Towards the inclusion of ecological liabilities in the System of National Accounts, first proposals

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Based on the following manuscript:

<u>Focusing on what matters – Structuring ecosystem accounts for assessing an ecological debt in monetary terms</u>

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Resume for the London Group

<u>Main issues identified:</u>

1. The SEEA CF focuses on the (chemical-physical) pressures and little the services provided by the environment whereas the SEEA EA does the opposite, but on different aspects (biotic issue).
    a. The monetary accounts of the SEEA EA are based solely on the benefits provided by ecosystems (simple materiality), and deal very little with pressures on the environment (necessary to assess double materiality)
    b. The monetary accounts do not represent all dimensions of interest for environmental management. In particular, natural entities whose preservation concern is not linked to their use.
2. There is a weak connection (partial correlations) or even a disconnection between the condition account and monetary accounts.
3. The net present value approach models entire markets and is relatively complex as it combines different valuation methods.
4. Monetary accounts are linked to relatively restrictive uses (cost-benefit analysis and ecosystem state analysis only) and provide little decision support in several existing normative frameworks (e.g. distance to planetary boundaries, pressure reduction, European directives)

<u>Answers proposed by this paper:</u>

1. The ecological debt approach can be used to describe and monetise pressures on ecosystems.
    a. It would institutionalises a different relationship to the environment, based on double materiality
    b. It allows the creation of monetary accounts linked to all the environmental entities that one wishes to manage and preserve (said differently, they include non-use values).
2. The ecological debt approach allows for a full connection between condition and monetary accounts, while allowing the management of ecosystem services too (thought a little bit differently)
3. We think ecological liabilities could be credible complements to the current monetary approach. They are based on exchange value and are conceptually simpler. However, they raises similar implementation difficulties.
4. It is more directly relevant to some important existing public policies and to the achievement of collectively defined environmental objectives. In Europe in particular, existing institutions are designed in a very similar way to this accounting model (European directives, impact assessment, non-financial business reporting heading to double materiality).

<u>Questions for the London group:</u>

Do you agree with the issues raised?

Do you think of the answers proposed are appropriate?

Abstract

Targeted and quality information on ecosystems is needed for the transition towards sustainable societies. This requires focusing and prioritizing information acquisition and delivery. As a boundary object between ecosystem monitoring, research and public decision-making, ecosystem accounting can serve this purpose.

We develop an argument in favour of a set of accounts, consistent with the statistical standard on environmental-economic accounting (SEEA-CF and physical accounts of the SEEA-EA), which explicitly **links monetary accounts with ecosystem condition** and **simplifies the issue of monetary valuation to bring it closer to exchange values**.

Building on the analysis of the historical discussions of the UNCEEA and the London Group, a literature review and feedbacks from potential users, we discuss how the **assessment of ecological liabilities in monetary terms** could be used to monitor the costs of ecosystem degradation at different scales. Like any liabilities, environmental liabilities are contractual commitments to pay a certain amount in the future. Conceived in this way, the cost-based approach to monetary valuation can constitutes an exchange value. We propose the general accounting framework in which such liabilities can be monitored and how it relates with the SEEA EA accounts.

In particular, we show that liabilities can be rooted in the **ecosystem condition account.** It can encompass three categories reflecting the main values motivating integrated ecosystem management targets and notions of “good ecological status”. These categories are (i) the maintenance of their heritage dimensions, (ii) the maintenance of their overall functionality, and (iii) their capacity to sustainably provide ecosystem services. To develop monetary accounts based on these categories allow to fully and directly manage all of them.

Very briefly, we introduce what would be an **account of ecosystem uses**. It structures information on pressures. This step brings the SEEA EA closer to the central framework by taking the latter's framework (focusing on pressures, and less on services) and extending it to ecosystems. It opens the treatments of all pollutions (including GHG) in the same way.

The methods are discussed in the light of their neutrality with respect to the **political process and the institutional arrangements** envisaged to build the accounts. We discuss how such an approach could develop through discussions involving scientists, politics and civil servants and how it could inform **diversity of decision-making processes** once institutionalised.

An appendix proposes a possible sequences of accounts incorporating these liabilities to extend the SNA.

Keywords

Ecosystem accounting, ecosystem condition, ecological debt, monetary valuation, cost-based approach

Introduction

On March 2021, the Ecosystem Accounting framework of the System of Environmental-Economic Accounting (SEEA-EA) was adopted as a statistical standard in its biophysical dimension and as a recommendation in its monetary dimension by the United Nations Statistics Division (UNSD). This system organizes an integrated and spatialized framework to monitor and account for ecosystem extent, condition, services and asset values. This new standard leaves margins to regional and national statistical offices for implementation. At the European level, harmonization of methods within a reporting framework will be supervised by Eurostat.

Ecosystem accounts gather multiple data in a structured framework and derive standardized accounts on this basis. It is useful to distinguish the accounts from the underlying integrated information system as both could be useful in different ways depending on their design (Fig. 1). The information system required to build the accounts is spatialized and organized around basic spatial units (BSU) to which diverse information can be attributed. Through a set of categories and conventions[1], ecosystem extent, condition, use and service supply accounts are derived from this spatial grid. They form a set of biophysical ecosystem accounts. These accounts in turn shape the information system as they focus attention and resources on monitoring specific ecosystem features.

