datasets (some of which we have already included within our existing compilation) that meet our criteria of being national scale and consistently mapped across space and ideally time (as multiple time steps are often needed to characterise trends in socio-ecological systems). The list also allows us to identify key variables within datasets and note data gaps, including where there are currently no national-scale datasets that meet our needs. Key variables and potential indicators to describe each asset class in terms of influence on environmental outcomes are provided in Table 5-2 below.

Table 5-2. Key variables, indicative indicators and data sources for understanding integrated nature–human systems.

Capital	Generic variables	Relevant to: Marine	Terrestrial	Indicative indicator(s)	Data source(s)*
Natural	Forests		✓	Forests – natural	DAWE
	Significant ecological communities and species	✓	✓	Threatened ecological communities and species, totem species	DAWE
	Underground water		✓	Underground water	GA
	Surface water		✓	Surface water	GA
	Soil		✓	Fractional coverage	GA/CSIRO
	Extreme events	✓	✓	Recent fires, floods, drought, cyclones/tropical storms	NRRA
	Vegetation cover		✓	Vegetation cover	NVIS, GA, CSIRO
	Sea floor, benthic habitats, vegetation cover	✓		Seagrass, kelp etc	NISBHD
	Ocean use zoning classification	✓		Conservation zones, habitat protection zones etc	CAPAD, GBRMPA
	Land use and management classification		✓	Land use and management classification	ABARES
	Climate	✓	✓	Seasonal rainfall, temperatures, windspeeds, humidity	BOM
	High volume shipping traffic	✓		Shipping lands and high-volume shipping areas	AMSA
	Commercial fishing	✓		Catch per unit effort by gear type	AFMA
Human	Population density	✓	✓	Population and land area	ABS Census
	Visiting population	✓	✓	International and domestic visitors	TRA
	Household size	✓	✓	Average household size	ABS Census
	Family composition	✓	✓	One-parent families, families with >3 or 0 children	ABS Census
	Gender	✓	✓	Number of women	ABS Census
	Age	✓	✓	Median age	ABS Census
	Employment	✓	✓	Unemployment rate	ABS Census
	Education	✓	✓	Schooling, degree	ABS Census
	Natural resource management skills	✓	✓	Natural resource management training	*Not identified*
	Green-economy skills	✓	✓	Green economy training	*Not identified*
	Health	✓	✓	Disability payments, life expectancy	DSS/NDIS, ABS
Social/Institutional	Land concentration		✓	Land concentration	ABARES
	Land tenure		✓	Land tenure	ABARES
	Number of individual landholders		✓	Number of individual landholders	ABARES
	Average block size		✓	Average block size	ABARES
	Protected lands and waters	✓	✓	Land designated as natural parks, protected areas, heritage or Indigenous heritage, protected areas (land and sea Country)	CAPAD, DAWE, NIAA
	Native Title	✓	✓	Native Title determination outcomes	NNTT

Capital	Generic variables	Relevant to: Marine	Relevant to: Terrestrial	Indicative indicator(s)	Data source(s)*
	Agreements over use of Indigenous-held lands and seas	✓	✓	Indigenous land-use agreements, traditional use of marine resources agreements	NNTT, GBRMPA
	Landcare boundaries		✓	Landcare boundaries	DAWE
	Tenure of forests		✓	Tenure of forests	DAWE
	Polices including environmental considerations	✓	✓	Environmental laws, regulations, standards for industry (in particular, building, manufacturing, agriculture and mining)	Federal/state/territory legislatures, Standards Australia
	Subjective sense of health	✓	✓	Self-reported health	HILDA
	Sense of place	✓	✓	Mobility	ABS Census
	Sense of wellbeing	✓	✓	Self-reported life satisfaction	HILDA
	Corporate responsibility	✓	✓	Companies with sustainability targets	*Not identified*
	Social: cultural background	✓	✓	Place of birth, English spoken at home, religion, Indigeneity	ABS Census
	Attitudes towards environmental behaviours	✓	✓	Strategies/campaigns promoting pro-environmental behaviours	*Not identified*
	Environmental behaviour	✓	✓	People recycling, using public transport etc	*Not identified*
	Environmental technologies	✓	✓	Solar panels, low consumption appliances, home insulation	*Not identified*
	Environmental activities	✓	✓	Contributions to environmental education, promotion, working on land and sea	*Not identified*
	Environmental activities	✓	✓	Participation in conservation activities	ABS
	Subjective norms/peer influence	✓	✓	Membership/following environmental organisations/activists; self-reported influence of peers	*Not identified*
	Perception of ability to act environmentally	✓	✓	Self-reported belief in being able to act/make a change	*Not identified*
	Trust in governing institutions	✓	✓	Self-reported trust	*Not identified*
	Social cohesion	✓	✓	Volunteering	ABS Census
	Social networks and communication preferences	✓		To locate, activate, interact with to enable change mechanisms	*Not identified*
	Policies including Indigenous considerations/traditional management practices	✓	✓		NIAA
	Environmental management and conservation	✓	✓	Funding (federal, state, council)	*Not identified*
	Environmental management by Indigenous people/groups	✓	✓	Funding (federal, state, council)	*Not identified*

Capital	Generic variables	Relevant to: Marine	Relevant to: Terrestrial	Indicative indicator(s)	Data source(s)*
	NRM/conservation plans funded/implemented	✓	✓	Number of plans, area of land covered	*Not identified*
	Environmental incentive/schemes for landowners	✓	✓	Uptake of funding, area of land covered	*Not identified*
	Political party	✓	✓	Party incumbent, party preferences	AEC
	Support for community groups and NGOs	✓	✓	Funding for environmental activities by community and NGOs	*Not identified*
	Support for Indigenous groups and programs	✓	✓	Number of land and sea rangers, funding for activities	NIAA
	Support for culturally appropriate environmental activities	✓	✓	Funding targeting culturally appropriate activities	*Not identified*
	Land and sea management by NGOs/Indigenous organisations	✓	✓	Area of land and sea managed by NGOs/Indigenous organisations	ILSC
Financial/Built	Income	✓	✓	Personal income, household income	ABS Census
	Home ownership	✓	✓	House fully owned or being purchased, medium housing loan	ABS Census
	Rental costs	✓	✓	Median rent	ABS Census
	Economic participation	✓	✓	Employment, unemployment, businesses (including Indigenous)	ABS Census
	Economy	✓	✓	$$$s or employment from sectors of the economy	ABS Census (for employment)
	Environmental incentive schemes for land managers	✓	✓	Participation in environmental incentive schemes	*Not identified*
	Cost of SME borrowing	✓	✓	Interest from SME borrowing	ABA
	Environmental best practice in lending	✓	✓	Banks/financial institutions following best environmental practice	*Not identified*
	Green borrowing	✓	✓	Green loans	*Not identified*
	Credit trading schemes	✓	✓	Number and value of trades: carbon credits, reef credits	Clean Energy Regulator, QLD government
	Environmentally responsible business conduct	✓	✓	Requirements for best-practice/best-available techniques, investment in environmental research and development by business and government	*Not identified*
	Indigenous land and management businesses	✓	✓	Number and income of businesses	ORIC
Physical /built	Transport	✓	✓	Airports, ports, road network	CSIRO
	Telecommunications	✓	✓	Mobile phone coverage, household access	ABS Census
	Commercial buildings	✓	✓	Businesses	*Not identified*

Capital	Generic variables	Relevant to: Marine	Relevant to: Terrestrial	Indicative indicator(s)	Data source(s)*
	Fishing/boating infrastructure	✓		Boat ramps, ports	GA
	Marine tourism infrastructure	✓		Pontoons, platforms	*Not identified*
	Production infrastructure	✓	✓	Factories, power generation, pipelines	*Not identified*
	Mines		✓	Mine location and status	GA
	Offshore petroleum		✓	Offshore petroleum exploration and leases	NOPIMS
	Social infrastructure	✓	✓	Schools; health, community and sports facilities	*Not identified*
	Remoteness	✓	✓	Remoteness index	ABS
	Dwellings	✓	✓	Homes	ABS Census
	Home rental	✓	✓	Homes rented commercially or from community organisation	ABS Census
	Access to internet	✓	✓	Homes without internet connection	ABS Census
	Access to motor vehicle	✓	✓	Home without access to motor vehicle	ABS Census
	Overcrowding	✓	✓	Number of persons per bedroom	ABS Census
	Occupied private dwellings	✓	✓	Occupied private dwellings	ABS Census
	Housing and public utilities at risk from biosecurity pests	✓	✓	Housing and public utilities at risk from biosecurity pests	CEBRA

Not identified = data source not identified (i.e. potentially not available, or not available consistently across different regions of Australia).

* For explanation of acronyms, please see the Glossary.

6. Discussion and conclusions: the practical uses of this work

Our dataset provides resource managers with useful *contextual information* – across multiple capitals for all of Australia. In this section, we describe how our dataset and the supporting information from sections 3, 4 and 5, provides a platform that can be used in subsequent investigations, with significant value-add:

1. **Identifying the right plan for the right place – section 6.1**. There are many different types of regional plans, some of which may be relatively easy to implement, and some of which are not. Before developing potentially expensive regional plans, it is thus important to determine what type of planning is needed: the goal should be to ensure that plans are sufficient to manage the problem at hand, but not superfluous. Requirements for planning depend on context. Our regional-planning decision tree (Figure 6-1) can be used in conjunction with our dataset to help scope planning needs. Below, we outline plans to do that.
2. **Identifying places where insights from a research project undertaken at a specific study site might be transferred to (potential transfer sites) – section 6.1**. It makes no sense to transfer the findings of research undertaken in Timbuktu to a vastly different environment such as Antarctica. But it may make sense to transfer findings between places that are contextually 'similar' (e.g. sharing similar social, economic, and biophysical characteristics). Our dataset can be analysed to identify regions that are contextually similar, so it may help research dollars (and findings) stretch further. Below, we outline plans to do that.
3. **Prioritising activities to fill identified data gaps – section 6.3**. We have identified clear data gaps but note that it would be prohibitively costly to fill all. As above, the goal should be to ensure that activities undertaken to fill data gaps are sufficient to inform the problem at hand, but not superfluous. We have discussed broad types of data needed to address broad problems – explaining why that data/information is required. Data requirements depend critically on context. We have outlined a process for working with local stakeholders to clearly determine which of the data gaps identified in our reality check need filling to address specific problems in specific contexts and to co-design a system for doing so.

6.1 Identifying the right plan for the right place

Our dataset helps improve understanding of regions by allowing for the selection of planning approaches that meet, but do not exceed, contextual needs. It thus helps avoid either expending scarce resources on unnecessarily complex plans, or conversely, implementing approaches that are under-resourced and likely inadequate/unsuitable/insufficient.

There are numerous frameworks for understanding and conceptualising the relationship between humans and nature, and so too, there are many planning frameworks. In this section, as examples, we summarise and contrast 4 key regional-planning approaches; threat abatement planning, regional spatial planning, coastal-zone planning and cumulative impact assessment. We also describe how and when the frameworks can be used, associated methods, decision-support tools and some of the data considerations.

Matching the right planning approach to the context is driven by the planning question as well as the overall context. The aspects of the planning context we focus on are the presence of multiple uses or users, the spatial overlap or potential conflict between these uses, the involvement of multiple threatening processes and the presence of sensitive species and ecosystems. These represent strong planning 'signals' around the type of planning context and thus the level of complexity that the chosen approach must be equipped to deal with. Where there are not multiple complicating factors, the policy context is likely to be simple enough to support site-based or single intervention traditional planning. Where multiple complicating factors co-exist, regional approaches with more sophisticated analyses and more extensive stakeholder-engagement processes are warranted.

In addition to the overall goal or planning objective, often immediately informing the type of planning approach to choose, we have developed a decision tree (Figure 6-1) to help navigate when and where these regional-planning approaches might be deployed. The decision tree captures key binary choices that a planner will have to make in differentiating context. The context can be defined based on the data summarised in this report, demonstrating the power of the data that we have assembled. It is possible to use the data compiled within this project to identify regions that are most suited for each type of regional-planning approach identified in the decision tree. This will allow managers to readily identify the type of planning approach most suited to their region and planning context.

