Agriculture, nature conservation or both?

Managing trade-offs and synergies in sub-Saharan Africa

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Boosting agricultural production to meet the food demands of growing and more prosperous populations increasingly comes with a cost to the ecosystems upon which human life more broadly depends. Yet many developing countries (and some developed countries) do not acknowledge or understand these trade-offs. This is becoming one of the greatest challenges in achieving sustainable land use and the Sustainable Development Goals. Greater understanding of trade-offs, and how to analyse and better manage them, is needed. This paper summarises key concepts relating to trade-offs and synergies, including trade-off analysis and management, to make approaches and methods more accessible.

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Acronyms and abbreviations

ARIES	Artificial Intelligence for Ecosystem Services
BRMP	Buccoo Reef Marine Park
CSA	Climate-smart agriculture
EU	European Union
ES	Ecosystem service
GIS	Geographic information systems
ICD	Integrated conservation and development
ICM	Integrated catchment management
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
LUCI	Land Utilisation Capability Indicator
MA	Millennium Ecosystem Assessment
MC	Multicriteria analysis
NGO	Nongovernmental organisation
PES	Payments for ecosystem services
PPF	Production possibility frontier
REDD+	Reducing emissions from deforestation and forest degradation in developing countries
Sentinel	A project that seeks to address the challenge of achieving 'zero hunger' in sub-Saharan Africa, while reducing inequalities and conserving ecosystems

Summary

Context

Over the past 30 years, many projects and programmes addressing both conservation and development objectives claimed 'win–win' benefits for people and nature. But too often they failed to deliver either. Boosting agricultural production to meet the food demands of growing and more prosperous populations increasingly comes with a cost to the ecosystems upon which human life more broadly depends. Yet many developing countries (and some developed countries) do not acknowledge or fully understand these trade-offs. This is becoming one of the greatest challenges in achieving sustainable land use and the Sustainable Development Goals.

Greater understanding of trade-offs, and how to analyse and better manage them, is needed. Such a process would engage applied researchers, policymakers and practitioners involved with both conservation and development. To that end, we have summarised key concepts relating to trade-offs and synergies, including both trade-off analysis and management, to make approaches and methods more accessible.

Key findings

Various interactions between ecosystem services and drivers of change affect the flow and use of ecosystem services that lead either to trade-offs or synergies. In a trade-off, management interventions to enhance one ecosystem service directly decrease the supply or benefits of another. In a positive synergy, enhancing one ecosystem service also increases the supply of another.

Interactions between the services themselves may cause trade-offs and synergies, but they are most likely to result from interactions between processes and functions within the system. Of the many direct drivers (immediate causes) of ecosystem degradation and biodiversity loss, the most significant from a global perspective is agricultural expansion. In Africa, agricultural expansion is driven primarily by growing domestic food demand, which is a consequence of increasing populations and of much needed improvements in living standards. These are indirect drivers of ecosystem degradation and biodiversity loss. Other indirect drivers include increased meat consumption and climate change. Political and institutional factors, such as weak governance, can also be very significant.

Analysis of trade-offs has different levels of depth. At its most basic, the phrase "agricultural production and nature conservation trade-offs" is a broad framing for the trade-off between one ecosystem service (agricultural production) and other ecosystem services. In a more sophisticated analysis, the framing can be further extended from ecosystem services to the benefits derived from their use, and how these benefits contribute to wellbeing.

Ecosystems services framework. Within the context of agriculture and biodiversity conservation, trade-off analysis usually uses the ecosystem services framework developed for the Millennium Ecosystem Assessment (MA) of 2005. This MA framework, however, is increasingly contested. Among other concerns, critics highlight several ethical issues. These issues relate to the way values are ascribed to services, and the failure of the framework to recognise services that negatively impact human wellbeing – ecosystem dis-services – such as damage to crops and livestock by wildlife.

Indeed, the lack of social dimension to the MA framework is a key limitation. Increasingly, analyses differentiate between ecosystem services and the values of the benefits they generate. Stakeholders vary greatly in their preference for different ecosystem services. Changes will thus affect groups in different ways. By disaggregating beneficiaries, policymakers can more accurately assess the impact of ecosystem changes on wellbeing.

Socio-ecological framework. A socio-ecological framing of trade-offs and synergies analyses multiple considerations, including social, economic, institutional, political and ecological factors, as well as stakeholder preferences. One such approach further categorises stakeholders into influential users, non-influential users and context setters. This 'social' side is framed together with the ecological side, in which the trade-off management process focuses on the target ecosystems. Socio-ecological framing also addresses the feedback between social and ecological systems.

Trade-off management. Trade-off management responses can be viewed through the lens of communication and governance (public meetings, participatory processes and so on); problem-solving (landuse planning, new regulations and technology, and so on); and investment in generating new knowledge (research). Such interventions, however, may not be enough to overcome barriers to change. Analysis of efforts to successfully address such barriers reveal a set of enabling conditions that relate mostly to governance.

As well as enabling change, efforts to improve governance can be perceived as a valuable contribution to human wellbeing in their own right.

Analysis of trade-offs should begin with understanding who makes final decisions, both in theory and practice. It should then map the various influences on decision making and their relative impact to identify 'leverage points' for interventions. At the same time, since the external environment is in constant motion, management of trade-offs may change over the medium to longer term.

Better trade-off management. Because of basic ecological limitations, it is usually not possible to design interventions that completely eliminate trade-offs and generate 'win–win' solutions for all stakeholders. Better trade-off management, then, means improving on the current situation. But improvements for whom, in what way and compared to what?

Trade-off analysis methods. Building on earlier research, this report reviews the strengths and weaknesses of six categories of methodologies for analysing trade-offs between agricultural production and nature conservation. Using a combination of these methods is increasingly common.

- **Simulation methods** assess future trade-offs in quantitative terms, comparing a baseline against estimated future indicators. Among its strengths, this approach can illustrate the effects of different scenarios on important indicators. This method is hampered by its dependence on reliable data, and its inability to consider qualitative criteria, and social and political aspects, among others.
- **Optimisation methods** develop a mathematical model using real or simulated data, defining all variables as benefits or costs. This method may deliver insights about the optimal allocation of scarce resources and inform decisions by local and regional policymakers, landowners and land managers. But the concept of 'optimal allocation' from a societal perspective often hides a highly inequitable distribution of benefits and costs within society.
- **Multicriteria analysis** evaluates different policy or management options that capture relevant dimensions of decision making, often in a participatory manner. As one strength, it could compare different criteria, such as economic, social and ecological aspects. Participatory approaches also allow stakeholders to see how different options may affect criteria that matter to them. Such approaches, however, are time-consuming and resource-intensive, and may not represent preferences across the entire population.
- **Spatially explicit methods** combine spatial mapping of services with correlation and cluster analysis. The tools generate maps that can easily identify the type and location of ecosystem services, as well as synergies and trade-offs among ecosystem service bundles. The tools and results, though, tend to be descriptive rather than analytical. The usefulness of the tools also depends on the availability and quality of data. Moreover, many ecosystem services cannot be quantified, requiring the use of proxy data that may be inaccurate.
- **Integrated modelling methods** include Integrated Valuation of Ecosystem Services and Trade-offs, Artificial Intelligence for Ecosystem Services, Land Utilisation Capacity Indicator and GLOBIO. They combine natural and human subsystems to allow quantification, spatial mapping and sometimes economic valuation of ecosystem services. As a group, integrated modelling tools can model interactions between human and ecological subsystems. They are based on state-of-the-art knowledge, giving them sound scientific foundations. Data requirements, however, are significant. The tools cannot quantify important social and cultural dimensions of ecosystem services or social aspects related to equity, power or access. The tools are also complex to use, especially for non-experts.
- **Stakeholder-centred methods** identify the perspectives, needs and interests of different stakeholders, and the value they attribute to different outcomes. As a group, these methods increase opportunities for social learning, trust-building, ownership and consensus, legitimacy and successful implementation. In addition, local stakeholders often hold informal information about context inaccessible to outsiders. Considering local knowledge may lead to more creative problem-solving. Yet stakeholders may have different motivations, needs, uses or values, even with the same group. They may focus on short-term benefits at the expense of ecosystem health. Such methods are also time-consuming and costly, requiring a broad range of social skills.

Conclusions

In many developing countries (and some developed countries) there is still little acknowledgement and understanding of the major trade-offs between agricultural production and nature conservation. But a continuation of business as usual spells disaster for fragile ecosystems, many smallholder farmers and others – rural and urban – dependent on ecosystem services. Avoiding this disaster will require transformative change. This means a change in the power balance to enable outcomes to better and more fairly reflect the diversity of stakeholder interests and the interests of future generations. Better understanding and management of trade-offs lies at the heart of this challenge.

1

Introduction

This section introduces questions and approaches related to 'trade-offs', 'synergies' and 'trade-off management' that are explored in this paper. It points to the increasing complexity in the choice between growing food and conserving nature and its biodiversity, and introduces ways to frame the discussion. Understanding how to analyse and manage trade-offs is key to achieving the Sustainable Development Goals.

There are major trade-offs between increasing agricultural production to meet the food demands of growing, more prosperous populations, and conserving nature to protect the biodiversity and ecosystem services on which human life more broadly depends. But practitioners and policymakers in many developing countries (and some developed countries) do not acknowledge or fully understand these trade-offs. This is one of the greatest challenges in achieving sustainable land use and the Sustainable Development Goals (FAO 2018). The challenge is particularly serious in sub-Saharan Africa where domestic food demand will have doubled or even tripled between 2010 and 2050 (Franks et al. 2017; Van Ittersum et al. 2016). Most countries in the region continue to assume they will meet this demand through domestic production. In Ethiopia, for example, food demand is projected to increase by 2.6 times within this period. Furthermore, agricultural area is projected to expand by 3.9% per year, and 70% of existing agricultural land comes from conversion of natural forests and woodland. At the same time, the country has committed to eliminating deforestation by 2030 (Franks et al. 2017).

How can a country like Ethiopia be seemingly so blind to such major trade-offs? A recent analysis of why trade-offs are often ignored in policy and practice identifies three possible explanations (Galafassi et al. 2017):

- **Trade-offs might be invisible to those making decisions,** complex and hard to understand, and span multiple temporal and spatial scales.
- **Trade-offs can be differently perceived**. What appears as a trade-off from one perspective appears as a win–win from another. These perspectives vary according to knowledge, values and beliefs, but also in relation to material assets, property rights and other livelihood capacities.
- **Trade-offs are not always explicit, and can be hidden, intentionally ignored or downplayed.** This means that institutions, incentive structures, political processes and social narratives can deliberately mask and hide trade-offs from decision-making processes. Narratives that emphasise win–win solutions are often more socially, psychologically and politically attractive.

In their landmark paper, McShane et al. (2011) stated: "Win–win solutions that both conserve biodiversity and promote human wellbeing are difficult to realise. Trade-offs and the hard choices they entail are the norm." This conclusion challenged the wisdom (or in retrospect the wishful thinking) of 20 years of major donor investments in integrated conservation and development (ICD) projects. These projects often claimed to deliver win–win outcomes for people and nature, and all too often failed to deliver either (McShane and Wells 2004).

In the nearly 10 years since McShane et al. (2011), knowledge and tools to better manage trade-offs have greatly improved. Yet this progress is largely buried deep in the academic literature. Understanding trade-offs often goes no further than the basic idea that gains are accompanied by inevitable losses – some win, some lose.

Greater awareness and understanding of trade-offs, and how to analyse and manage them, are needed to do things differently. This process would engage applied researchers, policymakers and practitioners involved with conservation and development. To support this process, through a comprehensive review of the literature, we have summarised key concepts relating to trade-offs and synergies, including both trade-off analysis and management.

We break down 'better' trade-off management into three questions: better for whom, better in what way and better compared to what? Building on Klapwijk et al. (2014), we identify a range of different trade-off analysis methods used in the context of agricultural production and nature conservation. We put them into six categories, and review them (and some examples) for strengths and limitations.

Ultimately, we aim to make these concepts and methods more accessible to key audiences. These audiences range from agricultural and conservation scientists in applied research organisations to technical advisers in international agencies working on nature conservation and agricultural development.

Trade-off is a term widely used in English, but rarely understood beyond the basic idea of competing objectives. In many other languages there is no direct translation. For instance, in French and German, the word is translated as 'compromise'.

There are different ways to frame the concept of trade-offs. Agricultural production is generally regarded as a form of ecosystem service, albeit with a major element of coproduction.[1] Therefore, trade-offs can be framed as an issue of competition between different ecosystem service objectives and conservation of the underpinning biodiversity.

We adopt an anthropocentric approach to trade-off management, which has important implications, in particular:

a) analysing the competing objectives in terms of their contribution to human wellbeing (in the broadest sense, including all aspects of quality of life), and

b) looking beyond technical interventions to the actions of different stakeholders and their institutions at all levels that may enable or hinder trade-off management.

