Wellbeing and natural capital

Understanding the sustainability and risks

NZIER report to the Treasury

November 2022

About NZIER

NZIER is a specialist consulting firm that uses applied economic research and analysis to provide a wide range of strategic advice.

We undertake and make freely available economic research aimed at promoting a better understanding of New Zealand's important economic challenges.

Our long-established Quarterly Survey of Business Opinion and Quarterly Predictions are available to members of NZIER.

We pride ourselves on our reputation for independence and delivering quality analysis in the right form and at the right time. We ensure quality through teamwork on individual projects, critical review at internal seminars, and peer review.

NZIER was established in 1958.

Authorship

This paper was prepared at NZIER by Michael Bealing and Peter Clough.

It was quality approved by Dr John Yeabsley.

The assistance of Sarah Spring is gratefully acknowledged.

How to cite this document:

NZIER. 2022. Wellbeing and natural capital: Understanding the sustainability and risks. A report to the Treasury.

Registered office: Level 13, Public Trust Tower, 22–28 Willeston St | PO Box 3479, Wellington 6140
Auckland office: Ground Floor, 70 Shortland St, Auckland
Tel 0800 220 090 or +64 4 472 1880 | econ@nzier.org.nz | www.nzier.org.nz

Key points

Purpose and scope

The Treasury commissioned NZIER to investigate the existing empirical evidence on the sustainability of the contribution of New Zealand's natural environment to the wellbeing of its people. The research was also interested in any risks to the sustainability of the natural environment's contribution to New Zealanders' wellbeing.

The scope of the research was existing estimates from academic literature and other sources such as official statistics. The development of new or revised estimates was out of scope.

How can sustainability and wellbeing be practically defined in this context?

Wellbeing is difficult to measure objectively, so policy often focuses on measuring the means of improving wellbeing rather than wellbeing itself. For this report, we take an economic view that wellbeing is broadly about people's capability to live fulfilling lives, and the means to that capability include personal incomes (both private earnings and state support transfers), availability of and access to public services (such as health and education) and conditions in the natural environment (good air quality and absence of restricted activity days, stable climate and low incidence of disruptive weather events).

The prospects for these capability sources can be expressed as capital, i.e. the embodiment of future flows of value that contribute to wellbeing. Natural capital refers to the sources of future value derived from aspects of the natural environment and functioning ecosystems. It can complement the future value from produced capital (machinery and infrastructure) and human capital (population health, skills and know-how).

Natural capital is distinguished from other environmental indicators by its characterisation of stocks of environmental resources from which future flows are expected. Monetary estimates of natural capital can change because of variations in the price of future services or changes in volume. Volume can vary with the extent of environmental resources or its quality in yielding future services. This multi-dimensional characteristic of natural capital means that estimates cannot be read directly as indicators of sustainability without understanding the underlying drivers of change in capital.

An economic definition of sustainability, drawing on the United Nations Inclusive Wealth Report (2018), is non-declining per capita wellbeing over time so that all generations face at least the same (if not more) wellbeing potential as their predecessors. One way of achieving that is to ensure that the combined value of stocks of natural capital, produced capital and human capital should be non-declining over time, although individual capitals may have variable proportions over time.

The ecosystem services framework is useful for identifying how ecosystem functions translate into services of value to people in four broad headings – provisioning, regulating, cultural and supporting.

What is the relevant and practical timeframe of interest?

A practical timeframe for assessing impacts on natural capital is likely to be in the range of 10–20 years to assess progress and any policy change. Longer than this could enable significant changes in the condition of natural capital to progress to a state from where it is difficult to recover. Shorter than this creates a risk of responding to short-term perturbations that could resolve themselves without action and lead to rapid shifts in policy in which it is difficult to discern whether the condition of natural capital is responding in the way intended.

Periodic reviews of plans under the resource management legislation take 10 years or a little longer to become operative, so a 10-year timeframe for natural capital reviews would align with this process.

Can the contribution of the natural environment be defined and quantified?

The contribution of the natural environment can be defined using the ecosystem services framework, which links ecosystem conditions to natural functions and services of value to people. It focuses on four different kinds of ecosystem services that nature provides for humans:

- **Provisioning services** such as the supply of wild food, timber, sources of energy and water.
- **Regulating services** such as flood mitigation and erosion control and water quality.
- **Cultural services** such as providing settings for recreation and non-use or passive nature appreciation – simply knowing that species like the kākāpō exist or that sites with heritage associations will remain for future generations to enjoy.
- **Supporting services** such as basic processes like nutrient cycling or pollination on which all other services depend – but supporting services are rarely subject to separate estimation because of their interconnection with other services and the risk of double counting.

A natural landscape with pristine landcover will have a certain mix of ecosystem services and values, but transforming part of it for agriculture can increase the overall values of the provisioning and cultural services, support a larger population with more asset values in place and increase the overall ecosystem services value from the landscape. At some point, however, further development and transformation of the landscape can become counterproductive, increasing the value at risk of disruption from adverse events that overcome the ecosystem's reduced regulating services capacity. Finding a balance between conservation and developmental use of the landscape that optimises the long-term value obtained from the landscape is one approach to sustainability.

Quantification varies with the type of ecosystem services. Many provisioning services are already subject to market provision, so the value can be attributed according to the supply and demand observed in the markets for these services. Regulating services are not so often supplied through market processes, so while some may be readily quantified, others require bespoke estimates to be compiled. Cultural services of ecosystems are often not supplied through market processes or they involve public goods for which it is not practicable to monitor who benefits or by how much, so quantification requires field observation, and valuation requires bespoke exercises that may involve non-market valuation techniques.

The monetary value of the cultural and regulating services varies according to the supply and demand for such services and the availability of substitutes in different locations. This implies that numerous bespoke valuations of different categories of natural capital that take account of locational factors would be needed to build up a national picture of the value of natural capital. Such studies are expensive, and available estimates are few in number and cover relatively few broad categories of natural capital. This means that national-level estimates that use such estimates are likely to miss local variability and be fairly crude.

What do the available quantifiable measures suggest about the risks to the sustainability of the contribution of the natural environment to the wellbeing of New Zealand?

Most available estimates of natural capital and ecosystem services are more focused on the current or past environmental performance rather than on future risks. Estimation of the adequacy of natural capital to cover needs and offset risks in future is less often explicitly done. Some estimates of asset values or economic rent implicitly do consider future risks, but how this is done is not explicit in the figures presented.

Sustainability of resource use and the natural environment is frequently referred to as a policy goal but rarely defined in quantitative terms. Some notable exceptions are the fisheries quota management system and greenhouse gas emissions target monitoring, both of which are aimed at improving resource sustainability. However, neither of these quantified measures have been valued in terms of natural capital or ecosystem services, and the links to human wellbeing need further investigation.

Market-based measures of natural capital are subject to noise from the inherent volatility of market prices that make it difficult to use these measures for assessing the sustainability of the contribution of the natural environment to human wellbeing without decomposing the volume and value drivers of the measures. Ecosystem services values are potentially more useful for answering the sustainability question, but the approach is complex with considerable data requirements and demands a greater investment. As such, the most comprehensive ecosystem services studies are sporadic one-off estimates that do not provide the consistent measurement over time needed to answer the sustainability question.

There are three approaches that do track changes over time relevant to sustainability:

- **United Nations (UN) System of Environmental-Economic Accounting (SEEA)**, which is being implemented by Stats NZ and other countries' statistical agencies to varying degrees and applies a framework closely aligned to the main economic accounting in the System of National Accounts (SNA), with annual estimates from 1995 to 2019.
- **World Bank comprehensive or total wealth measures**, which are being compiled by the World Bank for numerous countries on a common framework from 1995 to 2018, the cross-country comparability of which depends on the quality of inputs and treatments for each country and in New Zealand's case exhibits some unexplained anomalies.
- **UN Inclusive Wealth Index**, which extends coverage further to include natural capital and human capital but has only been prepared for 5-yearly intervals from 1990 to 2014.

This synthesis shows that it would be possible to develop a natural capital-based assessment of the sustainability of and risks to the contribution of the natural environment to human wellbeing. Doing so would require targeted long-term investment in developing the assessment framework, data collection and repeated application of the economic valuation over time to build up the robust trends needed for a high-quality investigation. Such an investment would benefit multiple uses and audiences and enrich research and policy analysis far beyond the Te Tai Waiora: Wellbeing in Aotearoa New Zealand 2022. It requires a long-term commitment for the value of such research to be realised.

On the risks to the contribution of the natural environment to wellbeing, the findings indicate that the risks are being assessed and monitored by various domestic and international agencies. The risks include pressure from local human activities and global climate change risks. Impacts from extreme weather events will affect ecosystems and human systems and have short-term and long-term effects on the contribution of the natural environment to human wellbeing.

Risk events that could affect natural capital include potential climate change impacts such as:

- likely increase in New Zealand of heavy rainfall intensity and periodic drought
- increased disruption for agricultural production due to weather variability and extreme weather, with adverse flow-on effects on mental wellbeing in rural communities and the risk of a decline in the overall productivity of agricultural production
- further loss of glaciers, affecting tourism businesses and associated settlements
- compounding and cascading effects of extreme weather, including flooding, storm surges and damage to infrastructure, housing and human settlements
- increased pressure on governments to respond to the combined effects of climate change.

These risks include increased disruption and shifts in productive resources that will affect human wellbeing. However, these risks have not been quantified in terms of the value of natural capital. Doing so would be complex and fraught with difficult judgements.

There are further questions of interest:

- Where is New Zealand positioned on average compared to other countries across the natural capital domain of wellbeing?

  This would require reference to an international data series such as the World Bank's total wealth measures or the United Nations' inclusive wealth measures. These allow comparisons between countries, but the accuracy depends on how these measures are compiled, which may depend on questionable inputs and assumptions.

- Has New Zealand's situation improved, worsened or stayed stable over time?

  This requires a time series of natural capital estimates of which Stats NZ's SEEA series, the World Bank's total wealth measures and the United Nations' inclusive wealth measures are all examples. The SEEA is the most reliable for New Zealand time series but focuses on a narrow range of natural resources that show up as products in the standard SNA accounts. The World Bank series are questionable for New Zealand, with some large jumps in series that are not explicable in terms of recent history. The inclusive wealth series may be better in relating natural, produced and human capital, but New Zealand's relative position against other countries is clouded by it having a far higher share of natural capital in its inclusive wealth estimate than other countries that it is commonly compared with.

- Are there any notable differences in the distribution of wellbeing across various groups in the population?

  Current estimates of natural capital and contribution to wellbeing in New Zealand do not show differences in wellbeing across subgroups in the population. There is limited information about wealth distribution across income bands in the population in the inclusive wealth reports, but this is not disaggregated by subsets of wealth such as natural capital. Internationally, the most incisive investigation of the availability of ecosystem services to geographic subsets of the population is in the UK National Ecosystem Assessment in 2011. This was a large-scale exercise involving a broad range of academics and other researchers, which has not been repeated there or in other countries.

Three deep dives in specific ecosystems

We explored the sustainability of three sources of the natural environment to wellbeing – agriculture, forestry and the marine environment. There are other choices such as protected areas and minerals, but we chose these three for the deep dive because they were the largest in magnitude. The findings for each ecosystem are summarised below.

Agriculture and wellbeing

- A cursory glance at the World Bank's assessment of the contribution from agricultural natural capital might lead the reader to believe the contribution is increasing and increasing sustainably. A deep dive shows a more mixed and complex story.
- The contribution was measured using the market value of agricultural products. Other ecosystem services such as regulating, supporting and cultural services are not measured. This means that it is a one-dimensional assessment of the contribution that only reflects output and the prices determined by market forces locally and abroad.
- The proportion of New Zealand's land area used for agriculture is decreasing. Meanwhile, the value of the production from that land has increased significantly since the 1990s, but the increase in output from the land coincides with six-fold increases in the use of synthetic nitrogen fertiliser and an almost doubling of the area of land that is irrigated.
- Further research is needed to investigate the sustainability of the contribution from agriculture after adjusting for the natural resources consumed through irrigation and the sustainability of increasing fertiliser application. This could include a detailed assessment of the pollution associated with the production, consumption, transport and leakage of inputs to agricultural production – for example, pollution and the negative impact of agricultural chemicals on biodiversity. The vulnerability of the contribution from agriculture to external macro risks such as climate change should also be considered.

Forests and wellbeing

- There is a government-led objective to plant more trees in New Zealand.
- New planting data suggests the physical stock of forests in New Zealand has been increasing. However, the wellbeing contribution of forests is likely to vary with the type of forest.

- Production forests may offer different contributions to wellbeing than native forests in terms of provisioning, regulating, cultural and supporting services.
- Evidence shows that different species of trees offer varying levels of regulating services. The cultural services of exotic species and indigenous species are likely to be very different as well. The time to maturity for native trees is longer than the plantation pine, which will also have an impact on ecosystem services benefits.
- Mature indigenous trees store more carbon per hectare than faster-growing exotic conifers, and the latter are periodically harvested in production forests. Long-term carbon storage should reflect that fluctuation or approximate it by using an average value per hectare roughly that of mid-rotation-age trees (assuming continuous rotations in which harvested areas are replanted).
- Further research is needed to investigate the sustainability of ecosystem services from forests. This should include:
  - separating the contribution of indigenous and exotic species
  - understanding the different contributions of plantation and natural growth forests
  - investigating how much the accessibility of the forest for recreation would affect the value of the contribution to the forest.

The marine environment and wellbeing

- The contribution of fisheries and mangroves to the wellbeing of New Zealanders has varied over the last three decades.
- The ecosystem services contribution to wellbeing from the marine environment is far greater than fisheries (MacDiarmid et al. 2013).
- Using Costanza et al.'s (2014) approach to valuing the ecosystem services from the marine environment would suggest the value would approach 1 trillion dollars.
- The latest assessment of the marine environment suggests that the sustainability of the contribution of the natural marine environment to wellbeing is under pressure from human activities and pollution (Ministry for the Environment and Stats NZ 2019).

The current estimates of natural capital in New Zealand have limited use in predicting impacts on wellbeing. More monitoring is required of the trends in the physical extent and condition of natural resources and in their contribution to wellbeing through the non-market value of natural capital to various subsets of the population.

Contents

Figures

Tables

1 Objectives and scope

The Treasury commissioned NZIER to provide a synthesis of the literature on the measures of the contribution of the natural environment to the wellbeing of New Zealand, including the risks associated with the sustainability of the contribution to wellbeing.

1.1 Research objectives

The objective of this report is to review and summarise measures of natural capital (NC) and ecosystem services (ES) for New Zealand and what they say about New Zealand's natural environment in relation to the sustainability of and any risk to the state of wellbeing in New Zealand. The measures of NC/ES will be sourced from both cross-country and domestic analyses. The report will be published as a background paper to *Te Tai Waiora: Wellbeing in Aotearoa New Zealand 2022*.

1.2 Research questions

This assessment involved answering the following research questions:

- How can sustainability and wellbeing be practically defined in this context?
- What is the relevant and practical timeframe of interest?
- Can the contribution of the natural environment be defined and quantified?
- What do the available quantifiable measures suggest about the risks to the sustainability of the contribution of the natural environment to wellbeing?

1.3 Scope of the research

The scope included a synthesis of existing research on the measures of and risk to the sustainability of the contribution of the natural environment to the wellbeing of New Zealand. The scope excluded new empirical analysis of the measures beyond minor revisions to present values because the budget was too limited for new analysis.

1.4 Structure of the report

1 Objectives and scope

2 Research approach and key definitions

3 Measuring wellbeing from the natural environment

4 Trends in the sustainability of wellbeing and natural capital

5 Identifying risks to wellbeing from natural capital

6 Conclusions and next steps

1.5 Funding statement

NZIER was funded by the Treasury to complete this research.

2 Research approach and key definitions

2.1 Research approach

The synthesis was drawn from local and international literature, which included peer-reviewed academic research and reports published by government agencies.

2.2 Defining wellbeing

For the purposes of the report, wellbeing in relation to natural capital is defined in the 2021 version of the Living Standards Framework (LSF) under the headings “Environmental amenity” and “Natural environment”.

> ***Environmental amenity***
>
> *Having access to and benefiting from a quality natural and built environment, including clean air and water, green space, forests and parks, wild fish and game stocks, recreational facilities and transport networks.*
>
> (New Zealand Treasury 2021, 36)

The built environment aspect of the definition of environmental amenity used in the LSF 2021 was out of the scope of this research. Therefore, environmental amenity is covered by the definition of the natural environment and the ecosystem services associated with it.

> ***Natural environment***
>
> *All aspects of the natural environment needed to support life and human activity, valued for spiritual, cultural and economic reasons.*
>
> (New Zealand Treasury 2021, 53)

There is a well-developed set of concepts for relating the natural environment to human wellbeing with a focus on four different kinds of ecosystem services that nature provides for humans:

- **Provisioning services** such as the supply of wild food, timber, sources of energy and water.
- **Regulating services** such as flood mitigation, erosion control and water quality.
- **Cultural services** such as providing settings for recreation and non-use or passive nature appreciation – simply knowing that species like the kākāpō exist or that sites with heritage associations will remain available for future generations to enjoy.
- **Supporting services** such as basic processes like nutrient cycling or pollination on which all other services depend.

These ecosystem services offer society direct and indirect benefits. Wellbeing is realised through access to ecosystem services and the benefits the services generate directly or indirectly. This implies that quantifying the wellbeing benefits of the natural environment depends heavily upon the ability to quantify the quantum and value of ecosystem services.

These definitions sit within an overall approach to wellbeing in the LSF that continues to draw from the Sen/Nussbaum concept of capabilities (Sen 1999; Nussbaum 2003).[1] Under the capability approach, what is of primary importance is people's substantive freedom (capability) to be and do what they value and have reason to value (New Zealand Treasury 2021, 28).

2.3 The rationale for measuring the contribution of the natural environment

Understanding the sustainability of and risks to the contribution of the natural environment to wellbeing demands addressing the following questions:

- In what ways does it support human wellbeing? The ecosystem services approach provides a framework for addressing that question.
- How much natural capital is there? This is a function of the physical extent and condition of natural capital such as forests, soils, freshwater services and so on.
- How long is natural capital likely to last? This is a function of its supply relative to its demand, the rate at which it is being utilised and depleted and the rate at which it is regenerating (if at all).
- How could contribution from the natural environment change due to climate change as a driver of ecosystems?

