Chapter 3
Ecosystem Services

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Abstract Ecosystem services are increasingly incorporated into explicit policy targets and can be an effective tool for informing decisions about the use and management of the planet's resources, especially when trade-offs and synergies need to be taken into account. The challenge is to find meaningful and robust indicators to quantify ecosystem services, measure changes in demand and supply and predict future direction. This chapter addresses the basic requirements for

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collecting such observations and data on ecosystem services. Biodiversity regulates the ability of the ecosystem to supply ecosystem services, can be directly harvested to meet people's material needs, and are valued by societies for its non-tangible contributions to well-being. Societies are deeply embedded within ecosystems, depending on and influencing the ecosystem services they produce. The different types of ecosystem services (provisioning, regulating, and cultural), and their different components (supply, delivery, contribution to well-being, and value) can be monitored at global to local scales. Different data sources are best suited to account for different components of ecosystem services and spatial scales and include:

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census data at national scales, remote sensing, field-based estimations, community monitoring, and models. Data availability, advantages and limitations of each are discussed. Progress towards monitoring different types of services and gaps are explored. Ways of exploring synergies and trade-offs among services and stakeholders, using scenarios to predict future ecosystem services, and including stakeholders in monitoring ecosystem services are discussed. The need of a network for monitoring ecosystem services to synergise efforts is stressed. Monitoring ecosystem services is vital for informing policy (or decision making) to protect human well-being and the natural systems upon which it relies at different scales. Using this information in decision making across all scales will be central to our endeavours to transform to more sustainable and equitable futures.

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3.1 Introduction

Ecosystem services are the benefits people obtain from ecosystems and are co-produced by the interactions between ecosystems and societies. Since the Millennium Ecosystem Assessment (MA 2005) governments have embedded ecosystem services and natural capital in explicit policy targets. Globally, for example, the Parties to the Convention on Biological Diversity (CBD; www.cbd.int) have committed to 'enhancing the benefits to all from biodiversity and ecosystem services'. The CBD Aichi Target 14 is of particular relevance to ecosystem services: '*By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable*'. Beyond the conservation sector, interest in ecosystem services is increasingly aimed at the development of policies at national and global scales (Griggs et al. 2013). Regionally, the European Union Biodiversity Strategy to 2020, for example, aimed to halt the degradation of ecosystem services, and to map and assess the state of ecosystems and their services in their national territories by 2014 (Maes et al. 2016). This study also aimed to assess the economic value of such services, and promote the integration of these values into accounting and reporting systems at EU and national levels by 2020. Non-EU governments of nations such as Australia, Canada and Mexico are also incorporating ecosystem services and natural capital into national accounts.

At a national and sub-national scale, ecosystem services can be an effective tool for informing decisions about the use and management of the planet's resources, especially when trade-offs and synergies need to be taken into account. Without this information, decisions that determine the fate of terrestrial, coastal, and marine systems and the benefits they provide, are made in the dark, with little understanding of the ecosystem services outcomes (benefits and costs) of any given

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decision or its consequences for the different stakeholders depending on these services.

While many observations and datasets are available to measure progress towards global, regional, and national goals for ecosystem services, and to ensure effective decision-making for sustainable human use of the planet's resources (Egoh et al. 2012), their coverage is patchy, incomplete and inconsistent. The challenge is to find meaningful and robust indicators to quantify ecosystem services, measure changes in demand and supply and predict future scenarios. At present, most governments are not effectively measuring or monitoring ecosystem services. This chapter addresses the basic requirements for collecting information on ecosystem services.

3.2 Biodiversity and Ecosystem Services

Biodiversity is related to ecosystem services through a variety of mechanisms operating at different spatial scales (Fig. 3.1) (Mace et al. 2012). Biodiversity regulates the state, the rates and in many cases the stability of ecosystem processes fundamental to most ecosystem services (Cardinale et al. 2012). Components of biodiversity are also directly harvested to meet people's material needs, and are also valued by societies for their non-tangible contributions to well-being, for example to psychological health, people's identity and the asset it can be for future generations. Fundamentally, biodiversity provides the evolutionary building blocks of

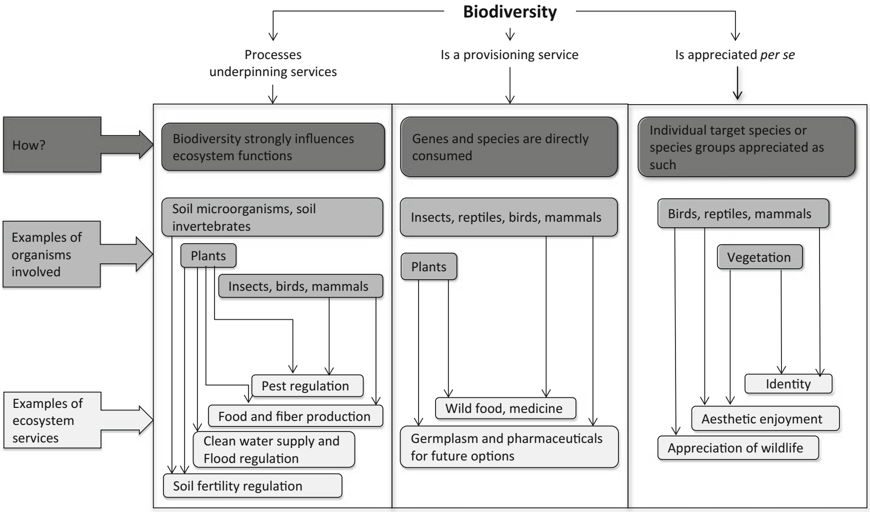

Fig. 3.1 Biodiversity is linked to ecosystem services in three different ways: (*i*) as a regulator of the ecosystem functions that lead to the supply of provisioning, regulating or supporting services, (*ii*) as a provisioning service, (*iii*) as something that is appreciated in itself rather than for the benefits obtained from it. Selected examples are used to illustrate these linkages. *Source* Modified from Mace et al. (2012), Reyers et al. (2012)

life on Earth and therefore provides important adaptive capacity through its continued ability to support desired ecosystem services and processes in the face of often rapidly changing selective pressures (Mace et al. 2014).

Due to the complexity of the links between biodiversity and ecosystem services, as well as the important role played by other non-biophysical inputs into the goods and benefits we obtain from ecosystems (Díaz et al. 2015), monitoring biodiversity alone is not sufficient to understand the status and trends of the services it provides. In fact, monitoring annual changes in the state of ecosystems and determining trends in ecosystem services, can contribute to our understanding of changes in biodiversity and inform on the underlying dynamics of the complex interactions between societies and ecosystems.

3.3 Key Ecosystem Service Concepts

Societies are embedded within ecosystems, depending on and influencing the ecosystem services they produce. The characteristics of ecosystems, such as species composition, tree cover or growth conditions, modulate the type and magnitude of ecosystem services that can flow to societies. Management regimes, technologies, as well as tenure and access arrangements modulate the ways by which ecosystem services are produced and benefit societies. In other words, ecosystem services result from the interactions between ecosystems and societies, which together form a social-ecological system.

Four types of ecosystem services can be distinguished (MA 2005), though we focus only on three of them in this chapter. *Provisioning services* are the goods that can be extracted and consumed from ecosystems and are often valued in markets: for example, water, food, wood and biofuels. *Regulating services* are the benefits derived from ecosystem processes that modulate the conditions which we experience: such as the regulation of climate, soil fertility or floods. They seldom have markets, and must be valued indirectly. *Cultural services* are the real but not physical ('intangible') benefits that emerge from interactions between humans and ecosystems (Chan et al. 2012), for instance employment, sense of identity, spiritual value, aesthetic value and cognitive development. Some cultural services, such as recreation, do have markets, while others do not. The fourth category, which we do not elaborate on, is *supporting services*, the fundamental ecosystem processes such as photosynthesis, nutrient cycling and evolution, which permit the delivery of the first three categories, and thus find societal benefit through them.