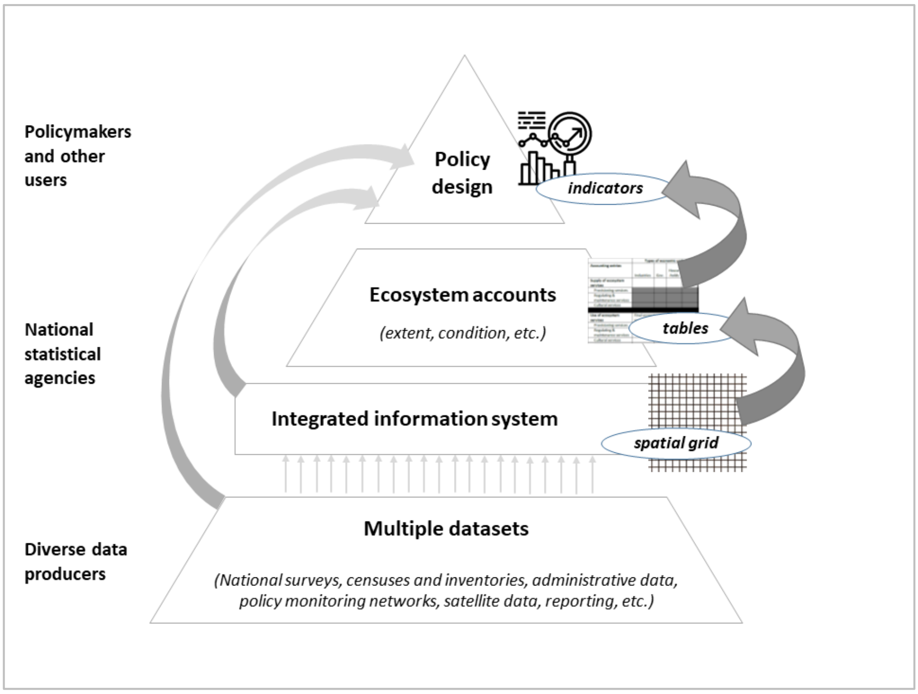

Figure 1. Ecosystem accounts as a boundary between data producers and policy makers.

Comment: indicators supporting policies can both be derived from a structured accounting system where elements are progressively built through a set of rules and conventions motivated by its conceptual framework (arrows on the right) or directly from the underlying information system (arrows on the left). In such a perspective, the accounting system not only serves the production of indicators but can also shape the information system on Nature by emphasizing data gaps.

[1] Examples in the SEEA-EA include the delimitation of ecosystem assets or ecosystem accounting areas.

As a boundary object[2] between ecosystem monitoring, research and public decision-making, such a framework offers great potential for multiple uses. However, and despite a diversity of exploratory implementation for ecosystem accounting, the effectiveness of these approaches to improve decisions remains unsupported (Razzaque et al. 2019). Achieving this potential requires adopting relevant definitions, categories and valuation methods. Related questions are numerous and complex. How to design a relevant dashboard for ecosystem extent and condition? Which values could be derived from such a dashboard that are relevant to support sustainable ecosystem management? Answering these questions crucially depends on the explicit identification of the main uses of such a statistical system.

In this article, we propose answers to such questions and derive their implication regarding the features of an ecosystem accounting system fit to support integrated ecosystem management and monitor the costs of ecosystem degradation at different scales. Doing so, we emphasize the need for a close articulation of various perspectives (ecological, economic, institutional, etc.) and for the involvement of diverse communities in a dynamic socio-political process.

In the first section, we describe how a meaningful "ecological debt" indicator could be derived from a cost-based approach. In a second section, we discuss how such an approach could inform the socio-political process of target setting and implementation. In a third section, we discuss the requirement that biophysical ecosystem accounts draw from existing management targets and their multiple underlying values. Finally, in a fourth section, we discuss how such a system of accounts could be used to an extent comparable to economic accounts and provide substantial support for the transition to sustainable societies. We conclude with the main line of research to realize such a perspective.

Monitoring our liabilities – ecosystem degradation as an ecological debt

The need to complement traditional economic indicators such as GDP, employment or public debt with a list of indicators able to account for a long-term and broader vision of social progress is widely recognized as a key component of sustainable pathways[3]. Among existing proposals, a monetary indicator of ecosystem degradation could offer a measure comparable with economic outcomes. The monetary valuation of degradation can be done according to two distinct approaches.

- The *damage-based approach*, which assesses the value of the losses of ecosystem goods and services associated with the deviation from a given reference capacity to current capacity. The SEEA-EA recommends valuing the costs of ecosystem degradation using such an approach (see. ch. 10; see also United Nations 1993, United Nations et al. 2003). The asset account is the main place to record such value. Thus it considers ecosystems as mere means.
- The *cost-based approach* assesses the costs of the measures needed to maintain or to restore the condition of an ecosystem from its current condition to some reference condition. Such an approach has been emphasized as a potentially relevant valuation approach to support complex system management (see e.g. OECD, 2018). The liability side is a place where we can record such values. This opens the door to consider ecosystems as thing to preserve for themselves, even though they can be useful too.

[2] "Boundary objects are those objects that both inhabit several communities of practice and satisfy the informational requirements of each of them. [...] Such objects have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting communities." (Bowker and Star 1999)

[3] See e.g. IPBES (2019), message D10.