2.4 The rationale and benefits of environmental valuation

The original and enduring primary purpose of an environmental valuation is to allow for impacts on the environment to be incorporated into decision analysis such as cost-benefit analysis. This includes the valuation of the contribution of the natural environment to assessments of human wellbeing. Environmental valuation is an imperfect lens that adds to the understanding of the trade-offs when making decisions about policy or investments involving the consumption or conservation of natural resources.

In the context of this report, the focus is on the sustainability of and risk to the contribution of the natural environment to wellbeing in New Zealand. Measuring the contribution from the environment through a variety of natural resources fundamentally requires a common unit of measure. The monetisation of the stocks and flows linked to the natural environment employs a common money metric and allows for comparison to other economic measures.

2.5 Natural capital

Natural capital consists of natural assets in their role of providing resource inputs and environmental services for economic production (OECD 2005). It is not just an environmental indicator but rather a way of defining natural stocks that provide a flow of benefits of value to people and the economy, both now and in the future. It is a measure of the capacity of the natural environment to provide valuable flows into the future.

[1] The LSF currently draws most heavily on the capabilities literature for the purposes of operationalisation – for example, in populating the LSF Dashboard. More broadly, the Treasury recognises that wellbeing is a concept with multiple definitions. Reflecting the Treasury's pluralist approach, some other definitions will be drawn upon in the *Te Tai Waiora: Wellbeing in Aotearoa New Zealand 2022*, but these are outside the scope of this report.

In aggregate, it includes the world's stock of natural resources, including its geology, soils, water and all living organisms. The use of mineral resources may be considered unsustainable in one sense because individual resources are finite and can be fully depleted. But the Earth's crust contains vast quantities of minerals, and the main concern for the sustainability of use is not so much in resource depletion as in increasing cost of accessing them, as mines have to be dug deeper or more widely to recover more-dispersed sources of material after more-accessible, concentrated resources are fully worked out.

The main sustainability concern with natural capital is about the depletion of renewables, many of which are organisms or biological communities whose depletion below the level at which they can regenerate spells future shortage and perhaps permanent loss. There can also be sustainability concerns over inorganic systems, such as the composition of the atmosphere and its impact on climate change that affect the ability to sustain the conditions under which natural capital remains valuable to people and the economy.

2.6 Linking natural capital to wellbeing

Wellbeing is a measure of the capability of people to live fulfilling lives. Wellbeing is felt subjectively and can be difficult to measure objectively, but measurement can be made of the means of improving wellbeing rather than wellbeing itself. The means to people's capability include personal incomes (both private earnings and state support transfers), availability of and access to public services (such as health and education) and conditions in the natural environment (good air quality and absence of restricted activity days, stable climate and low incidence of disruptive weather events).

The future prospects for these capability sources can be expressed as capital, i.e. the embodiment of future flows of value that contribute to wellbeing. Natural capital refers to the sources of future value derived from aspects of the natural environment and functioning ecosystems. It can complement the future value from produced capital (machinery and infrastructure) and human capital (population health, skills and know-how).

An economic definition of sustainability, drawing on Dasgupta's foreword in the Inclusive Wealth Report (United Nations 2018), is non-declining per capita wellbeing over time so that all generations face at least the same (if not more) wellbeing potential as their predecessors. One way of achieving that is to ensure that the combined value of stocks of natural capital, produced capital and human capital should be non-declining over time, although individual capitals may have variable proportions over time.

The significance of treating natural capital as stocks embodying future value flows is that it makes explicit the value lost or gained with changes in the extent or condition of natural capital and clarifies trade-offs that may be made between environmental management and other objectives in society's welfare function. Ideally, natural capital value estimates need to indicate not only aggregate values of resources but also marginal values of change.

2.7 The framework underpinning natural capital valuation

The value of natural capital is the combination of a number of factors that vary over time as markets and social preferences change. A generalised formula of the value of natural capital captures the various inputs and considerations. The formula provides a framework of the market and non-market factors that influence the value of natural capital.

$$V = \sum_{t=1}^{N} \frac{P_t \times F_t}{(1+r)^t}$$

where:

V is the value of natural capital

P is the unit price of the flow of natural capital, which can include market and non-market values

F is the flow of natural resources

r is the social discount rate to convert the future flow into present value

N is the timeframe being considered

t is the year of interest.

This formula captures three types of risks to the value of natural capital:

- Changes in P could include market dynamics and a shift in society's valuation of the benefits of a resource.
- Risks from the changes in flows of beneficial services from the natural environment.
- Changes in the social discount reflect social preferences over time.

Such an approach can be applied quantitatively to decision-making assessments such as cost-benefit analysis to incorporate considerations for the effects of decisions on the provision and consumption of natural capital. It provides a means to convert a physical change in environmental condition to a value of change, which may be compared with the cost of measures to mitigate that change. It could also be used to consider the sustainability of natural capital and its contribution in dollar value terms, reflecting other factors that influence prices. This would require consistent measurement over time.

2.8 Defining sustainability

The discourse on defining sustainability is wide-ranging. There is no single unifying agreement on what the definition of sustainability should be. The challenge of defining sustainability is at the core of independency between the economy and the environment and measuring the natural environment's contribution to wellbeing (Perman et al. 2003). There is agreement that sustainable economic development is about balancing the drivers for economic growth against the social and environmental limitations on the rate of natural resource use (Hartwick 1977, 1978)

The drivers of economic growth and development

Population growth requires increasing the size of the pie to ensure that the growth does not lead to wellbeing decreases for some or all. Poverty alleviation also requires increasing the size of the pie if redistribution of wellbeing is to be avoided. Increasing the size of the pie can affect the level of natural resources consumed, and those resources exist in complex and fragile ecosystems. The challenge is to understand how natural resources can be used to support economic and societal demands without undermining the contribution of the natural environment (Perman et al. 2003).

Social and environmental limits on economic growth and development

The desirability of the consumption of natural resources for economic growth and development is conditioned by concern for future generations and the potential for irreversible resource depletion, extinction and lost biodiversity (Daly 1987, 2017).

Renewable environmental resources can be sustainably used indefinitely as long as the rate of utilisation and depletion is less than the rates of regrowth or replenishment. Depletion may be caused by reasons other than utilisation such as changes in climate or other environmental factors, which would also need to be accounted for in determining a sustainable level of use. Finite natural resources (like minerals) are depleted by any use, so there is a case, following the Hartwick rule (Hartwick 1977), for using part of the proceeds of use (the economic rent) to invest in other capital so that overall capital value is maintained even while the natural capital volume is depleted. Natural capital is a function of both volume and value components, and these need to be separated to identify the cause of changes in natural capital and implications for wider ecosystem services.

Fundamental distinctions for considering the long-term value of natural capital are whether natural resources are renewable or non-renewable and whether their use is extractive (like pumping water from a stream for irrigation or potable uses) or non-extractive (like valuing river flow for use in boating or swimming or passive non-use appreciation such as scenic or heritage qualities). There are many definitions of sustainability. A primary distinction is between strong sustainability and weak sustainability. The key difference or contention between the two definitions for sustainability is the extent that resources that generate wellbeing benefits are substitutable for each other.

- **Strong sustainability** defines the wellbeing benefits from natural capital and other capitals as different and therefore not substitutable, especially in regard to the natural environment, which implies that a certain minimum standard of natural capital stocks should be sustained into the future.
- **Weak sustainability** assumes the wellbeing benefits generated from natural capital and manufactured capital are equivalent. Therefore, natural capital and manufactured capital are substitutable (Ekins et al. 2003; Dietz et al. 2006), which implies that natural capital can be used as long as its depletion is offset by creating other capital so that the value of total capital is sustained.

The proponents of applying strong sustainability in the case of natural capital emphasise three reasons:

- **Qualitative difference** – the qualitative difference between natural capital and what is variously termed artificial, manufactured or produced capital, as the manufactured capital is reproducible whereas natural capital is not reproducible using human technology.
- **Natural capital originated without manufactured capital** – where manufactured capital consumes natural capital in its creation.
- **Future consumption –** benefits of consumption in the future do not offset natural capital losses in the past.

Table 1 compares the key ideas, consequences, sustainability issues and key concepts.

Table 1 Main differences between weak and strong sustainability

	Strong sustainability	Weak sustainability
Key idea	The substitutability of natural capital by other types of capital is severely limited	Natural capital and other types of capital (manufactured etc.) are perfectly substitutable
Consequences	Certain human actions can entail irreversible consequence	Technological innovation and monetary compensation can offset environmental degradation
Sustainability issue	Conserving the irreplaceable stock of critical natural capital for the sake of future generations	The total value of the aggregate stock of capital should be at least maintained or ideally increased for future generations
Key concept	Critical natural capital	Optimal allocation of scarce resources

Source: Colin (2013)

A key implication of the discussion between weak and strong sustainability is that this is not an either/or choice for all components of the natural environment. Some components can be considered critical natural capital because of the serious consequences of their depletion and require a stronger approach to sustainability than other components that are less rare and more readily substituted by other things. Critical natural capital can be defined as that part of the natural environment that performs important and irreplaceable functions or as parts of the environment that are essential for the continued existence of the human species. Defining what is in this category and what is not often lacks specificity and is discussed in scientific or socio-cultural terms without reference to the choices and trade-offs that are made in practice.

Treating natural capital as critical implies it is not subject to trade-offs and requires protecting at any cost, but this is not how human societies operate. While protecting the last habitat of an endangered species may be critical from the viewpoint of biodiversity maintenance, it is not so clear that it would be a critical matter for the survival of the human species. Society is likely to make trade-offs as it does for other sensitive matters, such as preventing fatalities in transport, weighing up the risk of potential loss of life against the cost incurred in avoiding it. There is no universally accepted list of critical natural capital, and countries may choose to treat different components of natural capital as more critical than others as an expression of their social welfare function, determined through social and political means.

For this report, the definition from the Brundtland report is workable

For this report, the sustainability of the contribution of the natural environment to the wellbeing of New Zealand will be defined as the (ongoing) ability of natural assets to meet the wellbeing needs of the present without compromising the ability of people in the future to have at least the same level of wellbeing over the long term. This definition is an application of the definition used in the Brundtland Commission Report 1987 (World Commission on the Environment and Development 1987).

3 Measuring wellbeing from the natural environment

3.1 Systems of accounting for the contribution of the environment

There are several systems of accounting for the contribution of the natural environment in generating various measures of wellbeing. This section provides an overview of them and draws conclusions about which best suits the objectives of this research. The systems for accounting for natural capital reviewed are:

- UN System of Environmental-Economic Accounting (SEEA)
- World Bank comprehensive or total wealth measures as presented in the Changing Wealth of Nations (World Bank, 2021)
- UN inclusive wealth measures.

Table 2 compares the objectives, strengths and weaknesses of the three systems discussed above. The three systems vary in complexity, but the ability to determine the contribution of the natural environment to wellbeing improves with more complex methods of measurement.

Table 2 Summary assessment of the merits of accounting systems

System	Objective	Strength	Weakness
System of Environmental-Economic Accounting	Providing better national accounting linkages between the economy and the natural environment	Utilises information that is easier to gather and comparable with other national accounts	Relies solely on the market valuation of natural resources and excludes the non-market components of the social value
Comprehensive or total wealth measures	Understanding what is happening to the total stock of assets in the context of economic growth	Tracks trends in natural resources over time to show whether resources are being utilised at a sustainable rate	Assumes substitutability between produced, natural and human capital (weak sustainability), which may undermine the contribution from natural capital over time
Inclusive wealth	Measures the intergenerational sustainability of using produced, natural and human capitals	Seeks to capture the social value of natural resources and environmental services beyond those traded in the market	Demands much more information and a more complex assessment

Source: NZIER

3.1.1 UN System of Environmental-Economic Accounting (SEEA)

What is it?

The UN SEEA is an extension of the UN System of National Accounts (SNA) aimed at better accounting for the linkages between the economy and the natural environment. It extends the production boundary of the SNA to include production in the biophysical environment.

It may also be used to cover impacts on household consumption that do not pass through a production stage.

The current SEEA (United Nations 2014) has three broad components:

- The SEEA Central Framework, which is focused on attributing to natural asset classes areas of production already covered in the main SNA accounts.
- The SEEA Experimental Ecosystem Accounts (EEA) extend the accounting boundary to include effects that are not covered in transactions in the current SNA production (for example, the flood protection values of forests and mangroves).
- The SEEA subsystem accounts cover energy, water, fisheries, forests and agriculture.

Countries have adopted the SEEA to varying degrees. Most countries have stuck with the Central Framework, in effect attributing natural resources as part of the production that the SNA attributes to industrial sectors. Stats NZ has done this by preparing satellite accounts in physical and monetary units for fisheries, forests, minerals, energy, water and the marine economy, which have been repeated at irregular intervals. The UK's Office of National Statistics has gone further in exploring EEA and subsystems for agriculture and forestry. Its subsystem accounts include experimental values for ecosystem services such as the cooling effect of woodlands on urban areas. To the extent that these experimental values reflect avoided costs that would otherwise have been incurred (for example, air conditioning in the case of urban cooling), they go beyond the value in the production SNA but are not yet regarded as entirely compatible with the main SNA.

EEA requires spatially explicit physical and monetary accounts prepared sufficiently frequently to enable time series to be compiled to identify asset appreciation and depreciation. Such EEA applications adopt the ecosystem services categorisations of provisioning, regulating and cultural services. Links between biophysical flows and provisioning services are identifiable and capable of being matched to aspects of the SNA production accounts, but cultural and regulating services are less readily linked to the SNA – tourism draws on cultural services but can only be linked through the creation of tourism satellite accounts with sufficient disaggregation to associate tourism activity to specific ecosystem types (as in the case of Stats NZ's marine economy satellite account).

While the SEEA and the EEA are extending the boundaries of accounts beyond the production base of the SNA, they continue to emphasise exchange values to remain compatible with the SNA, but exchange values in general, and market values in particular, are not a complete measure of societal value. EEA may use non-market valuation techniques, but the emphasis on exchange values precludes the use of the majority of non-market valuations that estimate value based on consumers' surplus and, in so doing, also preclude most of the attempts to estimate non-use values. Such non-use values remain difficult to account for in the SEEA framework.

Could it be used to consider the sustainability of and risks to the contribution of the natural environment to human wellbeing?

It could be used to consider the sustainability of and risks to the contribution of the natural environment to human wellbeing.

However, we have not found any examples of this being done in New Zealand. Key reasons are likely to be linked to that it requires a specific focus on using it for that task and comprehensive data required to assess the trends and outlook of the topic of interest.

Critically, the data requirements for considering the sustainability and risks linked to the contribution of the natural environment to long-term human wellbeing include:

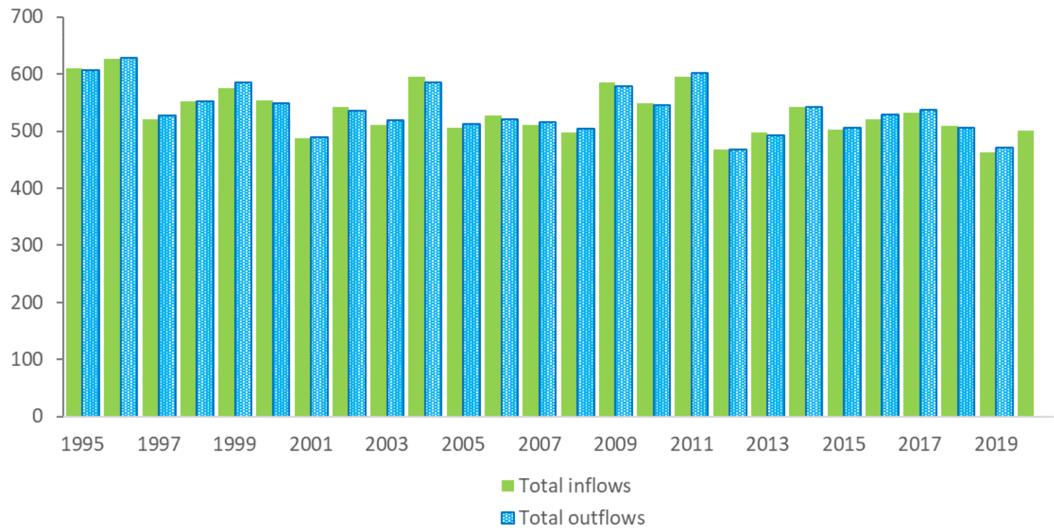
- sufficient time-series data on the quantity and quality of physical stocks of the relevant flora and fauna using consistent measurement methods over regular intervals
- a clear description of any valuation method that has been applied, including the sources and limitations
- mapping to wider ecosystems and biological processing in the short and long term
- a model of the link between the natural environment resources of interest and the human wellbeing associated with them.

There are examples of environmental-economic accounts statistics that go some way towards the question of the sustainability of and risks to the contribution of the natural environment to human wellbeing. Stats NZ published EEA data for a few areas. These measure physical stocks and flows of natural resources, with some regard to use or consumption for human wellbeing.

Water stocks are an example of EEA accounts and the limitations for assessing the sustainability of and risks to the contribution of the natural environment to human wellbeing. Figure 1 shows the measured total inflows and outflows of water stocks for New Zealand from 1995 to 2020. Total outflow data for 2020 was not published. Inflows are measured based on rainfall and other precipitation. Total outflows are the combination of use in ecosystems, estimates of outflows to the sea and abstraction and the temporary use of water in hydro power (the water is returned to the system so the net outflow is zero). Measured inflows and outflows decrease slowly over the time series. Measured total outflows frequently exceed measured inflows by relatively small amounts. However, in isolation, this data is not detailed enough to support robust conclusions about the contribution of the natural environment to human wellbeing. The context for a decrease in measured rainfall is important for considering where the data and trends might be useful. For example, a decrease in rainfall in the catchments for hydroelectric power generation and for the replenishment of aquifers used for irrigation would require location-specific consideration of rainfall trends to consider risks to the sustainability of the contribution of the natural environment.

