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The natural capital framework for sustainably efficient and equitable decision making

Ian J. Bateman[1] ✉ and Georgina M. Mace[2] ✉

The concept of 'natural capital' is gaining traction internationally as recognition grows of the central role of the natural environment in sustaining economic and social well-being. It is therefore encouraging to see the first signs of a 'natural capital approach' to decision making being accepted within government policy processes and the private sector. However, there are multiple different understandings of this 'approach', many of which misuse or omit key features of its foundations in natural science and economics. To address this, we present a framework for natural capital analysis and decision making that links ecological and economic perspectives.

While recent reviews of natural capital and ecosystem services describe the essential principles, concepts and tools[1], the field is large and growing rapidly, yet becoming increasingly fragmented across different knowledge and practice communities[2,3]. Our focus here is specifically on the natural capital approach to making decisions which are sustainable, use resources efficiently, and equitable.

The natural capital concept is fundamentally an anthropocentric framing based on the understanding that aspects of nature, in certain forms and functions, underpin human well-being and are therefore a central concern for sustainable development. Natural capital assets are those renewable and non-renewable natural resources (such as air, water, soils and energy), stocks of which can benefit people both directly (for example, by delivering clean air) and indirectly (for example, by underpinning the economy). These stocks yield flows of 'ecosystem services' such as energy, water, plant and fibre growth, from which people derive benefits. Classifying and reporting on natural capital as if it were simply all of nature misses this key point. Natural capital approaches to decision making consider the stocks of natural assets, and not just the flows of services they produce, and will therefore incorporate sustainability considerations which can be missed in simple flow-based assessments. This is especially important for appraisals of spending options where the requirement is to secure benefits for people beyond those immediately affected, including future generations.

The most basic principle is that the resources embedded in natural assets cannot be used as if they are infinite. While technology might expand their usefulness, almost all natural resources are limited in some way. These resource constraints mean that every time a decision is taken to do one thing this rules out the possibility of doing something else, generating an 'opportunity cost' that may or may not be recognized when the decision is taken but is there nonetheless. This has several consequences. The choice between different options is in effect a trade-off between alternative benefits and costs, across different groups of people (winners and losers), and over space and time. Deciding to do one thing rather than another has consequences not just for those immediately benefiting from that decision but also for other uses and users, and these consequences may be positive (called synergies or co-benefits) or negative (trade-offs). For example, planting a forest in a certain location might contribute to timber production and mean that those forest soils start to accumulate carbon, but it also means that the area can no longer be used for conventional agriculture and food output[4]. These 'efficiency' concerns, regarding which option is best in terms of generating the greatest benefit, are often accompanied with 'equity' (or more accurately 'distributional') implications, regarding who gets those benefits and when. These effects may be complicated, delayed and not immediately obvious. For example, building new transport infrastructure for urban areas might have positive consequences for local air quality, noise exposure and health, but it may, over time, raise local rents and push out the poorest from the area[5]. These distributional consequences should be assessed alongside efficiency effects and incorporated into the decision-making process.

Comparison of the multitude of different consequences of almost any decision, and particularly those concerning a complex system such as the natural environment, is inevitably challenging[6]; to paraphrase H. L. Mencken—for every complex problem there is an answer that is clear, simple and wrong. Decision makers must seek to assess all the major relevant effects of a potential decision, both positive and negative, expanding that appraisal to the point where the costs of further analysis clearly outweigh the benefits in terms of improved outcomes from decision making. This process requires knowledge and data from ecologists, economists and many other disciplines. However, an important element of this requirement is that it recognizes that the definition of 'relevant effects' may differ between, say, a social policymaker and a private business, setting up a potential tension between the two.