As will be argue later on, both valuation approach could inform ecosystem management at different stage of the policy cycle. Regarding the provision of a meaningful indicator of ecosystem degradation at the national level, we may stress two fundamental difficulties regarding the damage-based approach.

A first one is related to indeterminacy in the preferences required to conduct such an assessment. One major issue is related to the need to value future flows of ecosystem services, due to the difficulty of predicting future conditions but also because this requires to quantify and value these uncertainties consistently with existing attitudes regarding risks and uncertainties. This acrobatic exercise would weaken the confidence of users in the numbers. We may also emphasize that the values associated with ecosystems and biodiversity may not always pre-exist, but that they could emerge from individual reflection and public discussion and involve ethical, symbolic or identity-related considerations that may be obscured by too hasty an equation. Finally, non-use values, which could be high and cover important biophysical dimensions, are excluded of the asset value (United Nations, 2021; §6.72).

A second difficulty is related to the different nature of information required when facing complexity. In complex systems, local causal chains can no longer be assumed (Chavalarias, 2020). One consequence of this is that, ecosystem state may have to be monitored along with pressures. As a result, direct monitoring of pressure may be justified as such, as in the planetary boundary framework or as argued by the French *Cour des comptes* regarding eutrophication in France (*Cour des Comptes*, 2021, p.120). We will later further illustrate how the damage-based approach can lead to dismiss some core information required to manage complex systems and also discuss the relevance and utility of this approach as compared to the cost-based approach.

Related to national accounting, Vanoli (1995) also argued in favour of a cost-based approach as more reasonable and consistent with accounting practice. The research agenda of the London Group in the 1990' suggest the same idea, as well, as (Bartelmus, 2013; London Group, 2002, 2001; Radermacher et al., 1999; Statistiska centralbyran, 1996). Building on André Vanoli's proposal of "unpaid ecological costs", we present how an aggregate measure of the costs of ecosystem degradation could be built at national scale. We also discuss its potential to satisfy the criteria of official statistics.

In Vanoli's perspective, the "Economy" is equipped with its information system structured according to the SNA[4] and a specific institutional sector called "Nature" is considered as an entity distinct from the Economy and equipped with a specific information system. Relationships between nature and the economy could then be monitored according to liabilities between them. Unpaid ecological costs "represent the value, in terms of avoidance or restoration costs, of the degradation of ecosystem assets in a given period due to economic activities" (Vanoli 2017). In contrast with the imputed maintenance costs of the 1993 version of the Integrated Environmental and Economic Accounting (United Nations 1993) framework, these costs are considered as a liability, meaning a commitment to pay in the future. Following this perspective, we may define an ecological debt as the costs which would have to be paid in order to reach (back) some reference levels on ecosystem condition.

Fig. 2 presents how an ecological debt account could be built out of national economic and ecosystem accounting information.

[4] Which he proposes to rename SNE(conomic)A to make explicit its restricted scope.

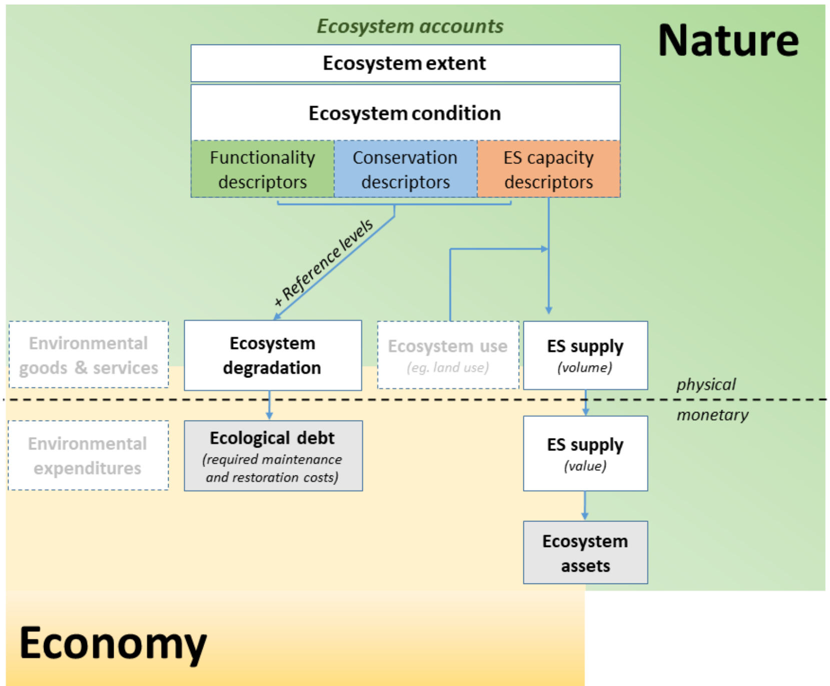

Figure 2. Structure of the accounts derived from an ecosystem monitoring framework.

Comment: Boxes reflect different accounts. Some of these components already are required in statistics as the biophysical side of the SEEA-EA. Other components are not explicit in the SEEA-EA. Accounts specific to the Nature information system are in the green area, accounts common to the Economy and Nature are in the Yellow area. Accounts in grey may have to be carried out in specific institutional context as they may fail to meet some official statistical quality criteria. Under some conditions, existing accounts represented with dashed borders could provide useful information to monitor pressures (e.g. ecosystem use) or monitor the actions taken and their effectiveness, thereby fostering learning regarding solutions (e.g. environmental goods and services accounts).