Figure 1 Water physical stock account for the year ended June 1995–2020

Billions of cubic metres, June years

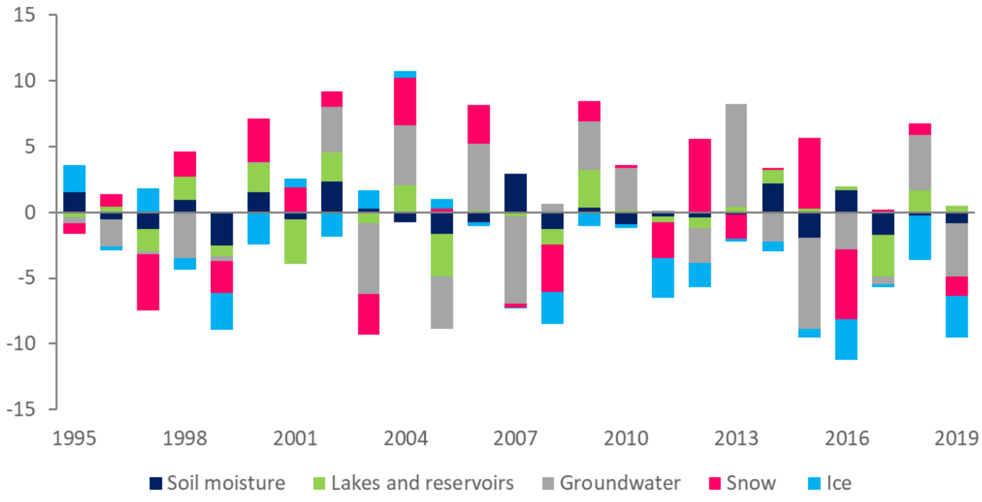


Source: Stats NZ

Figure 2 shows the EEA's change in measured water storage from 1995 to 2019. The change in water storage stocks considers soil moisture, lakes and reservoirs, groundwater, snow and ice. Stocks are affected by seasonal variations in temperature, rainfall, and snowfall. Climate change is also a long-term driver underlying water stock. Unsurprisingly, climate variation means there is considerable volatility in the water stocks. However, measured water storage in ice decreased every year since 2007, while other stocks tended to vary between increase and decrease over the same period. This is consistent with the expectations of global warming. In the context of the contribution of the natural environment to human wellbeing, access to glaciers is at risk, which has implications for international and domestic tourism. In 2019, Fox Glacier was estimated to have been shorter than any time in recorded history, the current terminus was found to be unsustainable and further retreat of the glacier was expected (Purdie et al. 2021).

Figure 2 Change in measured water storage 1995–2019

Billions of cubic metres, June years



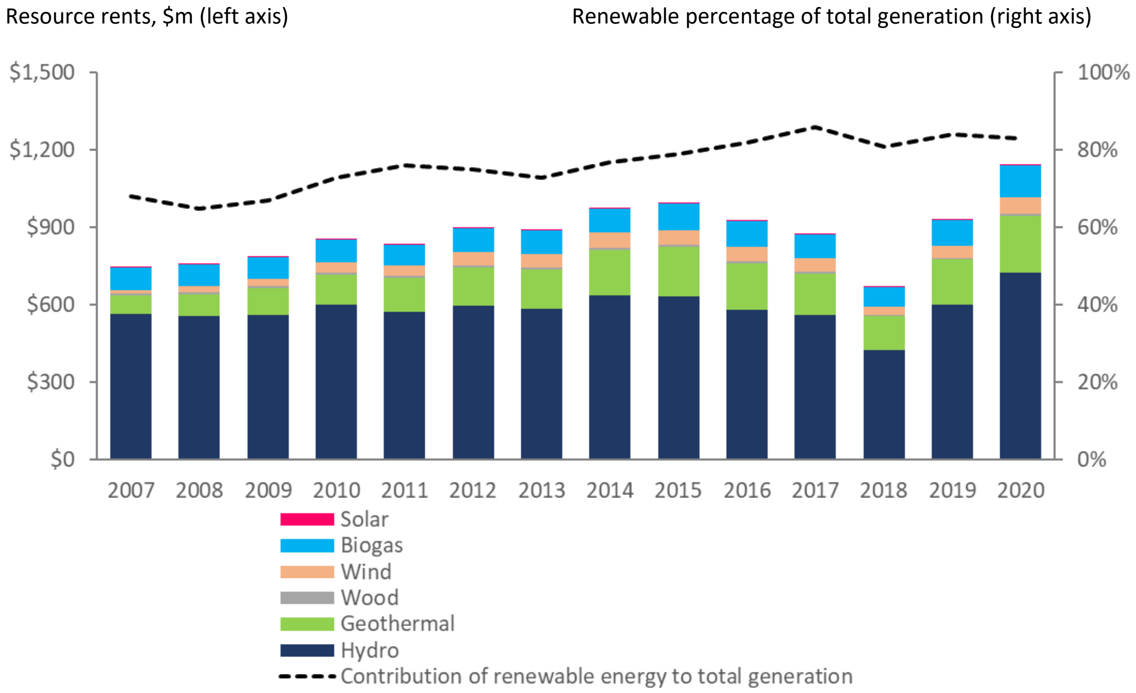
Source: Stats NZ

Other EEAs include:

- government expenditure on protecting the environment
- information on environmental taxes
- periodically produced monetary (and sometimes physical) stock accounts of fish, forestry, land cover and timber
- an assessment of the value-add to GDP from the marine economy from fishing, recreation, tourism, marine mineral extraction and shipping (see section 4 for further discussion on the marine economy trend)
- renewable energy accounts – include generation output, asset value and the value of resource rents associated with electricity generation.

Figure 3 shows resource rents from renewable electricity generation by generation source from 2007 to 2020. Hydroelectricity dominates the value of resource rents. In 2020, hydroelectricity contributed 71% of renewable electricity generation and 58% of total electricity generation. The percentage of electricity generated by renewable sources has increased from 68% in 2007 to 83% in 2020.

Figure 3 Resource rents from renewable electricity generation 2007–2020



Source: Stats NZ

These trends are not enough to draw conclusions about the sustainability of these stocks, but they suggest that, if current trends continue, New Zealand could face shortages that impact future production and consumption activities. Such potential impacts are a function of local supply and demand, requiring a detailed regional or subregional breakdown assessment. As indicators go, the SEEA accounts are not so much 'dials' (indicators whose value adjustment directly impacts useful outcomes) as 'can-openers' (indicators that signal something awry that warrants more detailed attention).

An example of a can-opener is the table in the water accounts, which suggests the volume of water held in snow and ice has been declining in recent years. This may raise issues about the sustainability of current winter sports and related tourism activity, as reducing snow volume may leave parts of the ski runs devoid of snow for longer in the year and hence shorten the ski season. In addition, a reduction in snow and ice volume may signal a shift in the spring meltwater patterns that are relied on for filling South Island hydroelectric lakes to provide generation capacity through the summer. Such potential effects in a national or regional account are only indicative and require more-localised investigation at the catchment or individual ski field level to assess or confirm the risk.

3.1.2 World Bank comprehensive or total wealth measures

The World Bank's work in developing comprehensive or total wealth measures – and before that, the genuine savings measure – arose to counter a possible misleading interpretation of growth when a country's GDP was expanding at the expense of its total wealth and future prosperity. The World Bank has been developing a database with time series of wealth estimates for all countries in the world compiled with a standard methodology to facilitate comparison and analysis of wealth management across countries and to provide country governments with guidance on monitoring wealth alongside GDP.

The World Bank approach draws on the SEEA to enable wealth measures to be integrated into balance sheets alongside the SNA. The components of the comprehensive total wealth measure are:

total wealth = produced capital + natural capital + human capital + net foreign assets

In *The Changing Wealth of Nations 2021* (World Bank 2021), the World Bank expands its coverage of natural capital by including in the core wealth accounts for the first time the 'blue' natural capital components of marine fisheries and mangroves, which are valued for their coastal protection service. The report also includes an analysis of the impact of air pollution exposure on human capital through premature mortality, making the link between environmental health risks and human capital accumulation.

In the comprehensive wealth measure, most natural capital was valued as the net present value of future resource rents over an assumed lifetime, which is feasible for all the natural capital items that give rise to streams of marketable goods and services.

Ecosystem services that support the production of goods and services would be captured in total wealth through the residual intangible assets but not through the natural capital figure. However, many cultural and regulating ecosystem services were not valued or included in total wealth. Assets such as water were omitted, and no adjustments were made for the impacts of externalities such as pollution damage on capital values.

The report also explores approaches for including additional asset classes in future editions such as renewable energy and biosphere (plants and other organisms), at least through its climate regulatory services. At present, the economic rental contribution of renewable energy is not included in the wealth measures, whereas that of fossil fuel is included in the wealth measures. For now, renewable rents appear negative, although rapidly declining costs for solar and wind energy generation suggest resource rents are approaching positive values. The recent high-volume growth in renewable electricity generation has outpaced the speed at which rents per unit of produced electricity are approaching positive values.

Figure 4 shows the World Bank's current estimate of the value of the natural capital provided by a selection of ecosystems (World Bank 2021). The World Bank's estimates suggest that the value of the contribution of the natural environment to the wellbeing of New Zealanders is increasing, but an in-depth understanding of the implication of sustainability requires three categories of information:

- Defining the physical stocks and flows of natural capital.
- Observing the trend in the physical stocks and flows.
- Decomposing the changes in quantities and value per unit to understand where market trends in the value of natural capital might be masking the underlying trend in the natural capital stock and flows. This is to counter the risk that, as a natural resource is depleted by use, scarcity increases the value of its produce, obscuring the decline in its remaining availability in a monetary natural capital account.

The World Bank figures show some unexplained and sudden changes in the value of some components of natural capital, such as the marked reduction in the value of protected areas between 2016 and 2017. This information for New Zealand has not been published in the World Bank's latest report, and its comparability with other countries' figures is open to question.

Table 3 summarises the sources of information used to estimate the value of natural capital in the World Bank report. It shows the estimate is based mainly on the market values of commodities. It is a reasonable approach when compared with many other countries with mixed data-gathering efforts. However, this approach will underestimate the value of nature from an ecosystem perspective.

Table 3 Summary of the sources of information used to estimate natural capital

Natural resource	Physical quantum	Monetisation
Forests, timber	Industrial roundwood: logs, pulp, chips and wood residue	Market prices
Forests, non-timber	Forested land area	Non-timber ecosystems valuation
Mangroves	Global Mangrove Watch database	Avoided flood damage
Fisheries	Maximum catch potential	Landed market price
Protected areas	Total terrestrial protected area	The lower value of cropland and pastureland
Pastureland and cropland	Agricultural production	Producer prices
Oil and natural gas	A range of estimates of production and reserves, e.g. International Energy Agency	Market prices
Coal	A range of estimates of production and reserves, e.g. International Energy Agency	Market prices

Source: World Bank (2021, app. A)

The World Bank's database on capital stocks is sufficiently extensive to identify the changes in the value of different capital stocks and decompose them into different causative factors, specifically changes in the volume of the stock, the value of its benefit stream and a lifetime adjustment effect reflecting an asset's changing quality and effectiveness in providing benefits. This is illustrated in Table 4 below, which shows changes in value and decomposed components for different natural stocks globally over a 23-year period.

Table 4 Three-part decomposition results for natural capital stocks, 1995–2018

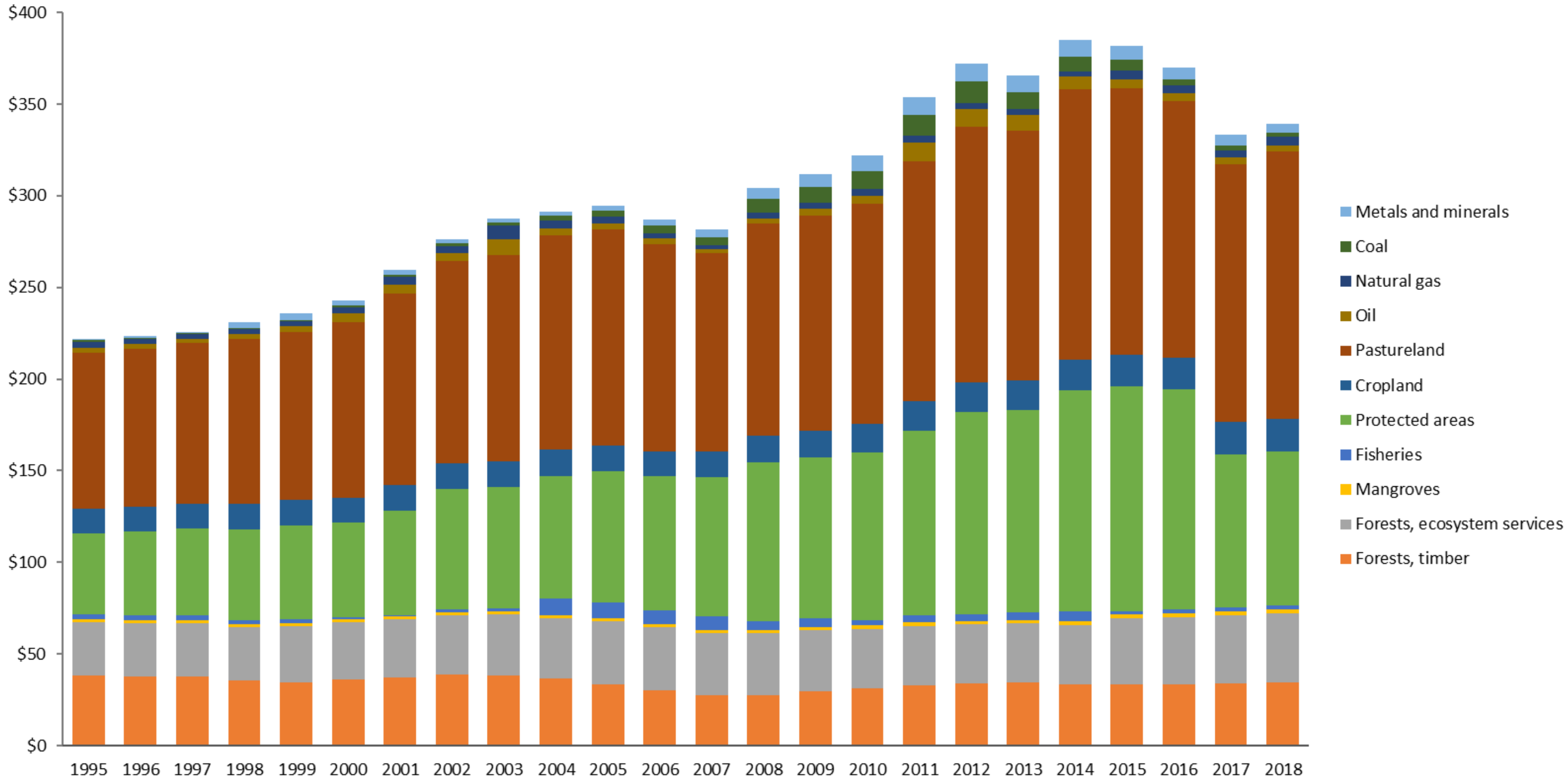
US$ billions (constant 2018 values)	1995	Volume	Rent impacts value	Lifetime	2018
Natural capital	**38,409**	**22,120**	**5,381**	**-1,370**	**64,542**
Renewable natural capital	***25,776***	***9,456***	***2,013***	***-1,660***	***35,586***
Forests, timber	2,544	239	99	-154	2,728
Forests, non-timber	4,879	91	2,487	0	7,458
Mangroves	213	-13	348	0	548
Fisheries	1,225	62	-1,080	0	207
Protected areas	1,927	971	849	0	3,747
Cropland	10,631	6,018	-456	-1,506	14,687
Pastureland	4,356	2,088	-233	0	6,211
Non-renewable natural capital	***12,633***	***12,665***	***3,368***	***290***	***28,956***
Oil	9,588	6,345	3,363	-188	19,108
Natural gas	1,090	1,695	559	-55	3,288
Coal	949	2,150	383	0	3,482

Source: World Bank (2021, tbl. ES 1)

Changes in wealth per capita provide some indication of how the country is tracking but are only suited to assessing weak sustainability because the wealth estimates implicitly assume a high degree of substitution across different asset classes (World Bank 2021). The emergence of global crises in biodiversity loss, climate change and oceanic pollution levels implies limits on replacing natural capital with other forms of wealth, and it may be necessary to look beyond the monetary accounts to stock accounts in physical units to identify whether safe minimum levels are coming under such pressure that they require remedial attention.

Figure 4 World Bank estimates of New Zealand's natural capital from 1995–2018

Billions, constant 2018 NZD



Source: Adapted from the World Bank (2021) converting USD to NZD using a 1.470 NZD per USD (OECD n.d.)

3.1.3 UN inclusive wealth measures

The Inclusive Wealth Framework has been described as a tool to analyse "society's sustainability", which may be defined as non-declining human wellbeing over time (Grimsrud et al. 2018). The framework defines aggregate wealth as the shadow value (or price) of the stocks of all assets in an economy, including those categorised as natural capital. Shadow values capture the substitutability of assets in the present and future and are more comprehensive measures of value than unadjusted market prices, reflecting more short-term influences.

The UN inclusive wealth measures, as described in the *Inclusive Wealth Report 2018*, are based on the proposition that a society's productive capacity reflects the consumption opportunities open to its members (United Nations 2018). It takes an intergenerational perspective to cover not only the wellbeing of those present today but also of people in the future. Wealth is the social worth of the economy's entire stock of assets. Assets are stocks, not flows, but future flows across time and generations can be encapsulated in the value of assets to give a multi-generational perspective of wellbeing.

The basic proposition of inclusive wealth measures is that:

inclusive wealth = productive capital + human capital + natural capital

Produced or manufactured capital assets include roads, buildings, machines and equipment. Human capital covers knowledge, aptitudes, education and skills of the available population and labour supply. It also includes the health of a country's population but does not apparently cover institutional or cultural characteristics.

Natural capital is defined broadly to include agricultural land, rivers and estuaries, the atmosphere and oceans and subsoil resources such as soil nutrients and groundwater, fossil fuels and minerals. It also includes current biological stocks such as forests and fisheries and wider biodiversity, which are conditionally renewable if utilised within their rate of regeneration but may otherwise be degraded and decline irreversibly if subject to excessive encroachment by extraction or changes in natural conditions needed for their survival.

