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A proposed framework for assessing ecosystem goods and services from planted forests

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ABSTRACT

The planting of forests has been met with both scepticism and support in international forest policy and management fora. Discussions regarding the values of plantations for extrinsic purposes such as timber supply, carbon sequestration, water quality and biodiversity conservation, reveal widely varying opinions across and within different settings. Recent research highlights the role of planted forests in providing multiple ecosystem services to human society. However, there has been little assessment of ecosystems services, partly due to lack of suitable frameworks and evaluation tools. Planted forests generally have low ecosystem services values initially and are more vulnerable to erosion and other impacts of mismanagement than natural forests. Careful monitoring of change in ecosystem services values over time is therefore vital to investors and all stakeholders in plantations. Drawing on lessons derived from ecosystem services assessment for various land use types, here we propose an easy-to-apply framework to assess ecosystem services from planted forests that could be used in various planted forest types around the world. A necessary next step for researchers and practitioners is to test the proposed framework under various settings.

1. Introduction

Planted forests are becoming an increasingly important part of the global forest estate. Commercial timber supplies from natural forests seem to have peaked (Warman, 2014) while supplies from planted forests are increasing (Boucher and Elias, 2014; Warman, 2014) and will have to increase further to meet future global timber supply needs (Payn et al., 2015). In fact, planted forests were estimated in 2010 to cover 278 million ha globally and are expanding, while the area of natural forests continues to decline (Keenan et al., 2015). Planted forests are expected to play a key role in achieving recently adopted, global restoration targets such as the Bonn Challenge (to restore 150 million ha of degraded and deforested land by 2020) and the New York Declaration on Forests as well as the objectives of Article 5 of the Paris Climate Change Agreement. As a whole, planted forests have the potential to provide a wide array of goods, services, ecological functions as well as direct benefits to society and the environment. The Food and Agriculture Organization of the United Nations defines planted forests as those 'composed of trees established through planting or seeding by human intervention' (FAO, 2014). Although there is evidence of conversion of natural-to-planted forests in the tropics and subtropics (e.g., Ainembabazi and Angelsen, 2014; Zamorano-Elgueta et al., 2015), loss of natural forest in these two biomes is primarily driven by agricultural expansion (FAO, 2016).

Forest ecosystem services (ES) include timber and non-timber forest products (provisioning services) and regulating, habitat or supporting services and cultural services (TEEB, 2010). Planted forests, either for productive or protective purposes, also have the potential to mitigate land degradation (e.g. Stanturf et al., 2014). Demand for regulating services such as carbon sequestration and water regulation, and for cultural services such as recreation and spiritual values, are expected to rise because of both increasing global population and rising standards of living (FAO, 2010; Miura et al., 2015). Therefore, the role of planted forests as ES providers has attracted increasing attention (Brockerhoff et al., 2008, 2013; Bauhus et al., 2010; Yao et al., 2014; Vihervaara et al., 2012, Barua et al., 2014). Although the potential to enhance the ecosystem values of planted forests has been recognised for some time (Keenan et al., 1999), Lindenmayer et al. (2015) returned to this topic more recently. Yet there is still a need for developing tools and assessment frameworks to guide informed decision making. Vihervaara et al. (2012) provides important insights into stakeholder perceptions of ES from planted

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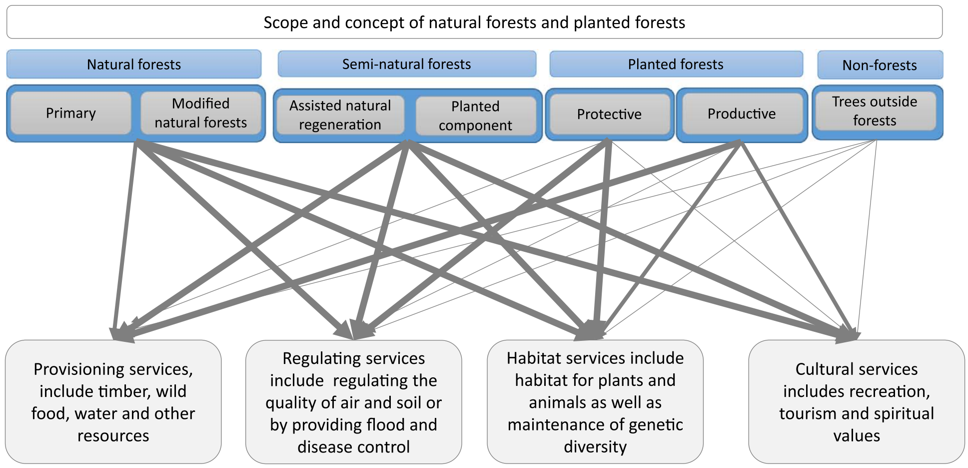