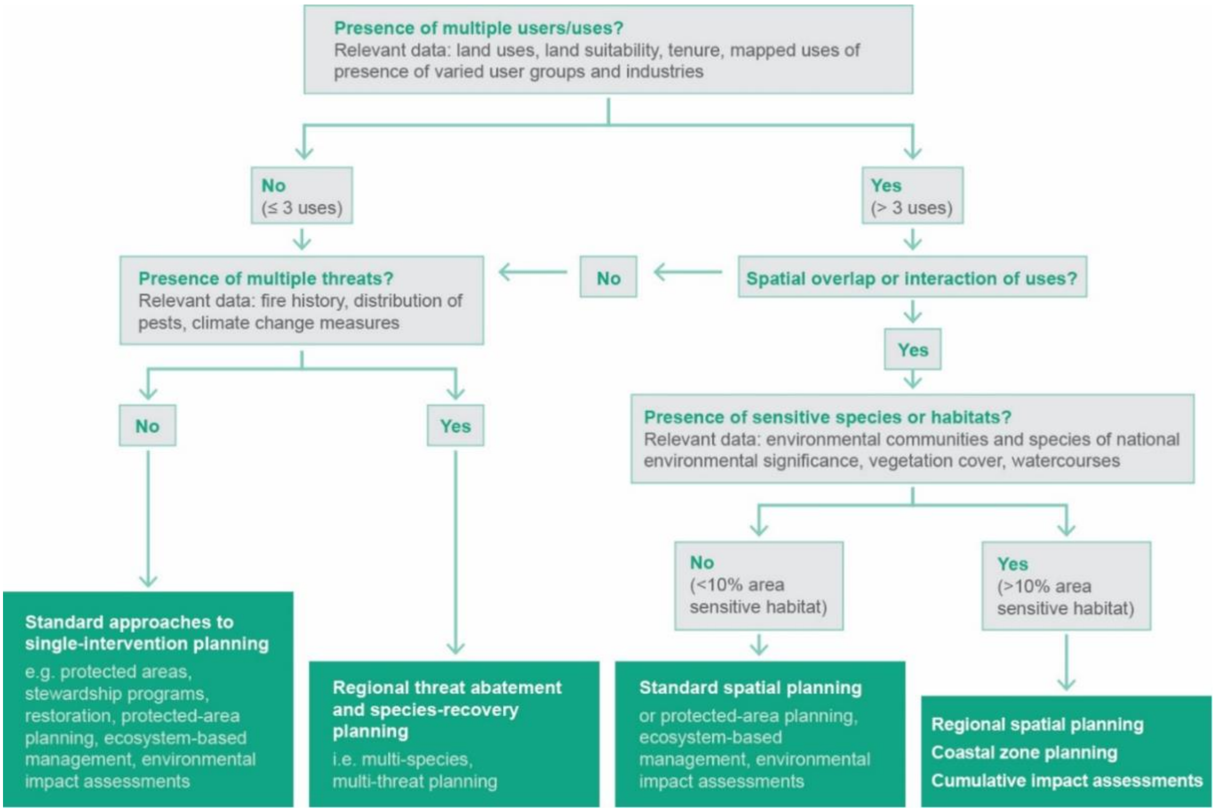

Figure 6-1. Regional-planning decision tree.

6.1.1 Threat-abatement plans

In contexts where the number of users or land and sea uses is limited (e.g. indicated by lower numbers of land uses or tenures) then standard approaches to single intervention planning or regional threat abatement planning for multiple species may be most appropriate. Threat abatement plans are statutory requirements designed to protect biodiversity from a threatening process, independent of land tenure (Leys, 2004). Broad-scale regional plans are needed to address threats to native species and communities that are rarely constrained by property or government boundaries. Threat-abatement plans are inherently regional given the need to address threats across different land tenures.

While statutory threat-abatement plans may be focused on a single threat due to planning obligations, efficient resourcing of actions guided by these plans is best achieved when plans consider multiple threats to multiple species at a regional level. Thus, a multi-threat planning approach at a regional level can guarantee better species recovery outcomes. Customised optimisation approaches have also been developed for spatial threat-abatement planning across multiple species and threats (Carwardine et al., 2012, Cattarino et al., 2015).

Outputs can show areas where development needs to be avoided or, conversely, where development would be least impactful. Data needed to populate such planning tools include data on ecosystem extent, presence of threatened species and ecological communities, presence of threats, and the responses of species to these threats.

While the data we have assembled on natural values often represents the best available spatial data it often remains insufficient for detailed spatial planning and is ideally complemented with finer resolution local scale data on presence of threatened species. Data on species' responses to threats (and management or abatement of threats) is typically absent and must be elicited specific to the region and species. Threat abatement planning for multiple species at regional scale is often most appropriate, as noted above, for regions where land tenure is reasonably homogenous, and number of competing uses limited. Thus, it is a planning approach that can be well supported by the data we have assembled but does still require targeted additional natural capital data. This is distinguished from the other planning approaches that are applied in increasingly complex socio-economic settings and thus require specific targeted data for other types of capital to support meaningful planning processes.

Threat-abatement plans are required under the EPBC Act and most state legislation, such as the NSW Threatened Species Conservation Act 1995 and Tasmania's Threatened Species Protection Act 1995. Threat-abatement plans are statutory requirements designed to protect biodiversity from a threatening process, independent of land tenure (Leys, 2004). Broad-scale, multi-tenure plans are needed to address threats to native species and communities that are rarely constrained by property or government boundaries. Threat-abatement plans are inherently regional given the need to address threats across different land tenures. Furthermore, while statutory threat-abatement plans may be focused on a single threat due to planning obligations, efficient resourcing of actions guided by these plans is best achieved when plans consider multiple threats to multiple species at a regional level. Thus, a multi-threat planning approach at a regional level can guarantee better species recovery outcomes. Customised optimisation approaches have also been developed for spatial threat-abatement planning across multiple species and threats (Carwardine et al., 2012, Cattarino et al., 2015). Outputs can show areas where development needs to be avoided or, conversely, where development would be least impactful.

6.1.2 Regional land-use spatial planning

Regional land-use spatial planning seeks to make structured decisions about the future of regions by planning for what land uses are acceptable, to what extent, and where. Land-use planning is a statute-based process that facilitates a discussion about future land use between stakeholders. Essentially, it is the set of rules about what can and cannot happen in areas of land and the conversation that occurs among the developer, decision-maker, and other interested parties, including the public. Regional plans thus provide the regional view around what local land uses can or cannot occur and where, ensuring that these uses add up to meaningful regional futures.

Regional spatial planning is most appropriate to apply to regions (both land and sea) where there are multiple possibly competing uses that would thus benefit from in depth planning to support spatial choices around best uses of limited resources. Regional-planning processes thus require data on the underlying environmental values (e.g. in our dataset we have summarised ecosystems and matters of national environmental significance (MNES) present at regional scales), threats to these natural values requiring management (e.g. fire, ferals), land and sea uses (e.g. in our dataset land uses, tenure, and land capability for agricultural uses), and the values or benefits that people receive from the environment (typically place specific and must be elicited in the context of the planning process).

To be effective, regional plans need to be statutory documents that are consistent with local planning schemes. Where there is conflict, the regional plan needs to take precedence. For example, Tasmania has 3 regional land-use strategies that are declared under the *Land Use Planning and Approvals Act 1993.* These strategies introduce urban growth boundaries and clarify the long-term goals for different zones within the region, such as the density of housing and overall objectives for the ways different areas contribute to the function of the region. Planning schemes administered by local government need to follow these regional plans. Spatial prioritisation methods, such as Zonation or Marxan, are increasingly used for regional planning because they can consider multiple potentially competing land uses and varied environmental and social values over large scales (e.g. Whitehead et al. (2017)). While some of the datasets assembled in our dataset are appropriate for inclusion (e.g. ecosystem mapping, threats to natural values), place specific detailed data at finer scale is typically needed (e.g. higher resolution mapping of where MNES are present, benefits or values associated with natural values).

In addition to state tools, the other mechanism available for regional planning is under Part 10 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The EPBC Act allows for strategic environmental assessment relating to an endorsed policy, plan, or program. However, despite this capacity under the EPBC Act for a suite of actions to gain approval, there have only been 26 formal strategic assessments since the EPBC Act was introduced, only 10 of which have been completed.

6.1.3 Coastal-zone planning

The coastal zone is where the terrestrial, freshwater, and marine realms mix. It is commonly heavily populated by residences and often contested developments such as ports and shipping. Coastal-zone planning (also often termed cross-realm, ridges-to-reed or catchment-to-coast planning) is a natural extension of regional planning and of integrated catchment management. It provides a planning process to guide the spatial allocation of land–sea uses and management actions to achieve explicit environmental and socioeconomic objectives across multiple realms.

Failing to account for the social and environmental relationships across these connected realms can result in unintended consequences, including loss of environmental values or unacceptable impacts on social, economic and environmental values. For example, approving a coastal development without considering the connection to marine values can result in downstream negative impacts to marine habitats and undesirable risks to the development, such as from unplanned-for sea level rise or storm events. Coastal-zone planning accounts for these spatial dependencies and relationships and thus supports decision-makers in avoiding undesirable consequences. It also facilitates the deployment of innovative planning solutions such as nature-based solutions.

Coastal-zone planning will often naturally guide development decisions taking into account the cumulative impacts of threats across realms. It may thus also be considered an extension of cumulative impact assessment (discussed below). The distinguishing factor between these regional-planning approaches is the spatial location (coastal zones) and the purpose of the planning. For example, cumulative impact assessment may be appropriate for evaluating or guiding single developments, whereas spatial land and sea planning, taking into account multiple uses, will require coastal-zone land–sea planning (Álvarez-Romero et al., 2015). The data and tools required to support coastal zone planning mirror those used for regional planning. However, the connections between land and sea necessitate further place specific data such as sediment flow, river plumes, and impacts to marine environments.

6.1.4 Cumulative and other impact assessments

An Environmental impact assessment (EIA) is designed to assess and approve individual developments and consider existing and historic land uses, assessing the impacts of existing and proposed developments. The term ‘environment’ includes the social, cultural and economic environment, so EIA is often referred to as ESIA – Environmental and Social Impacts Assessment (for example, by the World Bank Group, 2017[2]).

That said, evaluating and planning for individual environmental impacts using a standard EIA approach can fail to account for the multiple compounding and interrelated impacts on environmental values. Thus, even with high-quality EIAs, we often still observe declines in the values being managed, attributable to ‘death by a thousand cuts’. Cumulative impact assessment (CIA) is designed to fill a gap in project-based EIA by extending the EIA approach to consider multiple interacting, and often compounding, impacts on values (environmental, social, and economic). In expanding the scope from single to cumulative impacts, a regional perspective is often needed as impacts can be spatially dispersed and

[2] worldbank.org/en/projects-operations/environmental-and-social-framework

have various interactions and/or spatial dependencies. As with regional planning and coastal zone planning, CIA can be supported with similar decision support tools. The data needs required for CIA are similar to those described above and require further additional location specific and species-specific data in particular higher resolution data on threats to environmental values and how specific environmental values (e.g. ecosystems or threatened species) respond to these threats and management or mitigation of them. This type of data is similar to the data specific needs for multiple species threat abatement planning. Thus, CIA may require the most comprehensive place specific data to be assembled as a culmination of all data detailed across the other planning types.

6.2 Identifying places that are contextually similar

Our dataset can be analysed to identify regions that are contextually similar, so it may help research dollars (and findings) stretch further. To achieve the best outcomes (such as knowledge gains and ultimately, protection of ecosystems and biodiversity), funds allocated to research, planning and on-ground environmental action must be spent cost-effectively. This means being able to translate knowledge across regions in sensible ways to use the available evidence to build the most impactful environmental programs. Our integrated dataset, which provides contextual descriptors of 4 capitals across all of Australia, lays the foundations for doing just that. It consistently describes areas across Australia using metrics that can be compared and analysed to identify regions that share similar attributes.