Source: adapted from Comte et al. (2020).

The production of such an indicator requires addressing five critical issues.

- First, we need to observe all **dimensions of ecosystem condition of interest**. We will discuss in section 3 how this requirement would be satisfied by focusing monitoring towards dimensions of interest, including these that are subject to sustainable management targets or explicitly related with values.
- Second, we need to **choose relevant reference levels** on these dimensions. This difficult – but crucial – issue will be discussed in the next section.
- Fourth, assess the sources of degradation (pressures) in order to define relevant preservation measures. This part is not yet robust enough to be described in this paper. However, it is worth noting that it would be the basis of a new kind of monetary asset account that would be the counterpart of the ecological liabilities. This major change in comparison to Vanoli's approach seeks to answer its critics and to be more consistent with accounting theory (see appendix A for more details).
- Third, we need to **estimate the costs** required to bridge the gap between current and reference ecosystem condition. While the dominant approach in the SEEA-EA relies on a damage-based

approach (United Nations 1993, United Nations et al. 2003) for ecosystem "asset"[5] degradation, Vanoli's proposal follows a cost-based approach (ibid.) to measure, the costs of observed ecosystem degradation (Vanoli 2017).

- Fifth, define the accounting treatments and typologies in the sequence of accounts and possibly requalify reduction and restoration costs as variation of liabilities. As this part deserves more work too, see appendix B for an outline.

We now turn to present and discuss two distinct perspectives to such monetary estimation of ecological debts, which we may respectively call economic and accounting.

In the **economic perspective**, the estimation is carried out through different kinds of modelling. Technico-economic models are a first kind. They rely on a database of possible measures, their costs and their impact. From this, the estimation generally consists in adding the required cost for implementing measures from the least to the costliest until the reference level is reached[6]. Macroeconomic models are a second kind. They directly estimate the cost required to achieve the targets from a representation of how financial efforts translate into impact (dose-response models). They are calibrated on past observations and may include technical progress.

Resulting estimates are uncertain due to limited knowledge on future market conditions and technical progress. Given the limits and uncertainties associated with modelling, intercomparisons of model outcomes or regular model updates can be useful to ensure reasonable estimates. The estimation of the carbon value in France relied on such an intercomparison between results from technico-economic and macroeconomic models (Quinet et al. 2019, Bureau et al. 2021). Germain and Lellouch (2020) provide an estimation of a prospective ecological debt related to climate change mitigation targets for France. They develop a simple macroeconomic model which they show to be consistent with another pre-existing technico-economic model. They also show that the carbon value derived from their macroeconomic model is roughly consistent with the carbon value of the Quinet report, suggesting that convincing estimates can be proposed.

For biodiversity and ecosystems, numerous models relating responses with outcomes on dimensions of interest could be used to carry out similar estimations. For example, the scientific literature on wetland restoration costs can help to provide sound estimates of the required budget to reach specific ecological outcomes (Szałkiewicz et al. 2018). Recent reports also estimate how much it would cost to stop species and natural habitat erosion by 2030 (Deutz et al. 2020). However, greater complexity may arise due to the need to account for (i) the multiplicity of pressures and their non-linear combination (whereas greenhouse gases emissions can reasonably be aggregated on a single measure) and (ii) the multiplicity of dimensions of interest and their interactions[7]. Whereas carbon emissions have the same impacts regardless of their location, explicit spatial modelling would also be required for ecosystems,

[5] In this article, we simply use the term ecosystem and not ecosystem asset as this latter term evokes a narrow notion of value restricting the total economic value to flows of ecosystem services as well as an inclusion of ecosystem within the economy.

[6] Note that such a focus on (economically) efficient trajectories could be discussed due to non-market side effects, complex dynamic effects (lock-in, uncertainties, knowledge gaps, etc.) or difficult trade-offs. As a result, efficient trajectories as represented by these models may not be socially desirable and the resulting estimation may indicate a lower bound of required costs, whose practical reach, for instance as an indication of funding needs, requires careful consideration.

[7] This would be all the more critical that the interest of some measures, such as Nature-based solutions, is their multifunctionality, what is to say their potential to address multiple conservation and societal issues at the same time. A failure to account for these interactions may induce a systematic bias against these.

as allowed by the SEEA-EA approach. Multiple models may need to be articulated to sketch the contours of efficient trajectories and their overall cost. As for climate, such estimates would likely be associated with high uncertainty and credible values would also require intercomparisons of models and regular updates.

In the **accounting perspective**, and drawing from a comparison with national economic accounting, the estimation results from the aggregation of costs estimated and reported at the level of economic units (corporation, household, government, etc.). This requires widening organizational accounting in order to monitor impacts and liabilities at this level. Some legal procedures, although still partial, already exist in the form of impact assessments for development projects supported by corporations or governments. Non-financial reporting is also in the process of standardization (with the Corporate Sustainability Reporting Directive in Europe and the International Sustainability Standards Board). More ambitiously, extended and normalized accounting models can organize the production of suitable information.