In order to fully understand ecosystem services, we need to measure and monitor four different components: supply, delivery, contribution to well-being, and value (Tallis et al. 2012). Table 3.1 provides a detailed examination of each of these components across different categories of ecosystem services. The table includes a definition and some popular metrics or indicators used in the quantification and assessment of services. This list is not exhaustive since it does not cover all services or potential indicators, but rather presents a range of different types of services that have been found to be very relevant to societies.

Table 3.1 Examples of provisioning, regulating and cultural ecosystem services, including descriptions, drivers and potential indicators for each of the four components of the ecosystem service (supply, delivery, contribution to well-being and value)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Provisioning						
Crops	All cultivated edible plant products (e.g. maize, wheat, olive, apple)	Biophysical (e.g. climatic, soil), crop choice (e.g. species, genetic characteristics, amount of seed/plant), management (e.g. fertilizers, irrigation, labour and machinery) and societal (e.g. agricultural policies, crop market price, land tenure, agricultural institutional arrangements)	Potential amount of important crops	Total production of all commercial crops (t), caloric or micronutrient content of all commercial crops (g)	% caloric or micronutrient intake contributed by crops, % income or number of jobs contributed by crops	Market value of all commercial crops (US$)
Fodder	All vegetable tissue and grains grown in rangelands and pastures as well as in agricultural fields to feed livestock	Similar to that of crops	Amount of biomass available for fodder (pasture or forage) (t)	Total production of fodder (t), amount of protein, number of animals grazed	% contribution of fodder (to support cattle) to protein consumed	Market value of fodder (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Livestock	Includes beef, pork, goat and other species grown to obtain meat, milk and skin	Biophysical (climatic, feed, fodder), livestock choice (e.g. species, genetic characteristics), management (e.g. number of animals, target age, type of enclosure) and societal (e.g. demand, livestock policies, livestock grower culture, land tenure of feeding grounds)		Total production of meat, milk and other livestock products (t, m^3), protein content of all livestock products	% protein consumption contributed by livestock, % population reliant on livestock for income or food, % income or jobs contributed by livestock	Market value of all livestock products (US$)
Aquaculture	All fish and invertebrate species cultivated in continental, coastal or marine water bodies	Biophysical (e.g. water temperature), species choice (e.g. taxonomic identity), management (e.g. target harvest weight, feed, use of antibiotics), and societal (e.g. legislation, market price, access to suitable areas)		Total harvest (t), total protein content of landings (kg), total subsistence aquaculture production (t)	% protein consumption contributed by aquaculture, % population reliant on aquaculture for food or income, % income contributed by fishing, % jobs contributed by fishing	Market value of all aquaculture products (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Fisheries	Includes aquatic invertebrate and fish species harvested from continental, coastal or marine water bodies	Biophysical (e.g. biomass and abundance of target species), management (e.g. vessel type, fishing devices, fishing intensity), and societal (e.g. demand, institutional arrangements)	Biomass or abundance of (commercially) important species	Volume of weight of landings-harvest (t), protein content of landings (kg), total subsistence fish catch (t)	% protein consumption contributed by fisheries, % population reliant on fisheries for food or income, % income contributed by fishing, % jobs contributed by fishing	Market value of all fisheries products (US$)
Wood	Includes tree trunks (normally with diameter at breast height larger than 30 cm) harvested from natural forests, plantations, or some agro-ecosystems	Biophysical (e.g. biomass and abundance of target species, land cover), management (e.g. machinery, target size, forest management), and societal (e.g. demand, market price, institutional arrangements for forest management, legal access to forests)	Amount of woody biomass generated per year (m^3/y)	Volume of harvested wood (m^3)	% income contributed by wood harvesting, % jobs contributed by wood harvesting, % house constructed with wood	Market value of harvested wood (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Biofuels	Refers to fuels in which energy is derived from photosynthesis including woody materials, plant carbohydrates, vegetable oils and crop seeds	Biophysical conditions (e.g. climate, soil), biofuel choice (e.g. species), management (e.g. harvested from wild or cultivated), and societal factors (e.g. biofuel policies, demand, market price)		Weight or volume of biofuel, fuelwood or charcoal produced (kg, m^3), amount of energy produced (kJ)	Amount of fossil fuel use avoided (t), total GHG emissions avoided (t), % income or jobs contributed by biofuel production, % energy consumptions contributed by biofuels	Market value of biofuels (US$)
Harvested wild goods (including game meat, construction or weaving materials, medicinal plants)	All goods harvested from ecosystems, including fisheries, wild vertebrates consumed for food, wood, poles and other uses (e.g. honey, medicinal plants)	Biophysical (e.g. biomass of abundance of target species), biofuel choice (e.g. species), management (e.g. hunting intensity, technology), and societal (e.g. legal access to game meat, demand, cultural preferences)	Biomass or abundance of all potentially harvestable wild food products	Amount of wild products harvested (t), Amount of game meat harvested (t), protein content of game meat (kg)	% population reliant on harvested wild products for food, income and other uses, % protein consumption contributed by game meat, % population reliant on fisheries for food or income	Market value of harvested wild products (US$), market value of game meat (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Water	Volume of surface water flow and the amount of water stored in groundwater for domestic, industrial and agricultural use	Biophysical (e.g. climatic, land cover) and societal (e.g. location of user, demand per type of user)	Volume of superficial or ground-water available (m^3)	Volume of superficial or ground-water withdrawn per user (agricultural production, domestic and industrial)	% of population or water user or economic sector with available water above water needs	Market value of water to agriculture, tourism, industry, etc. (US$), marginal contribution of irrigation to crop market value
Hydropower generation	Energy produced in dams derived from water produced by the watershed	Biophysical (water yield, timing of water release) and societal (e.g. water consumption, dam location, energy production per dam, energy policies)	Potential energy produced by hydropower (kW)	Hydropower energy produced (kW)	% energy needs contributed by wind hydropower, % GHG emissions reduced by production of hydropower	Market value of hydropower (US $), avoided water replacement costs (US$)
Regulating						
Climate regulation (Carbon stocks and uptake)	Mediated by carbon stored over the long-term in vegetation that is not released and carbon taken from the atmosphere via photosynthesis	Biophysical (climatic, soil, land cover)	Amount of emissions avoided by maintaining carbon stocks (t of C), amount of carbon taken by vegetation from the atmosphere (t of C)	Amount of emissions avoided by maintaining carbon stocks (t of C), amount of carbon taken by vegetation from the atmosphere (t of C)	Reduced negative impacts (from floods, wind, drought) on society (% population, % more vulnerable area or people) from climate regulation	Market value of maintained carbon stocks and carbon uptake (US$), avoided costs from climate change (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Regulation of marine and fresh water quality	Can be impaired by nutrients (phosphorus and nitrogen), sediment, dissolved organic carbon content, temperature, pH, and concentrations of pathogens or toxic compounds. The abiotic and biotic components of ecosystems can contribute to mitigate such contaminants	Biophysical (e.g. land and sea bottom cover, aquatic biodiversity), management (e.g. fertilization or sewage upstream, water treatment) and societal (e.g. sanitation regulations, water quality standards per type of use)	Mass of nutrients, organic matter, sediments, or toxic organisms or compounds removed (kg), changes in temperature, pH	Water conditions in relation to standards for different water users at or above withdrawal point	Avoided disease by water treatment	Avoided water treatment costs (US$); cost of wetland construction for nutrient removal (US$)
Regulation of soil fertility	Refers to the physical, chemical, and biological characteristics of soils that underpin the amount of nutrients available for agriculture, fodder, forestry and biofuel production	Biophysical (e.g. geologic, topographic, soil, land cover) and management (e.g. rotation cycles, soil preparation, fertilizer, irrigation)	Soil nutrient availability (mg)	Marginal contribution of soils to agricultural, forestry and biofuel production	Marginal contribution of soils to food, wood or biofuel consumption	Marginal contribution of soils to economic value of agricultural, forestry and biofuel production (US$)