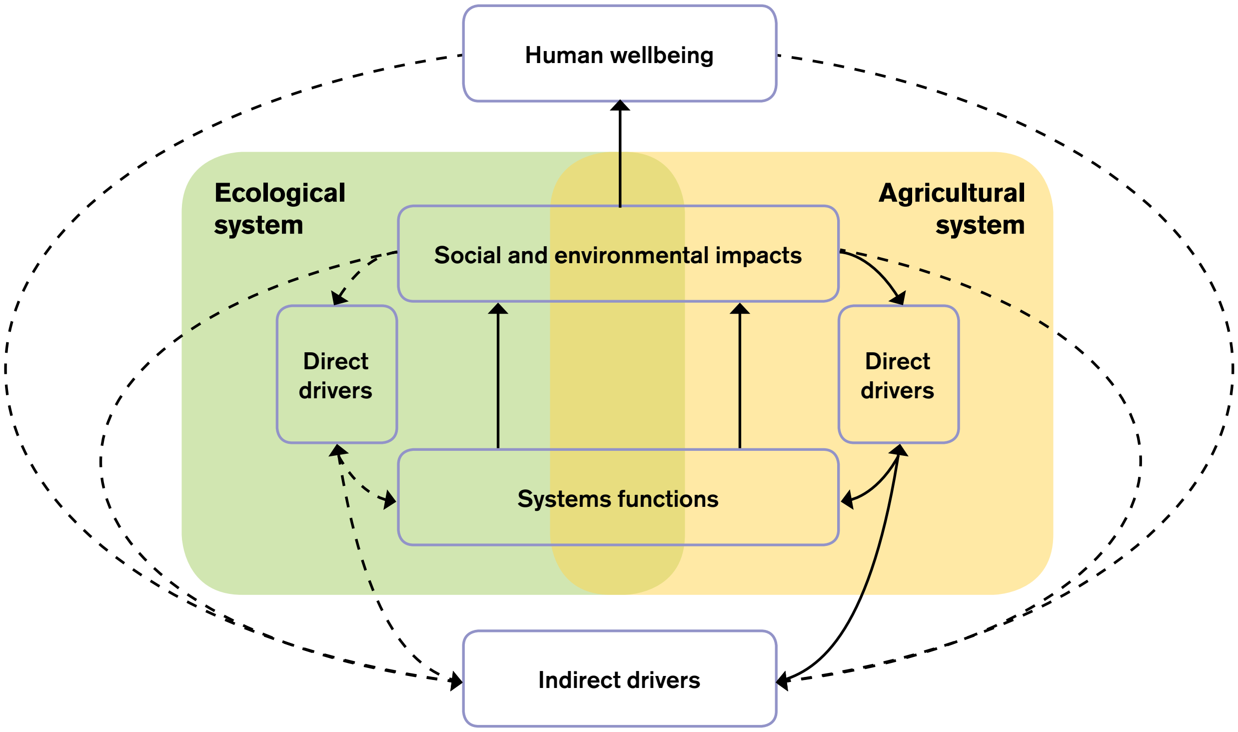
The agricultural/ecological system that is the focus of our work on trade-offs is also bounded by a focus on land use and land management practices and associated policies, strategies, plans and their implementation. That said, actions of stakeholders to bring about change in this system may extend far beyond the boundaries of what might be considered land use/management interventions. This is especially true with respect to addressing indirect drivers of change.

Figure 1 provides a conceptual model for this system used in the Sentinel project, which IIED leads. This interdisciplinary research seeks to address the challenge of achieving 'zero hunger' in sub-Saharan Africa, while reducing inequalities and conserving ecosystems.[2]

Understanding trade-offs often goes no further than the basic idea that gains are accompanied by inevitable losses – some win, some lose.

[1] Service generation depends on human activities.
[2] www.sentinel-gcrf.org

Figure 1. Conceptual model of the Sentinel project



Key: both dotted and solid arrows show impact pathways or feedback loops. Solid arrows indicate the pathways or feedback loops on which the Sentinel research project is focusing attention.

This model represents how drivers within the system cause changes in interconnected ecological and agricultural systems. It also shows how indirect drivers beyond the boundaries of the system lead to changes in drivers that directly affect system functions and processes (direct drivers), as well as social and environmental outcomes.[3] These, in turn, contribute positively and negatively to human wellbeing (often positively for some people and negatively for others). The graphic also shows the more important feedback loops. The solid arrows are the research focus of the Sentinel project.

[3] An 'outcome' is a flow of something over time and an 'impact' is a change in that flow caused by a change in the system. An impact is always related to a driver.

2

Concepts of trade-offs and synergies

This section explores trade-offs and synergies more deeply. It examines causes, drivers and interactions, as well as the role of processes and functions within a system, that lead to one outcome or the other. It also looks at strengths and limitations of frameworks for understanding trade-offs and synergies, the influence of social dimensions and concepts of trade-off management.

Turkelboom et al. (2016) provide good definitions of trade-offs and synergies. In a **trade-off,** the use of one ecosystem service directly decreases the supply of, or benefits derived from, another. In a positive **synergy,** the use of one ecosystem service directly increases the supply or benefits of another. Synergy can also be negative where one type of negative impact is linked to another type of negative impact (Figure 2).

What causes a trade-off or synergy can be understood in terms of 'mechanistic pathways' (Bennett et al. 2009). Figure 3 shows how the competition in supply of different ecosystem services may be related either to:

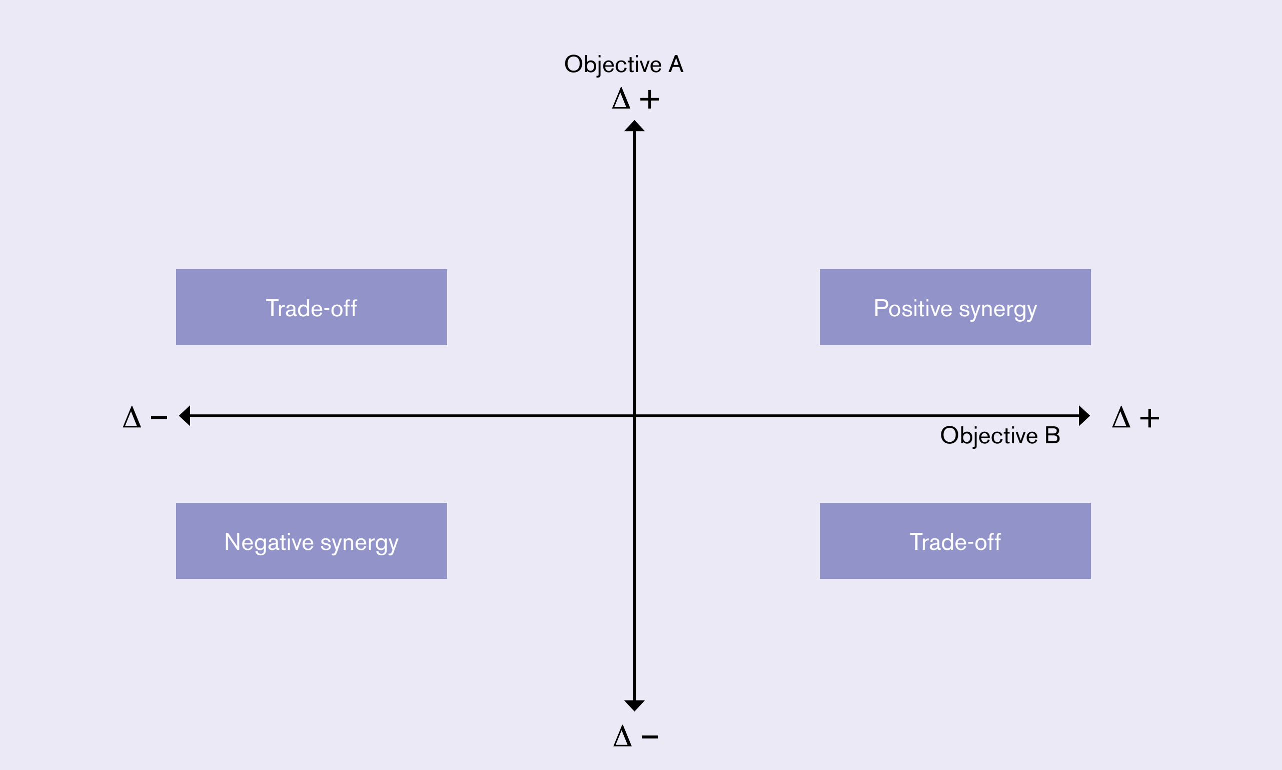
A. **Interactions** between ecosystem services and underlying process and functions – in this case, how forests being good habitat for bees improve yields of crops dependent on pollination by bees, but also harbour monkeys that damage the same crops (an ecosystem disservice)

B. Both ecosystem services differentially responding to a common **driver of change** – in this case, an expansion in the area of agricultural land.

Interactions between ecosystem services may cause trade-offs and synergies, but they are more likely to result from interactions between processes and functions within the system. Figure 4 shows an example of water purification in an ecological system based on the ecosystem services cascade model (Groot et al. 2007; Maes et al. 2012). A similar concept can apply to an agricultural system that involves complex interactions of processes and functions. These include interactions within the domain of human intervention (coproduction).

Interactions take many different forms with varying degrees of significance. The case of crop damage by wildlife in Figure 3 is a common example. In another frequent case, irrigation practices near the upper areas of a watershed can reduce water flows lower down that may seriously impact a natural habitat. One such notorious example is the seasonal drying up of the Great Ruaha River in Tanzania, which is vital to the Selous National Park. Interactions are fundamentally a biophysical phenomenon which in this context means ecological and/or agronomic.

Figure 2. Trade-offs and synergies



Interactions can be quite significant, but in most cases drivers are the dominant factor and therefore the main focus of efforts to better manage trade-offs. Globally, the most significant direct driver, or immediate cause, of ecosystem degradation and loss of biodiversity is agricultural expansion (IPBES 2019). In all five of the sub-Saharan African countries we studied, the primary driver of agricultural expansion is growth in domestic food demand. It is not, as is often assumed, the growth in export commodities (Franks et al. 2017).

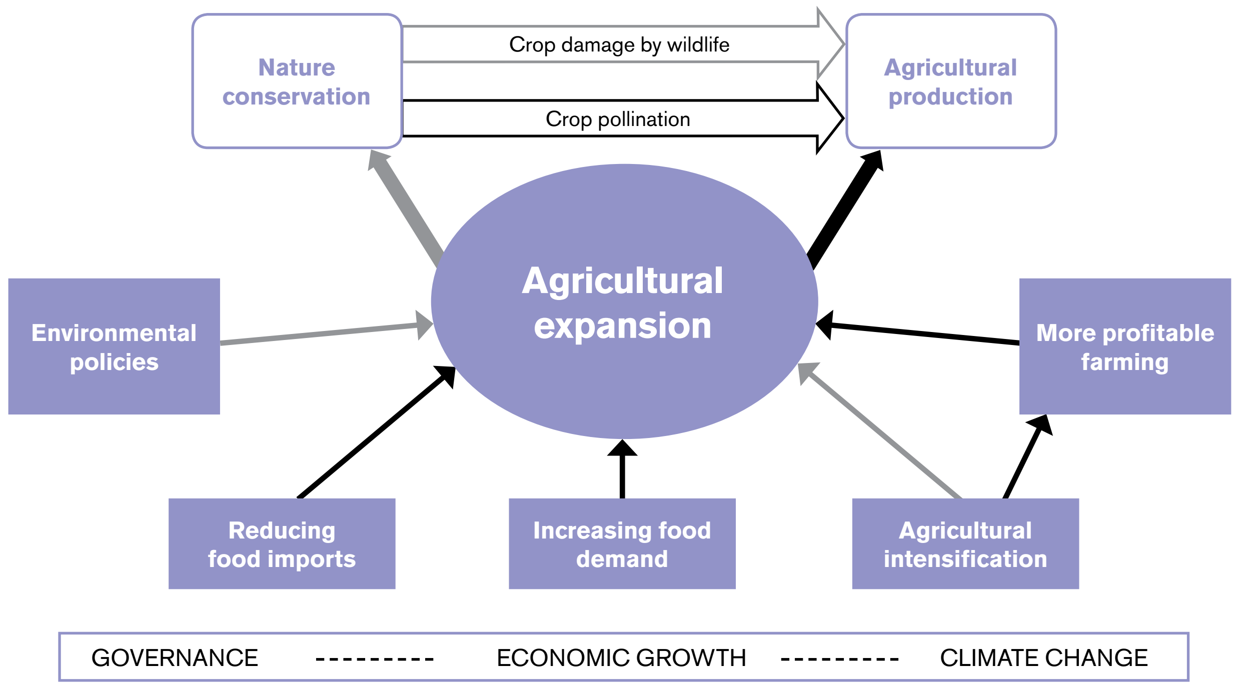
The extent to which increasing food demand drives agricultural expansion depends on four factors in particular: how much food a country imports; the extent to which environmental safeguard policies exist and are enforced; the success of efforts to intensify agriculture; and whether a 'Jevon's paradox'[4] effect is associated with this intensification. All of these drivers of expansion are, in turn, affected by major macro-level drivers. These are, notably, the quality of governance; the rate of economic growth; and the degree to which climate change will impact the agricultural sector. This is why there is both a black and a grey pathway between agricultural intensification and expansion in Figure 3.

Drivers and interactions can operate across scales. With drivers, for example, decisions on how agriculture–conservation trade-offs are managed take place at all levels. These range from an individual farmer with a chainsaw poised to clear a hectare of forest to a minister who decides to declare a new national park. Usually it is possible to identify an agency, organisation, committee or individual with the primary authority to decide the outcome. However, this authority may be expected to consult with other key stakeholders at their level and below. Other stakeholders not formally consulted may seek to influence the decision through less formalised processes such as advocacy/lobbying. That said, the level of authority and the locus of decision making may be different, especially in systems with weak governance. In theory, for example, the Forest Department in Ghana enforces forest protection, controlling expansion of agriculture into forest reserves. In reality, however, powerful traditional chiefs control the land under customary systems of ownership and allocate forested land to local farmers.

