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Natural capital accounting approaches for land-based activities

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Natural capital is used and managed by individuals, corporations, and governments. In general terms, natural capital represents all stocks of natural resources, which include geology, soil, air, water and all living things. From an economic perspective the concept of natural capital has been introduced as an approach to economically value the contribution of nature to the provision of ecosystem services (ES) as key factors of human-wellbeing. When both, a natural resource and economic perspectives are combined, natural capital can be defined as "another term for the stock of renewable and non-renewable natural resources on earth (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people" (Natural Capital Coalition, 2016a).

Natural capital accounting aims to document the state of nature, as well as understand, measure and assign values to nature contribution to human well-being, and their integration into decision-making. Natural capital delivers ecosystem services (ES) that affect the production of private goods (i.e., which benefits are excludable and their consumption rivalrous), and public goods (non-excludable and non-rivalrous). This dualistic private/public nature of natural capital necessarily bring synergies and trade-off concerns into natural capital assessment, and natural assets management and decision-making approaches.

There are two distinctive branches of natural capital accounting, one related to the extension of National Accounts, and the other to business. The branch of national accounting has yielded internationally adopted frameworks such as the United Nations System of Environmental and Economic Accounting (SEEA) Central Framework of the revised SEEA- Ecosystem Accounts. The business brand led to different natural capital assessment frameworks aimed at the integration of natural capital concerns into corporate decision making.

Business-oriented Natural Capital Assessment frameworks provide businesses a tool to understand their impacts and dependence on natural capital, but also to identify risks and opportunities that could be integrated into business models to respond to global environmental challenges. The methods used for accounting natural capital in the private business sector are increasingly being standardised, notably the Natural Capital Protocol (the "Protocol" hereinafter). The Protocol describes a process for assisting companies, large to small, to understand their links to natural capital and assess the magnitude and value of business dependence and impacts on natural capital. This framework brings together and builds on a number of existing approaches (tools, methods and conceptual frameworks) to help business integrate natural capital thinking into business strategies and management.

This document reviews different natural capital approaches to build the conceptual basis for natural capital valuation and accounting to operationalize the integration of natural capital thinking into land management decision-making to inform, support, and coordinate sustainable farmland use and management strategies. For doing so, this document offers, on one side, a comprehensive revision of ecosystem services and natural capital assessment and economic valuation approaches, and on the other side, guidelines to assess and measure impacts and dependencies of land-based business (focused on the farming systems) on natural capital. The later guidelines build upon the Natural Capital Protocol and its sectoral guides for Forest products, Apparel and Food and Beverage developed by the Natural Capital Coalition, and the practical guide for land managers and advisers developed by the trial application of the Protocol to Crown Estates Scotland (CES). This framework was used in the application of the Natural Capital Protocol at the Glensaugh farm, which is a research farm belonging to the James Hutton Institute.

1 Introduction

1.1 Natural capital assessment and accounting: a brief description of approaches

Though the term Natural Capital is widely used, it can have different meanings depending on the perspective of the user or the use of the term. From a more biophysical perspective natural capital can be referred to as to as "the stocks of natural assets, which include geology, soil, air, water, and all living things" (SFNC, 2016). From a more economic perspective this concept has been introduced as an approach to economically value the contribution of nature to the provision of ecosystem services as key factors of human-wellbeing (Costanza and Daly, 1992; Turner and Daily, 2008). When both perspectives are combined, natural capital can be defined as "another term for the stock of renewable and non- renewable natural resources on earth (e.g., plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people" (Natural Capital Coalition, 2016a: 2) Natural capital also encompasses ecosystem assets[1] (UNSD, 2014a). Ecosystems when viewed as natural assets comprise a stock of potential ecosystem services (Barbier, 2011) that contribute to diverse human activities and life systems, and ultimately to human well-being (MEA, 2005; TEEB, 2010). Those services represent nature's input to the goods and benefits obtained from nature (food, water, energy), beneficial ecosystem processes (water purification, pollination, pest control etc.), non-material benefits, such as recreation, cultural and aesthetic values, and key basic ecological processes underpinning all ecosystem functioning (Kettunen et al., 2012).

Natural capital accounting aims to document the state of nature, as well as understand, measure and assign values to nature contribution to human well-being, and their integration into decision-making. Both private and public sectors have been exploring how Natural Capital accounts may offer new approaches to decision-making towards more sustainable outcomes in socio-economic and environmental terms (e.g., Provins et al., 2015; Natural Capital Committee, 2014; Natural Capital Initiative, 2015; AECOM and JNCC, 2015; Natural Capital Coalition, 2016). Not surprisingly, diverse natural capital initiatives emerged over the last few decades (see Faccioli and Blackstock (2017) for a review), resulting in a variety of tools, methods and frameworks to produce environmental, qualitative and monetary data to inform decisions.

Natural capital accounts have grown from traditional accounting and popularised since the early 1990's within the creation of different international committees, statistical divisions and group of experts to develop natural capital and ecosystems services assessment and valuation frameworks (0). Today we can find are two distinct branches of natural capital accounts, one related to business; and the other to national accounting (Ruijs et al., 2018). The branch of national accounting has yielded an internationally adopted framework, the *System of Environmental and Economic Accounting* (SEEA) (UNSD, 2014a,b,2020), while the business brand led to different natural capital assessment frameworks aimed at the integration of natural capital concerns into corporate decision making. The methods used for accounting natural capital in the private business sector are increasingly being standardised, notably the Natural Capital Protocol (the "Protocol" hereinafter).

1.1.1 Business-oriented natural capital accounting

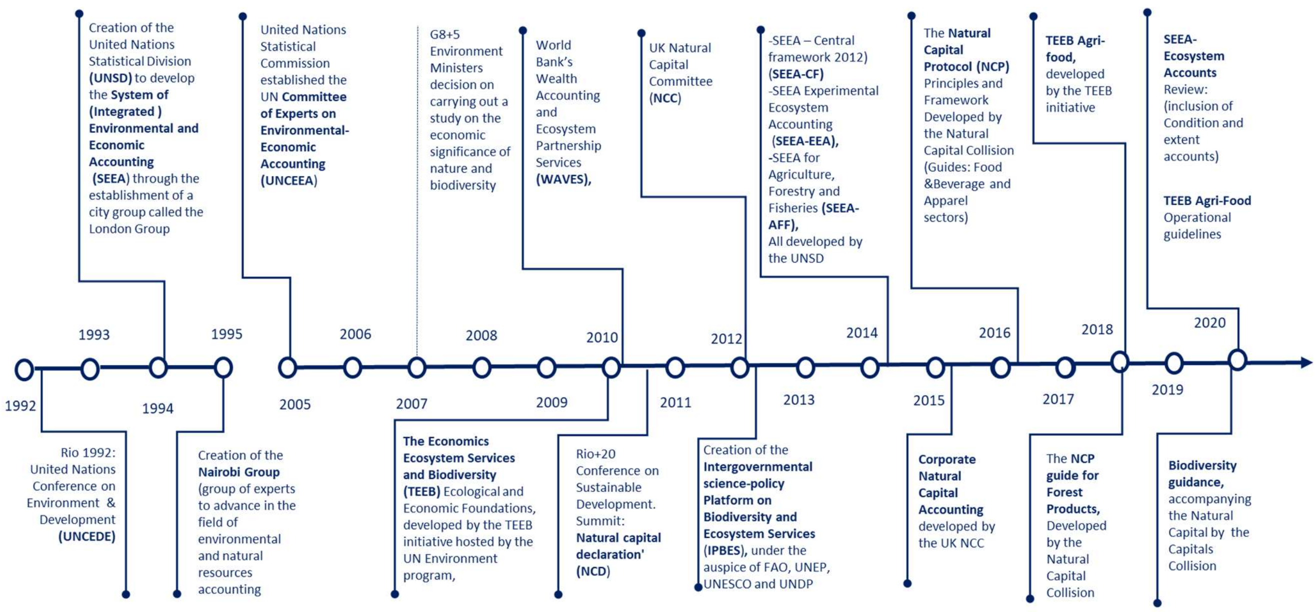
The business natural capital accounting branch is mainly intended to produce and analyse information to help corporations, industries, or land managers to integrate natural capital into decision making. Main examples of general frameworks for business-oriented approaches are the above mentioned Protocol, and the *Corporate Natural Capital Accounts* (CNCA) developed by the UK government Natural Capital Committee (Provins et al., 2015a).

The CNCA framework, is in turn conceived for private and public organizations that own, manage, or rely on significant stocks of natural capital. This framework aims to examine the interdependencies between natural capital (assets) and the organisation, focussing on its potential impacts on the health and long-term viability of

[1] Ecosystem assets, are turn defined as spatial areas comprising a combination of biotic and abiotic components and other elements which function together (UNSD, 2014b). Agricultural lands (and planted forests) are considered as ecosystems albeit they are strongly influenced by humans.

natural capital. The Natural Capital Committee encourages the development of natural capital accounts in form of balance sheets that report the value of natural assets and the ongoing costs of maintaining natural capital (liabilities). A relevant characteristic of these balance sheets is that they can account for two components of value. The private value representing the internal economic benefit of the natural capital to the organizations (based on market prices), and the external value, reflecting the value natural capital provides to other beneficiaries (Provins et al., 2015a). According to the CNCA guidelines, external values can also account for the net present value of non-market benefits (disbenefits) produced by the activities of the organization (Provins et al., 2015b).

The Protocol is a standardised framework that brings together and builds on a number of existing approaches (tools, methods and conceptual frameworks) to help business to identify, measure and value their impact and dependencies on natural capital (Natural Capital Coalition, 2016a). The Protocol was launched in July 2016, and today a number of corporations have applied the Protocol, including water utilities (Yorkshire Water, Thames water), and more recently land-based business in Scotland (e.g., Silcock et al., 2018; Silcock et al., 2019; Ovando, 2020).



Source: *Own elaboration* inspired in the TEEB time line in connection to global events (TEEB, 2018)

Fig. 1 Ecosystem and Natural Capital Approaches timeline

The Natural Capital Coalition has produced sectoral guides that provide a practical advice to apply the Protocol to the specific sectors. Those sectoral guides include Apparel, Food and Beverage, Forest Products and Finance. The Food and Beverage and Apparel sector guides encompass the full value chain of those sectors, including all businesses operating in the production, processing, or retailing of food and beverage products and clothing (Natural Capital Coalition, 2016c; 2016d). For the food and beverage sector, the Protocol guide considers the dependencies and impacts of growers and producers of grains, fruits and vegetables, meat, dairy, oils and fat on natural capital. The Apparel sector, on the other hand, accounts for dependencies and impacts of sheep farming, cattle ranching, cotton and other cellulosic farming, that deliver raw materials for the fibre and fabric producers. The forest products guide encompasses the entire forest products value chain, from forest producers, to primary processing, secondary processing, use and end of life use (Natural Capital Coalition, 2018). More recently the Coalition has launched a guidance to integrate (measure and value) biodiversity into natural capital assessment (Capitals Coalition, 2020a).

In 2020, the Natural Capital Coalition along with the Social and Human Capitals Coalition have former the Capitals Coalition, which aimed to offer a more integrated decision framework based on the capitals approach. There is some debates on the number of different capitals (4 or 5 or more), though in general terms the multiple capital approach aims to provide a broader perspective on what is valuable for delivering economic, social, and ecological utility. The Social and Human Capitals Protocol was published in 2019 (Social & Human Capital Coalition, 2019). This protocol mirrows the Natural Capital Protocol in terms of the stages and steps of the assessment, in a way it intends to help identifying, measuring and valuing impacts and dependencies of business on people and society.

The Capitals approach aligns with the TEEB for Agriculture & Food, which has been recently delivered by "The Economics of Ecosystems and Biodiversity" initiative (TEEB, 2018). The TEEB-Agri-food provides a more comprehensive evaluation, similar to the inclusive wealth framework, of "eco-agri-food-systems. The TEEB framework proposes a holistic systems approach for evaluating the impacts and dependencies between natural systems, human systems and agriculture and food systems. The framework establishes "what should be evaluated", covering human, social, economic, and environmental dimensions of eco-agri-food-systems, from production through to consumption. The metrics proposed to evaluate this production systems include, beside yields, social and environmental impacts. The framework uses a multiple-capital-based approach (considering natural, human, social and manufactured capital) and supports the use of monetary and non-monetary approaches to impact assessment. This framework aims to inform decision-making (also from a wider perspective) and has been applied to a number of case studies that represent different aspects of the eco-agri-food-systems value chain (see TEEB, 2018). In Summer 2020, the Capitals Coalition has published a draft report for consultation on the operational guidelines to applied the TEEB Agri-food approach, with study cases in seven countries (Capitals Coalition, 2020b)

1.1.2 National natural capital accounting

Policy-makers require integrated information on the environment and its relationship with the economy and society for evaluating the potential impacts of policies (WAVES, 2016). The System of Environmental and Economic Accounting provides an internationally recognized and consistent framework, that includes definitions, classifications, accounting concepts and methods for developing natural assets physical and monetary accounts (UNSD, 2014a). The international accepted standards of the SEEA approach are developed through its central framework (SEEA-CF), which builds up a framework to construct physical and monetary flow and stock accounts for individual environmental assets, such as timber, land, minerals or water in connection to activities and goods and services already reflected in the System of National Accounts (SNA)[2], meaning that the SEEA-CF does not go beyond the SNA[3] boundaries. The fully valuation and integration of assets and flows related to natural resources and land beyond the SNA, such as non-market values remain an unresolved issue. Another relevant limitation of SEEA-CF is that the aggregated nature of these accounts restricts its usefulness to broader cross-cutting policy areas. This highlights the need of extending the SEEA-CF accounts to subnational scales in connection with geographic information systems (GIS) and spatial disaggregated data sets (UNSD, 2017).

The *Ecosystem Accounts* (SEEA-EA) is a complementary framework to the SEEA-CF, which ongoing revision aims to become the internationally accepted standards to develop ecosystem accounts (UNSD, 2020), once its final report is published early in 2021. The SEEA-EA is an integrated statistical framework for organizing biophysical information about ecosystems, measuring ecosystem services physical and monetary values, tracking changes in ecosystem extent and condition and linking this information to measures of economic and human activity. For the entries in monetary terms this framework applies the concept of *exchange values*, where ecosystem services and ecosystem assets are valued at the prices they are or would be exchanged if there were a market for the services. Hence it support comparison and integration in a manner that is consistent with the national valuation principles of the SNA (Caparrós et al., 2017).

The SEEA-EA incorporates a wider range of benefits to people than captured in standard economic accounts and provides a structured approach to assessing the dependence and impacts of economic and human activity on the environment. In that way ecosystem accounting opens the way for national accounting extensions to include, besides the value of ecosystem services embedded in the market value of products already reflected in system of

[2] Natural capital asset accounts in physical and monetary units, have been rarely compiled, and those focus mainly on energy, timber and land accounts (Recuero Virto et al., 2018).
[3] "The production boundary comprises a specific set of economic activities carried out under the control and responsibility of institutional units in which inputs of labour, capital, and goods and services are used to produce outputs of goods and services (products)"(UNSD, 2014a:39)

national accounts (e.g., crops, timber), also the value of ecosystem services omitted and/or undervalued in the SNA, which concerns to non-market benefits (and costs) valuation (e.g., Ovando et al., 2016; Caparrós et al., 2017), to provide a more comprehensive picture of the dependence and impacts of economic and human activity on the environment.

A complementary framework to the SEEA-CF, is the *System of Environmental-Economic Accounting for Agriculture, Forestry and Fisheries* (SEEA-AFF). The SEEA-AFF framework applies the environmental-economic structures and principles described in the SEEA-Central framework to activities related to agriculture, forestry and fishery. The focus of the SEEA-AFF is the integration physical and monetary data describing management information relevant to the production of the former economic sectors. Notwithstanding, the SEEA-AFF does not incorporate the accounting approach described by the SEEA-EA, which implies that it omits measures on ecosystem services and ecosystem conditions. The need for closer integration between SEEA-AFF and the SEEA-EA is, nonetheless, recognized as an important area of future SEEA research. Likewise, the SEEA-AFF framework acknowledges that a relevant step forwards to ecosystem accounting is to estimate information at sub-national levels, involving the development of geospatial data sets for agriculture, forestry and fisheries (FAO, 2018). Georeferenced data on natural capital state and condition, and on ecosystem services provision can improve our understanding of the links between ecosystem services and land management at different spatial scales, and guide decision-making and policies. Since the restoration and improvement of natural capital represents one of the main objectives of the EU's rural development policy (Zasada et al., 2018), spatially distributed natural capital accounts that reflect the state (stock) and condition (quality, health) of natural capital, and their changes over time (i.e., degradation, depletion or improvement) can help the definition of priority investment areas.

According to the last available global assessment on the progress of environmental economic accounting, 69 countries had programs on environmental accounting at different degrees of implementation by 2017 (UN, 2018)[4]. Most of these accounts focus on energy, environmental protection expenditures, material flows and environmental taxes and subsidies (ibid, p. 6), with few countries experimenting with natural capital accounting (e.g. ABS (2013) in Australia or in the UK the (ONS, 2020a, 2018a)). In 2019, the Scottish Government has published aggregated experimental Ecosystem Service Account for 10 ecosystem services provided by natural capital in the country (Scottish Government, 2019). An updated version of these accounts have been published in 2020 considering additional ecosystem services (ONS, 2020b). The ecosystem services included in the 2020 Scottish natural Capital Accounts comprise oil and gas, minerals timber, agriculture biomass, fish caught, water abstraction, renewable energy, carbon sequestration, air pollutants removal, noise mitigation, urban cooling and aesthetic and recreation values captured in house prices.

The Scottish natural capital accounts are consistent with the UK natural capital accounts published in 2018 and 2020, which account for physical and monetary values associated to the flow of ecosystem services and providing only monetary figures for the asset values. The asset value is estimated as the discounted value of the stream of services (ecossytem services) natural capital is expected to yield, assuming that at each period the production/consumption pattern of the last 5 years would remain constant over the asset life, which is turn is capped to 25 years for non-renewable assets and 100-years for renewables (Scottish Government, 2019:42). The natural capital accounts do not provide physical asset figures, which are relevant for natural assets such as timber stocks, minerals, water or soil, in connection to the flow accounts.

The Scottish aggregated natural capital accounts reflect, mainly, changes in the patterns of production/ consumption of good and services flowing from natural capital, and associated markets over time. Those accounts, however, do not reflect explicitly natural capital depletion or degradation, which would account for quantitative or qualitative changes in renewable and non-renewable natural stocks. These later changes could be captured by biophysical information about ecosystems (ecosystem assets) to track changes in the extent and condition accounts, which are key elements in the final draft of the revised SEEA-EA (UNSD, 2020). Restricting natural asset account to only monetary values can mask natural capital depletion and degradation processes, as far as market prices respond to scarcity (Heal, 2012). For a more comprehensive understanding of interactions and trade-offs in the different dimensions of sustainability, environmental accounts need to go beyond the merely contribution natural capital to national wealth or income. Ideally, natural capital accounts should be framed as part of

[4] This numbers may have increased since 2017, considering the SEEA implementation target of 100 with ongoing, well-resourced programmes in SEEA Central Framework accounting by 2020

integrated information systems about the state and conditions of the various components of nature, at least in physical terms (Radermacher and Steurer, 2015). For example, by accounting for the outcomes of economic activity, in terms of pollutants, or land use changes, and detailing the costs and subsidies required for environmental protection, in connection to natural capital accounts. This later would require more integration and transparency in the existing environmental and economic accounting systems.

1.2 Objectives and scope of the conceptual and analytical framework

Pressures on natural capital are most likely to persist and intensify in the future, in connection to population growth, with the subsequent increases in the demand for food, energy, housing, transport, water and waste treatment and management. Supporting the provision of food, fibre, timber and energy for growing populations seriously challenges the future sustainability and resilience of agriculture systems (Godfray et al., 2010; Power, 2010). This can also be extended to the complex and extensive value chains of agriculture systems: from supporting ecosystems, to productive farms, intermediaries, wholesalers and retailers, food and beverage manufacturers, distributors and consumers (Muller and Sukhdev, 2018).

The growing scientific and political acknowledgement that natural capital is essential for maintaining healthy and resilient economies and societies, underpins the idea that future management and policy decisions involving natural capital will explicitly consider the interdependencies, synergies and conflicts between private and public objectives, actions and demands. New natural capital policies would demand more comprehensive evaluations of the dependencies and impacts of economic activities, such as agriculture, on the natural capital base, and careful analysis of the potential effect of changes in natural capital management on the provision of both private and public benefits. In this sense, there is need for improving our understanding of complexity involved in land management decisions, and their impacts on natural capital and ecosystem services through interdisciplinary research.

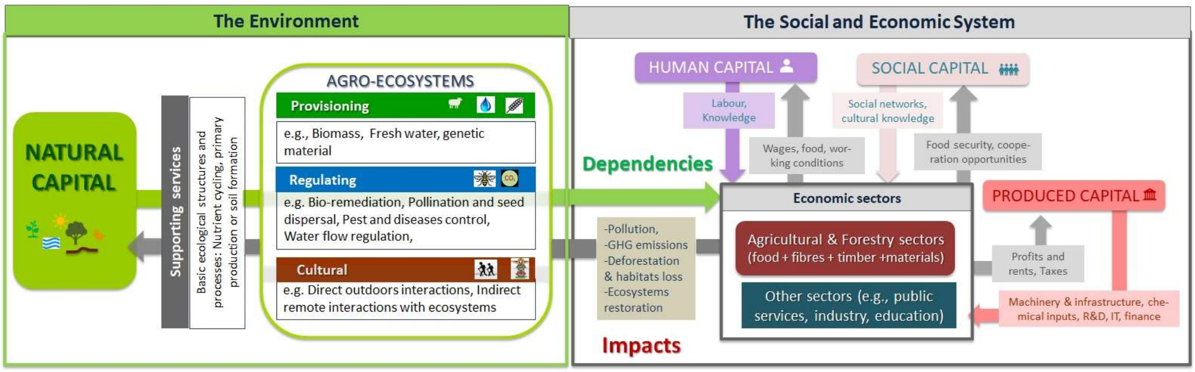
This document reviews different natural capital approaches to build the conceptual bases for natural capital assessment and accounting frameworks to operationalize the integration of natural capital thinking into land management decision-making involving farming systems. To this end, this document explores the use natural capital assessment and valuation approaches to inform, support, and coordinate sustainable farmland use and management strategies. For doing so, this work offers, on one side, a comprehensive revision of ecosystem services and natural capital assessment and economic valuation approaches, and on the other side, guidelines to assess and measure impacts and dependencies of land-based business (focused on the farming systems) on natural capital. These later guidelines builds upon the above referred Natural Capital Protocol and its sectoral guides published, and the practical guide for land managers and advisers developed by the trial application of the Protocol to Crown Estates Scotland (Silcock et al., 2018) and the Glensaugh farm (Ovando, 2020).

This document is organised as follows. Section 2 provides a comprehensive review of ecosystem services and natural capital classification and valuation approaches following internationally accepted classification and conceptual frameworks and models. Section 3 presents the Protocol framework in more details, and a proposal to adapt the Protocol to analyse the dependencies, impacts, risk and opportunities for land-based business in farmins systems in Scotland. Section 4 sets up the next steps in the integration of natural capital thinking into land management decisions making and policies.

2 Valuing Natural Capital and Ecosystem Services

The concept of nature as capital is not entirely a novel concept in the economic science. The historical roots of the notion of Nature as a producer can be traced back to mid-eighteen century, in the essays of French Physiocrats, and the Swedish botanist Carl Linnaeus' *Oeconomia Naturae*. This concept is also underneath the writings of classical political economists, such as Adam Smith, John Stuart Mill and Karl Marx, when they refer to the spontaneous production of the Earth and Nature's natural products. Although this category (land and nature) was considered to be rather unimportant in comparison with human and produced forms of capital (Desroches, 2015). E.F. Schuemacher introduced the term natural capital in 1973 in his book *the Small is Beautiful*. The natural capital concept has spread throughout in the economic literature since then, especially after the paper of Pearce (1988), who defined natural capital as the *set of all environmental assets* (Åkerman, 2003, Missemer, 2018). From an economic perspective, this concept has been coined as an approach to value the contribution of the elements of nature to the provision of ecosystem services as key factors of human-wellbeing (Costanza and Daly, 1992;Turner and Daily, 2008).

Natural capital accounting aims to understand, measure and assign values these contributions to human well-being, and therefore represents one way of integrating nature into decision-making (Bolt et al., 2016). A relevant question here is, what type of natural capital accounts are better suited to inform policy and decision-making? There are two contrasting views regarding the natural capital accounting in terms of how substitutable is natural capital by human-made capital[5] (Ekins et al., 2003; Böth, 2005). On one hand, natural capital is considered basically as non-substitutable (and non-reproducible), and as a result, its value is incommensurable and cannot be compared in monetary terms to other forms of capital (Missemer, 2018). Defenders of a strong interpretation of natural capital concept suggest that natural capital identified as critical needs to be integrated as a constrain into the economic decision-analysis (Ekins et al., 2003). This conceptualisation seems to emphasize on the development of physical natural capital accounts, the definition of critical natural capital stocks, and improving our understanding on dependencies and impacts of different productive systems on natural capital. On the other hand, an alternative economic approximation to nature is framing natural capital as "assets" (stocks) that deliver ecosystem services (Bolt et al., 2016), which in combination with other forms of capital contribute to produce an array of benefits for people (Fig. 2). From this perspective, stocks of natural capital have the property of storing wealth and being inputs to produce future consumption (Hulten, 2006), therefore bearing an economic value. In this framework, natural capital still has a limited substitutability and reproducibility, but this does not prevent from monetary valuation and cost benefits analysis (Missemer, 2018), using elements (tools, concepts) from capital theory (Jorgenson, 1963). The second approach to natural capital has led to many valuation studies of natural resources and ecosystem services (e.g., Costanza et al., 1997; Costanza et al., 2014; de Groot et al., 2012).



Source: *Own elaboration*, inspired in TEEB (2018: 26).

Fig. 2 Capital stock and value flows in agroecosystems

The net worth of capital stocks can be estimated as the discounted value of the stream of net revenues [or the economic value of the outgoing flow of goods and services] those assets are expected to deliver in the future (Jorgenson, 1963). As natural assets deliver services, the net worth of natural assets can be estimated, in theory, as the discounted flow of the monetary value of this future ecosystem services. This apparently simple procedure demands the quantification and valuation of the ecosystem service flow, and their aggregation in a way that is

5 Environmental sustainability can be described as "weak" or "strong" according to how substitutable are natural and human forms of capital considered. Weak environmental sustainability implies that welfare is not normally dependant on any specific form of capital, implying that the welfare can be maintained by substituting produced (human-made) capital by natural capital (and vice-versa). Strong environmental sustainability, on the contrary, implies that substitutability of human-made for natural capital is strongly limited by environmental characteristics such as irreversibility, uncertainty and the existence of critical components of natural capital, which make a unique contribution to welfare (Ekins et al., 2003).

consistent with the capital theory, as well as improving our understanding on how the flow of ecosystem services is affected by changes in natural capital stocks (Fenichel and Abbott, 2014).