In almost any area of policy or business, a wide diversity of choices are made by myriad actors, each with their own priorities and objectives. Generalizing slightly, while the decisions made by individuals and firms are primarily driven by the private well-being they expect to gain, public policymakers are (or at least should be) interested in the social welfare across all citizens that their decisions will deliver now and in the future. This difference is particularly important in policymaking because alternative decisions can yield very differing private and public values. So, for a farmer, the principle focus of a decision about how to use a given area of land might be the value of the 'private goods', such as agricultural output, which that area can produce. This is because the farmer owns that pro-

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[1]Land, Environment, Economics and Policy Institute (LEEP), University of Exeter Business School (UEBS), Exeter, UK. [2]Department of Genetics, Evolution and Environment, University College London, London, UK. ✉e-mail: i.bateman@exeter.ac.uk; g.mace@ucl.ac.uk

duction and can charge the market price for its sale. However, that land can often also produce a range of 'public goods' such as wildlife conservation, water quality, carbon sequestration, recreational opportunities and their allied physical and mental health benefits, and so on. The farmer generally cannot charge society for benefiting from such public goods and so has less incentive to provide these. In a society with private ownership of many resources, the public decision maker needs to take account of both the private and public goods generated by alternative policy decisions and incentivize the private resource owner towards decisions which will enhance overall social (private plus public) value. These private incentives can be both positive, such as subsidies or payment for ecosystem services (PES) schemes, or negative, such as taxes and regulations[7].

The relationship between decision making and natural capital accounting is important here. Typically, and especially at national level, accounts are intended to monitor the overall progress of an economy and highlight priorities and concerns. A key stimulus for natural capital accounting has been to develop measures comparable to gross domestic product (GDP), an influential measure of economic activity but one which was never designed to assess either human well-being or the environmental sustainability of an economy. Measures such as the United Kingdom's Natural Capital Accounts estimate 'exchange prices' for non-marketed public goods, that is, the price that they would be exchanged at if they were in fact traded in markets[8]. Such price-orientated metrics are directly comparable with GDP. However, whether society as a whole is on a sustainable development trajectory is best accounted for as the aggregate value of all capital assets, with this 'inclusive wealth' metric ideally being assessed using the same value (as opposed to price) measures used in social benefit–cost analyses[9–11]. Theoretical advances[12,13] have spurred a number of innovative developments of the use of natural capital accounting as a means of assessing sustainability[14,15]. International bodies have developed metrics such as the World Bank adjusted net savings (or 'genuine savings') measure[16] and the United Nations Environment Programme (UNEP) inclusive wealth accounts[17]. These methods have shown that both physical and monetary natural capital accounts provide important indicators regarding changes in stocks which can in turn inform policy and business objectives[18]. However, accounts generally do not indicate the best ways to address those objectives and allocate limited resources. Within the policy sphere, economic benefit–cost analysis of multiple options for change provides such guidance. Here the focus is upon the benefit value (sometimes referred to as shadow prices[9–11]) of environmental goods rather than their (often zero) market prices. The use of methods to estimate such values has become standard practice in the appraisal of public spending[19]. However, while assessment of the benefit and cost flows of alternative projects can identify the efficient (and, with extension, equitable) use of resources, additional requirements are typically needed to ensure that decisions are also environmentally sustainable. The framework below explicitly considers ways in which a natural capital constraint can be added to benefit–cost analyses to ensure they identify options which are both efficient and sustainable.

The framework

The framework (Fig. 1) represents the relationships between natural capital, ecosystem services, the economy and human well-being. This figure is necessarily a simplification of the many interactions, feedbacks and non-linearities of the whole system, focusing upon links between the environment and economy. The application of the framework has three components: (1) efficiency, assessing the flow of benefits and costs arising from alternative decisions; (2) sustainability, the effects of those alternative decisions upon natural capital stocks; and (3) equity, assessing the distributional aspects of implementing alternative decisions.

Efficiency. Failure to ensure that ecosystem service flows are used efficiently leads to over-use and degradation of environmental resources. Efficiency analysis is therefore a central requirement for sustainable development. However, the framework illustration in Fig. 1 starts (top, left) with the ultimate energy and material inputs to the system, provided by the Sun and Earth. These generate nature's capital (the stocks of natural assets, such as air, water, fertile soils, energy and so on, upon which all human well-being ultimately depends) and the natural processes (such as primary productivity, water and nutrient cycling, decomposition, the climate system, evolution and so on) which maintain those assets and support ecosystem functions. A variety of physical metrics for natural capital and changes therein have been developed together with different ways to classify natural assets, into major ecosystem types (for example, terrestrial, marine, soils) or major functional types that map onto key users or uses (for example, species and genetic resources, ecological communities, soils, freshwaters, land, minerals, atmosphere, subsoil, seas, oceans, minerals)[20]. Rather than treating natural capital as if it were simply all of nature, the classification of natural capital assets should be relevant to both utility and management, focusing on asset features that link to flows of ecosystem functions and services, and ideally the identification of those assets which are critical, at-risk, irreplaceable or non-substitutable[21,22].