Understanding and ‘matching’ areas that share similar attributes allows for translation of research findings from one place to others that are ‘similar’. We have thus taken the first step in supporting transferability of knowledge and solutions at scale by collating the necessary frameworks and baseline data, although we suggest that better contextualisation could be achieved, if our dataset were supplemented to include data about other critical additional climate variables and threats (e.g. climate hazards, projected changes in climate extremes, distribution of threatening processes such as invasive plants and animals).

The data can be analysed at different geographic scales, from small areas to larger regions. The ‘optimal’ size or type of region will be different for different decision-makers, although likely candidates include Interim Biogeographic Regionalisation for Australia (IBRA) subregions, Natural Resource Management (NRM) regions, and Local Government Areas (LGAs). These have been identified by participants in workshops as the ‘right’ size of region for planning as well as relevant governance scales. It is possible to use this regionally summarised data to identify regions that are similar or different (based on statistical matching methods as demonstrated in Larson and Alexandridis 2009), and thus indicate transferability of research findings from one region to another. Similarly, managers can query the dataset to discover regions most similar to their own to draw ‘lessons’ learned.

6.3 Prioritising data gaps that need 'filling' to support managers addressing specific problems

The integrated dataset compiled in this report provides important contextual background across a broad range of capitals. Significant data gaps mean that the dataset is unlikely to have sufficient detail to populate frameworks to inform many specific management issues. It would be prohibitively costly to fill all data gaps, and critically, it is not necessary to do so. The goal should be to ensure that activities undertaken to fill data gaps are sufficient to inform particular problems; but not superfluous. In this section, we outline a process for working with local stakeholders to clearly determine which of the data gaps identified in our reality check need filling to address specific problems in specific contexts and to co-design a system for doing so (Figure 6-2).

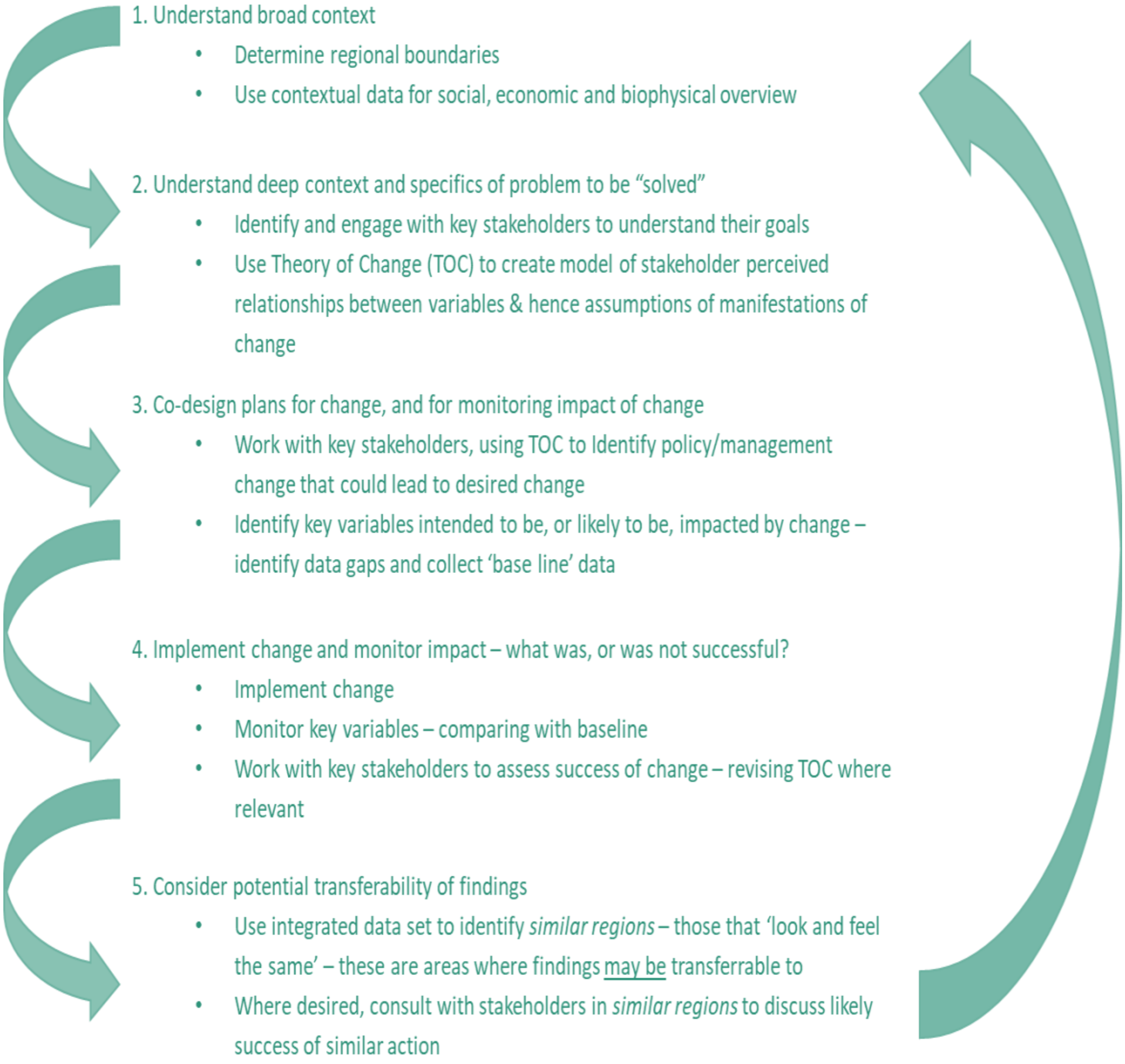

Figure 6-2. Potential process for working with stakeholders to identify and then fill data gaps. This process helps ensure that data-generating activities are sufficient to inform the problem at hand, but not superfluous. Note the final step: to update dataset and to consider the extent to which findings may be transferrable to other regions (section 6.2).

Step 1. Our generic list of potential indicators provides the foundations for what could (perhaps should) subsequently develop into a methodical process for defining the data (assets, variables, indicators) that are likely to be relevant in a particular setting or action situation and using it to solve specific problems. It provides important background context about a region and could assist one to identify potentially significant issues and stakeholders.

Step 2 requires one to develop a deeper understanding of the context. This will likely require the use of a holistic approach that highlights locational and managerial issues and thus helps to determine precisely the goals of decision-makers in that particular situation. A systemic change-management process such as the Theory of Change (Stein and Valters, 2012, Vogel, 2012) could be used to create a model of perceived relationships among variables and hence enhance understanding of the assumptions of manifestations of change (in assets, variables, indicators).

In line with Ostrom (2007), we agree with that frameworks are important as a means of organising inquiry and providing concepts and terms that may be used to construct causal explanations. However, the key value of a framework is that it can be used to populate a model (with data), with that model providing a more detailed manifestation and explanation of the functional relationships among variables, specific to and significant in a particular setting. Different models can be created that represent different aspects and explanations of a common conceptual framework, specifying which of a framework's basic elements (subsets of variables and their interconnections) are particularly relevant to certain kinds of questions or places (McGinnis and Ostrom, 2014).

Critically, not all management problems can be addressed by the same framework/model. One size does not fit all, and a framework/model that is 'best' in one situation may not be 'best' in another. Decisions about frameworks/models – and data used to populate models – must vary according to the question at hand, the setting, processes and the desired outcomes (e.g. valuation of assets and flows, valuation of past investments, conservation of animal or plant species, improved human wellbeing or wellbeing of a specific segment of society, e.g. Traditional Owners). In seeking to use frameworks and models, it is thus vitally important to first specify the problem to be addressed, and from that, select and appropriate framework.

Step 3 would enable co-design of research, management or policy action that leads to impact (Blythe et al., 2017, Van Kerkhoff and Lebel, 2015) while ensuring that solutions are both socially and environmentally responsible (Bernstein, 2015). This would likely also involve the identification of key data/knowledge gaps required to support the action and the development of plans to fill them.

The integrated dataset compiled for this report is not specific enough to fully populate all frameworks &/or inform particular management issues. It is important to ensure that the data used to populate the chosen framework is high quality. The information and data feeding into any assessment process are central to the quality of the outputs and insights delivered to decision-makers (Hardy et al., 2021a). The effort required to identify existing relevant datasets and knowledge and to gain access to that data/knowledge is considerable (Hardy et al., 2021a). In Australia, data and information of relevance are housed across multiple jurisdictions, agencies, organisations, and community groups. Some holders of relevant information and knowledge may be unwilling to provide access (as noted for the mining industry by Larson and Alexandridis (2009)), or data might be sensitive such as Indigenous cultural knowledge (Woodward et al., 2020).

The generic list of variables provided in Table 5-2 can be used in conjunction with the discussion of section 4 and alongside Table 5-1 to guide the compilation of data relevant to a specific problem at hand. Critically, such compilations should be done with relevant stakeholders to help make informed decisions about which variables and indicators should be used and why.

Step 4 highlights changes that could also, potentially, be monitored, with the intention of assessing whether desired goals and impacts have been achieved. Notably, at least some of the information gathered during steps 2–4 of the bespoke process could be added to our integrated database. Over time, a pool of variables and indicators could be identified for each process (plan, activity, intervention) that are context-specific and fit for purpose, noting that variables and indicators are liable to change over time given evolving literature/data collection.

Step 5 suggests that one can use the ideas outlined in section 6.2 to identify other regions that share similar characteristics, the intent being to find other areas, where the solutions developed in the study region might also be relevant.

Adopting this type of place-based, socio-ecologically integrated approach will enable informed decisions on which variables and indicators should be used in a particular context and why – improving both human and environmental outcomes. As we note from the literature, purpose-specific variables and indicators are commonly discussed; context-specific, less so. Understanding both purpose and context-specific characteristics would potentially allow for the development of typologies of places (Larson et al., 2013), to improve our ability to identify locations for particular studies or interventions based on their similarities or difference. Thus, although variables utilised in any place-based model of environmental management should be relevant to a broad range of environmental policies/plans, the particular set of variables should be driven by the problem/situation, the place/context and the actors/beneficiaries/users. For example, the SEEA framework recognises that the assessment of multiple values often requires the consideration of local context and a diversity of actors.

For complex planning approaches, such as those of international relevance, several frameworks might be of relevance. For example, United Nations Environmental Program guidelines for Integrated Environmental Assessment (UNEP, 2019) recommend analysing and synthesising existing environmental, social and economic data using the Driver-Pressure-State-Impact- Response (DPSIR) framework. Guidelines also call for consideration of all ecosystem components as well as processes, based on ideas of Millennium Ecosystem Assessment (MEA) and the Common International Classification of Ecosystem Services (CICES). The actual data gathered and used should provide inputs into the experimental ecosystem accounts within the System of Environmental-Economic Accounting (SEEA) process (UNCEEA, 2021). (Haines-Young and Potschin-Young, 2018)(Haines-Young and Potschin-Young, 2018)(Haines-Young and Potschin-Young, 2018)(Haines-Young and Potschin-Young, 2018)It is further recommended that all environmental dimensions of the

2030 Agenda for Sustainable Development (Sustainable Development Goals, SDGs) be woven with socioeconomic plans of development; with SDG targets and indicators also underpinned by data collected using SEEA system of accounts.

Not all planning needs to conform to these international systems, and a good example of work for informing local-scale land management activities is the Australian Ecosystem Models Framework developed by CSIRO (Richards et al., 2020). The aim of this project was to collate, synthesis and summarise scientific knowledge of ecosystem dynamics (including ecosystems responses to disturbance regimes) and capture this knowledge in a set of dynamic ecosystem models, as support tools for natural resource management. Five state and transition model case studies were developed in the initial project, to demonstrate the utility of the approach. Authors propose that future work could use the framework as a basis for developing an over-arching typology of generalised ecosystem states and threats linked to the current disturbance-based typology of archetype models; and analyse similarities and differences between ecosystem responses to endogenous and exogenous disturbances. However, as the name of the framework suggests, these models are based on ecological/ecosystem data only; and do not include human actors/beneficiaries/users and their characteristics. The framework does include ‘people’ only in terms of anthropogenic types of disturbances (i.e. what people do to nature, negative, such as building of a dam; application of a pesticide) and potential mitigative/ameliorative measures (i.e. what people do to nature, positive, such as change in grazing or fire regime). Creating integrated models that also bring into consideration diversity of human actors, their values and priorities, could improve such initiatives. We also add to this the need for identification and understanding of a particular management problem.