Translating ecosystem services into natural capital values is, however, not straightforward. The relationship between natural capital and ecosystem services is affected by the conceptualisation of the role that human-derived capitals (i.e., produced, human, social), play in delivering of ecosystem services (Jones et al., 2016). The contribution of different types of capitals to human-welfare in highly humanised systems such as agro-ecosystems, depends on complex interactions between the environmental structures and functions and human management. Determining the contribution of different types of capital in the provision of ecosystem in the context of domesticated plants and animals with an acceptable degree of certainty is difficult. Notwithstanding, environmental structures and processes, and genetic pool contribute to biomass growth for both cultivated plants and domesticated animals, and the main challenge here is to understand how changes in the state and condition of natural assets (e.g., soil, land, water) affect the provision of benefits derived from agricultural sector. Next two sections discuss the possible ways to classify, quantify and value ecosystem services, and how ecosystem services values can be translated into natural capital values.

2.1 Ecosystem services classification

The ways ecosystems contribute to human-wellbeing are multiple, and this contribution could be direct or indirect (de Groot et al., 2010; Fisher et al., 2009; MEA, 2005). The Millennium Ecosystem Assessment (MEA) recognised four categories of ecosystem services: (1) *provisioning services*, such as food, water, or fibre; (2) *regulating services* that affect climate, water quality, floods, disease or waste; (3) *cultural services* that provide recreational, aesthetic and spiritual benefits; and (4) *supporting services* that operate alongside more basic ecological structures and processes and are necessary for the maintenance of all other ecosystem services, such as soil formation, photosynthesis, or nutrient cycling. Since the publication of the Millennium report there has been a considerable debate on definitions and classification of ecosystem services. Different classification systems (e.g., TEEB, 2010; Haines-Young and Potschin, 2018) and varying understanding of ecosystem service supply-benefit delivery chains among scientists (Boyd and Banzhaf, 2007; Wallace, 2007; Fisher et al., 2009) could have inhibited broadscale practical applications so far (Burkhard et al., 2014). Reflecting the complex interactions between ecosystem structures and functions that underpin the capacity of ecosystems to deliver services, and the need of rather easy-to-apply approaches (Crossman et al., 2013) is at least challenging. The debate surrounding definitions and classifications is still open, and perhaps we should accept that no final classification can capture the myriad of ways in which ecosystems support human life and contribute to human well-being (de Groot et al., 2010)

Promising attempts for defining and categorising ecosystem services have been undertaken by the TEEB (2010), MEA (2005) and the CICES (Common International Classification of Ecosystem Services). Table 1 presents a brief comparison of the recently published CICES version 5.1 (Haines-Young and Potschin, 2018), and TEEB and MAE classification systems. The CICES is the most comprehensive classification system developed to present and offers a hierarchical structure that allows assessing ES with different levels of detail. The CICES classification has been developed in the context of SEEA (Haines-Young and Potschin, 2018), and widely used in ecosystems services mapping and valuation (see Czúcz et al., 2018 for a review). Both CICES and TEEB classifications took the MEA description of ecosystems services as starting point, and both refine definitions and classification of ecosystem function, services and benefits to people, which enables consistent economic valuation. TEEB proposes a typology of 22 ecosystem services divided into four main categories: provisioning, regulating, habitat, and cultural and amenity services. CICES proposes a larger list of ecosystems services grouped into three main categories: provisioning, regulating and maintenance, and cultural services, while making a distinction between biotic and abiotic services. The version 5.1 of CICES reflects the results of a relevant review of scientific literature and the results of a survey and workshops conducted as part of EU funded research projects (ESMERALDA and OpenNESS), and the experience gained in the EU-led work on Mapping and Assessment of Ecosystems and their Services (MAES)[6] (Haines-Young and Potschin, 2018).

The CICES structure organises ecosystem services in a hierarchical level, including section, referred to the main group of ecosystem services (e.g. provisioning), division (e.g. nutrition), group (e.g. biomass), class (e.g., cultivated crops), and class type (e.g., cereals). For comparison purposes, Table 1 shows CICES classification up to the class

[6] CICES webpage: https://cices.eu/

level[7]; and to avoid any confusion the main MAE and TEEB ecosystem services categories (section in CICES terms) are referred to as typology, while the class delimitation represents specific ecosystem services in the three systems compared.

Table 1 CICES V5.1 classification of ecosystem services and corresponding MAE and TEEB typologies

CICES V 5.1 Classification				MA classification		TEEB classification	
Section	Division	Group	Class	Typology	Class	Typology	Class
Provisioning (Biotic)	Biomass	Cultivated terrestrial plants for nutrition, materials or energy	-Cultivated terrestrial plants (including fungi, algae) grown for nutrition	Provisioning services	Food: crops	Provisioning services	Food
			-Cultivated terrestrial plants (including fungi, algae) grown as a source of energy		Fuel		Raw Materials
			-Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic materials		Wood and fibre		
		Reared animals for nutrition, materials or energy	-Animals reared for nutritional purposes,		Food: livestock		Food
			-Animals reared to provide energy (including mechanical)		Fuel (dung)		
			-Fibres and other materials from reared animals for direct use or processing (excluding genetic materials)		Fibre	Provisioning services	Raw Materials
		Wild plants (terrestrial and aquatic) for nutrition, materials or energy	-Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition		Food		Food
			-Wild plants (terrestrial and aquatic, including fungi, algae) used as energy sources;		Fuel		Raw Materials
			-Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)		Fibre, Bio-chemicals natural medicines, and pharmaceuticals, Ornamental resource		-Raw Materials -Medicinal resources
		Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals (terrestrial and aquatic) used for nutritional purposes		Food: Wild plant &anim.	Provisioning services	Food
			-Wild animals (terrestrial and aquatic) used as a source of energy;	Provisioning services	Fuel		Raw Materials
			-Fibres and other materials from wild animals for direct use or processing (excluding genetic materials)		Fibre, Bio-chemicals natural medicines, and pharma-ceuticals, Ornamental resource		-Raw Materials -Medicinal resources
	Genetic material from all biota (including seed, spore or gamete production).	Genetic material from plants, algae or fungi	Seeds, spores and other plant materials collected for maintaining or establishing a population; Higher and lower plants (whole organisms) used to breed new strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities		Genetic resources		Genetic resources

[7] The complete CICES V5.1 classification is available online at https://cices.eu/resources/ (last accessed 12/14/2018)

CICES V 5.1 Classification				MA classification		TEEB classification	
Section	Division	Group	Class	Typology	Class	Typology	Class
		Genetic material from animals	-Animal material collected for the purposes of maintaining or establishing a population; -Wild animals (whole organisms) used to breed new strains or varieties; -Individual genes extracted from organisms for the design and construction of new biological entities				
	Water	Surface water used for nutrition, materials or energy	Surface water for drinking, or used as a material (non-drinking purposes) or as an energy source		Fresh water		Water
			Surface water used as an energy source				
		Ground water for used for nutrition, materials or energy	Ground (and subsurface) water for drinking, used as a material (non-drinking purposes)				
			Ground (and subsurface) water used as an energy source				
Regulation & Maintenance (Biotic)	Transformation of biochemical or physical inputs to ecosystems	Mediation of wastes or toxic substances of anthropoge-nic origin by living processes	-Bio-remediation by micro-organisms, algae, plants, and animals	Regulating services	Water purification and waste treatment	Regulating services	Waste treatment (water purification)
			Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals		Air quality regulation, Climate regulation(?)		Air quality regulation Climate regulation(?)
		Mediation of nuisances of anthropoge-nic origin	-Smell reduction -Noise attenuation - Visual screening				
			-Control of erosion rates	Regulating services	Erosion regulation	Regulating services	Erosion prevention
			-Buffering and attenuation of mass movement				
	Regulation of physical, chemical, biological conditions	Regulation of baseline flows and extreme events	-Hydrological cycle and water flow regulation (Including flood control, and coastal protection)		Water regulation, Natural hazard regulation.		Regulation of water flows, regulation of extreme events
			-Wind protection -Fire protection		Natural hazard regulation.		Regulation of extreme events
		Lifecycle maintenance habitat and gene pool protection	Pollination (or 'gamete' dispersal in a marine context)		Pollination		Pollination
			-Maintaining nursery populations and habitats (Including gene pool protection)			Habitat services	Maintenance of life cycles of migratory species, maintenance of genetic diversity
			-Seed dispersal			Regulating services	Biological control
Regulation & Maintenance (Biotic)		Pest and disease control	Pest control (including invasive species) Disease control	Regulating services	Pest regulation.		
		Regulation of soil quality	Weathering processes and their effect on soil quality	Supporting ES	Soil formation		Maintenance of soil fertility
			Decomposition and fixing processes and their effect on soil quality				
	Regulation of physical, chemical, biological conditions	Water conditions	Regulation of the chemical condition of freshwaters by living processes	Regulating services	Water purification and waste treatment		Water purification
			Regulation of the chemical condition of salt waters by living processes				
		Atmospheric composition and conditions	Regulation of chemical composition of atmosphere and oceans	Regulating services	Climate regulation	Regulating services	Climate regulation
			Regulation of temperature and humidity, including ventilation and transpiration				
Cultural (biotic)	Direct, in-situ and outdoor interactions	Physical and experiential interactions	Characteristics of living systems that enable activities promoting health,	Cultural services	Recreation and ecotourism	Cultural & amenity services	Opportunities for recreation & tourism

CICES V 5.1 Classification				MA classification		TEEB classification	
Section	Division	Group	Class	Typology	Class	Typology	Class
	with living systems that depend on presence in the environment al setting	with natural environment	recuperation or enjoyment through active or immersive interactions				
			Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions				
		Intellectual and repre-sentative interactions with natural environment	Characteristics of living systems that enable scientific investigation or the creation of traditional ecological knowledge		Knowledge systems Social relations		Inspiration for culture, art and design
			Characteristics of living systems that enable education and training		Educational values		
			Characteristics of living systems that are resonant in terms of culture or heritage		Cultural and heritage values	Cultural & amenity services	Inspiration for culture, art and design
			Characteristics of living systems that enable aesthetic experiences		Aesthetic values		Aesthetic information
	Indirect, remote, often indoor interactions with living systems that do not require presence in the environment al setting	Spiritual, symbolic and other interactions with natural environment	Elements of living systems that have symbolic meaning		Spiritual and religious value		information and cognitive development
			Elements of living systems that have sacred or religious meaning				Spiritual experience
			Elements of living systems used for entertainment or representation		Recreation and ecotourism,		Opportunities for recreation & tourism
		Other biotic characteristic s that have a non-use value	Characteristics or features of living systems that have an existence value				
			Characteristics or features of living systems that have an option or bequest value				

Notes: *Genetic material from all biota (including seed, spore or gamete production).

Source: Modified from Czúcz et al., 2018, based on: CICES V5.1 Spread sheets[8], MEA (2005), and De Groot et al. (2012).

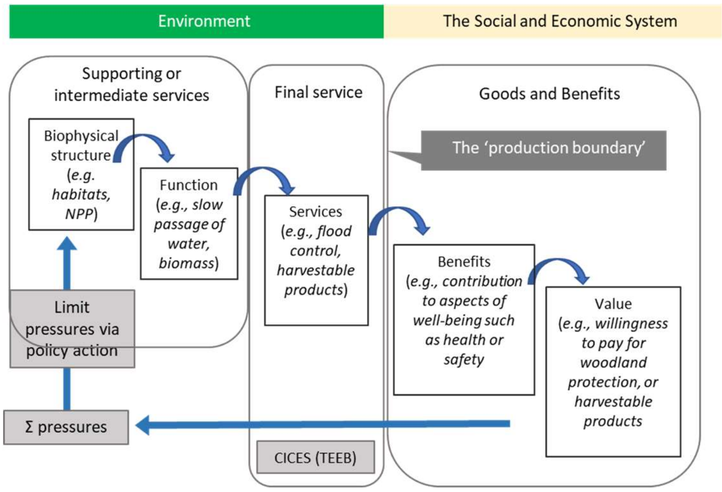
It is worth mentioning, that not all CICES classes are equally clear. Services such as pollination, seed dispersal, global climate change regulation, flood protection, erosion control, wild animals and their outputs, and cultivated crops are defined in a relatively clearly way, and frequently assessed as individual services. Some categories such as bioremediation and regulation of the chemical condition of freshwaters by living processes are ambiguous, and frequently assessed together. Bioremediation seems to denote the processing of wastewater, while the second category water quality regulation by living organisms or processes (see Czúcz et al., 2018 for a detailed review).

Some guidance (practical examples) is needed in regard to some regulation services such as decomposition and fixing processes and their effect on soil quality, which seem to fit more into the supporting services category. Filtration/sequestration/storage/accumulation by living processes also require some guidelines, for instance if carbon sequestration is considered within this category or by the category regulation of atmospheric composition and conditions. Similarly, the former category (filtration…) may also include water quality regulation, which is treated as a separated category (regulation of the chemical condition of freshwaters by living processes). CICES classification depict also practical problems among cultural services. The distinction between more direct (or intrusive) and more indirect (or remote or experiential) use of cultural services seems relevant form a theoretical perspective, but this distinction has been rarely addressed in the studies assessing cultural services (Czúcz et al., 2018). The maintenance of nursery populations and habitats is also a controversial ecosystem service, as some assessments consider the nursery function as an ecosystem service linked to the value humans give to the presence of wildlife, either for direct use (e.g. hunting) or non-use (e.g. bequest or existence value), which can lead to double counting with the assessment of other ecosystem services or with the assessment of biodiversity itself. (Liquete et al., 2016).

8 Available online at https://cices.eu/resources/ (last accessed 12/14/2018).

Supporting services are omitted in both TEEB and CICES classifications. The *cascade model* (Fig. 3) provides the conceptual framework for CICES and TEEB to define the pathway from ecosystem structures and processes to human-wellbeing (de Groot et al., 2012; Haines-Young and Potschin, 2018; Potschin-Young et al., 2018). This later model considers that biophysical structures, process and ecosystem functions[9], provide *final ecosystem services* that contribute to the provision of *ecosystem benefits* (Fig. 3). Those later are the direct and indirect outputs from ecosystems that have been turned into *products or experiences* that are no longer functionally connected to the systems from which they were derived. Benefits are things that can be valued either in monetary or social terms[10]. Normally those benefits are produced in combination with other forms of capital: human (labour, knowledge), social (social networks, cultural knowledge), and produced assets (machinery, infrastructure, R&D).

On the other side there is a difference between 'good' and 'benefit', as the same good can generate different benefit values depending on its context (e.g. location) and timing of delivery. For example a same good (e.g., a woodland) can generate much higher recreational benefits if located at the edge of a city than in more remote areas (Bateman et al., 2011). Establishing a clear delineation between the ecological processes (functions), their direct or indirect contribution to human welfare (services), and the welfare gains that they generate (benefits) is useful to avoiding double-counting problems (de Groot et al., 2012). Those problems arise when some services, mainly supporting and regulating ones, are inputs to the production of others (Boyd and Banzhaf, 2007; Wallace, 2007; Fisher et al., 2009). Therefore, having a fully consistent classification of ecosystem services, in particular regulating services, for economic valuation purposes is most of times challenging or not possible (de Groot et al., 2012). Notwithstanding, CICES classification system seems to be reasonably comprehensive and instrumental for provisioning and regulation systems, while, the MAE classification of cultural services seems more manageable. Nonetheless, no classification is exempt of gaps and ambiguities, and therefore, in order to avoid vagueness in the application of the Natural Capital Protocol, next sub-section identifies main ecosystem services associated to agricultural landscapes and discusses available methods for their assessment and economic valuation.



Source: Adapted from: Potschin-Young et al. (2018)

Fig. 3 The Cascade Model conceptual framework

[9] The ecosystem functions are defined as a subset of the interactions between ecosystem structure and processes that underpin the capacity of an ecosystem to provide goods and services. Those interactions can be physical (e.g. infiltration of water, sediment movement), chemical (e.g. reduction, oxidation) or biological (e.g. photosynthesis and denitrification) (de Groot et al., 2010). While accepting that no fundamental unambiguous definitions and categories exist, supporting services can be seen as ecosystem functions.

[10] Social valuation can include different dimensions, such as shared transcendental, cultural, communal, or group values (Kenter et al., 2015), and other relational values, including good quality of life, desirable relationships among people and between people and nature (Jacobs et al., 2018).

2.2 Economic approaches for the valuation of ecosystem services

The ways ecosystem services are conceived into the supply-benefits delivery chain affect their assessment and valuation. The cascade approach (Fig. 3) provides the framework to distinguish between ecosystem structure and functions generating supporting ecosystem services, from the final services that contribute to generate benefits to people, which in some cases can have a monetary translation. From welfare accounting perspective ecosystem services can be considered as inputs (intermediary services) or final services. Final services are end-products of nature, directly enjoyed or used. The distinction between final and intermediate services is fundamental. Ignoring this distinction, as commented before, may led to double-counting problems, since the value of the intermediate services is embodied in the value of final goods (Boyd and Banzhaf, 2007). For instance, the economic value of agriculture products would implicitly include the contribution of diverse provisioning (e.g. water supply) and regulating services (pollination, biological pest control) as inputs for growing cultivated crops or rearing animals.

Agroecosystems simultaneously provide and rely on ecosystem services to sustain the provision of harvestable goods, such as food, fibre and other materials These systems rely on ecosystem services provided by natural ecosystems, including pollination, biological pest control, maintenance of soil structure and fertility, nutrient cycling or hydrological services (Power, 2010). And, if managed properly, agroecosystems can also produce ecosystem services, such as habitat protection, water flows regulation or carbon sequestration (Godfray et al., 2010). The evaluation and management of ecosystem services in agricultural landscapes concerns diverse provisioning, regulating and cultural ecosystem services. The benefits (disbenefits) of land-based business, such as growing crops and livestock farming, operate at different spatial scales, comprising both on-farm and off-farm effects (0). The distinction between on- and off- farm effects is relevant for framing the scope of the valuation exercise. On-farm effects refer to the impacts that different farming practices have on the ecosystems around them, the farmer and on-site people. On the contrary, off-farm effects refer to those impacts, which could be environmental, social or economic, that transcend the spatial boundaries of the farm (e.g., de Vries et al., 2015). Off-farm, impacts can involve multiple spatial scales, including the landscape unit, the catchment, an administrative demarcation (e.g., Municipality) or even the regional and global levels, such as the global warming potential of greenhouse gas (GHG) emissions.

From a valuation perspective, environmental problems and conflicts are the consequence of trade- offs between values held by different groups of stakeholders, which frequently are not well represented in the decision-making process (Jacobs et al., 2016). This is frequently the case of stakeholders affected by farming off-site effects (both benefits or disbenefit). Within the neoclassical economic paradigm, ecosystem services that are delivered and consumed in the absence of market transactions can be viewed as a form of positive externalities. Those are 'free-of-charge' services that affect the utility function of off-farm users of ecosystem services, or the production function of other sectors or activities, such as an increase on upstream forest cover lowering downstream drinking water supply costs (Abildtrup et al., 2013). Negative externalities (disbenefits), on the contrary, can reduce the utility function of off-farm users, or increase the production costs of off-farm sectors or activities, such agriculture diffuse pollution increasing the cost of downstream water treatment plants to reduce concentrations of pollutants (OECD, 2017: 54). Other off-farm externalities such as maintaining (or depleting) habitats, air filtration (or non-GHG emissions), and carbon sequestration (or GHG emissions), fit more in the public goods[11] domain (Hein, 2011). Meaning that in absence of incentives (e.g., subsidies, tax exemption, payment for ecosystem services) or command and control measures concerning negative externalities (i.e., standards-setting, regulations) those externalities are barely considered into decision making processes.

[11] Public goods are associated with the principles of non-excludability, meaning that is not possible to deny people the benefit from the ecosystem service concerned and non-rivalry, meaning that one person's enjoyment of an ecosystem service does not reduce the availability to the service to others (UNSD, 2014b)

Table 2 Ecosystem service description and related on-farm and off-farm benefits

Ecosystem service	Description	On-farm benefits/ disbenefits	Off-farm benefits/ disbenefits
Provisioning			
Cultivated terrestrial plants for nutrition, materials or energy	Harvestable goods from agroecosystems	Food and other goods for on-farm consumption or sale	Goods for agricultural, food and beverage, apparel, and other manufacturing industry and energy markets
Reared animals for nutrition, materials or energy	Reared animals and their products from agroecosystems	Food and other goods for on-farm consumption or sale	Goods for agricultural, food and beverage, apparel, and other manufacturing industry markets
Wild plants (terrestrial and aquatic) for nutrition, materials or energy	Harvestable goods from agroecosystems	Food and other goods for on-farm consumption or sale	Goods for food and beverage, apparel, and other manufacturing industries markets
Wild animals (terrestrial and aquatic) for nutrition, materials or energy	Wild animals and their products from agroecosystems	Food and other goods for on-farm consumption or sale	Goods for food and beverage, apparel, and other manufacturing industry markets
Genetic material from all biota	Seeds, spores and other plant materials, and animal material collected for maintaining or establishing a population; Wild plants and plants (whole organisms) used to breed new strains or varieties; Individual genes extracted from higher and lower plants for the design and construction of new biological entities	Distinct genotypes (cultivars) allow fruit set in orchards and hybrid seed production trait diversity (from landraces and wild relatives) supports disease resistance, new hybrids, and climate adaptations	Prevention against large-scale crop or animal rearing failure
Regulation & maintenance			
Air quality regulation	Filtration and absorption of air pollutants by living organisms	Clear air for onsite people	Clear air available for downwind people
Biological pest and diseases control	Control of vertebrate, invertebrates and botanical pests by their natural enemies – predators, parasites, and pathogens, suppressing weeds, fungi, and other potential competitors through physical and chemical properties of cover crops, intercrops, and other planted elements	Minimize crop damage and limit competition with crops Minimize weed competition with crops Minimize damaged to reared animals due to parasites or diseases	-May limit need for pesticides, including herbicides, that threaten environmental and human health -May limit the use of antibiotic or other pharmaceuticals that threaten environmental and human health
Carbon sequestration (Climate regulation)	Removal of carbon dioxide from the atmosphere and stored in vegetation (especially forest) and soil carbon pools	Higher soil carbon stock seem to affect positively agriculture productivity (Sanderman et al., 2017)	Regulation of the carbon cycle; mitigation of greenhouse gas contributions to atmospheric change
Control of erosion rates	Soil retention, limiting soil loss through wind and water erosion	Maintain soil and the nutrients it contents to support production	Potential reduction of sediments transferred to downstream systems and users
Maintaining nursery populations and habitats	Production of individuals that recruit to adult populations	Supporting of pollinators, pest predators Nursery of wild species of market interest (e.g., big and small game species, wild berries) (Liquete et al., 2016) used for on- farm consumption or sale	Necessary to support the provision of goods for agricultural and industry markets
Pollination	Transfer of pollen grains to fertilize flowers	Necessary for seed set and fruit production in flowering plants and crops	Necessary for outcrossing in non-cultivated flowering plants
Regulation of the chemical condition of freshwaters by living processes	Filtration and absorption of pollutants by soil and living organisms in the water and soil	Clean water available for human consumption, irrigation and other uses in the farm	-Clean water available to downstream users -May reduce drinking water treatment cost

Ecosystem service	Description	On-farm benefits/ disbenefits	Off-farm benefits/ disbenefits
Water flow regulation (flood protection)	Buffering and moderation of variability of water flows, including water infiltration into soils and aquifers, and regulation of plants transpiration	Water in soil, aquifers and surface bodies available to support plant growth and livestock	Stabilization of stream base flow and mitigation of flooding to downstream areas, recharge into aquifers and bodies of patter, evapotranspiration may support precipitation patterns downwind (Creed and van Noordwijk, 2018)
Cultural services			
Aesthetic, cultural and heritage values Educational values Knowledge systems Social relations Recreation and ecotourism Spiritual and religious value	The non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g. knowledge systems, social relations, and aesthetic values (MEA,2005).	Aesthetics and inspiration; Knowledge systems Social relations, spiritual and religious values; sense of place; cultural heritage; recreation and ecotourism	Aesthetics and inspiration; Knowledge systems Social relations, spiritual and religious values; sense of place; cultural heritage; recreation and ecotourism
Bequest and existence values	Other biotic characteristics that have a non-use value	-	Satisfaction of knowing that other people of future generations will access to nature benefit, or that specific species or ecosystem exists

Source: Adapted and extended from Garbach et al. (2014)

Concerns have been raised that the economic valuation of ecosystem services can contribute to commodification of nature (e.g., Gómez-Baggethun et al., 2010; Fairhead et al., 2012; Sullivan, 2013). However, when appropriately applied, ecosystem service monetary values can help reflecting the full array of our inter-dependencies with and impacts to natural capital, and useful information about changes to welfare that will result from ecosystem changes in management, state or condition of ecosystems. Prices and values are often not the same thing. For example some of the most valuable recreation sites have a zero-entrance price, which does not equate to the value of these resources and any decision maker who ignores this difference is likely to make poor decisions (Bateman, 2018). Monetary valuation can provide helpful information for decision making, but the analysist should be caution about the limitations of valuation methods and exercises.

The economic value of ecosystem services accounts for the utility that those services have to individuals, which is typically based on willingness to pay (WTP) and social preferences for the services involved. Economic valuation is based on the notion that the values assigned by an individual reflect that person's preferences or marginal willingness to trade one good or service for another, while societal values represent the aggregation of individual values. Those values can be derived from information of individual behaviour provided by market transactions relating directly to ecosystem services. Market prices can provide, in some cases, an acceptable starting point for the valuation of ecosystem services. Nonetheless, adjustment should always be made to correct for market distortions such as taxes and subsidies (which are effectively merely transfers from one part of society to another) as well as for non-competitive practices (Bateman et al., 2011). Economists have developed a variety of methods for estimating the value of goods whose market are an imperfect reflection of that values or for non-existent markets (Box 1, and Table 3). In such cases, monetary values can be derived from parallel market transaction that are associated indirectly with the service to be valued, or if both direct and indirect prices are absent, hypothetical markets can be created to elicit people's preferences concerning the provision of ecosystem services (de Groot et al., 2010).

The economic valuation methods intend to span the range of valuation challenges raised by the application of economic analyses to the complexity of the natural environment (Bateman et al., 2011). The methods available for valuing ecosystem services can be classified into six main categories: (1) market-price, (2) production-function methods, (3) revealed preference approaches, (4) the stated preference method, (5) cost-based approaches, and (6) value transfer. Stated preference techniques are often the only way to estimate non-use values, which do not involve direct or indirect uses of ecosystem service, and reflect the satisfaction that individuals derive from the knowledge that ecosystem services are maintained, and that other people have or will have access to them (de Groot et al., 2010).

