Ecosystem services provisioning depends on landscape structure
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CHAPTER 2

Typology and metrics of ecosystem services and functions as the basis for payments, rewards and co-investment

Betha Lusiana, Shem Kuyah, Ingrid Öborn and Meine van Noordwijk

Highlights

- Ecosystem structure and how it functions determine services it provides
- Prototypes of PES schemes can be developed based on ecosystem services functions
- Quantification of ecosystem services for PES development requires stepwise process of clarification and development
- The metrics used in ecosystem services assessment and monitoring must be agreed by service providers, beneficiaries and intermediaries
- The negotiation for metrics usage is an essential part of PES contract agreements

Illustration by World Agroforestry Centre/Beria Leimona

2.1 Introduction

To successfully and sustainably develop and implement payment, reward or co-investment schemes for ecosystem services (ES) there is a need to define typologies of ES and to develop and agree on robust metrics to monitor ecosystem services and functions as the basis for quantifying, and translate in monetary terms, the services provided or benefitted. The starting point for the most commonly used classification of 'ecosystem services' (MEA [1]) are the types of benefit humans derive from provisioning, regulating, cultural and supporting services. Provisioning services refer to products obtained from agro- or wild ecosystems, and include agricultural, forestry, animal husbandry, fishery and wildlife management activities; regulating services are benefits obtained from the regulation (reduced variability) of environmental and ecosystem processes such as water infiltration; cultural services are non-material benefits people obtain from ecosystems through spiritual enrichment, recreation and cultural aesthetics, and supporting services relate to ecosystem dynamics necessary to produce any of the other ES for example nutrient cycling and pollination. This classification based on human benefits is a step towards economic valuation of the goods and services provided [2]. However, at the level of ecosystem structure and function, other ways of grouping can help to understand interactions with land use and the potential synergy in structural interventions at the level of soils, vegetation, flora, fauna or climate. An understanding of ecosystem function in the water, nutrient and carbon balances, the life histories and population dynamics of its component species, and the wider biodiversity patterns; can connect ecosystem structure, through functions to human benefits. Various effective ES typologies exist [3,4,5,6].

The objectives of this chapter are: (i) to link the conceptual definition of ES with implementable indicators and methods to quantify ES useful for monitoring, and (ii) review tools for a landscape approach to ecosystem structure and function that is consistent with the Millennium Ecosystem Assessment ES concepts. Throughout this chapter we use the term *ecosystem services* (ES) to describe the four services: provisioning, regulating, cultural and supporting provided by ecosystems, while the *environmental services* as ecosystem services minus the provisioning services.

2.2 Typology of ecosystem services based on benefits and functions

Figure 2.1A, known as the cascade model of ES[2,7]describes human benefits as products of ecosystem structure and processes. It suggests that the 'services' can only be secured if institutions and human decisions are effective in management and restoration at the ecosystem level. In many cases more than one service will be influenced by land use change in a specific landscape, and the providers may also receive direct benefits and services from the landscape (Figure 2.1B).

A common grouping of ES in the context of incentive mechanisms has been at the 'function' level. For example, the water cycle between oceans, atmosphere and land supports a range of provisioning services: clean drinking water, and for those nearby the land-water interface building materials (e.g. reeds for roofing) and food (fish and fishery products). However, ecosystems also provide major regulating services with respect to water, in hydrological processes such as infiltration, runoff and streamflow. In the absence of such regulating services rainfall would cause alternating conditions of excess (devastating floods) and shortfalls (drought), and rivers could not be used as means of transport. Regulating functions also include biological water purification in streams and lakes. Lakes, and rivers also regulate local climate, as winds blown across water bodies bring a cooling effect and also prevent dust. The hydrological cycle (supporting service) make it possible for the ecosystems to provide the regulating services. The water environments, finally,also provide aesthetic, religious and cultural values, as well as relate to historical aspects of peoples' heritage and sense of identity. Bird watching, fishing and white water rafting are some of the recreational activities linked to rivers, streams and lakes. People travel to resorts situated close to water bodies to experience these activities; waterfalls have spiritual significance in many cultures; water-related tourism can induce other service sector activities that provide incometo communities that protect the water resources.