What planning approaches do have in common is the goal of identifying and assessing past and potential management actions; and providing guidance for decision-makers on the consequences of varying management actions, including inaction (UNEP, 2019). One important link between science and policy – of relevance to this project – is that of determining risk and uncertainty in the information. We do not have sufficient data to adequately describe the integrated socio-ecological systems that support us. We trust this report provides guidance on finding efficient ways of improving the information that is available for policy-makers to generate better human–nature outcomes, specifically, how we (i) use the information we do have and (ii) prioritise the collection of new data. The underpinning dataset provides resource managers with useful *contextual* social, economic, and biophysical background across Australia. Our dataset and the supporting information within this report provide a platform that can be used in subsequent investigations.

7. Glossary

ABARES............Australian Bureau of Agricultural Resource and Environmental Science

ABA....................Australian Banking Association

AEC ....Australian Electoral Commission

AFMA.................Australian Fish Management Authority

AMSA ....Australian Maritime Safety Authority

BOM...................Bureau of Meteorology

CAPAD ....Collaborative Australian Protected Areas Database

CEBRA ....Centre of Excellence for Biosecurity Risk and Analysis

CIA......................Cumulative impact assessment

CICES................Common International Classification of Ecosystem Services

CSIRO ....Commonwealth Scientific Industrial Research Organisation

DAWE................Department of Agriculture, Water and the Environment

DPSIR................Drivers–Pressure–State–Impact and Response

EEA....................European Economic Area

EIA ....Environmental impact assessment

EPBC Act...........Environment Protection and Biodiversity Conservation Act 1999

FEGS ....Final Ecosystem Goods and Services

GA......................Geoscience Australia

GBRMPA ....Great Barrier Reef Marine Park Authority

HILDA ....Household Income and Labour Dynamics Australia

IPBES ....Intergovernmental Platform on Biodiversity and Ecosystem Services

MA ....Millennium Ecosystem Assessment

NCP ....Nature's Contribution to People

NESP ....National Environmental Science Program

NGO...................Non-government organisation

NIAA ....National Indigenous Australians Agency

NISBHD ....National Intertidal–Subtidal Benthic Habitat Distribution

NNTT ....National Native Title Tribunal

NOPIMS ....National Offshore Petroleum Information Management System

NRM....................Natural resource management

NRRA ....National Recovery Resilience Agency

NVIS ....National Vegetation Inventory System

OECD ....Organisation for Economic Cooperation and Development

ORIC...................Office of the Registrar of Indigenous Corporations

SEEA ....System of Environmental-Economic Accounting

SES.....................Socio-ecological System

SME ....Small and medium enterprise

TEV.....................Total Economic Value

TRA.....................Tourism Research Australia

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9. Appendix 1. Total Economic Value

The Total Economic Value (TEV) framework (Krutilla, 1967) is an economic framework used to assess the value of natural resources (see, for example, (ten Brink et al., 2011)). The traditional economic approach only saw the value of the natural environment in raw materials and physical products generated for human production and consumption, which led to under-valuation resulting in economically sub-optimal outcomes. The TEV framework takes subsistence and non-market values, ecological functions and non-use benefits into account, presenting a more comprehensive picture of the economic importance of natural resources. TEV is the total willingness to pay (e.g. market prices, revealed or stated preference methods) for all types of benefits, aggregating individual values/preferences to derive a total value. The framework is well suited for valuation exercises; however, this approach concentrates on one directional interaction of nature providing benefits (value) to people.

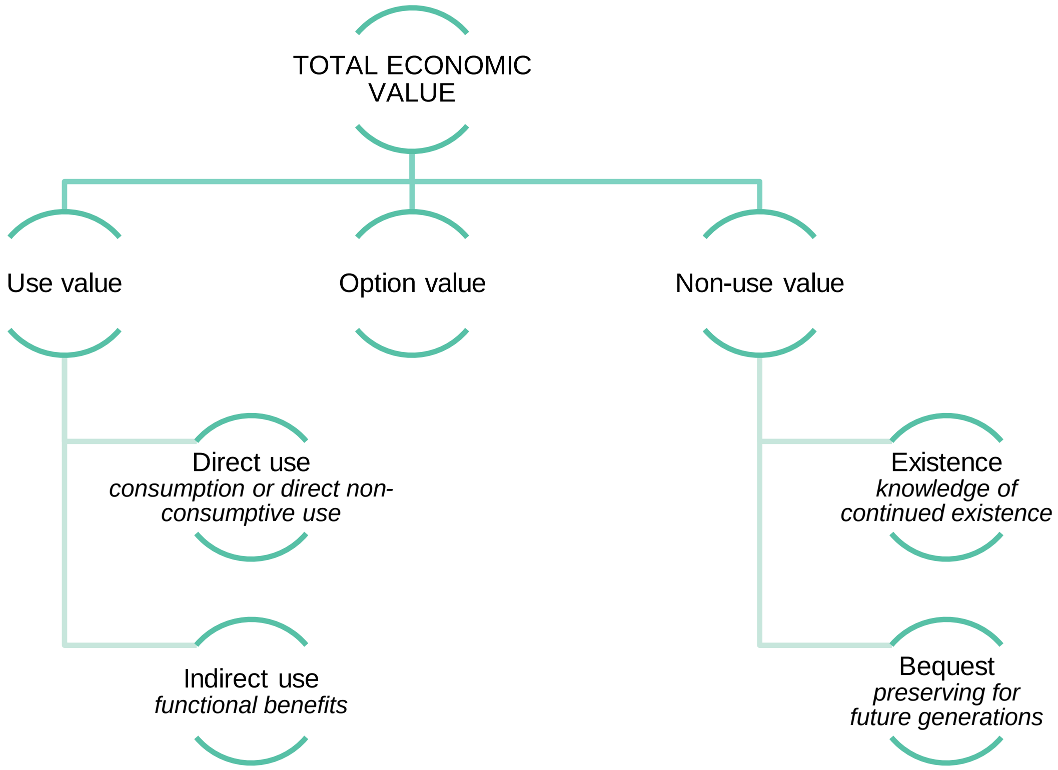

Figure A. The Total Economic Value framework (adapted from Krutilla (1967)).

10. Appendix 2. Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MA) is the result of a 4-year international work program designed by the United Nations to assess the conditions and trends of the world's ecosystem services (Toth, 2003). The MA categorised ecosystem services into 4 broad categories: provisioning services (direct use values), regulating services (indirect use values), cultural services (use and non-use values) and supporting services (MEA, 2005a). The MA framework highlights the benefits (social, ecological and economic) people obtain from nature/ecosystems and their contribution to human wellbeing, thereby highlighting people's dependency on ecosystems and providing policy-makers with a basis for reconciling economic development and ecosystems (Toth, 2003).

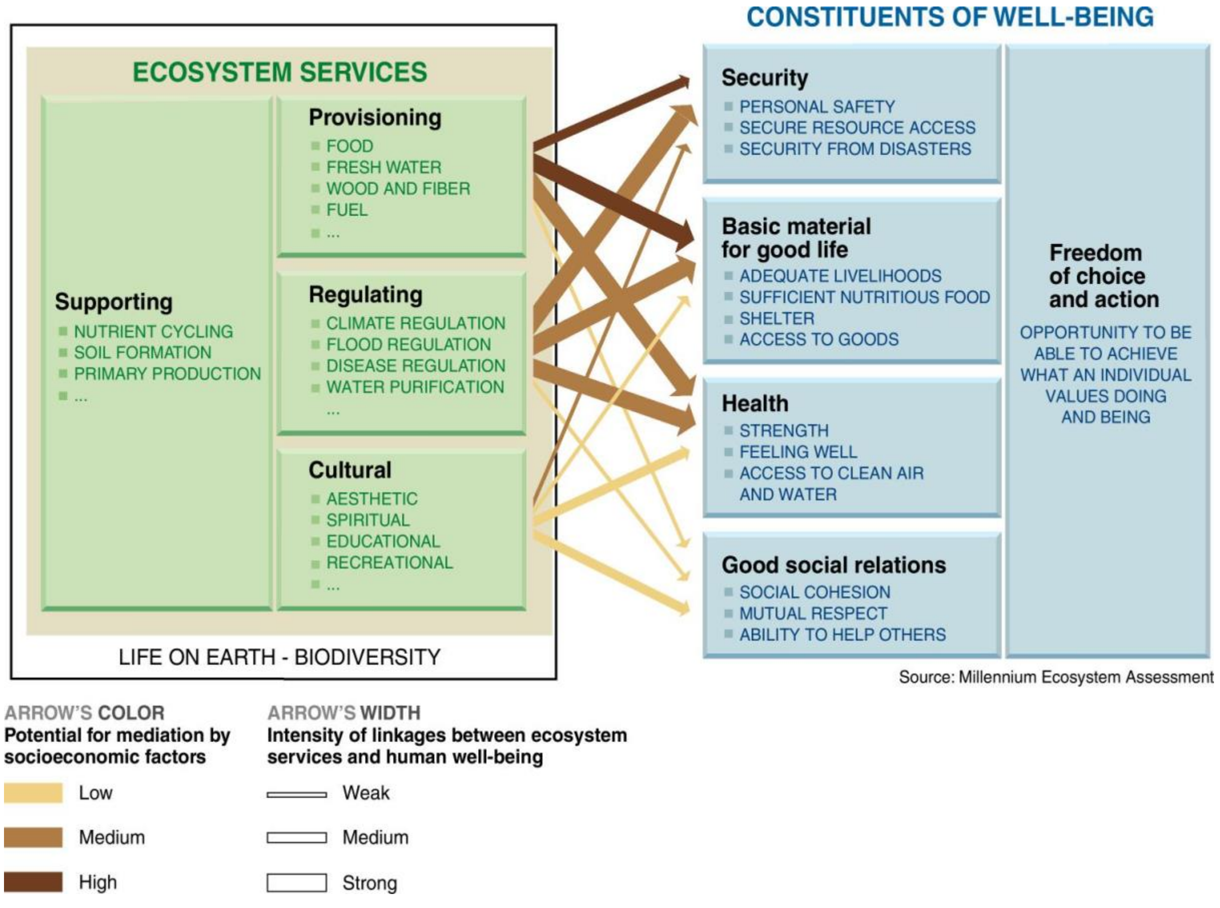

Figure 10-1. Millennium Ecosystem Assessment – linkages between ecosystem services and human wellbeing (MEA, 2005b).

11. Appendix 3. Common International Classification of Ecosystem Services

The Common International Classification of Ecosystem Services (CICES), derived from the MA classification system, was designed to help systematically measure, account for, and assess final ecosystem services (Haines-Young and Potschin-Young, 2018). These services are final in that they are the outputs of ecosystems (whether natural, semi-natural or highly modified) that most directly affect the wellbeing of people. A fundamental characteristic of final services is that they retain a connection to the underlying ecosystem functions, processes and structures that generate them (i.e. soil and water that allow the growth of wood used for timber). The ecosystem services and the resulting human wellbeing are considered systematically minimising the double-counting of related (ecosystem) values. The conceptual framework for the CICES is the cascade model shown in Figure 11-1. Services, in the cascade, give rise to goods and benefits, as in the case of timber when it is harvested, and this is the moment when the ‘production boundary’ between environment and social and economic system, is crossed. The concepts of goods (tangible things with assigned monetary value, e.g. processed timber) and benefits (less-tangible ecosystem outputs, e.g. recreation as a cultural service of woodland) describes things that ultimately have value for people (Haines-Young and Potschin-Young, 2018).