Moving rightwards across the centre of the figure, the combination of stocks of natural capital assets and processes produce flows of 'ecosystem services' for which metrics have been developed[23]. These occasionally yield value in their own right (for example, the inspiration that derives from seeing wild species or beautiful landscapes), but most often their value arises in combination with the services provided by other kinds of capital assets (for example, human, social and manufactured capital; see Fig. 1). For example, while there may be crop relatives that exist in nature, the benefits that people derive from food and agriculture require, at the very least, human labour and ingenuity, energy and machinery, and transport systems.

One area of particular difficulty in decision appraisal concerns the incorporation of biodiversity. Some confusion is caused by imprecise use of the term biodiversity which, from an ecological perspective, often refers to the species richness at a site, yet is frequently used as a label for human concerns such as 'wild species of conservation interest', or to refer to all of nature or life on Earth. A further complication arises from the diversity of services provided by biodiversity, ranging from its role in maintaining ecosystem functions[24], in enhancing productivity, resilience and adaptability[25,26], to increasing recreation benefits[27] and providing non-use value from the continued existence of species[28]. In practice, there are many ways in which biodiversity is included in ecosystem service assessments, for example as an underpinning service, or as a service in itself[29,30]. While it is common to include certain services that depend on wild species and places (for example, recreation and tourism), many ecosystem service assessments miss biodiversity out because estimating its value is fraught with difficulty. Valuing the continued existence of species and wild places in their own right (often and incorrectly termed 'intrinsic value'[31]) is also contentious and lies at the core of many commentators' concerns about the commodification of nature via ecosystem service approaches[32]. In contrast to ecosystem service analyses, natural capital assessments can more easily include species and habitats as an asset type in their own right, even if metrics and valuation are problematic. In the framework below we avoid using the term biodiversity. Instead we are specific about which of its several meanings we actually intend, and we differentiate between wild species as an asset, service delivery that relies on wild species (for example, pollination, pest control and eco-tourism), or enhanced resilience and adaptability that is attributable to the diversity of communities, species and genes.

Combinations of environmental and other services describe the potential set of goods which an economy could produce and