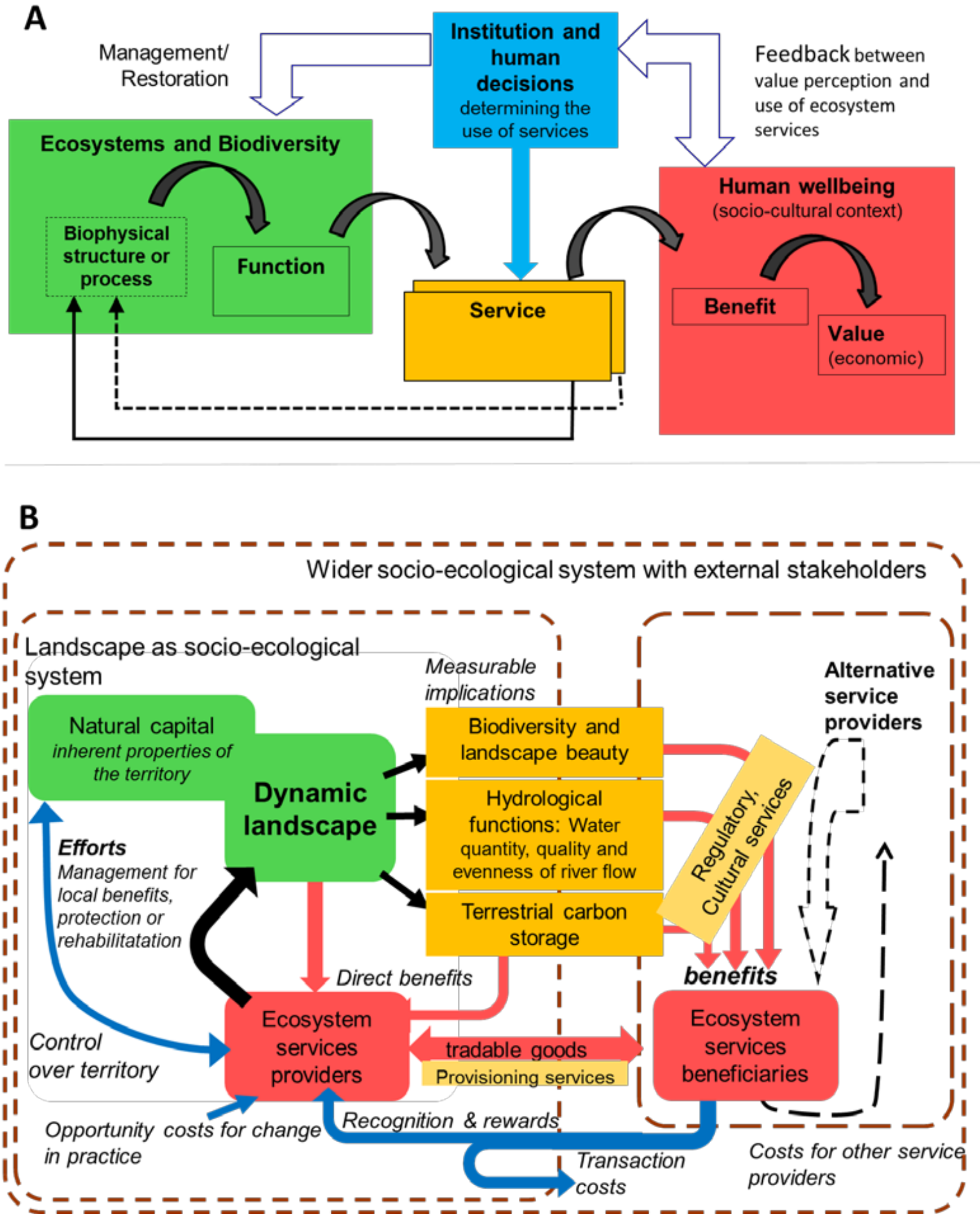

Figure 2.1 A. The cascade model of services: structure, services and human wellbeing; **B.** Ecosystem services as the emergent properties of dynamic landscapes which are partially under control of land users, and becoming services that provide benefits in the eyes of a group of external stakeholders (modified from references 2 and 5, respectively)