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Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Regulation of soil erosion	Mediated by the characteristics of a landscape, land cover and soils that regulate the amount of soil loss driven by rain and reduce the amount of sediments accumulated in hydraulic infrastructure	Biophysical (e.g. rain intensity, topographic, soil, land cover), management (e.g. soil preparation, fertilizer, irrigation) and societal (e.g. characteristics of dams and human made water canals)	Mass of retained soils (kg)	Mass of soils retained to support productive activities or to avoid dams, reservoirs and water canals; Mass of soils retained to prevent soil sedimentation in residential or industrial areas (kg)	Reduced negative impacts of soil loss and of sediment flows to different stakeholders	Marginal contribution of soils retained to productive activities and avoided costs of dredging (US$)
Flood regulation	A function of the vegetation and soils that increase infiltration rates and thus reduce the amount of surface water flow that contributes to floods	Biophysical (e.g. climate, soil, aquatic vegetation), management (e.g. hydraulic infrastructure) and societal (e.g. people's location, infrastructure characteristics)	Flood volume regulated by vegetation and soils (m^3)	Area of avoided flood damage due to regulation by vegetation and soils (ha)	Number of people protected from flood by regulation from vegetation and soils	Avoided economic loss by flood regulation from vegetation and soils (US$)

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Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Coastal protection	Refers to the idea that coastal habitats can serve as natural shields against waves, storms and wind that may lead to infrastructure loss, flooding and erosion	Biophysical (e.g. climatic, wave, land and sea bottom cover) and societal (e.g. people's location, infrastructure characteristics)		Area of avoided infrastructure loss, flood and erosion (ha)	Number of people protected from infrastructure loss, flooding and erosion from coastal protection	Avoided economic loss by coastal protection (US$)
Regulation of commercially important marine species populations	Mangroves, coral reefs and sea grass provide nursery grounds and refuge for many recreationally and commercially valuable marine species	Biophysical (e.g. land and sea bottom cover, dependence of target species on these habitats) conditions that contribute to marginal increased fisheries yield		Marginal contributions of coastal habitats (e.g. mangroves) to fisheries production		Marginal contribution of coastal habitats (e.g. mangroves) to market value of fisheries production (US$)
Pollination	Bees, bats, birds and other animals pollinate fruit and seed crops, contributing to increased yield, quality, and stability	Biophysical (e.g. pollinator identities and abundances) and management (e.g. types and density of crops, land use and land cover type around agricultural fields)	Pollinator abundances and pollination rates	Marginal contribution of pollinators to crop production	Marginal contribution of pollinators to food or biofuel production	Marginal contribution of pollination to crop market value (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Pest control	Insects, bats and birds regulate the abundances of agricultural pests	Biophysical (e.g. pest identity and abundance, trophic interactions among insects, birds and bats) and management (e.g. crop type, landscape configuration)	Abundances of pests and their natural enemies	Regulation of pests by their natural enemies	Marginal contribution of pest control to food or biofuel production	Marginal contribution of pest control to crop market value (US$)
Cultural						
All non-tangible benefits	Includes a large array of non-tangible benefits from ecosystems that include heritage (cultural or religious), inspiration (spiritual or artistic), sense of place, identity, social relations, and education, among others	A suite of biophysical (e.g. biodiversity, topography), management (e.g. dominant management activities) and societal (e.g. culture) conditions	Non-material benefits from ecosystems and the interactions among them			

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Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Aesthetic views	Refers to various landscape features that convey aesthetic characteristics that are appreciated and enjoyed	Biophysical (e.g. topography), management (e.g. land use and land cover type), and societal (e.g. access roads or boating areas, number of visitors, cultural preferences)	Area that provides aesthetic views	Area that is enjoyed by visitors or local inhabitants for its aesthetic views, number of visitors	Marginal contributions to income or well-being of visitors and to local inhabitants derived from aesthetic views	Economic revenues derived from visits to aesthetic areas or marginal contribution to real estate prices by aesthetic characteristics (US$)
Nature-based tourism	A function of multiple characteristics of landscapes, water bodies and biodiversity that determine whether areas are attractive to tourists	Biophysical (e.g. bird richness, characteristics of water bodies), management (e.g. land use and land cover type), and societal (e.g. protection status, facilities to support visits, distance from cities)	Area that is suitable for nature-based tourisms	Area where nature-based tourism occurs, number of visitors	Marginal contributions to income or well-being of visitors and local inhabitants derived from nature-based tourism	Economic revenues derived from or costs associated with undertaking nature-based tourism (US$)

(continued)

Table 3.1 (continued)

Service	Description	Drivers	Ecosystem service component			
			Supply	Delivery	Contributions to well-being	Economic value
Recreation	Includes hiking, angling, cycling, birding, swimming, diving, and others	A suite of biophysical (e.g. biodiversity, topography), management (e.g. land use and land cover type) and societal (e.g. access roads or boating areas, number of visitors, facilities to support visits, distance from cities)	Areas that are suitable for recreation-based tourisms	Area where recreation-based tourism occurs, number of visitors	Marginal contributions to income or well-being of visitors and local inhabitants derived from recreation-based tourism	Economic revenues derived from or costs associated with undertaking nature-based recreation (US$)

Supply refers to the potential of a social-ecological system to generate a service, typically quantified as a flow (i.e., an amount per unit time). Ecosystem condition (e.g., intact or degraded, stressed or unstressed) and processes (e.g., primary productivity), as well as the way ecosystems are managed, are taken into account when determining supply. This is the component of ecosystem services that has been most commonly measured.

Delivery accounts for how much of the service is actually extracted (e.g., amount of timber harvested), used (e.g., area of avoided flood damage, area that is enjoyed by visitors), and delivered to societies (e.g., spatial location of those benefiting from flood regulation), and how societies have access to these services (e.g., laws rules, norms and restrictions that limit access to a service). Delivery thus depends on the links between ecosystem services supply and people's location, activities and societal factors determining access to services.

Contribution to well-being accounts for the change in people's well-being, which results from consuming, using, or having access to the service. Changes in living standards, nutrition status, mortality rates, social conflicts, security in the face of extreme environmental conditions, or happiness partially depend on the delivery of ecosystem services. This component of ecosystem services is the least understood and seldom quantified. One of the issues is that well-being typically has many components and many causes, so it hard to isolate the contributions of a particular service.

Value refers here to the relative importance society attributes to the service. The value of ecosystem services is often accounted in monetary terms, but other ways of establishing the socio-cultural value are potentially equally valid, and may be more appropriate than monetary valuation for some services. For instance, contributions to longevity or perceived quality of life need not be expressed in monetary terms. The monetary value of most provisioning services (e.g., timber) is provided by markets. Where freely-traded markets do not exists (for instance, this is frequently the case for water service), the value can be estimated through a variety of methods, such as the cost of delivering a substitute, or the marginal value addition of the service to other services which do have markets. Valuation approaches, based on willingness to pay, damage costs avoided, travel costs, or hedonic values, have been used to attribute economic value to many regulating and cultural services. Socio-cultural values of ecosystem services to an individual can be assessed through various valuation methods, such as through preference surveys, paired comparisons, and narrative or participatory methods. What is frequently reported is the aggregate societal value resulting from some combination of individual valuations.

These components of ecosystem services feed back into the way social-ecological systems are managed and governed. Supply allows for delivery which allows for contributions to well-being which, in turn, influences value. Ecosystem service contributions to well-being, shape the status of and vision for the well-being of individuals and societies, which directly influences the way formal and informal institutions are designed to modulate interactions with the environment. Value determines which services are fostered, and shape institutions and management interventions, aimed at modifying social-ecological conditions to promote the supply of the desired services at the cost of other services (Díaz et al. 2015).