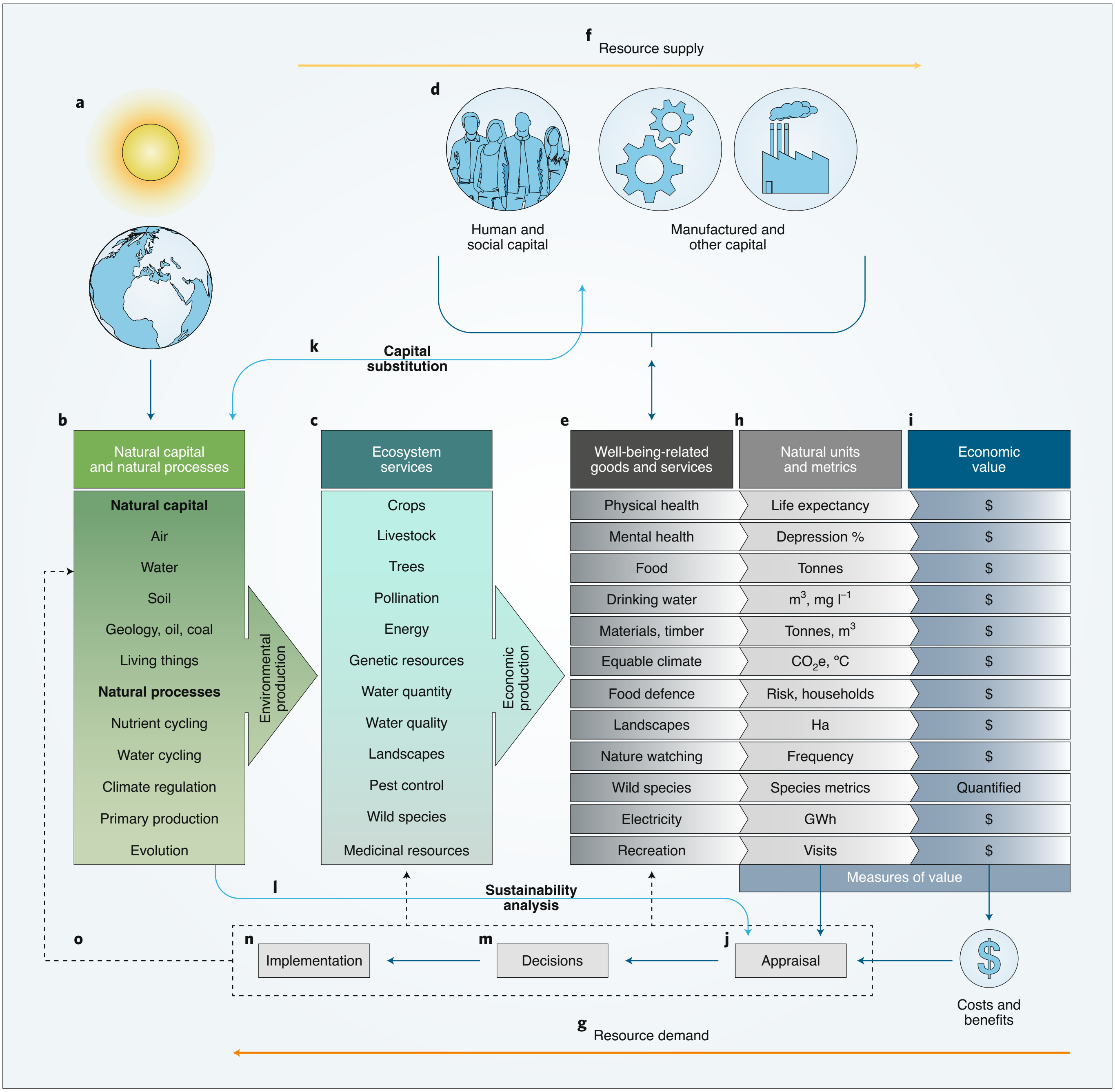

Fig. 1 | Natural capital framework. a–c, Energy and material inputs ultimately originate from the Sun and Earth systems (**a**) which underpin stocks of natural capital assets (such as air, water and soils) and processes (**b**) which can deliver flows of ecosystem services such as water flows, plant growth, fibre production and natural resources (**c**). **d**,**e**, Stocks of human, manufactured and related capital assets yield flows of labour, technology and other inputs (**d**) which combine with ecosystem services flows to produce the welfare-bearing goods and services which underpin human well-being (**e**). **f**,**g**, While resource supply (moving from left to right; **f**) describes what is feasible, it is the interaction of this supply with human demand (moving from right to left; **g**) which determines production and resource use. **h**, The use of any good or service can be quantified using a range of physical metrics but these are not comparable with each other and do not convey the magnitude of benefit delivered. **i**, Using economic value expressed in common monetary units is certainly imperfect but has many practical advantages (see text). **j**, The various benefits and costs of a particular investment option can then be appraised but this process also needs to consider the sustainability of each alternative option. **k**, The past century has seen radical conversion of natural capital into other forms of capital to the extent that stocks of the former are now depleted. **l**, Sustainability analysis should be considered in terms of ensuring non-declining opportunities for well-being across generations. At the very least, this means that the aggregate value of all capital stocks (natural, human, manufactured and so on) should not decline over time, but where crucial services of an asset are not replaceable this will be an inadequate definition of sustainability (see text for discussion). **m**, Decisions should therefore consider the costs, benefits and inter-generational sustainability of alternative resource uses. This process should also consider behavioural responses and human adaptation to decisions as well as wider objectives such as the intra-generational distribution of costs and benefits across society. **n**,**o**, Once a decision is made its implementation (**n**) can also substantially affect outcomes which in turn feed back (**o**) into natural capital assets and processes, the expected consequences of which should be incorporated within the decision-making process. Figure adapted with permission from an original schematic drawn by the authors and developed by Mark Foster, Fine Print.

