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E-CHAPTER FROM THIS BOOK

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Ecosystem accounting to value ecosystem assets and services provided by agroforestry

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1 Introduction

Much of the global economy is dependent on natural capital. Natural capital is defined as the stock of renewable and non-renewable resources that combine to provide flows of services and benefits for humanity (Natural Capital Coalition, 2016). These benefits are generally derived from the ecosystem services that natural capital generates. In many situations, the benefits that humanity receives from these ecosystem services can be significant. Recent analysis suggests that over half the global gross domestic product (GDP) is highly or moderately dependent on the goods and services that nature provides (Dasgupta, 2021). Increasingly, climate change and ongoing loss of nature are being seen as significant risks not just to ecosystems but to the economic

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systems that these ecosystem goods and services underpin. Nature-related risks represent six of the top ten risks to the stability of the global economy over the next decade (World Economic Forum, 2023), and there is an urgent need to adopt production systems that are more resilient to this changing risk profile to ensure the ongoing sustainability of production. Agricultural systems are highly dependent on natural capital, and agricultural producers are important stewards of large reserves of natural capital. Agricultural producers have a significant opportunity to manage their natural capital in a manner that increases the sustainability and transparency of agricultural produce within global supply chains and to take advantage of the emerging demand for market-driven natural capital opportunities.

Agricultural landscapes are under increasing pressure to increase food, fibre and energy production, while simultaneously increasing nature and biodiversity outcomes (Hajkowicz and Moody, 2010). Agroforestry has been recognised as playing an important role in protecting or increasing natural capital (Dudley and Alexander, 2017; Benton et al., 2021) and enhancing ecosystem services within agricultural systems (Nair, 1993; Nair, 2012). There are many types of agroforestry systems in practice around the globe (van Noordwijk et al., 2020), but it can be broadly defined as the deliberate retention and/or incorporation of long-lived woody perennials into the production system with the intent of lifting farm enterprise and landscape productivity by enhancing the flows of ecosystem services to the farm enterprise (private benefits) and/or to the broader community (public benefits) (Nair, 1993). Agroforestry has the potential to prevent or remediate environmental degradation, enhance agricultural productivity, increase carbon sequestration and storage, promote healthy soils and provide habitat for the maintenance of biodiversity and diversify agricultural incomes (Jose, 2009).

Quantitative information on the natural capital benefits associated with agroforestry remains relatively sparse, despite decades of research and much qualitative work. Many benefits are self-evident and quantifiable, e.g. carbon sequestration and habitat provision for biodiversity (Paul et al., 2013; Torralba et al., 2016), but the key recipients of such benefits are typically external to the farm enterprise. There is a strong belief that there are benefits to the landowner that agroforestry provides, including increases in crop and livestock productivity (Baker et al., 2018) or the livestock and human welfare and amenity values (Polyakov et al., 2014); however, these beliefs are often based on information that is largely observational and/or anecdotal (Gregory, 1995; Baker et al., 2018; England et al., 2020). The lack of ability to quantify and account for the full range of public and private benefits often hampers the adoption of agroforestry practices and constrains analysis of costs and benefits associated with agroforestry (Fleming et al., 2019).

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Regardless of the challenges in quantifying natural capital values, recognition of the benefits that agroforestry provides for agricultural systems is growing. Further, agroforestry systems are increasingly being promoted as nature-based or natural climate solutions (Brown et al., 2018; Terasaki Hart et al., 2023; Telwala, 2023) and can contribute to emerging demand and markets for nature repair (Convention on Biological Diversity, 2022; TNFD, 2023). The UN Environment Program (UNEP, 2022) noted agroforestry as the nature-based solution requiring the greatest investment (US$3600 B by 2050) to limit global warming to 1.5°C, in line with the Paris Agreement. Nature-based solutions are actions that protect, conserve, restore and sustainably use and manage natural resources or modified terrestrial, freshwater coastal and marine ecosystems while simultaneously addressing significant social economic and environmental challenges (IUCN, 2020). The potential of agroforestry as a nature-based solution is largely unquantified and most likely unrealised. For example, Terasaki Hart et al. (2023) found a large gap between the actual and potential climate mitigation benefits of agroforestry on all continents except Africa.

Recognition of agroforestry as a nature-based solution comes with the additional responsibility that the outcomes need to be verified and tracked through time (IUCN, 2020). There is a pressing need to develop approaches to more formally recognise the services and benefits associated with agroforestry. Natural capital accounting has recently emerged as an approach to address this problem. Derived from environmental and economic accounting, e.g. the System of Environmental Economic Accounting (United Nations, 2014; United Nations, 2021), natural capital accounting promotes the recognition of natural and modified ecosystems as assets. The adoption of an accounting approach is deliberate and designed to enable formal recognition of the environmental contributions to the economy and society more broadly or when framed appropriately provide the capacity to quantify the natural contributions to the environmental and financial performance of an enterprise (Ogilvy, 2015; Hein et al., 2016; Barker, 2019; Ogilvy et al., 2022).

In this chapter, we demonstrate how individual agroforestry projects could be recognised as assets (albeit natural capital assets) on the balance sheet of an enterprise, using a case study in Tasmania, Australia. Quantifying the natural capital benefits associated with various agroforestry systems will increase the adoption of agroforestry by land managers (Fleming et al., 2022). Ultimately, our aim is to see formal integration of the financial and natural capital performance of farm businesses and to provide farmers and their advisors with the frameworks required to better analyse the costs and benefits associated with agroforestry.

Section 2 of this chapter highlights some of the ecosystem services commonly associated with selected agroforestry systems (focusing on

belts that provide shelter to crops and livestock) and provides a high-level overview of approaches to quantifying these for accounting purposes. Section 3 demonstrates how the values associated with these services might be represented on the enterprise balance sheet. Section 4 summarises stakeholder perspectives and insights gained from this form of presentation. Finally, we provide a discussion and some suggestions for future research directions.

2 Key ecosystem services associated with agroforestry

Agroforestry systems provide bundles of ecosystem services with both private and public benefits. Different systems and configurations of trees will have differing levels of provision of these services. For example, shelter belts composed predominantly of exotic species may provide more forest and wood products but lower habitat conditions for biodiversity compared to a block of mixed native species. In order to recognise benefits associated with these varying configurations in a formal accounting process, it is important that ecosystem services be quantified in a manner that faithfully represents the ecosystem services generated by the ecosystem asset (AASB, 2022). In this study, we focussed on a subset of the possible spectrum of ecosystem services associated with agroforestry systems (Table 1). While these selected ecosystem services are not exhaustive, they are representative of the range of ecosystem services commonly associated with agroforestry. Each of the ecosystem services chosen requires its own metrics, some are relatively easy to quantify (such as from the sale of forest products), and some require the development of robust metrics that are scalable and can be implemented for individual agroforestry assets, allowing integration into the farm's balance sheet.