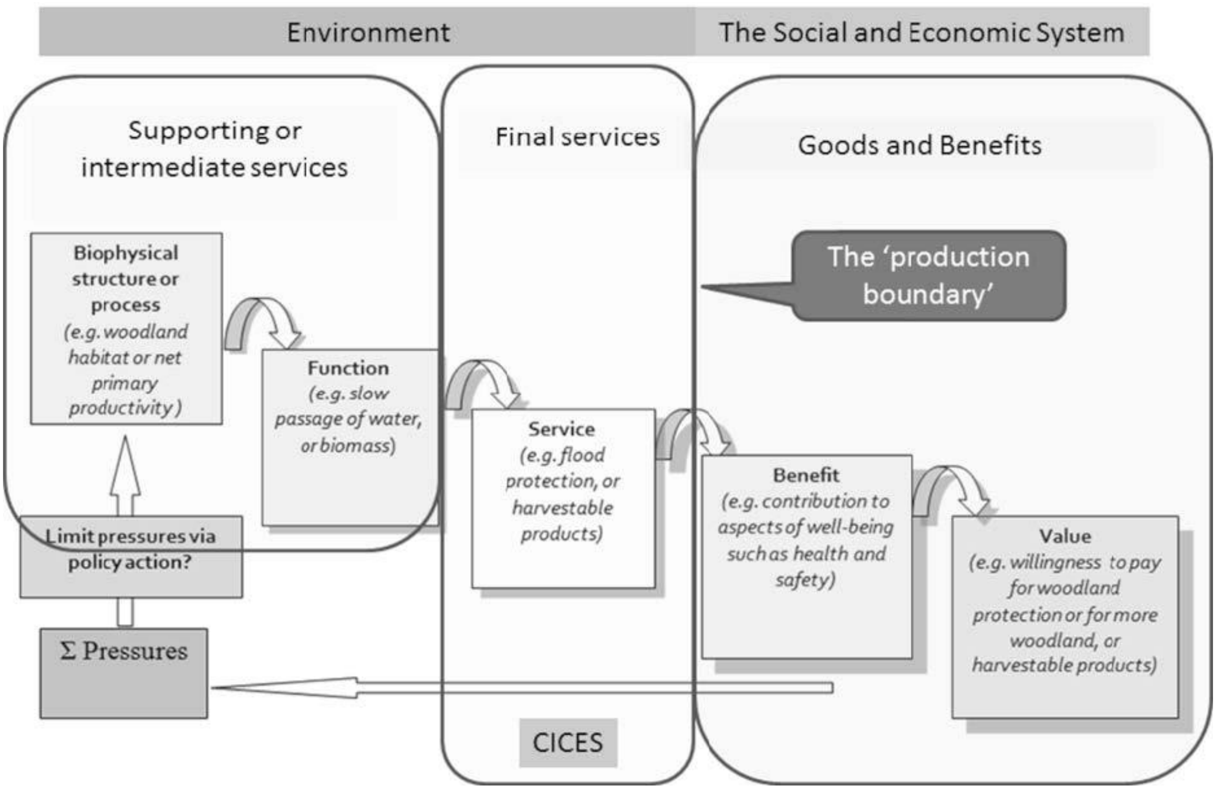

Figure 11-1. The CICES cascade model (from Potschin and Haines-Young (2011)).

12. Appendix 4. System of Environmental-Economic Accounting

The System of Environmental-Economic Accounting Ecosystem Accounting (SEEA-EA) builds on 5 core accounts: ecosystem extent (spatial extent of the ecosystem, physical terms); ecosystem condition (health of the ecosystem, physical terms); ecosystem services flow (physical terms); ecosystem services (monetary terms); and monetary ecosystem asset (UNCEEA, 2021). The SEEA-EA provides an integrated and comprehensive statistical framework for organising data about habitats and landscapes, presenting biophysical data on the extent and condition of ecosystems (stocks), measuring changes in these ecosystems and the ecosystem services provided (flows), and linking this information to economic and other human activities and wellbeing (UNCEEA, 2021). Significantly, this approach broadens the focus beyond ecosystem services to include stocks of both natural and social assets, thus explicitly linking nature, ecosystem services and society. Further, the system explicitly links the flow of ecosystem services from specific ecosystems to specific groups of beneficiaries (e.g. households, businesses), highlighting co-benefits and trade-offs within these relationships. Values are based on exchange values in line with standard economic accounting principles allowing natural capital to be integrated with the existing system of national account measures and enabling comparison of ecosystem contributions to society with other goods and services. The framework also allows identification of changes to ecosystem contributions to society on a temporal and spatial level.

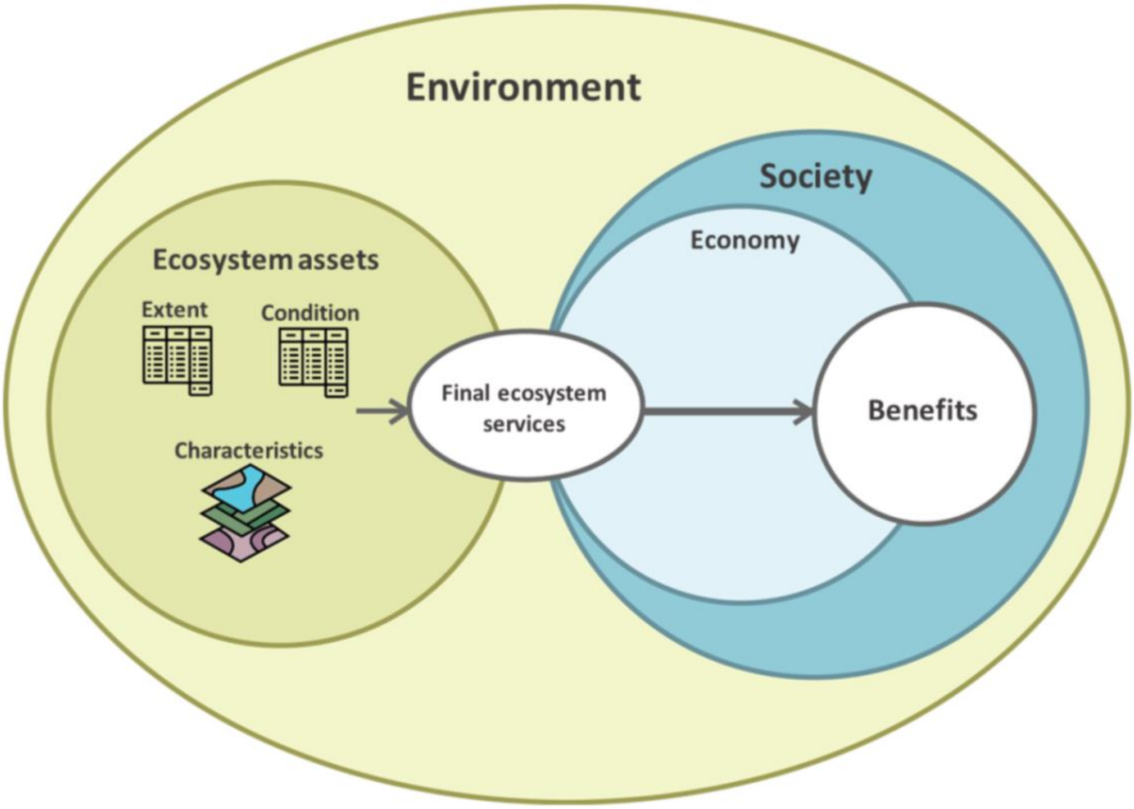

Figure 12-1. The SEEA ecosystem accounting framework (from UNCEEA (2021)).

While the SEEA does not incorporate all relevant data in assessing the relationship between environment, economic and human activity, it provides a structured framework to support further analysis and places various perspectives in context. The SEEA framework can be used independently or contribute to cost–benefit analysis or economic impact analysis, providing a greater level of context crucial for integrated decision-making (Farrell et al., 2021). In identifying changes in the economic value of ecosystems within an accounting area, the aggregate effect of different combinations of policies can be evaluated (Chen et al., 2020). However, the framework only captures a portion of significant cultural and spiritual relationships with the environment; for example, there is no mention or incorporation of Indigenous worldviews.

13. Appendix 5. Final Ecosystem Goods and Services

In 2013, the US Environmental Protection Agency (EPA) developed the Final Ecosystem Goods and Services (FEGS) classification system to define, describe and standardise specific groups of ecosystem services (Landers and Nahlik, 2013). The EPA's argument for developing FEGS was that common categorisation schemes stemming from the MA approach were relevant but did not provide a rigid framework in which ecosystem services can be identified on the landscape and explicitly associated with people. They argue that the FEGS: (i) avoids much of the ambiguity inherent in other ecosystem services definitions; (ii) minimises or avoids double-counting; (iii) acts as a bridge between natural and social sciences that facilitates direct communication and collaboration; and (iv) is beneficiary-specific and may be understood by people without translation or interpretation (Landers and Nahlik, 2013).

FEGS are explicitly defined by the landscape in which they occur and the interests of people who interact (i.e. enjoy, consume, or use) with them. Thus, there is a need to specify both Environmental Class (addressing the questions 'Where does the FEGS occur?' or 'Which FEGS occur in the area of interest?') and the Beneficiary Category (addressing the question 'Who is the beneficiary of which particular FEGS?'), thus hypothesising FEGS received by each Beneficiary Category from a specific Environmental Class (Landers and Nahlik, 2013). Beneficiaries are defined as 'the interests of an individual (i.e. person, organisation, household or firm) that drive active or passive consumption and/or appreciation of ecosystem services resulting in an impact (positive or negative) on their welfare' (Landers and Nahlik, 2013). Like other existing ecosystem service classification systems (e.g. MA), categories of FEGS and beneficiaries are rather generic. It is the next step that is viewed as crucial to the analysis: connecting a FEGS category to a specific beneficiary and an environment.

14. Appendix 6. Co-production of capitals models

The Five Capitals Model developed by the Forum for the Future distinguishes between human, social, financial, manufactured and natural capital (Porritt, 2012). The Five Capitals approach has been used to organise valuations and understand potential future changes and their impacts on sustainability; for example, Chesson (2014) look at biosecurity threats via ecosystem services to several different capitals. Increasingly, when using this approach, concerns specifically related to perceptions of the system by stakeholders are considered. An important contribution by Costanza et al. (2014) was to make explicit the interactions between different forms of capital (financial, built, social, human and natural) required to produce human wellbeing. They argue that the contribution of natural capital to human wellbeing is not direct. Instead, it flows via ecosystem services and indirectly via relative contributions to built, human and social capital, and the economy. Further, the relative contribution of each of the capitals varies depending on the ecosystem service explored (for example, built capital might play a larger role in recreational services than in existence values (Costanza et al., 2021)). The benefits people derive from nature depend interactively not only on the state of nature itself but also on the state of other capitals which combine with ecosystem services to produce wellbeing. Therefore, they argue, it is important to consider both the different types of capitals and how they interact. For this, it is essential to adopt a broad, transdisciplinary perspective when exploring and addressing ecosystem services and environmental outcomes (Costanza et al., 2014, 2021).