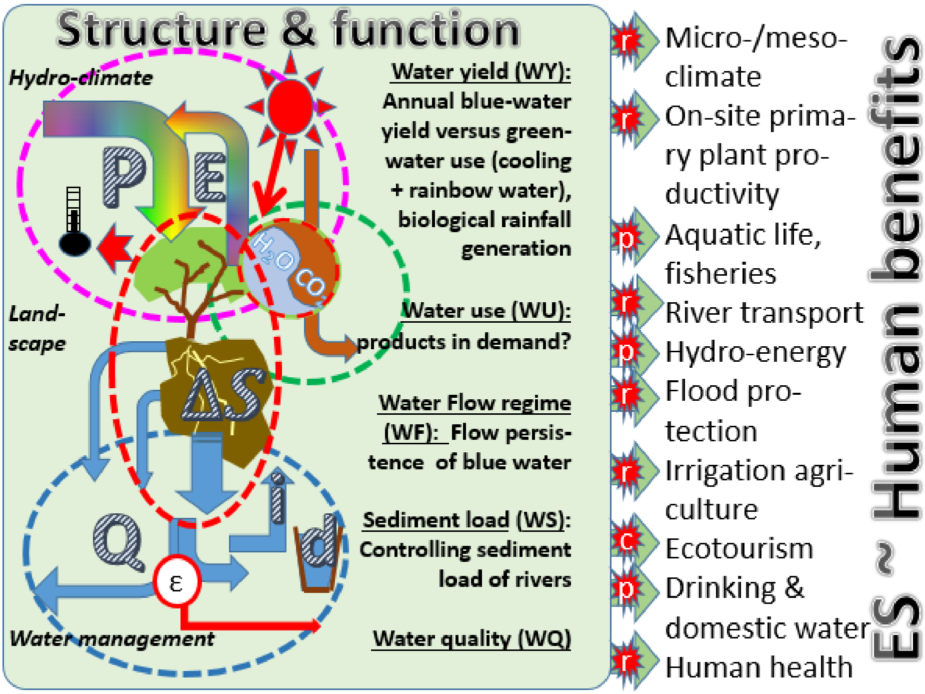

Figure 2.2 Aspects of the full hydrological cycle in which (agro)ecosystem functions at the nested scales of hydroclimate, plant, patch, and watershed[8] (P = precipitation; E = evapotranspiration; ΔS = change in soil water storage; Q = river flow; ε = energy; I = irrigation; d = domestic water use), are related to human benefits, and thus to ecosystem services (p = provisioning; r = regulating; c = cultural)

Similarly, carbon storage, greenhouse gas emissions and biodiversity[9] can be linked to the four ecosystem service categories of provisioning, regulating, cultural and supporting services, as elaborated in Table 2.1.

Underpinning functions and benefits (Figure 2.1A), a third way of approaching ES is through the spatial dimensions of ecosystem structure[10]. Structure interacts with ecosystem functioning in many aspects simultaneously, and the interaction shapes the human benefits derived, especially where existing regulation of human activity is linked to concepts such as 'forest'. Spatial approaches have advantages in terms of data collection, with the rapid advance of remote sensing, satellite and drone-based observations and open-access databases. However, the land cover legends used may not match important functional distinctions on the ground, hence interpretation of land cover to land use and the various types of benefits produced are often ambiguous. In landscapes quantified by remote sensing we can recognize both texture (the various pixel-level land cover types distinguished, for example characterized by % tree cover) and structure (spatial arrangement of components).

Table 2.1 Examples of direct and indirect benefits on the intersections of two classification systems of ecosystem services, according to functions as in Fig 1B and human benefits (MEA[1])