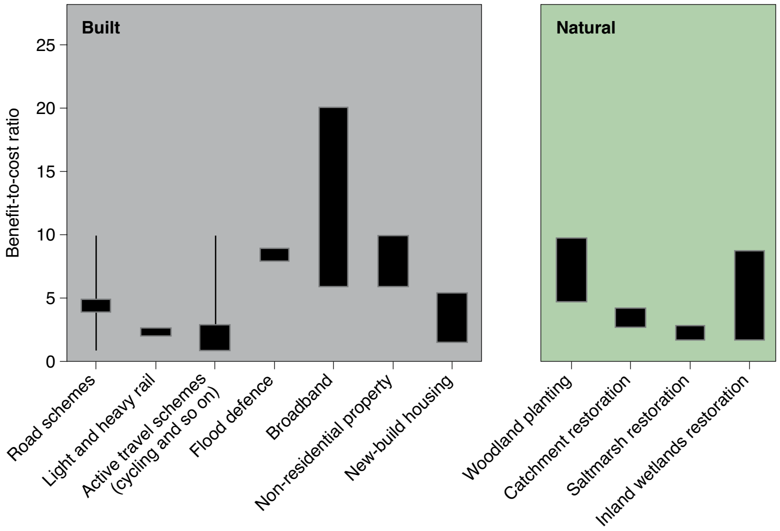

Fig. 2 | Estimated benefit-to-cost ratios for potential large-scale investments in built and natural assets in the United Kingdom. Investments in natural capital assets can be very competitive relative to spending on built infrastructure. All estimates include market and non-market benefits and costs. Data sourced from refs. [68,69].

people benefit from. However, while this supply (moving from left to right in Fig. 1) describes what is feasible, it is its interaction with human demand for well-being (moving from right to left in the figure) which determines resource use and value. Furthermore, that demand can manifestly alter the supply side[33]. The condition of natural capital asset stocks and associated ecosystem functions depends not only upon evolving ecological networks and their physical environment, but also upon further drivers, such as pressures from people, the economy and policy decisions. This agglomeration of natural and anthropocentric drivers (for example, land-use change, climate change and so on) alters ecosystem functions as the biotic community responds, evolves and reassembles itself over space and time in response to these pressures. These relationships are further complicated by their multiscale and dynamic nature, making the definition and measurement of ecosystems, their properties and functions, challenging[6,34]. In contrast, ecosystem service measurement is conceptually straightforward as, typically through combination with service flows from other forms of capital, they generate measurable well-being-related goods and services[35].

A challenge for decision making is that these goods and services often arise in a variety of different natural units. For example, land-use change might generate goods measured as tonnes of food produced, mg l^{-1} of water pollution, numbers of recreational trips, tonnes of CO_2e emitted, and so on. These are non-commensurate units, and not the relevant units for a decision maker seeking to improve well-being. Resource constraints mean that any rational form of decision making should seek to compare the importance and value of goods.

The process of decision making is, at its most fundamental, one of choosing between options. Provided that this process is not random, then it must be placing values on the options available and choosing that which is most valuable. Valuation is therefore unavoidable; it is the very essence of decision making. Every time a decision is made values are expressed, whether explicitly as part of an appraisal or implicitly revealed by the choice that was made and the alternative options that were therefore rejected. The objective of measuring values and making them explicit and open to challenge is, therefore, an important element of good decision making[31]. Conversion to a common unit which reflects the importance and hence value of these differing impacts is therefore desirable for decision making at scale. While there is no perfect unit, most economists argue that monetization is the least-worst of a range of imperfect measures. Money has the advantage of being explicitly designed as a unit of value (being highly divisible, clearly quantified and giving measures which are readily contestable and comparable) and familiar to decision makers who have to allocate limited budgets not just between competing environmental projects but across a wide range of potential investments and benefits in other sectors. While non-monetary metrics have been used for allocating pre-determined budgets (for example, spending agreed conservation funds), they struggle when used for the more fundamental task of determining funding between different ends (for example, conservation versus social security funding). That said, subsequently we acknowledge the limitations of monetary valuation (particularly regarding biodiversity assessment) and propose solutions to that challenge.

While some of the well-being-related goods and services derived from natural capital are traded in markets and hence have market prices (for example, food and timber), many do not (for example, water quality and air pollution). Economics explicitly recognizes the difference between price and value, and a variety of methods have been developed to value non-market goods[31,36,37]. These are increasingly mandated for use in official decision appraisal guidelines and open-access, online valuation tools are progressively available[38,39].