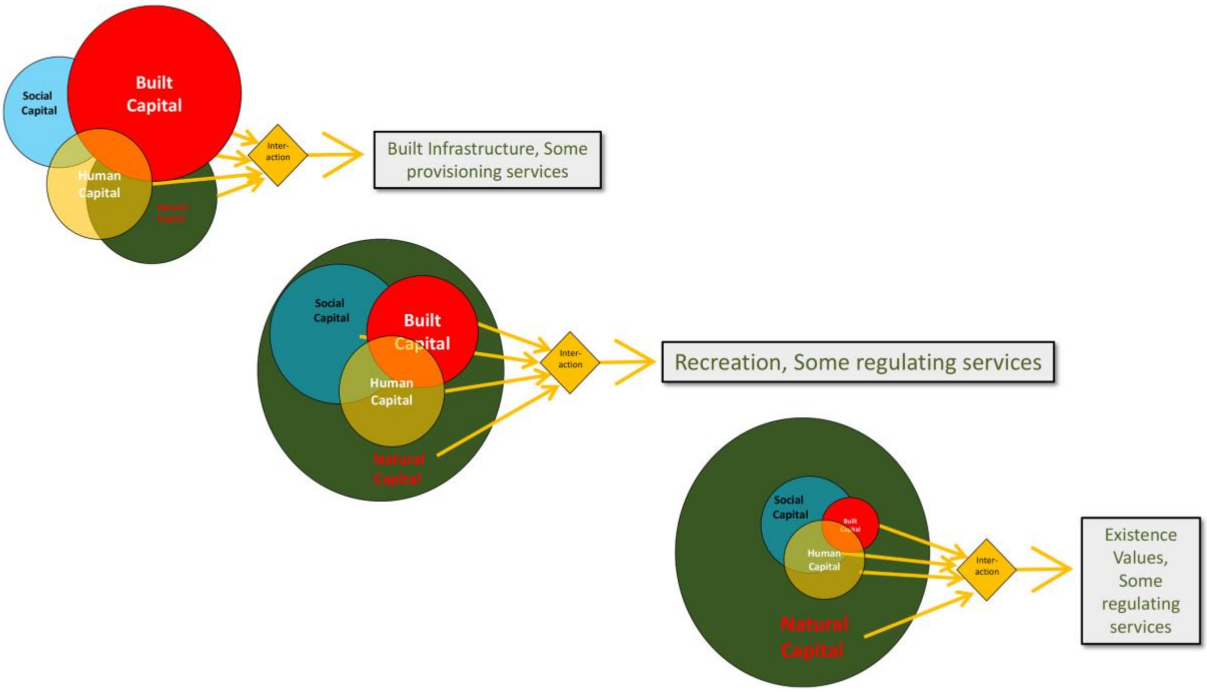

Figure 14-1. Different types of capital combine in different ways to generate different types of ecosystem services (from Costanza et al. (2021)).

15. Appendix 7. Social Cognitive Theory

Social Cognitive Theory (SCT) derives from a theory of learning that explains behaviour modelling, i.e. individual behavioural decisions being guided by observation and recollection of others' behaviours and the consequences of that behaviour (Bandura et al., 1977, Bandura, 1986). The model has been applied to health promotion and other large-scale social issues (Bandura, 2011) and allows for the analysis of both small-scale and large-scale influence on individuals. SCT relies on the perceived self-efficacy of the observer, i.e. belief that they have the capacity to execute the behaviours necessary to achieve the performance result, which can be encouraged by others, including through persuasive communication and providing resources to support execution of the behaviour. Negative as well as positive behaviour may be modelled, which may guide the observer when negative consequences are not observed, recalled or appropriately understood. The 'triadic reciprocal determination' (Figure F) refers to the 3 interacting factors that influence behaviour: personal (e.g. beliefs, self-perception, physical characteristics), behavioural and environmental (social influences).

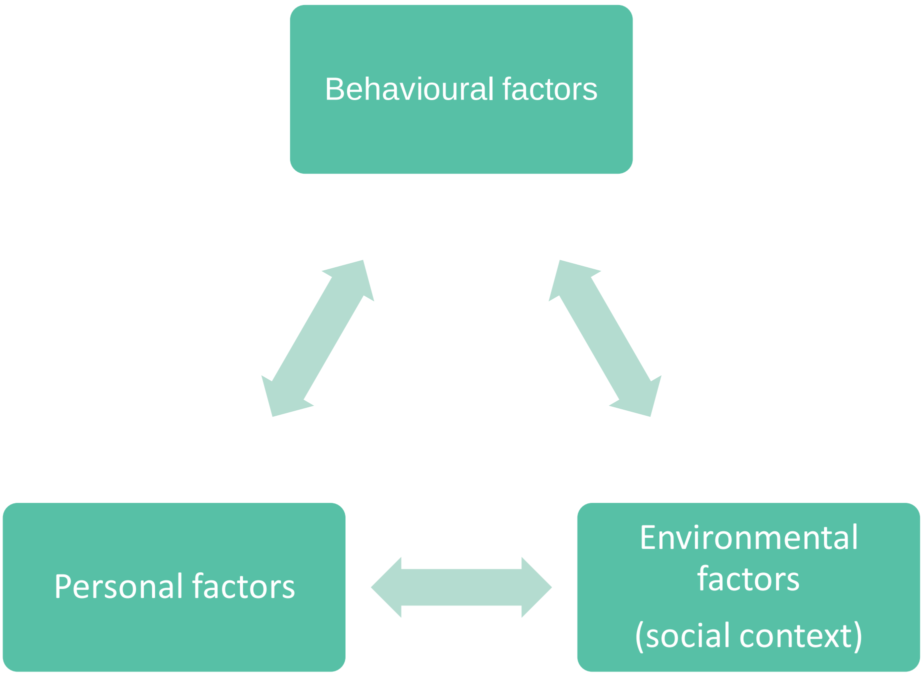

Figure 15-1. Social Cognitive Theory: triadic reciprocal determination (adapted from (Bandura, 1986, Bandura et al., 1977)).

16. Appendix 8. Theory of Planned Behaviour

A common socio-psychological model in the literature on social cognitive behaviour is the Theory of Planned Behaviour (TPB) (Ajzen, 1991). The TPB proposes components that predict the performance of a behaviour, namely: the individual's attitudes toward the behaviour, subjective norms (the degree to which one feels that significant others think one should perform the behaviour), social norms (customary codes of behaviour in the social group), perceived power (factors that may facilitate or impede the performance of the behaviour) and perceived behavioural control (the degree to which one feels able to perform the behaviour/has control over it) (Beedell and Rehman, 2000, Burton, 2004). The TPB extended the Theory of Reasoned Action by adding perceived behavioural control to remove the uncertainty created by the assumption of individual volition (the ability for an individual to decide on or commit to a course of action). Perceived behaviour control is a component of self-efficacy theory, which derives from social cognitive theory. Data for the TPB model is collected through surveys with questions applying a Likert-type scale generating a probability score for the likelihood of the individual performing the targeted behaviour. The TPB has been applied in multiple studies and across disciplines with reported predictive power (Hagger et al., 2002).

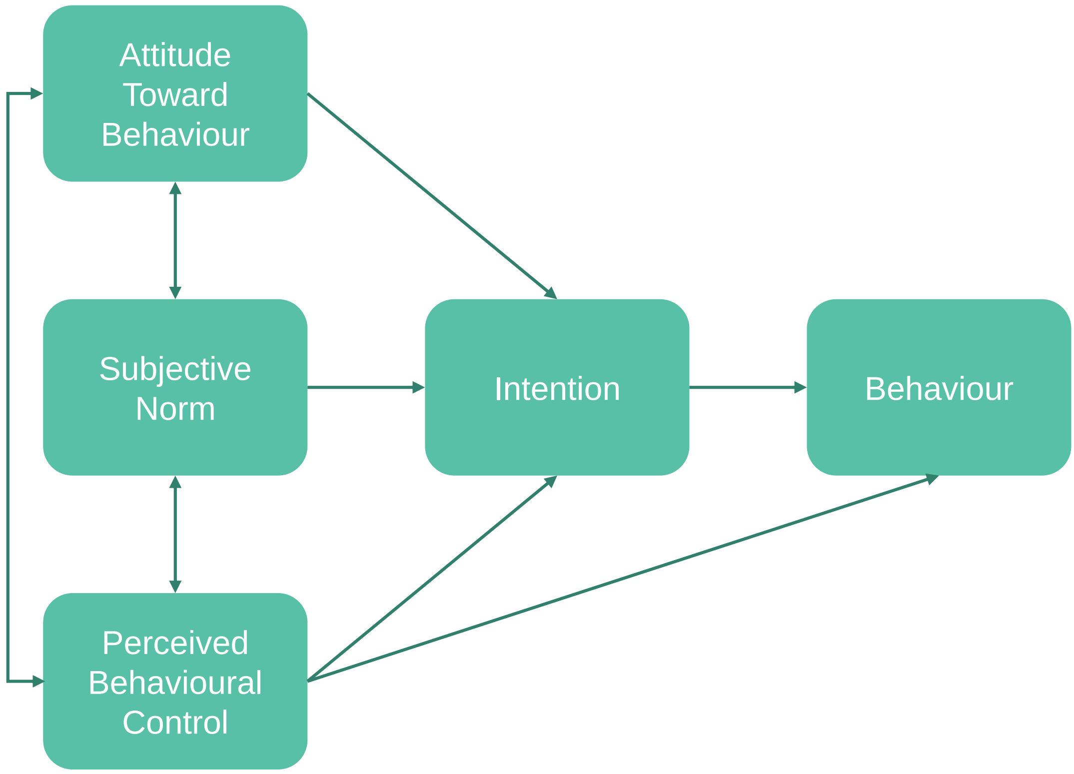

Figure 16-1. Theory of Planned Behaviour (adapted from Ajzen (1991)).

17. Appendix 9. Drivers–Pressure–State–Impact and Response

The Drivers–Pressure–State–Impact and Response (DPSIR) framework is based on the concept of causality: human activities exert pressures on the environment and change the quality and quantity of its natural resources. Drivers of changes to the natural environment result in pressure on the natural environment and its changed state. This changed state impacts on human society and drives its response. The response aims to improve the state of the environment either by alleviating pressure or primarily changing the drivers. These changes in the condition of the environment result in society developing responses to the new conditions (EEA, 1999).

DPSIR has been used with increasing frequency for problem-solving both by natural and social scientists, who have further refined/defined and applied the framework and its derivatives in an ongoing process tailored to many different uses. DPSIR has been used as an analytical framework in a wide range of human–ecological systems, from watershed management (Larson and Stone-Jovicich, 2011, Fassio et al., 2005), coastal management (Patrício et al., 2016), assessments of environmental degradation (Agyemang et al., 2007) and evaluation of conservation measures (ten Brink et al., 2011). The framework is most commonly used for the development of indicators (Bowen and Riley, 2003, EEA, 1999); however, it has also been used to organise information contained in management plans (Giupponi, 2007), evaluate conservation outcomes (ten Brink et al., 2011) and assist stakeholder communication (Larson and Stone-Jovicich, 2011).

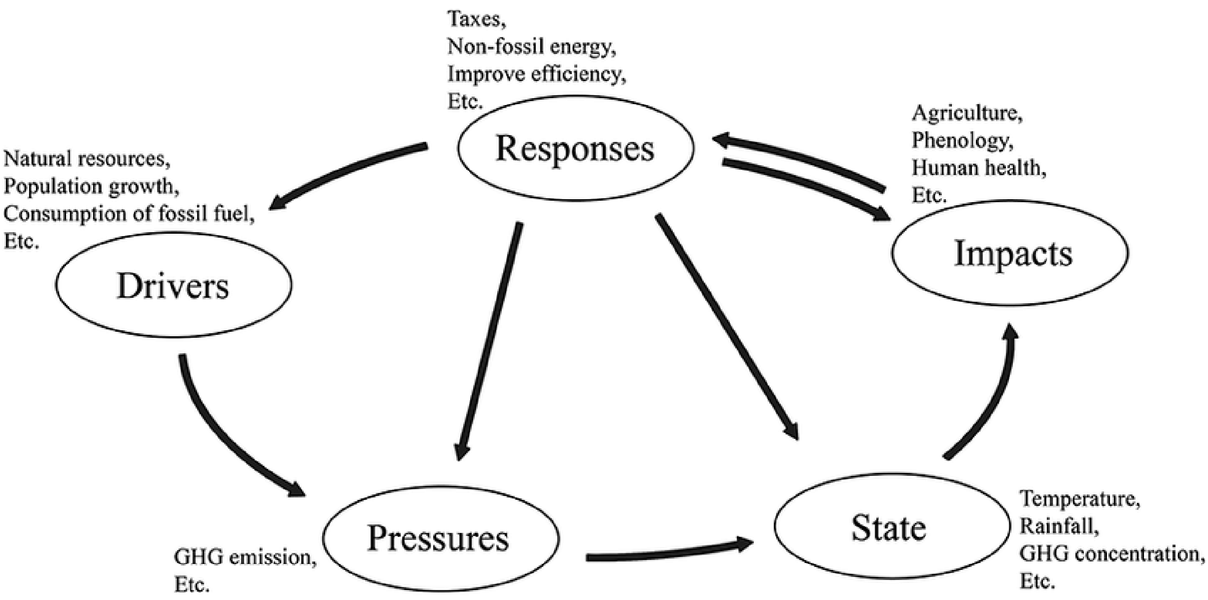

Figure 17-1. The DPSIR framework (from EEA (1999)).