2.1 Biomass provisioning services

Biomass provisioning services from agroforestry systems include food, forage, wood products (solid wood, wood chips, firewood, etc.) and oils and fuels (Báder et al., 2023). The demand for wood products, in particular from agroforestry, is likely to grow significantly. This growth in demand for wood products is being driven by rising populations, increasing substitution of carbon-intensive materials coupled with a declining supply of native forest timbers and limited opportunities for the establishment of new large-scale plantation assets (O'Grady and Mitchell, 2018; Monckton and Mendham, 2022).

Standing wood volume in agroforestry assets can be estimated using site-specific measures of stem diameter and height through allometric equations, or it can be modelled using a range of empirical or process-based models. To estimate standing wood volumes in our case study, a modified version of the dynamic forest growth model, CABALA (Battaglia et al., 2004), was employed, with modifications to reflect the challenges of agroforestry systems, particularly

Table 1 Example ecosystem services associated with agroforestry in temperate agricultural systems

Category	Ecosystem service	Beneficiary	Description
Provisioning (biotic)	Biomass provisioning	Private	Cultivated plants for nutrition, materials or energy, predominantly wood products
Regulating and maintenance (biotic)	Life cycle maintenance, habitat and gene pool protection	Public/private	Habitat provision for biodiversity
	Global climate regulation services	Public/private	Carbon sequestration to help stabilise climate
	Local (micro- and meso-climate regulation services)	Private	Shade and shelter for crop and livestock production
	Pollination	Private/public	Pollination of crops
Cultural (biotic)	Visual amenity services	Private/public	Characteristics of nature that enhance aesthetic experiences
	Other cultural services	Private/public	Characteristics of nature that enhance cultural experiences

Source: Haines-Young and Potschin-Young (2018). Note that this is not an exhaustive list, but a list of key services that we have chosen to account for here.

shelterbelts (England et al., 2018b). Indicative volumes of harvested log products were then estimated as 85% of standing volumes (Stewart and O'Grady, 2020). An alternative approach could rely on the application of functions that relate log size to product recovery, but there is little published information currently available to inform this approach for agroforestry systems.

2.2 Habitat provision for biodiversity

Biodiversity is an ecosystem attribute critical to a wide range of ecosystem services that are recognised as being globally important (Dasgupta 2021). Biodiversity is an emergent property of the biophysical environment (including climate, soils, condition and configuration) ecological interactions and co-evolutionary history. As such, this presents a complex measurement challenge. Habitat-based assessments of biodiversity have emerged as a valuable tool in accounting for biodiversity (Horner et al., 2022; Mokany et al., 2022). Habitat-based biodiversity assessments rely on observations of changes in the extent, condition and configuration of habitat (King et al., 2021). Many of these characteristics can be derived from remote sensing and can provide scalable, consistent and comparable reporting for areas through time (Mokany et al., 2022). Agroforestry systems provide habitat for biodiversity as they influence the extent, composition and connectivity of habitats within the landscape. The contribution these systems make to biodiversity can be

estimated as a function of their similarity to extant ecosystems in conditions where human influence on biodiversity is minimal, i.e. difference from the reference state. Different species compositions, configurations and ages of agroforestry systems will convey different levels of similarity to the original native vegetation. These can be expressed as an index of 0–1, where ideally, 1 represents the full suite of native species in the reference, or other easier to assess but less optimal measures such as species richness or habitat condition scores can be used as proxies (Prober et al., 2025). Using this approach, a measure of the effective habitat area (E_{Ha}) of an agroforestry asset (ha) can be produced by multiplying the extent of the asset (Ext_A, ha) by the average habitat condition (Cd_A), as defined above, for each area on a farm, such that

$$E_{Ha} = Ext_A \times Cd_A \quad (1)$$

This approach can also be used to forecast changes in habitat conditions using state and transition modelling approaches to estimate the upper limit of change in habitat conditions, and how this change is likely to occur over time since planting (Ogilvy et al., 2022). This approach has a number of advantages over inventory approaches to biodiversity accounting, e.g. Jones (1996) or Horner and Davidson (2020), as the metric is simple, repeatable and potentially more robust than measures built on more complex biodiversity indicators.

2.3 Global climate regulation services

Commercial and environmental plantings have the potential to increase on-farm carbon storage in woody biomass through afforestation, integration of belt plantings or by increasing the length of rotations in plantings designed to be harvested (Paul et al., 2022a). The capture and storage of carbon in vegetation will play a critical role in managing changing climates in the future (Bastin et al., 2019), as emissions reductions alone will not be enough to avoid global warming exceeding the 1.5°C ambition set under the Paris Agreement (Wood et al., 2023).

Carbon stocks in agroforestry assets of varying configurations can be modelled or estimated using site-specific measures. Australia uses the stand-level carbon accounting model FullCAM as the national carbon accounting tool for reporting against the country's national greenhouse gas emissions. The model is also applied at project scales under some methods of the Australian Carbon Credit Units (ACCUs) Scheme. Predictions of carbon stocks in FullCAM are predominantly influenced by an input layer of the maximum potential biomass for a location (Roxburgh et al., 2019) and calibrated yield curve parameters, including for 12 categories of plantations and 10 categories of environmental and mallee plantings (Paul and Roxburgh, 2020; Paul et al., 2022b). Where calibrations for agroforestry assets are insufficient, such as for

shelter belts specifically designed for the production of commercial timber, further refinement of carbon sequestration estimates can be based on stand inventory (Marais et al., 2022; England et al., 2018a) and scaling of biomass/carbon through the application of allometric equations, expansion factors, and conversion to carbon or CO_2 equivalents (Paul et al., 2016).

2.4 Microclimate regulation services

Shade and shelter benefits of trees for the agricultural part of the enterprise are one of the key ecosystem services that can convey a substantial private benefit, depending on the configuration of the trees and the responsiveness of the agricultural system (Mendham, 2018). These benefits include improved crop and pasture productivity (Baker et al., 2018), reduced physical damage to crops (Cleugh, 1998), mitigation of extreme weather (i.e. heat waves, frost) (Cleugh and Hughes, 2002; Baker et al., 2021) and provision of shade for livestock (Giro et al., 2019; Gregory, 1995). The scale of microclimate regulation, and the subsequent agricultural benefit that occurs, varies depending on weather conditions (Kort, 1988), biophysical characteristics of trees (e.g. age, height, porosity and species) (Cleugh, 1998; Marais et al., 2022) and landscape configuration. This means that there are few generalisable approaches to quantifying these benefits. A recent global quantitative analysis developed a typical productivity response to the shelter provided by windbreaks and alleys, with a competition zone typically occurring within 0–2 tree heights, followed by a zone of benefit (increased pasture/crop production compared to unsheltered control) occurring from 2 to about 20 tree heights (Baker et al., 2018).