In the Comprehensive Accounting in Respect of Ecology (CARE) model, for example, corporations are required to monitor and account for their impact in relation to ecological reference levels (Rambaud and Richard 2015, Rambaud and Chenet 2021). In this framework, organizations report as liabilities in their own accounts the difference between (biophysical) reference levels and their impacts. They translate the liabilities in monetary terms estimating the cost of the reduction and restoration measures required to ensure the achievement of such reference levels[8]. With a similar auditing procedure as financial reporting, reliable data would thus be produced at organizational level. Would the reference levels set at the level of organizations be consistent with environmental norms at upper scales, the bottom-up aggregation of liabilities would provide an estimation of the costs of ecosystem degradation at these levels, including the national level.

The economic and accounting approaches differ regarding the scope of the information on costs covered by the estimation. They both cover investment and recurrent costs, in exchange value, for achieving existing targets. However, in the accounting perspective, costs reported cover reduction and restoration measures[9] while in the economic perspective, the set of measures can also cover avoidance measures, which are the opportunity costs of renounced projects.

Both approaches also differ regarding the nature and origin of the information on costs covered. The economic perspective departs from the mere observation of actual transactions and other facts. It involves models, hypotheses, normative inputs and requires interpretation (e.g. intercomparisons of model results). Many authors have argued against such “hard modelling” approaches in official statistics as they would undermine accuracy and trust in the information produced (Desrosières and 2009, Vanoli 2017, Radermacher 2020). The economic perspective may therefore be best carried out outside official statistics, in a specific institutional context involving research and other public institutions in close articulation with official statistics. The accounting perspective, on the contrary,

[8] Note that such reference levels may – but need not – reflect actual legal obligations. They may be defined and distributed between economic units (corporations, government, etc.) according to conventional rules for reporting purposes.

[9] In the CARE accounting model, preservation costs are the expenditures that do not change the business model of an organization and whose primary function is to preserve the environment. They include reduction costs (preventive actions) and restoration costs (repairing actions). In contrast, avoidance costs are related to actions which change the business model with the secondary objective of having less impact on the environment (e.g. electric cars). To prevent double-counting and “hard modelling”, they are not included in the calculation of ecological debts.

relies on the observation of approved accounting information. It is thus more in line with the role of public statistics and traditional national economic accounting.

The monetary value of financial liabilities constitutes an exchange value because it is validated by the lender and borrower in the form of a contract or implicit agreement that implies repayment with certainty (United Nations et al. 2009, §§3.40-41). Other liabilities, which are uncertain or do not involve external parties (such as certain provisions), are excluded from national accounts because they are strictly internal and their valuation cannot be considered sufficiently reliable and stable (ibid.). Ecological liabilities estimated from an economic perspective can at best only be modelled exchange value. On the other hand, if there is a third party validating its amount and ensuring its execution, the concept of ecological debt would fit into the framework of SNA liabilities and valued at exchange value. Besides, from a conceptual point of view, interpreting the sum of liabilities would be easier, because only one valuation method underlies.

Whether conducted within or outside official statistics, the regular estimation of an ecological debt would reflect the sustainability of the relationship between Nature and the Economy. Interpretation of such an aggregate indicator may depend on the perspective taken to its implementation. In the accounting perspective, for instance, variations of such an aggregate indicator from an accounting period to the next could be further decomposed and interpreted in a similar way as SNA variations of assets and liabilities (United Nations et al. 2009, §§12.1-3):

1. physical improvement or degradation of ecosystems attributable to an economic unit (e.g. the destruction of a hedge by a farmer or the revegetation of a degraded area by a manager); treated as economic transactions,
2. changes in the reference levels reflecting changes in collective preferences (just as prices can result, in national accounting, from changes in individual preferences and public budgets from changes in collective preferences); treated as other volume change,
3. physical enhancement or degradation of ecosystems resulting from exogenous causes (e.g., hurricane damage to a coral reef); treated as other volume change,
4. revaluations resulting from improved data and assessment methods; treated as other volume change,
5. technical progress and the evolution of prices conditioning the costs of maintenance and restoration actions necessary to reach the objectives of good ecological status; treated as a revaluation (change in the level or structure of prices).

Having described the general framework of ecological liabilities, we need to discuss their underlying biophysical ground.

Focusing on what matters: ecosystem extent and condition as the component of a broad information system on Nature

According to the SEEA-EA, “the first stage in measuring ecosystem condition involves setting the measurement focus and defining and selecting ecosystem characteristics and associated variables.” (United Nations 2021, §5.23). Currently, the measurement of ecosystem condition is primarily oriented by the natural science categories as reflected in the SEEA-EA ecosystem condition typology. Such an orientation does not directly link with targets or values, which may eventually limit its usefulness for sustainable management. In contrast, Comte et al. (2020) propose to structure an ecosystem condition dashboard according to three main categories motivated by an explicit relationship with existing policy targets and the diversity of underlying values, so that all dimensions of interest are reflected in a suitable form:

- Heritage (the maintenance of their heritage components),
- Functionality (the maintenance of their overall resilience and functionality), and
- Capacity (their capacity[10] to sustainably provide explicit ecosystem services).

Through a quick correspondence with existing targets for marine integrated ecosystem management, Comte et al. (2020) find that these categories can easily be matched with the dimensions actually monitored within the Marine strategy framework directive (MSFD) (Fig. 3). In support of the importance of a holistic perspective on ecosystem functionality, they further note that the second category provides a rationale for most of the dimensions defining good ecological status for the marine environment (8 out of 11 descriptors) while they may easily be dismissed in analytical frameworks such as the SEEA-EA.