In a trade-off, the use of one ecosystem service directly decreases the supply of, or benefits derived from, another.

[4] In a Jevon's paradox, intensification of agriculture intended to reduce pressure on forests has the opposite effect. It happens where intensification leads to increased profits, and thus an incentive to expand, and where environmental regulations and governance that might limit expansion are weak. This phenomenon is widely recorded in the Amazon Basin (Ceddia et al. 2014).

Figure 3. Trade-offs between ecosystem services: mechanistic pathways



Key:

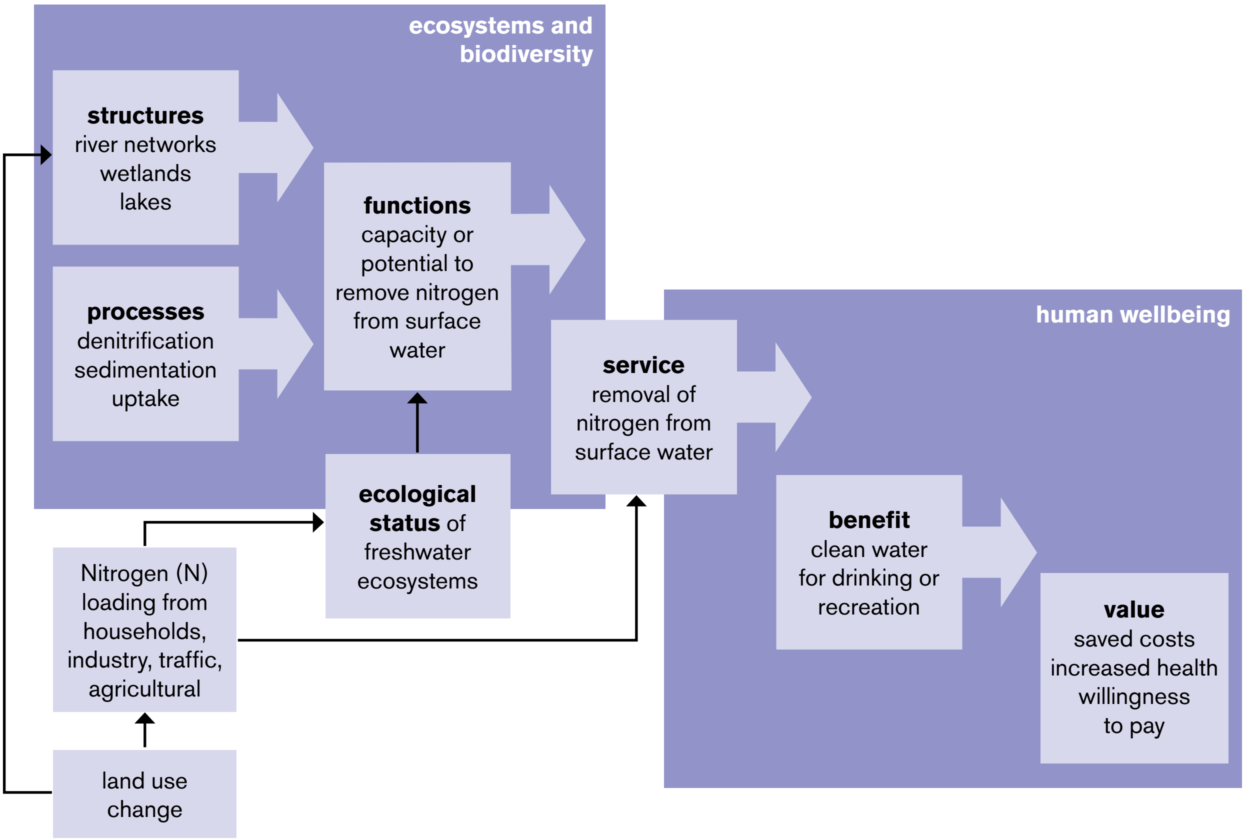
- Solid oval indicates direct driver and solid rectangles indicate indirect drivers of trade-offs between ecosystem services
- Solid arrows are actions of drivers, hollow arrows are interactions of ecosystem services and associated functions and processes
- Black arrows indicate drivers/interactions causing an increase, grey arrows indicate drivers/interactions causing a reduction
- Governance, economic growth and climate change are major macro-level drivers of change

The phrase "agricultural production and nature conservation trade-offs" is a broad framing of a trade-off between a provisioning ecosystem service (agricultural production), and a range of provisioning, regulating, cultural and supporting services and the biodiversity upon which they depend. As suggested in Figure 4, the framing could be further extended from ecosystem services to the benefits derived from their use and ultimately to how these benefits contribute to wellbeing – in this case, improved health. The latter would, however, greatly increase the complexity of the trade-off analysis since many other factors help determine the extent to which a particular benefit contributes to wellbeing. Stakeholder perception of benefit, however, might be considered a proxy for the contribution to their wellbeing.

For trade-off analysis, the framing can be broad or narrow depending on the research question. Trade-off management that seeks to inform and influence policy and planning has specific requirements. Research must be aligned with policy and planning that usually have more specific objectives or indicators. These could include production of staple foods in agriculture, species richness for biodiversity and carbon flows for climate change mitigation. That said, as Bennett et al. (2009) point out, an overly narrow focus on a limited set of ecosystem services can, all too often, result in unexpected declines in other key ecosystem services.

Where research focuses on trade-offs – as in IIED's Sentinel project – synergies are still important as they can mitigate the trade-offs and thereby reduce the net trade-off. For example, payments for ecosystem services (PES) give farmers an incentive to not convert more forest to farmland. Providing farmers with a financial benefit from forests reduces the negative impact of forest conservation on farming enterprises. However, the experience of reducing emissions from deforestation and forest degradation in developing countries (REDD+) offers some insights. With respect to forest conservation, incentives from carbon finance will rarely be high enough to fully eliminate this trade-off. Expansion of agriculture into peatlands is a possible exception.

Figure 4. Water purification in an ecological system based on the ecosystem services cascade model



Source: Maes et al. 2012.
Note: Throughout the example, nitrogen is used as a common water quality indicator.

2.1 Limitations of an ecosystem services framing of trade-offs

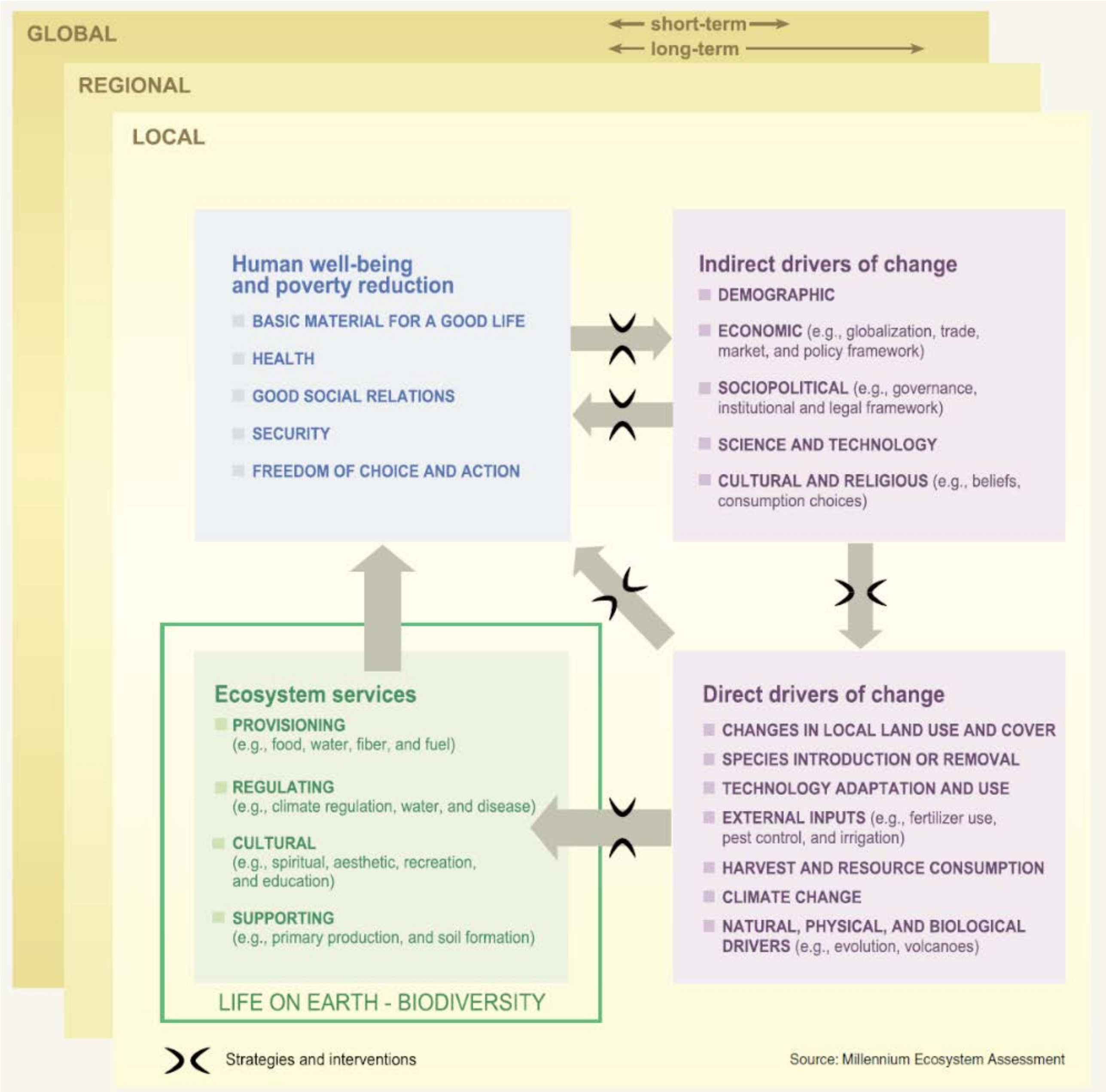
Within the context of agriculture and biodiversity conservation, the analysis of trade-offs usually uses the ecosystem services framework developed for the Millennium Ecosystem Assessment (MA) of 2005 (Figure 5). In this framework, agricultural production is considered a provisioning service. Conservation goals, conversely, relate more to regulating services, cultural services and supporting services, and the functions, processes and biodiversity that underpin these and provisioning services.

While highly influential, the MA ecosystem services framework is increasingly contested. Much of the literature implicitly or explicitly accepts an economic valuation framework for assessing human wellbeing. Many conservation biologists and ecologists assert that ecosystems degrade because society is unaware of the 'true value' of the contributions that ecosystem services make to human wellbeing. If they were aware of the contributions, the argument goes, decision makers could better consider them, which would reduce environmental degradation (Lele et al. 2013).

Critics, however, highlight ethical concerns with the valuation focus of the MA framework. These are related to difficulties in the valuation of ecosystem service contributions to, for instance, human lives, basic human needs or social justice, as well as methodological flaws. In particular, they question the use of 'contingent valuation methods' to elicit values for goods and services for which no markets exist.

Another important critique relates to the omission of 'dis-services' – negative impacts of ecosystem functions on human wellbeing. A classic example is damage to crops and livestock caused by wildlife. In some cases, such as soil erosion by streams, the same ecosystem process can generate a dis-service (siltation of dams) or a service (fertilisation of the floodplain) (Lele et al. 2013).

Figure 5. Conceptual framework of the Millennium Ecosystem Assessment

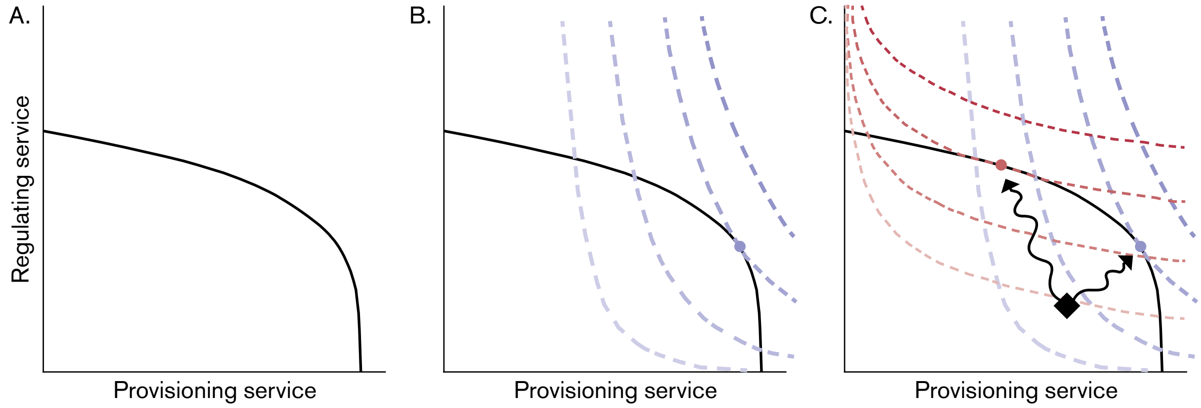


The MA framework further fails to accommodate the coproduction (dependence on human activities) element of many ecosystem services. Water supply provides a clear example where the ecosystem service ensures a reliable supply of clean water. But for the vast majority of people this service only has value if there is water distribution infrastructure. Coproduction is also a major issue with agriculture where the benefits of the basic provisioning service are hugely increased by technology and infrastructure.