3.4 Monitoring Ecosystem Services

Ecosystem services can be monitored at multiple spatial scales. For global observation systems, emphasizing the nation state as the focal unit allows for better tracking of progress towards national targets for ecosystem services. In addition, many key global policies, such as the Convention on Biological Diversity (CBD; www.cbd.int), the Sustainable Development Goals (https://sustainabledevelopment.un.org/), and the Commission on Climate Change and Development (www.ccdcommission.org) are governed by mutual agreement of participating nations, requiring monitoring of progress toward global targets. Monitoring, however, can also take place at the local scale, and data can then be aggregated up to the national and global scales, but this is not always a straightforward procedure (Scholes 2009). A multiple scale approach makes it possible for information from one spatial scale to be tested or refined using data produced at other scales. Such comprehensive monitoring at different spatial scales can include national statistics and remote sensing to cover national to global scales, as well as remote sensing and field-based assessments to cover local scales. Models can be developed at all spatial scales.

Different data sources are best suited to account for different components and spatial scales of ecosystem services (see Table 3.2). Supply is best characterised by data sources that consider the condition of social-ecological systems, for example, from remote sensing and models. Delivery is often based on societal characteristics and can be accounted for from national statistics, field-assessment and models. Contributions to well-being are documented in different ways (mostly field assessments, national statistics and census) and have seldom been explicitly incorporated into models. Economic value can be derived from markets, national statistics or from economic models. Sociocultural value can be obtained from field assessments of preferences, or from the analysis of cultural norms. Different types of value have been incorporated into models.

3.5 National Statistics

Census data at national scales are readily available for several ecosystem services. In most cases the census has been conducted at a much more resolved scale (the census district, which may be as small as a neighbourhood). Sometimes such data is available for local analysis, subject to special procedures designed to protect the privacy of individual respondents. The United Nation's Food and Agriculture Organisation publishes a global database (http://faostat.fao.org/) of the amount produced or extracted (delivery), traded, and the monetary value (value) of several ecosystem services, for example, total production of all commercial crops for countries or regions, export or import quantity of trade crops and their economic value per unit. Other databases, such as that of the World Bank (http://data.worldbank.org) report water withdrawals and water availability to people. Some of

Table 3.2 Comparison between different ecosystem service data sources

	National statistics	Remote sensing		Field estimations		Models				
	FAOSTAT WORLD BANK	High resolution	Low resolution	TESSA	Natura	InVEST	LPJmL	ARIES	ESTA	MIMES
Ecosystem service component										
Supply		✓	✓			✓	✓	✓	✓	✓
Delivery	✓	✓		✓	✓	✓		✓		✓
Contribution to well-being				✓	✓					✓
Economic value	✓			✓	✓	✓		✓	✓	✓
Spatial scale										
Local/landscape		✓		✓	✓	✓		✓	✓	✓
National	✓	✓	✓			✓	✓	✓		✓
Global			✓			✓				✓

FAOSTAT: The Statistics Division of the Food and Agriculture Organization of the United Nations (FAO 2012), TESSA: Toolkit for Ecosystem Service Assessments (Peh et al. 2014), Natura: Assessing Socioeconomic Benefits (Kettunen et al. 2009), InVEST: Integrated Valuation of Environmental Services and Tradeoffs (Tallis et al. 2013), LPJmL: Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model (Bondeau et al. 2007), ARIES: ARtificial Intelligence for Ecosystem Services (Bagstad et al. 2013a), ESTA: Ecosystem Service Tradeoff Analysis (White et al. 2012), and MIMES: Multiscale Integrated Models of Ecosystem Services (Altman et al. 2014) the services are monitored in most countries and updated annually (e.g., crops), while others are only available for a small subset of nation states and updated infrequently ($\sim$5 years; e.g., water withdrawal). While these statistics provide very relevant information for assessing provisioning ecosystem services, they imperfectly reflect their delivery and economic value. They cannot, for instance, inform on the supply of the services. They further inform only partially on the delivery of the services, as they can only account for the fraction of the food production that enters markets and national statistics. The stronger biases are for economic values, which are the product of markets and incentives, and do not necessarily account for the marginal contribution of ecosystems to food production through primary productivity, water for irrigation, soil fertility, pollination, or pest regulation, relative to those contributed by society. Also, these values do not include the negative impacts of agricultural intensification and expansion, nor that of industrial fisheries, on biodiversity conservation and the degradation of supporting and regulating ecosystem services. The societal costs of intensive agriculture or fisheries are not accounted for either.

Data accuracy in national statistics is quite variable and is dependent on national monitoring infrastructure (human and technical capacity), relative importance of informal activities (e.g., subsistence production or unreported extraction cannot be accounted for), and governmental policies on transparent reporting. Temporal data gaps are common for many countries and are often filled using a variety of techniques, including interpolation, models or expert judgement, which all have well-documented biases. In all cases, uncertainty analyses are needed to quantify and help improve reliability of existing data.

3.6 Remote Sensing

Remote sensing (see Chap. 8) consists of data collection ‘at a distance’: from sensors on the ground, in the water, on aircraft, or in space. Remote sensing of ecosystem services relies on hybrid methods, that use models to combine in situ information (collected either by humans or machines) with that collected at coarser spatial scales (e.g., climate, landform, social or economic variables).

Remote sensing has not been used directly to measure ecosystem services, yet in combination with other data sources it can contribute to the assessment of many ecosystem services (e.g., water quantity and quality, erosion prevention, moderation of extreme events; Horning et al. 2010). These data sources can either contribute to assessing the potential supply of ecosystem services or to assess the social-ecological drivers that influence the supply, delivery, contribution to well-being, and value of ecosystem services (Andrew et al. 2015).

Products from multiple frequencies within the range of visible and near-infrared bands contribute to vegetation indices, such as greenness measures like the Normalized Difference Vegetation Index (NDVI) that indicates plant vigour. Such information can be used as one of several data sources to assess crop delivery (through potential productivity of known plant/crop species), carbon stocks and carbon uptake, fisheries (through ocean productivity), water quality (through changes in water colour), and land use change (a driver). High-resolution data can inform on small-scale ecological features, such as individual trees. Information on roads, fields and habitat patches can be used to provide information on drivers of many ecosystem services. Products from radar devices provide high-resolution information for topography, vegetation and water cover, and potentially on the aboveground biomass. These can contribute to assessing land use change, crops, or water cover (superficial water bodies) over a targeted region. Products based on Laser Imaging Detection and Ranging (LIDAR) devices provide high resolution information on above-ground carbon stocks, water (water surface elevation, and in combination with bathymetry, the volume of freshwater bodies), and ecosystem structure, that can be used to model a range of provisioning, regulating and cultural services. High resolution images (with individual pixels of around 1 m^2) are increasingly available from commercial satellites and can be used to refine information for particular locations. The cost is currently high, but may still be cost-effective if compared with manual mapping on the ground, and is being driven down by the advent of unmanned autonomous vehicles or 'drones' (e.g., see www.conservationdrones.org) equipped with cameras.

3.7 Field-Based Estimations

Field-based estimations contribute to local or site-based monitoring and assessment, as well as to validation of models and remotely sensed data products. Ultimately, field-based estimations are a principal source of new data on the supply, delivery, contributions to well-being and value for all services. Some services, such as the flow of water in rivers, are routinely monitored by in-field devices, and new technologies such as eddy covariance are extending the range of in situ observations of services such as carbon sequestration.