Both the wear and tear on productive capital and degradation of natural capital need to be explicitly provided for and deducted from the estimates of current income available for consumption. Otherwise, current consumption will be depleting wealth and its capacity for future income and consumption. Natural capital can be further divided into renewable capital, which is managed within certain conditions and can continue to provide future services indefinitely, and non-renewable natural capital, including stocks of fossil fuels and minerals in the Earth's crust. The latter are finite and subject to depletion through use, but inclusive wealth is open to the use of Hartwick-style diversion of the economic rent on natural capital extraction into investment in alternative assets that can contribute to future income streams even after a natural resource has been depleted.

As noted by Dasgupta in the foreword to the *Inclusive Wealth Report 2018* (United Nations 2018), researchers on the UN Human Development Programme 1990 have frequently criticised prescribing policies and economic assessments based on quantitative indicators that reflect the means (such as production or transactions) rather than the ends (such as wellbeing). The use of GDP and its derivatives have been routinely criticised for confusing means for ends and countries' opulence for their wellbeing. However, for reasons of convenience, it is more practical to evaluate change in terms of the means for achieving the ends than by attempting to examine the extent to which the ends are being met. The

Inclusive Wealth Report 2018 constructs approximate ways of valuing means in terms of the ends served by assets, including human capital and natural capital.

While inclusive wealth has some commonalities with both the SEEA and the World Bank's total wealth measures, it significantly deviates from them in the way it approaches societal valuation. The societal value of an asset is the worth of the stream of goods and services society can obtain from it and may include both market values and other sources of value (for example, avoided costs, non-market preference values). As an example, a mangrove forest can be a habitat for fish populations available for human harvesting, it can be a source of timber for nearby human inhabitants and it can protect shorelines against storm damage and coastal inundation. It can provide value through these different services simultaneously, although extreme timber extraction may detract from the forests' value for fish populations and shoreline protection. Whereas timber or fish harvested from the mangrove may have value expressed in market exchanges, the mangroves' values for shoreline protection or fish nurseries have more public-good characteristics (non-rival, non-excludable in consumption), which are less likely to be fully covered in market prices.

Societal value is the 'price' that natural assets should have in comprehensive natural capital accounting. It can be very different from market value. Fish harvesters do not pay for extracting fish from the ocean, but they sell their catch at a landed price over and above the cost incurred in catching them, pocketing an economic rent from the conversion of the natural bounty while depleting the natural stock of fish that could otherwise be available to breed and provide more fish for the future. Identifying and accounting for such instances of asset depletion leads to asset values diverging from those expressed through markets. In theory, new markets can be created to explicitly price depletable resources such as through individual transferrable quotas in marine fishing.

The inclusive wealth measures extend the boundaries of accounting beyond the confines of the current SNA production accounts, the SEEA and the World Bank comprehensive wealth measures. If government statistical offices were to prepare inclusive wealth accounts and track movements in that wealth over time, they could check the extent to which social wellbeing has risen over time and identify risks to the continuation of the benefit streams derived from the assets in that wealth. Inclusive wealth per capita has been proposed as a measure of intergenerational wellbeing that could be used for monitoring sustainability and policy analysis, but it would represent a departure from and break in continuity with existing national accounting conventions.

However, the current inclusive wealth reports, which have been prepared at 5-yearly intervals with data back to 1990 and up to 2015, tend to compress information into an Inclusive Wealth Index for comparison purposes, which conceals details between countries. The relative significance of different capitals across the index for all countries is:

- produced capital – 21%
- human capital – health 26% and education 33%
- natural capital – 20%, within which shares of total natural capital are split between forests (37%), agricultural land (14%), fisheries (2%), oil (22%), coal (17%), gas (7%) and minerals (1%).

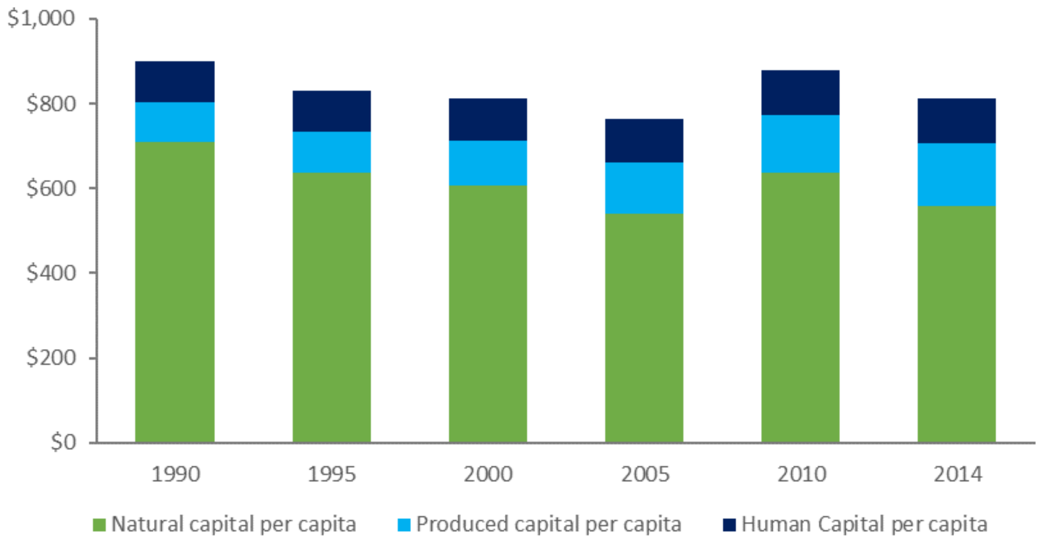
The inclusive wealth approach, therefore, applies heavy weighting to the human capital components of health and education, and within the natural capital component, it still attributes 44% of the value to fossil fuels, most of which need to be left in the ground if the

2015 Paris Agreement on climate change is to be met. Fossil fuels' contribution to wellbeing is compromised by their contribution to climate change and enhanced risk of damage and disruption to economic and social activity, so individual countries' wellbeing derived from natural capital requires unpicking from the aggregated figures presented in the Inclusive Wealth Reports.

The corresponding numbers for inclusive wealth composition are quite different for New Zealand, where human capital accounts for 12%, produced capital for 14% and natural capital for 74% of inclusive wealth. Within natural capital, about 4% is ascribed to agricultural land, 87% to forests, 1% to fisheries and 8% to fossil fuels (and 0% for minerals). In the inclusive wealth tables, New Zealand's inclusive wealth is dominated by natural capital, and forests contribute the most to the estimates. This pattern appears at an aggregate level and at the per capita level, as shown in Figure 5.

Figure 5 New Zealand's components of inclusive wealth

Thousands, NZD



Source: United Nations (2018)

Table 5 shows information about inclusive wealth for New Zealand and some comparator nations, including several other countries with around 5 million population. While all the countries have experienced per capita inclusive wealth growth from 1990 to 2015, the growth rate has been considerably less than that in GDP in all cases. The table also shows the value of renewable energy and its share of the estimated produced capital in the calculation, which shows New Zealand as having the smallest value of renewables of all the countries in the table. The Inclusive Wealth Reports cover only 'new renewables' of solar and wind generation, so countries with significant hydro generation capacity such as New Zealand and Norway perform poorly in this comparison. In the data contained in the report's appendix, New Zealand is shown as having the highest per capita contribution of renewables of any country in the study, its nearest rival being Iceland – another country with an abundance of hydroelectric and geothermal energy and a small population.

Table 5 Comparison of Inclusive Wealth Index and other measures, 1990–2015

Country	Inclusive wealth[1]	GDP[1]	GDP growth/IWI growth	Renewable energy $m[2]	RE/produced capital[2]
	Per capita growth		Ratio	National aggregates	
Norway	1.5%	10.0%	6.67	678	0.001
Australia	1.6%	9.8%	6.13	10,551	0.003
New Zealand	2.4%	7.6%	3.17	502	0.001
Denmark	2.5%	7.0%	2.80	3,567	0.004
Ireland	7.9%	21.6%	2.73	1,777	0.002
Finland	3.5%	9.0%	2.57	546	0.001
USA	3.0%	7.6%	2.53	85,042	0.002
UK	4.3%	8.0%	1.86	21,184	0.003

Source: United Nations (2018) ISER Seminar, 1 Table 2.6; 2 Table 3.7

Considering the use of Inclusive Wealth measures for informing assessments of wellbeing, three broad questions can be addressed:

- Where is New Zealand positioned on average in comparison to other countries across various domains of wellbeing?

  Identifying a country's position relative to its peers on specific measures of wellbeing is a principal purpose of the inclusive wealth measures. The 2018 report contains a number of graphs and tables for selected countries, including New Zealand. The published reports focus on cross-country patterns in the data and do not report on the position of individual countries. It is necessary to examine the measures for selected comparator countries in the report's appendix (United Nations 2018) to assess New Zealand's relative position. The reliability of this depends on the consistency of the method and data inputs used to compute the measures for the different countries. It is clear, however, that New Zealand has a distinct composition of its inclusive wealth with a high weighting on natural capital, which implies it will be subject to different influences than its comparator countries.

- Has New Zealand's situation improved, worsened or stayed stable over time?

  This can be inferred by looking at data for reports prepared at different times across the series. Figure 5 above suggests New Zealand's estimated inclusive wealth per capita declined slightly between 1990 and 2014 at a compound annual growth rate of -0.4%. This was largely driven by movements in natural capital (-1%), which in turn reflected movement in forest capital (-0.8%). It was the only country of the eight listed in Table 5 to experience negative growth in per capita inclusive wealth over that period. All eight countries experienced negative growth in per capita natural capital over the 24 years, ranging between -0.7% in Finland and -5.8% in the UK. New Zealand's rate of -1% is at the smaller end of the range and is likely affected by its population growth and the exceptionally high weighting of forests in New Zealand, as it was the only country of the eight in which aggregate natural capital exhibited a positive compound annual growth rate (0.3%).

- Are there notable differences in the distribution of wellbeing across subsets of the population?

  The Inclusive Wealth Reports examine issues of wealth distribution across the global dataset as a whole but do not report on such distinctions within individual countries. The reports' appendices do not show data on wealth distribution within individual countries, and the quality of information inputs and adjustments required to fit within the international template is not evident from the published reports.

3.1.4 The ecosystem services approach

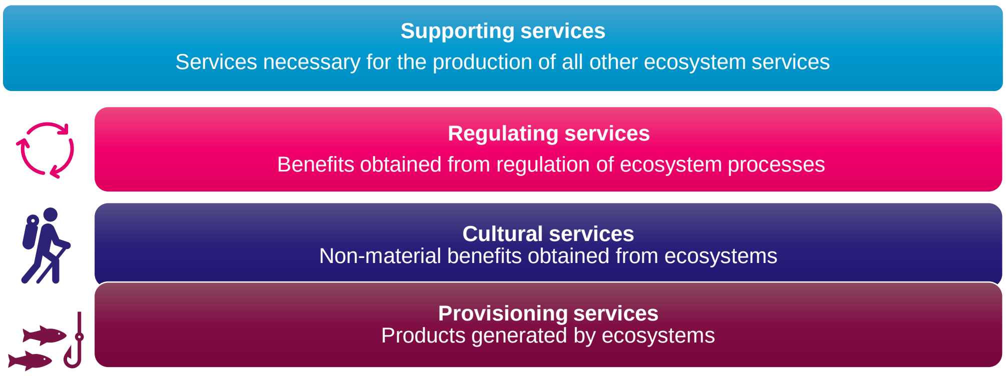
The ecosystem services approach attempts to express the 'worth' of natural resources in terms of the services flows for human wellbeing, including effects that are relatively hidden from view but would entail real value impacts if natural resources were degraded. It is a method for extending the scope of natural capital beyond the narrow confines of measures based on market values by identifying different sources of value that vary with changes in the state of the environment.

The term 'ecosystem services' came into common use in the 1990s and provided a more coherent frame for various ad hoc valuations already being undertaken. It received prominence in 1997 when Costanza et al. published in *Nature* an estimate of the value of the world's ecosystem services, which concluded they were collectively worth about three times the world's total GDP output in that year (Costanza et al. 1997). This drew on a range of market and non-market valuation techniques to assign value to particular services, although it was criticised by many economists for mixing valuation concepts and not providing meaningful values for marginal changes in ecosystem services outputs.

In a 2014 update of this study, Costanza et al. concede that their estimate could not be used for marginal analysis (Costanza et al. 2014), but it was still useful as an illustrative tool in drawing attention to the unstated values associated with ecosystem services.

In 2001, the UN initiated the Millennium Ecosystem Assessment (MEA), which was charged with assessing the consequences of ecosystem change on human wellbeing (Alcamo and Bennett 2003). It described ecosystems as "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit". It proposed in its 2005 report a four-fold division of the benefits of natural assets into provisioning, supporting, regulating and cultural services (Millennium Ecosystem Assessment 2005). This provides a framework for inferring the economic value of different functions and services. These categories are summarised in Figure 6 below.

Figure 6 Categories of ecosystem services



Source: NZIER

In practice, the distinction between regulating and supporting services can be difficult to make and may be subject to double counting. Some countries that have attempted to implement the MEA guidelines omit the supporting services category. The European Environment Agency has suggested a Common International Classification for Ecosystem Services (CICES), which would be used for translating the characteristics of a natural asset into services of value for people. This would follow a sequence of steps:

- Biophysical structure or process – woodland habitat or net primary productivity.
- Function – slow passage of water or biomass production.
- Service – flood protection or harvestable product.
- Benefit – contributions to human wellbeing, health and safety, food and materials.
- Value – willingness to pay for woodland protection or value of harvestable products.

Various countries have attempted to prepare natural capital accounts under the ecosystem services framework. One of the most ambitious has been the UK's National Ecosystem Assessment (2011), a highly resourced, one-off exercise that is more extensive than most.

Table 6 outlines the correspondence between ecosystem services categories and the various attempts at natural capital accounting by the United Nations and World Bank. Provisioning services are most closely aligned to market values covered in the SNA and the market-focused extensions in the core set of the SEEA. Cultural services are also aligned to the SNA to the extent that they are related to marketed services such as tourism, but other aspects of cultural services entail non-market values that are outside the SNA and SEEA, except for some that might qualify as experimental valuations. For instance, heritage and scientific values are strongly oriented towards option values for retaining natural resources for future uses and existence values in retention for their own sake. Neither of these value categories are comprehensively reflected in the SNA or core SEEA.

Regulating services are largely about the avoided costs of things that have not happened because of the intervention of ecosystem services. For instance, the Ministry for the Environment has identified a positive association between indigenous land cover and freshwater quality and negative associations between modified urban and agricultural land and higher water contaminants and nutrient levels. Such regulating services are generally outside the SEEA, with rare exceptions such as the UK's experimental SEEA, which includes a value for the cooling effect of tree cover on urban heat islands. Such regulating services generally require bespoke valuations, which often require a bottom-up amalgamation of multiple valuations of localised impacts. Only rarely are they reflected in natural capital accounts such as the World Bank's inclusion of mangroves in total wealth.

Table 6 Correspondence of ecosystem services and natural capital accounts

Ecosystem services category	Calculation method	Means of inferring sustainability	Interpretation commentary
Provisioning services	Attribution of income-earning activity to natural environmental resources	The long-term trend in availability of per capita natural resources underpinning the production	Measures anchored in the SNA and SEEA core accounts
	Attribution of economic rent to natural resources, after all other inputs receive a normal return	Availability of other inputs (like fertiliser) to replenish natural resources and sustain productive capacity into the future	Also relevant to the World Bank's total wealth measures and the UN's inclusive wealth measures
Cultural services	Services for recreation, heritage, education, scientific research and Māoritanga	The long-term trend in availability of per capita natural resources underpinning the production	Monetary values in the area of SEEA experimental accounts
	Have public good characteristics, so mean availability per capita is a primary measure	Direct market values are limited, but non-market valuation may be appropriate	Also relevant to the UN's inclusive wealth measures
Regulating services	Services of natural resources would result in costs if the resources were depleted	The measure is of things that have not happened, e.g. reduced erosion rates, flood incidence due to differences in land cover (natural or modified)	Monetary valuation in the SEEA experimental accounts and the UN's inclusive wealth measures may be appropriate
	Measured through avoided costs and next best alternative for getting similar results, so not ready series of values to uplift	Requires bespoke estimates of issues likely to cause major future costs; some indicators of future changes in risks of adverse events	Adverse effects avoided are intrinsically localised, and valuations need to be approached in a bottom-up fashion
Supporting services	Fundamental ecological processes that support life on Earth such as nutrient cycles and atmospheric composition	The sustainability of local supporting services may be inferred from trends over time and the decline in replenishment per capita	Monetary valuation in SEEA experimental accounts and UN's inclusive wealth measures could be relevant
	Greenhouse gas emissions can be measured and valued and also localised water and soil nutrient cycles	Supporting services that are global in scope (e.g. oxygen supply) are beyond national control unless subject to international agreements for action (like climate change)	Value attributable to supporting services is difficult to distinguish from that for provisioning and regulating services, so a separate assessment is not worth pursuing

Source: NZIER, drawing from Millennium Ecosystem Assessment and other sources

Using ecosystem services to infer the sustainability of natural capital's contribution to people's wellbeing may require viewing available information in specific ways:

- Tracking trends over time expressed in per capita terms to indicate how much ecosystem services flow or natural capital stock is available to each person as the population grows over time.
- Tracking the value of the services obtained over time separately from the volume of natural capital stock from which it is derived, as the latter is the more critical measure for ascertaining whether sustainability is weak or strong.
- Identifying if there is a persistent direction of changing availability over time, whether that is fluctuating over time with changes in external conditions and what the main drivers of changing availability are – for example, changes in the value of the service, the volume of stock providing it, the size or tastes of the population demanding it and whether substitutes have emerged providing similar services.
- Where there is a persistent and ongoing decline in the volume of natural capital per capita, dividing the total stock by the rate of decline to indicate the number of years left of the available resource under current demand and technology conditions and the number of years left to find ways of reversing depletion or changing demand to fit with a sustainable level of natural resource use.
- For some natural capital, aggregate measures of flows or stocks at the national level give limited information about the availability of natural capital across diverse communities across the country – for example, national-level measures of protected areas per head of population are not informative about the accessibility of natural protected areas for recreational use where the geographical distribution of protected areas is different from that of population. The UK's National Ecosystem Assessment illustrates a way of using geographical information systems to compare the demand from population centres with the accessibility to natural protected areas through a function based on travel costs in regional estimates that can be amalgamated into a national figure. This requires detailed bespoke estimates beyond the routine compilation of national accounts and environmental data for annual or other frequent reporting.