Economic analysis can be avoided and trade-offs between ecosystem services analysed in purely biophysical terms, but management decisions are driven by interests and preferences for different ecosystem services, not the quantity/quality of the ecosystem services per se. In other words, while an analysis in a biophysical dimension provides useful information, such analysis in the absence of social, economic institutional and political dimensions is likely to be of little use in informing better trade-off management.

Ignoring how the value of a particular ecosystem varies from one person to another, and how this might change over time, seriously limits the potential for better trade-off management. Figure 6A, for example, represents the classic ecosystem services trade-off in the form of a production possibility frontier (PPF). The PPF shows

Figure 6. Production possibility frontier and stakeholder preferences



Source: King et al. 2015.

the theoretical maximum productivity of the system and how an increase in the use of one ecosystem service inevitably decreases availability of the other. The actual performance of the system – indicated by the position of the black diamond – can be anywhere below this line depending on how well the system is being managed. The black diamond will move closer to the PPF as management improves.

In Figure 6B, the blue dashed lines represent a stakeholder who values the provisioning service more highly, but still values the regulating service to some extent. In other words, they would need to see a big win in terms of regulating service to offset even a small loss in provisioning service. Figure 6C shows the opposite – a stakeholder who attaches a high value to the regulating service and low value (but not zero) to the provisioning service.

The black diamond and arrows show how the system performs and the possibility for improving its efficiency in two different ways. Where the red dashed line meets the black curve would be the best possible outcome for the red group. For the blue group, this represents about a 25% loss of the provisioning ecosystem service that is their primary interest. But this loss is largely compensated by improved regulating service, which is still of some value to them. If the blue dashed lines were slightly straighter, the blue group could have lost 25% of the provisioning service but still be happy with the overall outcome. In other words, from a biophysical perspective, what looks like a serious trade-off (a big win for the red group and big loss for the blue group) could, in fact, be a win–win outcome (though the gains do not seem to be fairly shared).

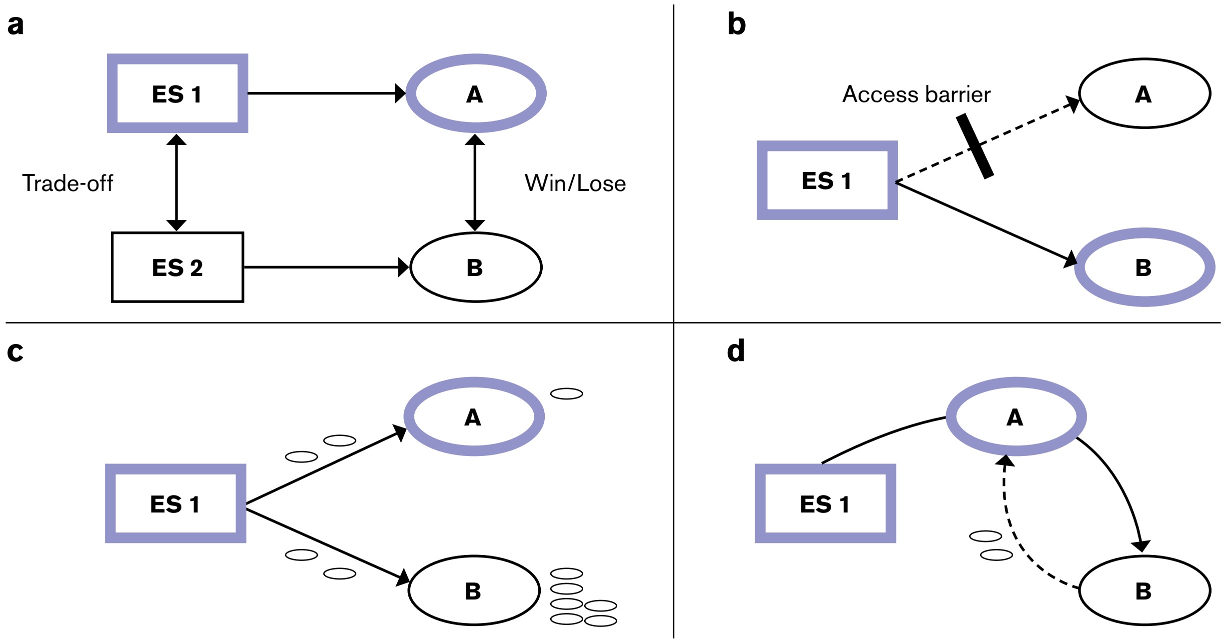
In trade-off management, considering both stakeholder values and biophysical outcomes can provide more room for compromise, especially if preferences for different ecosystem services are changing over time.

2.2 Social dimensions

There is a key limitation in the MA framework, which is also true of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) framework that may replace it: stakeholders vary greatly in their preferences for different ecosystem services. Changes in ecosystems services will therefore affect groups in different ways. To understand the differential impacts on wellbeing and thus address distributive issues, Daw et al. (2011) highlight the need to disaggregate beneficiaries (Figure 7).

Each of the scenarios presented in Figure 7 shows an increase in the flow of one ecosystem service (highlighted boxes) and the differential impacts on two potential beneficiaries (A and B). In (a), trade-offs among ecosystem services result in winners and losers depending on who is set to use which ecosystem service. In (b), access mechanisms determine who is placed to benefit from an increased flow. In (c), both groups benefit equally in absolute terms, but the relative contribution to their wellbeing depends on their 'wellbeing context' (such as wealth and vulnerability). Finally, in (d), direct benefits go to B rather than A. But A still benefits through payments made by B to A.

Figure 7. Disaggregating human beneficiaries of ecosystem services to assess wellbeing effects



Source: Daw et al. (2011).

This shows the need to disaggregate beneficiaries to accurately assess wellbeing implications arising from ecosystem changes. As Daw et al. (2011) point out, in many cases improving equitable and secure access might matter more than simply increasing supply of an ecosystem service.

Logically, the starting point for work on the social dimension of trade-off analysis must be stakeholder analysis. However, stakeholders don't exist in a vacuum. They are always embedded in a specific context, shaped by both ecologically determined and socially constructed circumstances. Formal and informal institutions structure how individuals behave and relate to each other. Socioeconomic, political and cultural factors shape differences in power and access to resources such as education, land or capital. This social context determines management choices that change and maintain ecosystem functions and services. Understanding and managing trade-offs therefore requires consideration of all these social, economic, institutional, political and biophysical factors (Turkelboom et al. 2016) where in our context biophysical means ecological and agronomic.

The 'socio-ecological framing' of trade-offs (and synergies) aims to take account of all these factors. In their pioneering work in this area, King et al. (2015) add consideration of stakeholder preferences. Moreover, they analyse barriers to better trade-off management related to stakeholder influence and other factors, and how these barriers might be addressed.

Institutions refer to the "underlying rules of the game" and are both formal and informal. Formal institutions include the written constitution, laws, policies, rights and regulations typically enforced by official authorities. Informal institutions are the unwritten codes that shape thought and behaviour, such as social norms, customs or traditions (Carter 2014).

Figure 8 shows another approach to socio-ecological framing. This includes both stakeholder preferences (interests) and the influence of different stakeholders that may shape trade-off management (Turkelboom et al. 2018).

Stakeholders don't exist in a vacuum. They are always embedded in a specific context, shaped by both ecologically determined and socially constructed circumstances.

On the social side, stakeholders are categorised into:

- Influential users – high influence and interest/concern as directly experiencing the impacts
- Non-influential users – low influence but high interest/concern as directly experiencing impacts
- Context setters – high influence but low interest as not as directly experiencing the impacts.

On the ecological side, the target ecosystem services focus on the trade-off management process. The impacted ecosystem services are not consciously traded off, but are nonetheless affected. While this distinction is simplistic, it reflects the realities of decision making in policy and planning processes.

When it comes to better managing a trade-off, an understanding of the possible influence of different stakeholders on the process is also important. But it is completely absent in a purely biophysical analysis.

As a further problem, analysing a trade-off purely in biophysical terms does not account for how some key socioeconomic drivers may change rapidly over time. As countries become more developed and their citizens better educated, for example, trade-offs can change. Poorer people once highly dependent on provisioning services (such as forest products) typically find easier and more profitable ways to secure their livelihood and are less focused on immediate benefits. Either could lead to more interest in regulating and cultural services and biodiversity than was previously the case. This transition might be encouraged by public awareness campaigns as a trade-off management intervention (see Table 1).

As another important strength, socio-ecological framing addresses the feedback between the social system and the ecological system. This is done implicitly in the case of King et al. (2015) and more explicitly in Turkelboom et al. (2018) depicted in Figure 8.

2.3 Trade-off management

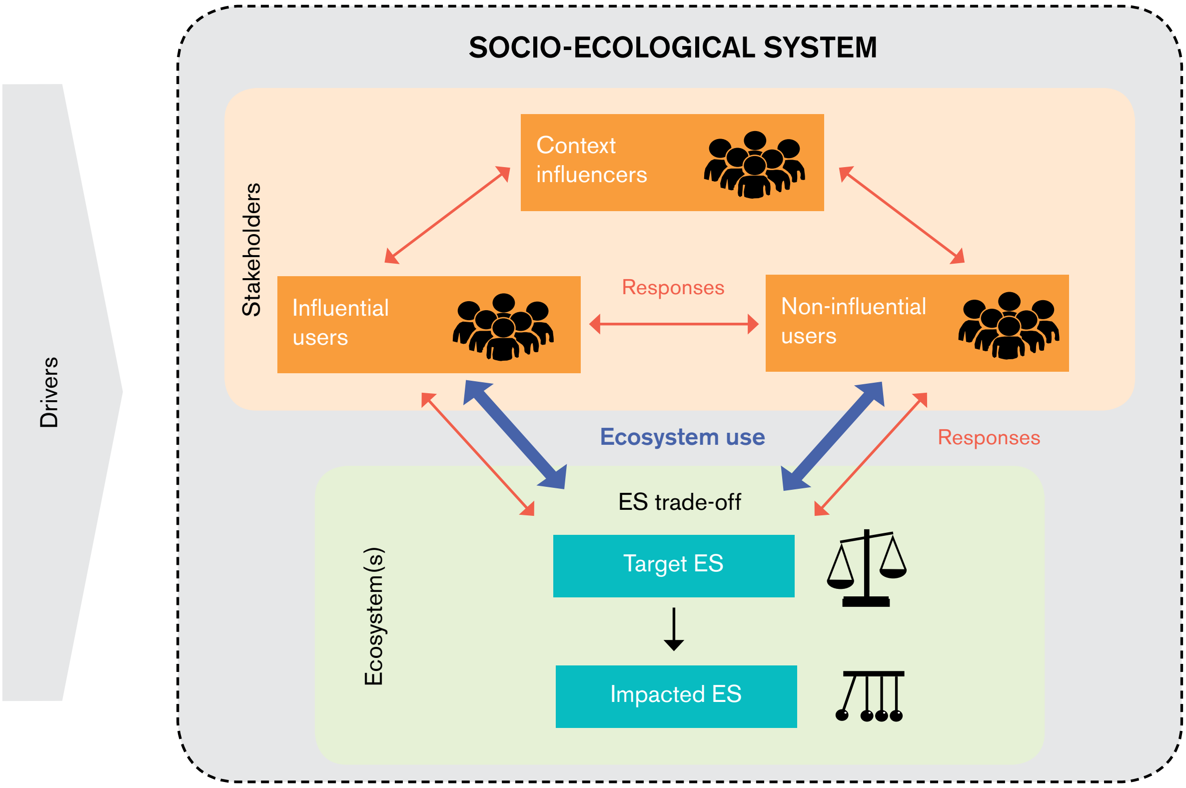
Turkelboom et al. (2018) propose three major categories of trade-off management response:

A Communication and governance-oriented actions.

B Problem-solving actions that aim to modify use of the ecosystem services.

C Investment in new knowledge.

Figure 8. A stakeholder-centred framework of ecosystem service trade-offs



Source: Turkelboom et al. 2018.

In addition, Turkelboom et al. (2018) notes there is a trade-off avoidance strategy – essentially escaping the trade-off by delinking peoples' livelihoods from the trade-off.

Table 1 shows examples of different types of intervention within each of the categories A-C.

The examples in Table 1 of interventions to improve trade-off management are necessary, but often insufficient to bring about the desired change in trade-off management because of barriers to change. Analysis of efforts to successfully address such barriers reveal a set of enabling conditions that are mostly governance issues (Sayer et al. 2013; Hou-Jones et al. 2019) – see Box 1. As well as enabling change, efforts to improve governance can be perceived as a valuable contribution to human wellbeing in their own right. For example, empowerment of women is both a means of delivering more equitable distribution of benefits and costs, and a contribution to women's subjective wellbeing.

BOX 1. ENABLING CONDITIONS FOR BETTER TRADE-OFF MANAGEMENT

1. Understanding and reconciling competing land-use needs
2. Building trust among key stakeholders
3. Engaging multiple stakeholders
4. Clear land rights, responsibilities and accountability
5. Transparent and fair benefits and costs
6. Strengthened stakeholder capacities
7. Participatory and user-friendly monitoring
8. Multiple spatial scales
9. Financial and institutional sustainability, and
10. Continuous learning and adaptive management.

Source: Hou-Jones et al. 2019 based on Sayer. et al. 2012.