Conducting primary data collection can be costly, time consuming and technically specialised, and the methods and information from different data sources need to be standardized. Toolkits are emerging to deal with these issues, and promote standardized rapid assessments at the site scale. Such toolkits provide guidance on the steps to be followed, the kind of data to be gathered and the methods suggested to gather or model quantitative data at this scale that can then be used in an assessment under a range of contexts. Assessments incorporate local knowledge, basic local data collection and other data sources to create fine scale, locally-relevant assessments of multiple ecosystem services.

Two of these toolkits have been particularly useful (Table 3.3). The Toolkit for Ecosystem Service Site-based Assessments (TESSA; Peh et al. 2014) was developed to assist site-scale users with limited capacity and resources, to develop simple estimates of ecosystem services. The Natura toolkit was developed for assessing the

Table 3.3 Examples of toolkits available to assess ecosystem services and their advantages and disadvantages

Model (website)	Basic principles	Advantages	Disadvantages
TESSA: Toolkit for Ecosystem Service Assessments www.birdlife.org/datazone/info/estoolkit	Field-based estimations to develop and deploy a rapid assessment tool to understand how far conserving sites for their biodiversity importance also helps to conserve different ecosystem services relative to a converted state	Aimed at local decision-makers. Easy to use. Allows for the assessment of multiple components of ecosystem services. Can be applied to a range of conditions. Emphasizes alternative states and the identification of stakeholders that win or lose from these states	Applicable only at local scales. Not scalable from local to regional as its use is highly context dependent
Natura: Assessing Socioeconomic Benefits www.natura.org/	Practical guide for practitioners (e.g. site managers, landowners and other land users) involved in the management of sites in Europe. Toolkit will help these practitioners in exploring the different values and socio-economic 'potential' of their sites, e.g. possible socio-economic benefits gained by managing sites and land in a sustainable manner	Aimed at local decision-makers. Easy to use. Applicable at local to regional scales. Emphasizes what benefits are obtained by which stakeholders	Mainly focused on conservation projects and thus current and potential protected areas. Emphasizes only economic and social and cultural benefits obtained from ecosystem services

socio-economic benefits associated with the ecosystem services of 200 conserved or protected sites in Europe (Kettunen et al. 2009).

3.8 Community Monitoring of Ecosystem Services

Ecosystem services that are locally relevant can be monitored by local stakeholders, such as land owners and consumers (see Chap. 9 on Citizen Science). Several studies have shown that local communities without conventional scientific training have successfully collected accurate data on a wide range of ecosystem services such as forest carbon storage and sequestration, water quantity and quality, and their links to well-being (Hein et al. 2006; Dinerstein et al. 2013).

Involving communities in data generation enables year-round, low cost generation of local data (plot to landscape level) and wide spatial coverage. It provides information for local-level decision-making for ecosystem service management, and it can also generate employment, enthusiasm, and personal investment in ecosystem service based initiatives. Additionally, it can better incorporate traditional ecological knowledge and help maintain cultural heritage, identity, and values. Community involvement in monitoring can increase local interest and investment in the maintenance of ecosystems and the services they provide.

Information generated by locally-based monitoring systems, however, can be influenced by power struggles and incentives surrounding the monitored resource and validation mechanisms need to be implemented.

Numerous data collection and management tools have been developed in the last 5–10 years to facilitate gathering, storage, and sharing of data by communities.

3.9 Models

Numerical models, understood here as practical tools that predict how ecosystem services change through time and space, are increasingly being used to support decision-making. These models are often developed when data availability is scarce, when spatially explicit information is needed, and in order to assess trade-offs among services under alternative future management scenarios.

A wide variety of approaches have been used for building and applying such models. Five of the more commonly used modelling platforms are described here (Table 3.4).

- The Integrated Valuation of Environmental Services and Tradeoffs (InVEST) suite is a free and open-source software tool to help inform and improve natural resource management and investment decisions (Tallis et al. 2013).
- The Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model (LPJmL; www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/lpjml) is a tool that was not specifically designed for ecosystem service assessment, but still allows deducing a number of ecosystem services consistently from the same process based model (Bondeau et al. 2007).
- The ARtificial Intelligence for Ecosystem Services (ARIES; www.ariesonline.org) can be used to model supply, demand (delivery), flow (the link between the areas of supply and those of delivery), depletion (the balance between supply and delivery), and values (differential preferences among stakeholders) of ecosystem services (Bagstad et al. 2013b). A range of tools (www.ariesonline.org/resources/toolkit.html) and models for a range of case studies (www.ariesonline.org/resources.html) is available.

Table 3.4 Comparative table of the ecosystem services models described in this chapter and their individual advantages and disadvantages

Model (website)	Basic principles	Advantages	Disadvantages
InVEST (www.naturalcapitalproject.org/InVEST)	Set of spatially-explicit process-based models. Predict services from social-ecological conditions. User-defined future scenarios. Biophysical and monetary assessments of ecosystem services. Emphasis on relationships among multiple services	Broadly applicable across a variety of social-ecological contexts. Models use the minimum data required allowing application in many data-scarce regions. Moderate time consuming models and not technically specialized allowing its broad use. Modules of either biophysical modelling and economic valuation	Models do not simultaneously feedback on one another. Simple models, assuming that the provision of ecosystem services change linearly with land use change. High uncertainty when models are applied with coarse secondary data and no validation
LPJmL (www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/models/lpjml)	Simulates vegetation dynamics and their impacts on hydrological processes up to global scale; sensitive to land use and climatic change. 35 land cover classes including potential natural vegetation, 9 plant functional types and 13 crop types (irrigated or not)	Useful for modelling mid- to long-term change in ecosystem services provision under alternative climate change and land-use scenarios. Variability estimates over time	Models require high resolution climate data that is only available in few countries. Time consuming models requiring technically specialized skills. Low resolution of final outputs (50 km^2) for most countries
ARIES (www.ariesonline.org)	Models built from Bayesian belief networks informed by user data. Uncertainty associated with its estimates quantified. Generic models adapted to specific applications at different spatial scales and for particular social-ecological contexts	Useful to quantify flows of the services to beneficiaries. Models incorporate an uncertainty measure in its estimates done through Bayesian networks and Monte Carlo simulation	Time consuming models requiring technically specialized skills. Models have a low level of generalization (specific application at particular social-ecological contexts)

(continued)

Table 3.4 (continued)

Model (website)	Basic principles	Advantages	Disadvantages
ESTA	Coupled, dynamic bio-economic models to simulate the production and value of multiple ecosystem services. Focus on understanding the trade-offs that emerge when management has multi-service objectives	Models developed using best available data for a region. Include direct and indirect interactions among services. Any number of services can be assessed simultaneously	Time consuming models requiring technically specialized skills and data-rich contexts
MIMES (www.ebmtools.org/mimes)	Models simulate changes in biophysical conditions and economic activities over time and through space. Developed in collaboration with stakeholders. Functional and dynamic models over space and time developed from multiple data sources	Integrated dynamics and interactions among services. Values emerge from trade-offs and impacts on human well-being. Incorporate an uncertainty measure in its estimates	Time consuming models requiring technically specialized skills. Models have a low level of generalization
Co$ting Nature (www.policysupport.org/costingnature)	Web-accessible tool to map ecosystem services and conservation priority areas. Also analyses the benefits provided by the natural environment, the beneficiaries of those ecosystem services, and assesses the impacts of possible human interventions on the continued provision of these benefits	Rapid analysis of indexed, bundled services based on global data, along with conservation priority maps. Models have a high level of generalization	Models require high resolution biophysical and socio-economic data that is only available in few countries
WaterWorld (www.policysupport.org/waterworld)	Details process-based modelling of selected provisioning and regulating hydrological services. It incorporates high resolution spatial datasets for the entire world, spatial models for biophysical and socio-economic processes along with scenarios for climate, land use and economic change	Rapid analysis of bundled services based on global data. The biophysical and socio-economic consequences of alternative interventions (policy options) can be modelled Models have a high level of generalization	The high resolution datasets needed are only available for a few countries

- The Ecosystem Service Trade-off Analysis (ESTA) was initially developed to inform and evaluate the trade-off between biodiversity and fisheries objectives, and has been applied to an increasing number of case studies with a range of ecosystem services, including offshore wind and wave energy, aquaculture, and ecotourism (White et al. 2012).
- The Multi-scale Integrated Models of Ecosystem Services (MIMES; www.ebmtools.org/mimes.html) platform is designed to address the magnitude, dynamics, and spatial patterns of ecosystem service values (Altman et al. 2014).
- Co$ting Nature (www.policysupport.org/costingnature) is a web-based tool for natural capital accounting and analysing the ecosystem services provided by natural environments (i.e., nature's benefits), identifying the beneficiaries of these services and assessing the impacts of human interventions (Mulligan 2015a).
- WaterWorld (www.policysupport.org/waterworld) is a web-based tool can be used to understand the hydrological and water resources baseline and water risk factors associated with specific activities under current conditions and under scenarios for land use, land management and climate change (Mulligan 2015b).