While the capitalisation of services flows fits well with the idea of natural capital, for some things, the capital description is less useful – for example, biodiversity, for which diversity is critical, may be managed better through a suite of separate indicators of the different components of diversity than by fitting into a natural capital account with questionable dollar values.

The implementation of an ecosystem services approach that links the sustainability of the natural environment to human wellbeing requires three actions (Guerry et al. 2015):

- Developing solid evidence linking decisions (on environmental policy or resource use) to impacts on natural capital and ecosystem services and then to human wellbeing.
- A partnership between leaders in government, business and civil society to develop the knowledge, tools and practices necessary to integrate natural capital and ecosystem services into all decision making that affects them.
- Institutional reform to change policy and practices to better align private short-term goals with long-term societal goals.

3.1.5 The application of ecosystem services to New Zealand

Ecosystem services and Genuine Progress Indicators

In applying Costanza et al.'s ecosystem accounting approach, Patterson and Cole prepared "Total Economic Value' of New Zealand's Land-based Ecosystems and Their Services", which appeared in Manaaki Whenua – Landcare Research's *Ecosystem Services in New Zealand* (Dymond 2013). This provides a single year's estimate of supporting value, regulating value and provisioning and cultural value for 12 land-based ecosystem types, including horticulture and cropping, agriculture, forest, agriculture-forest and a range of other scrub and wetland ecosystem categories. The authors use non-market value estimates to identify use values and gross values to yield gross value for each ecosystem type and also present a net value comprising gross less the supporting value of each ecosystem. While of some interest in showing the relative value of different ecosystems and their component values, it does not standardise the values in terms of value per hectare of each ecosystem or value per resident accessible to each ecosystem, and it provides no obvious connection to wellbeing.

That edition contained various other papers on the contributions of different ecosystems to services of use to people, including tussock grasslands, plantation forests, urban ecosystems and marine ecosystems. Most of these papers did not progress much further than identifying different types of ecosystem services under the four categories of supporting, regulating, provisioning and cultural. Some of them quantified the services in physical terms such as the area of particular land cover providing a certain mix of services, and some cited values per hectare, either from international sources or from local studies of particular sites or locations, which may or may not be representative of a class of land cover in New Zealand. However, few of these papers explain how a physical effect translates to services of value to people or what that value might be in light of the number of people affected or the availability of substitutes to the natural services being provided, nor do they resolve the inherent conflicts that may arise between mutually exclusive services that arise from choices over ecosystem management. For instance, a river provides one set of services if left to flow in its natural state, which may be higher in regulating and some regulating services but lower in provisioning services than if the river is dammed to provide water storage for electricity generation, irrigation or potable extraction. Different mixes of ecosystem services are obtained from ecosystems of different levels of modification, and it is the strength of demand and availability of alternative sources of such services in particular locations that determine which is the most valuable mix of uses in any particular place and how that value contributes to people's wellbeing.

Among the alternatives to conventional economic accounting measures, a more ambitious measure is the Genuine Progress Indicator, which was pioneered in Canada and has been applied in New Zealand at Massey University (Patterson et al. 2019). This builds on the UN's Human Development Index (HDI) to include a number of measures of environmental gain or loss that are used to adjust GDP to account for net environmental impacts. Usefully, this includes impacts per capita of a number of environmental measures over the years 2007 to 2016, including:

- air pollution
- greenhouse gas emissions
- loss of indigenous forests

- loss of soil ecosystem services
- loss of wetland ecosystem services.

Unfortunately, these estimates are not particularly up to date and provide little indication of these ecological systems' current or future capability to continue providing services.

Another approach to reporting ecological capacity is the assessment of planetary boundaries developed at the Stockholm Resilience Centre. This posits a "safe operating space" of the world's biophysical systems and a "just and fair share" of resources for each country, based largely around per capita availability of environmental resources and their sustainable annual use. It can be used to compare an individual country's resource use in production and consumption activities against this theoretical share to conclude whether the country is operating within or outside its planetary boundary. Results can be presented from either a production perspective (covering all production within the country both for domestic use and for export) or a consumption perspective (resource use in total production – exports + imports).

In a high-level application across 150 countries, O'Neill et al. (2018) found that no country meets the basic needs of its citizens at a globally sustainable level of resource use. Physical needs such as nutrition, sanitation, access to electricity and the elimination of extreme poverty could likely be met for all people without transgressing planetary boundaries, but universal achievement of higher-level, more qualitative goals (such as life satisfaction) require a level of resource use that is 2–6 times the sustainable level, based on current relationships.

In another paper, Kim and Kotzé (2021) conducted a systematic review of 80 peer-reviewed articles on the notion of planetary boundaries as embodying a set of interdependent and politically constructed environmental limits that are global in scale. This identified different problem framings and governance solutions offered in the literature, which broadly relate to the ideas of institutionalising, co-ordinating, downscaling and democratising the governance of planetary boundaries. Although claiming to examine how Earth sciences and social scientists converge on the planetary boundaries concept, economics is not one of the social sciences included in its scope, which focuses rather on the disciplines of law and governance. The review found that discussions are relatively restrained and limited about law and its role in planetary boundaries governance. It noted criticisms of the planetary boundaries approach for being driven by technocrats and reflecting perspectives from a minority of (mainly developed) countries and the suspicion this arouses in the global south about restrictions on their autonomy over the use of resources. Despite this, its proposed solutions are oriented around strengthening global institutions to monitor countries' adherence to planetary boundaries, and it appears oblivious to recent signs of resurgent nationalism in China, Russia, the UK and the US, which have weakened the institutions it proposes to strengthen and rely on.

In a report commissioned by the Ministry for the Environment, the Stockholm Centre and associated research institutions applied the planetary boundaries approach to New Zealand, specifically five measurable aspects of New Zealand's environmental condition (Potsdam Institute for Climate Impact Research, Stockholm Resilience Centre, and Mercator Research Institute on Global Commons and Climate Change 2020). It concluded that, on all five, New Zealand exceeded its planetary boundary, but closer inspection reveals two of those are in a zone of uncertainty, so there were three definite plus two possible breaches.

These are the five measures assessed:

- Climate change, assessed on the national share of remaining carbon budgets for 1.5°C or 2.0°C temperature increases above pre-industrial levels.
- Land systems change is assessed on two metrics: the fraction of land converted to cropland (in which New Zealand appears within its boundary due to its small share of cropland compared to extensive pastureland that is outside the measure) and the fraction of natural forest remaining (of which less than 50% remains, so New Zealand transgresses the planetary boundary of forest loss).
- Freshwater, assessed on the direct use of 'blue water' drawn from natural water bodies and the remaining 'green water' available for ecosystem functioning. New Zealand is a profligate user of blue water but has abundant natural supplies, so the measures at the national level mask some localised hot spots of declining water quality.
- Biogeochemical flows, measured as the application of nitrogen and phosphorus to agricultural and other soils, were among the measures in which New Zealand exceeded its planetary boundary by the highest multiples.
- Biosphere integrity, assessed on biodiversity intactness using an index for species abundance, was another area in New Zealand that exceeded its planetary boundary.

The two uncertain boundary breaches where for land systems and freshwater. The planetary boundary approach shows New Zealand has a high intensity of impact on a number of environmental systems, but the approach is not without its criticisms. It is based on a notion of a country's "fair share" of some environmental resources based on a formula largely reflecting per capita availability across different countries' populations, with some simple adjustments for resources not being evenly distributed across countries. The planetary boundaries approach does not give much weight to the economic considerations that resource use will reflect the relative abundance or scarcity of different resources in different places. Many other assumptions used in the assessments are open to question.

Ultimately, the planetary boundaries approach sets boundaries at a global level as if strong sustainability applies to all the defined Earth systems wherever they occur. In doing so, it misses the dynamism, complexity and resilience of environmental systems at local levels, which have enabled ecosystems to be much modified by human use and adjusted to allow those uses to be sustained over prolonged periods in some (although not all) cases. Planetary boundaries may be an arresting concept giving pause for thought, but it is mainly a notional target setting exercise that offers little insight into what is driving the pressures and impacts on environmental systems, how to change those driving forces or how the pressures and proposed solutions affect the wellbeing of people facing such changes.

Considering the use of ecosystem services estimates for informing assessments of wellbeing, three broad questions can be addressed:

- Where is New Zealand positioned on average in comparison to other countries across various domains of wellbeing?

  The New Zealand ecosystem services estimate of Patterson and Cole (2013) was a single estimate of a point in time, and while it is modelled on the Costanza et al. (1997) approach, it cannot be considered as a direct comparator with other countries, nor does it provide comparisons over time. As with the Costanza original, it is more useful as an indicator of how big ecosystem services might be rather than as a monitoring tool of how large they are.

- Has New Zealand's situation improved, worsened or stayed stable over time?

  As a one-off study, the Patterson and Cole (2013) estimates do not indicate changes over time. Repeating such an exercise at 5-yearly intervals might give some indication of change, but such sequential studies are not yet available. The Genuine Progress Indicator of Patterson et al. (2019) does provide more time series of a range of matters going back in time, but its coverage stops around 2016, and it gives no indication of more recent changes or how they might unfold in future.

- Are there notable differences in the distribution of wellbeing across subsets of the population?

  The ecosystem services estimates currently available for New Zealand do not show the distribution of effects across the country and contributions to wellbeing. Such estimates have been tried overseas for some regions and indeed for whole countries in the case of the UK's National Ecosystem Assessment (2011), but that was a very resource-intensive exercise unlikely to be repeated in a hurry.

Landcare's environmental stewardship and wellbeing

Maanaki Whenua – Landcare Research (Ausseill et al. 2021) provides a review of a range of environmental indicator frameworks and datasets and assesses their relevance to wellbeing measures using the LSF 2018 as the prime example of wellbeing frameworks. The authors propose a better tracking of connections between nature and people's wellbeing from the Driver-Pressure-State-Impact-Response framework used for organising environmental statistics and the reduced Pressure-State-Impact framework used for environmental reporting in New Zealand. Reviewing the LSF's more than 60 indicators to monitor progress across 12 current domains and four future capital stocks, they conclude that most indicators track state and pressure rather than impact, and they develop an environmental indicator set drawing on the ecosystems services approach, the nature's contribution to people model (IPBES 2018) and EU indicator framework for discussion with potential users and managers, seeking suggestions for refinement. They propose their refined measures could identify ways in which ecosystems supply functions of use to people and also the demands people place on the environment. Their indicators, however, are not unitised into values per person or per hectare, and their implications for wellbeing are not immediately apparent.

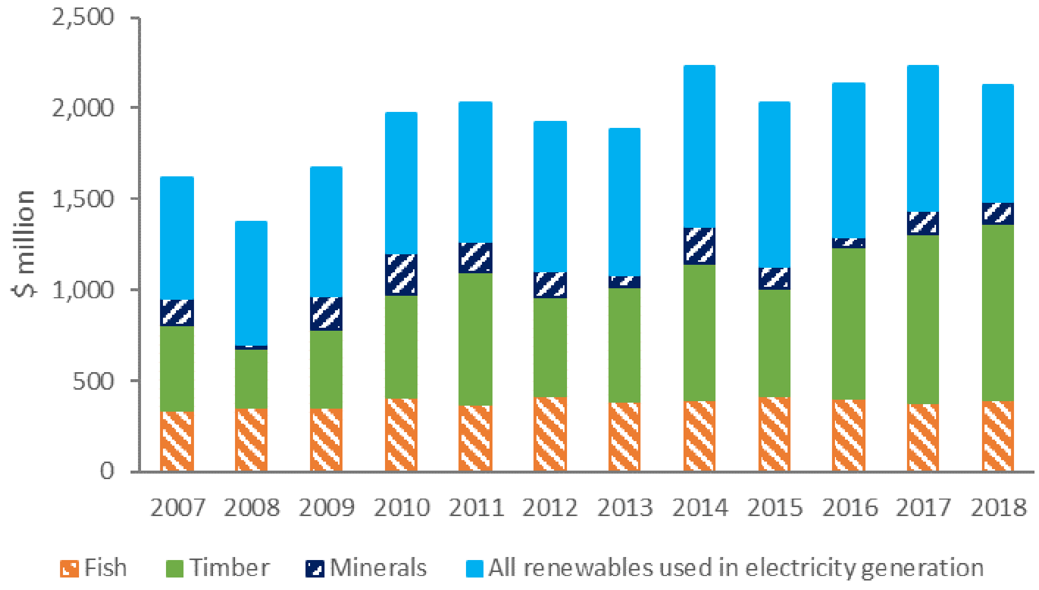
Resource rentals from New Zealand's natural capital stocks

Parallel to multi-dimensional assessment frameworks of ecosystem services, Stats NZ continues to develop resource accounts under the UN SEEA. These are mostly stock accounts of the value obtained over time from fish stocks and renewable energy, accounts covering environmental protection expenditure and environmental taxes and the contribution of the marine economy to illustrate the value associated with New Zealand's economic exclusion zone, which is three times larger than its land area above sea level. There is also a natural capital account that records both the economic rent earned from natural resources on an annual basis and an estimate of asset values expected in future from these natural resource stocks.

Figure 7 shows the value that flows from a selection of natural capital stocks in the latest data published by Stats NZ. Over the full 12-year period, fish have accounted for 20% of the total rental value, forests for 33%, minerals for 7% and renewable energy for 40%. Fish values have been relatively constant, with limited variation in the volume of fish caught under the quota management system and fairly stable prices. Forestry and minerals vary more in the production volume and the prices received. Renewable energy varies with the utilisation of storage capacity that reflects rainfall, snowmelt and electricity demands.

A similar set of accounts on natural resource asset values reflects the capitalised value of future rent earned from these natural stocks. The asset account covers just stocks of fish, timber and renewable generation. Minerals are excluded as there is practically no limit to the amounts that could be extracted as new resources are discovered in the Earth's crust or new technologies emerge to better extract minerals from geological material.

Figure 7 Value obtained from natural capital flows from stocks over time



Source: NZ Natural Capital Account (Stats NZ 2022)

Due to the UN SEEA's requirements for consistency in accounting with the main SNA, this natural capital account is limited in scope to readily identifiable inputs into the economic production system. It also omits the carbon sequestration value of forests – the forests in question are limited to exotic plantation forests and include only timber values.

3.1.6 Beyond economic accounts

Economic accounts still struggle to include all the things that contribute to wellbeing, so a number of multi-attribute measurement frameworks have arisen to capture the full breadth of progress across different dimensions of wellbeing. These include the UN's HDI, which compiles a summary measure of a country's average per capita achievement across different dimensions of wellbeing – for example, health represented by life expectancy at birth, educational capability by years of schooling received by adults aged 25 or older and standard of living by gross national disposable income per capita.

The HDI has its uses for development studies and has clearly influenced economic measures such as the Inclusive Wealth Report (United Nations 2018) and the OECD's *How's Life* assessments of wellbeing (OECD 2017, 2020). However, the HDI lacks attention to economic accounting principles and what they imply about the values of resource use changes.

3.2 Environmental indicators in the LSF

Environmental indicators can serve a number of purposes in identifying impacts on wellbeing. These include:

- tracking movements over time – for which time series are needed to identify trends
- tracking progress against specific targets – for which targets are required linking desired environmental outcomes with wellbeing outcomes
- comparing one country's performance with that of others – usually snapshots in time and subject to a consistent compilation of indicators across countries
- informing future policy tweaking – which requires greater disaggregation of data to obtain detailed distributional insights than is normally possible from macro-level accounts.

The Treasury document *Trends in Wellbeing in Aotearoa New Zealand: 2000-2020: Background Paper for the 2022 Wellbeing Report*, released in April 2022, provides a "backwards-looking" assessment of wellbeing achievement, including against the environmental amenity components of current wellbeing domains. A forward-looking assessment of risks to wellbeing from environmental sources also needs to take account of that risk being a function of:

- the severity of the impact of a risk should it eventuate
- the probability of that impact occurring over a foreseeable timeframe
- the exposure and vulnerability of at-risk populations and assets
- the resilience characteristics of the at-risk populations and assets.

Environmental indicators in the LSF have evolved with the successive iterations of the LSF. Table 7 below lists indicators as of April 2022, identifying indicators that are new, altered or relocated from previous LSF iterations and, by default, those continuations of existing measures. The principal differences from the 2018 LSF are the inclusion of health impacts (air and water quality) under the natural environment domain, the addition of purely climatic measures (prevalence of droughts, mean air temperatures, coastal sea-level rise) and the inclusion of new natural capital measures drawing on the environmental, economic accounts for stocks of fish, groundwater and timber.

The list of environmental indicators has been enlarged from previous versions of the LSF. However, *Trends in Wellbeing in Aotearoa New Zealand: 2000-2020: Background Paper for the 2022 Wellbeing Report* covers only current wellbeing indicators, and the accompanying spreadsheet provides data for only three items relating to perceived environmental quality and access to the natural environment. It also points out that New Zealand has good air quality compared to other OECD countries, although New Zealand does not have a comprehensive measurement of the international comparator measure $PM_{2.5}$ (OECD 2017).

The background paper contains no information on the natural environment (future wellbeing) indicators, how far these have been compiled or even what units they appear in (annual volumes or cumulative stocks). The new natural environment measures have more indicators of stocks that could be adapted for forward-looking analysis. For instance, current extractions of fish, groundwater and timber could be combined with their stock figures to compile indicators of the future availability of these resources. Net greenhouse gas emissions, which are a function of gross emissions and carbon sequestration, might be better split into those two components to better indicate where progress is being made in emissions restraint or carbon sequestration and draw connections to timber stocks (which cover both forest resources likely to be harvested and those unlikely to be).