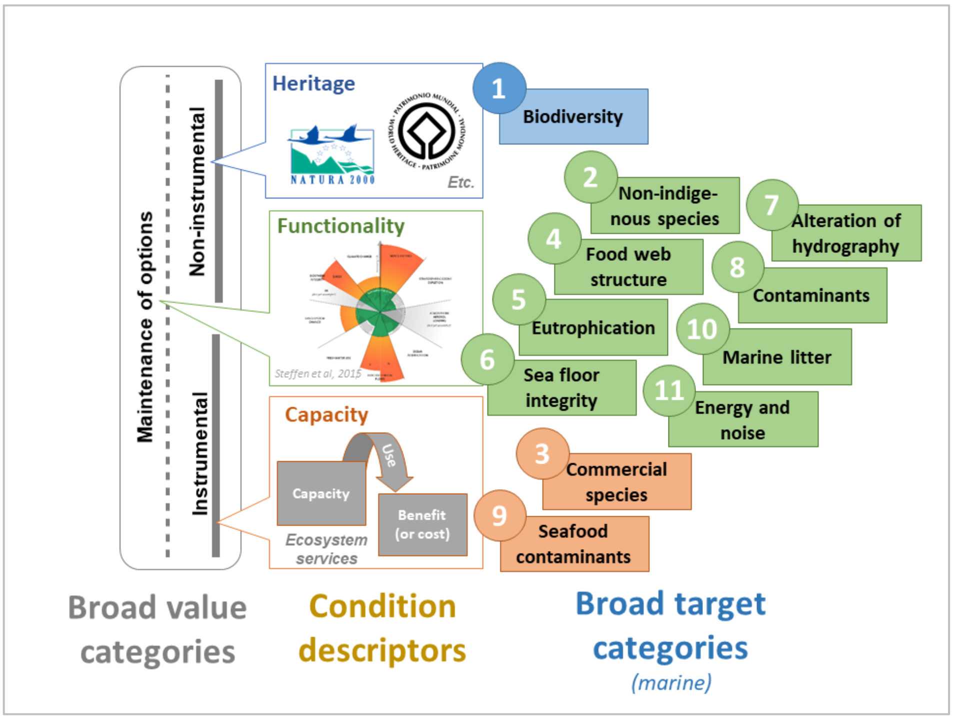

Figure 3. Linkages between categories of ecosystem condition indicators, broad value concepts and broad categories of integrated management targets.

Comment: The Heritage category includes the conservation status of all ecosystem elements with intrinsic or non-instrumental worth as recognized through labels of diverse sort (species of Community interest in the EU, World Heritage, etc.). The Functionality category refers to the dimensions which need to be monitored in order to ensure that the overall functionality of the ecosystem is not threatened as indicated by resilience indicators or when

[10] It may be noted that capacity as defined here includes those state indicators most directly related to the ability of the ecosystem to deliver a given service sustainably and at an optimal or satisfactory level (status of a fish stock, water quality with respect to aquaculture uses, etc.). For these purposes, the measure of capacity is not necessarily one-dimensional and it is not required that these dimensions be expressed in the same unit as the ecosystem service concerned as recommended by the SEEA-EA (§ 6.149). The capacity category will thus be considered from a more "upstream" perspective by designating the dimensions included in the measurement of ecological condition that inform us about the capacity of ecosystems to deliver specific services in a sustainable manner, as are, for example, the indicators associated with descriptors 3 and 9 in the framework of the MSFD.

some pressures are over some safe thresholds. Finally, the Capacity category monitors the capacity of ecosystems to contribute to specific dimensions of human welfare (ecosystem services). Targets categories are the 11 descriptors of the good ecological status of the EU Marine strategy framework directive.

Credit: Planetary boundaries are designed by Azote for Stockholm Resilience Centre, based on analysis in Persson et al. (2022) and Steffen et al. (2015).

While being consistent with the SEEA-EA, such a framework embraces a wide and inclusive perspective on values whose need is evidenced by existing management targets and recent debates around ecosystem valuation (Comte et al. 2020, Pascual et al. 2021). It also solves some of the main pending issues for its implementation. By requiring the direct monitoring of heritage dimensions, it ensures considering all relevant non-instrumental values, thereby alleviating the SEEA-EA restriction of non-instrumental values to non-use values with limited possibilities for integration in valuation[11]. As the third category directly encompasses indicators underlying the capacity to provide services, it also bridges the gap between ecosystem condition and services and ensures monitoring the biophysical component of interest for the category of instrumental values (such as e.g. the state of commercial fish stocks in the marine environment).

The functionality category also provides a direct and explicit rationale for monitoring resilience and pressures that are central to sustainable ecosystem management. Facing complex systems, the definition of a safe operating space is a rational way to manage risks and uncertainties consistently with our collective attitudes towards them. Planetary boundaries or the IUCN Red list of threatened species are prominent examples of methods using data on pressures to ensure adequate management under risk and uncertainty. Yet, the SEEA-EA only accommodates pressure indicators as surrogate for state indicators (United Nations 2021, §5.103).

Lastly, this framework places ecosystem accounting and related data at the core of a broad information perspective on Nature fit for supporting policymaking. As it explicitly relates dimensions of interest to their multiple underlying values, it provides a way to discuss and prioritize monitoring effort. As an example, the second category would help prioritizing monitoring on the greatest threats. Given the limited resources devoted to monitoring and data acquisition, this would be precious support for the implementation of a dashboard balancing parsimony with inclusiveness. Starting from the example of a potential flagship indicator, the next section will further discuss how such monitoring of ecosystem condition can be useful in a wide variety of ways.