Fig. 1. Natural, semi-natural, planted forest and planted trees outside the forests, and their relative degree of provision of ecosystem services.
The thickness of the arrows indicates relative rate of delivery of ecosystem services (figure adapted from Carle and Holmgren, 2008; Brockerhoff et al., 2013; Ferraz et al., 2013).

forest (but it has been criticized for inadequate research design; Paruelo, 2012). Brockerhoff et al. (2013) review biodiversity-dependent ecosystem services and associated management options. Several other papers outline various aspects of ES associated with planted forests such as climate change adaptation (Ray et al., 2014), water conservation (Van Dijk and Keenan, 2007; Keenan and Van Dijk, 2010 ; Ferraz et al., 2013) and prioritisation of ES for conservation efforts (Moore, 2013). To our knowledge, a robust framework for assessing ES from planted forests is lacking. This paper aims to fill this gap.

Assessment of ES from planted forests can serve many purposes, including: (i) raising clarity and awareness of the relative importance of planted forests to policy makers, investors, environmental NGOs and local communities, (ii) improving the efficient use of limited funds by identifying where planted forests can achieve greatest benefits at lowest cost, (iii) supporting new opportunities to link planted forests with markets for ecosystem services, (iv) providing guidance for decision makers in understanding user preferences and the relative value that people place on ecosystem services, (v) generating information for designing planted forests so as to maximize their contribution to local communities, broader society and the global environment, and (vi) informing land use planning. In the approach outlined here, the values ascribed to various ES is determined by the beneficiaries of the particular ES, which range from local to national and global markets (Baral et al., 2013).

Here we review current approaches for identifying and assessing ES from various types of planted forests and propose a simple and pragmatic framework for assessing ES, applicable to any type of planted forests. To this end, we first review existing typologies of planted forests. Second, we re-visit classification systems and approaches used to assess ES and show their relevance to planted forests. Third, we construct a matrix where different types of planted forests are linked to specific ES. Finally, we propose an approach to assess ES from planted forests that is generalizable to a wide range of settings.

2. Planted forests – typologies and associated ecosystem services

A wide range of objectives, definitions, associated typologies and classifications for planted forests exist in the literature (Sohngen and Sedjo, 1999; Helms, 1998; Ingles et al., 2002; Evans, 2009; Batra and Pirard, 2015). Objectives are mainly based on (i) purpose, such as industrial use, environmental, agroforestry, farm forestry; (ii) species choice, such as monoculture or mixed species, hardwood or softwood, native or exotic species; (iii) management objectives such as production or environmental protection; (iv) rotation length – short (< 10 yrs), medium (10 – 20 yrs), long (> 20 yrs); (v) end use – e.g. timber, non-timber products, pulp, bioenergy; (vi) intensity of management – intensive or extensively managed; (vii) scale of operation – large and contiguous or small and fragmented; (viii) ownership – company, communal, share farming, out growers. A broad classification of natural, semi natural and planted forests is commonly used to reflect the different capacity of various planted forests to supply ecosystem services (Fig. 1). It is important to note that planted forests generally differ from natural forests in species diversity, regeneration characteristics, ecosystem functioning and associated ecosystem services provision – especially in their early stages of establishment. However, in some cases, the number and types of ecosystem services from planted forest may be similar to those of natural forests – especially later in their establishment. A summary list of ecosystem services from planted forests is shown in Table 1.

The magnitude (or value) of ecosystem services provided by various types of planted forests may differ (see De Groot et al., 2010). For example, a plantation estate of exotic monoculture managed on a short rotation basis may ultimately provide high fibre supply but is likely to provide lower regulating and cultural services than a long rotation estate (Pirard et al., 2016) or than a mixed species or native tree plantation (Felton et al., 2016). The human beneficiaries of provisioning, regulating and cultural services can also differ (Fig. 2).