3.10 Current Tools to Monitor Ecosystem Services

Ecosystem services can be monitored and assessed at different spatial scales using readily available data sources (Table 3.5). However clear gaps exist, especially when one considers all four components requiring data per ecosystem service (see Table 3.6). We explore progress and gaps per ecosystem service category below.

Mismatches can occur between data sources and data needs. Some data sources, such as LPJmL models or the older remote sensing data, are only available at low spatial resolution (50 km^2 grid cells in the case of LPJmL) and might not be suitable for assessments at landscapes scales. Similarly, assessments of changes in services within very short time frames are incompatible with some data sources that are only available on a yearly basis, as is the case of national statistics, or those that are modelled from data for which data sources are not updated regularly, as is the case of governmental land use and land cover maps in Mexico. The converse situation can also be true: changes in soil carbon or soil fertility within the same land cover type through time could be estimated from repeated remote sensed data, but changes would not be observed given the long time frame over which the processes that regulate them operate.

The data needed for ecosystem service estimation is often the flow of service rather than the particular conditions of the service in one point in time. This is the case of water flowing from a river, or the amount of carbon being taken up by vegetation. The most commonly found approach is for rates to be estimated from differences in the magnitude of the stock which provides or receives the service between two selected dates, as is the case of carbon uptake, most commonly

Table 3.5 Data sources for ecosystem services

Service	Global and National statistics	Remote sensing	Field estimations	Models	Additional data sources and comments
Provisioning					
Crop	FAOSTAT	✓	TESSA	ARIES, LPJmL, MIMES	(www.teebweb.org/agriculture-and-food/) for further discussion on limitations to FAOSTAT data
Fodder		✓		MIMES	
Livestock	FAOSTAT			MIMES	
Aquaculture	FAOSTAT	✓		InVEST, ESTA	
Fisheries	FAOSTAT	✓		ARIES, ESTA, MIMES	Only subsistence fisheries from ARIES
Wood	FAOSTAT	✓		InVEST, LPJmL, MIMES	
Biofuels	FAOSTAT	✓		MIMES	IEA, CDM, ISO14040/44
Game meat	FAOSTAT	✓		MIMES	
Harvested wild goods		✓ i	Natura	ARIES, MIMES	
Water	FAOSTAT, WORLD BANK	✓ i	TESSA	InVEST, LJPmL, ARIES, MIMES, Co$ting Nature, WaterWorld	
Hydropower energy		✓ i		InVEST, ESTA, MIMES	
Regulating					
Climate regulation (Carbon stocks and uptake)	WDCGG	✓	TESSA	InVEST, LJPmL, ARIES, MIMES, Co$ting Nature	IPCC, National statistics available for selected countries. Carbon uptake needs monitoring through time
Regulation of marine and freshwater quality		✓	Natura	InVEST, ESTA, MIMES, Co$ting Nature, WaterWorld	Only nutrients-freshwater for Natura. Highly patchy data availability. Quality defined with respect to users
Regulation of soil fertility				MIMES	Multiple local survey methods

(continued)

Table 3.5 (continued)

Service	Global and National statistics	Remote sensing	Field estimations	Models	Additional data sources and comments
Regulation of soil erosion		✓ i	Natura	InVEST, ARIES, MIMES, WaterWorld	Marine/coastal and terrestrial erosion models from InVEST
Flood regulation		✓ i		ARIES, MIMES, Co$ting Nature	
Coastal protection		✓ i		InVEST, ESTA, MIMES, Co $ting Nature	
Contribution of coastal habitat to fisheries		✓ i		InVEST, ESTA, MIMES	
Pollination			Natura	InVEST	
Pest control			Natura, IPM		
Cultural					
All non-tangible benefits				MIMES	Growing literature available on this topic
Aesthetic views		✓ i		InVEST, ARIES	
Nature-based tourism		✓ i	Natura, TESSA	InVEST, ESTA, Co$ting Nature	
Recreation		✓ i	TESSA	ARIES	

This list of data sources is not exhaustive but rather refers to the data sources reviewed in this chapter. Additional sources: IEA: International Energy Agency (www.iea.org/stats/prodresult.asp?PRODUCT=Renewables), provides information on land cover by biofuel crops, CDM: Methodologies developed by the Clean Development Mechanism (CDM; http://cdm.unfccc.int/methodologies/index.html), ISO14040/44: Standard methodologies for full life cycle assessments of biofuels (Finkbeiner et al. 2006), TEEBAgFood: The Economics of Ecosystem and Biodiversity for Agriculture and Food (http://www.teebweb.org/agriculture-and-food/), WDCGG: World Data Centre for Green House Gases (WDCGG; http://ds.data.jma.go.jp/gmd/wdcgg), IPCC: Standards for measuring carbon stocks and uptakes developed by the Intergovernmental Panel on Climate Change (www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=7), IPM: Integrated Pest Management protocols for field surveys developed by University of California, Davis (www.ipm.ucdavis.edu). i: Contribution of remote sensing as one of the information layers

Table 3.6 Ecosystem service data sources for different ecosystem services components

	National statistics	Remote sensing		Field estimations		Models						
	FAOSTAT	High resolution	Low resolution	TESSA	Natura	InVEST	LPJmL	ARIES	ESTA	MIMES	Co$ting nature	WaterWorld
Ecosystem service component												
Supply		✓	✓			✓	✓	✓	✓	✓	✓	✓
Delivery	✓			✓	✓	✓		✓		✓	✓	✓
Contribution to well-being				✓	✓					✓	✓	
Value	✓			✓	✓	✓		✓	✓	✓		
Spatial scale												
Local/landscape		✓		✓	✓	✓		✓	✓	✓	✓	✓
National	✓		✓			✓	✓	✓		✓	✓	✓
Global			✓			✓				✓	✓	✓

National statistics: FAOSTAT, The Statistics Division of the Food and Agriculture Organization of the United Nations (FAO 2012). TESSA: Toolkit for Ecosystem Service Assessments (Peh et al. 2014), Natura: Assessing Socioeconomic Benefits (Kettunen et al. 2009), InVEST: Integrated Valuation of Environmental Services and Tradeoffs (Tallis et al. 2013), LPJmL: Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model (Bondeau et al. 2007), ARIES: ARtificial Intelligence for Ecosystem Services (Bagstad et al. 2013b), ESTA: Ecosystem Service Tradeoff Analysis (White et al. 2012), MIMES: Multi-scale Integrated Models of Ecosystem Services (Altman et al. 2014) estimated from changes in carbon stocks. Actual flows of ecosystem services, such as in the case of water, can be assessed by some of the models such as ARIES, or by in situ flow measuring devices.