18. Appendix 10. Socio-ecological System

Ostrom's Socio-ecological System (SES) is a nested, multi-tier framework of analysis that integrates (i) a resource system (e.g. fishery, lake, grazing area), (ii) the resource units generated by that system (e.g. fish, water, fodder), (iii) the users of that system (actors), and (iv) the governance system needed. The 4 elements of the system are conceptualised as affecting and being affected by (v) interactions with each other and (vi) the resulting outcomes; and affecting and being affected by the larger (vii) socioeconomic and political, and (viii) ecological settings in which they are embedded (Ostrom, 2007, Ostrom, 2009).

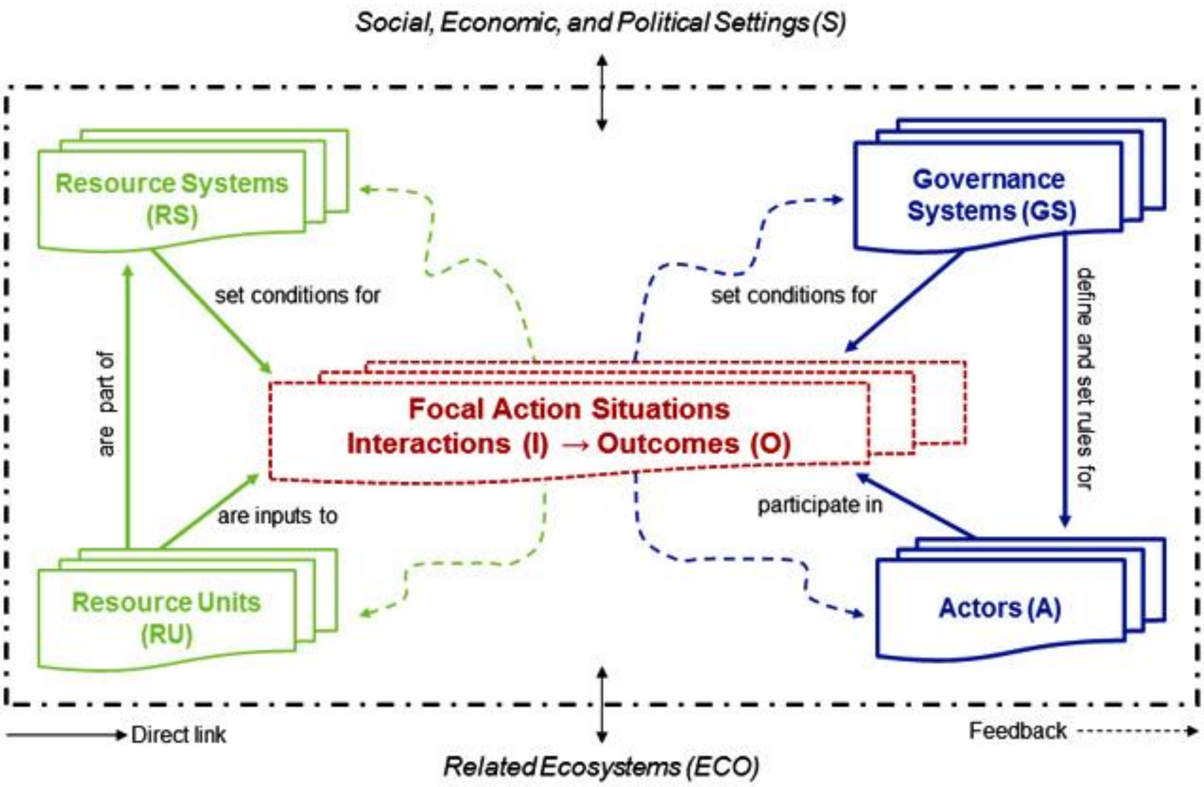

Figure 18-1. Social-ecological System (from McGinnis and Ostrom (2014)).

The SES, like most complex systems, is decomposable (i.e. arranged in levels, the elements at each lower level being subdivisions of the elements at the level above) and exhibits 3 significant characteristics: conceptual partitioning of variables into classes and subclasses; the existence of relatively separable subsystems that eventually affect each other's performance; complex systems are greater than the sum of their parts. Because SES is a decomposable system, each of the 8 highest-tier conceptual variables (domains) can be unpacked and related to other variables in testable theories. Ostrom unpacks the highest-tier into a list of more than 50 second-tier variables that have been reported in the literature as potentially affecting incentives, actions and outcomes related to sustainable resource governance (updated list of variables presented in Table 1 in McGinnis and Ostrom (2014)). However, due to the decomposable nature of the system, Ostrom argues that not every variable is relevant to every study and that many more specific variables are identifiable at deeper levels (Ostrom, 2007). The framework also allows for multiple manifestations or instances of the top-tier components; for example, if one is to study aggregates of resource systems (i.e. watershed rather than any specific reach of the river). In such instances, different sets of actors may be engaged in extracting or producing different types of resource units drawn from one or more resource systems, and their activities may be guided by rules drawn from overlapping governance systems.

Ostrom warns against exclusive devotion to a particular research method as this would threaten the capability of scientists to contribute to the development of the diversity of institutions needed to sustain the diversity of ecological settings over time. Several scholars have conducted meta-studies to determine common variables of relevance to SES system outcomes (see, for example, Pagdee et al. (2006) for metanalysis in forestry Schlager et al. (1994) for fisheries or Brooks et al. (2006) for conservation strategies). These authors found that studies reported a wide diversity of variables rather than testing a common set of factors potentially associated with desired outcomes, resulting in a powerful critique of such inconsistent approaches (Agrawal and Redford, 2006). However, by accepting a multi-tier nested framework, scholars and policy-makers could contextualise their work while complementing the work and research methods used by others and at other levels. Without such a framework, Ostrom warns that further unnecessary research method ‘wars’ will continue (Ostrom, 2007).

19. Appendix 11. Intergovernmental Platform on Biodiversity and Ecosystem Services

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) and other scholars found the ecosystem services framework too narrow to capture a range of world views, knowledge systems and stakeholders (Kadykalo et al., 2019). Therefore, the broader notion of Nature's Contribution to People (NCP) was developed, incorporating a more inclusive set of perspectives and stakeholders to address human–nature relationships and placing culture at the centre of all links (Díaz et al., 2015). NCP emphasises the importance of cultural context, such that ecosystem services are framed differently across different communities and places worldwide. The importance of incorporating less-presented knowledge systems into assessments is emphasised (Peterson et al., 2018), as is knowledge co-production with Indigenous and local knowledge holders. The IPBES reframes services to contributions, covering both negative and positive contributions of living nature, and wellbeing to people's quality of life (Díaz et al., 2018). Contributions are categorised as material, non-material and regulating. In NCP, the flow of benefits from nature to people builds on the ecosystem services concept popularised by MA; however, conceptualisation is extended to include people's contributions to nature (PCN), i.e. how people interact with natural processes and, together with these processes, condition the state of ecosystems and biodiversity (Díaz et al., 2015, 2018, Peterson et al., 2018, Kenter, 2018, Pascual et al., 2017, Kadykalo et al., 2019).

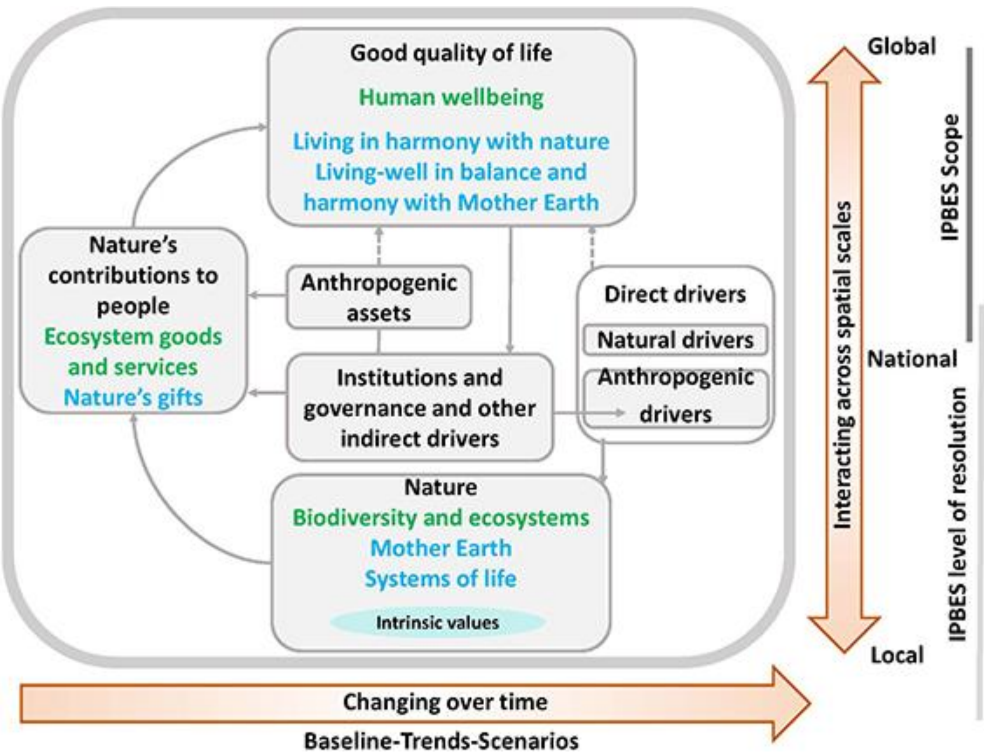

Figure 19-1. IPBES analytical conceptual framework (from Díaz et al. (2015)).

20. Appendix 12. Insights from First Nations People

A First Nations worldview is not an analytical framework; it does not follow a systematic Western science approach. It is a shared mental model of the world, and every Indigenous community has their own, yet to some extent shared, view of the world. Understanding a worldview requires discussions with local Indigenous communities to explore values, human–nature relationships, concerns, basic rights, practices and aspirations of that place and to refine external frameworks and achieve a blended model, weaving Western science and Indigenous knowledge and empowering the voices of Indigenous people (Hill et al., 2021). These include stories about connection to Country, activities for Country (e.g. management activities, priorities, actions), and how concepts and ideas developed (National Oceans Office, 2002, Stoeckl et al., 2021). There are highly diversified sets of values regarding nature in different Indigenous communities which relate to different ecosystems with no one-size-fits-all approach.