Table 1. Trade-off management responses: examples of interventions

CATEGORY OF RESPONSE	EXAMPLES OF INTERVENTIONS
A Stakeholder engagement: communication and governance	1. *Awareness-raising campaigns* 2. *Public meetings* 3. *Contacting the press* 4. Multi-stakeholder, participatory processes 5. Women's empowerment 6. Strengthening land rights 7. Adaptive management informed by monitoring and learning
B Problem solving: increasing benefits, reducing costs, enhancing synergies, alleviating trade-offs	8. *Land-use and spatial planning* 9. *New regulations and safeguards* 10. *Enforcing regulations* 11. *Improved land/natural resource management* 12. Conditional incentives, eg payments for ecosystem services 13. Processing and marketing of agricultural products
C Producing new knowledge	14. *Commissioning research*

Adapted from Turkelboom et al. 2018. Examples in italics are from Turkelboom et al. (2018).
The others are drawn from a variety of sources, including work by IIED (Hou-Jones et al. 2019).

2.3.1 Trade-off analysis and cross-scale interactions

Efforts to improve land use/management trade-offs should logically start with understanding how such arrangements are working. Key pieces will be identifying who actually makes decisions in practice, who has ultimate authority on particular decisions and the factors large and small that influence their decisions. In situations of weak governance, the *de facto* locus of decision making will often be at the lowest level (individual or village level), while higher levels may have jurisdictional authority.

Outside of areas with specific land use/management controls such as protected areas, stakeholders at higher levels have no direct control, but may seek to influence local decisions through policies, laws and regulations that may or may not be respected, and sometimes through education campaigns. Failure to realistically acknowledge discrepancies and dynamics of influence between decision authorities and decision makers in practice frequently undermines the effectiveness of well-intentioned interventions.

In recent years, we have seen new mechanisms through which stakeholders at higher levels seek to influence grassroots decisions on land use/management and their implementation. In an environmental context, PES provide farmers with payments conditional on meeting agreed environmental objectives. In an agricultural context, contract outgrower schemes are a mechanism to support farmers and provide a guaranteed market conditional on meeting certain production standards. EU standards for pesticide residues in vegetable imports are one example.

Thus, an initiative to encourage better management of certain trade-offs needs to first look at where key decisions are made. It would then map the various influences on this decision-making process and their relative impact. From this analysis, it would identify promising 'leverage points' for intervention. In principle, a simulation model can represent this process. One example would be the model developed by SUSFANS, a multidisciplinary research programme that studies metrics, integrates modelling and develops foresight for European sustainable food and nutrition security. Such a model can help decision makers understand alternative approaches that might be used and the significance of specific drivers and interactions, but it is not intended to come up with specific prescriptions for action.

Of course, we should not assume the external context remains static. How particular trade-offs can be better managed over the medium to longer term will depend on macro-economic and political scenarios. When an exploratory scenario-building process has generated alternative future scenarios (as with the IIED Sentinel project), the approach to better management of certain trade-offs may vary greatly from one scenario to another.

The evolution of trade-offs under different scenarios can be examined in several ways. How might different management options play out? How would different stakeholders be affected? What might be good 'no regrets' options that deliver better trade-off management under most or all scenarios?

2.3.2 What is better trade-off management?

What is 'better management of trade-offs'? Through effective mitigation measures, for example, it may be possible to completely eliminate the trade-off from the perspective of different stakeholders. Fencing a protected area to stop crop damage by wildlife, for instance, may improve outcomes for conservationists and farmers. But such scenarios are rare, and may overlook secondary effects. In most cases, the name of the game is improving on the current situation. But making it better is not specific enough to inform policy. Better for whom? Better in what way? Better compared to what?

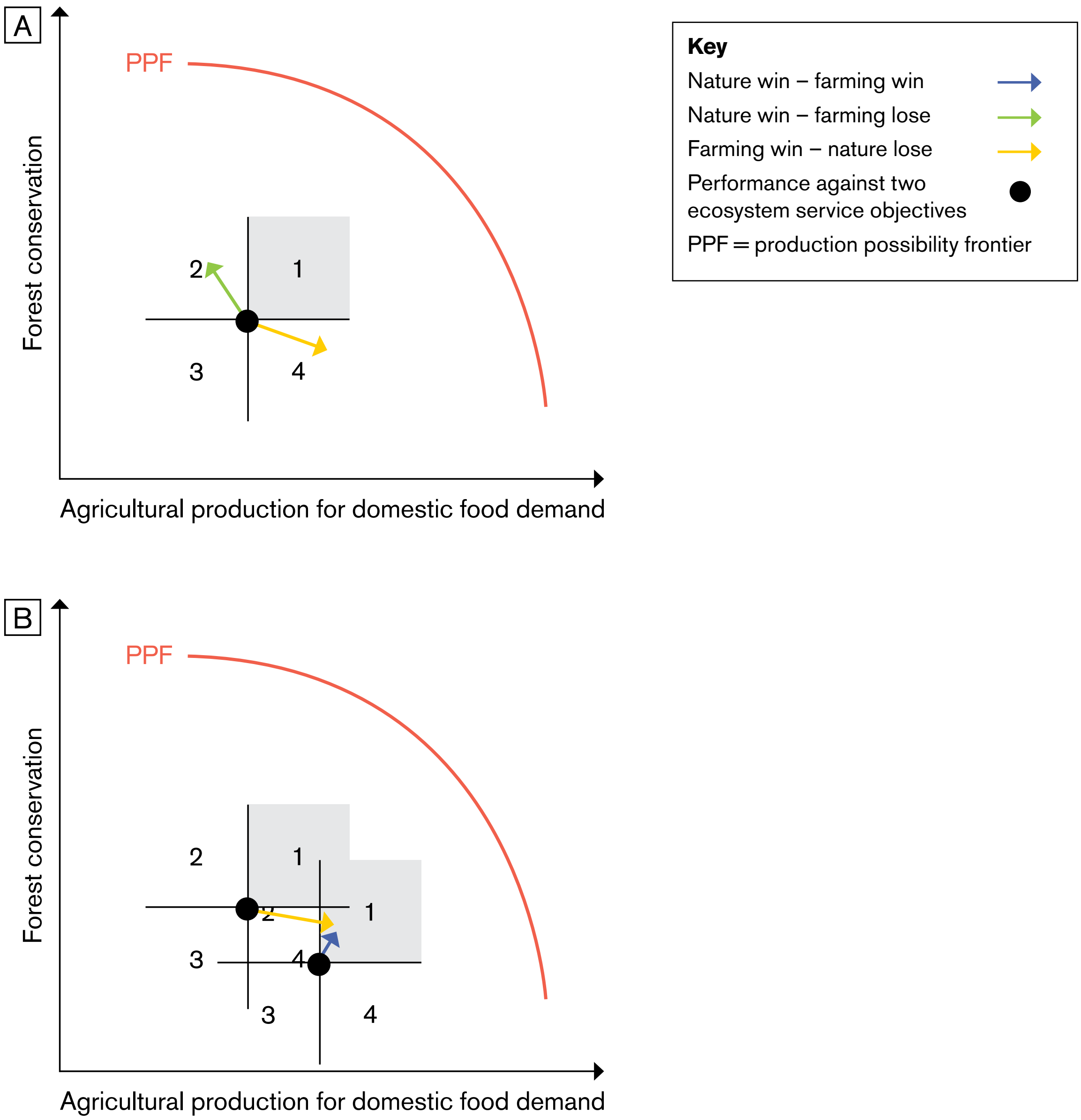
Better for whom?

One or more interventions may change the balance in how the system performs. Figure 9A shows how the balance shifts with respect to two ecosystem service objectives in four different trajectories represented by the four quadrants labelled by numbers. Interventions that lead to movement in quadrant 1 clearly represent better management since performance versus both objectives is improved – win–win (positive synergy). Likewise, if the trajectory is in quadrant 3, trade-off management clearly deteriorates – lose-lose (negative synergy).

In quadrants 2 and 4, there is increased performance towards one objective at the expense of the other. The yellow arrow illustrates a change that delivers a win for agriculture, but a loss for forest conservation. Meanwhile, the green arrow is a win for conservation and a loss for agriculture. With a single metric for the two objectives, it would be simple to determine whether trade-off management is improving. Growing two different crops on a farm, for example, allows us to work out the optimal balance in terms of maximum profit.

But when the two competing outcomes cannot be expressed in the same terms, and where different stakeholders attribute different values to the two outcomes, the question becomes 'better for whom'? This is a critical question in terms of aggregate outcomes for stakeholder groups as a whole, such as farmers and conservationists. It is also critical in terms of difference in outcomes within a particular group. For example, community-based land-use planning in Ethiopia generally delivers better trade-off management at the level of a whole community. But the outcome can be bad for poor people who can no longer farm the low-value land with fragile soils that they had previously farmed, and who have no other land (Hou-Jones et al. 2019).

Figure 9. Better management of forest conservation/agricultural production land use-related trade-offs



Notes: Quadrant 1 represents a move to better trade-off management. B also considers 'better' in relation to a new reference scenario rather than only a static baseline.

Better in what way?

This question relates back to the discussion on the breadth of framing the competing objectives of a trade-off. At one extreme, our objective could be halting the loss of biodiversity, while at the other end we could have a very specific objective such as saving one iconic species from extinction; this could be the goal of a species-focused nongovernmental organisation (NGO). From a management perspective, the former may be unrealistic, but the latter is perfectly possible. In the agricultural domain, we have increasing agricultural production at one extreme versus increasing the value of coffee production near the other, which may include coproduction (eg roasting) that adds value to the raw product. A coffee farmer at village level is particularly interested in the latter, while at the other end of the spectrum an economist in the planning ministry is interested in the contribution of agriculture to GDP.

In some ways, this question is a subsidiary to 'better for whom?' In other words, both the stakeholder group and their particular interest must be specified before exploring interventions to deliver better trade-off management from their perspective. Whether objectives are described in terms of quantities of services or their values to the different stakeholders can greatly affect the interpretation of an analysis; this must be explicitly considered and reasoned.

Better compared to what?

Without interventions that help better manage trade-offs, it is often believed the situation would stay the same. Therefore, the argument goes, the change in outcomes resulting from better trade-off management can be determined by comparing the situation after the improved management started with the situation before. This may work with sustainable land use/management or well-managed protected areas where their condition changes little over time. But the argument does not hold up where there is no effective control over land use/management, or where land use/management decisions adapt to changing conditions. In such systems, the absence of intervention may result in further degradation of the land and its resources or ongoing shifts in uses. In such cases, 'better' should logically be judged against a business as usual reference scenario that accounts for current dynamics. This would evaluate the outcomes versus what would have been the case in the absence of the project. Considering 'better' with respect to the reference scenario rather than a static baseline shifts the frame of reference. In Figure 9B, for example, the yellow arrow appears to be a win–lose outcome with reference to a static baseline. But it is actually a win–win outcome (colour-coded blue) when compared to a dynamic business as usual scenario that accounts for an ongoing shift towards greater agricultural production and less forest conservation.

2.3.2 Is the trade-off concept too complex to be useful?

Merely recognising trade-offs poses a challenge to the win–win rhetoric that continues to be associated with many initiatives at the interface of nature conservation and rural development. These range from ecotourism and PES to community-based conservation and agricultural intensification. McShane et al. (2011) point out the dangers of win–win rhetoric that cannot be delivered and argue for a fundamental change of mindset from win–win thinking to a much more realistic approach grounded in the analysis and better management of trade-offs.

There is now growing acceptance of this viewpoint. But do we really need to get to the bottom of what objectives are in a trade-off situation and why this is happening to figure out how to do it better? What's wrong with 'expert judgement'? With the limited understanding on trade-offs, however, expert judgement is often little more than gut feel and wishful thinking. This can be prone to bias by the particular mindset of the 'experts'. In effect, this is what happened in the hundreds of ICD projects of the 1990s and 2000s that mostly failed (McShane et al. 2011). Equally, if not more problematic, is the blindness to major trade-offs or deliberate denial that we referred to in Section 1 that occurs even when serious symptoms, such as policy disconnects, appear to be obvious. All of these are common problems in the world of agricultural and conservation policy and practice.

3

Review of trade-off analysis methods

Based on a comprehensive literature review, this section reviews six categories of methods for analysing trade-offs between agricultural production and nature conservation. While we analyse each category for strengths and weaknesses, we give particular attention to four stakeholder-centred methods. We believe such approaches could enable transformative change where other methods have all too often failed.

We have built on Klapwijk et al. (2014) to identify six main categories of trade-off analysis in agricultural systems: simulation methods, optimisation methods, multicriteria analysis, spatially explicit methods, integrated methods and stakeholder-centred, deliberative methods.

Using a combination of methods is increasingly common and inherent to integrated methods and participatory approaches. This is very much the case with the last category where we review four specific methodologies in more detail. We believe that such stakeholder-centred approaches could enable the kind of transformative change that is now being strongly advocated for the 2021-2030 strategy of the Convention on Biological Diversity, and in light of the recent global assessment of biodiversity and ecosystem services (IPBES 2019).

Table 2 lists examples of the different types of methods reviewed in the next subsection. This analysis includes our assessment of their strengths and weakness in relation to analysing agricultural production/nature conservation trade-offs.

Indicators

All methods of analysis of trade-offs between competing objectives share a common first step: defining objectives that will focus the analysis in terms of indicators. For example, a trade-off analysis that looks at biodiversity in terms of overall species richness will generate different results from one focused on one or more specific 'indicator species'. Likewise, on the agricultural side, staple crop production can be considered in at least three ways: in terms of tonnes of specific staple food crops; energy value (calories), which can be considered a common metric for all staple food crops; or financial value.