2.5 Pollination services

Pollination is a critical ecosystem function that is thought to be enhanced by agroforestry (Bentrup et al., 2019; Centeno-Alvarado et al., 2023). Over 85% of the world's flowering species are dependent on animal-mediated pollination services (Ollerton et al., 2011), and it has been estimated that approximately 35% of global food production is also dependent on pollination by animals (Porto et al., 2020). Thus, agriculture is highly dependent on the pollination services provided by nature. Declines in pollinator diversity and abundance are fuelling rising concern (Potts et al., 2010; IPBES, 2016), with climate change, habitat loss and fragmentation, disease and the use of pesticides all contributing to global pollinator decline (Dicks et al., 2021).

Ecosystem service models typically focus on pollinator abundance rather than the actual process of pollination. The Lonsdorf model (Lonsdorf et al., 2009) is commonly used to model pollinator abundance and has been adapted for various research and ecosystem services modelling applications (Joseph et al., 2020; Sharp et al., 2020; Villa et al., 2014). The model uses information on

forage distance, habitat suitability, and floral resource availability to estimate where pollinators are most likely to be active across the landscape. Alternate approaches based on species distribution and richness modelling have also been developed but so far have not been widely applied (Perennes et al., 2021).

2.6 Visual amenity services

Trees and forests have been shown to provide health and well-being benefits to people through multiple pathways including the provision of visual and aesthetic improvements (Lin et al., 2018). The Helliwell System (Helliwell, 2008) provides a measure for valuing the visual amenity of trees using factors including tree size, location, life expectancy, suitability of the tree in the landscape and the number of other trees in the surrounding area to evaluate a tree value. The Helliwell System, combined with sophisticated spatial mapping methods, has been applied to examine the visual amenity values of trees and forests in rural areas in Scotland (van der Horst, 2006). However, assigning dollar values to the amenity benefits of trees and forests is controversial. The Helliwell System, despite being used to provide evidence in court, is still based on expert judgement on the value of the tree rather than the market value of the tree. Other methods, such as the hedonic property price approach (see e.g. Tapsuwan et al., 2009), are unable to disentangle the visual amenity value of trees from other amenities that they provide. Other methods that might be able to separate out the amenity value are mostly based on stated willingness to pay of people to preserve the visual amenity value of trees (see e.g. Grala et al., 2012) rather than how much people have actually paid. Another economic approach that has been used to assign monetary values to visual amenity is the replacement cost approach. The premise behind using the replacement cost approach is that the enhancement of visual amenities of trees and forests can have a significant impact on people's mental and physical health (Barton and Pretty, 2010; Bowler et al., 2010), which in turn reduces the burden on the cost of medical care to society (Ulrich et al., 1991; Shaw et al., 2006). The difficulty in objectively measuring the visual amenity of forests lies in two main areas: the standard of measurement of aesthetic quality and the method for eliciting the monetary value of the aesthetic quality.

2.7 Other cultural services

Cultural services from trees in the landscape include the 'nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences' (Millennium Ecosystem Assessment, 2005). In addition to visual amenity services, other cultural services include values for education, heritage and sense of place. This definition recognises the contributions of ecosystem to formal and informal education, their contributions to historically or culturally significant ecosystems

and landscapes, and the 'sense of place' that people associate with features of their environment and aspects of the ecosystem (Millennium Ecosystem Assessment, 2005; de Groot and Ramakrishnan, 2005).

Systematic reviews of papers that attempt to evaluate, define, measure or assess cultural ecosystem services find that, although cultural services are experienced and appreciated more directly by people than some other kinds of services, they are the most difficult type of ecosystem service to quantify in monetary, or even quantitative terms (Horcea-Milcu et al., 2013; Hølleland et al., 2017). For this reason, cultural services are sometimes sacrificed in favour of other types of services that are easier to value in economic or ecological terms (Horcea-Milcu et al., 2013). The flow of cultural services is influenced by the interaction of stakeholders and the environment, including the managers who influence the supply of cultural services and the beneficiaries who receive the services (Xiao et al., 2017). People's values, beliefs and norms mediate their interpretation of sense data and other information they receive about the environment and are therefore likely to influence how they value cultural services (Stern et al., 1999). This means that some provisioning services can also be perceived as having a traditional or heritage value (e.g. Asah et al., 2014).

As a way to integrate the visual and cultural amenity values of trees, Polyakov (2014) explored the effect of the proportion of native forest on land value across a 3 million ha region of north-Central Victoria, Australia. They found that increasing the area of trees on a property was associated with an initial increase in land value, followed by a decrease, and peaked at between 20% tree cover (for a 1000 ha property) and around 37% tree cover for a 10 ha property. They found that trees increased property values by a maximum of 5% and 16% at the 1000 ha and 10 ha properties, respectively. This work provides a guide for separating out the amenity value provided by the trees compared to the amenity value of other factors (landscape features, residence quality, proximity to services, etc.).

3 Integration into ecosystem accounts for agroforestry

3.1 Accounting approach

Ecosystem accounting provides a standardised approach for the measurement and monitoring of ecosystems and their contribution to the economy. The capacity to value goods and services that ecosystems provide is designed to enhance economic decision-making. Historically, decisions related to the allocation of resources or management of the underlying ecosystem have occurred without consideration of the capacity of the ecosystem to continue providing goods and services, leading to a distortion of markets and ongoing depletion and degradation of natural capital. The primary methodology for

ecosystem accounting developed by the United Nations Statistical Division is the System of Environmental Economic Accounting-Ecosystem Accounting (SEE-EA) (United Nations, 2021). Designed primarily to meet the needs of countries to develop national environmental accounts and inform the System of National Accounts there has been increased focus on the application of these accounting principles at enterprise scales (Ogilvy, 2015; Ogilvy, 2020; Stewart and O'Grady, 2020). The conceptual model for ecosystem accounting is shown in Fig. 1. Ecosystem accounting relies on measuring changes in the extent and condition of ecosystem assets through time. Ecosystem assets represent the basic accounting unit in SEEA-EA and are defined as contiguous spaces of a specific ecosystem type characterised by a distinct set of biotic and abiotic components and their interactions (United Nations, 2021). The definition is not constrained to ecosystems in a relatively natural state and can include highly modified ecosystems (e.g. a wheat paddock or an individual shelter belt). Changes in the extent and condition of ecosystem assets directly influence the flows of ecosystem services that these assets generate, and thus the value of the underlying ecosystem asset base and the benefits that are derived from the assets.