3.11 Provisioning Services

Most provisioning services are already observed at national and local scales in most parts of the world using one or more of the data sources above. National statistics are available (at least partially) for many provisioning services, but are typically blind to subsistence ('informal', family consumption, not traded in monitored markets) or illegal operations that can contribute to large proportions of delivery in some countries. Remote sensing data are available for services related to vegetation primary productivity, biomass harvest and water quantity. Field estimations are available for provisioning services (from e.g., TESSA and Natura). Models are available for most provisioning services, from at least one of the four platforms described above.

Observations of supply, that largely depend on biophysical conditions are only available for a few provisioning services. Instead, delivery data sources are commonly reported for services associated with commonly used goods, although only those that are accounted for in statistics. As many provisioning services are commercialised in markets, economic (especially monetary) values are also readily available, but such values do not reflect all the contributions of the ecosystem to these services, nor the consequences. Data on the contributions to well-being are largely missing or in development for most services.

Information on the balance between the demand of the services and the supply, or other estimators of the long-term ability of the ecosystem to sustain the supply of these services are not currently available for most provisioning services.

3.12 Regulating Services

Data on regulating services is increasingly available from national statistics or from remote sensing in conjunction with models, particularly for carbon stocks and uptake (climate regulation). The emphasis has been put on carbon stocks and carbon uptake through primary productivity, which is relatively easily measured and quite relevant to climate change mitigation, while the links to actual carbon dynamics and climate processes is largely absent. Models of regulating services associated with hydrological processes (water quality, erosion regulation), those on the impacts of extreme meteorological events (flood and coastal regulation), as well as those for pest regulation and pollination are increasingly available. Today models are available for most regulating services and most of these models have been developed at landscape and regional scales, but seldom at national scales. Field estimations are available for services (most of which are available from TESSA or Natura, and from a plethora of approaches).

Both supply and delivery of regulating services are accounted for in most models. Data and models for contributions to well-being are absent or in development. Economic values are largely related to avoided costs or marginal contributions to economic activities from regulating services.

Given that regulating services depend on multiple social-ecological processes operating at several spatial and temporal scales, data, models and field estimations of regulating services are necessarily a simplification and, in some cases, they may be an oversimplification which is more misleading than useful.

Box 3.1. The Demand for Ecosystem Services at Drinking Water Treatment Facilities in Barcelona

Engagement with drinking water managers in Barcelona, Spain allowed for the identification of ecosystem services relevant for decision-makers. Discussions revealed that treatment costs were particularly sensitive to three water quality parameters: stream temperature, ammonium and conductivity. In particular, high stream temperature increased water treatment costs because of the water treatment technology used and the high concentration of sterilisation products during warm summer months (Valero and Arbós 2010). Understanding the demand for reduced stream temperatures by water treatment managers allowed for the development of a targeted research program focusing on ecosystem structures that would reduce thermal heating in the Llobregat River. It was found that the restoration of riparian forests upstream would be able to recover ecosystem processes, reduce stream temperature in the summer and therefore reduce water treatment costs. After modelling multiple restoration scenarios, nearly half of the investment in riparian river restoration was estimated to be recovered in a 20 year period through a reduction in water treatment costs (Honey-Rosés et al. 2013). Understanding the demand for reduced stream temperatures by water treatment managers allowed for the development of a targeted research program focusing on ecosystem structures that would reduce thermal heating in the Llobregat River.

3.13 Cultural Services

Cultural services present a challenge when it comes to observation and assessment because some of them are not easily disentangled from other ecosystem services, such as provisioning services. For instance many important cultural services are co-produced by the same ecosystem components and human activities that produce material objects for consumption (Chan et al. 2012), such as agricultural landscapes or harvested forests. The different cultural services are highly intertwined, and unlike with provisioning or regulating services, it is not possible to clearly delineate the different components of the services. Cultural services are highly context dependent and thus information on these is often only available and relevant at local scales. This is not true for all cultural services: some are well-defined, discrete and routinely monitored, such as the use of national parks, or the income from nature-based tourism and recreation.

Readily available sources of information on cultural services are very wide ranging. These include local assessments of cultural preferences (for aesthetic views; Bagstad et al. 2013c) (can be obtained from the above toolkits), and databases on use of particular areas or ecosystems for ecotourism at national scales (governmental database). Further sources of information on cultural services are embedded into local artistic expression (e.g., poetry, music) or in social norms that articulate a value or impact of nature on the human condition.

3.14 Observing Multiple Ecosystem Services

Historically, ecosystem management has often focused on delivery of a single service from that ecosystem (often a provisioning service, such as timber or grazing) without recognition that the same ecosystem produces multiple, often interacting services which are also affected by management interventions. This often leads to trade-offs (where one service decreases while the other increases), but can also lead to synergies (where increasing the supply of one services also increases the supply of another). Moving observation systems beyond single services to the full bundle of services (a set of services that tend to co-occur in space or time), to quantify and reflect the synergies (positive interactions) and trade-offs (negative interactions) is a major challenge for current research efforts. Also, an understanding of the interactions among stakeholders that have differential preferences for the traded-off services is needed.

The identification of bundles of services that arise under particular biophysical, management, and societal conditions is particularly relevant. Data needed for these assessments is hindered by the reduced replicability of the same measurements across different social-ecological conditions. It is seldom that they supply exactly the same sets of provisioning, regulating and cultural services, at the same spatial and temporal scale, and measuring the same components (e.g., supply or value). While still patchy, such datasets have been increasingly available in the past few years. Comparisons across studies are nevertheless faced with the lack of interoperability among them.

Additional observations of biodiversity (see other chapters) and multiple ecosystem services at different spatial scales will contribute to a better understanding of their inter-linkages, patterns of interactions across scales and time, and common trade-offs and synergies.

3.15 Using Scenarios in Modelling to Predict Future Ecosystem Services

Scenarios are stories about plausible futures, with the power to capture public attention and inform more sustainable decisions (Henrichs et al. 2010). They can help communicate the outcomes of different choices for societies and ecosystems while at the same time involving stakeholders in a powerful learning process. It is important to consider the explicit goals for the use of scenarios in determining which type of scenario will best address those goals and reach their intended audience. Three main uses of scenarios include: (1) assessing the impact of decisions under consideration, (2) exploring hypothetical but plausible futures, and (3) building consensus around a shared vision for the future (e.g., see IPBES 2016).

Certain characteristics can make scenarios more effective. Scenarios that are relevant to the decision context or stakeholder interests will align with the problems and questions of interest to stakeholders. To be legitimate, the scenario development process should include diverse stakeholder views and beliefs. To be credible, scenario storylines should be developed using scientifically robust methods. To be plausible, scenarios should tell coherent stories that could conceivably happen. Finally, to tell a compelling story, scenarios should be distinct enough from one another that they show contrasting ecosystem service impacts. Iteration of scenarios can greatly enhance many of these characteristics, as they are refined over time to incorporate stakeholder feedback, as well as emerging knowledge, trends and issues.

Translating scenarios to decision-support tools requires that storylines be made spatially-explicit, with each scenario corresponding to a map of land cover, or coastal or marine habitats and uses that feed into the biophysical and/or economic models underlying ecosystem service assessment. Converting scenario storylines into maps can be accomplished by asking stakeholders to simply draw maps for each scenario; more analytical methods of forecasting where change is most likely to occur on the landscape or seascape are based on past trends; rule-based approaches define which areas are likely to be most suitable for particular uses or activities. Models of future supply, delivery, value and benefit of ecosystem services into alternative scenarios are increasingly being developed.

All the modelling platforms described above may be used to predict ecosystem services under different future scenarios for land/sea use and management patterns. Different models have been built to be differentially sensitive to alternative future issues. For instance, the LPJmL, is highly sensitive to climate change, which is particularly helpful when looking for mid- to long-term effects.