Table 7 LSF environmental indicators of current and future wellbeing

as of April 2022

Domain	Indicator	Statistic	Source
Indicators of current wellbeing from the environment			
Environmental amenity	Health impact of air quality (PM_{10}) (new/revised)	Modelled health effects (annual restricted activity days per 100,000 people) from exposure to anthropogenic PM_{10} [International comparison based on 3-year moving average population-weighted exposure to $PM_{2.5}$ concentrations, micrograms per cubic metre]	Stats NZ & MfE [This replaces the national average PM_{10} concentration]
Environmental amenity	Access to the natural environment	Percentage of adults who said they could easily get to all or most of the green spaces in their local area	Stats NZ New Zealand General Social Survey
Environmental amenity	Perceived environmental quality	Percentage of people who rated the overall state of the environment in New Zealand as good or very good	Subjective responses from Lincoln University Survey
Environmental amenity	Swimmability (rivers)	Percentage of state of environment monitored river sites in each *E. coli* band	Land, Air and Water Aotearoa
Environmental amenity	Drinking water management (relocated)	Percentage of people served with drinking water that met all treatment management standards	Annual report on drinking water quality (MoH)
Natural capital indicators			
Environmental amenity	Drought (new)	Prevalence of agricultural drought	Environmental Reporting Series, Stats NZ & MfE
Natural environment	Average temperature (new)	The annual national average temperature	Environmental Reporting Series, Stats NZ & MfE
Natural environment	Biodiversity and genetic resources	Percentage of assessed indigenous species classified as threatened or at risk of extinction	Environmental Reporting Series, Stats NZ & MfE
Natural environment	Coastal sea-level rise (new)	Annual mean coastal sea-level rise relative to 1986–2005 mean baseline	Environmental Reporting Series, Stats NZ & MfE
Natural environment	Net greenhouse gas emissions	Net greenhouse gas emissions in kilotonnes of CO_2 equivalent	New Zealand Greenhouse Gas Inventory

Domain	Indicator	Statistic	Source
Natural environment	Renewable energy	Renewable energy as percent of total primary energy supply	MBIE Energy in New Zealand
Natural environment	River health (new)	Percentage of state of the environment monitored river sites in each of the macroinvertebrate community index bands	Land, Air and Water Aotearoa
Natural environment	Soil quality	Percentage of tested sites within targets for at least six of the seven types of soil test	Environmental Reporting Series, Stats NZ & MfE
Natural environment	Fish stocks (new)	Total allowable commercial catch	Stats NZ Environmental-Economic Accounts
Natural environment	Groundwater stocks (new)	The volume of groundwater stocks	Stats NZ Environmental-Economic Accounts
Natural environment	Timber stocks (new)	The volume of total timber resources, including timber both available and unavailable for wood supply	Stats NZ Environmental-Economic Accounts

Source: New Zealand Treasury (2021)

4 Trends in the sustainability of wellbeing and natural capital

In this section, we outline some trends in the sustainability of wellbeing from the natural environment.

4.1 Our cross-cutting themes

The discussion is grouped into the broad ecosystem themes of.

- land use and soil
- forests
- marine environments, which include fisheries, mangroves and wetlands
- biodiversity.

However, it is recognised that the boundaries between these ecosystems are blurred in the natural environment – for example, a wetland can be a mix of land, river and marine environments.

Why these themes?

The basis for selecting these was informed by the desire to have a broad view of the natural environment and align with the typical themes focused on by the Ministry for the Environment and Stats NZ in their published environmental reporting, while recognising the grouping of these themes often changes slightly with the publication of each report from the Ministry for Environment.

What was considered for each theme?

A common assessment framework was needed to deliver consistency in the review across the themes. Three key aspects are considered for each broad ecosystem:

- Measures of the physical natural capital.
- Measures of the contribution of the natural capital to wellbeing.
- Highlights of the discussion about the sustainability of the natural environment and its contribution to wellbeing.

Information gaps are an opportunity

Where gaps emerged in the assessment, it was due to a lack of publicly available and enduring data collection. These gaps are an opportunity to strengthen understanding of the natural environment and wellbeing through deliberate investment in expanding the collection and publication of environmental statistics.

4.2 Land use and wellbeing

Land and land-based production are fundamental to human society and are central to New Zealand's economic development and cultural identity. Land-based ecosystems support economic production and export commodities and are the basis for housing, community and natural amenity for recreation and tourism.

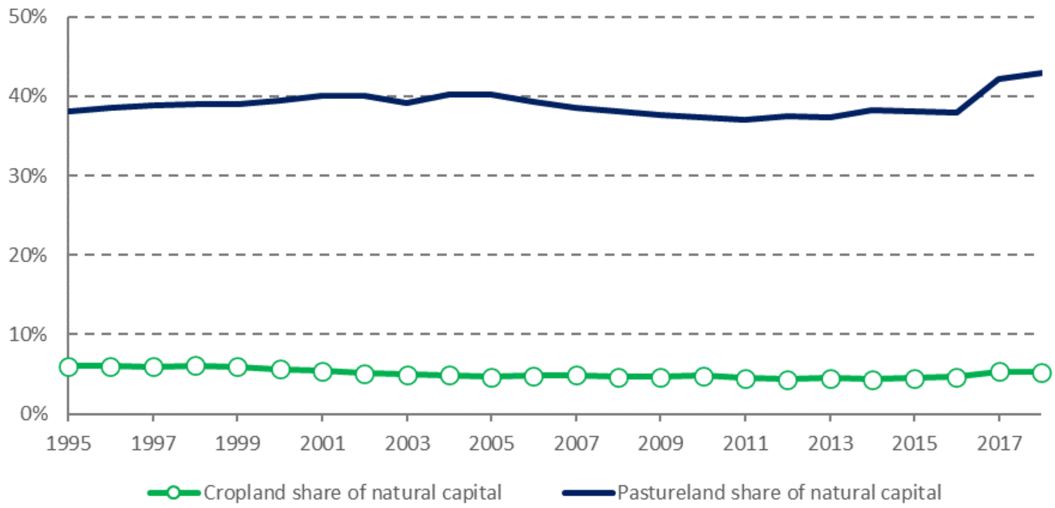
4.2.1 Agriculture and wellbeing

Agriculture has been a significant source of economic development for New Zealand. While urbanisation has increased and the economy has diversified into other areas, agriculture remains an important aspect of our economy and our national identity.

The World Bank estimates the contribution of cropland and pastureland as a dominant component of its estimate of the value of New Zealand's natural capital. Figure 8 shows that agriculture's share of the estimated natural capital has been stable over three decades. In 1995, agriculture's share of the value of natural capital was 44%. By 2018, it had increased to 48%. The average share from 1995 to 2018 was 44%, making agriculture a steady and large contributor to the overall estimated value of natural capital.

Figure 8 Agriculture as a share of New Zealand's natural capital

% of the total value of natural capital

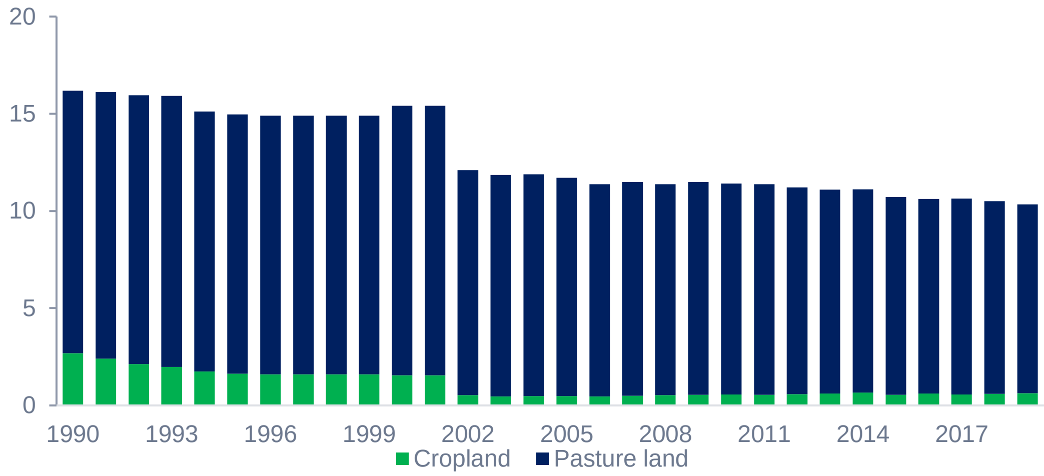


Source: World Bank (2021)

The area of land used by agriculture has decreased over time as the land is used for other purposes (see Figure 9). However, the marked drop between 2001 and 2002 looks anomalous compared to land-use changes in that period and raises questions about whether the definition of what is being measured have changed over time.

Figure 9 Agricultural land area

Millions of hectares

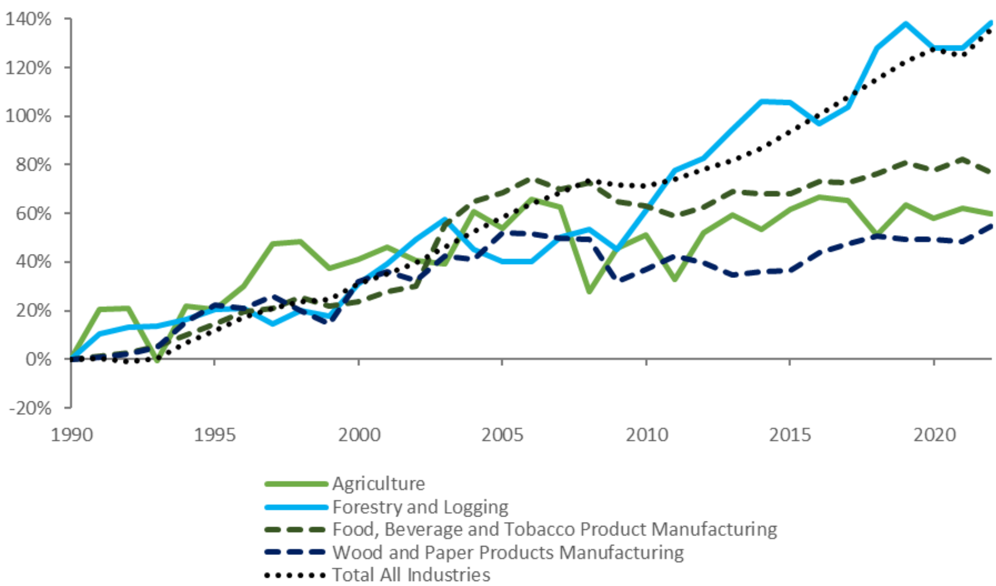


Source: Food and Agriculture Organisation (2022)

The contribution to GDP from agriculture increased by 60% compared to 1990 levels, measured in constant prices (see Figure 10). This indicates the contribution of the natural environment to the economic wellbeing of New Zealand is increasing through the combination of greater yields from the land and market demand for New Zealand agricultural products. The relative contribution of agriculture to GDP has also decreased compared to 1990. In 1990, agriculture was 5.5% of total GDP from all industries, and in 2022, agriculture was 3.7% of total GDP from industries. These statistics do not include the contribution of food processing and manufacturing using the products from agriculture.

Figure 10 GDP from agriculture and forestry compared to 1990 levels

% change since 1990, constant 2009/10 prices



Source: Stats NZ (n.d.)

The increase in production output occurred as natural and synthetic inputs were increased:

- From 2002 to 2019, there has been a 91% increase in irrigated agricultural land (Stats NZ 2021b).
- From 1990 to 2019, dairy cattle numbers increased by 82%, from 3.4 million to 6.3 million (Stats NZ 2021c).
- Between 1991 and 2019, estimates of nitrogen applied to land in fertiliser increased from 62,000 to 452,000 tonnes (a 629% increase) (Stats NZ 2021a).

Broadly, it appears that agriculture's increase in production from 1990 has been assisted by marked increases in application of synthetic nitrogen fertiliser and also by increasing areas of land coming under irrigation (Ministry for the Environment and Stats NZ 2021). Attributing current production of agricultural land to natural capital needs to be tempered by recognition that the natural capacity of the land is being supplemented by additional inputs, in part to make up for the deterioration in the natural capacity. As long as product prices remain sufficient to maintain economic value of using such inputs, such an approach maintains the private viability and capital value of the land. However, if there are other effects of this approach outside the private viability considerations such as adverse externalities on water quality or natural ecosystems caused by intensification of agriculture, the sustainability of the approach becomes open to question.

Soil is a significant component of land's productive capability, and substantial effort is being put in to measuring and monitoring soil quality. Agricultural intensification is used to raise the production of specific livestock or crops from a given area of land, but it can also be associated with loss of soil quality and wider environmental damage (for example, run-off into waterways). There is National Environmental Standard for the management of soil contaminants that can affect human health, and target ranges have been set for the concentration of substances in soils specific to different farming activities to guide testing of soil quality (Ministry for the Environment and Stats NZ 2021). However, these soil quality indicators do not yet appear to have been collated into a process for estimating natural capital values.

4.2.2 Agriculture and climate change

In 2020, agriculture was the source of half of all New Zealand's greenhouse gas (GHG) emissions. GHG emissions from agriculture have increased over the last 30 years. Between 1990 and 2020, GHG emissions from agriculture increased by 17%. The main reasons for the increase were an increase in total dairy cattle (80%) and an increase in synthetic nitrogen fertiliser by approximately 693% since 1990. These increases in dairy and fertiliser have been partially offset by decreased populations of sheep, beef cattle and deer since 1990 (Ministry for the Environment 2022)

Since 1990, there has been a gradual decrease in the emissions per tonne of product produced from dairy cattle. However, these climate-positive productivity improvements were crowded out by the increase in the number of dairy cattle and the increase in inputs needed to produce the product (Ministry for the Environment 2022).

Recently, some progress has been made in decreasing emissions from agriculture. In 2020, emissions from agriculture decreased by around 0.2%. The main contributors to the decrease were fewer sheep being farmed and using less lime and urea fertiliser. Emissions rose from other sources such as inorganic fertiliser and beef and dairy cattle, but these increases were not enough to offset the overall decrease in agricultural emissions (Ministry for the Environment 2022).

The climate is an input to agriculture and is impacted by agricultural emissions – climate viability, flooding and drought negatively and positively affect agricultural production. Flooding and drought years yield lower production, but the subsequent years can often yield high production as extreme weather has a delayed positive effect on the fertility of the soil (Ministry for the Environment 2022).

This means New Zealand is getting more agricultural products from the natural environment through increasing intervention, making it harder to discern how much of the current level of wellbeing from agricultural land is directly due to the natural environment or human inputs to the land. This makes answering the sustainability question quite challenging. Further research is needed to understand the relationship between inputs and outputs over time to understand the sustainability of the contribution of the natural environment to wellbeing.

The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report has identified several risks and impacts of climate change for New Zealand. Impacts from extreme weather events will affect ecosystems and human systems, and they will have short-term and long-term effects on the contribution of the natural environment to human wellbeing:

- Heavy rainfall intensity is likely to increase in New Zealand, as is the risk of drought.
- Increased disruption for agricultural production due to weather variability and extreme weather with adverse flow-on effects on mental wellbeing in rural communities. There is a risk of a decline in the overall productivity of agricultural production.
- Further loss of glaciers will occur and affect tourism business and associated settlements.
- Compounding and cascading effects of extreme weather events such as drought and flooding on infrastructure, housing and human settlements.
- Increased pressure on governments to respond to the combined effects of climate change.

4.3 Forests and wellbeing

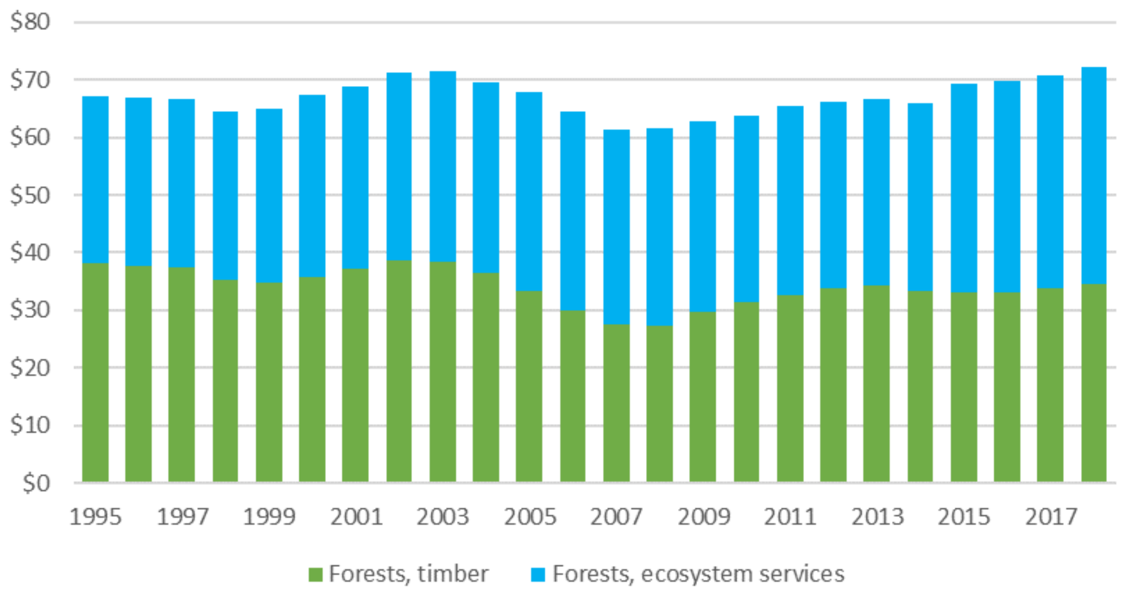
Forests provide a range of ecosystem services that contribute to the wellbeing of New Zealanders. These include:

- provisioning services such as timber, logs, fibre and forest products (berries and native herbs)
- regulating services such as erosion reduction, water filtration and carbon storage
- supporting services such as nutrient recycling, water management, oxygen production and habitat for biodiversity
- cultural services such as cultural identity, recreation, and access to conservation (Scion 2017).

In the *Changing Wealth of Nations 2021*, the World Bank (2021) estimated the ecosystem values for forested land, excluding the timber's provisioning value and the timber production market value, in recognition of the need to go beyond using market values alone to value natural capital. Figure 11 shows the value of forest ecosystem services and forestry production for New Zealand from 1995 to 2018. The combined value for the natural capital was estimated to be $74 billion, of which $38 billion (51%) was from non-timber ecosystem services.