An ecosystem accounting system is comprised of five core accounts (United Nations, 2021):

- Ecosystem extent accounts record changes in the area or stock of ecosystem assets within an ecosystem accounting area (e.g. a farm enterprise) between accounting periods (e.g. 1, 2, 5 years).
- Ecosystem condition accounts record the condition of ecosystem assets that are under control or management. Changes in the extent and condition of ecosystem provide valuable insights into the health of the ecosystem and the capacity of these assets to continue the production of the ecosystem goods and services the enterprise is reliant on.
- Ecosystem flow accounts record the supply of ecosystem services by ecosystem assets. These are presented in two formats, accounts that describe the physical flows and accounts that describe ecosystem service flows in monetary values. Physical ecosystem services accounts provide

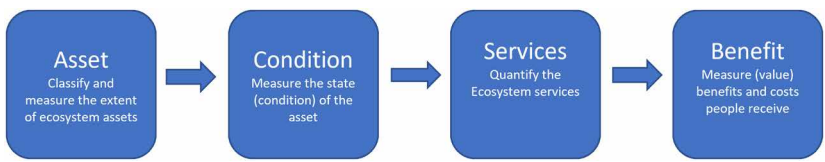

Figure 1 Ecosystem accounting conceptual model with the quantifiable components of each step.

the foundation for the valuation of the ecosystem assets (monetary ecosystem service account).

- The monetary ecosystem asset account records changes (additions/reductions) in the stock of ecosystem accounts in monetary terms, including contributions to this valuation associated with ecosystem enhancement or degradation. The value of the ecosystem asset can be approximated as the net present value of the future flows of ecosystem services, enabling translation of a diverse set of ecosystem services with differing physical units into a common unit, in our case study, the currency of interest, e.g. AUD.

An important feature of ecosystem accounting is that it enables the contributions of ecosystems to be recognised as part of a broader set of environmental economic accounts in physical and/or monetary terms enabling the valuation of nature's contributions to economic position or performance. Increasingly, the concepts of ecosystem accounting are being adapted to enterprise scales, commonly referred to as natural capital accounting, with a growing emphasis on the recognition of the ecosystem assets that produce goods and services for the enterprise. Doing so may provide valuable insights into the contributions that ecosystems make to an organisation's financial position (Ogilvy, 2015; Houdet et al., 2020). This is likely to be particularly important in agricultural contexts as agricultural businesses are typically highly dependent on natural capital (Ogilvy, 2015; Smith et al., 2021). As such, changes in the extent or condition of ecosystem assets under stewardship may have significant impacts on the generation of the ecosystem services that the entity is reliant on, leading to increased operational or capital costs or lost revenue. More broadly, natural capital accounts provide a framing of natural capital information in a manner that facilitates comparisons between organisations environmental stewardship in a consistent and comparable format (Ogilvy et al., 2022). This is becoming increasingly important as a growing number of organisations grapple with climate- and nature-related financial disclosures that span supply-chain boundaries (TNFD, 2023).

To some extent, existing accounting standards already incorporate some aspects of natural capital. For example, the IAS 41 standard defines agricultural activities as the 'management by an entity of the biological transformation and harvest of biological assets for sale or conversion into agricultural produce or into additional biological assets' (AASB, 2015). Standards also exist that cover the human-produced capital of an agricultural entity, such as property, plant and equipment (IAS 16) or inventory (IAS 2). However, these provide an incomplete picture of an entity's assets (Fig. 2). Natural capital accounting provides an opportunity to present an extended view of the entity's assets and the goods and services associated with that asset base (Fig. 3).

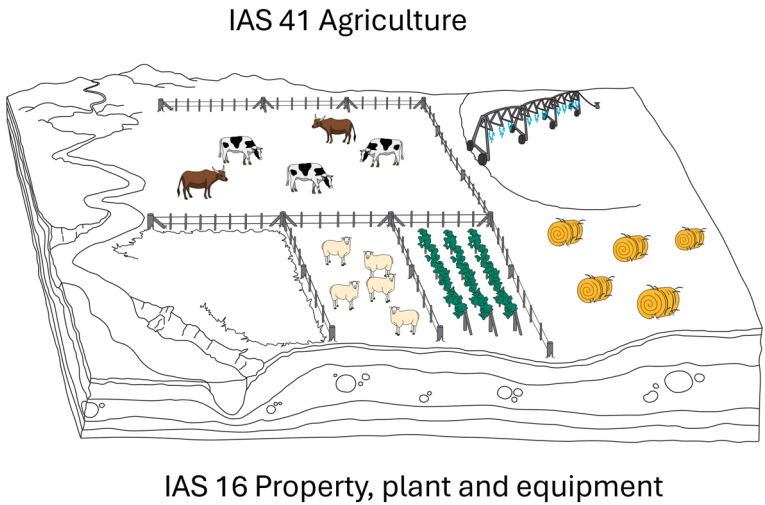

Figure 2 An illustration of the present coverage of financial accounting standards for agriculture. Present financial accounting standards already cover crops and livestock and property, plant and equipment. However, the property valuation does not formally or explicitly include detail of the ecosystem assets on the land. Source: Reproduced with permission from *Farming for the Future*.

In financial accounts, assets are defined as a present economic resource controlled by an entity because of past events. This control confers a right to potentially produce economic benefits (AASB, 2022). Decisions on recognition of assets on an entity's statement of financial position (i.e. balance sheet) require that such recognition conveys useful information about the asset and any resultant income, expenses or changes in equity of the entity, that the recognition is relevant to the user of the information and that the asset can be measured in a manner that provides a faithful representation of the asset and any resultant changes in the financial position of the entity (AASB, 2022). These characteristics of useful information apply equally to decisions to recognise natural capital assets, and it is equally important that this rigor is applied in the recognition of natural capital assets particularly if natural capital accounting is to inform and or be integrated into the entity's financial statements (Fig. 4).

The conceptualisation of the equivalent of a statement of financial position for natural capital, i.e. the ecological balance sheet, has been articulated in detail by Ogilvy (2015). Examples of natural capital accounts and environmental profit and loss statements prepared for individual businesses are emerging (Forico, 2020; Ogilvy et al., 2022), suggesting that broader adoption of financial accounting concepts and standards for the presentation of useful information on natural capital could enhance decision-making both within the organisations and for stakeholders with an interest in the financial and environmental position of the entity (e.g. lenders and buyers of agricultural produce).