3.16 Linking Ecosystem Service Observations to Decision-Making

Monitoring for ecosystem services to support decision-making is greatly enhanced with early involvement of the actual stakeholders involved in the decisions. One key advantage to examining ecosystem services with a stakeholder driven agenda includes the easy identification of key services recognised and preferred by societies, as well as the identification of indicators that are most meaningful to them. Stakeholders can also participate in community-based or citizen science-based monitoring of ecosystem services. Successfully integrating decision-makers in the assessment and valuation of services also allows for speedier adoption of the ecosystem services framework in practice, and the use of ecosystem service data into actual decision-making.

Emphasis has increasingly been put on the use of ecosystem service indicators towards agreed upon policy goals. That is the case of indicators that can inform on progress towards the Aichi Targets and more recently progress towards the Sustainable Development Goals. The challenge is to identify those indicators that are most relevant to measuring progress towards the goal, while at the same time being supported by actually available data, conceptual understanding and credibility.

Monitoring for ecosystem services at local to national and global scales needs to take into account how preferences and ecosystem services can change in space and time. Services that are most relevant at national to global scales could be monitored systematically, while locally relevant services could be assessed within particular locations.

Box 3.2. Monitoring Ecosystem Services for Coastal Planning in Belize

The coast of Belize includes hundreds of kilometres of mangrove forests, extensive seagrass beds, and the largest unbroken reef in the Western Hemisphere. 800,000 tourists visit the area for its renowned snorkelling and diving sites. Tourism, as well as commercial, recreational, and subsistence fisheries, contribute to income and livelihoods, but at the same time threaten the very ecosystems that make these activities possible. Efforts to put the Belize Barrier Reef on the United Nations Educational, Scientific and Cultural Organization's list of World Heritage Sites in Danger and the creation of a visionary legislation in 1998 calling for cross-sector, ecosystem-based management of coastal and marine ecosystems were insufficient to halt degradation. In 2010 The Natural Capital Project (www.naturalcapitalproject.org) partnered with the Coastal Management Authority and Institute to use ecosystem-service approaches and models to design a spatial plan (Arkema et al. 2015). Interactions with a range of stakeholders and government agencies led to the identification of different categories of human activities, a zoning scheme, and three alternative future scenarios. The supply and economic value of lobster fisheries, tourism, coastal protection and habitat (to support fisheries) were modelled for current and future scenarios using InVEST. Data sources included: (i) field assessments of lobster catch and revenue; (ii) high resolution land use cover maps developed from remote sensed data, (iii) model of lobster migration, (iv) current visitation data obtained from social media (e.g., flickr). Risk under alternative scenarios for individual services as well as trade-offs among services across zones were assessed using additional spatial data on human activities and habitats, as well as information from the peer- reviewed and grey literature on the expected impacts of human activities on the services and the habitats. The most desirable future scenario was identified and further refined to increase expected delivery of almost all services in all regions into 2025. The results from this future scenario were incorporated into the Coastal Zone Management plan for Belize in 2012. It was refined through further stakeholder involvement and expert review during 2013 and led to changes in national legislation such as the creation of marine reserves and the revocation of offshore drilling contracts issued earlier by the government of Belize.

3.17 Creating a Network for Observing and Managing Ecosystem Services

The ultimate goal of many efforts to monitor ecosystem services is to inform decision-makers and policy to ensure the long-term supply of services and the flow of benefits to societies. While progress has been made on the quantification and mapping of services, less attention has been given to the needs of decision-makers and resource users from local to global scales. Meaningful engagement with resource users and policy makers should occur early, explicitly and formally when monitoring services (Menzel and Teng 2010).

A network for monitoring ecosystem services is necessary to synergise work done by multiple partners, taking advantage of others' insights, increasing consistency, and reducing duplication of efforts. Creating such a network for monitoring ecosystem services at local to global scales will require significant effort from stakeholders from the research, policy and practice communities across the globe. National monitoring systems could create mechanisms by which local stakeholders can provide input and feed into the national system. City and regional governments may help facilitate the engagement with local stakeholders, and help assess the status of services at local scales. Stakeholder participation in monitoring activities will vary widely depending on many factors including local relevance of the services they are monitoring, and whether incentives are provided.

Local scale monitoring could dovetail into existing ecosystem services research which may have very different objectives but could contribute to an observation network. Examples of such on-going efforts include: the already existing networks associated with ARIES, and MIMES the Ecosystem Service Partnership (www.es-partnership.org/esp), the International Long-Term Ecological Research Network (www.ilternet.edu), the Natural Capital Project (www.naturalcapitalproject.org), the Program for Ecosystem Change and Society (PECS; www.pecs-science.org), the Sub-Global Assessment Network (www.unep-wcmc.org/sga-network_770.html), the Tropical Ecology Assessment and Monitoring Network (www.teamnetwork.org), the ESCom Scotland (http://escomscotland.wordpress.com/) and Vital Signs (http://vitalsigns.org/).

One major challenge to date is that multi-scale cross-site comparisons are only possible if comparable approaches and indicators are used. To date a wide diversity of approaches and indicators complicate such comparisons. Great emphasis has been given over the last decade to the development of new metrics, tools and approaches, which has fostered creative solutions. Yet, standard procedures will eventually need to be identified and practical examples be provided to operationalise the ecosystem services concept (e.g., OPERAs; www.operas-project.eu/).

Efforts through the Group on Earth Observations Biodiversity Observation Network (GEO BON; www.geobon.org), to further develop and communicate standards and protocols for the collection of new ecosystem services observations to enhance comparability across scales and data sources, are on-going. Ecosystem Service tools are being incorporated into GEO BON developed toolkits, namely BON-in-a-Box.

Automated, remotely sensed Earth observations will increasingly be used in the future to assess ecosystem services as well as the drivers that modify their supply and delivery. Changes in environmental and socio-economic features are more available than ever with the new sensors, such as those in the Sentinel fleet. The critical issue is integration of the data in ways that make it readily usable for ecosystem service assessments (Cord et al. 2015).

3.18 Monitoring to Support Policy Design

Ecosystem services monitoring can be directly linked to on-going assessments that support policy design. Timely information from monitoring ecosystem services can be useful to the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; www.ipbes.net) that aims to strengthen the science policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. IPBES is aiming to establish strategic partnerships, such as with monitoring programmes, to assist in the delivery of its work programme.

Similarly, National governments are also signatories to Multilateral Environmental Agreements. In most cases (for instance the CBD), these rely on technical and scientific bodies to assess progress towards implementation of agreed decisions. National progress reports and assessment of needs towards achieving targets rely on monitoring ecosystem services.

Agreements and commitments across different scales (national to global) on biodiversity and ecosystem services would benefit greatly from the extension and linking of various observing networks, which can promote the collection, access, packaging and communication of data. This often will require engagement with existing mechanisms such as the assessments to be performed by IPBES, CBD and individual nations.

3.19 Conclusions

Monitoring ecosystem services is vital for informing policy (or decision-making) to protect human well-being and the natural systems upon which it relies at different scales. While ecosystem services are linked to biodiversity, the social factors involved in their supply, delivery and value to human well-being implies that they cannot be predicted from biodiversity monitoring initiatives alone. Here we emphasise that monitoring systems for ecosystem services must take into account provisioning, regulating and cultural services as well as their components of supply, delivery, contribution to well-being and value. A wide variety of data sources is available and relevant to ecosystem services monitoring, including national statistics, field-based assessments, remote sensing and models. Their elaboration will help ensure monitoring at relevant (and where necessary multiple) scales of interest.

Outputs from monitoring a range of ecosystem services and their components at different spatial scales can actively support decision-making. Analyses of multiple services and biodiversity can inform decision-makers such as land managers as to trade-offs and synergies among them. Modelling and exploring future scenarios of ecosystem services can then clarify the impacts of alternative policies on such trade-offs and synergies.

Monitoring our life support systems and using this information in decision-making across all scales will be central to our endeavours to transform to more sustainable and equitable futures.

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