Table 2. List of trade-off analysis methods according to category

SIMULATION METHODS	
Quantifying trade-offs between future yield levels, food availability and forest and woodland conservation in Benin	Duku et al. (2018)
Agricultural intensification scenarios, household food availability and greenhouse gas emissions in Rwanda	Paul et al. (2018)
Addressing future trade-offs between biodiversity and cropland expansion to improve food security	Delzeit et al. (2017)
OPTIMISATION METHODS	
Reconciling agriculture, carbon and biodiversity in a savannah transformation frontier	Estes et al. (2016)
Exploring multi-scale trade-offs between nature conservation, agricultural profits and landscape quality	Groot et al. (2007)
Using optimisation methods to align food production and biodiversity conservation beyond land sharing and land sparing	Butsic and Kuemmerle (2015)
Assessing social-ecological trade-offs to advance ecosystem-based fisheries management	Voss et al. (2014)
MULTICRITERIA ANALYSIS	
Social multicriteria evaluation	Healy et al. (2015)
Multicriteria decision analysis in ecosystem service valuation	Saarikoski et al. (n.d.)
Trade-off analysis for participatory coastal zone decision making	Brown et al. (2001a)
Multicriteria tools for the trade-off analysis in rural planning between economic and environmental objectives	Van Huylenbroeck (1997)
Spatial multicriteria analysis for sustainability assessment: A new model for decision making	Boggia et al. (2018)
SPATIALLY EXPLICIT METHODS	
A review on trade-off analysis of ecosystem services for sustainable land-use management	Deng et al. (2016)
Ecosystem service bundles for analysing trade-offs in diverse landscapes	Raudsepp-Hearne et al. (2010)
Synergies, trade-offs and losses of ecosystem services in urban regions	Haase et al. (2012)
Ecosystem service trade-offs from supply to social demand: A landscape-scale spatial analysis	Castro et al. (2014)
INTEGRATED METHODS	
Integrated valuation of ecosystem services and trade-offs	Zulian and Palomo (n.d.); Nelson et al. (2009) https://naturalcapitalproject.stanford.edu/software/
ARIES	Bullock and Ding (2018); Balbi et al. (2015) http://aries.integratedmodelling.org/
Land Utilisation Capability Indicator	www.lucitools.org/
GLOBIO	www.globio.info/

STAKEHOLDER-CENTRED METHODS	
Trade-offs in ecosystem services and varying stakeholder preferences: Evaluating conflicts, obstacles and opportunities	King et al. (2015)
Understanding trade-offs in upscaling and integrating climate-smart agriculture and sustainable river basin management in Malawi	Schaafsma et al. (2018)
Trade-off analysis for participatory coastal zone decision making	Brown et al. (2001b)
Participatory decision making for sustainable development – the use of mediated modelling techniques	Antunes et al. (2006)
Learning about social-ecological trade-offs	Galafassi et al. (2017)

As the fundamental units of any analysis, indicators must be carefully selected to convey reliable and relevant information. This is key for the meaningful assessment of trade-offs and thus decision making. Indicators can be direct, single-factor measurements or indices based on several specific indicators (Kanter et al. 2018).

Indicators may be **internally defined**, that is, developed by local stakeholders, according to their own objectives and measurements. As such, they form part of a more 'contextual' and often participatory methodological approach. Being usually more meaningful to local actors, internally defined indicators often explore issues that matter locally in more depth, at the expense of statistical generalisability. **Externally defined** indicators, on the other hand, are typically constructed by non-local experts. They form part of a more 'non-contextual' methodology designed to achieve broad coverage and statistical generalisability of results (Schreckenberg et al. 2010).

3.1 Simulation methods

Several studies adopting a forward-looking perspective use agroeconomic and/or agroecological simulation methods to assess future trade-offs in quantitative terms. Typically, these studies compare a baseline and estimated future indicator values under different scenarios and/or assumptions. Results are presented either as tables displaying indicator values or (if spatial data are included) as colour-coded maps with different shades representing figures.

Duku et al. (2018) quantify future trade-offs between per capita food availability and forest and woodland conservation under different scenarios. Each scenario represents a combination of four variables: (i) climate change; (ii) population growth; (iii) cropland expansion with varying degrees of deforestation; and (iv) different degrees of yield gap closure. The focus is on Benin and three major food crops (maize, cassava and yam). Population growth affects required food availability, while climate change is assumed to affect agroecological conditions. The study simulates the levels of yield increases and/or cropland expansion required to at least maintain per capita food availability for the decades 2040s and 2090s compared to the baseline decade (2000s).

Paul et al. (2018) use a similar method to compare the *ex-ante* impacts and trade-offs of household food availability and greenhouse gas emissions under three different scenarios in Rwanda.

Delzeit et al. (2017) combine ecological and socioeconomic modelling with spatially explicit tools to investigate trade-offs between food security and biodiversity conservation on a global scale. The study uses a three-step approach: (i) simulating impacts of cropland expansion on food security in terms of production and prices; (ii) identifying areas agronomically suitable for potential expansion of cropland under specific climate scenario conditions; and (iii) using data on areas with high biodiversity and statistical analysis to identify hotspots with endemism richness where biodiversity could be most affected by cropland expansion.

Key strengths and opportunities

- Simulation methods may deliver concrete and comparable assessments of different management options.
- They can illustrate the effects of different scenarios on important indicators, which policymakers and planners can use to help understand trade-offs.

- In some situations, outputs may provide a relatively objective input to guide policy development, planning and other decision making.
- If combined with spatial data, simulation methods can map future trade-offs, identifying 'hot spots' in which actions may be needed.

Key weaknesses and limitations

- Lack of consistent and reliable data may constrain applicability of the tool.
- Social and political aspects of trade-offs are difficult to quantify and therefore typically not considered.
- Qualitative criteria are not considered.
- Simulation methods typically rely heavily on expert judgement and assumptions that may compromise the validity of outputs for the 'real world'.
- What is happening in the intermediate steps of the models essentially remains a 'black box', especially for non-experts who may, as a result, have little confidence in the results.
- If considered, wellbeing effects are typically assessed on an aggregate level. This hides any differential impacts on different social groups that may greatly concern stakeholders on the ground.
- Relying heavily on empirical data, the applicability of simulation methods is further compromised by lack of reliable data, notably in sub-Saharan Africa.

3.2 Optimisation methods

Another school of quantitative trade-off analysis relies on mathematical optimisation. Typically, these methods first develop a mathematical model using real or simulated data. In principle, all variables included are defined as either benefits or costs. A target variable is then chosen to be maximised (or minimised) under certain constraints using methods such as linear programming. Such optimisation methods usually yield a combination of variables that are quantitatively optimal in terms of cost-efficiency.

Estes et al. (2016) explore the potential for targeting agricultural expansion in ways that achieve quantitatively optimal trade-offs between competing economic and environmental objectives in Zambia. Their model seeks to find optimal land-use configurations that satisfy the production targets for several crops while minimising four costs: the total land area required; transportation; carbon released from land conversion; and impacts on biodiversity. The use of spatial data allows them to produce maps indicating which areas should be converted to cropland depending on the desire to maximise yields or minimise biodiversity loss. Linear programming (as presented by Estes et al. 2016) allows for varying weights for different objectives, for instance, according to stakeholder preferences. This feature enables users to explore the outcomes of various objective weightings that may inform discussions on participatory land-use planning.

Groot et al. (2007) present a similar methodology, exploring trade-offs between nature conservation, agricultural profits and landscape quality in the Netherlands. They combine agronomic, economic and environmental indicators with biodiversity and landscape quality indicators to develop a spatially explicit, land-use optimisation methodology based on geographic information systems (GIS). Using context-free and simulated data, Butsic and Kuemmerle (2015) present an optimisation framework that maximises agricultural production, while satisfying a set of other targets.

Other applications of optimisation methodologies in natural resource management use ecological-economic modelling (Voss et al. 2014).

Key strengths and opportunities

- Optimisation tools may deliver insights about the optimal allocation of scarce resources. When combined with spatial data (as done by Estes et al. 2016), they may illustrate what efficient, multi-purpose landscapes could look like.
- Linear programming can weigh multiple objectives differently. This, in turn, permits setting priorities according to stakeholder preferences, for instance.
- It may support discussions and inform decision making by local and regional policymakers, landowners and land managers.

Key weaknesses and limitations

- Each variable included is either considered as benefit or cost, typically computed directly from biophysical quantities, which may be an inappropriate representation of the plural values that characterise the real world.
- Yield 'optimal allocations' may not be meaningful to stakeholders on the ground. What some consider socially optimal may conflict with the interests and needs of others (eg vulnerable or marginalised groups).
- It is purely quantitative, which leaves relevant qualitative criteria underexplored. Notably, optimisation tools ignore differences in wealth/poverty, vulnerability and adaptive capacity.

3.3 Multicriteria analysis

Natural resource governance often presents situations with multiple and often competing objectives that stakeholder groups and/or decision makers value differently (Saarikoski et al. n.d.). Due to conflicting views and trade-offs, often no neutrally optimal solutions exist. For example, stakeholders may have different preferences related to use of a given landscape. Some may focus on food, timber, employment and business opportunities, while others are concerned about grazing areas, recreation, water regulation, species habitats or other ecosystem services. Some objectives may be mutually exclusive, while others may be complementary. In these cases, multicriteria analysis (MCA) methods can support decision making.

MCA evaluates different policy or management options based on selected criteria that capture relevant dimensions of decision making. These dimensions include, for example, economic, social and ecological aspects. A key characteristic is the combination of information about the impacts of different options on the criteria with subjective judgements about their relative importance (Saarikoski et al. n.d.).

A wide range of quite distinct approaches to MCA exist. While they differ in how they combine data, all MCA make explicit their options and contribution to different criteria. This requires judgement. In general, MCA techniques can be used to

- identify a single most preferred option
- rank different options
- select several options for detailed appraisal, or simply
- distinguish acceptable from unacceptable options (Department for Communities and Local Government 2009).

MCA was originally designed as a decision-support tool for single decision makers. Increasingly, it is embedded into participatory processes where multiple stakeholders and researchers perform criteria selection, weighting and aggregations steps in a collaborative manner (Healy et al. 2015).

Brown et al. (2001a, 2001b) present an approach to trade-off analysis for natural resource management combining MCA with participatory methods. Their holistic approach is designed for multiple-use, complex systems. In these systems, many users are apparently in conflict and there are interactions and feedbacks between various aspects of the ecosystem and economy (see also Section 2.6). This approach is but one way to conduct MCA. Other applications are closer to optimisation methods discussed above, relying on sophisticated mathematical and computational models (Van Huylenbroeck 1997), or integrating MCA with GIS to conduct spatial multicriteria analysis (Boggia et al. 2018).

Key strengths and opportunities

- It could include and compare different types of criteria (ecological, social, economic) in one structured and shared framework (Saarikoski et al. n.d.).
- It is possible to make trade-offs explicit, and rank different priorities and criteria systematically (Brown et al. 2001b).
- If done in a participatory manner, stakeholders can be explicit about their priorities, and can see how different options may affect criteria that matter to them (Brown et al. 2001b). This helps promote mutual understanding, improve social relations and trust, and enhance the legitimacy of the decisions taken.
- MCA methods can deal with complexity and incomplete or uncertain information (which is characteristic of many socio-ecological trade-offs) by allowing mixed sets of both qualitative and quantitative information to be included in impact matrices (Brown et al. 2001b; Saarikoski et al. n.d.)
- MCA methods are widely applied to land-use planning (Brown et al. 2001b).

Key weaknesses and limitations

- Designed for relatively small-scale settings with a limited number of relevant stakeholders, participatory MCA methods do not necessarily represent preferences across the entire population (Saarikoski et al. n.d.). It is therefore unclear how insights may be aggregated or scaled up to a higher level.
- Typically, participatory MCA methods are time-consuming and resource-intensive, and require a broad range of both social and technical skills.

3.4 Spatially explicit methods

A popular way (notably among ecologists) to assess ecosystem services trade-offs combines GIS-based spatial mapping of services with correlation and cluster analysis (Deng et al. 2016). Using spatially explicit data on the provision of various ecosystem services, Raudsepp-Hearne et al. (2010) calculate Pearson correlation coefficients. In this way, they identify interactions between pairs of ecosystem services. Similarly, they use cluster analysis to identify ecosystem services bundles, as well as trade-offs and synergies among services. This kind of analysis can be especially useful when the ecological aspects of an area are unknown (Deng et al. 2016).

But this type of analysis mostly assesses interactions across space and not across time, providing only a 'snapshot' of the given landscape. This is, at least in part, owed to limited data availability regarding the historic provision of ecosystem services. Haase et al. (2012) present an exception, studying interactions in the provision of five ecosystem services in the rural-urban region of Leipzig-Halle in Germany. They combine land-cover data and modelled ecosystem service indicators from 1990–2006 to examine pairwise interactions (synergies and trade-offs) across time and space. Results are presented in a map format with differently coloured grid cells indicating the type of change of two ecosystem services. For example, both systems could experience positive change, negative change, no change, a trade-off, etc.

Additionally, spatial methods tend to focus on the supply of ecosystem services, while the demand (use) side remains typically unexplored. One notable exception is Castro et al. (2014) who analyse spatial mismatches across landscape units and among services between three value-dimensions: biophysical, sociocultural and economic. The sociocultural and economic values were quantified based on survey results.[5] To assess trade-offs, they first quantified the biophysical supply of different ecosystem services and then explored the mismatch between sociocultural and economic values of those services. A trade-off, as defined in their study, emerged in two instances. First, the supply or value of one or multiple ecosystem services compromised another. Second, disconnects exist between the biophysical capacity of a particular landscape to provide services, and the sociocultural and economic values for one or multiple services, as stated by stakeholders. The authors examined the spatial correspondence between the three value-dimensions of ecosystem services across landscape units with Spearman's rank correlation.