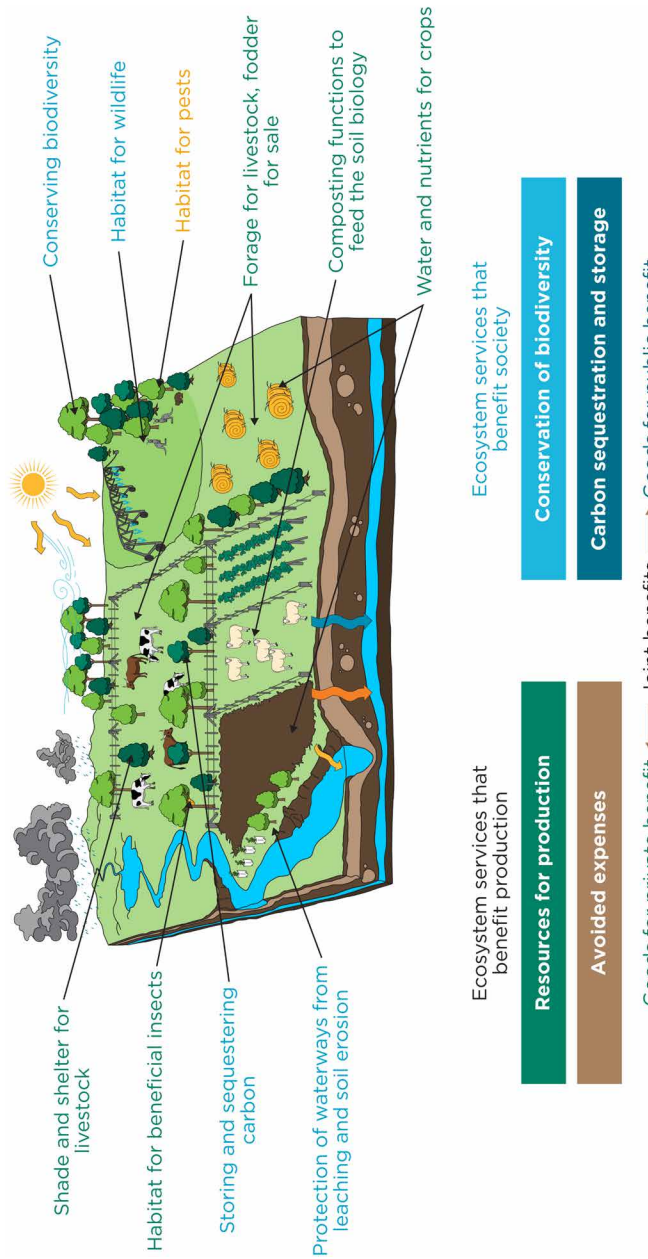

Figure 3 A natural capital accounting perspective of an agricultural enterprise that illustrates the ecosystem services – public and private economic goods – being delivered by different ecosystem assets of the property. Joint benefits indicate the maintenance of ecosystem assets for private benefit that also produces public benefit. Source: Reproduced with permission from *Farming for the Future*.

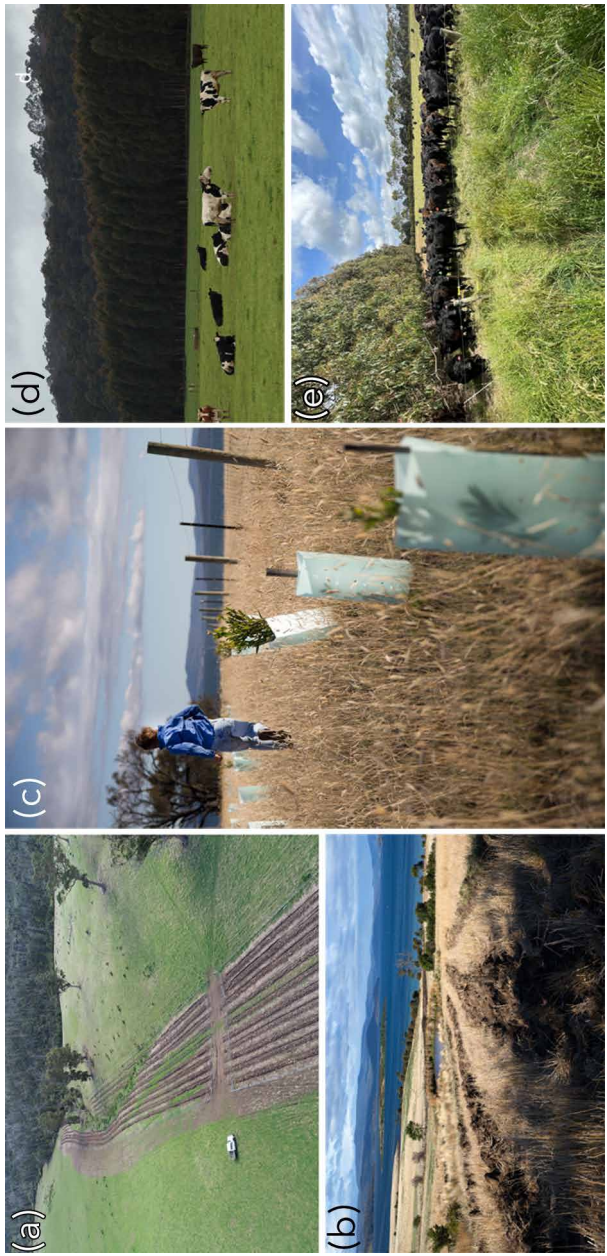

Figure 4 Temperate agroforestry can build natural capital on farm, generating a range of ecosystem services that increase both the productivity and amenity of temperate farming systems. Photo credits (a, b, c). A. Gray, (d) A. O'Grady, (e). S. Brooks.

Here, we present an example of how the value being generated by the trees on a farm – the private benefits received by the farming business could be presented on a farm business balance sheet using approaches to valuation already commonly used by farm accountants (Table 2). Where:

- Natural capital assets are represented as long-term productive ecological resources (in this case the trees) attached to the land controlled by the entity, and where changes in the composition or condition of these resources can enhance or diminish economic services to the entity (Ogilvy, 2015).
- Natural capital liabilities represent unmet nature-based obligations, e.g. to restore degraded or overused assets to a predetermined condition. A liability is recognised in the financial accounts when satisfaction of the obligation is expected to result in an outflow of economic resources for the entity (Ogilvy et al., 2018; Horner et al., 2022).
- Natural capital equity is the difference between the value of the entity of its natural capital assets and natural capital liabilities (Smith et al., 2023).