3. Revisiting the concepts – defining and classifying ES

Ecosystem services have been defined and classified in many ways and the ongoing debate about the implications of these classifications for assessment and valuation is well covered in the literature (MEA, 2005; Boyd and Banzhaf, 2007; Costanza, 2008; Fisher et al., 2009; Haines-Young and Potschin, 2009; Patterson and Coelheo, 2009; Baral et al., 2014). For our purposes, we use the definition and classification proposed by The Economics of Ecosystems and Biodiversity (TEEB), which defines ES as, 'the direct and indirect contributions of ecosystems to human well-being' (TEEB, 2010). TEEB classification replaced the 'supporting services' in the Millennium Ecosystem Assessment (MEA) with 'habitat and supporting' services, which helps to prevent double counting in ecosystem services audits. Other influential definitions and classifications frequently cited in environmental literature are listed in Appendix A. We use the TEEB classification as it has been much refined and shown to have great utility since the original classification of the MEA.

Table 1
List of Ecosystem Services (ES) from planted forests, description/indicators, beneficiaries, scale of production and unit of measurement. Letters in brackets represent The Economics of Ecosystem and Biodiversity (TEEB, 2010) ES categories: provisioning (P), regulating (R) and cultural (C) services. Scale): 'O' on-site (in situ delivery), 'L' local (off-site, 100 m–10 km), 'R' regional (10–1000 km), 'G' global (> 1000 km). The provision of specific types of ES depends on a variety of factors such as type of planted forest (see Fig. 1), rotation age, species type, position in the landscape, and management intensity.

Ecosystem Service type	Description and relevant references	Beneficiary/use*	Scale*	Unit of measurement
Food (P)	Provision of wild foods such as mushrooms, berries, fruits (e.g., Evans, 2009;FAO, 2010)	Private/public	O	Number of foods or kg ha^{-1}
Raw materials (P)	Provision of raw materials for construction, pulp and wood, biofuels and essential oils (e.g., Carle and Holmgren, 2008; Buford and Neary, 2010; FAO, 2010)	Private	O	m^3 or tons ha^{-1}
Fresh water (P)	Filtering, retention and storage of freshwater available for human consumption or industrial use (e.g., Baillie and Neary, 2015)	Public	O-R	ML ha^{-1} yr^{-1}
Medicinal resources (P)	Availability of plants for traditional medicines as well as raw material for pharmaceutical industry (e.g., FAO, 2010)	Public	O-R	Number of species or kg ha^{-1}
Local climate and air quality (R)	Enhancement of rainfall and water availability at local scale, and regulating air quality by removing pollutants from atmosphere (e.g., Pramova et al., 2012)	Public	L-R	
Carbon sequestration and storage (R)	Regulation of global climate by sequestering and storing greenhouse gases (e.g., Peng et al., 2014)	Public/Private	O-R	Mg ha^{-1}
Moderation of extreme events (R)	Buffering against extreme weather events or natural hazards, such as floods storms and landslides, and hence reducing damaging impacts (e.g. Calder and Aylward, 2006)	Public	O- L	Number of events protected
Erosion prevention and maintenance of soil fertility (R)	Capacity to provide vital regulating services by preventing soil erosion (e.g., Oliveira et al., 2013)	Public/Private	O	ha yr^{-1}
Pollination (R)	Capacity to support habitat for insects and birds that provide pollination and other services essential for the development of products, e.g. fruit, vegetables and seeds (e.g., Taki et al., 2013)	Private/Public	O-R	Number of, or impact of pollinating species
Water regulation (R)	Provision of land cover and hence regulation of erosion and hydrology (e.g., Keenan and van Dijk, 2010)	Public /Private	O-R	m^3 ha^{-1}
Biological control (R)	Habitat for natural fauna and flora that act as natural controls of predators and parasites (e.g., Nagaike, 2002)	Public/Private	O-R	Number of beneficial species
Habitat for species (H)	Habitat for a variety of native plants and animals (in biodiverse planted forests, e.g., Nagaike, 2002).	Public	O-R	Number of species present
Maintenance of genetic diversity (H)	Capacity to support high biodiversity – by number of species which makes them more genetically diverse than others	Public	O-G	
Recreation and mental and physical health (C)	Provision of scenic and natural landscapes that provide recreation areas important in maintaining mental and physical health (e.g., Dhakal et al., 2012; Smailes and Smith, 2001; Turner et al., 2011)	Public	O-L	
Tourism (C)	Natural ecosystems as sites for eco-tourism, outdoor sport, local tourism opportunities (e.g., Dhakal et al., 2012; Smailes and Smith, 2001; Turner et al., 2011)	Public/Private	O-R	Number of visitors yr^{-1}, \$ ha^{-1} yr^{-1}

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* Adapted from Baral et al. (2013).