Good ecological status as a boundary object for the strategic discussion of environmental targets and reference levels

While recognizing the existence of a large diversity of approaches, the SEEA-EA recommends defining reference condition levels "using the natural state as the reference condition" (United Nations 2021, § 5.72). The rationale is that the methodology "should allow accounts to be developed devoid of value judgements and which do not imply a policy goal or a desired condition" (Keith et al. 2020). However, and in order to be interpreted as an ecological debt, the costs required for reaching some reference levels on ecosystem condition would have to be somehow related with our collective willingness to

[11] "it is not considered, from an accounting perspective, that a transaction has taken place consistent with the framing used for recording ecosystem services in the SEEA EA" so "these values can be presented in complementary valuations" (United Nations 2021, §6.72-73)

pay for maintaining and restoring ecosystems. This is why, on the contrary, Vanoli (2017) estimates the ecological debt on the basis of environmental norms determined "in the form of societal standards", as revealed, precisely, by policy goals. While simple in principle, such a perspective raises difficult practical questions. In this section, we discuss how a collective willingness to pay for maintaining and restoring ecosystems can emerge from a dynamic political process involving different communities around the discussion and collective legitimation of the targets defining good ecological status.

The detailed description of such a process first requires careful consideration of how the scientific, political and administrative spheres can be involved in the dynamic processes of target setting and implementation at different scales. We shall thus also describe good ecological status as a boundary object, consistently involving different communities without having them to drastically change their referentials. To finely define such a process, we will elaborate on the useful distinction between environmental limits and targets initially proposed by Usubiaga-Lião and Ekins (2021) with greater emphasis on the processes and communities involved in their construction. Environmental limits come from scientific arenas. They alert about the risks of crossing certain thresholds, as for example Steffen et al. (2015) did at the global level with planetary boundaries. Although they may encompass some normative content, they leave the most crucial trade-offs to public discussion. Environmental targets are elaborated through the political process. They integrate political preferences and economic and social considerations through a process which ensures a sufficient level of legitimacy. At this level, targets may still be insufficiently consistent, specific, measurable, ambitious or realistic for actual implementation[12]. While environmental targets may be directly expressed in laws, regulations, plans and strategies, they often require reinterpretation to ensure their applicability. Thus, we may define environmental norms as the operationalization of environmental targets performed by the administration in order to enforce them.

With these distinctions in mind, an ideal socio-political process can be described that articulates – rather than opposes – existing valuation approaches in informing sustainable ecosystem management. First, the warnings given by scientists lead, for example, to identify limits beyond which the community is exposed to risks or other considerations. Within political arenas, the discussion and interactions between politicians, scientists and the public leads to the setting of environmental targets informed by science. We may note at this stage that such an approach does not constrain the expression of values presiding over the formulation of targets associated with good ecological condition. They may even not pre-exist but emerge from reflection and public discussion, involving different valuation frameworks allowing, alongside economic considerations, the integration of ethical, symbolic or identity-related considerations that a too hasty equating of values may lead to obscure. Such an indirect approach of valuation can be particularly relevant for solving complex problems, where public discussion plays a central role in value formation, as is the case of issues related with ecosystems and their biodiversity (Sen 1995, OCDE 2018, Pascual et al. 2021). These objectives are then translated into operational norms at relevant levels for implementation.

[12] These requirements are the widely used SMART criteria, where "Specificity" requires targets are set at levels (scales, time horizons, sectors) suitable for implementation, "Measurability", that indicators are specified so that progress towards the target can be evaluated, "Ambition", that the norm is fully consistent with the ambition of the target, and "Realism" that an action plan consistent with the achievement of the target is identified.