Figure 11 The value of natural capital from forests 1995–2018

Constant 2018 NZD, billions

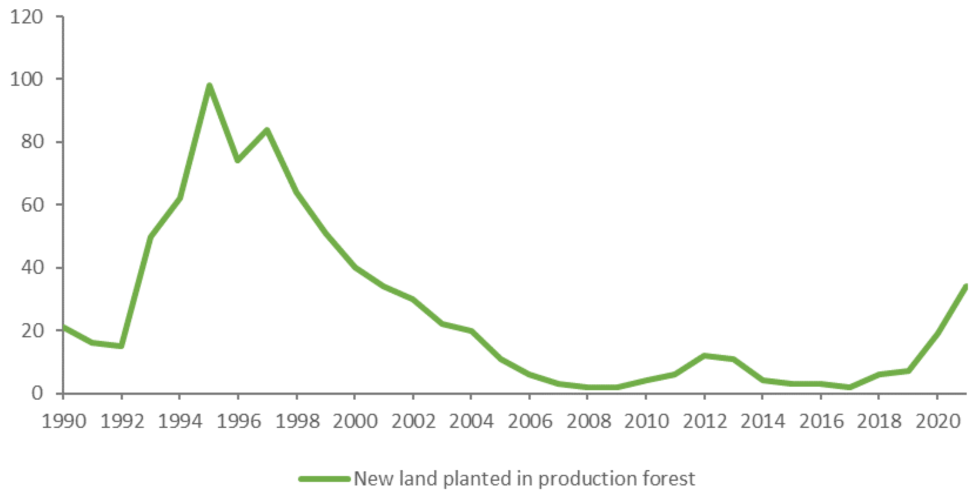


Source: NZIER based on World Bank (2021)

Figure 12 shows that there has been an increase in new land being planted in production forests in recent years. In 2021, 34,000 hectares were newly planted in production forest, which is the largest area in two decades. These plantations will store carbon for 20–30 years before harvesting (Farm Forestry New Zealand n.d.). In 2015, the estimated carbon storage in New Zealand's forestry was 2 billion tonnes, which would be worth $154 billion at a carbon price of $77 per tonne (Carbon News 2022). However, as there is some risk of some portion of that forest area succumbing to wildfire and becoming a net carbon emitter, there is a case for adjusting that value downwards to reflect that risk.

Figure 12 New land area planted in production forest 1990–2021

Thousands of hectares



Source: Ministry for Primary Industries (2022)

In 2012, the value of the forest ecosystem was estimated using an ecosystem services approach. The value of forest ecosystem services was estimated to be between $10.7 billion and $14.2 billion annually (2012 prices) depending on a judgement about whether there is double counting associated with supporting services provided by forest ecosystems (Patterson and Cole 2013). Such valuations are snapshots in time providing an estimate of the value of the contribution of forest ecosystems to human wellbeing at the time of the evaluation. Updating the estimates is not straightforward, and the existing estimate was subject to data and time constraints. In principle, a robust series of repeated ecosystem services valuation measured on a regular and consistent basis might begin to provide a sense of the sustainability of the contribution of the forest ecosystem to human wellbeing. A single estimate from nearly a decade ago offers no understanding of the trend or issues. The valuation method is useful – and very useful when the investment is made to develop a data series rather than a data point.

On the question of the sustainability of the contribution of forests to the wellbeing of New Zealand, the following conclusions emerge from the data and literature:

- There is a government-led objective to plant more trees in New Zealand.
- New planting data suggest the physical stock of forests in New Zealand has been increasing.
- If this continues, in broad terms, the sustainability of the contribution to wellbeing from the forest is likely to improve under broad measures.
- However, the devil is in the detail because the wellbeing of forests is likely to be different as the type of forest varies. Production forests may offer different contributions to wellbeing than native forests in terms of provisioning, regulating, cultural and supporting services. There is evidence that different species of trees offer varying levels of regulating services. The cultural services of exotic species and indigenous species are likely to be very different as well. The time to maturity for native trees is longer than plantation pine. Mature indigenous trees store more carbon

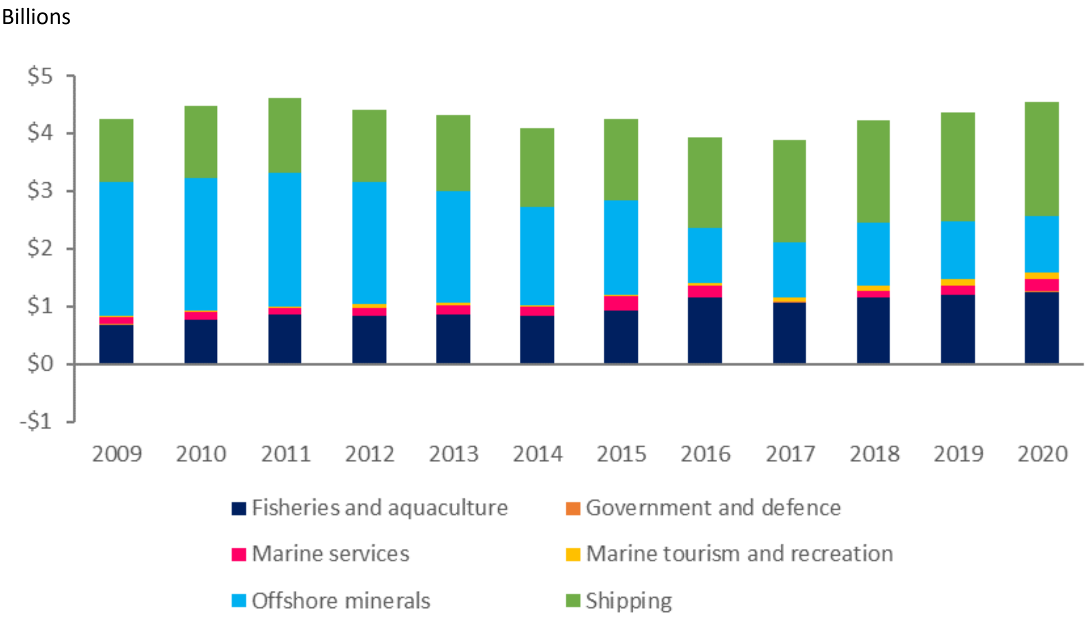
per hectare than faster-growing exotic conifers, and the latter are periodically harvested in production forests. Long-term carbon storage should reflect that fluctuation or approximate it by using an average value per hectare roughly that of mid-rotation aged trees (assuming continuous rotations in which harvested areas are replanted).

4.4 The marine environment and wellbeing

New Zealand's large marine environment contributes to wellbeing through market and non-market benefits. An in-depth study of the natural capital associated with the marine environment would warrant a large report on its own. The synthesis of measures of the contribution of the marine environment to human wellbeing considers market-based measures and ecosystem services measures that seek to capture benefits not reflected in the price of goods and services. The estimates of the value of the contribution of the marine environment varied markedly due to the scope of what is valued and the assumptions applied in the valuation.

The value of the marine economy in terms of its contribution to GDP is shown in Figure 13. The contribution includes estimates of GDP from fisheries, offshore mineral extraction, marine services,[2] government defence, shipping and marine tourism and recreation. The contributions from fisheries, marine tourism and recreation have been increasing, while the contribution from offshore extraction has decreased in more recent years. Overall, the relative contribution of the marine economy to GDP has decreased since 2010 (see Figure 14).

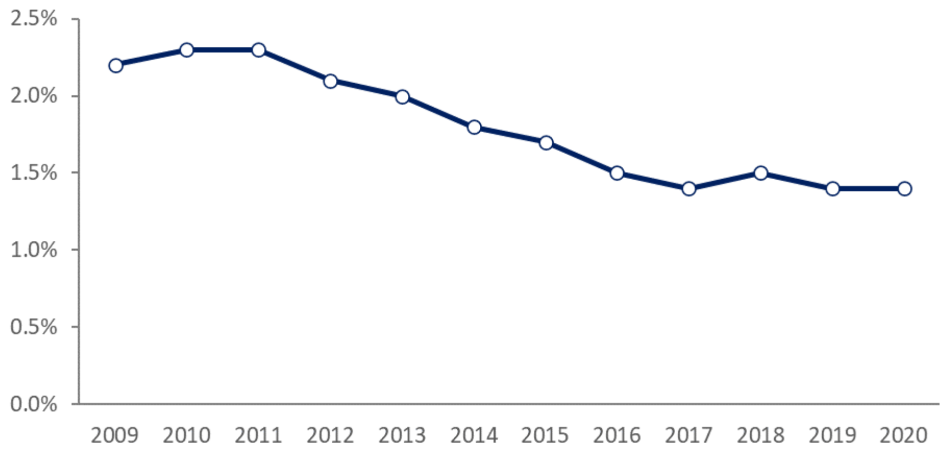
Figure 13 Marine economy contribution to GDP



Source: Stats NZ (2022)

[2] Marine services include other water transport services such as salvage, towing and pilotage services. Losses in 2017 caused the contribution from marine services to be negative.

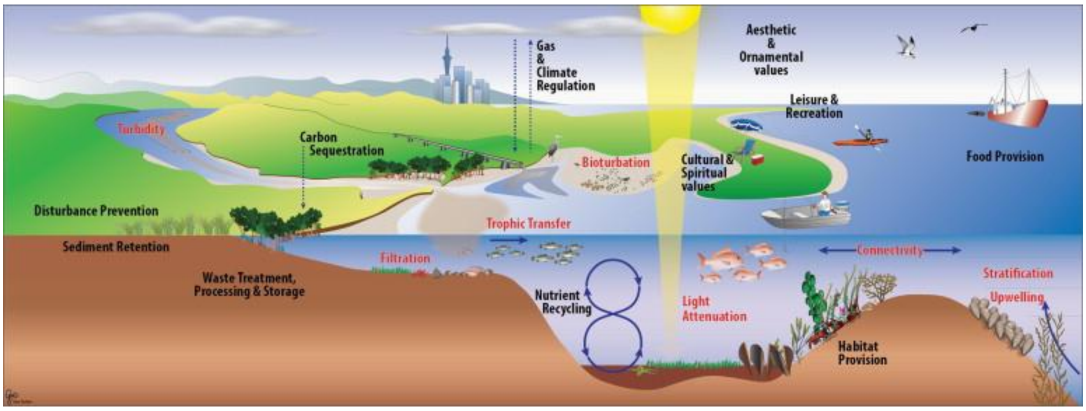
Figure 14 Percentage of GDP from the marine economy



Source: Stats NZ (2022)

Marine ecosystems are far more complex and valuable than what is associated with fisheries and mangroves. Figure 15 shows the wealth of ecosystem services New Zealand derives from the marine environment.

Figure 15 An illustration of ecological processes and attributes (red) and ecosystem services (black)



Source: Townsend et al. (2014)

In an assessment of the ecosystem system services provided by New Zealand's marine environment, MacDiarmid et al. (2013) found that New Zealand has one of the most diverse ranges of marine ecosystems on the planet, with marine flora and fauna that provide at least:

- 12 regulating services
- 5 provisioning services
- 9 non-consumptive services.
- two-thirds of the value of services provided by New Zealand ecosystems annually.

They also estimated that the value of New Zealand's marine ecosystem services stocks could be worth around US$357 billion based on the estimate by Costanza (1997) and New Zealand's share of the global marine area. Applying the same approach to Costanza's 2014 estimate of the value of global marine ecosystem system services would suggest that New Zealand's ecosystem services have increased to US$845 billion.

The value of taking an ecosystem services approach for the marine environment is considerable for shaping policy making. However, the data requirements are large, and the cost of the robust and regularly repeated assessment is not immaterial. The cost will be less than the benefits of a robust assessment, and the competition for marine environment resources is bound to increase with population growth and climate change (Scorse and Kildow 2015).

Wetlands and other aspects of the contribution from the marine environment

Wetlands are also important marine environments. The protection and restoration of wetlands contribute to sustainability services from the natural environment by providing carbon storage, wildlife habitat food production, flood regulation, clean water and society's overall wellbeing (Clarkson, Ausseil, and Gerbeaux 2013).

Dencer-Brown et al. (2018) found that mangrove cover in the North Island had increased between 1991 and 2017. Better management of mangroves requires two areas of investigation:

- A more holistic approach to assessing the biodiversity in mangroves.
- A multi-cultural approach to understanding the value of mangroves in New Zealand.

In assessing willingness to pay for the ability to safely collect shellfish from an estuary, Miller, Tait, and Saunders (2015) found the Māori and non-Māori values vary widely. Māori valued the ability to collect shellfish more highly than non-Māori. This shows why a multi-cultural approach is important when assessing the value of ecosystem services associated with the natural environment.

What do we know about the health of New Zealand's marine environment?

An assessment of the health of indigenous marine species found that some species are expected to decline in the next decade while some will grow or remain stable.

Many indigenous marine seabird and shorebird species are threatened with extinction or at risk of becoming threatened (Ministry for the Environment and Stats NZ 2019), including:

- 90% of seabirds (86 of 96 species)
- 82% of shorebirds (14 of 17 species).

For shorebird species, population trends show:

- 29% are predicted to decrease (5 of 17)
- 18% are expected to increase (3 of 17)
- 53% are not expected to change (9 of 17).

In addition, 29 marine taonga species are threatened with extinction, of which:

- 18 have populations that are predicted to decrease
- 1 has a population predicted to increase

- 10 have populations that are not predicted to change.

The 2021 assessment of the health of New Zealand's fisheries found that 85% of the monitored fish stock was above levels associated with an indication of overfishing, while 15% of fish stocks required reductions in catch limits for recovery (Fisheries New Zealand 2022).

Risks to the contribution of the marine environment

A range of risks to the sustainability of the contribution from the natural marine environment to human wellbeing have been identified:

- Climate change (Pörtner et al. 2022)
  - New Zealand will experience a loss of southern kelp forests as climate change increases the overgrazing by marine herbivores and sea urchins.
  - Loss of low-lying natural and human systems due to sea-level rise and bigger storm surges.
  - Increased pressure on governments to respond to the combined effects of climate change.
  - Insurance risk in coastal areas.
- Biodiversity
  - An assessment of the health of indigenous marine species found that some species are expected to decline in the next decade while some will grow or remain stable.
- Geopolitical
  - Marine shipping is critically important to exports and imports.

Summary conclusions on the marine environment and wellbeing

- The ecosystem services that contribute to the wellbeing of New Zealand are greater than the value of the fisheries, but fisheries are a useful indicator of the health of the marine environment.
- MacDiarmid et al. (2013) suggested that New Zealand's marine ecosystem services could be in the region of US$357 billion – two orders of magnitude larger than the value of fisheries estimated by the World Bank.
- Applying the same approach to Costanza's 2014 estimate of the value of global marine ecosystem system services would suggest the value of New Zealand's ecosystem services has increased to US$845 billion.

4.5 Biodiversity and wellbeing

Biodiversity is an important cross-cutting theme in sustainable development that assists in the measurement of the contribution of and risk to the natural environment because biodiversity provides the following benefits to human and ecological wellbeing (Perman et al. 2003):

- Biodiversity provides life-support systems such as carbon cycling, soil fertility maintenance, climate and temperature regulation and watershed flows.

- Amenity benefits are derived from the presence or existence of flora and fauna.
- Production sources such as natural fibres, pharmaceutical inputs, genetics for biotech and the fundamental basis of agricultural initiatives.
- Sources of ecological resilience and diversity that provide the capacity to adapt to environmental changes.

In many ways, biodiversity measures the links between economic activity and the natural environment. Biodiversity loss is considered an indicator of a risk that economic growth may not be sustainable.

Unfortunately, biodiversity is a particularly challenging area to generalise in natural capital valuation. International and domestic research tends to focus on estimating the value placed on specific species or habitats. Such valuations are important and useful for decision making but are species-specific or site-specific and therefore have limited transferability out of the context in which they were originally evaluated (Hanley and Perrings 2019). For example, in New Zealand, the willingness to pay for the protection of Hector's dolphins was estimated to be $335,000 per dolphin (Hoyt, Bossley, and Knowles 2014). This estimate of the value of Hector's dolphins would be immensely useful in a cost-benefit analysis of options to protect them. However, the transferability of that value to other species of marine mammal would be open for debate and not recommended. A value for one species is not representative of other species that might be less scarce and less valued by society.

Another example includes an estimate of Waikato residents' willingness to pay for bird conservation in their area. The results suggest people in the region were collectively willing to pay $13 million (2008 $) for bird conservation, which was more than the expenditure at the time of the research. In the context of natural capital and wellbeing, the results suggest that, at least in some regions, society values wildlife more than accounting measures of expenditure for conversation (Kaval and Roskruge 2009).

Environment Aotearoa 2022 contains an assessment of threats to New Zealand indigenous species (Ministry for the Environment and Stats NZ 2022). This indicates the risk of losing biodiversity. It does not reveal anything about the value society might place on biodiversity at risk. It has limited use as an indicator of natural capital or the contribution to wellbeing derived from it.

5 Identifying risks to wellbeing from natural capital

The idea of natural capital gives expression to sources of value to human activities and communities given by the services of functioning ecosystems. However, just as natural systems provide sources of value, they can also be sources of risk to life and property and disruption of normal activity, all of which entail economic cost and detraction from wellbeing. These range from high-frequency low-impact risks such as periodic temporary flooding of low-lying land to low-frequency high-impact risks such as earthquakes and volcanic eruptions. Collectively, these risks are known as natural hazards.

New Zealand has a range of natural hazards resulting from its unique maritime setting on an active tectonic boundary. Volcanic unrest, earthquakes and related effects, including tsunamis, landslides and liquefaction, for example, and periodic high-intensity storms – both warm and cold – are likely to affect one or more regions of New Zealand every decade. A high-impact natural hazard can give rise to a natural disaster, but human decisions often exacerbate such disasters. Disaster risks can be managed by reducing the exposure of highest-value activities away from high-risk zones, controlling vulnerability by modifying or strengthening buildings and infrastructure (water, waste, flood protection) to reduce the harm posed by adverse events and transferring risk to a larger pool that can more readily bear it and prepare for it through insurance and compensation provision.