Human benefit based typology	Ecosystem function based typology <------------------ Indirect benefit ------------------>			Direct benefits
	Water (W)	Biodiversity conservation and landscape beauty (B)	Climate change mitigation: Carbon stock protection, net reduction of GHG emissions (G)	Production (P) (markets generally exist)
Provisioning	Drinking, domestic & industrial water Hydropower Irrigation agriculture Fisheries	Forest products (timber and non-timber) and other wild harvests (Semi-) domesticated flora and fauna (incl. "bushmeat") Pollination of harvestable plants.	Reduce the footprint of products: reduce GHG emissions and decline in C stock that are side effects of efforts to increase provisioning	Production of crops, trees, livestock, fish and derived products such as medicines
Regulating functions	Avoided floods and droughts Avoided siltation of reservoirs Hydro-climatic effects [11], [12]	Pest and disease control in plants, livestock and humans	Reducing anthropogenic climate destabilization Soil structure enhancement from increased soil organic matter content	Facilitating production of crops, trees, livestock, fish via buffered climate, water, biotic relations
Cultural & Religious functions [13]	Waterfalls, white-water rivers, lakes, other recreation opportunities	Sacred forests and spiritual retreats, Targets for ecotourism Existence value of wildlife	Relationships from shared rules and responsibilities for emission reduction & avoidance	Ecotourism as business opportunity
Supporting	Hydrological cycle, restoring soil water storage and infiltration	Species and genepool for future use Dispersal agents and agency Evolutionary services of continued adaptation	C and N cycles in terrestrial systems, interacting with atmosphere and ocean	Restoration of soil fertility (physical, chemical and biological dimensions).

Many ecosystem services are linked with buffer and filter functions in the agroecosystem: buffers reduce variability from what it would be if external forces are directly translated to internal system components, while filters separate components from a carrier flow. Many ES are derived from flows or movement in the landscape (or interception of undesirable transport) of water, soil particles and nutrients, animals, fire or similar. As the spatial arrangement of landscape elements interacts with such 'lateral flows', it matters for ecosystem services [14, 15, 16]. For different configurations of the forest-agriculture interface watershed services are likely to be appreciated differently. Ten prototypes of PES configuration were recently distinguished [17] that relate a 'ES provider', to a 'service' and 'beneficiary'. Useful classifications exist[5, 18] of spatial relations between ES provider and beneficiaries (as Chapter 1):

- *in situ* — where the services are provided and the benefits are generated in the same location,
- omni-directional, local benefits -where the services are generated in one location and benefit the surrounding landscape without directional bias,
- directional — where the service provision benefits a specific location due to the flow direction,
- omni-directional, global benefits.

2.3 Quantifying ES as part of emerging PES schemes

Ecosystem services are often taken for granted and seen as normal parts of the local environment. In situation where the benefits available for all, quantification of ES appears to be unnecessary until they are affected by change. The change can involve the access - e.g. through change of land tenure rules, or the total amount of services provided - e.g. through change of land use and land cover in neighbouring areas. Consequently, issues regarding ES often arise in the context of conservation, such as reducing rates of conversion and understanding underlying drivers of land use change. Subsequently, restoration of functions often aims at returning the structure that were lost, e.g. through 'reforestation' even though this may not bring the original forest back. In debates about loss or return of ecosystem services, it is important that the services and/or underlying functions can be quantified and that the processes that lead to positive or negative change is understood.

A quantitative review of recent ES literature[19] showed a diversity of approaches and uncovered a lack of consistent methodology. Comprehensive but critical involvement of stakeholders within assessment studies appeared to be a major quality characteristic of ES studies, balancing the need for global comparability of results. Where global comparability supports efficiency concepts of primarily global, external stakeholders, local fine-tuning may be essential for local stakeholders and their perceptions of fairness[20]. The need for quantification of ES in the specific local context occurs along the different stages in the development of a 'PES' agreement or contract[21]. Table 2.2 suggests multiple stages. As the interests of ES providers and ES beneficiaries may initially not be aligned (otherwise no 'issue' would arise), it may be essential to have an 'intermediary' involved in the early stages of the process. The caveat is that an intermediary will often add to rather than reduce transaction costs. The landscape approaches toolbox[22] is meant to guide through such a stepwise process with a combination of participatory and external-science based approaches. High-precision quantification may not be needed nor cost-effective in any stage of the process, but discussions on reliability of methods can distract progress towards solutions, while in 'performance-based' instruments different interpretations of 'evidence' can have financial consequences and motivations.