Table 2 Example presentation of an ecologically extended financial statement that 'itemises' the ecosystem assets of a farm

Ecologically extended financial balance sheet entries	Notes	2015	2020
Assets			
Agricultural assets livestock (fair value)	1	$1 517 091	$1 548 366
Agricultural assets – trees – timber (fair value)	2	$15 600	$76 825
Agricultural assets – land (market value)	3	*$4 898 217*	$5 284 884
Residual – amenity values	4	$1 130 358	$1 219 589
Agricultural assets – ecosystems (value-in-use)	5		
Ecosystems – paddocks for crop and livestock production	6	$3 438 528	$3 509 412
Ecosystem – trees – reference woodland biodiversity stewardship	7		$200 000
Ecosystem – trees – storm refuge for livestock	8	$252 907	$252 907
Ecosystem – trees – shelter for crops/pasture	9	$34 100	$67 320
Ecosystem – trees – carbon sequestration	10	$26 677	$20 007
Ecosystem – trees – pollination	11	$15 648	$15 648
Ecosystem – trees – amenity		$244 910	$264 244
Sub-total ecosystems	12	*$3 767 590*	*$4 065 295*
Total assets (less market value of land)	**13**	**$6 415 590**	**$6 833 249**

Per normal accounting practice. The increase in value is based on an increase in the number of livestock.Source: Reproduced with permission from EcoFarmCo NC Reports and Accounts prepared by Integrated Futures Pty Ltd. (unpublished).

To demonstrate how these values may appear in a financial balance sheet for a farm business, we have prepared a set of values. The values presented are for a hypothetical farm business and, following the convention for financial accounting, the methods used are explained in notes to the accounts. To provide a context for the relative economic contribution that the trees might be providing to the business, some values of the types of assets that are normally seen on a farm balance sheet according to current accounting standards are provided. However, methods for valuing ecosystem assets of a farm business are still emerging and experimental. The illustrations provided here to do not imply that these have been finalised in accounting standards. The hypothetical farm business is EcoFarmCo which is managed by Jill and Joe Einstein. They started accounting for their natural capital in 2015 at which time they realised changes to the ecosystem assets of the farm would assist them in decreasing their greenhouse gas emissions and increasing carbon storage and biodiversity of the farm. Table 2 sets out these changes in an experimental ecologically extended financial balance sheet.

Notes to Table 2:

1 Under the requirements of the present accounting standards for agriculture, the value of livestock as assets of a farm business is already normally included on the farm balance sheet. The values are estimated at the Fair Value of the livestock.
2 Under the requirements of the present accounting standards for timber, the value of standing timber as assets of a farm business can be included on the farm balance sheet. The values are estimated at the Fair Value of the standing timber (sale price less costs to sell). The increase in value between 2015 and 2020 reflects the increase in the size and condition of the timber. These values for the hypothetical farm reflect the value of 52 ha of radiata pine plantings that could be sold as peeler logs in 2015 and as small sawmill rounds in 2020 plus the potential value in 2020 of an additional 40-ha radiata pine block planted in 2016 that could supply a Christmas tree market in 2020.
3 Under the requirements of present accounting standards, the value of the farm property is already included on the farm balance sheet. The value is usually the present market price of the property and is commonly estimated by a property valuer who uses a comparison to recently sold similar properties to provide the estimate.
4 This value is an experimental value and is calculated as the residual of the property value (in note 3) less the sum of the experimental agricultural ecosystem asset values described in notes 6–14 inclusive. It might be interpreted as the value of the amenity of the property,

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its proximity to town, the features of the house and garden or other intangible (hedonic) values. Note that this approach to an experimental ecologically extended balance sheet may reveal, via a negative residual value, situations in which the value in use of the individual ecosystem assets may be higher than the present market value of a property.

5 Agricultural assets – ecosystems (value-in-use) is the asset concept developed in this project that may provide a way for the value of agricultural ecosystems to be included on the balance sheet of a farm business. The goal is to 'itemise' and make visible the contribution that ecosystems found on a farm are probably generating for the farm business. This can be thought of as being similar to explaining how many bedrooms and bathrooms are in a house that is being offered for sale. The heading provides visibility that the subordinate line items are a different asset concept.

6 Experimental valuation: net present value (NPV), to reflect the interannual variation of prices and seasonal condition of net cash flows from livestock and crop production. The valuation method for the 2200 ha of grazed area, pastures and croplands of the farm is consistent with the methods used in financial accounting when assets are valued for what they produce for the business, their 'value in use' rather than what they would be worth if they were sold. In this example, the value is estimated from the net income or amount of money that would be earned if the farm business was paying for access to the land for livestock grazing (known as agistment in agriculture) (Ogilvy, 2018) . The farm business could sustainably carry 12 040 sheep in 2015 and was able to increase this to 12 289 sheep in 2020 because of improvements it made to the condition of its grazing areas. The estimates use a daily agistment rate of $0.30 and assume that the net income to the farm business is 0.5 of this. The NPV uses a 10-year period and a risk-adjusted rate of 0.14 (Ogilvy, 2018).

7 Experimental valuation: the hypothetical farm business was able to secure a contract for environmental stewardship payments of $20 000 per year for 10 years. This was possible due to the excellent condition of the grassy woodlands of the property. The valuation of this in 2020 is at the total value of the contract at its inception. The asset value would be decremented by $20 000 per year until the value reached zero and this asset would be removed from the balance sheet.

8 Experimental valuation: NPV of avoided loss of livestock in severe weather. It is well known that significant stands of trees can provide shelter from severe weather and avoid significant losses of livestock. The estimates here are based on the availability of trees that are suitably arranged to provide a storm refuge. The estimate here is based on the

avoided loss of 10% of lambs and adult sheep worth an average value of $63.00 net income per head. The NPV uses a 10-year period and a risk-adjusted rate of 0.14.

9 Experimental valuation: In 2015, the value in this case study is based on the cost to acquire or cost to establish 31 ha of shelter belts. While this might normally be treated as an expense in farm accounting, it is not inconsistent with the methods of valuing many other assets (such as cars and tractors) which are commonly initially recorded at historical cost and then depreciated. The 2020 value is the NPV of the additional pasture and crop production attributable to the shelter belts. Described earlier in this chapter, there is a zone near trees where crops and pastures tend to grow more vigorously (be more productive) due to the shelter from wind. The estimates provided here for 2020 multiply the area sheltered by the trees as they grow with the average amount of the additional productivity estimated by scientific models. We used 0.7%. This amount is multiplied by the value of the additional pasture, in this case study we use $0.30 per day consistent with the valuation logic used in 7. The NPV uses a 10-year period and a risk-adjusted rate of 0.14.

10 Experimental valuation based on the consumption of expected total economic value from establishing a block of trees for a contract for ACCU production. Standard accounting methods have been applied assuming that the asset in 2015 has its greatest potential value due to its ability to store carbon. The quantity of inflows of economic value to the business from this asset diminishes as it approaches the point at which it cannot store further carbon.