4. Recent trends in assessing ES

To manage planted forests for multiple ES we must be able to recognize, quantify and value the full suite of services they provide. In the case of planted forests, this assessment process must start at or before establishment and continue through various stages of plantation development – so investors can keep track of their investment and foresters can adapt rapidly to changes in management needs. Since the publication of the Millennium Ecosystem Assessment (MEA, 2005)

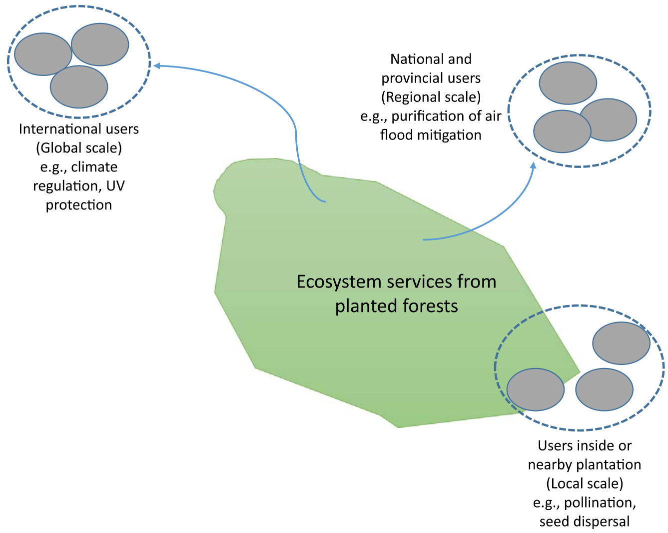

Fig. 2. Conceptual diagram showing local, regional and global users of regulating and cultural services produced by planted forests. Certain services are enjoyed at multiple scales, for example, climate regulation via carbon sequestration by planted forest is beneficial to local, regional and global users. See Table 1 for ES provided by planted forests and Table 2 for provision of ES from planted forests in relation to different land use.

there has been rapid growth in the science of assessing ES and its application in land use planning (Nelson et al., 2009; Tallis and Polasky, 2009; Braat and de Groot, 2012; Crossman et al., 2012; Goldstein et al., 2012). Numerous global, national and sub-national initiatives on ES assessments are underway to make the concept of ES operational and linked to policy (UKNEA, 2011; IPBES, 2014; Ruckelshaus et al., 2013). A brief summary of these initiatives and associated outcomes is outlined in Table 3. Similarly, international NGOs, international donor organizations, and international financial institutions are involved in promoting ES assessments to link policy and decisions associated to ES (Perrings et al., 2010; World Bank, 2015). Recently, the President of the United States of America issued a memorandum requiring all Federal agencies to incorporate ecosystem services into Federal planning and decision making (White House, 2015). Moreover, business and private sector organizations are involved in assessing and valuing ecosystem services which they often refer to as 'natural capital' (BSR, 2014; WBCSD, 2014). In spite of the growing awareness and progress towards ES assessment, there are still difficulties in applying ES assessment to policy and decision making for investment (Knight et al., 2008; Laurans et al., 2013; MacDonald et al., 2014). This is mainly due to the wide diversity of approaches, unclear terminology that causes misunderstanding among non-specialists, lack of consensus about benefit of an ES approach for land use planning and conservation, high cost of implementation (Polasky et al., 2014) and too theoretical (Lele et al., 2013; Bull et al., 2016). The framework proposed here is intended to enhance communication and awareness and local stakeholder engagement, as well as sound information to investors.