Box 1 Economic methods for ecosystem services valuation

(Adjusted) Market-price based approaches (use value) are most often used to obtain the value of provisioning services, as the commodities produced by provisioning services are often sold, for example, on agricultural markets. In well-functioning markets, preferences and marginal cost of production are reflected in a market price, which implies that these can be taken as accurate information on the value of commodities. Nonetheless, the market price of commodities needs to be adjusted to correct market distortions such as taxes and non-competitive practices (Bateman et al., 2011). On the other hand, adjusted market prices do not provide the economic value of ecosystem services as also those reflect the contribution of human-related capital into the production process. The valuation approach proposed in the SEEA-EEA guides (UNSD, 2014b) is to use the unit resource rent as a proxy for the economic value of provisioning ecosystem services (e.g., Sumarga et al., 2015). This unit price reflect the residual value after covering labour, intermediary marketable inputs and the produced assets costs. Ovando et al. (2017) applies this method to estimate the value of timber, cork and grazing resources as provisioning services.

Production function methods are based on market prices and consists on the estimation of the effect of changes in a biological resource or an ecosystem services on an economic activity, in terms of the corresponding change in the marketed output (benefit) of the relevant activity. The ecosystem service in this case is treated as an input to the economic activity, and like other inputs, its value can be equated with the impact on the productivity of any marketed output (National Research Council, 2015). Typical examples are the contribution of pollination to food production (Winfree et al., 2011), or variations in rainfall on crop productivity (Fezzi et al., 2014).

Revealed preference approaches (use-value) are a family of methods based on market prices. Revealed preference techniques are based on the observation of individual choices in existing markets that are related to the ecosystem service that is subject of valuation. In this case it is considered that economic agents “reveal” their preferences through their choices (de Groot et al., 2010). Those approaches can be divided into three main categories: (a) hedonic pricing; (b) travel costs, and (c) approaches based on production functions:

- *Hedonic pricing* is most relevant to estimate the implicit demand for an environmental attribute in marketed commodities; such as the economic value of water quality regulation (Bin et al., 2017) and recreational function of water (VanDijk et al., 2016) though housing market fluctuations.
- *Travel cost method* is most relevant to estimate cultural ecosystem services related to direct physical and experiential interactions with nature (e.g., Martín-López et al., 2009). Basically, considers the travel costs paid by tourists and visitor against the environmental values of the recreation sister.

Stated preference methods (use and non-use values) simulate a market and demand for ecosystem services by means of surveys on hypothetical (policy-induced) changes in the provision of ecosystem services. Those methods are used to estimate both use and non-use values of ecosystems when no surrogate market prices exists from which the value of ecosystem services can be deducted (de Groot et al., 2010). Main types of state preference techniques are: (i) *Contingent valuation*, using questionnaires to ask directly the people about their WTP to enhance the provision of an ecosystem services, or their willingness to accept (WTA) a compensation for the lost or degradation of ecosystem services; and (ii) *Choice modelling*, providing individuals a context that include two or more alternatives with shared attributes, though with different levels, of the services valued, from which they are expected to choice the preferred or ranks their preferences. Those techniques have been applied to numerous cases and ecosystem services (Milcu et al., 2013). Choice modelling can be applied through different methods, which include choice experiments, contingent ranking, contingent rating and pair comparison de Groot et al. (2010)

Cost-based approaches assume that the expenditure for producing or maintaining environmental benefits is a reasonable estimate of their values. Cost-based approaches do not provide strict economic values, as they are not based on social preferences (i.e., based on aggregated individual WTP for specific services). Those approaches include: (i) the *avoided cost methods*, which relates to the cost that would have been incurred in absence of the ecosystem service, for example to price erosion and flood control services, in cases where hydro-power reservoirs get congested as a result of deforestation related sedimentation (Arias et al., 2011); (ii) *replacement cost method*, which estimates the cost incurred by replacing ecosystem services with artificial technologies, for example valuing mangrove’s storm protection services using the replacement costs for building seawalls (Huxham et al., 2015); (iii) restoration costs, which estimates the cost incurred by replacing ecosystem services through restoring ecosystems; and (iv) opportunity cost, which consider the forgone revenues for adopting practices that increase the provision on non-marketed ecosystem services.

Value (benefit) transfer, though not a valuation technique itself, is an approach to overcome the lack of specific information on the value of ecosystem services in a relatively inexpensive and timely manner. This is the procedure of estimating the value of an ecosystem service by transferring an existing valuation estimate from a similar ecosystem (de Groot et al., 2010). The value transfer methods can be divided into four categories: (i) unit value transfer, involving the transfer of the unit average ecosystem service value of the study site to the policy site (the place where values are transferred); (ii) adjusted unit value transfer, which involves making simple adjustments to the transferred unit values to reflect differences in site characteristics, such as difference in income; (iii) value function transfer, which uses functions estimated through valuation applications (travel cost, hedonic pricing, contingent valuation, or choice modelling) for a study site together with information on parameter values for the policy site to transfer values; and (iv) meta-analytic function value transfer, which uses a value function estimated from multiple study results together with information on parameter values for the policy site to estimate values (e.g., Brander et al., 2006).

Source: Own elaboration.

Different methods can be applied to estimate the economic value of single ecosystem services or natural assets, depending on available data, budget constraints, or institutional arrangements, such as definitions on property rights and the existence of markets for trading the good and benefits to which ecosystem services are inputs. The economic valuation techniques are diverse, and more or less appropriate to estimate different economic values. Table 3 offers a brief description of main economic valuation methods, their data requirements, and indicative budget and time requirements, along with the main advantages and disadvantages reported in the literature. Table 4 offers an overview of the methods that can be potentially for assessing ecosystem service' values, with some qualitative indication on how often different approaches are applied. Market-based and production function methods are the most frequently used to value provisioning services, while stated preference are the most frequently used ones for cultural services. The methods used for estimating the value of regulating and maintenance services are diverse, being avoided cost frequently used for valuing biological pest control, erosion control, flood and climate regulation services. Replacement costs are frequently used for valuing water purification, regulation of freshwater chemical conditions, air and soil quality regulation. These later including booth alternative artificial technologies to provide these services and substitute goods (for example chemical fertiliser in case of regulation of soil quality).

Economic values refer to marginal changes in welfare from small or marginal changes in the provision of ecosystem services. Most economic decisions concern incremental, often relatively modest changes in natural assets and their service flows Economic valuation of such changes requires an initial understanding of the value of changing a single unit of a stock and the number of units being provided, given changes in the environment, policies and socio-economic trends (Bateman et al., 2011). These incremental changes are often referred to as the 'marginal' value of the ecosystem service in question.

2.3 Moving from ecosystem services to natural capital valuation

Natural capital is the economic metaphor for the direct and indirect contribution of nature, in form of ecosystem services, for generating goods and benefits to people. As most of natural assets (i.e. soils, water, ecosystems) provide a bundle of services, their (economic) valuation should consider not only marginal values from the flows of individual services but also take account of the "stock value" (i.e. the entire ecosystem) providing the total bundle of services. Estimating natural capital as the aggregated value of ecosystem services, needs to account for the trade-offs and synergies in the provision of ecosystem services, since the land-uses and management may have differential effects on the provision of different services. For example, Ovando et al. (2017) shows relevant trade-offs but also synergies in the provision of climate regulation services (through carbon sequestration), water yield and provisioning services (e.g., timber, cork) in forest ecosystems. This situation demands for the simultaneous modelling/accounting of ecosystem services (e.g., Barbier, 2011).

The concept of Total Economic Value (TEV) is useful to define all direct and undirect use and non-use values that confer an economic value to ecosystems, as they affect people's utility functions. TEV encompasses all components of utility derived from ecosystems using a common unit of account: money or any market-based unit of measurement that allows comparisons of the benefits of various goods. (de Groot et al., 2010). TEV accounts for the flow of services that natural capital generates, both now and in the future (appropriately discounted).

These flows of services are summed across the categories (use and non-use values) and valued for marginal changes in their provision. Fig. 4 shows an example of the type of values with the TEV approach, which is the framework used to define the type of economic values derived from ecosystems, and the economic valuation alternatives (Table 3). The value of ecosystem service flows affects the value of natural capital, however, they are not equivalent (Fenichel et al., 2016). Economic literature and more practical natural capital accounting approaches propose different frameworks to price natural capital (assets). The next sub-sections introduce the net present value approach proposed by System of Environmental – Economic Accounts (UNSD, 2014a, 2014b), and more comprehensive natural asset valuation approaches in line with the classic asset valuation economic literature (Jorgenson, 1963; Fenichel et al., 2016).

Table 3 Comparison of economic valuation techniques for ecosystem services and natural assets

Technique	Description	Data requirements	Time[(1)]	Budget[(2)]	Advantages	Disadvantages
Market prices	Include costs/prices paid for goods and services traded in markets (e.g. timber, carbon, value of water bill or pollution permit) Other interpretations of market data (e.g., derived demand functions, opportunity costs, mitigation costs)	Market prices of ecosystem goods and/or services Costs involved to process and bring the product to market (e.g., crops)	↑	£	-Transparent method since based on market prices Reflect actual willingness to pay	Only applicable where a market exists for the good or service and price data are readily available Market prices may be distorted by imperfect competition and/or policy failures, hence not a good measure of societal value
Production function	Empirical modelling approach that relates change in the output of a marketed good or service to a measurable change in an ecosystem services as input of the production process (e.g., pollination for soft-fruit production)	Data on changes in output of a product Data on cause and effect relationship between changes in output due to changes in the environmental input (e.g., crop losses due to reduced water availability, or pollination services)	↑	£(£)	When all required data are available, the technique can be implemented fairly easily	Difficulties on obtaining data on the effect of changes in the provision of ecosystem services and their effect on production Needs a deep understanding on the relationship between changes in ecosystem services and output of product
Replacement cost	The cost of replacing ecosystem services (or natural assets) with an artificial substitute (product, infrastructure, or technology)	Cost (market prices) of replacing an ecosystem services (e.g., bottled water) or an asset with human-made equivalent (e.g. using flood defence infrastructure to replace the mass control flow of ecosystems)	↑	£	-Provides surrogate measure of the value for regulating services -Transparent method when based on market prices	Does not consider social preferences for services or behaviour in absence of services
Avoided damage	The potential cost that would have been incurred in absence of the ecosystem service, or due to natural capital degradation	Data on costs incurred to property, infrastructure, or production as a result of the loss ecosystem services. Damages under different scenarios	↑↑	££	-Provides surrogate measure of the value for regulating services (e.g. flood, erosion control, climate change regulation)	Limited to services related to properties, assets and economic activities Can overestimate values
Hedonic pricing	Based on the observation that environmental factors are one of the determinants of the market price of certain goods (e.g., prices of properties close to green-urban areas). By estimating a demand function for property, the value of a change in the non-marketed environmental benefits generated by the environmental asset can be inferred	Data relating to differences in property prices that can be ascribed to the different environmental (e.g., status of river, area of green space, distance from the green area)	↑↑	£££	Readily transparent and defensible method since based on market data -Property markets are very responsive , so can be a good indicator of value	Limited to costs and benefits related to property The property market is affected by a number of factors in addition to environmental attributes, that need to be identified and controlled for (e.g., number of bedrooms)
Travel cost	Based on the observation that environmental and marketed goods and services are often complements (i.e., there are direct expenses and opportunity costs of time for visiting a site of recreational or leisure interest).	The amount of time and money people spend visiting a site for recreation or leisure purposes Motivations for the travel	↑↑↑	£££	Results are relatively easy to interpret and explain	-Limited to use of recreational benefits Limits for assigning travel and time costs when the trips are to

Technique	Description	Data requirements	Time[1]	Budget[2]	Advantages	Disadvantages
	The value of changes in the quantity or quality of the site can be inferred from estimating the demand function for visiting it.				Based on actual behaviour rather than a hypothetically stated WTP	more than one place or for more than one purpose
Contingent valuation (CV)	Infers ecosystem services or asset values by asking individuals their maximum WTP (or WTA a compensation) for a specified change in the relevant non-market good or service	A representative sample of survey questionnaires in the targeted population Socio-economic and demographic information on survey respondents	↑↑↑	£££	Captures both use and non-use values. Extreme flexible methods that can be used for the economic valuation of diverse good and services, or changes in the quantity or quality in the provision of environmental good and services	The results are hypothetical in nature and subject to numerous different biases from respondents
Choice experiments	Individuals are presented with alternative options with different features (i.e., various attributes or levels, such as number of species present, quality level of water), as well as different prices. They are asked to choose their preferred option, from which the value for the relevant non-market good or service may be inferred	Same as CV above An appropriate set of levels (indicators) are required for key parameters (e.g., poor, medium, good, and excellent river water quality)	↑↑↑	£££	Captures both use and non-use values. Good for providing breakdown of estimated marginal changes	The results are hypothetical in nature and subject to numerous different biases from respondents Choices given to respondents must be limited to what they can understand and weigh up during the duration of the survey
Value transfer	Transferring an existing valuation estimate or evidence from one context (e.g. a forest ecosystem) to another comparable or related context (e.g. a similar ecosystem). Specific adjustments should be made to account for differences between the two contexts	Valuations based any of the above techniques applied to similar studies elsewhere Common starting place for many non-academic studies Data on key variables from different studies (e.g., GDP per capita, area of the site, population)	↑	£	Low cost and rapid method for estimating value	Needs to be applied carefully Results are likely to be subject to a higher level of uncertainty compared to primary research. Existing valuation studies will be more robust and numerous for some services / impacts than for other (e.g. recreation)

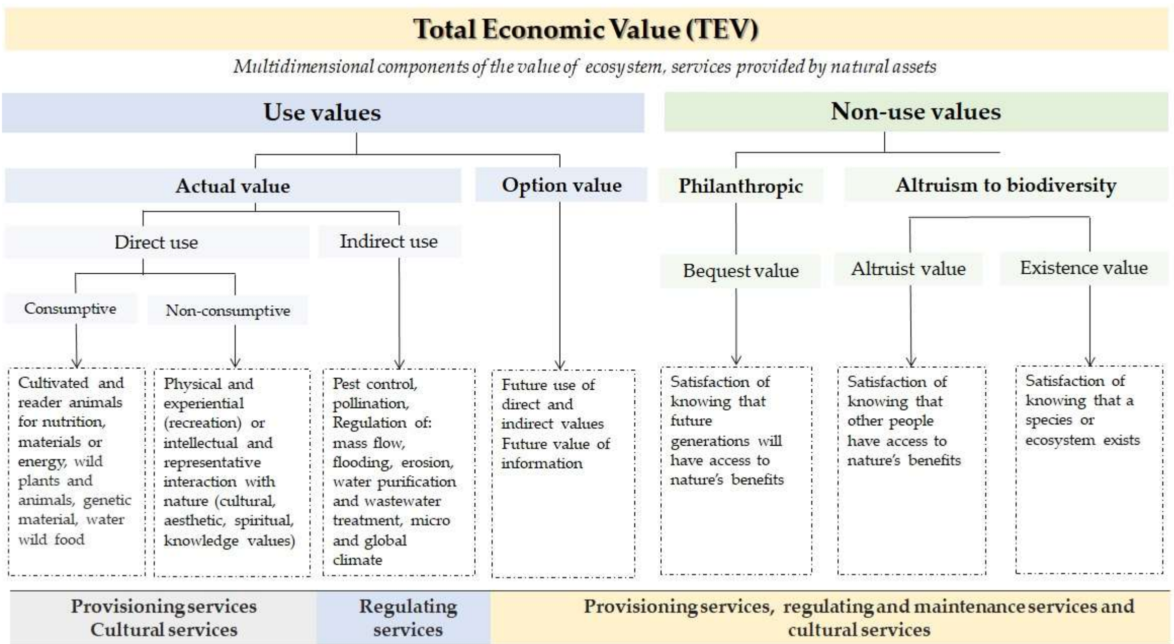
Notes: [1] ↑, ↑↑;↑↑↑ indicate low, moderate and high time demanding studies, respectively; [2] £, ££,£££ refer to low, moderate and high costs, respectively.

Source: Adapted from Natural Capital Coalition (2016b).

Table 4 Common economic valuation methods applied to monetize specific ecosystem services

Class	Revealed preferences				Stated preferences		Cost-based				VT/BT
	MP	HP	TC	PF	CV	CM	AC	RC	OC	RT	
Provisioning											
Cultivated plants and reared animals for food, fibre, and materials											
Wild plants and animals for food, fibre, and materials											
Genetic material from all biota											
Water											
Regulating & maintenance											
Air quality regulation											
Biological pest and disease control											
Carbon sequestration (climate regulation)											
Control of erosion rates											
Gene pool protection (endangered species)											
Habitats and populations nursery											
Pollination											
Regulation of the chemical condition of freshwaters by living processes											
Regulation of soil quality (fertility)											
Water flow regulation including flood control											
Water purification and waste water treatment											
Cultural services											
Aesthetic											
Cultural and heritage values											
Educational values											
Knowledge systems Social relations											
Recreation and ecotourism											
Spiritual and religious value											

Notes: MP: market-price; HP: hedonic pricing; TC: travel costs; PF: production function; CV: contingent valuation; CM: choice modelling; AC: avoided costs; RC: replacement costs; OC: opportunity costs; RT: restoration costs: VT/BT: value/benefit transfer functions/data. The colour indicates: dark purple most frequent method used; medium purple moderately used; light purple used seldomly (adapted and extended from de Groot et al. (2010:103-116) on a review of valuation approaches used for valuing ecosystem services in forest and wetlands).



Source: *Own elaboration* inspired in de Groot et al. (2010).

Fig. 4 Type of values within the Total Economic Value Approach

2.3.1 SEEA Natural Assets Accounting approach

The natural capital accounting system conceptualises the ecosystem as the asset (stock), rather than the constituent parts (Badura, et al., 2017). Those assets are frequently valued on the basis of the expected flow of ecosystem services. The SEEA Central Framework (UNSD, 2014a), proposes to estimate natural assets as the net present value (NPV) of future returns [to natural/environmental assets] assuming current consumption patterns (Badura, et al., 2017), which is the standard rule for pricing capital in the deterministic case (Dixit and Pindyck, 1994). The underlying assumption for estimating aggregated values of ecosystem assets is that the expected future flows of each ecosystem service can be valued and then discounted to the current period. This follows the same accounting logic applied in standard asset accounting.

In more formal terms, natural assets produce a flow of *k* ecosystem services that may vary over time and across space. Assuming no capital gains, and a well-known periodic monetary flow of ecosystem service defined by RR_k, which reflects the economic value of return to natural, and is estimated as the product of the biophysical units of ecosystem services (B_k) delivered by the unit return to the environmental asset that deliver the *k* service (p_k): $RR_k=p_k \cdot B_k$.

The capital value of those (V_k) is defined by:

$$V_k=\sum_{t=0}^{N}\frac{RR_k(t)}{(1+r)^t} \qquad (1)$$

Where *r* is the discount rate, *t* to time and *N* the asset life. An asset life (N) is the expected period of time over which the ecosystem services are to be delivered. The asset life is affected by the potential of ecosystems to regenerate, which would happen in case of sustainable management (Ovando et al., in press). The SEEA proposes to estimate asset life based on consideration of the available physical stock of the asset and assuming rates of extraction and growth, in the case of renewable resources (e.g., a forest stand rotation length). For biological resources, such as aquatic resources, it is necessary to consider biological models and sustainable yields of biological resources.

A selection of an appropriate discount rate (r) is not a straightforward choice and, depending on the context, may require consideration of equity and other issues, including intergenerational equity (UNSD, 2014b). The SEEA Central Framework concludes that for the purpose of alignment of SEEA values with the SNA, it is necessary to select marginal, private, market-based discount rates in NPV calculations. For the UK ecosystem and natural asset accounts follow the HM Treasury Green Book recommendation of using a schedule of declining discount rates, suggested by the Green Book (2003) (Freeman and Groom, 2016).

As with aggregation within ecosystems, understanding dependencies between ecosystem services and assets and the nature of those dependencies in future periods is critical to estimate the expected pattern of ecosystem service flows (B_k) an asset would deliver in the future. Ideally knowledge would exist not only about relationships in the present period but also about how those relationships might change in the future. Accounting for the likely non-linear dynamics involved, involving positive or negative feed-back loops, is relevant. As far as possible those dynamic interactions have to be considered for natural assets valuation (UNSD, 2014b).

Valuing ecosystem service flows in the context of extending or/and integrating natural capital into the SEEA accounts implies valuing final ecosystem services. While the biophysical definition of ES often refers to provision, regulating, cultural services, and supporting services, this classification needs to be further adapted for economic assessment (Fisher et al., 2009). There are flows of ecosystem services between ecosystem assets (i.e. intermediate or supporting ecosystem services), but for the construction of monetary ecosystem services accounts, only final ecosystem services should be accounted for and valued, otherwise double counting might occur.

The unit return to environmental assets are defined (p_k) in the SEEA framework, using the concept of economic rent, which is considered the (unit) surplus value accruing to the extractor or user of an asset calculated after all costs and normal returns to produced assets used in the production process have been accounted for (UNSD, 2014a). The SEEA recommends using an exogenous approach to estimate the rate of return to produced assets.

Ideally, the expected rate of return should relate to activity-specific returns and considering risks in investing in particular activities, in case information of financial markets is available for the specific activity. In absence of such markets, it recommends using an economy-wide rate of return, such as government bond rates, where these exist (UNSD, 2014a)

The valuation of assets for the SEEA framework is based on exchange prices, i.e. the value at which the asset would be transacted if it were exchanged between a willing buyer and a willing seller instead of welfare values (Obst and Vardon, 2014). In the case of ecosystem services, for which markets often don't exist, exchange values essentially represent an assumed transaction between an ecosystem asset and economic units, or "the monetary value of the ecosystems to economic production and consumption" (UNSD, 2014b). The valuation methods that can be used are described in detail in sub-section 2.2.

To integrate monetary estimates of ecosystem services within broader accounting frameworks, it is necessary to undertake aggregation, which must be considered in its different forms: (a) aggregation of the value of different ecosystem services within a single ecosystem; (b) aggregation of the value of ecosystem services across multiple ecosystems; and (c) aggregation of the value of expected ecosystem services flows to obtain an estimate of the value of an ecosystem asset, which is the aggregation level that matter in terms of natural capital valuation. The term aggregation is understood as the combination of comparable elements across temporal and spatial scales (Borja et al., 2014). In the simplest aggregation case, it is assumed that each ecosystem service is independent, and their values can be aggregated without further considerations. In practice, it may be difficult to isolate ecosystem services in terms of their price and quantity. Aggregation should ideally take into consideration cross-ecosystem dependencies, and inherent trade-off and synergies (e.g., Bateman et al., 2013; Campos et al., 2019; Ovando et al.,in press). If dependencies between ecosystem services are not considered, then the contributions of individual ecosystem services might be double counted. Solving these issues requires a thorough understanding of both, the relevant ecosystem processes in physical/scientific terms and the contributions of ecosystem services to human well-being.

2.3.2 Natural capital valuation from inclusive wealth theory

From the neoclassical economics there are at least two ways to describe capital. Capital can be conceived as an inventory of goods, whereas the consumption good can be stored and shifted directly from one period to the next, but also as an intertemporal factor of production (Hulten, 2006). Capital is accumulated to provide capital services, which are inputs to the productive process and the demand of capital stock is determined to maximise net worth (Jorgenson, 1963).

The long-run value of natural stocks as durable assets is affected by the expected flow of services the asset yields over time, and by other important social, economic, and biophysical data (Fenichel et al., 2016a). Form the inclusive wealth theory standpoint, wealth represents the aggregated value of productive assets, valued at appropriate accounting prices (shadow prices[12]). Those accounting prices measure the social worth of an additional unit of the asset, and wealth is "inclusive" if all assets, including natural capital, enter this sum (*ibid* 2383). To operationalize the inclusive wealth framework, information about the accounting price for valuing stocks is needed. Those prices should be marginal prices grounded in capital theory (Jorgenson, 1963), and should reflect the change in current and future well-being due to increases or decreases in stocks (Nordhaus et al., 2006). It is relevant to mention that accounting prices show the value of capital in the world as it is, not at is should be which be. This provides operational insights to policymakers about trade-offs and sustainability, which won't be possible if optimized or idealized prices are used (Fenichel et al., 2016b). Note that accounting prices may not be identical to market prices if no market, and thus no price, exists or if subsidies or externalities skew the market price (Dasgupta, 2009).

Fenichel et al., (2016b) propose to determine unit natural capital values jointly with biophysical, human behavioural, and price dynamics and their associated feedbacks. The accounting price of natural capital *j* (P_j) for a stock of natural capital K_j, and accounting for the feedbacks in the coupled socio-ecological system is:

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[12] Shadow prices often reflect the marginal changes in the objective function (i.e. utility maximization) due to marginal changes in the constrains of the optimization problem.

$$P_j(K_j(t)) = \frac{MD\big(K_j(t),x(K_j(t))\big)+\dot{P}_j\big(K_j(t)\big)}{\delta\text{-}MG\big(K_j(t)\big)\text{-}MHI\big(K_j(t),x(K_j(t))\big)} \quad (2)$$

Where MD is the marginal flow of benefits from a small increase in the natural capital stock j (e.g. the ecosystem service marginal net benefit) MD depends directly on the stock of natural capital (K_j), and indirectly through the economic program[13] ($x(K_j(t))$ (in that case ignoring the dependencies on other stocks for simplicity. The term δ is the discount rate, which reflects intertemporal consumption preferences, or in other words the degree to which people value benefits now versus in the future. MG is the marginal change in growth rate (appreciation) of stock j from having an extra increment of stock, which could be positive and negative. The MHI is the marginal human impact that results from stakeholders' behavioural responses to changes in resource j, indicating whether people increase or decrease exploitation of the stock as the stock changes. Finally, the term $\dot{P}_j\big(K_j(t)\big)$ reflects changes in the accounting price of asset j. This changes in the asset accounting price could be estimated using collation approaches[14], given process-based models linking capital stock dynamics and human investment or consumption behaviour in these stocks (Fenichel et al., 2016b).

2.3.3 Pathways to natural capital assets valuation

Natural capital assessment is a land-scape focussed and spatially-explicit appraisal that provides information on the natural environment of a planning unit (Brown et al., 2016). More specifically natural capital assessment involves the processes of identifying and measuring what assets and what services nature provides, how those assets can be managed to avoid depletion and degradation, and how this information can be integrated into decision-making. Depending on the needs for conducting a NC assessment, this can purely focus on measuring the state (e.g. extend) and condition of assets and ecosystem services (e.g., Maes et al., 2012), or encompassing more participatory mapping and planning approaches (e.g., Benami and Wilkinson, 2013; Brown et al., 2016). Natural capital assessment should be framed as dynamic processes considering quantitative and qualitative changes in the state and conditions of elements of nature. In order to offer useful insight for decision making, there is need to improve our understanding on how changes on asset state and condition affect human well-being. Still crucial evidence gaps relating to the condition of individual natural assets, such as soils, the atmosphere, wild species and oceans remain (Natural Capital Committee, 2014).