Table 2.2 Steps in the development of location-specific PES/co-investment contracts and information needs (qualitative/quantitative)

Stage	Perspectives			
	Land use regulators	**ES-providers**	**Intermediaries**	**ES-beneficiaries**
Scoping	Identifying legality of the land uses that influence ES	Clarifying land use as part of the causation of changes in ES	Clarifying the scales and system boundaries of an ES relationship	Clarifying 'issues' as changes in perceived ES levels
Identifying specific services	Identify supportive policy environment; perverse incentives		Defining the specific ES or combination of ES's that is at stake	
Quantifying baseline	Overall monitoring of environmental quality	Creating a shared understanding among the main stakeholders of the land use systems that influence ecosystem structure and function, influencing ES levels		
Clarifying the desirable and achievable changes and associated costs	Reconsideration and redefinition of regulatory 'minimum standards' for legal land use	Quantifying opportunity costs and willingness to accept/co-invest as function of expected improvement in ES	Negotiation support to bridge the mutual positions and find common ground	Quantifying willingness to pay/invest as function of expected improvement in ES
Agreeing on contracts with performance-based incentives	Abolish perverse incentives, agree on synergies	Contracts that define win-win outcomes (if only with respect to a lose-lose *status quo*) and provide incentives (co-investment) for a change of land use, that can be linked to specific ES outcomes at landscape level, and to benefits for all co-investors		
Implementation, compliance	Monitor effectiveness	Periodically re-evaluate the fairness and efficiency of the scheme, including the 'proxies' used for monitoring ES impacts of actions; early warning on emergent secondary issues		

Ecosystem services provisioning depends on landscape structure
(Photo: World Agroforestry Centre/Atiek Widayati)

Box 2.1 provides an example on how quantification of ES was implemented across the stages in a specific learning landscape for PES.

Box 2.1 The process of ES quantification: an example from Sumberjaya, Indonesia

Sumberjaya is a sub-district located in West Lampung District, Lampung Province that lies in the southern part of Sumatra Island, Indonesia. The 55 000 hectare sub-district almost coincides with the Way Besai upper watershed with elevation ranged from 720 to 1900 m above sea level. In 2010, coffee gardens covered around 70% of the total area, mostly 'illegally' grown in Protected Forest owned by the Government. The Way Besai watershed supplies a hydroelectric run-off dam of PLTA (Pembangkit Listrik Tenaga Air = Hydro Electric Power Plant-HEPP) Way Besai. Electricity generation started in 2001 with a maximum capacity of 90 MW. The Government (HEPP and Forestry District Office) believed that uncontrolled deforestation and conversion to coffee on sloping land in Sumberjaya had led to serious increase in erosion that threatened the operation of the newly constructed Way Besai hydropower dam. It resulted in the eviction of thousands of farmers from the area between 1991 and 1996. Conflict between farmers and the government ensued.

ICRAF, acting as 'honest and trusted intermediaries', started out the process of 'negotiation' between the two parties. PES concepts were used to resolve the conflict by clarifying the ES involved. Scientific evidence through observations, experimental plots and simulation modelling helped to resolve differences between local and policy perspectives at the start of the negotiation process (Table Box 2.1). Two pilot PES schemes were implemented. Establishing multi-strata systems of coffee linked to land use rights for a contract period of 25 years as 'conditional tenure' and implementing soil conservation strategies with paid contract. The process that took more than 5 years succeeded in showcasing the success of 'evidence-based' negotiation in developing PES to better manage the landscape.

Table Box 2.1 The different sets of question and measurement at different stages of PES development

Stage and objectives	Specific questions	Scale	Methods	Data and Metric
<u>Scoping</u> What are the issues?	Was it land-cover change or rainfall pattern that causes shortage of water supply to HEPP?	Landscape	Hydrological modelling	Historical rainfall (mm) and river flow (m^3/second) Soil map
<u>Identifying specific ES</u> Understanding what and how ES are being provided, and who provided the ES	How much run-off and erosion produced by different form of coffee systems?	Plot	Field measurement	Run-off (mm), erosion (gr/L)
	Was forest able to filter sedimentation better than coffee systems?	Landscape Plot	Visual observation Field measurement	Photograph during intense rainfall, Litter layer thickness (cm)