Combining valuations of the market and non-market benefits and costs of different spending options provides policymakers with important decision support information and can reveal the value of natural capital restoration and enhancement. For example, investments in natural capital improvements, such as woodland and catchment restoration show economic returns that equal or exceed those in many other capital infrastructure investment areas, including road and rail projects (Fig. 2).

While most natural capital benefits and costs can be robustly valued, one prominent exception is the full value of biodiversity[40]. Certain elements of this value, such as the production contribution of pollinators[41] and the enhancement of recreation experience[42] can be estimated, although many biodiversity contributions are poorly understood especially at spatial scales relevant for natural capital appraisal. Importantly, the 'non-use' value which people hold for preventing the extinction of wild species cannot readily be observed. One approach is to rule out all investment options which reduce the viability of species of conservation concern; the additional costs which such constraints impose can be modest and yet secure wider biodiversity benefits[43,44].

Sustainability. While comparison of benefits and costs is a necessary element of good decision making, it is not sufficient to ensure decisions are also sustainable. Since the 1950s, massive conversion of natural capital to manufactured, human and other forms of capital (see **k** in Fig. 1) has generated unprecedented improvements in well-being[45] but induced ongoing global environmental degradation, igniting heated debate regarding the definition of sustainability and means to achieve it[46]. Many commentators define sustainability in terms of ensuring non-declining opportunities for well-being across generations[47]. This requires, at very least, that the aggregate value of stocks of all capital assets (natural, human, manufactured and so on) should not decline over time. If all capital is perfectly substitutable (that is, the functions of one type of capital may be undertaken by another kind of capital), then ensuring that the total value of capital does not decline over time is sufficient for sustainability; this is known as the 'weak sustainability' rule[48]. Conversely, if there are limits to the substitutability of certain 'critical' types of capital beyond which future generations will be harmed, then a 'strong sustainability' rule is needed which both protects the aggregate value of all capital across generations and prevents the use of such 'critical' types of capital beyond those limits. Recent reviews suggest that substitutability between natural capital and other forms of capital may be moderate to low[49] and the replaceability of many ecosystem services, especially supporting services, by technology is limited[50].

Technological change should work to increase substitutability over time. Furthermore, both in principle[12,13] and increasingly in practice[14,15], improvements in the understanding and modelling of natural–human systems should extend the viability of a weak sustainability approach. Nevertheless, the crucial role which natural capital plays in maintaining life support systems, and concerns about the limits of substitutability suggest that a strong sustainability approach will remain both prudent and justified for most natural capital assets. While each case has its own characteristics, general principles can be identified. For example, renewable resources cannot consistently be used at greater than their rate of self-replenishment (for example, fish catch cannot exceed natural replenishment rates for long periods without depleting those stocks), while use of non-renewables (such as oil) needs to recognize both externalities (such as greenhouse gas emissions) and address intra-generational sustainability by investing sufficient proceeds in maintaining the services of those resources[46] (for example, by developing renewable energy resources). These concerns are elevated where there is evidence of tipping points beyond which further exploitation of a resource results in accelerating degradation and impacts[51].

Equity. Appraisals should also capture the distribution of benefits and costs across society, revealing impacts on disadvantaged groups. Indeed, distributional objectives, such as access to environmental quality, may well be the motivator for policy change and investment. Official guidance sets out approaches to appraising and enhancing the distributional benefits of options and their implementation[19].

Sensitivity analyses should examine the effect of changes in the location and timing of any investments along with lags and dynamics[52] as well as contentious issues such as discounting (the treatment of future benefits and costs). Alternative uses of the resources concerned must also be considered to assess the opportunity cost (that is, the benefits of foregone alternatives) of any particular investment. Similarly, appraisals need to incorporate how individuals may change their behaviour in response to whatever decision is made. For example, the switch from conventional to gasoline/electric hybrid vehicles does not reduce emissions as much as prior behaviour would suggest as individuals exhibit a 'rebound effect', purchasing larger engine cars and driving them more than previously in response to lower per mile costs[53]. The intended mode of implementation (for example, via incentivization, regulation and so on) also needs to be considered at this stage as this is likely to affect both behavioural response and outcomes[54].