Accounting for the whole pathway between drivers, supporting process, natural capital properties, ecosystem services and benefits to people (both private and public goods), can provide insights not only into ecosystem services, but also changes in natural capital stocks, the resilience of natural system and the economic implications making the business case for change (Bassett and Davies, 2018). This pathway is inspired UK in the Valuating Nature Network (VNN)[15], and is consistent with the cascade model (Potschin and Haines-Young, 2016), as a conceptual framework to move from ecosystem services to benefits to people for economic valuation purposes. The VNN natural capital valuation pathways provide a comprehensive framework to guide both natural capital assessment and valuation and help to frame key knowledge and information gaps. The next paragraphs introduce the pathway for soil natural capital assessment and valuation, as an example, and discuss the connexion and interactions of soils with other natural capital assets to provide ecosystem services and valuation procedures.

Abiotic component of nature, such as mineral soils, air or energy interact with living organisms as part of landscapes or land units that support vegetation. Those interaction are complex and operate at different time and spatial scales, involving synergies and trade-off in the provision of ecosystem services that enable many human activities, and support life-systems. Those interactions are affected by both natural (e.g., climate change or geology) and anthropogenic driver pressures, involving land use and management practices, and other drivers affecting the socio-economic and policy domains (e.g. government structures, regulatory framework, environmental and development policies and incentives). But also, by inherent and manageable properties of

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[13] The economic reflect real- world institutions, technology, and management.
[14] Methods of numerical solution that uses a finite-dimensional space of candidate solutions (normally polynomials) and a number of points in the domain (called *collocation points*), and to select that solution which satisfies the given equation at the collocation points (see Fenichel and Abbott (2014:10-11), for details).
[15] www.valuing-nature.net.

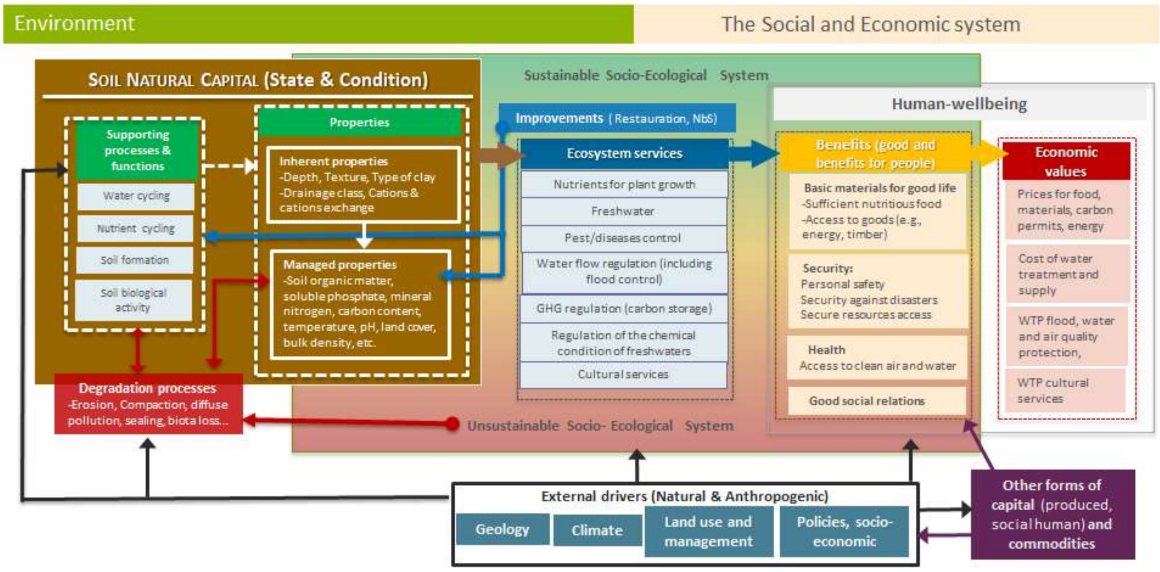
natural assets, and supporting processes and function, that affect the delivery of ecosystem services, and wellbeing values ultimately.

2.3.3.1 Soil natural capital valuation

Fig. 5 shows, as example, the pathways to soil natural capital valuation, indicating linkages between soil properties, driver pressures, ecosystem services and benefits to people. Soils interact with other natural assets (all living things, water, solar energy) to deliver multiple ecosystem services (e.g., nutrient for biomass growth, freshwater, water flow and quality regulation, GHG regulation, etc.), that are partially captured in market values or people's willingness to pay for goods and services that are essential to provide basic materials for good life and health (e.g. food, energy, freshwater), secure access to resources and protection against disasters. Still there are relevant knowledge gaps in our understanding of the interactions between soil properties, supporting functions and ecosystem services provision as response to degradation processes. Those include, for example, a partial understanding of how biological activity affects, nutrients cycling, and water cycling, and hence agriculture or forestry yields (Bassett and Davies, 2018). Cultural services have been systematically omitted in soil valuation studies, which is somehow surprising if we consider the sacred nature that earth (soil-sub-soil) has for various cultures (Dominati et al., 2010). A relevant challenge for soil ecosystem services and natural capital valuation is the intimate and complex interaction of soils with living organism at the landscape unit. This affects, for example, the valuation of services such as water quality and flow regulation (including flow control), but also landscape cultural services valuation. Not surprising that a full valuation of soils natural capital does not seem practicable, as most ecosystem services result from complex, and not yet fully, understood interactions between biotic and abiotic elements and function of ecosystems, climate variables and management.

Therefore, from a natural capital perspective what matters is the effect of changes in soil state and conditions due to degradation processes on food production, water quality, or carbon stocks (Graves et al., 2011). The recommendation of the System of Environmental and Economic Accounts (SEEA) Central Framework is developing biophysical accounts for soil natural capital. These recommendations involve defining initial state and condition of soils assets using one of the natural systems classifications and estimating changes in soil state and conditions by tracking soil materials such as carbon, nutrients and soil moisture. Robinson et al. (2017) proposes to use land cover for reporting, rather than a soil classification, as this classification is more readily understood by policy-makers. Biophysical asset accounts based on land cover, can then be populated using soil monitoring data to capture change in soil state and conditions. This implies using models to account for soil stock, and changes due to soil degradation using soil properties-based mapping, given external driver pressures on soil resources (see Igwe et al. (2017) for a review on soil dynamic models).

Soil degradation involves at least six main processes namely: erosion, compaction, decline in organic content, loss of soil biota, diffuse contamination and surface sealing. A relevant challenge for soil ecosystem services and natural capital valuation is linking soil degradation (or improvement) to changes in the capacity of soils to support provisioning services such as food and fibre production, regulating services associated with water quality regulation, flood control and climate, and cultural services associated with landscapes, recreation and habitats (Graves et al., 2011)(Graves et al., 2015). A comprehensive figure of soil degradation costs is challenging. Most of economic approaches to soil degradation consider the economic value of decays in agricultural and forestry yields caused by the reduction in soil depth, the cost of a reduction in the stock of carbon, and the cost of replacing losses in N, P and K, and the offsite cost associated with impacts on environmental water quality, drinking water quality, and greenhouse gas regulation (Brady et al., 2015; Graves et al., 2011; Graves et al., 2015; Telles et al., 2013; Tsiafouli et al., 2015). Counterparty, soil erosion control services can be estimated considering the avoided costs in terms of nutrients and carbon losses, and water treatment cost avoided when certain types of landscapes or agricultural practices are maintained or adopted, respectively.



Source: *Own elaboration* inspired in Bassett and Davies (2018) and Dominati et al. (2010).

Fig. 5 Soil natural capital valuation pathways

2.3.3.2 Agroecosystem assets valuation

Agroecosystems comprise a large part of Earth surface, and can be defined as the ecosystems in which humans have exerted a deliberate selection of the crops and the livestock to be maintained, replacing to a greater or lesser degree the natural flora and fauna of the site (Alhameid et al., 2017). Agroecosystems provide food, forage, bioenergy, and pharmaceuticals, which production is affected by complex interaction between biotic and abiotic elements and functions of agro-ecosystems, and their response to anthropogenic and natural drivers, climate change and land use and management. Agricultural biomass –as provisioning service from cultivated terrestrial plants for nutrition, materials or energy– relies on other ecosystem services, such as pollination, biological pest control, maintenance of soil structure and fertility, nutrient cycling and hydrological services (Power, 2010, and Fig. 2). Similar to the contribution of soils to the delivery of ecosystem services, quantifying the specific contribution of each individual ecosystem service, and other forms of capital (i.e. produced and human) to biomass production is challenging and potentially prone to double counting if not carefully undertaken.

Frequently, natural capital accounts for agroecosystems are restricted to monetary and physical flow values for biomass associated to crops and grazing areas, and in few cases net carbon sequestration and air pollution removal services (e.g., White, et al., 2015; ONS, 2018; Scottish Government, 2019). Agriculture biomass account reflects the market component of natural capital to the provision of food, energy, grazed biomass for livestock production and other materials for industry, and it is usually valued considering the resource rent. This later rent represents the return to environmental assets, and ideally should be adjusted to further include natural assets' depletion (UNSD, 2014a:152). There are different approaches to estimate the resources rent: the residual value method, the appropriation method and the access price method[16] (*ibid*). The *residual value* is the most commonly used approach, and basically implies deducting any user costs of produced assets (including consumption of fixed capital and rates of return returns to produced assets) from the gross operating surplus[17] after adjustments for any

[16] The appropriation method estimates the resources rent using actual payments made to owners of environmental assets

[17] The gross operating surplus (GOS) represent the part of income derived from production that is earned by the capital factor (which includes also the natural capital). This is estimated as a balancing item of the national accounts. GOS is essentially the total output less the cost of any intermediate services (good and services used as inputs of the production process), and less the compensation to employees.

specific subsidies and taxes. The *appropriation method* estimates the resource rent as the actual payments to the owners of natural assets, using mechanism such as fees, taxes or royalties. Finally, the *access price method* is used when the access to a resource is controlled through the purchase of licenses and quotas, as frequently observed in the forestry and fishing industries. In competitive market conditions is expected that the value of the natural assets use rights should be equivalent to the future returns from the asset (after all cost including user costs of produced assets are deduced). In practice those use rights can be provided by a price lower than the market, when other considerations such as employment creation prevail, and the market does not internalize future scarcity values (Macian-Sorribes et al., 2014). As both, the access price and the appropriation methods can be heavily influenced by institutional arrangements, they are barely used to natural asset flow and stock values.

2.3.3.3 Forest ecosystem asset valuation

Forest ecosystems, when properly managed, are deemed as a source of many beneficial services, including carbon sequestration, water quality regulation, maintenance and nursery of populations, and diverse cultural services (e.g., Abildtrup et al., 2013; Quine et al., 2011; Pichancourt et al., 2014; Campos et al., 2019). Timber is one, and not necessarily the most relevant, service delivered by forest ecosystems. Nonetheless, timber is in many –if not most – cases the only forest ecosystem service considered in private and public national accounts, which has led to a very narrow understanding of the contribution of forest ecosystems to human-wellbeing. Carbon sequestration, in particular, and air pollutants removal by trees are two of the "non-market" services gaining traction in private and public decisions (Favero et al., 2017; Nowak et al., 2018). There are different alternatives to price carbon sequestration in forests, from the social cost of carbon, based on the avoided damage of CO_2 emissions of carbon to carbon prices in proxy and specific markets (Ovando et al., in press); while air pollution removal usually signals avoided health costs (Whiteley et al., 2016).

Timber *standing prices* have been frequently used to value biomass as provisioning service, which is not strictly a resource rent as it implicitly accounts for the value of pre-commercial forestry investment (Ovando et al., 2017). In the natural capital accounts literature, we observe two ways of estimating timber stock values. The flow approach followed by the office of national Statistics in the UK (ONS, 2018; Scottish Government, 2019), which considers the capitalized value of the expected future flows of biomass services over the asset life. The pattern of expected flow of services in this case is estimated considering the historical flow of timber extracted[18]. The second approach is the stock one, based on real forest inventories (e.g., National Forest Inventory), and estimates the standing value of timber in view of harvesting probabilities given the expected forest management schedules and actual tree's diametric (or age) classes distribution (e.g., Caparrós et al., 2003; Ovando et al., 2017). Ideally, stock models should introduce the effect of climate change forest growth and productivity (Susaeta et al., 2017).

2.3.3.4 Aquatic ecosystems assets valuation

Aquatic ecosystems (rivers, lakes, groundwater coastal waters, seas) support the delivery of critical ecosystem services, such as water provisioning, fish biomass and cultural services. Other key ecosystem services connected to the hydrological cycle at the catchment level, such as water purification, water retention or climate regulation. The ecosystem functions and processes to deliver the former water-related services intrinsically depend on the interaction of water and land in different ecosystems, such as forests, agricultural lands, riparian areas, wetlands, and water bodies (Grizzetti et al., 2016). Water purification services are often valued considering avoided water treatment costs (Price and Heberling, 2018).

Frequently, natural capital accounts for aquatic-related ecosystems services are restricted to water abstraction flow and monetary values (e.g. ONS 2018; Edens and Graveland, 2014). The valuation of water provisioning services can account for economic transactions associated with the use of water for industries, households and governments, considering for example the resource rent approach to estimate the contribution of natural assets to production. A relevant limitation of economic transactions related to water resources is that those prices are frequently determined administratively, by government or water authority, using flat rates that in the best of cases cover the full cost of water supply. This limits the use of market prices as they do not necessarily reflect people's preferences regarding water provisioning services, and the cost associated to future water scarcity. Alternative

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[18] For a period of 5-years in case of UK timber stock accounts.

valuation methods for water provisioning services include the replacement cost method and stated preference methods to elicit individual WTP for improving water provisioning services (Grizzetti et al., 2016; ABS, 2018; Edens and Graveland, 2014). In case of agriculture, water can be also integrated as an input of agriculture production function, as valued considering the monetary value of marginal contribution of water irrigation to agricultural outputs.

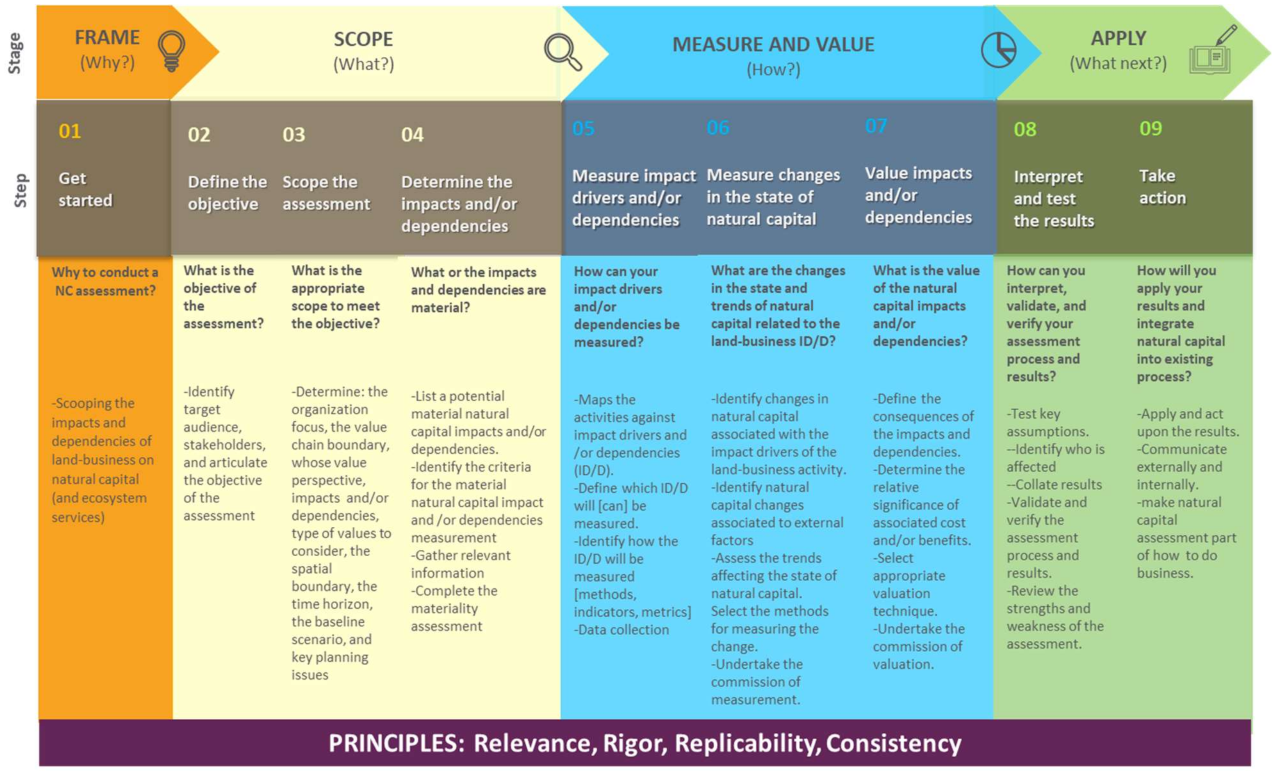
Former methods help to estimate the economic value of the flow of water provisioning services at certain period. Yet, moving from the ecosystem service to the natural capital valuation perspective is not trivial. Different to timber or minerals, water is in continuous movement through the processes of precipitation, evaporation, run-off, infiltration and flows to the sea. Natural asset valuation concerns the estimation of the expected flow of water provisioning services in the future, and these estimations are complex for water resources. Ideally the expected flow of water provisioning services would consider the effect of climate change on future water supply, but also changing water demands in response to economic and population growths. Hydro-economic models representing the hydrological cycle, water supply and demand can be used to estimate shadow prices for water using optimization procedures, in a way that these prices reflect the scarcity condition and opportunity costs of water (Ovando and Brouwer, 2019). Valuation of water resources as natural asset value is complex and riddled with uncertainty as it highly depend on uncertain climatic variables. Similar to soils, from a natural capital valuation perspective it seems more relevant to track and examine the effects of changes in the water availability and conditions, and on the water supply or treatment cost functions for domestic use and industries.

3 The Natural Capital Protocol applied to land-based business

Land-based (and environmental) sectors can be broken down into three major categories: land management and production, animal health and welfare, and environmental industries (Lantra, 2009). Land management and production compromise diverse farming activities, such as agricultural crops, livestock rearing, aquaculture, horticulture, fencing, florist, land-based engineering, and trees and timber production, as well as non-farming activities, such as water resources and catchment management, or renewable energy production. Animal health and welfare encompasses activities related to animal care and technology, farriery, equestrian activities or veterinary nurse. Environmental industries cover activities that are gaining relevance in the management of agriculture systems, such as environmental conservation, fisheries, game and wildlife management, landscaping and sports turf. Hereinafter land-based (and environmental) sectors are jointly referred to as land-based business. This conceptual framework puts emphasis on farming and forestry activities, though also explores potential impacts, dependencies, risk and opportunities of land management non-farming activities and environmental industry.

The Natural Capital Protocol offers a standardised framework to identify, measure and value the impact and dependencies of business activities on natural capital (Fig. 6). When land-based businesses are concerned, the direct dependency on natural assets, such as land, water, soil and ecosystems, and the services that flow from them is more evident. While the impacts of agriculture systems on natural capital can be diverse, and operate at different spatial scales from local, to drainage systems, the catchment or even to regional or global levels for certain outcomes such as GHG emissions, respectively. The Protocol can help identifying and, when feasible, measure impacts, and the dependencies on natural capital. The Protocol goes beyond the assessment of impacts and/or dependencies, to identify and value risk and opportunities related to natural capital, which can be more directly connected to decision-making, and helping land managers to improve the economic and environmental performance and resilience (Natural Capital Coalition, 2016d).

The Protocol is structured in four stages and nine steps that are summarised in Fig. 6 and described in more detail in the next sub-sections. The principles that underpin the application of the Protocol for the natural capital assessment are relevance, rigor, replicability and consistency. Relevance entails considering the most important issues throughout the natural capital assessment, including the impacts and/or dependencies that are most material for the business and its stakeholders. Rigor involves using technically robust (from a scientific and economic perspective) information, data, and methods that are also fit for purpose. Replicability seeks to ensure that all assumptions, data, caveats, and methods used are transparent, traceable, fully documented, and repeatable, which allow for an eventual verification or audit. Finally, consistency implies ensuring that the data and methods used for an assessment are compatible with each other and with the scope of analysis, which depends on the overall objective and expected application (Natural Capital Coalition, 2018).



Source: Adapted from the Natural Capital Protocol Guide (Natural Capital Coalition, 2016d)

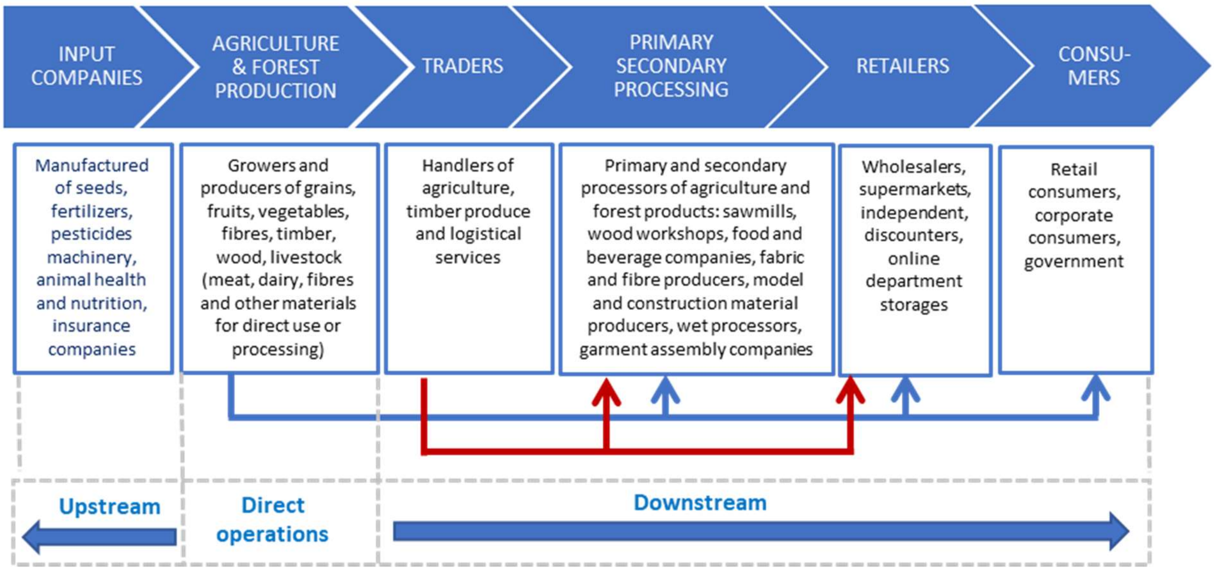
Fig. 6 The Natural Capital Protocol Framework, Stages and Steps

The steps follow a similar structure, beginning with an overarching question and a detailed description of the actions that are required to complete the step (Natural Capital Coalition, 2016b). The next sub-section provides a revision of the four stages and their steps, considering the guidance and templates offered by the Food& Beverage, Apparel and Forest products guides, as well as, the new material produced by the Protocol trial applied to land-based business by Crown Estate Scotland (Silcock et al., 2018a).

3.1 FRAME STAGE (Why?): Framing the natural capital assessment

The overarching question of this stage is why to conduct a natural capital assessment? This initial stage involves getting familiar with natural capital and ecosystem services concepts (Step 01 of the Natural Capital Protocol) (see Section 2) and analysing how these concepts relate to the specific land-based business context. This first approach to natural capital concepts intends to identify potential impacts and dependencies on natural capital (and ecosystem services), and explore the potential risks and opportunities related to natural capital in any or all aspects of the value chain that are relevant to land-based business (Fig. 7), and its stakeholders. The value chain includes all economic activities that mostly depend on the production of goods and services from enclosed farm and forest lands

Natural capital impacts and dependencies of land-based businesses can consider all agriculture and forest products value chain, including the consumer use stages and companies that supply inputs into the value chain. While all stages of the value chain are important for an accurate assessment, the analysis of impacts and dependencies of land-based activities focus mainly on farming production stages, considering that in most cases land manager' decisions operate and can influence natural capital state and conditions at this stage. Natural capital dependency is more direct for agricultural and forest producers than for all those who depend on agricultural or forestry products in their value chain, in terms of the dependency on soil, water and ecosystem assets. Furthermore, biodiversity is critical to the health and stability of natural capital and to flows of ecosystem services, as it supports fundamental processes such as the carbon and water cycles and soil formation (Natural Capital Coalition, 2016b).



Source: *Own elaboration* based on (Natural Capital Coalition, 2018).

[(1)]End-life uses such as recycling, reuse, and other end-of-life options should be considered within every stage of the value chain. Arrows indicate different options of vertical integration within the production and distribution stages

Fig. 7 Land-based business value chain [(1)]

Natural capital dependencies in case of agriculture and forestry sectors span all categories of ecosystem services (Table 1). These dependencies can be consumptive, when water energy, nutrients or materials are inputs of crops, livestock and forest production and primary processing activities. They can be also be non-consumptive, when they depend on the regulation of processes and functions of the physical and biological environments, and on cultural services involving shared knowledge, experience or ethical and spiritual values that condition the producer and society relationships with nature (see 0).

Over-exploitation of natural resources, particularly where water, fertile soils and land are scarce and land demand for agriculture and development is also high, which can generate a financial risk to land-based business. Agriculture and intensive forestry pose a great threat to critical ecosystem services, though soil erosion and compaction, water pollution, deforestation and degradation of habitats, GHG emissions, and biodiversity losses (MEA, 2005). All of these impacts increase the financial risk for land-based business and other natural-resources dependent sectors. Correspondingly, well-managed natural capital can create positive opportunities to reduce the negative impacts of farming, in a way they mitigate future financial risks, reduce production and environmental liabilities associated costs or improve efficiency. The risks and opportunities involving natural capital for land-based business can be diverse. Table 6 shows some examples of risks and opportunities for main risk categories that have a direct link with land-based business performance, including operational, legal and regulation, reputational and marketing, financial and societal risks. Those risk and opportunities can have a direct or indirect impact on the farm revenues and profits, the cost of produced goods and services, taxes, and even the market value of the farm holding.