5. Methods and tools for assessing and monitoring ES

Maintaining and enhancing the ES available from planted forests requires thorough assessment and documentation. Each particular ES can be assessed at different spatial and temporal scales in relation to their potential supply, demand and consumption, and using a range of indicators or metrics. This process usually involves two approaches, (i) qualitative assessment using expert or user opinion of the potential flow or capacity in relative terms such as increasing, stable and decreasing (Burkhard et al., 2012; Baral et al., 2014; Paudyal et al., 2015; van Oort et al., 2015; Zarandian et al., 2016), and (ii) quantitative assessments that require measurement of field-based biophysical outcomes, local and regional proxies, or their combination such as tonnes of C per ha or ML of water per ha (Nelson et al., 2009; Raudsepp-Hearne et al., 2010; Egoh et al., 2011; also see Appendix B for summary of recent studies on qualitative and quantitative assessment of ES) that are linked to societal benefits. The assessed values from both approaches are often transferred into a "GIS environment" and displayed in ES "flow maps" to produce spatially explicit results and analyse trade-offs and synergies in the provision of multiple ES (Baral et al., 2014). An alternative approach, monetary valuation, is becoming a popular ES assessment tool that can facilitate communicating the importance of ES to policy makers (Hayha et al., 2015). However, economic evaluation is also a part of quantitative assessments and so a separate categorisation may not be required. Qualitative assessments provide valuable insights from information not necessarily obvious from quantitative data, but can be subjective and error-prone and contingent on the knowledge and experience of

Table 2
Example of ecosystem services (ES) provided by intensively managed planted forests and qualitative comparison of services relative to native forests, peatlands and degraded or cleared land. The relative provision of ES may depend on many factors, such as species, objectives, site conditions and management regime, and so is indicative only (adapted from de Groot and van der Meer, 2010; Baral et al., 2013, 2014; Brockerhoff et al., 2013; Ferraz et al., 2013). See Table 1 for description of ecosystem services categories, beneficiaries and scale.

Ecosystem services	Provision of ES from planted forests in relation to			
	Native forests	Native grasslands	Managed pasture	Agriculture
Provisioning services				
Food Production	Lower	Lower	Similar	Lower
Timber production	Higher	Higher	Higher	Higher
Medicines	Lower	Lower	Higher	Higher
Freshwater	Lower	Higher	Lower	Higher
Regulating services				
Fresh air regulation	Lower	Higher	Higher	Higher
Carbon sequestration and storage	Higher	Higher	Higher	Higher
Groundwater recharge	Lower	Lower	Lower	Higher
Natural hazard regulation	Lower	Higher	Higher	Higher
Water purification	Lower	Lower	Higher	Higher
Disease regulation	Lower	?	Higher	Higher
Pollination	Lower	Lower	Lower	Higher
Erosion prevention and soil protection	Similar	Lower	Similar	Higher
Habitat or supporting services				
Habitat for species	Lower	Lower	Higher	Higher
Maintenance of genetic diversity	Lower	Lower	?	Higher
Cultural services				
Spiritual and religious values	Lower	Lower	?	?
Aesthetic values	Lower	Lower	?	?

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Table 3
Some current international initiatives that shape the way ecosystem services are assessed and their influence in policy formulation.

Initiatives	Brief description/ aim	Influence on ES assessment and policy	Reference
UN Millennium Ecosystem Assessment (MEA)	A multilateral initiative aimed at detailing global and sub-global assessments of the links between ecosystem change and human wellbeing	Documents wide-spread impacts – leading to improved awareness - many government and non-governmental organizations started adopting this concept	Tallis et al. (2009); Pistorius et al. (2012)
The Economics of Ecosystem and Biodiversity (TEEB)	To provide global assessment of economic benefits of biodiversity and ecosystem services, and the costs associated with their loss	The launch of the TEEB reports has led to various countries initiating TEEB studies to demonstrate the value of their ecosystems and to encourage policy that recognizes and accounts for their ecosystem services and biodiversity	TEEB (2010)
UK National Ecosystem Assessment (UKNEA)	An analysis of the UK's natural environment in terms of the benefits it provides to society and continuing economic prosperity – commenced in mid-2009 and reported in June 2011 in an inclusive process involving many government, academic, NGO and private sector institutions.	Indicates policy options for high level policy makers to secure the continued delivery of the UK's ecosystem services; evidence base to policy makers to strengthen decision making and ensure effective management in the future; lessons applicable to globally	UKNEA (2011)
Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES)	A body committed to bridging the gap between science and policy, seeking to advise governments on how to halt further degradation	Provides a mechanism recognised by both the scientific and policy communities to synthesize, review, assess and critically evaluate relevant information and knowledge generated worldwide by governments, academia, scientific organizations, non-governmental organizations and indigenous communities	http://www.ipbes.net/about-ipbes.html
A Long-Term Biodiversity, Ecosystem and Awareness Research Network (ALTER-net)	A network linking 27 institutes from 18 European countries focusing on ecosystems services	Integrates research capacities across Europe: assessing changes in biodiversity, analysing the effect of those changes on ecosystem services and informing policymakers and the public about this at provides a European scale with global impact	http://www.alter-net.info/
Natural Capital Project	A partnership combining research innovation at Stanford University and the University of Minnesota with the global reach of conservation science and policy at The Nature Conservancy and the World Wildlife Fund US	Has improved the state of ecosystem services and human well-being by integrating the values of nature into all major decisions affecting the environment; test and demonstrate how accounting for nature's benefits can support more sustainable investment and policy decisions	http://www.naturalcapitalproject.org/