Appraisal information then feeds to the decision stage. It is important to note here that appraisals and economic analyses are not identical to decisions. For example, while analyses can show the distributional effects of different decisions across society, it is typically a policy decision to determine the weight accorded to different outcomes. Similarly, 'rights-based' objectives[55] such as promoting access to green-space may influence decisions, although benefit–cost highlighting of the opportunity costs of different options is an important input to such initiatives and provides a useful curb on poorly thought-out schemes. Once a decision has been made it is then implemented using the approach identified at the appraisal stage. The actions and outcomes induced by decision implementation (for example, changes in land use or other resource use) then feed back via changes to stock levels, service flows, goods, health and well-being.

Research gaps

The use of a coherent framework that integrates the inputs and insights from different disciplines has a role in identifying critical knowledge gaps and hence research priorities for improving the incorporation of the natural environment into policy and decision making. We highlight some of these priorities here.

A central issue is understanding the relationships between natural capital stocks and the flow of benefits to society. In principle, natural capital management aims to ensure the flow of benefits through securing the condition of natural assets (Fig. 1) by conservation, restoration and/or management of ecosystems. However, the complexity of ecosystem processes means simple or predictable relationships between ecosystem condition and benefit flows are likely to be elusive[6] and restoration may not achieve all the benefits of an intact ecosystem[56]. While management is necessary to provide improved benefits, even well-intentioned interventions may undermine conditions needed for resilient and sustained benefits, as has been evident in certain intensive agricultural, fishery and forestry systems[57,58]. Additionally, good ecosystem condition depends upon what features are highly valued at a point in time. For example, climate change resilience and novel pathogen resistance have become more important in recent decades. Therefore, prescriptions for natural asset management and metrics for natural asset condition require an understanding of this complexity alongside practical approaches to the adaptive management of a complex system. Emerging techniques that use outcome-based metrics and incremental management to progressively enhance ecosystem condition, and incorporate diverse stakeholders across scales, sectors and knowledge systems, are promising but under-developed at present[6].

A corollary is that the sum of current ecosystem service values, even considering future flows, cannot be equated to the natural capital value of the ecosystem from which they are derived; it would always represent an under-valuation of the ecosystem which might support many alternative and future potential goods and services, some which are not currently known. The dynamic nature of ecosystems means that the system can reassemble and reorganize in the face of altered conditions and changing drivers to provide other novel services and benefits. As a result, while we promote the valuation of ecosystem services and the benefits they provide as a means of making choices between options, we urge due caution in valuing entire ecosystems.

As presented, our framework simply shows the movement from stocks of assets to flows of services and then on to the delivery of benefits, but there is substantial variation in the form of these relationships. Most exhibit non-linearities and thresholds and vary across spatial and temporal scale[34]. Consistent approaches to the understanding and measurement of stock–service–benefit relations need to be developed so that knowledge can be shared across projects, places and practitioners.

These stock–service–benefit relationships are also strongly interdependent; for example, the condition of a woodland for recreation may also affect its suitability for rare species conservation. These spatial interdependencies extend to include off-site impacts and feedbacks over time, that are often omitted from the decision-making process[59]. There needs to be a move away from traditional, single objective approaches towards the management of ecosystems for multiple functions and services[57,58,60], for example avoiding the subsidy of terrestrial food systems which generate pollution compromising the potential for marine food production. Such trade-offs among ecosystem services are common[57] with intensive production being an historic source of conflict[61]. Less intensive land use (potentially delivered through a 'land sparing' approach of technology-led concentration of production[62]) and higher biodiversity levels are often associated with greater multifunctionality[63], but there are important aspects of local and specific ecosystem condition as well as demand-side differences that will affect the achievement of multiple functions simultaneously[60]. Decision making needs to be able to consider and coherently compare (in quantitative and economic terms) the various trade-offs of alternative options at differing scales and to understand how these vary between locations and across time periods. Yet to date only a few decision support tools provide such analyses[39,64].

Multifunctionality is also a key feature of natural as opposed to engineered systems. Ecosystems have the capacity to deliver multiple functions simultaneously, and can require very little input to shift from one function to another. For example, coastal mangrove forests provide protection from storm surges, habitat for fisheries, carbon sequestration and pollution control. Each one of these functions might be replaced by technology or engineering and potentially achieve a higher level of individual service delivery, but usually only for one service at a time rather than all simultaneously. A barrage or levee may prevent a storm surge but provides few other benefits and requires continuing investment and maintenance in order not to fail, potentially with catastrophic consequences. Decisions taken between investing in engineered solutions versus natural ecosystems have often been based on very limited evidence and the topic is generally under-researched and yet of great importance[65].