Table 5 Natural capital dependencies in the agriculture and forest production stages

Dependency	Consumptive	Non-consumptive: regulation of the environment and cultural services
Agriculture products	-Nutrients supply -Water supply (ground and surface waters) -Energy supply -Genetic material from all biota	**Regulation of the physical environment** -Soil physical support ,-Decomposition and fixing processes and their effect on soil quality , -Buffering and attenuation of mass movement -Hydrological cycle and water flow regulation (Including flood control, and coastal protection), - Weathering processes and their effect on soil quality -Regulation of temperature and humidity **Regulation of the living environment** -Pollination and seed dispersal -Biological pest control -Maintaining nursery populations and habitats **Regulation of waste and emissions** -Bioremediation of waste and toxic substances - Regulation of the chemical condition of sallwaters by living processes **Cultural services** - Intellectual and representative interactions with natural environment that enable scientific investigation or the creation of traditional ecological knowledge, education and training, or resonance in culture and heritage
Livestock products	-Biomass: grazing resources and forage crops - Water supply (ground and surface waters) -Energy supply	**Regulation of the physical environment** -Regulation of temperature and humidity **Regulation of the living environment** -Biological pest control -Maintaining nursery populations and habitats **Cultural services** - Intellectual and representative interactions with natural environment that enable scientific investigation or the creation of traditional ecological knowledge, education and training, or resonance in culture and heritage
Forest product	-Nutrients supply -Water supply (ground and surface waters) -Genetic material from all biota	**Regulation of the physical environment** -Soil physical support -Decomposition and fixing processes and their effect on soil quality,-Buffering and attenuation of mass movement -Hydrological cycle and water flow regulation (Including flood control, and coastal protection), - Weathering processes and their effect on soil quality -Regulation of temperature and humidity -Wind protection **Regulation of the living environment** -Pollination and seed dispersal -Biological pest control -Maintaining nursery populations and habitats **Regulation of waste and emissions** -Bioremediation of waste and toxic substances - Regulation of the chemical condition of saltwater by living processes **Cultural services** - Intellectual and representative interactions with natural environment that enable scientific investigation or the creation of traditional ecological knowledge, education and training, or resonance in culture and heritage
Renewable energy	- Water used as an energy source - Biomass used as an energy source -Solar and Eolic energy	**Regulation of the physical environment** -Soil physical support,-Hydrological cycle and water flow regulation (Including flood control, and coastal protection), -Wind protection -Buffering and attenuation of mass movement
Recreation/ tourism	-Biomass from wild plants and animals for nutrition - Water supply (ground and surface waters) -Energy supply	**Regulation of the physical environment** -Soil physical support -Hydrological cycle and water flow regulation (Including flood control, and coastal protection) -Regulation of temperature and humidity **Regulation of the living environment** -Maintaining nursery populations and habitats **Cultural services** -Physical and experiential interactions with natural environment that enable activities promoting health, recuperation or enjoyment - Intellectual and representative interactions with natural environment that enable scientific investigation or the creation of traditional ecological knowledge, education and training, or resonance in culture and heritage

Source: *Own elaboration*.

Table 6 Categories and examples of key natural capital risk and opportunities for land-based business

	Operational	Legal and regulation	Reputational and marketing	Financial	Societal
Risk categories	-The availability and quality of natural assets (capital) can affect the supply and cost of raw materials, energy and water used in the production process.	-Regulations and legal actions involving natural capital can restrict the access to resources, increase the cost of access, and influence the expansion option of the activity	-Verifiable improved environmental performance, such as environmental certification can improve the reputation of the company, or organization, with positive impacts in the market share of sales.	-Investors are increasingly committed to integrating environmental data to inform decision making and adding value. -Improve the opportunities to access to green funds (green bonds), or to preferential financial rates by reporting progress on environmental risk	-The relationship with the wide community process could be influenced positively or negatively depending in the impact of the productive activities undertaken on local natural resources.
Examples of risks	Disruption in the supply change for animal feedstock Increase in occurrence of drought and flooding events causing crop and livestock yield losses	Increased compliance cost for achieving certain environmental standards, as regulation become more stringent	Reduced market shares due to reduced demand for product perceived to be linked to unsustainable forestry and farming practices	Increased financial costs and reduced financing options due to the lack of transparency and environmental metrics	Reputational costs due to local community protest, for example as results of agrochemicals leaching and negative effects over fish population, or other off-farm negative effects to the community
Examples of opportunities	Reduce the use of inputs (e.g. fertilizers) to the production process Use nature-based solution (habitats restoration, buffer strips woodland plantation, hedgerows) to enhance water quality, biodiversity and protect soils	Sale carbon credits into voluntary or regulatory markets	Increase market shares or sales due to the presences of forest and farm management certificates recognising sustainable management practices	Increase funding opportunities through access green funds (e.g., green-bonds), preferential financial rates, or future farming-funding schemes based on public payments to public services	Improved community relationship resulting from restoring ecosystems, that help for example, to improve flood prevention or creates new recreational opportunities, and other public benefits

Source: *Own elaboration* based on the Natural Capital Protocol Sectoral Guides (Natural Capital Coalition, 2016b; 2018)

3.2 SCOPE STAGE (What?): Defining the objectives and scope of the natural capital assessment

This stage of the Protocol comprises three steps: (i) Setting out the specific objective for the natural capital assessment; (ii) defining the scope of the natural capital assessment, and (iii) determining the impacts and dependencies on natural capital. Next sub-sections discuss the most relevant issues to consider through all the steps and sub-steps contemplated in the objective and scope stage, which are summarised in Table 7.

3.2.1 Step 02: Definition of objectives

The objective definition step involves three actions that include identifying the target audience and the relevant stakeholders and the articulation of the objective of the assessment. The target audience refers to the main users of the assessment to make decisions. This audience can be internal stakeholders or decision-makers, such as the farm manager, senior executives, board members, departments of finance, marketing, communications, strategies, employees, and in some cases shareholders. This latter can be also external such as shareholders, suppliers, investors, civil society, communities and other affected stakeholders (local residents, special interest group, farmers, hunters, etc.), government and regulators or customers. The identification of the relevant stakeholders' concerns any of different parts of the value chain. Both internal and external stakeholders can participate and contribute to the natural capital assessment, by providing information, their viewpoints and helping the verification, validation and interpretation of the results of the assessment. The choice of stakeholders and the nature of their engagement would depend, among others, on their relative importance and influence. According to their relative importance, the assessment can include primary stakeholders, referred to those who depend on the resources affected (internal and external) and secondary stakeholders that are not directly affected but interested. Apart of their relative importance, the selection and engagement of stakeholders can be also influenced by the objective and envisioned transparency of the assessment, as well on the legitimacy, willingness, and ability of stakeholders to engage and contribute (Natural Capital Coalition, 2016d).

Table 7 Summary of issues to consider for the definition of objectives and scope of the natural capital assessment

Steps/issues	Options/observations
Defining the objectives	
Identifying the target audience	**Internal:** farm manager, senior executives, board members, departments of finance, marketing, communications, strategies, employees, and in some cases shareholders **External:** shareholders, suppliers, investors, civil society, communities and other affected stakeholders, government and regulators or customers
Identifying the relevant stakeholder	**Internal and external** stakeholder concerning any of different parts of the value chain **Primary stakeholders**: those who depend on the resources affected **Secondary stakeholders**: not directly affected but interested Considerations on the transparency of the assessment, legitimacy, willingness, and ability of stakeholders to engage and contribute
Articulation of the objective	Anticipating the benefits of undertaking the natural capital assessment for the land-based business, and which internal and external stakeholders need to be involved and the nature of their engagement
Scope of the natural capital assessment	
Organizational focus	Whole business firm, a project or a product
Value chain boundaries	Upstream, direct operation and downstream elements of the value chain
Perspective of the assessment	Business value or societal value
Coverage of dependencies and impacts	Only impacts, only dependencies, both impacts and dependencies
Type of values	Qualitative valuation, quantitative valuation or monetary valuation
Baseline (benchmark)	Historical situations, a point in time (e.g. just before a project starts), or industry-wide average levels
Scenarios	Intervention, exploratory, vision and counterfactual scenarios
Spatial boundaries	Geographical area for the assessment: the vicinity of a project, a farm/estate, the whole farm, catchment area, a landscape unit, a region.
Temporary boundary	Past, present and /or future impacts and dependencies
Key planning issues	Timescale, resources, capacity, data, relationships with stakeholders
Determining the materiality of impacts and or dependencies	List potential material impacts and dependencies, define the criteria for the materiality assessment, gather relevant information and complete the materiality assessment.

The articulation of the objective requires anticipating the benefits of undertaking the natural capital assessment for the land-based business. The articulation of the benefits can help to justify an appropriate level of staffing and other resources used for the assessment. This task can also help to define which internal and external stakeholders need to be involved, as well as the level and nature of their engagement. The objectives should be ideally SMART (*specific, measurable, attainable, relevant and time-bound*). This later implies that the objectives set the specific reasons for undertaking the assessment (e.g., assessing how the value chain can be affected by changes in natural capital in the next 10 years to minimize future supply chain risks; evaluating the positive effect of new management alternatives on natural capital to increase sales, through supporting communication and marketing strategies within the next 5-years; or estimating the potential revenue streams linked to natural capital, and communicate this to senior managers).

3.2.2 Step 03: Scope of the assessment

The scope the assessment step requires defining the appropriate span to meet the specific objectives of the assessment. This step involves determining the organizational focus, the value chain boundaries, the spatial boundaries, the baseline, scenarios and temporary boundary, as well as, specifying the perspective of the assessment, deciding on the assessment of impacts and dependencies and the type of value to consider, and addressing key planning issues for the land-based business. The organizational focus refers to the parts of the business to be included in the natural capital assessment, whereas the assessment can comprise the whole business firm, a project or a product. The value chain boundaries can consider upstream, direct operation and downstream elements of the value chain (Fig. 7). The value perspective attends to the business value (e.g., financial implications) or to the value for society (e.g., risk of some environmental externalities, enhanced public goods provision), with a complete assessment including both perspectives of value. The baseline is the starting point or the benchmark against changes in natural capital can be compared. They can include historical situations over a specific period of time, the state of natural capital at a point of time (e.g., just before a project starts) or an industry-wide average level of an impact or dependency. The scenarios can refer to interventions or real alternatives being considered. They can be exploratory when they include risk assessment for unexpected situations, or reflect visions describing desirable or undesirable futures, including business as usual situations. These scenarios can be also counterfactual when they account different stakeholders perspectives (Natural Capital Coalition, 2016d).

The assessment may cover dependencies or impacts, with a complete assessment considering both impacts and dependencies in order to improve the understanding of risk and opportunities for land-based business. Impacts and dependencies are interrelated, as business dependencies usually return in impacts. For example, a dependency of farming activities on soils and water resources can result in soil degradation through erosion, compaction and soil and water pollution due to mechanization and agrochemicals. The dependencies on natural capital are exclusively referred to the own land-based business, and they can be expressed in terms of value (monetary and societal), current financial cost, potential financial costs or indirect costs of dependencies in the supply chain. Impacts, on the other hand, can affect own land-based business, which usually translates directly into financial costs or benefits, or have an impact on society through the off-farm positive and negative externalities, which rarely translate into financial benefits and costs, even if monetised.

Own-business impacts and dependencies on natural capital do not have necessarily a direct and quantifiable translation into financial cost and benefits, given the gaps in our understanding of the complex soil, water, biological activity, climate and land management interactions (see sub-section 2.3). The valuation of impacts and dependencies can be assessed considering qualitative, quantitative and/ or monetary values, depending on the decision that the assessment attempts to inform, and information and resource constrains. Qualitative valuation can be used as a preliminary identification of impacts and dependencies. This type of valuation often focusses on the description and a subjective perception of changes and it is normally implemented through questionnaire surveys (see Appendix), deliberative approaches or expert opinions. Quantitative valuation is about expressing the value of impacts and benefits in numerical (non-monetary) terms. This type of valuation can apply indicators (e.g., water stress index, biodiversity index). The monetary valuation should provide information on the marginal value of changes in the impacts and dependencies on natural capital considering specific activities, projects of products, over a specific point in time or a period. Both market and non-market values should reflect social preferences, reflected in observed or stated willingness to pay or willingness to accept for specific changes in environmental conditions in the provision of good and services affected by the dependencies and impacts on natural capital. Monetary valuation requires the use of sophisticated statistical techniques, which is expertise and resources demanding (see sub-section 2.2).

Finally, the assessment needs to be adjusted by planning and resources constrains. Key planning issues involve timescale, concerning the urgency of the assessment, funding and human resources available for the assessment, the capacity or skill within the business to undertake the assessment and the additional skills needed, data availability and accessibility, and the need to stablish and extend of relationships with stakeholders participating in the assessment.

3.2.3 Step 04: Determining the materiality of impacts and dependencies on natural capital.

This step takes stock of the potentially material natural capital impacts and dependencies, by defining the criteria, and gathering and analysing information for the materiality assessment. Materiality is an accounting and auditing concept relating to the importance of an amount, transaction, or discrepancy. The materiality concept from an accounting perspective indicates the extent to which disclosed data is relevant for key stakeholders to make a proper judgement about a firm (Gualandris et al., 2015). Materiality can be judged for each organizational focus, that is for the whole organization, a project of a product, and this assessment itself can be qualitative, quantitative, or monetary.

The first activity in a materiality assessment is to list all potentially relevant impacts and dependencies given the objective and scope of the assessment. The materiality assessment takes accounts of the impact drivers, impact pathways, and dependency pathways. Impact drivers is either a measurable quantity of a natural resource that is used as an input to production (e.g., water used for irrigation of agricultural crops) or a measurable output of the land-based business activity. Table 8 provides examples of impact drivers, both input and output, of farming activities, and the metrics commonly used for these impact drivers. In this point is relevant to indicate that an impact driver is not the same as an impact. An impact is a change in the quantity or quality of natural capital that occurs as a consequence of an impact driver. One impact driver can have many impacts, for example, and impact driver such as changes in terrestrial ecosystem uses can have an effect on soils, water resources, air quality and ecosystem assets.

Table 8 Examples of impact drivers for land-based business activities

Business input/output	Impact driver category	Examples of specific measurable impact drivers (metrics)
Input	Water use	Volume of surface and ground water consumed (water abstraction)
	Terrestrial ecosystem uses	Area of terrestrial habitat used by type (following the EUNIS classification)
	Freshwater ecosystem use	Area of freshwater habitat used by type (e.g., wetland, water bodies, etc.) Using also the EUNIS classification, used to provide ecosystem services such as water purification
	Wild plant or animals use*	Number of wild fish caught by species Number of wild mammals caught by species Number of wild birds caught by species Mass of wild mushrooms collected
	Other resources use	Volume of mineral extracted Volume of peat extracted
Output (outcomes)	GHG emissions	Mass of the carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), Hydrofluorocarbons (HFCs) and perfluorocarbons (PFC)
	Carbon sequestration	Mass of the carbon dioxide (CO_2) removed from the atmosphere and store in soils and biomass
	Non-GHG air pollutants	Mass of the particulate matter (PM2.5) and coarse particulate matter (PM10), Volatile Organic Compounds (VOCs), mono-nitrogen oxides (NOx), Sulphur dioxide SO_2, carbon Monoxide (CO)
	Water pollutants	Mass discharged to receiving water body of nutrients (nitrates and phosphates), or other substance (pesticides), faecal indicator organisms, etc.
	Soil pollutants	Mass of water matter discharged and retained in soil over a given period
	Soil erosion*	Mass of soil loss, or mass of sediment deposition
	Solid waste	Mass of waste by classification (i.e. non-hazardous, hazardous, and radioactive), by specific material constituents (e.g., lead, plastic, organic matter) or by disposal methods (land fill, sludge sewage, incineration, recycling, specialist processing)
	Disturbances	Decibels and duration of notice. Lumen and duration of light Visual disturbances (e.g., number of wind turbines, area occupied by solar panel fields)

*Additional to the Protocol guides.

Source: *Own elaboration* based on the Natural Capital Protocol for Forest Products Sector Guide (Natural Capital Coalition, 2018)

Impact pathways describe how, as a result of a business activity, an impact driver results in changes in natural capital and how these changes impact different stakeholders. For example, intensive agriculture produces water pollutants, which is an impact driver (Table 8). This impact driver leads to changes in natural capital, in that case a decrease in water quality due to increases in the concentrations of pollutants. Changes in natural capital result in that case on an increased drinking water treatment cost for water utilities or industries depending on good water condition or has direct impacts on human health and the living systems in general. In a similar way, dependency pathways show how a particular business activity depends upon specific features of natural capital, and how observed or potential changes in natural capital affect the costs or benefits of the pertain business. For example, soft-fruit production has a dependency in pollinators. Changes in natural capital state and condition causes a decrease in the pollinator population, mainly due to overuse of pesticides, climate change or land use changes involving habitats conversion. These changes affect the profits of the soft fruits growing when pollinators have to be provided externally.

The dependencies on natural capital are also multiple, and those can be categorised as consumptive or non-consumptive (Table 9). Consumptive dependencies imply direct natural capital use (Fig. 4), and a reduction of the stock of natural assets. Example of consumptive dependency categories can involve energy generation using solar, wind, hydro, biomass or fossil fuel energy. This type of dependency also includes the use of freshwater resources and the dependencies on natural resources for nutrition (human or animal) or the provision of materials, such as fibre, wood, metals, minerals and other materials from plants, animals, algae or fungi. Non-consumptive dependencies are referred mainly to the regulating and cultural type-services. Those include flood attenuation, water quality regulation, crop pest control, pollination, waste assimilation, mitigation of noise, but also nature-based recreation, tourism, information from nature and symbolic and spiritual interactions with nature (Natural Capital Coalition, 2016d).

Table 9 Examples of dependencies of land-based business on natural capital

Type of dependency	Dependency category	Examples of specific measurable dependencies (metrics)
Consumptive	Energy	Kilowatts hours of energy
	Water	Volume of surface and ground water Turbidity of water
	Nutrition	Joules of energy consumed
	Materials	Volume of mass of wood (e.g., timber stock)
	Other resources use	Mass/volume of mineral stock Mass of soil carbon stock
Non-consumptive	Regulation of the physical environment	Hectares of habitats providing water filtration; Volume of water filtered by vegetation
	Regulation of the biological environment	Risk level of an incident (e.g., flood frequency); Resilience against diseases (e.g., trees or crops)
	Regulation of waste and emissions	Mass of pollutants (e.g., micrograms) assimilated per kilometre of river
	Experience	Estimation of time required for ecosystem restoration based on previous experience
	Knowledge	Importance of particular species for the resilience of ecosystems
	Well-being, spiritual and ethical values	Mental or physical health benefits of access to green space or clean air and water

*Additional to the Protocol guides.
Source: *Own elaboration* based on the Natural Capital Protocol Guide (Natural Capital Coalition, 2016d)

The criteria to judge materiality may include the business financial implications, potential environmental and societal consequences and business stakeholder interest (Natural Capital Coalition, 2016b). The business and financial criteria indicate the extent to which the natural capital impact or dependency affect the business operations, the cost of capital (e.g., interest rates), the access to capital finance, as well as legal processes or liabilities, such as environmental impact mitigation requirements. The potential environmental and societal consequences refer to reputational and marketing criteria, which in turn affect the firm business image, the product portfolio, or societal criteria, involving the judgement of the extent to which dependencies and impacts may generate significant impacts to society. The business stakeholder interest implications affect the relationship with stakeholders and customers, and henceforth the reputational and marketing criteria in the materiality impact assessment. Table 10 shows some of the information needs to assess the potential material significance of impacts and dependencies, and some practical steps for organizing and gathering the information.

The materiality assessment should be judged for each natural capital impact and dependency based on the assessment criteria (i.e., operational, legal and regulatory, financing, reputational and marketing and/or societal). This assessment aims to identify which of the natural capital impacts and dependencies are the most significant for the business and/or for the society. For the assessment it is recommended to stablish a panel of relevant people with a broad range of skills to complete the materiality assessment. The panel should be able to rank potential material natural capital impacts of dependencies, as well as to identify which of them are material (i.e. those relevant to make a proper judgement about a business-firm, project or product), which are not definitely material, and for which materiality is still uncertain. The results of the materiality assessment is a short list of the impact drivers and/or dependencies that should be included in the assessment. Where uncertainties remain, collecting further information or consultation with experts may be needed.

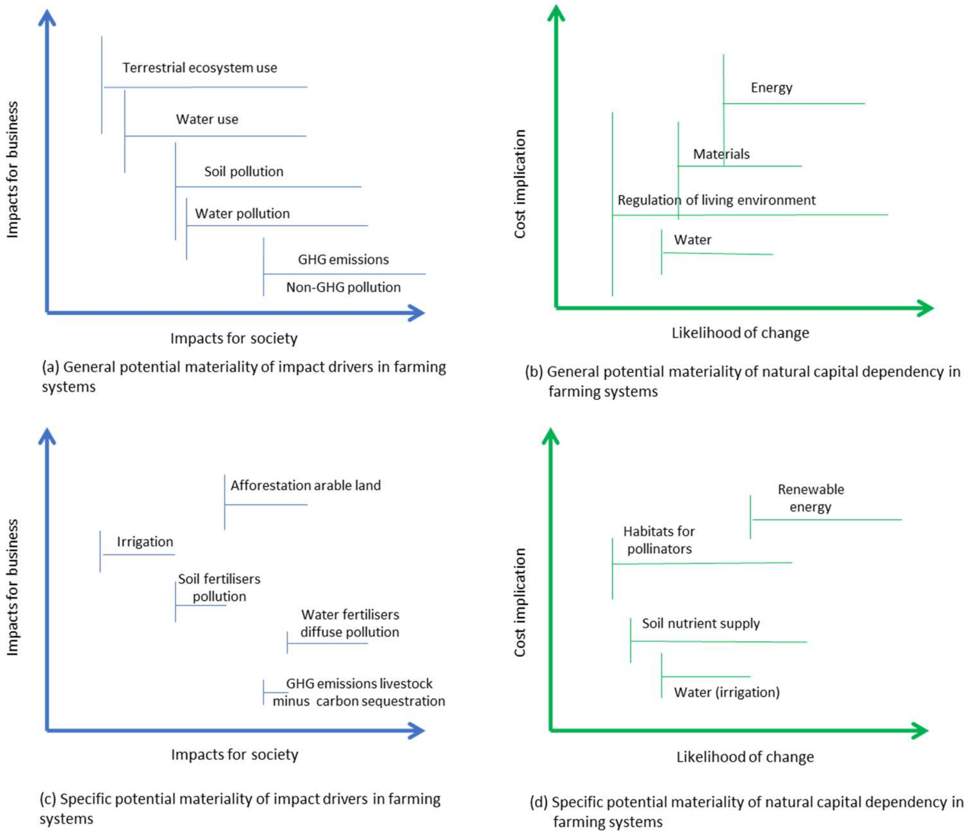
Fig. 8 shows some examples of materiality charts that can serve as guide for the materiality assessment of natural capital impacts and dependencies in land-based business. These examples can show synergies and trade-offs in the importance of natural capital impacts [or dependencies] for the business and society or for stakeholders, as well as between the cost implications of these impacts and dependencies and the likelihood of change (Natural Capital Coalition, 2016b). Charts (a) and (c) in Fig. 8 show a hypothetical example of a selected group of impact drivers and dependency of farming activity on natural capital and their importance for business and society. The first referring to general impact drivers and the second to specific ones. This importance can be defined in terms of on-site and off-site effect of impact drivers, whereas off-site effect are deemed to be more relevant to society. The arrows indicate that the potential range of impacts for both the business and society can vary from one site to the other depending on the characteristics of the farming systems, as well as, on land management practices, technology and local environmental and climate conditions. Charts (b) and (d) show the hypothetical effects of consumptive and non-consumptive dependencies on business costs and the likelihood of changes. The cost implications and likelihood of change can be also affected by several factors, such as the type of energy, materials and living environmental regulating services, their investment costs, and the economic effect of changes in natural capital state and condition on the business cost structure, among others. Fig. 8 charts indicate potential levels of uncertainty in the materiality judgement in a preliminary qualitative assessment.

Table 10 Information needed to assess the potential materiality of impacts and dependencies on natural capital

Type of information	Practical steps
Type of impact and/or dependency	-Pre-definition of the criteria to judge the materiality of impacts and dependencies (operational, legal and regulatory, financial, reputational and marketing and/or societal) -List of impacts and dependencies by project, product or enterprise (see Table 10: Materiality matrix)
Scale of impact and/or dependency	-Define if the impact is on-farm and/or off-farm (which will affect the materiality judgment criteria) -Define the scale of the dependency (e.g. the whole catchment, specific habitats within the farm), this can help identifying natural capital risk and opportunities
Consequence of impact and/or dependency	-Define if the consequences are on business or on society or both. -Revise the criteria to judge the materiality of impacts, according to their on- and off- farm consequences, environmental regulations affecting legal processes and liabilities of land-based business, and potential reputational, marketing and societal implications
Time scale	Short, medium, and long-term associated to each impact and dependency
Seeking expert opinion and/or analysis, or leveraging existing information	-Including literature review, consultation with experts and validations of materiality analysis, using questionnaires surveys, workshops or interviews -Defining the uncertainties involved
Consulting stakeholders	-Including internal and/or external stakeholders using interviews, workshops, or questionnaire surveys
Compiling publicly available information on specific issues	Compiling information of case studies from relevant locations, land-use, land cover and land capability maps and other thematic maps (e.g. soil maps, hydrological maps, species threat or richness assessments)[19]
Conducting a rapid assessment of value	For example, what proportion of total sales revenue depends upon a specific ecosystem and/or abiotic service? What is the financial value of the production asset involved?

The materiality of impact drivers and dependencies on natural capital can be judged, as commented before, considering three criteria: (i) business financial implication, (ii) potential environmental and society impacts, and (iii) business stakeholder interest. The materiality can be judged as "High", when there is evidence for all the three criteria, "medium" when there is evidence for two of the three criteria, and "Low" if one or none of these criteria are met. Evidence on the materiality comes from literature review, but also from the consultation with relevant stakeholder. Table 11 offers an example of indicative materiality matrices for farming and forestry activities. The potential materiality for natural capital impacts and dependencies does not necessarily indicate the level of impacts or dependencies, rather the potential consequences of natural capital impacts and dependencies on the business finance, the environmental and social consequences and the interest of the business stakeholders. The materiality assessment can be performed from different lenses, as impacts and dependencies can depend upon different environmental, socio-economic and institutional factors.

[19] See Appendix section A.3 for the type of data sets and maps publicity available in Scotland and the UK that can help the natural capital assessment in Scotland, including data to construct a natural capital asset register, and definition of risk and opportunities associated to natural capital resources (Table A.3.1). This section of the appendix includes some template tables for a preliminary assessment of impacts and dependencies of different farming activities on natural capital (see Tables A.3.2 and A.3.3)



Source: *Own elaboration Inspired in the Natural Capital Protocol materiality matrices.*

Fig. 8 Examples of materiality charts

Table 11 Indicative examples of materiality matrices for farming and forestry activities

Dependencies												Farming system/ activity	Impact drivers													
Consumptive					Non-consumptive								Inputs				Output									
Energy (non-photosynthetic)	Water	Nutrition	Materials	Land use	Regulation of physical environment	Regulation of the living environment	Regulation of waste and emissions	Experience	Knowledge	Well-being	Spiritual and ethical values		Water use	Terrestrial ecosystem use	Freshwater ecosystem use	Other resources use	GHG emissions	CO_2 sequestration	Non-GHG air pollutants	Water pollutants	Soil pollutants	Soil erosion*	Solid waste	Disturbance	Restored habitat
o	o	o	o	o	o	o	o					Growing cereals	o	o	o		o		o	o	o	o			
o	o	o	o	o	o	o	o					Growing forage crops	o	o	o		o		o	o	o	o			
o	o	o	o	o	o	o	o					Intensive livestock farming	o	o	o		o			o	o	o			
o	o	o	o	o	o	o	o					Extensive livestock farming	o	o	o		o			o	o	o			
	o	o	o	o	o	o	o					Shooting/fishing	o	o	o					o	o				o
o	o	o	o	o	o	o	o					Plantation forest		o	o			o		o	o				o
o	o	o	o	o	o	o	o					Semi-natural forest		o	o			o							o

Notes: **o** Impacts or dependencies that are material. Likely high materiality, Likely medium materiality and Unlikely to be significant or non-applicable.
Source: *Own elaboration* based on the Natural Capital Protocol Sectoral Guides (Natural Capital Coalition, 2018, 2016c), literature review and interviews with stakeholders.