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Table 3 (continued)

the expert in a particular landscape (Baral et al., 2014; Paudyal et al., 2015). Quantitative assessments may be more reliable but usually require considerable financial and human resources. Qualitative assessments are useful for preliminary planning and understanding broad trends but quantitative assessments may be required for detailed planning, policy formulation and payment for ecosystem services mechanisms.

A number of tools have been developed for assessing multiple ES and display on maps, such as Integrated Valuation of Ecosystem Services and Trade-offs (InVEST, Tallis et al., 2014), the Multi-scale Integrated Models of Ecosystem Services (MIMES, Boumans and Costanza, 2008), Artificial Intelligence for Ecosystem Services (ARIES; Villa et al., 2009), Social Value of Ecosystems Services (SoLVES, Sherrouse et al., 2011) and the Toolkit for Ecosystem Service Site-Based Assessment (TESSA, Birch et al., 2014). These tools require qualitative and/or quantitative information about sink or flow of ES and often represented in maps. Detailed description of each tool and its associated strengths and limitations is beyond the scope of this paper. Bagstad et al. (2013) provide an overview of 17 popular ES assessment tools and evaluate their performance using eight criteria such as intended uses, services modelled, analytical approaches, data requirements and outputs, as well time requirements. The authors found that, (i) tools differed greatly in their performance against the evaluative criteria, (ii) a number of tools are feasible for immediate widespread use while other require development of supporting databases and, (iii) some complementarity exists as certain tools could be used together. The approaches and tools associated with ES assessment at a landscape scale can be useful in the sphere of planted forests, as proposed by Burkhard et al. (2010), Hayha et al. (2015) and Paudyal et al. (2015). For example, Burkhard's and Paudyal's approach to assessing the relative capacity of different land cover types can be applied to planted forests in the context of their provision of multiple ES.

6. Toward a framework for assessing ES from planted forests

Drawing from lessons from various ES frameworks and other relevant ES assessments described above we propose a simple framework to assess the provision of ES from planted forests (Fig. 3). It comprises three key components, (i) Silviculture and management for planted forests (Fig. 3a), (ii) ES classification using TEEB categories (Fig. 3b), and (iii) common approaches to assessing ES (Fig. 3c). First, the assessor defines the scope of the assessment and identifies the objectives and process of the assessment. Second, the key ES provided by planted forest are screened using one of the ES classification system (i.e. the TEEB classification suggested in Fig. 3b) and prioritised based on types of planted forest and management practices (Fig.3a). Third, beneficiaries of ecosystem services are determined, and an appropriate approach and tools selected depending on available time, data and resources (Fig. 3c). Finally, data on ES provision are analysed, synthesised and communicated to relevant stakeholders.

Clarification about the scope of the assessment including key questions such as underlying objectives, relevant actors, available/potential ES flows and sinks in the management area, can all be very useful. Other essential tasks at the scoping phase include ensuring adequate budget, data availability, suitable approaches, starting dates and frequency of measurements, and clarifying potential roles and responsibilities of different stakeholders (Rosenthal et al., 2014).

The monetary and non-monetary values of ES are dependent on the beneficiaries (Fisher et al., 2009; Bennett et al., 2009). That is, beneficiaries can vary from local land owners and communities to purchasers or users of ES in other parts of a catchment, or those at the scale of national or global markets (Fig. 2). The nature of the benefit also varies. For example, those purchasing ecosystem-based goods are generally receiving a private benefit (Baral et al., 2013). For services such as water regulation, carbon sequestration or biodiversity conservation, benefits go to a wider range of stakeholders, both public and private. Determining the beneficiaries of each ES is a key requirement as this allows focus on defining 'benefit relevant indicators' (Olander et al., 2015).