Key strengths and opportunities

- Correlation and cluster analysis using spatially explicit data can be useful to identify ecosystem service bundles, as well as synergies and trade-offs among services. In other words, these tools allow detection of spatial congruence and divergence of ecosystem services (Deng et al. 2016).
- Spatially explicit tools can provide useful (visual) descriptions of coupled ecological and social subsystems. They enable identification of the type and location of ecosystem services perceived as important by the general public. This can be useful to identify priority areas for conservation or potential use-conflicts, for example (Castro et al. 2014).
- When combined with time-series data as in Haase et al. (2012), spatially explicit tools can provide integrative pictures regarding the temporal and spatial development of ecosystem services and natural resources in a region.
- The tools generate maps, an output generally well understood and used by planners and policymakers. Such maps allow for a relatively easy identification of synergies and trade-offs among ecosystem service bundles (Haase et al. 2012). They may stimulate discussion among stakeholders.

Key weaknesses and limitations

- The tools and their results tend to be descriptive rather than explanatory.
- The usefulness of spatially explicit tools rises and falls with data availability and quality, a concern particularly important in a sub-Saharan African context. In many cases, the tools can only present a 'snapshot' rather than an evolution over time.
- Correlation analysis is limited to pairwise assessments, which oversimplifies the complex interactions among services.
- Many ecosystem services (notably regulating) cannot be quantified directly, which requires use of proxy data that may not accurately represent the service under study. Also, the assumption of linearity between selected ecosystem services and the biophysical proxies may be problematic (Castro et al. 2014).
- Spatial mismatches may occur outside the study area that may decrease the validity of results. Some ecosystem services deliver benefits mainly on a local scale, such as recreation. Others deliver benefits, such as carbon storage, mainly on a global scale.
- Consideration and disaggregation of different stakeholders' preferences are difficult.

3.5 Integrated modelling methods

A variety of integrated modelling tools for analysing ecosystems and trade-offs has been developed in recent years. These help overcome some of the shortcomings of spatially explicit tools (Deng et al. 2016). Integrated models combine natural and human subsystems, and can often do spatially explicit modelling. Typically, such modelling tools allow the quantification, spatial mapping and sometimes economic valuation of ecosystem services and

[5] The share of respondents (a sample consisting of both residents and tourists) who considered the given service important for their wellbeing was used as a proxy for the sociocultural value of an ecosystem. The economic dimension was assessed using contingent valuation methods, establishing (through survey questionnaires) how much people are willing to pay to preserve services.

other aspects of ecosystems (Sharps et al. 2017). Both IPBES and the Ecosystems Knowledge Network offer lists and of a wide variety of modelling and policy support tools, including for integrated ecosystem modelling. Soesbergen (2016) provides a comprehensive review of land-use change models.

The following subsections describe specific integrated modelling methods, and then offer general comments on the strengths and weaknesses of all integrated models.

3.5.1 Integrated Valuation of Ecosystem Services and Trade-offs (InVEST)

One of the most promising tools for analysing trade-offs is the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST), a suite of open-source software models developed by the Natural Capital Project. InVEST covers a range of GIS-based spatial models that enable users to quantify and map changes in ecosystem services and biodiversity under different land use or management scenarios (Zulian and Palomo n.d.). The models use spatial input data (maps/GIS data and information in tables) to estimate how changes in ecosystems will affect the flow of benefits provided to people. Outputs are presented as maps with values that can be expressed in either biophysical terms, such as a quantity, or economic terms.

One of the main merits of InVEST is its versatility: it can be applied to different scales (site to national, and even multi-scale), types of ecosystems (terrestrial, marine, freshwater) and a broad range of regulating, provisioning and cultural ecosystem services (Ecosystems Knowledge Network n.d.).

InVEST can be run at different levels of complexity, and on spatial units of any resolution, which makes it sensitive to data availability and an understanding of system dynamics (Nelson et al. 2009). Underlying most models is an 'ecological production function' approach. This means that ecosystem services, biodiversity conservation and commodity production values are a function of environmental conditions and processes such as land characteristics and land use/land cover. Recent developments allow ecosystem service supply, as well as demand (for some services) to be incorporated (Ecosystems Knowledge Network n.d.; Zulian and Palomo n.d.).

The merits and limitations of the tool are best explored by reference to an example application. Nelson et al. (2009) apply InVEST to three plausible land-use/land-cover change scenarios in the Willamette Basin, Oregon. They assess impacts on hydrological services, soil conservation, carbon sequestration, biodiversity conservation and the value of several marketed commodities. They also explore spatial patterns of ecosystem service provision across the landscape, and highlight synergies and trade-offs between services, biodiversity conservation and returns to landowners. A 1990 land-use/land-cover map of the area served as base map. Three stakeholder-defined scenarios of land-use/land-cover changes from 1990 to 2050 were then assessed. Each scenario contained data in 30m x 30m grid cells and at 10-year intervals (from 2000 to 2050). Assumptions on population increase were included as well. Outputs included trends in normalised landscape-level ecosystem services, biodiversity conservation and market value of commodity production, as well as colour-coded maps illustrating the changes.

3.5.2 Artificial Intelligence for Ecosystem Services (ARIES)

Artificial Intelligence for Ecosystem Services (ARIES) is an open-source technology and online platform rather than a model itself. It enables users to select and run models from a library of ecosystem services models and spatial data sets at multiple scales. Using artificial intelligence, ARIES chooses ecological process models where appropriate, and turns to heuristics where process models do not exist or prove inadequate. That way, the most appropriate models can be assembled automatically in a modular fashion (Sharps et al. 2017; Bullock and Ding 2018).

Two main features distinguish ARIES. First, it focuses on beneficiaries, probabilistic analysis and spatio-temporal dynamics of flows and scale. Second, it can automatically assemble the most appropriate models, driven by context-specific data and machine-processed ecosystem services knowledge. With its modular structure, ARIES intends to avoid pitfalls of the common 'one model fits all' paradigm (Villa et al. 2014).

Sharps et al. (2017) note that, like InVEST, ARIES can be used to examine the spatial patterns of service provision across landscapes under a variety of future scenarios and can demonstrate trade-offs among multiple services. Its probabilistic approach can cope with data gaps, which makes it a good option in data-scarce areas.

Balbi et al. (2015) apply ARIES to model trade-offs among ecosystem services in agricultural production systems in a landscape in the Basque Country. They present a spatially explicit application that captures and quantifies trade-offs of selected ecosystem services such as crop yield, water supply and quality, climate regulation and air quality. The authors conclude that their model successfully quantifies synergies and trade-offs between various ecosystem services arising from climatic conditions and management practices.

3.5.3 Other integrated models

Bullock and Ding (2018) present a guide to selecting ecosystem service models for decision making.

The Land Utilisation Capability Indicator (LUCI) is an ecosystem services modelling tool that estimates the impacts of land use on various ecosystem services. As a key feature, LUCI can compare service provision of landscapes with estimates of potential capabilities. The information is used to identify areas where interventions or changes in land use might help improve ecosystem services. In addition, LUCI has a unique module for evaluating trade-offs that enables users to compare multiple services at once. Its output identifies areas in the landscape where trade-offs or co-benefits/synergies in ecosystem services exist. Users can vary the weightings of services to highlight or exclude services (Sharps et al. 2017).

GLOBIO assesses past, present and future impacts of human activities on biodiversity. Unlike tools such as InVEST or ARIES, GLOBIO focuses on biodiversity in terms of Mean Species Abundance and the extent of the landscape in question. It allows exploration of impacts of human-induced environmental drivers (such as land use, infrastructure or climate change) and effects of policy responses (such as climate change mitigation or protected areas) under different scenarios.

3.5.4 Key strengths and weaknesses of integrated models

Key strengths and opportunities

- Integrated modelling tools can model the interactions between human and ecological subsystems. Combining spatially explicit information (maps) with change over time (scenarios), they may provide detailed information on possible future landscapes, biodiversity and ecosystem services.
- They are based on state-of-the-art knowledge in ecology and conservation biology, giving them sound scientific foundations.
- A broad range of variables related to ecosystems, biodiversity and commodity production can be modelled simultaneously.
- InVEST allows output to be presented in both biophysical and economic terms.
- Complex relationships between land use, biodiversity and ecosystem services make it difficult to explore potential future impacts with high levels of certainty. But integrated modelling tools may still provide important insights to inform decision making (Soesbergen 2016).

Key weaknesses and limitations

- Data requirements are considerable, and their collection and preparation tend to be costly and demanding. Lack of consistent and reliable data across time and space may limit the usefulness of the tools discussed.
- Most tools focus on ecosystem service supply, while demand remains largely unexplored. Where and how much services are actually used is often not considered. InVEST and ARIES, however, have taken first steps to incorporate and map ecosystem service demand (Balbi et al. 2015; Sharps et al. 2017).
- Important social and cultural dimensions of ecosystem services and social aspects related to equity, power or access cannot be quantified and are therefore absent.
- Most tools can accommodate only a limited number of drivers. In reality, a complex set of drivers such as technology, markets, climate change, demographic pressures, and so on influence land-use change.
- Due to their complexity, integrated modelling tools usually require advanced skills in GIS, as well as significant expertise and capacities with respect to (spatial) statistical analysis (Soesbergen 2016).
- The multiple feedbacks mechanisms and non-linear relationships that characterise coupled human and ecological systems are difficult to model. Modelling tools usually neglect the dynamic nature of ecosystems and assume relationships between interventions and ecosystem services to be static.
- What is happening at the intermediate steps of the models essentially remains a 'black box', especially for non-experts who may, as a result, have little confidence in the results.

[Further references]

https://Appendix_8_Review_of_trade-off_and_risk_assessment_tools.pdf

3.6 Stakeholder-centred methods

The methods described in the previous five categories typically pay little attention to the social dimensions of trade-offs. These dimensions include the perspectives, needs and interests of different stakeholders and value they attribute to different outcomes. Notably, groups differ in terms of access to, and reliance on, benefits of ecosystem services: "[t]he degree to which any individual benefits from ecosystems depends on a complex range of mechanisms of access including social relationships, institutions, capabilities, rights and various capitals" (Daw et al. 2011, p. 373). In other words, how ecosystem processes affect individuals' wellbeing can only be understood by considering the perspectives and circumstances of these individuals themselves. This should logically be at the core of any trade-off analysis.

The following subsections describe five specific stakeholder-centred methods, and then offer general comments on the strengths and weaknesses of all such methods.

3.6.1 Trade-offs in ecosystem services and varying stakeholder preferences

King et al. (2015) propose an analytical framework that combines PPFs and indifference curves representing values (see Figure 6) and participatory multi-stakeholder process. This method is particularly interesting because it includes an analysis of barriers to change and enabling conditions. These can inform the planning and implementation of concrete actions such as trade-off management. It enables users to visualise biophysical aspects (the PPF) and different stakeholder preferences (the indifference curves) in one relatively simple diagram. In workshops, this may enable stakeholders to discuss how and where the 'diamond' could be moved, thereby exploring enabling conditions and barriers to change. As another strength, the framework can separate biophysical constraints and value-based constraints/barriers. Setting the biophysical boundaries from the beginning has the advantage of excluding potentially desirable, but biophysically unattainable, options.

As one major limitation of the framework, only trade-offs relating to two dimensions (or objectives) can meaningfully be analysed at the same time. This likely oversimplifies the complex interactions in socio-ecological systems. Also, the framework requires a relatively high level of technical/economic understanding. This may limit its meaningfulness to stakeholders in practice. Policymakers, planners and particularly community representatives may find it too theoretical and abstract to inform decision making. Nonetheless, the framework can contribute to a better integration and understanding of biophysical and value-based aspects of trade-offs by stimulating discussion and deliberation.

3.6.2 Trade-offs in integrating climate-smart agriculture and catchment management

Through a case study in Malawi, Schaafsma et al. (2018) assess the potential trade-offs between social, economic and environmental objectives when upscaling and integrating climate-smart agriculture (CSA) with integrated catchment management (ICM) at landscape level. In a workshop, government and NGO representatives and experts assessed trade-offs between the goals of ICM and CSA under four different scenarios of climatic and economic changes. The paper presents a novel combination of scenarios and a trade-off matrix exercise. In this way, it critically evaluates trade-offs between CSA and ICM and links them to policy challenges and interventions. The analysis shows that the compatibility of CSA and ICM policies depends on future climatic and economic developments. It identifies a higher prevalence of perceived trade-offs in futures with low economic growth and high climate change. CSA is expected to have limited effect on reducing inequalities. Investment in literacy and skills development is critical to ensure that marginalised groups benefit from CSA.

As in King et al. (2015), this method was used with technical experts in a workshop setting. It does not explicitly seek to reveal stakeholder preferences for different outcomes, but it does so implicitly. To that end, it asks technical experts from different sectors to individually (or subjectively) score expectations for a trade-off or synergy between different combinations of objectives under the four different scenarios. Inevitably, many agriculturalists are likely to have a stronger preference for agricultural outcomes than environmental outcomes such as water quality. This method also demonstrates clearly how trade-off analysis can be used with scenario analysis.