When environmental consequences are concerned, specific materiality criteria can account for local ecological and climate contexts, for example, cultivating water-demanding crops of forest species on water stressed areas, risk of soil degradation and leaching potential. Societal consequences can account for both social and institutional criteria, such as the land ownership or wider national and jurisdictional land tenure regimes or the proximity to conservation areas. The relative materiality can be assessed and compared from a single lens, such as societal or environmental consequences of certain activities, land-uses or specific products developed, or rather from the business finance lens. The assessment criteria condition the data to be gathered for the specific objectives and scope of the natural capital assessment defined. Specific examples of material impact drivers and/or dependencies are collected in this step, and brought forward to the measure and value stage as it is detailed later.

3.3 MEASURE AND VALUE STAGE (How?): Measurement and value of impacts and dependencies on natural capital

This stage focuses on measuring and value the dependencies and impacts of specific land-based activities on natural capital and ecosystem services in more detail. It starts by mapping the specific activities that are dependent on, or give rise to impacts on ecosystem services. The valuation of impacts and dependencies means more than just monetization. It refers to the process of estimating the relative importance, worth, or usefulness of natural capital to people. Valuation can therefore be qualitative, quantitative or monetary or a combination of the three (Natural Capital Coalition, 2016d). As it was indicated before, the qualitative analysis describes and judges the nature of these relationships and their implications both for the business itself, and the environment and society. The quantitative analysis express these relationships in numerical (non-monetary) terms. Finally, impacts and dependencies can be translated into monetary costs or benefits for both the business stakeholders and the society.

This stage involves three steps as detailed next.

3.3.1 Step 05: Measure impact drivers and or dependencies

This step involves actions such as mapping activities against impact drivers and dependencies. The activities to be mapped can be disaggregated by operations, specific projects or even products according to the objectives of the natural capital assessment (e.g., Table 12 and Table 13). Depending on the scope of the value chain of the analysis, additional information should be gathered from suppliers and/or customers to understand the activities that may be driving impacts and dependencies outside of the direct farm operations, regardless of whether they are positive or negative.

This step also involves the selection of appropriate measures of each impact driver and or dependency considered, which depend on the indicator selected and method of analysis. The methods that can be used to measure impact drivers and dependencies on natural capital range from a simple environmental data collection through sophisticated ecological models and advanced econometric analysis. In the simplest case, the assessment of the impacts and dependencies can be assessed qualitatively as high, medium and low, based on available scientific evidence and/or relevant stakeholders' and expert's opinion (Table 12 and Table 13). More sophisticated approaches would base this approach on a range of numeric values. Table 8 and Table 9 provide examples of quantitative indicators for measuring impact drivers and dependencies, respectively.

The potential data sources for the qualitative or quantitative measurement of impact drivers and dependencies collection can include primary and secondary data options. Primary data include internal business data (e.g., farm accounts, maps, records), and data collected from suppliers or customers. Secondary data include published, peer-reviewed, and grey literature, maps, reports and data sets . They also may include estimates derived from modelling techniques, such as environmental extended input-output models, life-cycle inventories, productivity models, mass balance models, eco-hydrological models, and value transfer from published literature. This task should also consider data gaps and uncertainties in the measurement of impact drivers and dependencies.

Table 12 Hypothetical example of dependency matrix by land-based enterprise

Enterprise	Dependencies of the farm on consumptive and non-consumptive good and services																			
	Consumptive										Non-consumptive									
	Surface water	Groundwater	Rainwater	Nutrients	Forage crops/grazing	Timber/Wood /fibre	Genetic material	Fossil fuels	Renew. energy (no photosynthesis)	Land use	Filtration toxic substances (water)	Water flow regulation & Flood attenuation	Pollination	Biological pest /diseases control	Maintaining nursery populations & habitats	Buffering and attenuation of mass movement (falls, slides, flows)	Decomposition and fixing processes	Information from nature (knowledge)	Nature-based recreation (experience)	Spiritual and ethical values
Arable crops																				
Soft-fruit production																				
Forage crops																				
Beef-suckler farming																				
Dairy farming																				
Intensive forestry (plantations)																				
Native woodlands management																				
Renewable energy																				
Recreation/Tourism																				

Notes: High relevance , Moderate relevance Low relevance, Unknown or not applicable.

Table 13 Hypothetical example of impact driver matrix by land-based enterprise

Enterprise	Impact drivers												
	Inputs				Output								
	Water use	Terrestrial ecosystem use	Freshwater ecosystem use	Wildlife	GHG emissions	Non-GHG air pollutants	Water pollutants	Soil pollutants	Soil erosion	Solid waste	Disturbances	Air pollution filtration	Carbon sequestration
Arable crops													
Soft-fruit growing													
Forage crops													
Intensive forestry (plantations)													
Native woodlands management													
Beef-suckler farming													
Dairy farming													
Energy production													
Recreation/Tourism													

Notes: High relevance , Moderate relevance Low relevance, Unknown or not applicable.

3.3.2 Step 06: Measurement changes in the state of natural capital

This step considers the changes in natural capital that are like to results from the impact drivers estimated in the former step. Changes in natural capital can be associated with both internal and external factors. Internal factors involve changes that are influenced by changes in land use and management changes. Changes in land use and management may involve for example changes in GHG emissions resulting from afforestation/deforestation or changes in animals stocking rates or the use of fertilisers, all of them having an effect in mitigating climate change. They can also involve changes in nutrients entering in waterways, which would affect the ecological condition of water resources. Other examples include changes in terrestrial habitats use, which impacts can be detected in the capacity of ecosystems assets to deliver multiple ecosystem services. External factors include human and natural induced changes on natural capital. Human-induced external factors include, for example, diversion in water courses or drainage. Natural induced external factors may include meteorological, biochemical and geological processes. External factors can result in major changes in the state and condition of natural capital, and these changes may affect directly and indirectly the significance of impacts in the business itself, or the society, and business dependencies on natural capital.

The assessment of changes in natural capital is usually necessary to measure impact drivers and dependencies. The measurement of changes in natural capital should also include an assessment of how trends in natural capital may alter the costs and benefits associated with impact and dependencies over time. Two relevant elements to consider are: (i) the selection and application of methods to measure changes in natural capital resulting from the business impact drivers, and (ii) understanding how internal and external factors are affecting the state and trends of natural capital.

3.3.2.1 Qualitative assessment of changes in the state of natural capital

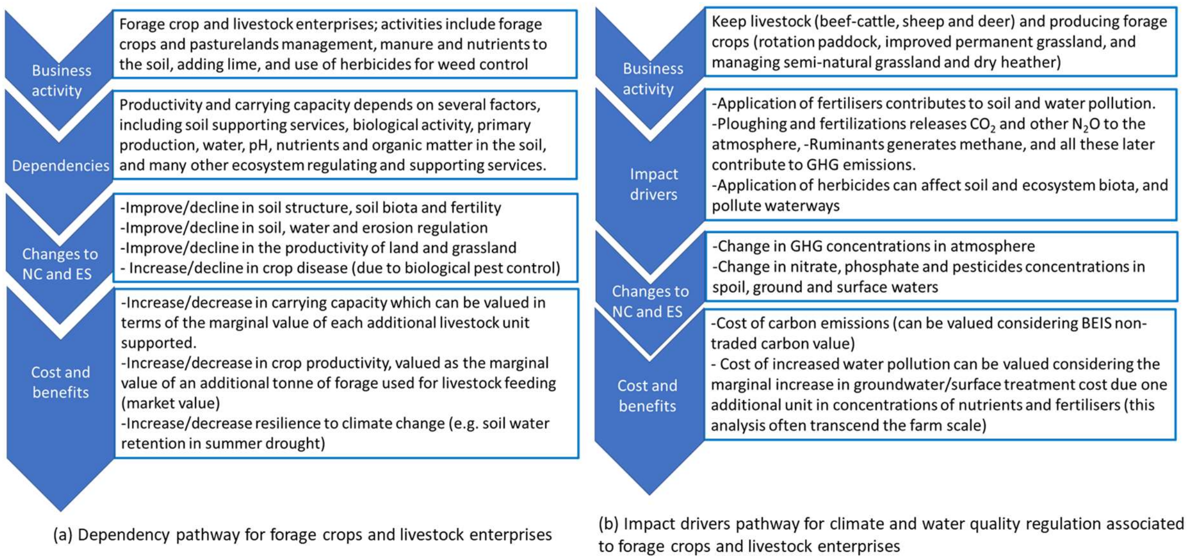
Impact pathways

Impact pathways and dependency pathways can be used to consider (in a qualitative way) the various changes in natural capital resulting from each impact driver, or affecting each dependency, in turn. This is the approach used by the trial application of the Protocol in Crown Estate Scotland farms through pathway diagrams for key farm or estate activities (Silcock et al., 2018a). As indicated before, the dependency pathway illustrates how different land-based enterprises depend on natural capital and ecosystem services and how changes in these may impact positively or negatively on the business or wider society. The impact pathways show the logic chain from business activity to natural capital and ecosystem services, and the cost and benefits that can be affected by these impacts. As indicated in the formal trial application, the Protocol impact pathway has a clear focus on the industrial/ supply value chain, which does not strictly fit for land-based business, where impacts and dependencies are sometimes difficult to distinguish. Silcock et al. (2018) propose to consider logic pathways from the outset: Enterprise → Activities (impact drivers) → impacts on habitat(s) / ecosystem(s)[assets] → impacts on ecosystem services → impacts on the business or wider society. It is relevant to consider that impact drivers are not necessarily inputs bought into the business, as they are likely to come directly from the land (e.g., grazing resources, manure), or activities undertaken by land managers. Fig. 9 provides examples of general dependency and impact driver pathway diagrams for changes in ecosystem services associated to crop and livestock productions. Those diagrams show general pathways reflecting either an improvement or decline in the extent and condition of natural assets, such as soil or water resources, as result of more or less sustainable land management practices.

Fig. 9 pathway diagrams suggest more linear and deterministic interactions between impact drivers, natural capital dependencies and changes in natural capital and ecosystem services. These relationships are not always well-understood, as changes in natural capital and ecosystem services can be governed by complex interactions that operate at different spatial and temporal scales, and are affected by properties of natural assets, but also by external natural and anthropogenic drivers, such as climate change or land management (e.g., Fig. 5). Namely, the effect of changes in natural capital, ecosystem services and many regulating ecosystems services, such as water purification, is not simple to predict. This later may demand the use sophisticated and data-intensive models. Therefore, measuring and valuing the wider-social costs and benefits of changes in land management at the farm level on water resources is challenging. Estimating the marginal cost or benefits of increasing or decreasing diffuse pollution by pesticides and nutrients transcends the farm scale, usually involving the catchment scale and different sources of diffuse and point water pollution that will affect the overall condition of ground and surface water.

Linking qualitative assessment of changes in the state of natural assets with the provision pf ecosystem services

When natural capital services are concerned, the dynamic interactions between pressure drivers, the state and condition of natural assets (e.g., ecosystem assets) and the flow of services delivered are key for a better understanding of natural capital-related impacts, as well as risks and opportunities. The state of natural asset often considers quantitative indicators on the extend, volume or pollution levels of asset (Natural Capital Committee, 2019, Tables 7 and 8). For ecosystem assets, the concept of extent is generally measured in terms of surface area, for example, hectares by land cover type. Where there is a mix of land covers within an ecosystem asset (e.g., a catchment or a landscape unit), ecosystem extent may be reflected in the proportion of different types of land cover (UNSD, 2014b). Changes in the proportions of different land covers within a defined spatial area may be important indicators of changes in ecosystem assets and their flow of services. Soil state can be measured in terms of volume. Unlike other environmental assets, such as timber resources or soils that are subject to slow natural changes, water is in continuous movement through the processes of precipitation, evaporation, run-off, infiltration and flows to the sea. Hence water asset accounts focus on the in and out flows of water to and from land surface and subsurface, and the destination of those flows (UNSD, 2014a).



Source: Adapted from Silcock et al. (2018b).

Fig. 9 Examples of dependency and impact driver pathways

Measurements of ecosystem conditions can be compiled in relation to key ecosystem characteristics, such as water, soil, carbon, vegetation and biodiversity, which in principle is expected to vary within the type of ecosystem asset. There is however not a single indicator for assessing the quality of a single characteristic. The selection of characteristic and indicators should be made on a scientific basis to ensure that there is an overall assessment of the functioning and integrity of ecosystem assets. The degree or nature of human influence on an ecosystem can be used as a reference of the condition of ecosystems. The reference condition in that case can reflect an ecosystem that is relatively undisturbed or undegraded by humans, or either a situation whereas the ecosystem is in relative stability (UNSD, 2014b). For example, long-standing forest and agricultural areas may be considered relatively stable ecosystem that are not undergoing degradation in terms of their ecosystem characteristics (e.g., soil condition) or of their capacity to provide a stable flow of forestry and agricultural products. In terms of water resources, the quantitative and qualitative good status of water bodies, as defined by the Water Framework Directive, is commonly used reference of the condition of this asset.

In general terms, the capacity of natural assets, such as soil or ecosystem assets, reflects the relationship between the characteristics of the asset and its expected uses, defined the later by the expected basket of ecosystem services to be delivered. The capacity of the natural asset to generate ecosystem services in the future will change as a function of changes in the state and condition of natural assets and the responses in the delivery of ecosystem services to those changes. For an expected basket of ecosystem services at a given point in time, an ecosystem asset may be generating services below or above its capacity to generate those services sustainably (UNSD, 2014b). In the context of a single resource, timber, for example, the notion of capacity may be aligned with the concept of a sustainable yield with harvesting not exceeding the net timber growth in the medium to long term. However, where a mix of ecosystem services is generated, the notion of sustainable yield becomes a complex concept, given the synergies and trade-offs in the provision of ecosystems services.

Land cover score matrices based on mapping data, a systematic a review of scientific evidence available and experts' knowledge on the capacity of different habitats to deliver ecosystem services can be used as a first approximation to the potential synergies and trade-off involved in the provision of ecosystem services. Table 14 shows the scores estimated by Burkhard et al. (2014) and Smith and Dunford (2018) for different land covers, management intensities and ecosystem services. These two studies offer complementary information regarding specific land covers and ecosystem services, though the comparability among these studies is limited, as they consider different degrees of detail in land cover classification.

Table 14 Land cover score matrix to deliver ecosystem services by land cover

Land cover [1]	Provisioning			Regulating & maintenance											Cultural services				
	Cultivated plants & reared anim. [a]	Wild plants and animals	Water supply	Air quality regulation	Biological pest and disease control	Global climate reg. (carbon seq.)	Local climate regulation	Control of erosion rates	Habitats and population nursery [b]	Pollination	Freshwater quality regulation	Regulation of soil quality [a]	Water flow regulation/flood control	Water purification & waste water	Aesthetic	Cultural and heritage values [a]	Knowledge systems Social relations	Recreation and ecotourism	Spiritual and religious value
Agriculture land [a]																			
Agriculture + nat. veg.	3	1	0	2	3	2	3	2	1	2	2	2	2	2	2	3	3	2	1
Agro-forestry areas	2	0	0	2	3	2	2	3	1	2	2	1	2	2	1	3	2	2	0
Annual +permanent crops	4	1	1	1	2	1	2	2	1	2	0	2	1	0	2	3	2	1	0
Complex cult. Patterns	4	1	1	1	3	1	2	1	1	3	0	2	1	0	2	3	2	2	0
Fruit trees and berries	4	0	2	2	3	2	2	2	1	5	1	2	2	1	2	4	3	3	0
Non-irrigated arable land	5	0	3	1	2	1	2	1	1	3	0	3	2	0	2	3	2	1	0
Perm. irrigated land	5	0	3	1	2	1	3	0	1	3	0	3	1	0	2	3	2	1	0
Grassland [b]																			
Unimproved acidic gr.	2	3	3	2	4	2	2	4	5	5	3	4	2	3	5	2	4	4	3
Unimproved neutral gr.	2	3	3	2	4	2	2	4	5	5	3	4	2	3	4	2	4	4	3
Unimproved calcar. gr.	2	3	3	2	4	2	2	4	5	5	3	4	2	3	5	2	4	4	3
Improved grassland	3	5	2	1	1	1	1	3	1	1	2	1	1	2	1	2	1	1	1
Marsh/marshy grassland		4	3	2	4	3	3	4	5	5	4		2	4	4	2	4	3	3
Forest and woodland [b]																			
Broad-lea. sem-nat woodland	4	2	2	5	4	5	5	5	5	5	4	5	5	4	5	2	5	5	5
Broad-leaved plantations	4	1	1	4	3	4	4	4	4	4	4	5	4	4	4	2	3	5	3
Coniferous sem-nat woodland	4	1	1	5	3	5	5	4	4	4	3	5	4	3	4	2	4	4	3
Coniferous plantations	4	0	1	4	2	4	4	4	2	2	4	5	4	4	3	2	3	3	2
Mixed sem-nat woodland	4	1	2	5	4	5	5	5	4	4	4	5	4	4	5	2	4	5	4
Mixed plantation	4	1	1	4	3	4	4	4	3	3	3	5	4	3	4	2	3	4	2
Dense continuous scrubs	0	2	1	3	4	4	4	3	4	4	3	2	3	3	2	2	3	2	2
Scattered scrub	0	3	2	4	4	3	3	3	4	5	3	2	3	3	2	2	3	2	2
Recent felled woodland	0	0	2	1	1	0	0	0	1	1	0	0	1	0	1	2	1	1	0
Heathland																			
Dry heath/acid grassland [b]	1	3	2	2	4	3	3	4	5	5	3	3	2	3	5	2	4	3	4
Moors and heathland [a]	1	1	0	0	2	2	4	2	5	2	3	3	2	3	4	2	4	3	1
Inland surface waters [b]																			
Standing water	3	1	5	1	2	3	3	1	5	3	4	3	2	4	5	2	4	4	5
Standing water - eutrophic	2	1	3	1	2	3	3	1	3	2	2	3	2	2	3	2	3	2	3
Other habitats [a]																			
Burnt areas	0	0	0	0	0	0		0		0	0	0	0	0	0	0	2	0	0
Inland marshes	4	1	0	0	2	2	2	1		1	2	4	3	2	1	2	3	1	0
Peatbogs	0	2	1	0	3	4	4	2		2	4	4	4	4	2	2	3	3	0
Constructed, industrial and other artificial habitats [a]																			
Urban fabric	0	0	0	0	1	0		2	0	1	0	0	0	0	3	1	2	3	2
Mineral extraction sites	0	0	0	0	0	0		0	0	0	0	0	0	0	0	1	2	0	0
Sport and leisure facilities	0	0	0	1	1	1		1	0	0	1	1	1	1	1	1	0	5	0

[1] Notes on the abbreviation used sem-nat: refers to semi-natural. The scores are based on a 0 to 5 ranking, where 0 indicates no relevance for the ecosystem service, 1 a low relevant potential, 2 low-medium a relevant, 3 a medium relevant potential, 4 a high relevant potential and 5 very high relevant potential for delivering ecosystem services.

Source: *Own elaboration* based on (a) Burkhard et al., 2014; (b) Smith and Dunford, 2018, scores. Smith and Dunford scores are round up to the closest whole number. Those scores in currently in revision.

Burkhard's scores consider ecosystem services flow potential for hypothetical European "normal" landscapes in Summertime, and before harvesting. The land cover maps in the Burkhard et al. study is based on the CORINE datasets, and scores represent experts judgements over the capacities of different land cover types to provide multiple ecosystem services, and those evaluations are conceptual or taken from different case studies (Burkhard et al., 2009). A limitation of the later study is that is restricted to relatively broad CORINE land cover classes (e.g. coniferous forest, natural grassland, water bodies)[20]. Smith and Dunford (2018) apply and extend Burkhard approach to estimate land cover scores for specific locations in Midwest England, using an in-progress eco-metric tool that is being developed by Natural England. This tool brings together experts and stakeholders' knowledge, with additional biophysical evidence, and literature review, covering 780 papers (60 for each of the 13 ecosystem services considered). Smith and Dunford (2018) scores are being revised currently.

Table 14 depicts Burkhard et al. scores for specific agricultural land covers, as those offer more detail of different types of agricultural lands, and for constructed areas and artificial habitats. This table also presents Smith and Dunford study offers an extended typology of for forest and grasslands, including forest plantations, seminatural-grassland and forest, and semi-improved grassland on different soils of different pH (acidic, neutral and calcareous). This table depicts Burkhard et al. scores for provisioning services from cultivated plants and reared animals, regulation of soil quality (fertility), and cultural and heritage values for the more general forest and grassland land covers considered in CORINE, which are transferred to the typologies of grassland and forest. While habitat and populations nursery services scores are taken from Smith and Dunford.

0 offer an indication of the potential improvement or decline in the provision of ecosystem services due to land cover changes across typologies. This potential is estimated as the difference between scores of the original land cover and the resulting one, for example by planting forest on arable or grasslands. This potential needs to be confirmed locally in view of specific climate conditions, soil, land and vegetation properties, or management practices. This analysis should also consider the short- and long- term effect in ecosystem service delivery after the cover of the land is changed, as well as the potential effect of land cover patterning and fragmentation.

0 suggests that in general forest plantations, regardless the species type (conifer, broadleaf or mixed broadleaf/conifer) are expected to improve the provision of biomass from cultivated plants, while reducing the provision of biomass from wild plants and animals. Similarly, in all cases those plantations are expected to reduce water provisioning services while improving the water quality regulation, which is consistent with specialised literature (e.g., Filoso et al., 2017; Abildtrup et al., 2013; Price and Heberling, 2018). It is also expected that forest plantations reduce aesthetic values when compared to un-improved grassland and heathland, and biodiversity-related ecosystem services, such as pollination or habitat and population nursery services.

Forest plantation are expected to generate relevant improvement for both global and local climate regulation, flood and soil erosion control. The overall positive environmental effect of forest plantations is higher when those plantations occur on crop land and improved pastures. In both cases, main trade-offs go beyond the environmental sphere, as those involve most likely higher opportunity costs for the use of land, and off-farm economic effects on the agri-food system's chain value, which would need to be addressed carefully.

[20] Burkhard et al. (2009) approach has been subsequently extended by Kopperoinen et al. (2014), by supplementing expert knowledge with that of local stakeholders, and providing more detailed land cover maps to reflect themes, such as conservation areas, peatland and water quality, in a southern Finland. Kopperoinen et al. scores rank (from -3 to 3) is not directly comparable with Burkhard and coauthors and Smith and Dunford scores (from 0 to 5), as the former also consider negative effects of specific geographic features or phenomena (refered to as theme) on ecosystems services provision.

Table 15 Potential improvement or decline in land cover scores for ecosystem services delivery: woodland expansion

Land cover	Provisioning			Regulating & maintenance											Cultural services				
	Cultivated plants & reared animals	Wild plants and animals	Water supply	Air quality regulation	Biological pest and disease control	Global climate regulation (CO_2 seq.)	Local climate regulation	Control of erosion rates	Habitats and population nursery	Pollination	Freshwater quality regulation	Regulation of soil quality	Water flow regulation/flood control	Water purification &waste water treat.	Aesthetic	Cultural and heritage values	Knowledge systems Social relations	Recreation and ecotourism	Spiritual and religious value
Woodland expansion on un-improved grassland																			
Coniferous (plantations)	Moderate improvement	Moderate decline	Moderate decline	Moderate improvement	Moderate decline	Moderate improvement	Moderate improvement	No improvement	Moderate decline	Moderate decline	Low improvement	Low improvement	Moderate improvement	Low improvement	Low decline	No improvement	Low decline	Low decline	Low decline
Broadleaved (plantation)	Moderate improvement	Moderate decline	Moderate decline	Moderate improvement	Low decline	Moderate improvement	Moderate improvement	No improvement	Low decline	Low decline	Low improvement	Low improvement	Moderate improvement	Low improvement	Low decline	No improvement	Low decline	Low improvement	No improvement
Mixed forest (plantation)	Moderate improvement	Moderate decline	Moderate decline	Moderate improvement	Low decline	Moderate improvement	Moderate improvement	No improvement	Moderate decline	Moderate decline	No improvement	Low improvement	Moderate improvement	No improvement	Low decline	No improvement	Low decline	No improvement	Low decline
Woodland expansion on improved grassland																			
Coniferous (plantation)	Low improvement	High decline	Low decline	Moderate improvement	Low improvement	Moderate improvement	Moderate improvement	Low improvement	Low improvement	Low improvement	Moderate improvement	High improvement	Moderate improvement	Moderate improvement	Moderate improvement	No improvement	Moderate improvement	Moderate improvement	Low improvement
Broadleaved (plantation)	Low improvement	High decline	Low decline	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	Low improvement	Moderate improvement	Moderate improvement	Moderate improvement	High improvement	Moderate improvement	Moderate improvement	Moderate improvement	No improvement	Moderate improvement	High improvement	Moderate improvement
Mixed forest (plantation)	Low improvement	High decline	Low decline	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	Low improvement	Moderate improvement	Moderate improvement	Low improvement	High improvement	Moderate improvement	Low improvement	Moderate improvement	No improvement	Moderate improvement	Moderate improvement	Low improvement
Woodland expansion on dry heath/acid grassland																			
Coniferous (plantation)	Moderate improvement	Moderate decline	Low decline	Moderate improvement	Moderate decline	Low improvement	Low improvement	No improvement	Moderate decline	Moderate decline	Low improvement	Moderate improvement	Moderate improvement	Low improvement	Moderate decline	No improvement	Low decline	No improvement	Moderate decline
Broadleaved (plantation)	Moderate improvement	Moderate decline	Low decline	Moderate improvement	Low decline	Low improvement	Low improvement	No improvement	Low decline	Low decline	Low improvement	Moderate improvement	Moderate improvement	Low improvement	Low decline	No improvement	Low decline	Moderate improvement	Low decline
Mixed forest (plantation)	Moderate improvement	Moderate decline	Low decline	Moderate improvement	Low decline	Low improvement	Low improvement	No improvement	Moderate decline	Moderate decline	No improvement	Moderate improvement	Moderate improvement	No improvement	Low decline	No improvement	Low decline	Low improvement	Moderate decline
Woodland expansion on crops																			
Coniferous (Plantations)	Moderate decline	Low decline	No improvement	Moderate improvement	No improvement	Moderate improvement	Moderate improvement	Moderate improvement	Low improvement	No improvement	High improvement	Moderate improvement	Moderate improvement	High improvement	Low improvement	Low decline	Low improvement	Moderate improvement	Moderate improvement
Broadleaved (plantations)	Moderate decline	No improvement	No improvement	Moderate improvement	Low improvement	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	High improvement	Moderate improvement	Moderate improvement	High improvement	Moderate improvement	Low decline	Low improvement	High improvement	Moderate improvement
Mixed forest (plantations)	Moderate decline	No improvement	No improvement	Moderate improvement	Low improvement	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	Low improvement	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	Moderate improvement	Low decline	Low improvement	Moderate improvement	Moderate improvement

Changes in ES delivery			
		No improvement	(light grey)
Potentially high improvement	(dark green)	Potentially low decline	(yellow)
Potentially moderate improvement	(green)	Potentially moderate decline	(orange)
Potentially low improvement	(light green)	Potentially high decline	(red)

3.3.2.2 Quantitative assessment of changes in natural capital

For a quantitative assessment of changes in natural capital on the land-based business or on society as a whole, the impact drivers need to be estimated or measured in physical terms (e.g., GHG and non GHG emissions to air, CO_2 sequestration, discharges to water and soil, and the use of land and resources, forest extent and quality, number of breeding pairs of birds, etc.). This also applies to the dependencies on natural capital, such as feed, water, wood, fuel, flood protection, which need to be estimated or measured in quantified units wherever possible (e.g., total m^3 of water abstracted, total MJ of metabolic energy provided). For some business quantifying the impacts may be seen as less important than dependencies. Nonetheless, the impacts are relevant when the result in physical changes in natural capital that are big enough to rebound and affect the business that generates this impact (e.g., through loss of social license to operate, or loss of financial opportunities) .