Undertaking an analysis of ES provision as well as status and trends under past and future management scenarios can also be valuable. Rosenthal et al. (2014) suggest that such a task should involve, (i) choosing appropriate analytical tools; (ii) defining alternative management scenarios; (iii) assessing trade-offs and synergies among different ES; and (iv) linking outcomes in terms of supply and value. Understanding trade-offs is critical, because many ES are not compatible with particular management practices. For example, intensive silvicultural practices in planted forests may enhance timber productivity and associated ecosystem goods while compromising biological diversity. In many cases, inputs and review from local experts and other stakeholders can be helpful in refining practices to achieve desired outcomes (Rosenthal et al., 2014).

Synthesising results in an appropriate format and communicating to relevant stakeholders in an appropriate manner are both crucial to the application of any ES assessment undertaking. Results can be communicated in a variety of ways, such as direct reporting (e.g. to managers and plantation investors) web-based maps, conferences and workshops, and peer reviewed papers. Clear, targeted and contextualised communication of results can extend the impact of ES assessment (Rosenthal et al., 2014). A strong communication plan may include, but not be limited to, (i) identifying the target audience; (ii) choosing an approach appropriate to the target audience; (iii) selecting appropriate media such as visual displays, maps and figures.

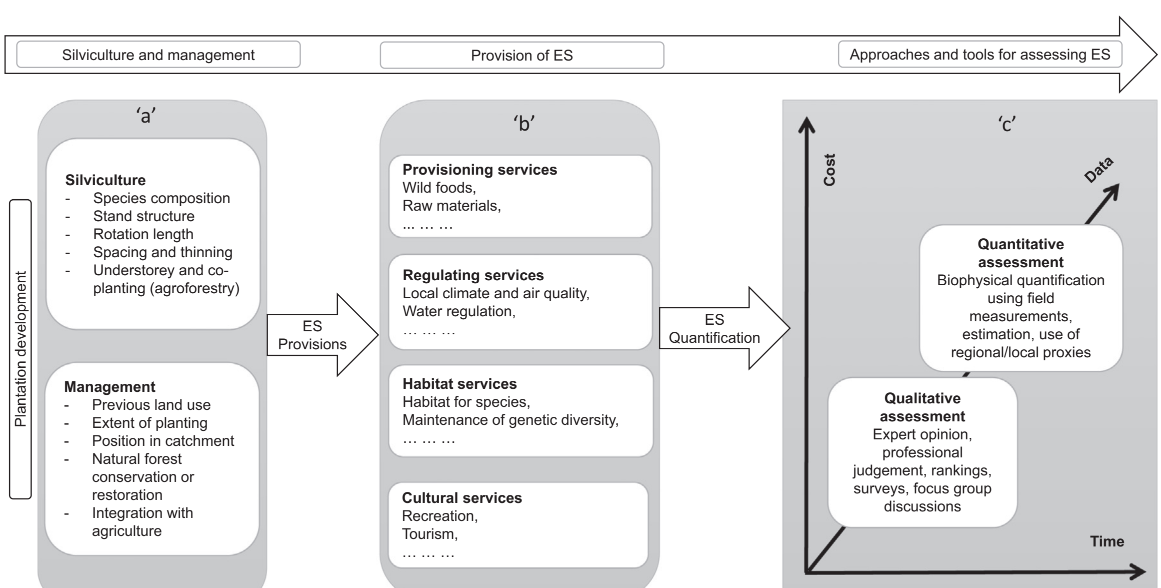

Fig. 3. A simplified framework for planning the assessment of Ecosystem Services (ES) from planted forests. The main components shown are (a) silviculture and management of planted forests, (b) potential ES from planted forests, and (c) common approaches to assessing ES, and associated time, data and cost.
The time, cost and data requirement depends on factors such as the number of services assessed and the size of the landscape and is indicative only (c) (figure adapted from TEEB, 2010; Busch et al., 2012; Baral et al., 2014; Olander et al., 2015).