Quantifying baseline	How to develop simple indicator of sedimentation that can be measured by farmers	Landscape	Experiments and field measurement	Turbidity – sediment concentration (gr/cm^3) Turbidity – semi quantitative using secchi disk (cm – height of observed disk)
<u>Implementation</u> Developing the PES scheme	What type of PES scheme is preferred by farmers, i.e. the length of contract, the density and combination of trees, the amount of fee How to fairly choose participants for pilot PES and who are entitled to join the pilot PES?	Community	Survey for Conjoint analysis [23]; determining the preferred combination of contract attributes Procurement auction [24]	Information from farmers on preference Socio-economic information on potential farmers Bidding from farmers
<u>Monitoring and evaluation</u>	Level of turbidity PES scheme participants performance	Landscape/ stream Community/ farmers group	Field measurement	Turbidity – semi quantitative using secchi disk (cm – height of observed disk) Activity based performance in implementation of soil conservation strategies

2.4 Methods for quantifying function-based ES

In Table 2.3, existing methods for quantifying ES, generally at the ecosystem function level, are summarized for various aspects of water, carbon stocks and greenhouse gas emission, biodiversity and landscape beauty, and production of goods.

Table 2.3 Land use based ecosystems functions with metrics and examples of methods to quantify and monitor change

	Land-use based ecosystem functions, potentially perceived as "services" providing benefits to humans	Metric	Measurement methods	References
Watershed functions				
W1	Water transmission	Total water yield per unit rainfall	Rainfall monitoring; stream flow data based on water level, rating curve and stream velocity (in meters/second).	RHA[22,7,10]
W2	Buffering peak river flows	Wet- and dry-season flow persistence River discharge per unit above-average rainfall	Monitoring river flow; monitoring precipitation (station or radar-based)[25]; derivation of flow persistence metric; river flow models based on land cover, terrain, climate and soil properties; riparian wetlands; reservoir intake capacity during hydrological year.	FlowPer and GenRiver[22, 26]
W3	Gradual release of stored water supporting dry-season flows	Dry-season flow persistence; Aquifer recharge	Derivation of flow persistence metric; subsurface hydrogeology to map source-sink relations of aquifers and springs; reservoir designs and operating rules	GenRiver and FlowPer[22, 27]
W4	Maintaining water quality (relative to that of rainfall)	Pollutants per unit volume of water Biological water quality indicators	Rapid turbidity assessment (*Secchi* disk); measuring suspended sediments in streams; biological oxygen demand (BOD) for organic pollutants; pesticides, heavy metals, and microbial pathogens	PaWaMo[22,24, 28]
W5	Stability of slopes, absence of land-slides	Woody roots for topsoil binding and anchorage Non-erosive pathways for overland flow	Proximal root observations linked to 3D root reconstructions of woody roots that provide coherence to topsoil and anchorage into substrate; trait-based interpretation of existing vegetation Drainage engineering of roads on slopes	RalMA[22]
W6	Tolerable intensities of net soil loss from slopes by erosion	Surface runoff pathways Volume of trapped sediment in filter zones Infiltration of topsoil ('sealing') and subsoil (macroporosity due to 'worms and roots').	Measurement of suspended solids, or suspended sediments in rivers (as for W4) Measure surface infiltration rates, overland flows (surface runoff) Litter layer dynamics: percentage soil cover throughout year, litterfall versus transport (downslope) and decomposition.	PaLa[22]
W7	Microclimate effects on air humidity, temperature and air quality	Wind speed; reduction in daily maximum temperature; land surface temperatures	Microclimate recordings (incl. temperature recording in ventilated shaded box); satellite recording of surface temperatures	CoolTree[22]