11 Experimental valuation: NPV of providing 'agistment' for bees. Beekeepers who supply pollination services to orchards and crops in spring and summer commonly seek places to put bees over winter so they can recover in numbers and health. Trees can provide very valuable floristic resources that are suitable for the overwintering of bees and landholders commonly agree to allow beekeepers to place hives on their farms over winter. Most commonly, this is done for free (or in exchange for honey). If the landholder was being paid an amount of money for this 'bee agistment' service, they might wish to recognise the value of these assets on their balance sheet. This experimental value uses the same valuation concepts as described in notes 7 and 9 using a net annual cash flow of $3000.00, a 10-year period and a risk-adjusted rate of 0.14.

12 Sub-total ecosystems is the sum of the ecosystem asset valuations.

13 The total asset valuation is the sum of the assets excluding the land (market value).

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Newly emerging, standards and conventions being developed for natural capital accounting can help a farm accountant explicitly include the contributions that trees make to the productivity, profitability and resilience of a farm business. People who are making economic decisions about changes to the land including farmers, financiers and markets may use this information to work together to improve farmers' ability to access financial capital to enable them to invest in trees on farms.

4 How are accounts viewed by stakeholders and what is the pathway to adoption

Natural capital accounting could help to shift the globe towards more sustainable and resilient management of the range of natural and production landscapes, especially if it is adopted broadly across all sectors of the economy. To achieve this transformation, farm accountants and advisors are especially influential stakeholders to drive the early stages of development and implementation of natural capital accounts. About 55% of Australia's natural capital is managed by the agricultural sector, comprised of thousands of small businesses (ABARES, 2023). These small businesses frequently work with agronomists, advisors and accountants to prepare farm management plans, apply for funding and loans and report to stakeholders. As well as this, stakeholders in the broader fields of finance and accounting, agriculture, forestry, government, community, conservation, science and research are also stakeholders in the adoption pathway of natural capital accounts (Fleming et al., 2022). How natural capital accounts are perceived by these stakeholders is an important factor in whether they will be regarded as relevant, useful, cost effective and practical.

The concept of natural capital can be variably understood by stakeholders and some may already consider natural capital in a range of ways in their decisions (Fleming et al., 2019). Consistent ways to measure, include and represent natural capital in accounts can be difficult to produce, because of the different objectives, scales and access to data that different decision-makers require. However, as digital technology and scientific understanding improve, ways to understand, measure and calculate natural capital are improving and natural capital accounts are now more feasible to prepare (Ogilvy et al., 2022). At the same time, there is increasing demand for natural capital information at both local and aggregated scales to help monitor progress on natural restoration initiatives, resilience and sustainability assessments and national commitments to global agreements such as the Paris Agreement, the Convention on Biological Diversity and Sustainable Development Goals, as discussed above (Dasgupta, 2021).

Previous work that interviewed over 60 stakeholders has identified that they perceived natural capital accounting to be a helpful method to consider

agricultural ecosystem assets as part of a farm business (Fleming et al., 2022). Accounts can be useful to transparently and consistently monitor and report on farm condition to identify opportunities for investment and improvement and track progress over time as well as to identify and manage risks. Natural capital accounts can be used to report to banks, insurance companies, investment companies, conservation groups, government and the public and new buyers.

To be practical for end users, natural capital accounts need to be simple to understand. In addition, they need to use reliable, consistent methods, that resist manipulation, be cost effective and be supported by financial services and insurance providers (Fleming et al., 2022). Natural capital accounting is relatively new, so stakeholder engagement is still emerging, and there is a need (and opportunity) for the implementation pathways of natural capital accounts to be co-designed and co-developed with end users across a range of sectors.

Digital technology continues to develop quickly, and this will impact on how natural capital accounts are produced and maintained. Developments in tools and methods to collect data, as well as software systems that can record and present data, are both opportunities to further streamline, reduce cost and aid the interpretation of natural capital accounts (Stewart et al., 2022). While there are opportunities for efficiency and standardisation improvements from digital technology, there are also considerations of equity (access to data), legal considerations (data ownership and use), skills and training (data collection and interpretation) and methods for maintaining accuracy and rigour that need to be managed as part of the shift towards increasing the use of digital technology (Eastwood et al., 2019; Jakku et al., 2019).

There is a real opportunity for natural capital accounts to be used at a range of scales, from individual entities through to regional and national accounts, to achieve different economic, environmental and social objectives. Involving a wide range of end users in the development of natural capital accounts is an important way that diverse use cases can be achieved from the same set of accounts (Kujala and Kauppinen, 2004). Natural capital accounts as a way to bring people together across sectors, disciplines and world views is an area of work that is yet to be explored, but there is potential for the accounts to work as a convergence point between many different points of view, such as conservation and industry groups, indigenous and western approaches, and national and local scale planning (Franco-Torres et al., 2020).

The range of potential uses of natural capital accounts means that coordination is required to direct and align the different approaches to development, use and implementation and to establish support and information networks. While it can be a difficult job to be aware of all of the different projects, initiatives, tools and approaches being used to develop natural capital accounts in Australia, let alone internationally, knowledge brokering, coalitions

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and national roadmaps are important to avoid unnecessary confusion and competition amongst stakeholders (Green, 2022).

It remains to be seen whether natural capital accounts are adopted alongside business-as-usual approaches to farm management, regional monitoring and national reporting or whether the use of natural capital accounting underpins a more transformative shift towards new business models for responsible investment in natural landscape management and restoration (Fleming et al., 2022). However, awareness of natural capital accounting and stakeholder perceptions of the relevance and useability of natural capital accounting is only one side of the adoption pathway, the other side is the momentum that arises from the outcomes that the use of natural capital accounts produces. How the accounts result in behaviour change and tangible outcomes to economic productivity, sustainability and resilience of farms and natural landscape management will likely determine how far natural capital accounts are integrated into the society. To be broadly adopted, natural capital accounts cannot become an administrative burden on farmers or be seen as a process that farmers are forced to comply with, but rather as a means to achieving other directly beneficial outcomes.

Natural capital accounting can support and improve accountability and responsibility over landscape management decisions, across sectors and scales (Fleming et al., 2023). It offers a way to achieve transparent record keeping over what natural ecosystem assets exist, their extent and condition and support decision-making, planning, risk analysis, investment and monitoring over time, enabling a range of people, not just individual landowners, to improve natural capital extent and condition. This requires a shift in a range of decision-maker roles, responsibilities and processes, towards evidence-based decisions, accountability for outcomes and new forms of green investment, as well as better coordination among and between sectors that have a role in environmental governance, which are the aspirations, if not yet the achievements, of global agreements like the Sustainable Development Goals (Biermann et al., 2022).