7. Final considerations

In this paper we reviewed the range of ES provided by planted forests and presented a conceptual framework to assess their delivery. As planted forests provide many ES beyond timber production and their expansion is increasing, effective planning and management of ES flows will require in the near future an improved evidence base. The three components of our framework outlined above follow a combination of methodologies used by Busch et al. (2012) and Baral et al. (2014). Yet our framework specifically covers the beneficiaries of ES while enabling both qualitative and quantitative assessments of ES sources and sinks in the context of planted forests. We recognize that this framework needs testing across various types of planted forests in different geographic locations. We close the paper with a few considerations for planning and management of ES of planted forests based on the available literature. A framework for assessment of ES in planted forest should enable users to design a special approach, process and methods to suit the particular needs of investors, local people, landscape and the predetermined objectives of the plantation project. The framework provided here is intended to be a valuable guide to enable users to discuss and then design an appropriate assessment approach for their particular landscape, forest, situation and needs. This guiding frame could be invaluable as a basis for participatory stakeholder process that could enhance transparency to all stakeholders, and encourage ongoing participation in collection of data and adaptive management of the plantation over time.

Certification of responsible forest management is now an established part of the forest management landscape (see Meijaard et al., 2011, 2014). Market pressures and community demands will require forest managers to demonstrate the benefits and impacts of planted forests on a range of values and services (see conceptual diagram, Fig. 2). However, reliable measurement, verification, and monitoring, and guarantee of the maintenance of ES are key requirements for certification (Meijaard et al., 2011, 2014).

Finally, there is considerable concern about negative effects of planted forests, which are often called ecosystem dis-services (Dunn, 2010) and not covered in this paper. For example, negative hydrological effects (Engel et al., 2005; Farley et al., 2005), weed infestation (Richardson and Rejmánek, 2011), water pollution (Baillie et al., 2015), soil erosion (Evans, 2009) or impacts of extensive industrial plantation development on communities, social values and food production. In our view, these are not the problem of planted forests per se but represent failures in policy planning, management and community engagement in the design and development of plantation estates. Although information on the occurrence of such impacts is vital to investors in plantations, their incidence can be minimised by proper planning and appropriate dialogue with stakeholders. Following best practices and environmental guidelines can help to minimise effects of weed infestation and soil erosion. Approaches such as limiting planted forests to less than 20% in each catchment to reduce hydrological impacts, limiting use of chemical and fertilisers to reduce water pollution, choosing appropriate species with low weediness potential, using genetic conservation guidelines, incorporating biodiversity, habitat and social values into planted forest design and integrating with food production and/or conservation at local and landscape scales can overcome many of the concerns raised about planted forests.

Definition of key terms used in this paper

Assessment: The analysis and review of information derived from research for the purpose of helping someone in a position of responsibility to evaluate possible actions or think about a problem. Assessment means assembling, summarising, organising, interpreting, and possibly reconciling pieces of existing knowledge and communicating them so that they are relevant and helpful to an intelligent but inexpert decision-maker (Parson, 1995).

Benefits: Positive change in wellbeing from the fulfilment of needs and wants (TEEB, 2010).

Biodiversity: The variability among living organisms from all sources, including inter alia terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part, this includes diversity within species, between species, and of ecosystems (cf. Article 2 of the Convention on Biological Diversity, 1992).

Ecosystem assessment: A social process through which the findings of science concerning the causes of ecosystem change, their consequences for human well-being, and management and policy options are brought to bear on the needs of decision-makers (UK NEA, 2011).

Ecosystem function: Subset of the interactions between biophysical structures, biodiversity and ecosystem processes that underpin the capacity of an ecosystem to provide ecosystem services (TEEB, 2010).

Ecosystem process: Any change or reaction, which occurs within ecosystems, physical, chemical or biological. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy (MEA, 2005).

Ecosystem service: The benefits that people obtain from ecosystems (MEA, 2005). The direct and indirect contributions of ecosystems to human well-being (TEEB, 2010). The concept of 'ecosystem goods and services' is synonymous with ecosystem services. The service flow in MEA's conceptual framework refers to the service actually used.

Trade-offs: Trade-offs among ecosystem goods and services occur when an increase in one service leads to a decrease in one or more other services, and can represent important externalities in current approaches to EGS management (Rodriguez et al., 2006; Bennett et al., 2009).

Synergies: Synergies occur when services either increase or decrease due to simultaneous response to the same driver or due to true interactions among services (Bennett et al., 2009; Chhatre and Agrawal, 2009).

Demand of ecosystem services: The sum of all ecosystem goods and services currently consumed or used in a particular area over a given time period (Burkhard et al., 2012).

Supply of ecosystem services: The capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period. Here, capacity refers to the generation of the actually used set of natural resources and services (Burkhard et al., 2012).

Conflict of interest

No potential conflict of interest was reported by the authors

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:http://dx.doi.org/10.1016/j.ecoser.2016.10.002.

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