When land-based business are concerned using a *natural assets register* can help to assess changes on the extent and condition of natural assets over time (e.g., Appendix Table A.4.1). Natural capital metric can be adopted to analyse changes in the state and condition of natural assets. As indicated before, the state of natural capital usually refers to the extent of habitats, or mass or volume indicators regarding soil and water resources. In case of land-based business the state metric can be referred to broad habitat areas. The natural capital assets register can also record changes in natural assets stocks that are observable, such as the volume of standing timber in a forest, or can be inferred from flows, such as reduced timber stock due to harvesting. Identifying internal and external factors that may influence the state of natural capital is useful to determine potential trends in changes in natural capital with these factors. Understanding these trends is especially relevant when changes in natural capital are not linear, are cumulative or are approaching to critical thresholds (e.g., drinking water quality standards). For changes in natural capital resulting from natural processes, the methods usually focus on ecological patterns and processes, while for human-induced changes the methods usually consider changes arising from emissions, resource use, and waste production. Resources use and emission are relevant indicators to analyse trends in the state of natural capital in land-based business. The natural capital assessment can consider a probabilistic approach that accounts for the likelihood specific scenarios or events to happen and the extend of the expected change (see Natural Capital Coalition (2016b) for a revision of methods available to measure changes in natural capital state).

There is currently no assessment of the condition of natural capital assets in the UK (Dickie, 2013). Available natural capital related GIS resources and accounts provide a snapshot at point in time on certain characteristics or properties (e.g., soil typologies, soil carbon content, water retention capacity, land capability) and economic values of natural assets, respectively, but none of them can indicate the natural capital condition. In case of land-based business, Silcock et al. (2018) suggest focusing the condition metric on soil health and biodiversity. The problem of using soil health as a metric is that soil health cannot be determined by measuring only crop yield, water quality, or any other single outcome, neither can be measured directly. According to the FAO soil portal[21], the status of soil health can be determined in two different ways. One way is to determine an absolute rating for soil health that considers the soil in function of its deviation of an ideal soil with ideal properties (deep, fertile, well managed, having an adequate water supply, etc.), whatever the land use is. The other option is connected to the soil degradation concept. This implies considering a relative rating that depends on the suitability of the soil for its actual use only. As an example, a slightly acid soil may be perfect for conifer plantations, meaning the relative soil health is high, but would be considered as having a low marginal soil health in absolute terms because the alternatives using it for cropping would be extremely limited. From a more practical standpoint, one need to develop a set of metrics indicating soil health that are relatively easy to monitor over time and at a cost that is affordable for the land-based business. Those may include three indicator categories: physical, chemical and biological soil quality indicators. Doran and Parkin (1996) suggest that soil organic matter, or more specifically soil carbon, transcends all three indicator categories and has the most widely recognized influence on soil quality. Nonetheless, carbon in soils must be monitored over long term periods and using sensitive measurement techniques for the detection of minimum detectable differences in soil carbon (Batjes and Wesemael, 2014). Alternative indicators, collected at the farm level to guide management decisions, include soil pH, particulate, organic matter, NPK content. Monitoring former soil quality indicators can give an idea of changes in soil quality condition over time.

The availability and quality of data for the assessment of impact and dependencies on natural capital is critical. Collecting and analysing information is time and resource demanding, and requires the appropriate expertise. Some statists and data sets, and other resources, such as models are free-to-use, but they may require the use of costly models or a long time to deploy, in particular when up and downstream activities of the value chain are considered (Fig. 7). Other relevant issue to consider in the analysis is the dynamic aspects of the business, such as seasonal change in output volume, range of products or efficiency drivers (Natural Capital Coalition, 2016d). Seasonality affect for example the concentration of pollutants in water and soils[22], and a proper impact assessment would consider seasonality variations in the analysis of trends in changes on natural capital and ecosystem services.

3.3.3 Step 07: Valuation of the consequences of impacts and dependencies

As indicated before, the valuation of consequences of impacts and dependencies on natural capital can be assessed in qualitative, quantitative and monetary terms. *Qualitative valuation* can be implemented using techniques such as opinion surveys, deliberative approaches or relative valuation. Opinion surveys are designed to collect the views of different stakeholders through a series of questions, using for example semi-structured interviews. Deliberative approaches include facilitated group discussion or focus groups that can involve debate and learning sessions or workshops. Relative valuation implies the use of qualitative indication of the relative value of the consequences of changes in natural capital on benefit or cost in categorical terms (e.g., low, medium or high) using experts judgement or available data. *Quantitative valuation* can be carried out using structured surveys or questionnaires, indicators or multicriteria analysis. Structured surveys are used to elicit quantitative values that allow a consistent statistical analysis. Various indicators can be used to quantify information, such as crop yields, visitor numbers, GHG emissions. Multicriteria analysis involves selecting a range of parameters, and scoring and weighting criteria that's are used as a valuation technique. *Economic valuation techniques* are also diverse and presented in more detail in sub-section 2.2. More details on the advantages, disadvantages and suitability of different qualitative and quantitative valuations techniques are discussed in the general Natural

[21] http://www.fao.org/soils-portal/soil-degradation-restoration/global-soil-health-indicators-and-assessment/en/
[22] See Environmental Change Network data (http://data.ecn.ac.uk/tsv/results.asp).

Capital Protocol guide (Natural Capital Coalition, 2016b: 84-85). The advantage, disadvantages, and suitability of different economic valuation methods are summarised in Table 3, referred to the economic valuation of ecosystem services, natural assets or changes in the provision of ecosystem services.

The impact drivers and dependencies on business are usually estimated in monetary terms, and those values frequently account for the marginal financial benefits or costs associated to changes in natural capital and ecosystem services. Changes in natural capital and ecosystem services can affect the productivity, operational costs, benefit, and efficiency levels associated to main production processes. The consequences for the business may be also less tangible. Less tangible consequences concern the reputation of the firm or the access to financial opportunities, including environmental market, such as carbon credits or biodiversity offsets, which can create new cost or benefits for the business. Therefore, if the scope of the natural capital assessment extends over several years, one need to consider not only potential future direct impacts on the land-based business, but also the possibility that future impacts on the business may arise indirectly through the firm's impacts on society. This later component of impact is more likely to capture the risk and opportunities on the impact being internalised in the future (e.g., public payments for public goods).

Wider societal impacts can be expressed in qualitative, quantitative or monetary terms. Business impacts on society include all cost or benefits accruing to individuals, communities, or organizations that are not captured in the market and are external to the business (i.e., externalities). Some relevant impact drivers can include business inputs, such as water use, or outputs, such as solid waste, water pollution, air emission or investment in ecological restoration. The potential long-term consequences impacts on society may also be considered. The impacts on society would be affected also by their location and the way the outputs of land-based system are dispersed (e.g. air or water pollution). One need to consider how impacts change over time, and the cumulative effect, especially when the outputs of land-based activities can breach thresholds. Economic valuation of social cost and benefits requires the physical quantification on input or outputs, and how they change over time.

The choice of valuation method depends on which natural capital impact driver or dependency needs to be assessed, as well as the valuation perspective (i.e., business, societal, or both), the objective of the assessment, and the time and resources available. The monetary valuation of impacts and dependencies at the business level demand fewer external resources, as relevant data (e.g., farm accounts) and relevant expertise maybe available within the business firm. The economic valuation of impacts on natural capital from a societal perspective typically need more resources, and specialist expertise on environmental economic valuation and/or welfare economics . There may be trade-offs between different valuation techniques in terms of their relative precision, time, and cost and utility for the desired use (Natural Capital Coalition, 2016d). Uncertainty around potential cost and benefits in the future poses a relevant limitation for the monetization of societal impacts (normally not represented in markets), in particular in presence of potential irreversibility, or the proximity of critical thresholds (TEEB, 2010).

3.4 APPLY STAGE (What next?): Interpreting the results and taking action

3.4.1 Step 08: Interpretation and test of results

This step embraces the identification of critical uncertainties, key assumptions, and important caveats to help explaining the strengths and weaknesses of the natural capital assessment, and to interpreting the results. This task can help to determine and communicate whether the assessment achieved its initial objective and can be used as a basis for decision making and action. This step may also include a formal verification (e.g., through discussion with relevant stakeholders) or external audit of the results, previous the communication of the assessment results to certain audiences (e.g., for external reporting). This step considers is underpinned on four overarching questions to help the interpretation of the results of the assessment. Those include, (i) what do the results mean? (ii) how reliable are the assessment process and results? which involves testing if the assumptions are correct and determining their level of confidence, (iii) does the documentation available provide a comprehensive and accurate representation of the assessment process and results? which attains verification processes, and finally (iv) was the assessment worthwhile? before exploring the action that can be taken.

In order to interpret your results, the values need to be brought together in a way that is appropriate for the assessment. This may need some form of analytical approach or framework such as cost-benefit analysis, multi-criteria analysis, environmental profit and loss account, or total contribution (e.g., A4S, 2015; WBCSD, 2013).

Results involved compared options can be presented using net present values when they involve the valuation of monetary consequences over a period of time (e.g., Russ and Silcock, 2018), and also differences numerical or categorical indicators of impacts and dependencies. The monetary valuation of impacts and dependencies can facilitate the comparison between diverse categories of impacts and dependencies. When the results are reported using quantitative valuation rather than monetary valuation, different metrics (e.g., kg and m^3) can be converted into scores for improved comparison (e.g., Table 14 and 0). Presenting different scores in the same chart or table can help identifying key analysis of trade-off and synergies. Those scores can be further weighted in terms of their overall importance. This later can help decision making in a way similar to multicriteria analysis often does.

For the determination of the reliability of the assessment process and results with confidence, key assumptions need to be tested and the process and results validated and verified. An appropriate interpretation of results of the assessment requires the identification of its strength and weakness, and of the key affected stakeholders. Testing the key assumptions is needed to understand the level of confidence one can have on the results. Whenever possible, a sensitivity analysis can be used to test how different level of assumptions or key environmental and economic variables affect the results (e.g., discount rate, population affected, prices on energy, or time horizon). This analysis can involve simulation to identify critical thresholds. Alternatively, this may imply reporting a range of potential values for a particular impact of dependency

Distributional analysis can be used to understand who is affected by each impacts or dependency on natural capital. This involves identifying who loses or who gains as result of a natural capital impact or a decision involving changes in natural capital, both today and in the future. The distributional analysis involves determining the distribution of costs and benefits of an enterprise, activity or project that have an impact on natural capital among the stakeholders concerned. Distributional effects can be used to inform benefit-cost analysis, sustainable financing opportunities, liability claims, and claims over creating shared value and net positive impacts (WBCSD, 2013). This analysis influence how the results may be interpreted and used.

Validation involves checking the accuracy and completeness of the results, while verification involves checking internally and/or externally that the data and methodologies used are fit for the purpose and the assessment of results are sufficient robust to be used as a basic for business decision or external communication (Natural Capital Coalition, 2016d). The recently published Natural Capital Checker (Natural Capital Coalition, 2019) can be used as tool to check if the assessment achieves the Protocol principles of relevance, rigor, replicability, and consistency (see Fig. 6). To ensure the objectivity of the natural capital assessment conclusion all relevant information has to be considered, as well as, risk-based approaches for determining most relevant issues. The use of evidence-based approaches for reaching reliable and reproducible results, being objective in choosing methods to fit the purpose, and transparently disclosing of assumption and subjective criteria adopted are all necessary to ensure the rigor of the assessment. The replicability can be ensured by using rational methods in a systematic and transparent, traceable and fully documented and reputable process. Finally, the consistency is ensured when the data and methods used in the assessment are compatible with each other, and with the scope of the analysis (*ibid*).

The review of strength and weakness of the assessment (or the assessment of the assessment) to inform future assessment and identifying what can be improved within the ongoing assessment. This assessment involves analysing in first place if the results of the assessment help to inform the decisions contemplated in its objective. This also comprises identifying the major gaps, limitation, strengths, or weakness perceived by different stakeholders. And among other aspects, an overall analysis of if the assessment worth the effort and was timely.

The main output of the results interpretation and test step include the key messages, caveat, assumptions, and uncertainty, including a sensitivity analysis if appropriate. This also should include the results of the validation and internal/external verification of the process and results, and an objective acknowledge of key assumptions and uncertainties around the results.

3.4.2 Step 9: Taking action: integration of results and natural capital into existing processes

The last step of the Natural Capital Protocol application aims to answer the overarching question on how to apply the results of the assessment and integrate natural capital into existing decision-making processes? This later concerns the resources or decisions that need to embed natural capital assessment in the business system. This step also concern the ways to the results should be used and communicated, keeping in mind confidentiality concerns.

The ultimate aim of the natural capital assessment is to bring new ways of natural capital thinking about the relationships of business and the natural environment. This concern the integration of natural capital into strategic and operational business decision-making processes. This later can involve, for example, exploring different types of land use or different markets, reduce or increase certain business activity, making specific investment (e.g. habitat restoration project), develop new products, including natural capital in the business reports, and monitoring natural capital over time. Natural capital assessment can also help the process of internalising externalities into decision making. Typical examples are the inclusion of carbon or water shadow prices in future decisions, or even accounting for these externalities in the financial books. The integration of natural capital also concerns communication strategies within the business sectors, customers, shareholders, the community and other relevant stakeholders.

A key aspect for the integration of natural capital thinking into business management, is developing a system to track and monitor relevant indicators on dependencies and impact drivers, preferably built into an existing system, such as the financial reporting system. Table 16 provides examples of usual business processes that can get some value added from including natural capital assessment.

Table 16 Example of decision process that can benefit from natural capital assessment

Existing process	Description	Value added of the natural capital assessment
Cost-benefit analysis	Compares cost and benefits of a project or policy, considering net present values, cost-benefit ratio or internal rate of return	-Help to identify cost savings and benefit opportunities associated to natural capital -Estimate shadow values for impact drivers associated to the business based on societal values
Natural resources damage assessment	Involves various techniques to calculate environmental damages, remediation requirements or cost associated to environmental liabilities	-Including the value of associated impacts on society, and restoration costs, and benefits to society and the business
Strategies target setting and monitoring progress	Natural capital assessments can help inform the target- setting process, including to establish baselines, scope assumptions, assess feasibility,	-Prioritize dependencies and impact drivers based on materiality -Establishing feasible targets -Measure the success of sustainability polices based on reliable data
Environmental management systems	Structured frameworks for managing an organization's significant environment impacts. Include assessment on activities, products, processes and services that can have an environmental impact (positive or negative)	-Provide a framework for ensuring a consistent use of natural capital information and analysis
Environmental and social impact assessment	A systematic approach to asses potential environmental and social impacts, associated with developments, projects, programs or polices. This can include wider socioeconomic impacts at the local or regional economies, such as multiplier effects, direct and indirect job creation and distributional impacts	-Adding valuation elements to decision making, creating a richer decision platform -Identify cost-effective options to minimize, mitigate or offset adverse impacts
Risk assessment	Analysis of the risk of the business operations or products to ecosystems, including impacts on people directly exposed or indirectly affected	-Adding valuation elements to decision making, creating a richer decision platform -Introduce a broader range of measures of value to assess risk in context
Internal audit	Process to provide independent assurance that an organization's risk management, governance, and internal control processes are operating effectively.	−Assure compliance with natural capital assessment procedures established by the company. −Improve the quantification of risks and their impacts.
Life Cycle Assessment (Analysis)	LCA is a structured management tool for quantifying emission, resources consumed, and environmental and health impacts associated with products over their entire life cycle	-Providing and structural approach for valuing and prioritizing environmental impacts to include in and LCA -Use monetary valuation for aggregating and comparing different impacts in an LCA

Existing process	Description	Value added of the natural capital assessment
Company reporting	Reporting of environmental, social and/or financial information for external use (shareholders and other stakeholders)	-Providing and structural approach for prioritizing environmental impacts to include in reports. -Enhance corporate reputation and reduce market risk by providing more rigorous and reliable information to shareholders and stakeholders
Financial accounting	Financial analysis for external or internal company purposes. It focuses on costs and benefits with direct financial implications for a company's bottom line. It includes inputs to the 'profit and loss account' and 'balance sheet' of a company or business unit.	−Specify which costs, revenues, assets, and liabilities are related to natural capital. −Develop a set of shadow prices or accounts for environmental costs and benefits, based on societal values
Management accounting	Financial analysis for internal company purposes, focused on cost and benefits with direct financial on a product line, activity or investment. Affect pricing decisions, budgeting, capital investment, NPV, returns to investment,	−Identify which financial costs and revenues are linked to significant natural capital impacts and/or dependencies. −Include a set of shadow prices or accounts for environmental costs and benefits, based on societal values

Source: *Own elaboration* based on (Natural Capital Coalition, 2016d)

4 Next steps for natural capital accounting

The document aims to build the conceptual bases for natural capital accounting approaches to operationalize the integration of natural capital thinking into land management strategies and decision-making involving farming systems. This framework aimed to guide the application of the Natural Capital Protocol in a group of farms belonging to the James Hutton Institute (JHI) for assessing changes in impacts and dependencies on natural capital due to specific investment decisions and changes in management strategies (e.g., Ovando, 2020).

A second next step associated to the development of this conceptual framework is to explore the potential links of natural capital Protocol methods, tools and results with sub-national (e.g. catchment level) and national Ecosystem Accounts. This exploration will include an analysis of the: (i) the opportunities and challenges to connect national ecosystem accounts, at different spatial aggregation levels (i.e. sub-regional: catchment, landscape, regional, and national) with land-based business assessments of natural capital, and (ii) the combination of top-down and bottom up data collection approaches to deliver robust and consistent information on the state, ongoing changes, and processes affecting agroecosystems and the ecosystem services that flow from and to them.

Farming and forestry activities are intrinsically and directly attached to natural assets at scales in which changes on land practices or uses can be observed, thought their consequences depend on complex interactions involving multiple scales that many times goes beyond the farm boundaries. Some consequences of farm activities are difficult to be attributed to specific lands, as the observed outcomes represent the aggregated effect of a large number of activities. For example, water quality condition at specific monitoring points reflect an aggregated outcome of a number of point and diffuse pollution upstream sources. Likewise, the relevant scale to reduce a number of environmental and human health consequences from economic activities usually transcend the farm (e.g., catchment, landscape unit). Nonetheless, specific measures for reducing environmental impact or enhancing biodiversity operate at the farm level. The interactions between the farm as the operative decision-(investment)-unit and the relevant environmental scale provides an opportunity to interconnect these levels of natural capital accounting to inform decision-making and policies.

The connection of these scales demand the development of cross-cutting and thematic accounts, showing physical and monetary natural capital accounts along with flow accounts of materials into the economy (e.g., inputs at the farm level) and expenditures in environmental protection; negative outcomes of economic activity (e.g., waste, pollution, GHG emission); and natural capital investment at the farm level (e.g., restoration projects). The combination of top-down and bottom-up approaches for data collection seems desirable, with special attention to the consistency problems for scaling information up and down. Public and private collaboration, through data sharing or standardization of approaches and concept, seems critical to mainstream the integration of natural capital thinking into decision making and policies, and to further develop a more transparent and integrated natural capital dialogue (Spurgeon et al., 2018).

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Appendix

Contents

A.1 Example of questionnaire for defining the objective and scope of the natural capital assessment in farming systems in Scotland

Name of the participant	

Relationship to the farm	

Farm		Place and date:	

A. GENERAL QUESTIONS BEFORE APPLYING THE NATURAL CAPITAL Protocol

I have some questions to guide the initial exploration for the Protocol application at the [__________] farm

1. How familiar were you with the natural capital Protocol before we start the contact regarding this project?

☐ Not familiar at all

☐ I was aware of the Crown Estate Scotland trial application

☐ I was aware of the Protocol before this application

Comments:

2. How familiar are you with the concepts of ecosystem services and natural capital?

☐ Not familiar at all

☐ I know the concepts, but I am not totally familiar on the meaning of the concepts

☐ I am familiar with the concepts

Comments:

3. What do you think are the main natural capital depletion risks in the farm? (if there is any)

This can include risk for an activity, the business, risk for society:

4. What do you think are the main environmental impacts of the farm activities on natural capital?

5. What information do you use for decision making?

6. Do you think that a natural capital assessment can help your decision making?

☐ YES (go to 7) ☐ NO (*) ☐ Not sure/I do not know (go to 7)

*If no please indicate the reasons, and if you want to continue with this questionnaire.

Comments (if any):

7. What kind of information on natural capital could help your decision-making in [__________] farm?

8. What kind of decisions do you think a natural capital assessment can help with in [__________] farm?

9. What could be in your opinion the main practical applications for the Protocol in [__________] farm?

10. What is (are) the main the main objectives for the farm business (management)?

B. DEFINING THE OBJECTIVES AND SCOPE OF THE NATURAL CAPITAL ASSESSMENT IN [_________] FARM

Next, I will start with the overarching questions for the application of the Protocol. Considering what we discussed before, I ask you to share your vision regarding the following questions.

The main idea is to define together the objectives and scope of the natural assessment at the [__________] farm. Please note that we can go back to any point of this questionnaire, and in the following weeks, to make any correction or clarification as needed.

Framing the natural capital assessment

11. Can you define the degree of relevance (where 1 is not relevant at all, 3 moderate and 5 very relevant) of the following aspects for a natural capital assessment at the [_______] farm? Please mark with and X, provide more details and please indicate if there are other aspects that are relevant for the natural capital assessment

Aspect	1 (—)	2 (–)	3 (0)	4 (+)	5 (++)	Comments
-Improving the farm productivity (yields)						
-Improving the farm income						
-Reducing production costs						
-Reducing the use of external inputs						
-Reducing the use of energy						
-Improve risk assessment and management						
-Improving farm long-term resilience						
-Finding potential funding opportunities						
-Farm income diversification						
-Adoption of innovative farming practices/technologies						
-Enhancing biodiversity conservation						
- Reducing the risk of natural hazards						
-Improving specific environmental indicators (specify)						
-Maintaining/improving relationships with: Farming community						
: Local area community						
: Science community						
-Maintaining/improving the farm reputation						
Other (specify)						

12. Why to conduct a natural capital assessment in [__________] farm?

Scope of the natural capital assessment

13. What should be the objective(s) of the natural capital assessment in [__________] farm?

14. What are the main stakeholders that should be considered in the natural capital assessment in [__________] farm?

15. What are the value chain aspects that the natural capital assessment should be considered? (*considering the information that would be relevant for the farm management and decision making*)

16. What should be the spatial boundary of the natural capital assessment? [Define using a map if possible]

17. What is the time horizon that should (could) be considered and why?

18. What should be the baseline scenario to which refer (for comparative purposes) the natural capital assessment results? (i.e., the starting point or benchmark against which changes in natural capital attributed to your business' activities can be compared (for example before and after any relevant investment or management change undertaken at the farm)

19. What are the key current (and/or) future planning issues that should be considered by the natural capital assessment?

A.2 Example of impact drive and dependency matrices

Table A.2.1 Dependency matrix (initial identification of dependencies and their relevance)

To discuss with relevant stakeholders. Indicate the relevance of the dependency: H: highly relevance, M: moderate, L: low relevance, N: no relevance, U: unknown.

Enterprises	Dependencies of the farm on consumptive and non-consumptive good and services																			
	Consumptive										Non-consumptive									
	Surface water	Groundwater	Rainwater	Animal food	Timber/Wood /fibre	Animal materials	Plant materials	Fossil fuels	Renewable energy (except photosynthesis)	Other	Filtration toxic substances (water)	Water flow regulation & Flood attenuation	Pollination	Biological pest /diseases control	Maintaining nursery populations & habitats	Buffering and attenuation of mass movement (falls, slides, flows)	Decomposition and fixing processes	Information from nature (knowledge)	Nature-based recreation/tourism	Other
Farm activities																				
Extensive crop systems																				
Intensive crop systems																				
Organic farming																				
Intensive forestry																				
Low intensity forestry																				
Extensive livestock farming																				
Intensive livestock farming																				
Deer rearing																				
Small game shooting																				
Big-game shooting																				
Fishing																				
Energy production																				
Peat extraction																				
Beverage & food industry																				
Wild-life conservation activities																				
Recreation/Tourism																				
Demonstration activities																				
Training/education activities																				
Others (specify)																				

Table A.2.2 Impact driver's matrix (initial identification of potential impacts)

To discuss with relevant stakeholders. Indicate the relevance of the impact driver: H: highly relevance, M: moderate, L: low relevance, N: no relevance, U: unknown.

Enterprises	Impact drivers												
	Inputs				Output								
	Water use	Terrestrial ecosystem use	Freshwater ecosystem use	Wildlife	GHG emissions	Non-GHG air pollutants	Water pollutants	Soil pollutants	Soil erosion	Solid waste	Disturbances	Air pollution filtration	Carbon sequestration
Arable crops (irrigated)													
Arable crops (rainfed)													
Organic farming													
Intensive forestry													
Low intensity forestry													
Extensive livestock farming													
Intensive livestock farming													
Deer rearing													
Small game shooting													
Big-game shooting													
Fishing													
Energy production													
Peat extraction													
Beverage & food industry													
Wild-life conservation activities													
Recreation/Tourism													
Demonstration activities													
Training/education activities													
Others (specify)													

Table A.2.3 Matrix of land cover and enterprises

Land cover/Broad habitat	Area (hectares)	Enterprises in the farm (indicate the share of land used)																
		Intensive farming	Extensive farming	Organic farming	Intensive livestock farming	Extensive livestock farming	Intensive forestry	Low intensity forestry	Small game shooting	Big-game shooting	Fishing	Energy production	Beverage & food industry	Wild-life conservation active.	Recreation / tourism	Demonstration farm activities	Training/education activities	Others (specify)
Enclosed farm																		
Arable land																		
Orchards																		
Fallow land																		
Temporary pasture (improved grassland)																		
Permanent pasture (improved grassland)																		
Acid grassland																		
Calcareous grassland																		
Meadows																		
Coastal and Floodplain Grazing Marsh																		
Hedgerows																		
Buffer strips																		
Field margins																		
Other ecological focus areas (EFA)																		
Woodland and forests																		
Coniferous seminatural woodlands																		
Coniferous plantations																		
Broadleaved seminatural woodlands																		
Broadleaved plantations																		
Mixed seminatural woodlands																		
Mixed broadleaved/coniferous plantations																		
Other habitats																		
Bogs (raised and blanket)																		
Heathland																		
Moorland																		
Others (specify):																		
Inland waters																		
Other land cover (specify)																		

A.3 Information resources available for the natural capital assessment

The desk-based preparation review includes the identification, design and production of materials, and collation of data resources, including public data sets: maps, reports, data sets and literature, and farm data. The general information sources available in Scotland and the UK to conduct a natural capital characterisation and impacts assessment approaches are defined in section A.3.1. While section A.3.2 includes templates for identifying and facilitating the collection of data, and other information resources (public and non-public) at the farm level.