3.6.3 Trade-off analysis for marine protected area management

Brown et al. (2001a, 2001b) present a methodology that combines stakeholder participation, scenario development, social and environmental impact assessment, and multicriteria analysis. They apply their approach to the Buccoo Reef Marine Park (BRMP) in Tobago, a coastal area with pressures from fishery and tourism development. The BRMP represents a common-pool resource. Many different users are apparently in conflict, and different aspects of the ecosystem and economy have linkages and feedbacks. With the aim to enhance decision-making processes, the study uses a framework based on MCA but involves stakeholders at all stages.

After identifying and grouping relevant stakeholder groups, the study identifies social, economic and ecological criteria in a participatory manner. These criteria relate to the impacts of national and local economic growth and environmental management on community, social development and cultural integrity, as well as to environmental conservation. In a similar way, it identifies key drivers of change for the site and develops four scenarios based on development plans and knowledge of challenges. Key drivers that defined scenarios were the number of new tourism developments, population growth and waste treatment in the region.

The criteria are operationalised into quantitative or semi-quantitative sub-criteria, and the impacts of the four scenarios on each sub-criterion are estimated.[6] To compare the scenarios, they then standardise the data using multi-attribute rating techniques. In this way, values or scores for each criterion are indicated on a scale from 0 (least preferable) to 100 (most preferable). The scenario with the highest average value represents the most preferable scenarios.

Participants were then asked to allocate weights between the three priorities (economic growth, social issues, ecosystem health) and discuss the performance of different scenarios with varying weights. Stakeholders then discuss priorities for decision making, and see how they resulted in different impacts and development scenarios. Finally, they reach consensus-based decisions about future action by trading-off the priorities for economic growth, social issues and ecosystem health.

As Brown et al. (2001a, 2001b) point out, stakeholder involvement goes beyond making explicit the diverse perceptions and values of different actors. Stakeholders can also see potential outcomes and impacts of different scenarios and policy priorities. In that way, they can be informed about the trade-offs inherent in decisions on resources and management. This creates opportunities for decision making and management based on consensus rather than conflict.

3.6.4 Participatory decision making for sustainable development

Antunes et al. (2006) tested a similar approach in the Ria Formosa coastal wetlands in southern Portugal. This area is subject to strong pressures from tourism, fishing, urban development, industry and pollution, which generate several environmental, social and economic conflicts. Their study presents a methodology for participatory decision making for sustainable development that combines mediated modelling with MCA. Mediated modelling "is the process whereby stakeholders […] collaborate together in the development of a simulation model about a specific problem, usually in a series of modelling workshops supported by a facilitator." (p. 46)

The approach presented by Antunes et al. (2006) resembles the one adopted by Brown et al. (2001a). First, relevant stakeholders were identified and invited to join the process. Then, in a series of workshops, stakeholders formulated the problem, and developed a system dynamics model with the support of a facilitator. The stakeholders also identified relevant evaluation criteria that were integrated into the model structure. Experts then refined the model, adding relevant data and conducting consistency and validation procedures. Scenarios were developed in a participatory manner. These were used as inputs for simulation runs of the model to obtain several different possible trajectories. The scenarios included different options for funding sources and budget. They also included options for policy decisions such as accessibility development, licensing of new activities, wastewater treatment, dredging and restoration of the barrier islands. Stakeholders then analysed the different outcomes and resulting trade-offs among objectives using MCA.

This approach combines the advantages of deliberative procedures, while providing a framework to apply a formal appraisal technique. Additionally, it allows for consideration of multiple perspectives and scales, uncertainty, time and space – all of which are essential in most sustainability decisions.

3.6.5 Learning about socio-ecological trade-offs

Galafassi et al. (2017) focus on knowledge coproduction and social learning as a practice that may contribute to tackling trade-offs in socio-ecological systems. Using a coastal area in Kenya as a case study, they integrate methods derived from systems thinking, dialogue, participatory modelling, ecological modelling, serious gaming and scenario analysis.

At the heart of their approach lies the conviction that dealing with trade-offs requires learning to identify and understand trade-offs. Knowledge coproduction processes, involving multiple actors and stakeholders, they argue, can be a strategy for developing sensitivity to trade-offs and learning how to put these insights into practice. Their coproduction process was composed of two workshops with a six-month interval between them. It was applied to a coastal fishery near the rapidly urbanising port city and tourism hub of Mombasa, Kenya. The system is characterised by many vulnerable stakeholders with limited alternative occupations and a heavily exploited ecosystem.

After analysing primary stakeholders, the process invited secondary stakeholders (local experts, NGO representatives, public administrators, policymakers, community leaders) to join. The first workshop explored trade-offs between broad systems objectives (such as food security and ecological status) and the wellbeing of various primary stakeholders (fisherfolk and traders), which is directly influenced by ecosystems. A scientific

[6] Not all criteria are represented in quantitative terms. The social criteria, in particular, can use qualitative data in ways that are meaningful and understandable to stakeholder groups.

group supported participants in mapping causal relationships on the broader system and how they might influence the wellbeing of primary stakeholders. Participants also discussed how short- and long-term impacts and drivers, such as political unrest or climate change, would affect the possible future pathways of development.

Between the first and second workshop, the scientific team created two artefacts to synthesise discussions to date with regard to socio-ecological dynamics: a flexible and simplified toy model and four storyline scenarios. The toy model, created in Microsoft Excel, brought together insights from wellbeing research, data from ecological modelling (based on the Ecopath/Ecosim software) and the systemic understanding created in workshop 1 (Figure 10). The model dynamically represented how changes in larger drivers such as population, economy, governance or tourism affected wellbeing of the five primary stakeholder groups. The model also provided dynamic outputs of system variables that corresponded to possible management objectives of the fishery such as ecological status, profitability or food security.

Scientist groups wrote the four storylines with support of local experts and a graphic artist did the illustration. Each storyline has a different policy emphasis (drivers), intermediate variables and potential outcome. The four policy emphases were a) conservation; b) welfare-based, populism; c) development and tourism; and d) offshore fisheries.

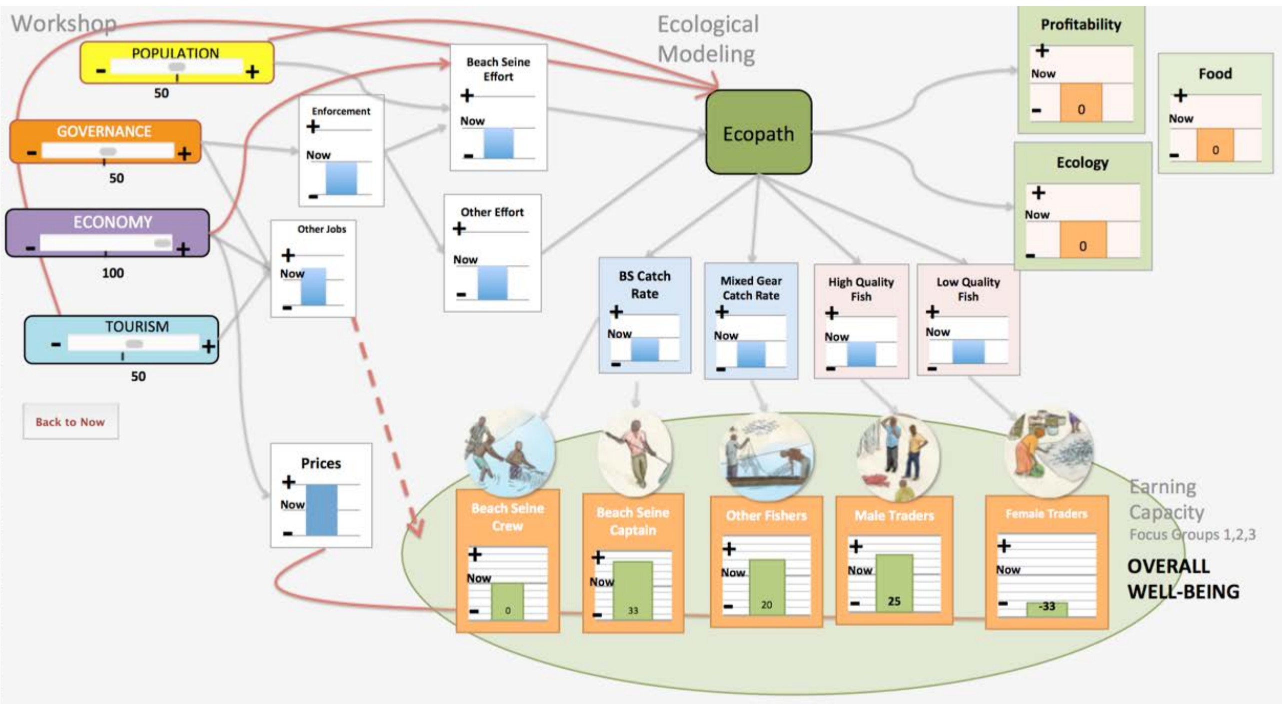
3.6.6 Key strengths and weaknesses of stakeholder-centred methods

All these methods can be described as stakeholder-centred. But we reserve the term ‘participatory’ for those methods where representatives of key stakeholder groups are directly engaged in the process. This has been the case with methods described in 3.6.3, 3.6.4 and 3.6.5. Methods noted in 3.6.1 and 3.6.2 have not been used with the stakeholders themselves. Rather, they engage experts who are assumed to understand and provide different stakeholder interests and perspectives.

Key strengths and opportunities

- When trade-off analysis aims to support planning or decision making, engaging with key stakeholders has many benefits. These include increasing opportunities for social learning, trust-building, ownership and consensus-building, legitimacy and success of implementation (Turkelboom et al. 2018).
- Local stakeholders often hold important informal and tacit information about the local (socioeconomic and ecological) context that is hidden or inaccessible to outsiders (Turkelboom et al. 2018).

Figure 10. Toy model for changes in economic, social and biophysical criteria



Source: Galafassi et al. (2017).

- Considering local knowledge and promoting dialogue may lead to creative problem-solving situations in which groups come up with novel interventions that otherwise would not have been identified (Galafassi et al. 2017).
- Stakeholder participation allows embracing the full complexity of the situation rather than dissecting the trade-offs into oversimplified subsystems (Turkelboom et al. 2018).

Key weaknesses and limitations

- Stakeholders may have different motivations, needs, uses or values even within groups (Turkelboom et al. 2018).
- The preferences of stakeholders are not necessarily compatible with what is ecologically desirable. For example, poor people might focus on short-term material benefits at the expense of ecosystem health.
- Some stakeholders may be unaware of the importance of some ecosystem functions and services. Turkelboom et al. (2018) found that stakeholders often express trade-offs between provisioning and cultural ecosystem services. But the literature focuses on trade-offs between provisioning and regulating ecosystem services, which affect human wellbeing less directly.
- Stakeholder-centred approaches tend to be time-consuming, costly and require a broad set of social skills, particularly the truly participatory methods.

Turkelboom et al. 2018 provide strong evidence of the value of adopting a stakeholder-centred approach to analysis of trade-offs and synergies. They characterise 24 case studies of trade-off analysis and management. To that end, they use the analytical framework presented in Figure 8 to analyse what type of stakeholder interests and influence informed the process. They conclude:

"The proposed ES trade-off framework [Figure 8] puts stakeholders and their ecosystem use (ie demand side in ES terminology) at the centre of the assessment. This is based on the premise that trade-offs not only originate primarily from stakeholders' values, needs and uses of ecosystems, but also that solutions can only be achieved via the involvement of stakeholders. The usefulness of this 'social' entry-point for analysing ES trade-offs seemed to be confirmed by the case studies, as these questions enabled the case respondents to quickly get a grip on the complexity at hand. Additionally, the fact that the drivers of ecosystem use and change are primarily dominated by socio-economic-institutional factors, confirms the importance of this social entry-point. Therefore, we argue that better understanding of stakeholders and their ecosystem use should always be at the core of any trade-off analysis."

4

Conclusions

This report attempts to explain the key concepts of trade-offs and synergies, including the concept of better trade-off management. Better for whom? Better in what way? Better compared to what?

We reviewed a range of different trade-off analysis methods in Section 3, which touched on measures that are commonly used to manage trade-offs more effectively and more equitably. Our review suggests that the combination of analytical and participatory methods offers a promising way forward. But trade-offs can be politically sensitive since no one in power wants to admit a downside to their policy. Therefore, even with obvious ways to improve management of certain trade-offs or a set of trade-offs, many barriers to implementation may exist. Conversely, important enabling conditions could also exist. This is an important topic addressed in other IIED publications (Hou-Jones et al. 2019).

In many developing countries (and some developed countries), there is still little acknowledgement and understanding of the major trade-offs between agricultural production and nature conservation. But a continuation of business as usual spells disaster for fragile ecosystems, many smallholder farmers and others – rural and urban – dependent on ecosystem services. The recent global assessment of biodiversity and ecosystem services by IPBES has forcefully made the point that avoiding this disaster – 'bending the curve' – will require transformative change (IPBES 2019). This means a change in the power balance to enable outcomes to better and more fairly reflect the diversity of stakeholder interests and the interests of future generations. Better understanding and management of trade-offs lies at the heart of this challenge.

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Boosting agricultural production to meet the food demands of growing and more prosperous populations increasingly comes with a cost to the ecosystems upon which human life more broadly depends. Yet many developing countries (and some developed countries) do not acknowledge or understand these trade-offs. This is becoming one of the greatest challenges in achieving sustainable land use and the Sustainable Development Goals. Greater understanding of trade-offs, and how to analyse and better manage them, is needed. This paper summarises key concepts relating to trade-offs and synergies, including trade-off analysis and management, to make approaches and methods more accessible.

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