Land-use based ecosystem functions, potentially perceived as "services" providing benefits to humans		Metric	Measurement methods	References
W8	Coastal protection from storm surges, tsunamis	Retardation of waves, reduced maximum run up height	Surface roughness of vegetation based on tree diameter distribution.	[29]
W9	Ecological rainfall infrastructure and biological rainfall generation	Recycling of atmos-pheric moisture; height above vegetation of rainfall generating events; ice-nucleating agents	Rainfall intensity recording, Trait-based interpretation of vegetation, Continental scale bookkeeping of 'rainbow water'.	[30]
Biodiversity and Landscape beauty (B)				
B1	Integrity of conservation areas by preventing loss of habitat and threats at population level around core protection site	Land cover change intensity Number and area of breeding and foraging sites Number of threatened species protected	Quantification of land cover change on satellite imagery, comparisons with historical baselines and reference locations with similar accessibility and human population density Trait based evaluation of flora (incl. wood density, dispersal traits) and fauna (functional groupings; camera traps)	[31]
B2	Habitat for a sub-set of the original fauna and flora inside agriculturally used landscapes	Presence and repro-duction relative to the least disturbed habitat remaining	Tree diversity records (seedling, sapling, pole, tree stages) as structural elements, Birds (and bats?) as cost-effective indicators of functional groups.	QBSur[22, 32, 33, 34]
B3	Connectivity between protected areas via corridors	Evidence of dispersal and movement between protected areas	Evaluation of landscape structure based on (potentially sex-specific) dispersal traits, camera traps, local knowledge of animal behaviour	[35]
B4	Opportunities for local-level 'restoration', in landscapes where connectivity is still maintained	Area restored with increased natural vegetation cover after disturbance (fire, hurricanes, earthquakes)	Trait-based evaluation of vegetation dynamics	[12]
B5	Various forms of *ex situ* and *peri situ* conservation	Species protection status according to IUCN red list	Current red list rankings of species present in historical records of local flora and fauna	
B6	Opportunity for active recreation (ecotourism)	Number of visitors for various recreation purposes Number of local residents employed in tourism	Entry ticket sales analysis Interviews and questionnaires on motivation (wilderness experience, relaxation, inspiration and education), distances travelled, expenditures	[36]

Land-use based ecosystem functions, potentially perceived as "services" providing benefits to humans		Metric	Measurement methods	References
B7	Presence and population dynamics in functional groups of organisms with desirable traits	Pollination effective-ness Biological pest control effectiveness	Trait-based analysis of B2 data; records of fruit set in key species; pest population dynamics; phenology records of vegetation-level fruiting	[37]
Carbon stocks and Greenhouse Gas Emission (G)				
G1	Protecting carbon stocks in natural forest areas, peat soils and other carbon storage areas	Area protected; vegetation cover, carbon stocks	As in B1; land cover change intensity; vegetation inventory used for allometric estimates of biomass and soil carbon stocks	ResFa[22] RePeat[22]
G2	Protecting above- and/or belowground carbon stocks in areas used for (agro)forestry and/or agriculture	Land cover change intensity, time-averaged carbon stocks	Vegetation inventory; estimating of biomass and soil carbon stocks throughout lifecycle of main land use systems	RaCSA in[22, 38, 39]
G3	Restocking with carbon	Increase in tree cover by area Increase tree cover by density	Remote sensing of tree cover change Sampling, vegetation inventory	[40]
G4	Accumulating wood and other products derived from recent plant production in, for example, the form of houses, furniture, paper, organic waste dumps	Carbon stored in harvested wood products	Estimating change in carbon held in harvested products	
G5	Closing nitrogen efficiency gaps and reducing unnecessary greenhouse gas emissions in agricultural production	N_2O emissions per unit external fertilizer N input CH_4 absorption or emission rates	Land cover analysis with default emission factors Chamber measurements of greenhouse gas fluxes throughout the year	[41, 42]
Production (P)				
P1	Extraction of potentially renewable resources	Amount of timber; growth rate; amount of growing-stock for removal purposes	Inventory data on net volume of timber, net merchantable growth, and the net volume of growing-stock	
P2	Non-renewable resource mining	Compliance with good management practices	Effectiveness of efforts to minimize effects on W, B and C Restoration after termination of mining	

Land-use based ecosystem functions, potentially perceived as "services" providing benefits to humans		Metric	Measurement methods	References
P3	Nutrient and water supply for agricultural crops, fodder and trees	Dependency on external inputs	Landscape analysis of local W services, local nutrient transfers	
P4	Biotic relationships: pollination, pests, diseases and their control	Dependency on external agrochemical inputs	Landscape analysis of local B services	

2.5 Way forward

The function-based understanding of landscapes and (agro-)ecosystems and their texture and structure can be translated to the four categories of services in common ES classification. Subsequent chapters will relate these services to 'value' concepts and further explore the development of PES mechanisms with their need for measurement and monitoring. Initial clarity on the character and quantities of ES is crucial in shaping any PES scheme, while robust metrics and monitoring is needed for ensuring the sustainability of such relationships between providers and beneficiaries.

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