Another feature of ecosystems compared to engineered or technological alternatives is their adaptability. This describes their potential to change or reorganize themselves in the face of pressures or changing environmental conditions. This natural adaptability arises from the complex structure of ecosystems and can be attributed to both redundancy and replaceability in ecosystem functions and components, as well as to genetic change and evolutionary processes in living systems from which novelty can emerge. Understanding the dynamics of these adaptive processes is important, both because they offer new solutions and innovation, but also because knowing their limits will be critical to using natural adaptability. There is increasing evidence that current pressures on ecosystems are more frequently approaching abrupt and potentially irreversible thresholds[66], making this a key topic for future research.

Given inequalities of power and influence, there is also a growing imperative to explicitly consider how limited resources at a variety of scales are shared between the competing claims of different groups in society. Within a political and moral economy such decisions cannot be guided only by simple heuristics. For example, while policies to introduce environmental net gain from greenfield development are welcome, tying compensation to the location of that development restricts gains to those moving into that area rather than nearby populations who have lost the use of that area, fails to benefit those in other more severely disadvantaged areas, and ignores the potential benefits of targeting enhancements to areas of highest conservation need[67].

Summary, rules of thumb and conclusions

As a framework for decision support, the natural capital approach clearly offers the potential for substantial improvements over commonly applied alternatives such as reliance upon markets and prices. These advantages are increasingly being recognized and incorporated into decision-making practice. For example, following collaboration between the authors and H.M. Treasury, UK guidelines for appraisal and evaluation of government spending now not only require that appraisals embrace the multiplicity of effects that spending may have on ecosystem services, recognizing that "Multiple impacts may need to be measured and valued"[19], but also, and for the first time, embody sustainability rules requiring that "Natural capital stock levels should be systematically measured and monitored", recognize that "Non-marginal effects such as reaching ecological tipping points might lead to dramatic or irreversible loss in the asset under consideration" and require that the "Cumulative effects of multiple investment decisions upon the underpinning stocks of natural capital should also be considered".

There are simple rules of thumb that can guide the application of such principles: (1) all of the major benefits and costs of a proposed change need to be considered and where possible robustly valued; (2) where values cannot be reliably estimated, explicit alternative assessments should be employed such as imposing no-loss requirements for biodiversity; (3) failure to consider alternative uses of resources will almost inevitably lead to poor decisions; (4) decisions must recognize the functional forms (including non-linearities and tipping points) relating change in natural capital asset stocks to shifts in services, benefits and costs, a requirement which means that decision making has to become an interdisciplinary undertaking; (5) the impacts of variation in the location or timing of change and the dynamics this spatial and temporal variation create are crucial to good decision making and resource use; (6) ensuring sustainable development requires more than simply ensuring benefits exceed costs, consequently explicit natural capital asset sustainability rules are necessary; (7) changes in all of the above not only alter the balance of benefits and costs (efficiency) but also their distribution across present and future society (equity), both of which are key decision criteria. These central elements of sustainability (of stocks), efficiency (with respect to benefits and costs) and equity (through governance and decision making) are highlighted in Supplementary Information.

We have described an integrated approach to natural capital that benefits from recent advances in economics and from relevant ecological knowledge. Applying a framework such as this is essential for making better, sustainable decisions for the benefit of society. Robust developments along the lines that we have proposed will have to be sensitive to emerging priorities for society, the economy and the environment as in the UN Sustainable Development Goals (SDGs) and Convention on Biological Diversity (CBD) Post-2020 Global Biodiversity Framework. Topics such as these are of critical importance but we are unlikely to make substantial progress quickly. Yet there is an urgent need to move the natural capital agenda on and into use. Hence there is a balance to be sought; do we know enough to act? Given that decisions are currently being taken on the basis of extremely limited evidence about benefits and costs, often restricted to just the value of market goods and with hardly any consideration of off-site or longer-term consequences, we suggest that we know enough already to start to put these approaches into practice. We should not let the perfect be the enemy of the good.

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Correspondence should be addressed to I.J.B. or G.M.M.

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