5 Discussion: the role of natural capital accounting

Natural capital will increasingly feature in the way the business is conducted in the coming decades. Post the United Nations' Convention on Climate Change and with the recent ratification of the Kunming-Montreal Global Biodiversity Framework at COP15, all parts of the economy are being urged to be proactive in the adoption of actions to reduce the key drivers of nature loss: land use change, resource use, pollution, invasive species and climate change (TNFD, 2023). Due to its fundamental role as the foundation of many global supply chains, and stewardship of extensive and diverse natural capital, agriculture

will play an important role in this global transition with agroforestry featuring as a key strategy to drive this transition (The Nature Conservancy, 2024). The concept of nature-positive agriculture is emerging quickly (OECD, 2016) However, the evidence base for many of the key benefits associated with agroforestry is limited, a situation made even more complex by the highly site and context-specific nature of many ecosystem services. This has tended to constrain the adoption of agroforestry as the value proposition is not always obvious (Fleming et al., 2019).

As with financial accounting, natural capital accounting should serve two broad objectives. Primarily natural capital accounting should provide information that is useful to the management of the entity. As such it provides a mechanism for tracking the entity's stewardship of natural capital in a manner that facilitates proactive management and provides evidence that investments in natural capital are generating desired returns to the entity. In this respect, natural capital accounting shares many similarities with financial accounting and can provide the required information for the entity to assess its position in relation to its goals. One of the barriers to the uptake of agroforestry is a lack of empirical evidence in relation to its benefits (Fleming et al., 2023). Recognition of both the private and public benefits associated with agroforestry in a formal accounting sense can enable the entity's management to monitor and track their agroforestry assets and if adopted at scale can be used to develop and refine practices that enable farmers to optimise the configuration and the amount of agroforestry on the farm to better meet the entity's financial and environmental objectives.

Secondly natural capital accounting should assist producers in communicating their natural capital stewardship and/or the benefits associated with their investments in natural capital. There is a rapidly growing demand for broader disclosure of environmental credentials, driven by initiatives such that the Taskforce on Nature-related Financial Disclosures (TNFD, 2023). While primarily targeted at large corporate organisations, the adoption of the whole of supply chain perspectives may increase pressure on producers to also adopt reporting systems that meet the needs of actors within their supply chains. Furthermore, there is growing evidence that financial institutions will increasingly price natural capital risk into their lending practices. Producers that can demonstrate good natural capital stewardship may be eligible for more favourable terms (EY, 2023). Natural capital assets, e.g. agriculture and forestry, are becoming more attractive to institutional investors as they look to de-risk their portfolios. Natural capital accounting at enterprise scales will be fundamental to building the trust in these emerging markets and mechanisms designed to address the global scale challenges of climate change and nature loss (Nicolle, 2023).

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Despite this, challenges remain for the broader adoption of natural capital accounting. As an information system, natural capital accounting is dense and is still technically complex. Agroforestry in particular can require high resolution data at fine spatial scales and the capacity to cost-effectively quantify ecosystem services at high spatial and temporal resolution is constrained. To some extent, demand for information on natural capital is outstripping the capacity to deliver, particularly in a format that satisfies the characteristics of useful information required for more formal integration into accounts. Despite this, our work demonstrates the capacity to better value and account for the benefits of agroforestry already exists. Technological improvements in data capture and interpretation are advancing rapidly, as are approaches for compiling accounts, such as digital twins (Purcell and Neubauer, 2023; Peladarinos et al., 2023). These should bring down the costs of adoption quickly and enable greater uptake by producers. This is particularly important for ensuring equity amongst producers, especially in relation to market access as customers consciously adjust procurement policies to reflect rising market expectations to address global sustainability challenges.

In addition to tangible benefits, natural capital provides a wide range of ecosystem services benefits of the non-market nature, such as cultural services. Lack of effort to account for non-market benefits of natural capital and evaluate these benefits in monetary terms create information asymmetry which can lead to inefficient decisions and ultimately market failure. As such, to ensure the sustainable use of natural capital in the future, we must also reward the production of non-market ecosystem services, as well as, the production of marketed commodities of our natural capital (Guerry et al., 2015).

6 Conclusion and future trends

Agroforestry has been identified as one of the key nature-based solutions for tackling our dual global crises of climate change and nature loss, with the UNEP (UNEP, 2022) suggesting that agroforestry is the nature-based solution requiring the biggest investment, to the tune of US$3600B between 2022 and 2050, to keep global warming to 1.5°C. However, frameworks to establish, manage and maintain agroforestry to best meet these global imperatives are still in the development and adoption by land managers is even further away. Natural capital accounting offers a key solution to achieve best practice agroforestry and encourage adoption through explicit recognition of the public and private goods from agroforestry systems. The capacity to integrate benefits into enterprise planning is needed to accelerate the adoption of agroforestry.

As pressure on the environment grows, land managers and society are becoming increasingly aware of the need to manage environmental values,

to protect and to restore them (Dasgupta, 2021), though environmental values often compete with production values. Agroforestry offers an option to minimise and manage the tradeoffs between the increasing societal demands for food, fibre, bioproducts and energy, as well as contributing to meeting the environmental and climate change outcomes that are needed from our landscapes. Establishment of agroforestry for single outcomes, such as wood production, is generally more expensive than from monocultures or extant forests due to the diversity of the system and additional management costs such as fencing and logistics. Agroforestry becomes a much more attractive system when multiple values are quantified and tracked in the enterprise balance sheet.

For the land manager, natural capital accounting can explicitly quantify and demonstrate the delivery of private and public benefits from agroforestry, including increased returns from agricultural production from sheltered paddocks, greater diversification and increased land values and resilience to extreme weather, increasing farm productivity, profitability and value. Natural capital accounting also explicitly quantifies the environmental benefits including addressing climate change and providing habitat for biodiversity. Having these values explicitly quantified, tracked and monitored further strengthens the case for, and adoption of, agroforestry, through supporting and improving accountability and responsibility over landscape management decisions, across sectors and scales (Fleming et al., 2023). It offers a way to achieve transparent record keeping over what natural ecosystem assets exist, their extent and condition and support decision-making, planning, risk analysis, investment and monitoring over time, enabling a range of people, not just individual landowners, to improve natural capital extent and condition. Robust natural capital accounting will assist in developing trust in producers' environmental credentials.

Agroforestry provides an excellent test case for the development of natural capital accounting, which is required to optimise the value of agroforestry and to recognise the many benefits needed for its business case to succeed. The natural value accounting methods developed will be relevant to other forms of land management and may assist decisions on land management as well as infrastructure developments in landscapes to optimise the provision of resources for society and the simultaneous protection of the environment.

Agriculture is operating in an increasingly complex market and where producers are likely to be required to balance production and environmental outcomes to maintain market access or to capture emerging opportunities in a carbon constrained and nature positive operating environment. Accountability is defined as 'the act of being responsible for what you do and able to give a satisfactory reason for it, or the degree to which this happens'. Natural capital accounting provides the model for underpinning this accountability.

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