A.3.1 General information resources (public data sets)

Available data resources include data sets, maps, and reports that are publicly available at the Scottish and UK level, and that can help the natural capital characterization and assessment for land-based business case studies. This information has been gathered using different data sources, including JHI reports, which will be discussed and completed with experts on specific natural capital related topic.

Class	Description of the resource	Potential limitations	Alternatives/Comments
Land-related			
CEH Land Cover (2007/2015)	Land Cover Maps: LCM2007 and LCM2015.	LCM2007 83% accuracy [1] LCM2015 same typologies as LCM2007, but does not consider Rough Grassland and Montane, which can limit the comparability with 2007	Satellite approach based in CORINE Local habitat surveys
Habitat extend (ha)	Scottish Natural Heritage (SNH) habitat survey. A record of the semi-natural vegetation and wildlife habitat over large areas of countryside. The habitat classification is based broadly on vegetation, augmented by reference to topographic and substrate features, particularly where vegetation is not the dominant component of the habitat. Digitalised from the field survey maps. The methodology is based on classifying each parcel of land in terms of 90 specified habitat type	Mapp 1:10000. 2010 data, revised 2013, published 2017 Archived dataset and is no longer updated or maintained. The data is dated – mainly from the 1980s and 1990s, it does not comply with the INSPIRE Directive, it is not in the EUNIS classification system and does not assist SNH in reporting on its statutory commitments.	Information available online (downloaded) Use the EUNIS data (standardised across Europe) The correspondences of National Vegetation Classification and EUNIS explained in the commissioned report 766 (available online, downloaded) (HabMos EUNIS)
	HabMoS EUNIS	EUNIS habitats for Scotland (2015 data) revised in 2017. Map based on EUNIS The map shows the wide diversity of land cover types across Scotland and at a local level, rather than its condition.	Information available online
	CSGN Integrated Habitat Networks: Integrates Habitat Networks (IHNs). The spatial position and extent of functional integrated habitat networks were determined through a landscape ecology model from the BEETLE (Biological and Environmental Evaluation Tools for Landscape Ecology) suite of tool	Useful for environmental characterisation of Natural Capital Assets (data from 2012) Archived dataset and seems to be no longer updated or maintained	Information available online
Land use data	IACS- JA data: Scottish government Integrated Administration and Control System. Information derived from the spatial land parcel information system and non-spatial data	Information access restricted. Changes in the grassland land use categories difficult the comparability among years	Not available online, data protection act restrictions apply
Ancient forest	SNH data set: ancient Forest: Ancient woodland inventory, Phase 1 Habitat Classification	Data set no longer updated or maintained, data mainly from 1980 and 1990. Doesn't follow the EUNIS classification	Information available online
Wild land areas and wilderness	Wild land Areas (2014) Boundaries of core wild land areas in Scotland as determined by their level of	Boundaries should be considered as 'fuzzy' rather than definitive to reflect the transitional nature of wild land.	Information available online

Class	Description of the resource	Potential limitations	Alternatives/Comments
	naturalness, remoteness, ruggedness and absence of modern artefacts		Potentially useful for analysing the opportunities to capitalise on cultural services
	Wildness: Perceived naturalness. He dataset is on a scale of 1-256 indicating relative levels of naturalness. The methodology is adapted from the 2008 Wildness Study in the Cairngorms National Park.	Data better suited for the national or regional scale.	Information available online Potentially useful for analysing the opportunities to capitalise on cultural services
Area of management	Data on forest management regime (timber, energy, recreation). Data derived from the ere derived from the FC's 'Managed Woodland' dataset	Not clear if this is available for Scotland. Data set does not match the LCD in 2 to 21% of the cases	Information potentially useful to characterise the farm catchment area
Length of hedgerows (km) Countryside	The survey has been carried out at regular intervals since 1978 and past assessments have taken place at intervals at least once a decade	The figures are calculated estimates based on a sampling strategy [(2)]	The usefulness of the information to characterise the farm catchment area seems limited
Land Capability maps (Agriculture)	The Land capability for agriculture map (partial cover) was originally mapped at 1:50 000 scale. It shows the distribution of the different land classes across virtually all of Scotland's cultivated agricultural land and adjacent uplands.	Partial coverage in Scotland	
Land Capability maps (Forest)	Classes range from F1 (land offering excellent flexibility for growth and management) to F7 (land unsuitable for producing trees) with seven types of limitations, these being climate, wind throw, nutrients, topography, draughtiness, wetness and soil.	The map was based on a reclassification of the 580 soil map units of the National soil map of Scotland with limited field validation. A set of rules were applied to each of the soil map units combined with information on climate and relief to assign the map units to a capability class for forestry.	The Scottish Forest Strategy 2019-2029 and Forestry and Land Management (Scotland) Act (2018),
Soil/Soil related			
Soil classification	National Scottish soil map: National coverage of the main soil types across Scotland mapped originally at 1:250 000 scale. The map is based on data collected between 1947 and 1981.	Data revised and corrected in 2013	Information useful to characterise soil natural capital
Topsoil carbon stock	Tonnes carbon in top 15 cm. Scotland soil data available through the JHI webpage[(2)], including 1:25,000 Soil Map (partial cover), 1:250,000 National soil map	Results are based on a sampling strategy.44 Some areas (e.g. littoral rock) are not sampled and have no associated data. The topsoil carbon data is only representative of 0-15 cm soil depth and so may under-represent deeper peat soils.45 Surveys	SNH also holds data on carbon rich soil, deep peat and priority peatland habitats which could potentially be used to refine the calculations[(3)]
Layer: carbon_and_peatland_2016	The dataset contains carbon and peatland class values, as well as over 439,000 records providing detail on the main soil types and habitat characteristics associated with each area mapped.	High level planning tool the map is a predictive tool which provides an indication of the likely presence of peat on each individually-mapped area, at a coarse scale	The accuracy of the map at the site level needs to be checked
Water			
Length of WFD rivers (km) and number of WFD waterbodies	Data on the Extend of rivers and water bodies. Data available through the Water hub at the SEPA webpage	Last available data: water overall conditions in 2014. Need of additional information to analyse evolution in water quality at the NVZ and catchment level. Difficulties to connect water quality data with farm management	
Standing Waters Sample Points	GIS dataset of survey sample locations used during the course of the Scottish Loch Survey Project. His involves identifying and estimating the abundance of emergent, submerged, floating leaved, and free-floating macrophytes that grow in or near the water.	Archived dataset and is no longer updated or maintained CEH land cover changes for 2000 and 2007 for the Loch Saugh catchment area (200 ha)	
Available water capacity (mm)	Available water capacity is the amount water a soil can provide for		

Class	Description of the resource	Potential limitations	Alternatives/Comments
	plants and so is a useful indicator of the ability of soils to grow crops. The available water capacity is derived from a number of different soil properties.		
Risk and Impacts			
Top soil compaction risk	Soil becoming compacted due to the passage of machinery.	High level planning tool the map is a predictive tool. Maps primarily covering the cultivated land in Scotland Those data do not indicate change on the state and condition of natural capital	Information available online. Useful to characterise natural capital related risk. This information need to be complemented with other qualitative and quantitative information collected at the site level
Sub soil compaction risk	The map shows the vulnerability of subsoils to compaction by heavy machinery		
Runoff risk	Risk of water flowing overland (runoff) carrying potential pollutants into water courses.		
Soil leaching potential	risk of potential pollutants and nutrients leaching through the soil to ground and surface waters		
Soil erosion risk	risk of a bare soil being eroded by water under intense or prolonged rainfall and		
Flood likelihood map for rivers, surface water and coastal areas	SEPA interactive map[(4)]		This information need to be complemented with other qualitative and quantitative models and information produced/collected at the site level
Other maps			
Deer count– deer groups	SNH. Metadata updated on 06/2018 Deer group locations and sizes are used in assessing deer populations living on the 'open range	There is a stand population of deer in Glensaugh (not sure if this map is useful)	Information available online. Potentially useful for analysing the opportunities to capitalise on provisioning and cultural services
RSPB reserves data	Boundaries of all land managed, leased or owned as part of public ally accessible RSPB reserves		Information available online Potentially useful to identify natural capital related opportunities
Biomass opportunity	Updated 2015: Composite map of opportunity for biomass energy with physical and policy constraints marked as well as areas of high and medium ecological sensitivity		
Soil energy opportunities	Updated 2015: Composite map of opportunity for solar energy with physical and policy constraints marked as well as areas of high and medium ecological sensitivity		
Heathland extent and potential	Information RSPB	Apparently not available for Scotland	

Notes:

(1) CEH (2011) Final Report for LCM2007 – the new UK Land Cover Map. CS Technical Report No 11/07. [online] available at: http://www.ceh.ac.uk/documents/lcm2007finalreport.pdf

(2) Available via The James Hutton Institute webpage, see https://www.hutton.ac.uk/learning/natural-resource-datasets/soilshutton/soils-maps-scotland/download#thematicmapdata

(3) Available via the SNH data gateway, see: https://gateway.snh.gov.uk/natural-spaces/index.jsp

(4) Available via SEPA webpage, see: http://map.sepa.org.uk/floodmap/map.htm

A.3.2 Example of information requirements at the site level

Table A.3.2 Information availability on land-based business inputs and outputs

Identify the data availability for the measuring dependencies and/or impacts of the land-based business on natural capital

Business input/output	Impact driver category	Potential metrics (measurable impact drivers)	Availability		Comments (including the contact person, format of data, period covered, frequency)
			YES	NO	
Input	Water use	Volume of surface and ground water consumed (water abstraction)			
	Terrestrial ecosystem uses	Area of terrestrial habitat used by type (see EUNIS classification: Table A.4.3) Considering more details on the type of crop and grasslands			
	Freshwater ecosystem use	Area (length) of freshwater habitat used by type (e.g., wetland, lakes, ponds, rivers, aquifers, etc.)			
	Game and wildlife	Number of wild fish caught by species			
		Number of wild mammals caught by species			
		Number of wild birds caught by species			
	Wild plants and fungi	Volume of wild plants and fungi extracted			
	Other resources use	Volume of mineral extracted			
		Volume of peat extracted			
	Others:				
Output	GHG emission	Mass of the carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), Sulphur hexafluoride (SF_6), Hydrofluorocarbons (HFCs) and perfluorocarbons (PFC)			
	Non-GHG air pollutants	Mass of the particulate matter ($PM_{2.5}$) and coarse particulate matter (PM_{10}), Volatile Organic Compounds (VOCs), mono-nitrogen oxides (NOx), Sulphur dioxide SO_2, carbon monoxide (CO)			
	Water pollutants	Mass discharged to receiving water body of nutrients (nitrates and phosphates), or other substance (pesticides), faecal indicator organisms, etc.			
	Soil pollutants	Mass of water matter discharged and retained in soil over a given period			
	Soil erosion	Mass of soil loss, or mass of sediment deposition			
	Solid waste	Mass of solid waste by type: domestic waste, building materials, plastic, silage, animal feed, animal health products, seeds, agrochemicals (concentrates), machinery waste (oil, batteries, tires, machine), cardboard cores, etc.			
	Disturbances	Visual disturbances (such as number of wind turbines, area occupied by solar panels or landfills)			
	Biodiversity effects	Bird populations (survey)			
		Insect populations (survey)			
	Others:	Bat survey			
		Moth traps in the farm			

Table A.3.3 Information availability on land-based business inputs and outputs

Data set/Information	Observations	Contact person
Habitat and Land cover maps at the farm level	Indicate years:	
Forest inventory	Indicate year, mix of species and diameter class	
Biodiversity surveys	Indicate species and years	
Ecosystem services maps (models)	Indicate ES and models used	
Soil data (analysis)	E.g., pH, Total organic matter, nutrients by location of the sampled plot, month and year	
Soil carbon	Indicate year, and location of the sampled plot	
Sediments		
Water quality data	Turbidity, nitrate, phosphates, or pesticides concentration in ground and stream water by location and year	
Production data (crops, livestock, wood)	By enterprise, location and area, month and year	
Detailed physical and monetary farm accounting data	(by month, year, enterprise and product)	

A.3.3 Examples of Ecosystem services and Natural Capital assessment and valuation models and tools

Model / tool	Description	Institution/Reference
Environmental Value Look-Up (EVL) Tool	-Searchable database which contains indicative monetary values for a range of environmental impacts. The unit values in the tool are based on a review of over 350 UK valuation studies that have been conducted since 2000. -Intended as a first-cut, rapid analysis of the economic values of environmental impacts and for including secondary or incidental environmental impacts in appraisals that might otherwise be overlooked.	EFTEC (Economics for the Environment Consultancy) and DEFRA
Co$ting Nature	Provides information on and access to spatial modelling and mapping tools for mapping ecosystem services, water resources and the impacts of climate and land use change upon them, including the effects of policy interventions.	http://www.policysupport.org/costingnature
Environmental Valuation Reference Inventory (EVRI)	EVRI, is a searchable storehouse of empirical studies on the economic value of environmental assets and human health effects. Online searchable compendium containing classified summaries for over 4,000 valuation studies.	http://www.evri.ca/en
BeST (Benefits of SuDS Tool)	W045 BeST (Benefits of SuDS Tool) provides guidance to help practitioners estimate the benefits of Sustainable Drainage Systems (SuDS) without the need for specialist economic input. Estimates are based on the performance of the whole drainage system rather than individual components. BeST uses the ecosystem services approach to understand the overall benefits that SuDS provide over conventional piped drainage. Using values input by the user, it provides support to quantify and monetise the benefits of a SuDS scheme for a given area over a specified time period. The benefits are presented as a series of graphs and charts that are based on the ecosystem service and Triple Bottom Line (accounting) frameworks.	Ecosystems Knowledge network
Product Biodiversity Footprint (PBF)	Crossing Life Cycle Assessment (LCA) analysis and biodiversity impacts of products, the PBF project aims to answer the lack of specific tool to assess their impact on biodiversity.	http://www.productbiodiversityfootprint.com/

Model / tool	Description	Institution/Reference
Water Footprint Assessment Manual: Setting the Global Standard	Standard is the internationally accepted methodology for conducting a Water Footprint Assessment (WFA). WFA provides comparable quantification of water consumption and pollution and robust analytics that can be used to understand water dependencies in direct operations and supply chains, for products, facilities and companies and at different geographic scales. The standard can be used to: Calculate the green, blue and grey water footprint of water used for industry, agriculture and domestic water supply; conduct a water footprint sustainability assessment which includes criteria for understanding the environmental sustainability, resource efficiency and social equity of water use, for both consumption and pollution;	Hoekstra et al. (2011)
Local Ecological Footprinting Tool	LEFT is a web-based decision support tool to help industry evaluate patterns of relative ecological value across a landscape to inform land use planning and minimize environmental impact.	https://www.left.ox.ac.uk/
BioScope	Biodiversity Input-Output for Supply Chain & OPerations Evaluation. Platform BEE's BioScope provides businesses with a simple and fast indication of the most important impacts on biodiversity arising from their supply chain.	https://www.bioscope.info/
ORVal: Outdoor recreation valuation tool	ORVal is a freely accessible web-based tool that predicts the number of visits to existing and new greenspaces in England, and estimates the welfare value of those visits in monetary terms. It is based on an econometric model of recreational demand derived from MENE data. Users can examine the recreational value of existing green space and test how the number of visits and the value of these visits might change if the land cover was changed, or if new green spaces were created. Results can be grouped by local authority area or catchment, and can be split by socio-economic group.	https://www.leep.exeter.ac.uk/orval/
i-Trees (tree and landscape)	Free and easy to use tools to quantify tree structure, threats, and benefits globally. Built upon peer-reviewed, public-domain science, also provide intangible benefits, such as removal of atmospheric carbon dioxide and pollution, stormwater reduction, temperature modification,	https://landscape.itreetools.org/ maps/
Green Infrastructure Valuation Toolkit (GI-Val)	The Green Infrastructure Valuation toolkit provides a set of calculator tools to assess the value of a green asset or a proposed green investment. Where possible, the benefits of green infrastructure (GI) are given an economic value. Other quantitative contributions (e.g. number of jobs) and qualitative contributions (e.g. case studies or research) can also be provided to give a complete view of the value of an asset	

Source: *Own elaboration based* on Natural Capital toolkit (Natural Capital Coalition) and other resources

A.4 Example of template for natural asset register

Other relevant information and data available at the farm level to construct a natural asset register (Table A.4.1), and to characterize and/or measure the state (current situation such as the stock of resources at the assessment period) and condition (quality of natural assets).

Table A.4.1 Natural assets register and accounting units

Land cover/broad habitat[1]	Unit	Quantity	
		Initial year	Final year
Woodland and forests	Hectare/acres		
Coniferous seminatural woodlands			
Coniferous plantations			
Broadleaved seminatural woodlands			
Broadleaved plantations			
Mixed seminatural woodlands			
Mixed broadleaved/coniferous plantations			
Enclosed farm	Hectare/acres		
Arable land			
Orchards			
Fallow land			
Temporary pasture (improved grassland)			
Permanent pasture (improved grassland)			
Hedgerows			
Buffer strips			
Field margins			
Other ecological focus areas (EFA)			
Semi-natural grassland			
Acid grassland			
Calcareous grassland			
Meadows			
Coastal and Floodplain Grazing Marsh			
Other habitats	Hectare/acres		
Heathland			
Bogs (raised and blanket)			
Moorland			
Others (specify):			
Inland waters (surface and groundwater)			
Eutrophic standing waters	Hectare, m^{3}:		
Mesotrophic lakes	Hectare, m^{3}:		
Oligotrophic and dystrophic lakes	Hectare, m^{3}:		
Ponds	m^{3}:		
Rivers	Km:		
Aquifer Fed Naturally Fluctuating Water Bodies	m^{3}:		
Other land cover (specify)	Hectare/acres		

(1) Broad habitats classification (see Table A.4.2 for the equivalence to the EUNIS classifications).

Table A.4.2 EUNIS habitats classification in Scotland (1),(2)

Code	EUNIS Habitat	Broad-habitat classification equivalent
A	**Marine habitats**	
A2	Littoral sediment	Intertidal chalk, Intertidal mudflats coastal saltmarsh, Sheltered muddy gravels, Sabellaria alveolata reefs, Seagrass beds…
A5	Sublittoral sediment	Subtidal chalk, Tide-swept channels, Estuarine rocky habitats, Seamount communities…
B	**Coastal habitats**	**Coastal**
B1	Coastal dunes and sandy shores	Coastal sand dunes
B2	Coastal shingle	Coastal vegetated shingle
B3	Rock cliffs, ledges and shores	Maritime cliff and slopes
	Others (not identified)	Machair
C	**Inland surface waters**	**Freshwater & Wetland**
C1	Surface standing waters	Eutrophic standing waters
	Surface standing waters	Mesotrophic lakes
	Surface standing waters	Oligotrophic and dystrophic lakes
	Surface standing waters	Ponds
C2	Surface running waters	Rivers
	Others (not identified)	Aquifer Fed Naturally Fluctuating Water Bodies
C3	Littoral zone of inland surface waterbodies and other swamp vegetation	
D	**D. Mires, bogs and fens**	**Freshwater & Wetland**
D1.1	D1.1 Raised bogs	Lowland raised bog
D1.11	*Active, relatively undamaged raised bogs*	Lowland raised bog
D1.12	*Damaged, inactive bogs*	Lowland raised bog
D1.2	Blanket bogs	Blanket bog
D1.22	*Montane blanket bogs, Calluna and Eriophorum vaginatum often dominant*	Mountain heaths and willow scrub
D2.1	D2.1 Valley mires	
D2.2	D2.2 Poor fens and soft-water spring mires	Lowland fens
D2.3	D2.3 Transition mires and quaking bogs	
D4	Base-rich fens and calcareous spring mires	
	Others (not identified)	Upland Flushes, Fens and Swamps
	Others (not identified)	Reedbeds
	Others (not identified)	Purple moor-grass & rush pastures
E	**Grasslands and lands dominated by forbs, mosses or lichens**	**Lowland/Upland**
E1.2	Perennial calcareous [dry] grassland and basic steppes	Lowland calcareous grassland/ Upland calcareous grassland
E1.7	Closed non-Mediterranean dry acid and neutral grassland	Lowland dry acid grassland
E1.9	Open non-Mediterranean dry acid and neutral grassland, including inland dune grassland	Lowland dry acid grassland
E1.B	Heavy-metal grassland	*Calaminarian* grasslands (?)
E2.1	Mesic grasslands: Permanent mesotrophic pastures and aftermath-grazed meadows	Lowland meadows /Upland hay meadows
E2.2	Low and medium altitude hay meadows	Lowland meadows /Upland hay meadows
2.6	Agriculturally-improved, re-seeded and heavily fertilised grassland, including sports fields and grass lawns	Coastal and Floodplain Grazing Marsh
E2.8	Trampled *mesophillous* grasslands with annuals	
E3	Seasonally wet and wet grasslands	
E4	Alpine and subalpine grasslands	
E5	Woodland fringes and clearings and tall forb stands	
F	**Heathland, scrub and tundra**	**Lowland/Upland**
F2	Arctic, alpine and subalpine scrub	
F2.1	*Subarctic and alpine dwarf willow scrub*	
F2.2	*Evergreen alpine and subalpine heath and scrub*	
F2.3	*Subalpine deciduous scrub*	
F3.1	Temperate and Mediterranean-montane scrub: Temperate thickets and scrub	

Code	EUNIS Habitat	Broad-habitat classification equivalent
F4.1	Temperate shrub heathland: Wet heaths	Lowland Heathland / Upland heathland
F4.2	Temperate shrub heathland: Dry heaths	Lowland Heathland / Upland heathland
F9	Riverine and fen scrubs	
FA.1	Hedgerows of non-native species	Hedgerows
FA.2	Highly managed hedgerows of native species	Hedgerows
FA.3	Species-rich hedgerows of native species	Hedgerows
FA.4	Species-poor hedgerows of native species	Hedgerows
FB	Shrub plantations	
FB.1	Shrub plantations for whole plant harvesting	
FB.2	Shrub plantations for leaf or branch harvest	
FB.3	Shrub plantations for ornamental purposes or for fruit, other than vineyards	
FB.4	Vineyards	
G	**Woodland, forest and other wooded land**	
G1.1	Riparian and gallery woodland, with dominant *Alnus, Betula, Populus* or *Salix*	Wet woodland
G1.2	Mixed riparian floodplain and gallery woodland	Wet woodland
G1.4	Broadleaved swamp woodland not on acid peat	Wet woodland
G1.5	Broadleaved swamp woodland on acid peat	Wet woodland
G1.6	*Fagus* woodland	Lowland Beech and Yew Woodland
G1.8	Acidophilous *Quercus*-dominated woodland	Upland oakwood
G1.9	Non-riverine woodland with *Betula, Populus tremula* or *Sorbus aucuparia*	Upland birchwoods
G1.A	Meso- and eutrophic Quercus, Carpinus, Fraxinus, Acer, Tilia, Ulmus and related woodland	Upland mixed ashwoods
G1.C	Highly artificial broadleaved deciduous forestry plantations	Lowland mixed deciduous woodland(?)
G1.D	Fruit and nut tree orchards	Traditional Orchards
G3.4	*Pinus sylvestris* woodland south of the taiga	Native pine woodlands
G3.D	Boreal bog conifer woodland	Native pine woodlands(?)
G3.F	Highly artificial coniferous plantations	
G4	Mixed deciduous and coniferous woodland	
G5	Lines of trees, small anthropogenic woodlands, recently felled woodland, early stage woodland and coppice	
G5.1	Lines of trees	
G5.7	Coppice and early-stage plantations	
G5.8	Recently felled areas	
H	**Inland unvegetated or sparsely vegetated habitats**	
H1	Terrestrial underground caves, cave systems, passages and waterbodies	
H2	Screes	Inland Rock Outcrop and Scree Habitats
H3	Inland cliffs, rock pavements and outcrops	Inland Rock Outcrop and Scree Habitats
H5	Miscellaneous inland habitats with very sparse or no vegetation	
I	**Regularly or recently cultivated agricultural, horticultural and domestic habitats**	
I1.1	Intensive unmixed crops	
I1.2	Mixed crops of market gardens and horticulture	
I1.3	Arable land with unmixed crops grown by low-intensity agricultural methods	
	Others (not identified)	Arable Field Margins
I	**Regularly or recently cultivated agricultural, horticultural and domestic habitats**	
I1.5	Bare tilled, fallow or recently abandoned arable land	
I2	Cultivated areas of gardens and parks	
X06	Crops shaded by trees*	
X07	Intensively farmed crops interspersed with strips of natural and/or semi-natural vegetation*	
J	**Constructed, industrial and other artificial habitats**	
J1	Buildings of cities, towns and villages	
J2	Low density buildings	
J3	Extractive industrial sites	
J4	Transport networks and other constructed hard-surfaced areas	
J5	Highly artificial man-made waters and associated structures	
J6	Waste deposits	
X	**Habitat complexes**	
X04	Raised bog complexes	
X09	Pasture woods (with a tree layer overlying pasture)	Wood-Pasture & Parkland
X10	Mosaic landscapes with a woodland element (bocages)	Open mosaic habitats on previously developed land

Code	EUNIS Habitat	Broad-habitat classification equivalent
X13	Land sparsely wooded with broadleaved deciduous trees	
X15	Land sparsely wooded with coniferous trees	
X16	Land sparsely wooded with mixed broadleaved and coniferous trees*	
X20	Treeline ecotones	
X28	Blanket bog complexes	

(1) Source: Strachan, I.M. 2017. Manual of terrestrial EUNIS habitats in Scotland. Version 2. *Scottish Natural Heritage Commissioned Report No. 766.*

(2) Jackson D.L. 2000. *Guidance on the interpretation of the Biodiversity Broad Habitat Classification (terrestrial and freshwater types): Definitions and the relationship with other classifications*. Report 307, and its update, by the UK Biodiversity Action Plan (2007). *Report on the Species and Habitat Review Report by the Biodiversity Reporting and Information Group (BRIG) to the UK Standing Committee.*

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