Periodic adverse events that disrupt people's lives through injury, property damage or loss of livelihood are detrimental to people's wellbeing, but people clearly tolerate the risk of infrequent adverse events from natural hazards as most remain to rebuild their lives after such events. At the same time, some may see an opportunity in the disaster to build back better than what was there before. The largest such events happen so infrequently that towns and cities may show remarkable inertia in the face of potentially catastrophic (but very low probability) impacts. Too much has been invested in towns located in flood zones or over known earthquake faults for them to be abandoned after a natural disaster. In New Zealand's shaky isles, even if moving to another location could be accomplished without too much loss of value in the location abandoned, the new location may not face significantly reduced risk from a range of meteorological and seismic hazards.

Climate change will accentuate the upward trajectory of natural hazard risks, particularly concerning flooding, coastal inundation, storms, wildfires and droughts. It does not affect earthquake or earthquake risk and exacerbates tsunami risk (due to its effect on sea level). However, it may also worsen some risks to human health (for example, through heat stroke) and also biodiversity risks as the climatic ranges of pests, weeds and pathogens shift with movements in the geographical spread of climatic zones.

In principle, just as natural capital can be valued as the flow of future services expected from that capital, the risks of natural hazards can be valued as a probability-weighted impact value on that flow of future services. If the expected value of impact is changing, either because of endogenous factors such as increased density of infrastructure or urbanisation in hazard areas or exogenous factors such as climate change, the marginal value of increases in expected damage can be compared with the marginal cost of measures to reduce the impact severity of those hazards to help guide the location and type of development in different areas.

To the extent that natural capital accounting reflects the future value stream expected from some natural asset or ecosystem services flow and that natural hazards pose a threat to that value stream, the risk ought to be reflected in the value calculation. We have not seen literature on natural capital that explicitly does this, but that does not mean that, somewhere in the calculations, adjustments have not been made to account for the risks of natural capital events. However, in most cases, the damage risks are likely to be either too small (for example, in the case of localised flooding) or too infrequent (for example, in the case of major seismic events) to make much difference to national or regional estimates of natural capital, particularly when converted to an expected annual value and discounted to account for frequency.

Given the uncertainties over the frequency and scale of many natural hazard events, monetary natural capital accounts are likely to be less practical to use than physical stock accounts that allow natural assets to be categorised according to different characteristics, of which natural hazard risk is one. Given sufficient granularity, such accounts could be useful to identify locations less suited for certain developments that could be taken into account when planning infrastructure in or around those areas. Areas vacated to avoid natural hazards may develop new forms of natural capital such as acting as green infrastructure to soften future climate impacts, reverting to indigenous land cover and habitat for wildlife and maybe also providing opportunities for recreation. All such outcomes can be positive for wellbeing, but the value of that will be situation-specific, depending on the number of people in proximity who can share in such benefits and the abundance (or scarcity) of substitute sites providing the same benefits in the district. These effects, in principle, may add to those of other locations to contribute to a lift in overall national wellbeing, but data is likely to be insufficient to do that to ensure no double counting in the aggregation process.

The first national assessment of climate risks considers the effects of climate change on the natural environment, society, the economy, the built environment and governance. The report flags the consequence of the risks of climate change to these domains and the urgency of the risk (Ministry for the Environment 2020). The evidence the assessment is based on could be an input to the assessment for the sustainability of and risk to the natural capital from the environment. In its current form, the findings focus on disruption in the natural environment without economic valuation.

6 Conclusions and next steps

This synthesis report shows that there have been a wide variety of estimates of the contribution of natural capital to the wellbeing of New Zealanders. Many of the estimates are not comparable, and forming a view of the full spectrum of natural capital and how it has changed over time is fraught with difficulty. In 2017, Clough and Bealing (2017) completed a stocktake of the use of natural capital in decision-making, finding the term more often talked about loosely than tightly defined as stocks yielding future value, and rarely expressed in ways useful for informing practical decision-making.. The absence of a consistent investment to develop a long-term view of natural capital is a major factor causing the difficulty.

The key defining characteristics of natural capital estimates that distinguish them from other environmental indicators is that they focus on environmental stocks and the flow of value that can be expected from them. Changes in natural value can reflect either change in volume or in value or combinations of the two. The value is expressed in monetary terms to assist in making trade-offs around the level of use the environment can sustain and the costs incurred in expanding or reducing that use. Values can extend beyond market values to non-market values, but there are challenges in using non-market value estimates that are mostly of specific, localised resources to infer values across the wider economy.

Most available estimates of natural capital and ecosystem services are more focused on the current or past environmental performance rather than future risks. The adequacy of natural capital to cover needs and offset risks in future is less often explicitly done. Some estimates of asset values or economic rent implicitly do consider future risks, but how this is done is not explicit in the figures presented.

This synthesis shows that it would be possible to develop a natural capital-based assessment of the sustainability of and risks to the contribution of the natural environment to human wellbeing. Doing so would require a combination of:

- targeted long-term investment in developing the assessment framework
- data collection
- repeated application of the chosen economic valuation over time to build up the robust trends needed for a high-quality investigation.

Such an investment would benefit multiple uses and audiences and enrich research and policy analysis far beyond the *Te Tai Waiora: Wellbeing in Aotearoa New Zealand 2022*. It requires long-term commitment for the value of such research to be realised.

Natural capital is quantified through two components – the volume measure and the pricing measure. The risks to the sustainability of natural capital are best understood through the volume measure because it indicates the scarcity of the resource from which the benefits are derived whereas the pricing measure captures the value of those benefits to society and aids the assessment of how important the natural capital in question is relative to other uses of the resource.

Ecosystem services values are potentially more useful for answering the sustainability question, but the approach is complex with considerable data requirements and demands a greater investment. As such, the studies that apply this approach are sporadic one-offs that do not provide the consistent measurement over time needed to answer the sustainability question – hence the need to develop a programme of work that ensures consistent and regular measurement over time so the potential from the economic valuation of the contribution of natural capital can be realised.

7 References

Alcamo, Joseph, and Elena M. Bennett, eds. 2003. *Ecosystems and Human Well-Being: A Framework for Assessment*. Washington, DC: Island Press.

Ausseill, Anne-Gaelle E, Suzie Greenhalgh, Pam Booth, Oshadi Samarasinghe, and Alison Collins. 2021. 'Environmental Stewardship and Well-Being'. Manaaki Whenua/Landcare. https://www.landcareresearch.co.nz/uploads/public/Publications/Working-papers-and-reports/LC3901_TechnicalReport.pdf.

Carbon News. 2022. 'Carbon Prices'. 2022. https://www.carbonnews.co.nz/tag.asp?tag=Carbon+prices.

Clarkson, Beverley R., Anne-Gaelle E. Ausseil, and Philippe Gerbeaux. 2013. 'Wetland Ecosystem Services'. *Ecosystem Services in New Zealand: Conditions and Trends. Manaaki Whenua Press, Lincoln* 1: 192–202.

Clough, Peter, and Michael Bealing. 2017. 'Capturing Natural Capital in Decision Making: Updated Stocktake of Recent Literature'.

Colin, Armand, ed. 2013. *Sustainable Development : Francois Mancebo*. 2nd ed. https://www.librairiedalloz.fr/livre/9782200285968-developpement-durable-2e-edition-francois-mancebo/.

Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, et al. 1997. 'The Value of the World's Ecosystem Services and Natural Capital'. *Nature* 387 (6630): 253–60. https://doi.org/10.1038/387253a0.

Costanza, Robert, Rudolf de Groot, Paul Sutton, Sander van der Ploeg, Sharolyn J. Anderson, Ida Kubiszewski, Stephen Farber, and R. Kerry Turner. 2014. 'Changes in the Global Value of Ecosystem Services'. *Global Environmental Change* 26 (May): 152–58. https://doi.org/10.1016/j.gloenvcha.2014.04.002.

Daly, Herman E. 1987. 'The Economic Growth Debate: What Some Economists Have Learned but Many Have Not'. *Journal of Environmental Economics and Management* 14 (4): 323–36. https://doi.org/10.1016/0095-0696(87)90025-8.

Daly, Herman E. 2017. 'The Economic Growth Debate: What Some Economists Have Learned but Many Have Not'. In *The Earthscan Reader in Environmental Economics*, 36. Routledge.

Dencer-Brown, Amrit Melissa, Andrea C. Alfaro, Simon Milne, and John Perrott. 2018. 'A Review on Biodiversity, Ecosystem Services, and Perceptions of New Zealand's Mangroves: Can We Make Informed Decisions about Their Removal?' *Resources* 7 (1): 23. https://doi.org/10.3390/resources7010023.

Dietz, Simon, Eric Neumayer, Simon Dietz, and Eric Neumayer. 2006. 'Weak and Strong Sustainability in the SEEA: Concepts and Measurement'. *Ecological Economics* 61 (4): 617–26.

Dymond, John. 2013. 'Ecosystem Services in New Zealand'. https://www.landcareresearch.co.nz/publications/ecosystem-services-in-new-zealand/.

Ekins, Paul, Sandrine Simon, Lisa Deutsch, Carl Folke, and Rudolf De Groot. 2003. 'A Framework for the Practical Application of the Concepts of Critical Natural Capital and Strong Sustainability'. *Ecological Economics* 44 (2–3): 165–85.

Farm Forestry New Zealand. n.d. 'Radiata Pine'. Accessed 16 June 2022. https://www.nzffa.org.nz/farm-forestry-model/species-selection-tool/species/pine/radiata-pine/.

Fisheries New Zealand. 2022. 'The Status of New Zealand's Fisheries 2021'. https://www.mpi.govt.nz/dmsdocument/44893-The-Status-of-New-Zealands-Fisheries-2021.

Food and Agriculture Organisation. 2022. 'FAOSTAT'. 2022. https://www.fao.org/faostat/en/#home.

Grimsrud, Kristine, Henrik Lindhjem, David N. Barton, and Ståle Navrud. 2018. 'Challenges to Ecosystem Service Valuation for Wealth Accounting'. In *Inclusive Wealth Report 2018*, 136–61.
Guerry, Anne D., Stephen Polasky, Jane Lubchenco, Rebecca Chaplin-Kramer, Gretchen C. Daily, Robert Griffin, Mary Ruckelshaus, et al. 2015. 'Natural Capital and Ecosystem Services Informing Decisions: From Promise to Practice'. *Proceedings of the National Academy of Sciences* 112 (June): 7348–55.
Hanley, Nick, and Charles Perrings. 2019. 'The Economic Value of Biodiversity'. *Annual Review of Resource Economics* 11: 24.
Hartwick, John M. 1977. 'Intergenerational Equity and the Investment of Rents from Exhaustible Resources'. *American Economic Review* 67: 972–74.
———. 1978. 'Substitution Among Exhaustible Resources and Intergenerational Equity'. *The Review of Economic Studies* 45 (2): 347–54. https://doi.org/10.2307/2297349.
Hoyt, E., M. Bossley, and T. Knowles. 2014. 'Assessing New Zealanders' Willingness-to-Pay to Protect the Endangered New Zealand Dolphin (Cephalorhynchus Hectori): A Benefit-Cost Analysis Comparing Three Scenarios'. https://uk.whales.org/wp-content/uploads/sites/6/2018/08/new-zealand-dolphin-report.pdf.
IPBES. 2018. 'Regional Assessment Report on Biodiversity and Ecosystem Services for Asia and the Pacific'. IPBES Secretariat. 26 June 2018. https://ipbes.net/node/28330.
Kaval, Pamela, and Matthew Roskruge. 2009. 'The Value of Native Bird Conservation: A New Zealand Case Study'. Department of Economics Working Paper in Economics 11/09. University of Waikato.
Kim, Rakhyun E., and Louis J. Kotzé. 2021. 'Planetary Boundaries at the Intersection of Earth System Law, Science and Governance: A State-of-the-Art Review'. *Review of European, Comparative & International Environmental Law* 30 (1): 3–15.
MacDiarmid, Alison B., Cliff S. Law, Matt Pinkerton, and John Zeldis. 2013. 'New Zealand Marine Ecosystem Services'. *Ecosystem Services in New Zealand—Conditions and Trends; Dymond, JR, Ed*, 238–53.
Millennium Ecosystem Assessment, ed. 2005. *Ecosystems and Human Well-Being: Synthesis*. Washington, DC: Island Press.
Miller, Sini, Peter Tait, and Caroline Saunders. 2015. 'Estimating Indigenous Cultural Values of Freshwater: A Choice Experiment Approach to Māori Values in New Zealand'. *Ecological Economics* 118: 207–14.
Ministry for Primary Industries. 2022. 'New Land Planted in Production Forest in New Zealand'. Figure.NZ. 2022. https://figure.nz/chart/Wfot8hmR8ElvhDfp.
Ministry for the Environment. 2020. *National Climate Change Risk Assessment for New Zealand. Main Report - Arotakenga Tūraru Mō Te Huringa Āhuarangi o Āotearoa. Pūrongo Whakatōpū*. Wellington, New Zealand: Ministry for the Environment.
———. 2022. 'New Zealand's Greenhouse Gas Inventory 1990–2020'. ME 1635. https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2020/.
Ministry for the Environment, and Stats NZ. 2019. 'Our Marine Environment 2019: New Zealand's Environmental Reporting Series'.
———. 2021. 'Our Land 2021'. https://environment.govt.nz/publications/our-land-2021/.
———. 2022. 'Environment Aotearoa 2022'. Wellington: Ministry for the Environment : Stats NZ.
New Zealand Treasury. 2021. 'The Living Standards Framework (LSF) 2021'. 2021. https://www.treasury.govt.nz/publications/tp/living-standards-framework-2021-html.
Nussbaum, Martha C. 2003. 'Capabilities as Fundamental Entitlements: Sen and Social Justice'. *Feminist Economics* 9 (2–3): 27.
OECD. 2005. 'OECD Glossary of Statistical Terms - Natural Capital'. 2005. https://stats.oecd.org/glossary/detail.asp?ID=1730.

———. 2017. *How's Life? 2017: Measuring Well-Being*. Paris: Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/economics/how-s-life-2017_how_life-2017-en.
———. 2020. *How's Life? 2020: Measuring Well-Being*. How's Life? OECD. https://doi.org/10.1787/9870c393-en.
———. n.d. 'Conversion Rates - Purchasing Power Parities (PPP) - OECD Data'. The OECD. Accessed 29 May 2022. http://data.oecd.org/conversion/purchasing-power-parities-ppp.htm.
O'Neill, Daniel W., Andrew L. Fanning, William F. Lamb, and Julia K. Steinberger. 2018. 'A Good Life for All within Planetary Boundaries'. *Nature Sustainability* 1 (2): 88–95.
Patterson, Murray G, and Anthony O Cole. 2013. '"Total Economic Value" of New Zealand's Land-Based Ecosystems and Their Services'. In *Ecosystem System Services in New Zealand*, 15. Manaaaki Whenua Press. F.
Patterson, Murray, Garry McDonald, Vicky Forgie, Joon-Hwan Kim, Derrylea Hardy, Nicola Smith, and Yanjiao Zhang. 2019. 'Beyond Gross Domestic Product: The New Zealand Genuine Progress Indicator to Measure the Economic, Social and Environmental Dimensions of Well-Being from 1970-2016'. Palmerston North: Massey University.
Perman, Roger, Yue Ma, James McGilvray, and Michael Common. 2003. *Natural Resource and Environmental Economics*. 3rd ed. Pearson Addison Wesley.
Pörtner, Hans-Otto, Debra Cynthia Roberts, Melinda M. B. Tignor, Elvira S. Poloczanska, Katja Mintenbeck, Andrès Alegría, Marlies Craig, et al., eds. 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.*
Potsdam Institute for Climate Impact Research, Stockholm Resilience Centre, and Mercator Research Institute on Global Commons and Climate Change. 2020. 'A Safe Operating Space for New Zealand/Aotearoa Translating the Planetary Boundaries Framework'. An independent report commissioned by the New Zealand Ministry for the Environment. https://environment.govt.nz/assets/Publications/Files/a-safe-operating-space-for-nz-aotearoa.pdf.
Purdie, Heather, Paul Bealing, Christopher Gomez, Brian Anderson, and Oliver J. Marsh. 2021. 'Morphological Changes to the Terminus of a Maritime Glacier during Advance and Retreat Phases: Fox Glacier/Te Moeka o Tuawe, New Zealand'. *Geografiska Annaler: Series A, Physical Geography* 103 (2): 167–85. https://doi.org/10.1080/04353676.2020.1840179.
Scion. 2017. 'Forest Ecosystem Services'.
Scorse, Jason, and Judith Kildow. 2015. 'Ecosystem Services and Their Economic and Social Value'. In *Routledge Handbook of Ocean Resources and Management*. Routledge.
Sen, Amartya. 1999. *Commodities and Capabilities*. *OUP Catalogue*. Oxford University Press. https://ideas.repec.org/b/oxp/obooks/9780195650389.html.
Stats NZ. 2021a. 'Fertilisers – Nitrogen and Phosphorus'. 2021. https://www.stats.govt.nz/indicators/fertilisers-nitrogen-and-phosphorus/.
———. 2021b. 'Irrigated Land'. 2021. https://www.stats.govt.nz/indicators/irrigated-land/.
———. 2021c. 'Livestock Numbers'. 2021. https://www.stats.govt.nz/indicators/livestock-numbers/.
———. 2022. 'Environmental-Economic Accounts: 2022 (Data to 2020)'. 2022. https://www.stats.govt.nz/information-releases/environmental-economic-accounts-data-to-2020/.
———. n.d. 'National Accounts'. Accessed 15 September 2022. https://www.stats.govt.nz/topics/national-accounts.
Townsend, Michael, Simon F. Thrush, Andrew M. Lohrer, Judi E. Hewitt, Carolyn J. Lundquist, Megan Carbines, and Malene Felsing. 2014. 'Overcoming the Challenges of Data Scarcity in Mapping Marine Ecosystem Service Potential'. *Ecosystem Services* 8 (June): 44–55. https://doi.org/10.1016/j.ecoser.2014.02.002.

UK National Ecosystem Assessment. 2011. ‘UK National Ecosystem Assessment’. 2011. http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx.
United Nations. 2014. ‘System of Environmental Economic Accounting’. 2014. https://seea.un.org/.
———. 2018. ‘Inclusive Wealth Report 2018’. http://www.unep.org/resources/inclusive-wealth-report-2018.
World Bank. 2021. ‘The Changing Wealth of Nations 2021: Managing Assets for the Future’. https://openknowledge.worldbank.org/handle/10986/36400.
World Commission on the Environment and Development. 1987. ‘Our Common Future’.