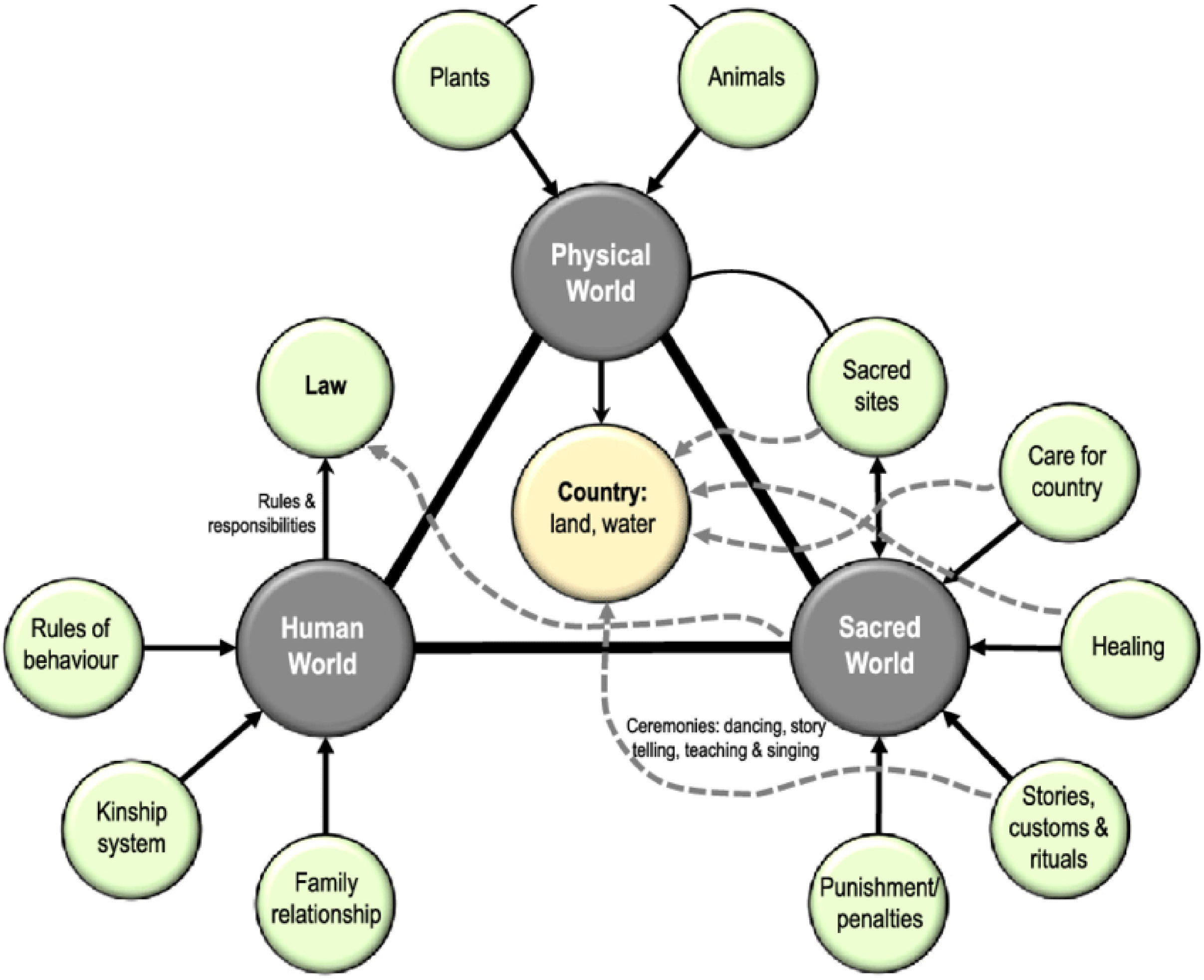

Figure 20-1. Conceptual model of Indigenous peoples' connections with nature (from Sangha and Le Brocque (2014)).

Studies that consider human wellbeing in non-western cultures tends to focus on people's relationship with the environment and are therefore more aligned with the health and vitality of natural resources. Lack of differentiation between 'human activity' and 'non-human environment' has been discussed previously in studies of traditional African (Fairhead and Leach, 1996), Pacific (Durie, 1998, McGregor et al., 2003), and Australian Aboriginal cultures (Larson et al., 2006, 2020, Stoeckl et al., 2021). In traditional cultures, natural resources are not only important for individual human wellbeing but are a base for perpetuating cultural traditions and communal identity. Groenfeldt (2003) explores the concept of 'sacred landscape' that merges territorial with the spiritual into a sense of identity found in many Indigenous statements about their view of the natural environment. The ecological model of Hawaiian wellbeing, developed by McGregor et al. (2003) looks into the main factors influencing wellbeing from individual to family, community, nation and the wellbeing of 'Aina'; a holistic concept of the natural system and resources that governs the life of the nation.

21. Appendix 13. Capitals, flows and settings relevant to frameworks with types of variables considered

Table M (below) captures the types of capitals – natural, human, social/institutional, and financial/built – adopted in the frameworks described in this report and the flows from these assets from/to nature and people, together with a broad description of the type of information/data relevant to each framework. Early frameworks tended to rely on a relatively narrow set of variables often focusing on just one or 2 assets/capitals and associated flows. There is now an emerging acknowledgement of the need to consider multiple assets, and interactions between assets including a range of actors. It is also apparent that scale matters – almost all models/frameworks include at least some variables that describe the natural and the human environment, but if seeking to solve small-scale, local issues, the variables that one will likely need to use will be different from those used by decision-makers operating at larger scale. Also evident is the importance of context – even when trying to solve problems at local scale, one may still need to consider global natural phenomena such as climate (in addition to local phenomena such as the presence of endemic species). Similarly in natural systems, it may not be sufficient to consider only current social and economic conditions, macroeconomic factors and geopolitical factors can and do influence local outcomes. For example, building a vast solar-energy generation plant will have negative local consequences for biodiversity but will contribute to positive national and global outcomes. Hence, frameworks considering multiple assets reference a broader context in which the assets operate.

Table 21-1. Managerial uses, outputs and data required by different frameworks that seek to address environmental issues.

Framework	**Managerial context and use**	**Outputs**	**Capitals considered**				**Flows**	**Context**
			Natural	**Human**	**Social/institutional**	**Financial/built**		
Total Economic Value	A way of thinking about the different ways natural assets benefit people – helps identify an appropriate non-market valuation 'tool' to generate a monetary estimate of the value of a natural asset	Estimates of the monetary value of a natural asset, highlight its 'worth' even if it is not something that generates wealth or income	*Need to describe and characterise the natural asset (could be an area, a species or other)*	*Need to describe and characterise the people who interact with the natural asset*			Need to describe the way in which the natural asset benefits people (*direct-use*, *indirect use, non-use) – in layman's terms,* how people interact with the natural asset (e.g. eating it, looking at it, thinking about it)	Almost all non-market valuation studies require researchers to describe and characterise the study context (social/economic and natural)
Millennium Ecosystem Assessment and Common International Classification of Ecosystem Services	A way of thinking about the different ways natural assets enhance human wellbeing, by providing ecosystem services	Clear understanding of the way an ecosystem contributes to human wellbeing – can also help understand how degradation of the ecosystem might degrade services, and thus impact wellbeing (some researchers extend to generate monetary estimates of those values)	*Need to describe and characterise the ecosystem and the ecosystem services provided by it (provisioning, regulating, cultural).* Supporting services are almost always acknowledged in biophysical studies but need to be omitted from whole-of-ecosystem 'valuation' studies to avoid double-counting.	*Do not have to consider the human system, unless wanting to extend to include dollar values, then also need to describe and characterise the people who benefit from the ES*			Need to understand the flow of ecosystem services (from a region to people or to other regions).	Almost all ecosystem-services studies characterise the study context (focusing, in particular on the natural environment)

Framework	Managerial context and use	Outputs	Capitals considered				Flows	Context
			Natural	Human	Social/institutional	Financial/built		
Final Ecosystem Goods and Services	A way of explicitly identifying and accounting for the beneficiaries of ecosystem services	Clear understanding of the way an ecosystem contributes to human wellbeing and of the people/stakeholders who benefit from it.	*Need to describe and characterise the ecosystem and the ecosystem services provided by it (provisioning, regulating, cultural) and also the beneficiaries of those services.*	*Need to identify, describe and characterise the people who receive benefits from different ecosystem services*			Need to understand the flow of ecosystem services (from a region to people – or to other regions) specifically identifying (human) recipients of the flow.	Need to be able to characterise the study context – and MUST consider both natural and humans when doing so
Co-production of capitals	A way to understand how ecosystem services can be 'produced' without necessarily benefitting people	A better understanding of factors that may enable, or prevent, people from benefit from ecosystem services	*Need to describe and characterise the ecosystem and the ecosystem services provided by it (provisioning, regulating, cultural) and also the beneficiaries of those services.*	*Need to identify, describe and characterise the people who SHOULD BE ABLE TO receive benefits from different ecosystem services*	*Need to be able to identify, describe and characterise social, institutional, financial, physical or other barriers and/or enablers in the system that are linked to these other 'capitals'….*		Need to understand the flow of ecosystem services (from a region to people – or to other regions) Also identifying potentially (human) recipients of the flow, and barriers or enablers of those flows.	Need to be able to characterise the study context – and MUST consider a full range of mediating factors
Norm Activation Theory	A way of understanding core 'values' that motivate a person	May help identify the best types of social-psychological 'levers' to encourage different behaviours (e.g. money in some cases, medals in others)		*Need to understand personal norms, ascription of responsibility (who is responsible for action/inaction?) and awareness of consequences of action on others*				Needing to better understand the social-psychological drivers of behaviour of core stakeholders whose behaviours you may want to influence

Framework	Managerial context and use	Outputs	Capitals considered				Flows	Context
			Natural	Human	Social/institutional	Financial/built		
Value–Belief–Norm Theory	Another way of understanding core 'values' that motivate a person	May also help identify the best types of social-psychological 'levers' to encourage different behaviours (e.g. money in some cases, medals in others)		*Need to understand intrinsic and extrinsic values; also need to understand general value orientations (egoistic, altruistic, bio spheric), also extent to which people feel responsible for their own actions, and awareness of the consequences of their actions*				Needing to better understand the social-psychological drivers of behaviour of core stakeholders whose behaviours you may want to influence
Social Cognitive Theory	A way of understanding the social context in which one is operating (Simplistically: who are the 'movers and shakers')	Identifies key influences (and influencers) of people's behaviours		*Need to be able to understand personal factors that govern behaviours (such as beliefs, self-perception, physical characteristics)*	Need to be able to understand social context – particularly the way in which people interact and influence each other		Need to be able to characterise the study context – mostly focusing on social context	Need to be able to characterise the study context – mostly focusing on social context
Theory of Planned Behaviour	A way of understanding the likely extent to which people will 'engage' (e.g. in a plan to improve the environment).	Highlights individual and social norms that influence behaviours – and the extent to which people feel their behaviours are able to make a 'real' difference	*Likely to need to understand environmental context; and also existing environmental behaviours of key stakeholders*	*Need to understand individual norms. Need to understand extent to which people feel able to have an impact – and this requires information about how they see themselves and their behaviours in the broader environment*	Need to understand social norms (customary codes of behaviour)	May need to also understand social, institutional, financial and physical 'context'[3].	Need to be able to understand core drivers of behaviour (e.g. social norms, individual values, internet connectivity, finances)	Need to be able to characterise the study context – this is likely to require an understanding of all 'capitals'
Drivers–Pressure–State–Impact and Response	A way to assess and evaluation relationships between human activity and the environment	Highlights way in which external drivers or pressures can change the state of a system, and flags the important of considering	*Need to describe state of environment; drivers, pressures and responses*	*Need to describe state of all human assets/capitals; also drivers, pressures and responses*			Model emphases flows as a causal chain	Do not only need to be able to characterise components, but the way they interact and 'cause' changes in each other

[3] Simplistically, without internet, people will not engage with a plan/policy that relies on the internet resources or communication.

Framework	Managerial context and use	Outputs	Capitals considered				Flows	Context
			Natural	Human	Social/institutional	Financial/built		
		responses and feedbacks						
Social-ecological systems	Describes way in which human–nature systems interact at different scales		*Need to think about resource systems, units, understanding rates of growth and change*	*Need to understand 'actors' and their behaviours/drivers (often different at different social scales)*	Need to understand social context and governance systems–in particular, the processes for coming to management decisions	Need to understand resource units and other	Need to consider multiple components and interactions at different scales	Need to consider multiple components and interactions at different scales
Intergovernmental Platform on Biodiversity and Ecosystem Services	Describes way in which human–nature systems interact at different scales			*Adds the importance of cultural context to insights from the MA and CICES models*				
First Nations insights	Incorporating First Nations views		People and Nature holistic and inseparable; spirituality paramount. It is not only important to consider components of system and flows, but also WHO is involved (undertaking stewardship activities, or benefiting from nature/people) and HOW that involvement is occurring (in respectful way).					
System of Environmental-Economic Accounting	Provides a system to 'account for' and monitor the state of assets, and flows between them	Multiple different accounts relating to different assets and flows	*Describes extent and condition of natural environment using both monetary and biophysical units. Focuses on ecosystem services Also aims to assess capacity of system to continue to provide services into the future*	Focuses on flows/transactions relevant to households, businesses and governments; considering issues around formal ownership.			Describes flow of benefits from nature to people, categorised as ES. Mostly in dollars; also considers money spent on activities where people aim to do things FOR the environment	Keeps track of the current state (and flow); does not attempt to understand WHY. Implicit assumption seems to be that large-scale outcomes can be inferred by adding small-scale (value of the whole is the sum of the parts)