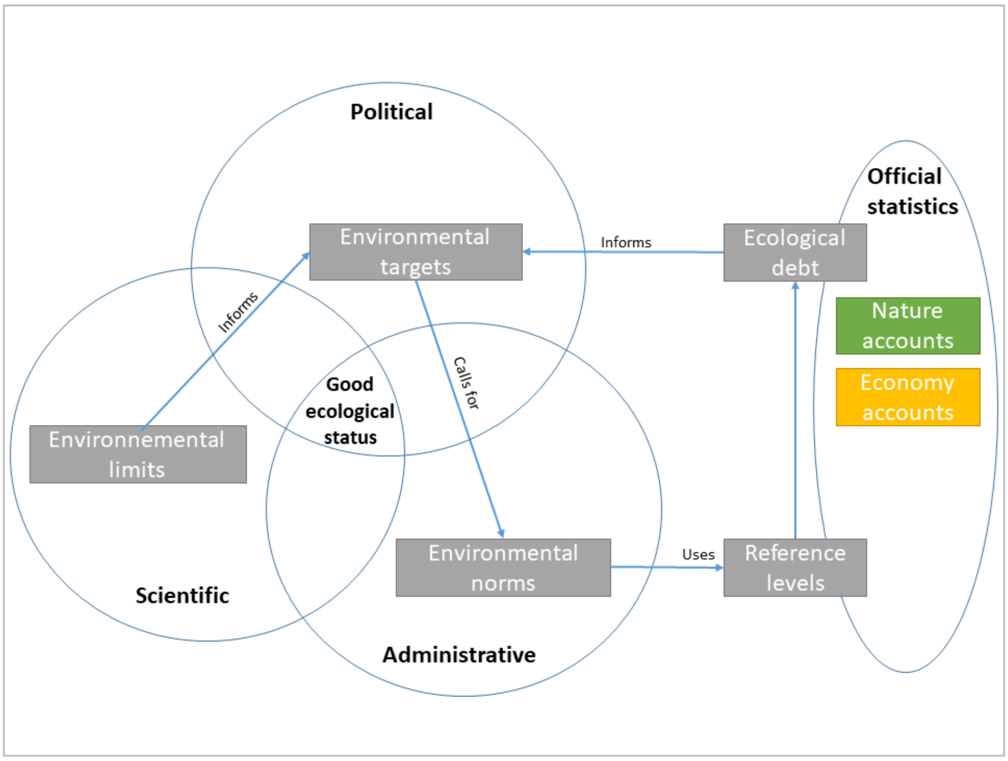

Figure 4. Good ecological status and ecosystem accounts as boundary objects at the level of strategic discussion around environmental targets.

Comment: Each of the spheres gathers a diversity of actors with adequate governance systems. Arrows represent the main linkages between spheres around the objects introduced in this article. They are not exhaustive of all interactions.

Of course, this process is fundamentally iterative and dynamic: scientific advances can induce updates of environmental limits just as societal changes can induce evolutions in targets and associated norms. Solving inconsistencies between existing norms, for example between scales and dimensions can also lead to adjust targets. Alongside other scientific inputs ecosystem accounts can inform this process at different levels, as illustrated in Fig. 4. From limits to targets, knowledge on ecosystem services (in biophysical and monetary terms) would enrich the reflection on environmental limits with economic and social considerations. This is particularly true regarding potential reference levels on capacity and some functionality condition indicators. Norms in turns clarify residual trade-offs or the realism of existing targets by making explicit the required measures and associated costs, possibly leading to their revision in an iterative dialogue. Such processes are at work, for example, in the management of terrestrial aquatic environments in the EU, where disproportionate costs may justify relaxing the targets, through the postponement of the deadline for achieving good status of water bodies (see e.g. Boeuf et al. 2018). The discrepancy between existing targets and actual policies as documented by the ecological debt and its evolution could also reinforce accountability and call for adjustments in ambition or actions in the political sphere.

Main potential uses of ecosystem accounts structured around such an ecological debt

Chapter 14 of the SEEA EA propose potential uses for its monetary accounts (United Nations, 2021). Describing economic dependencies and providing information's on the state of ecosystem services may be the most prominent potential uses. We can imagine that asset accounts could feed cost-benefit analysis to assess which kind of ecosystem we should restore first. As we have seen, this is particularly relevant to help defining targets. On the contrary, the SEEA authors' screening by the DPSIR framework (United Nations, 2021; part 14.4.5) suggests that these monetary accounts cannot provide relevant information for the analysis of pressures and responses, which are crucial once a target is set. At first sight, only the extent and condition accounts can be used for this purpose. We believe that ecological debt accounts can complement the analysis and provide information to fill these gaps.

This part discuss how such a system of accounts could provide integrated analysis with GDP and associated economic accounts to manage ecological issues. As for GDP, such an aggregate indicator of the costs of ecosystem degradation would not only be useful as such, but also because of the whole associated information system and the processes that go with its production. In considering these uses, a distinction can also be made between direct uses involving little institutional change that could result from the production of the ecological debt. We propose other uses that are potentially more ambitious, but also more speculative.

As such, the ecological debt could be part of the monitoring of sustainability through a dashboard of indicators (Stiglitz et al. 2009). Measures of the costs of degradation at the national scale are already explicitly required, for example in the initial assessment of the MSFD (Levrel et al. 2014) and the Water Framework Directive. The idea is to make visible the issue of ecosystem degradation alongside other indicators measuring other dimensions of national progress (GDP, employment, greenhouse gases emissions, etc.). Being established in a harmonized framework, it would allow analysing trends over time and between countries. Being monetary, it allows comparisons with wealth creation as measured by GDP. This could assist budgetary discussions to help reaching the good ecological status or stay below planetary boundaries. In contrast, the SEEA ecosystem (monetary) assets are weakly related to such existing normative framework.

As argued in this article, a first direct interest of this development would be to support and foster the development of integrated ecosystem management. First, it would support the design of SMART policy targets at international and national scales through the construction of relevant indicators and structuring data collection to monitor their achievement. Subsequent analyses would also inform discussions around these targets, in complement with the information provided by ecosystem service accounts, with trade-offs, actual measures, funding needs and their economic and social costs (thereby fostering target realism). Beyond the discussion on targets, a prominent interest of this approach is to channel economic valuation from the rationale for action (e.g. the cost of inaction) to an action-oriented focus on solutions, which is more in line with the needs of policy-makers and decision-makers. By focusing attention on implementation and the measures required to achieve the targets, this approach requires strengthening critical data and knowledge on solutions and their cost, thereby assisting the reflection on cost-efficient solutions.

Another direct interest of this approach is to foster the relevance of ecosystem accounting, and place it in a broad information system perspective on Nature as pleaded by Vanoli (2017). Policy relevance is ensured through a direct focus on what is at stake in ecosystem management. A tight line should be idealy be followed between on one hand scientific principles to provide an accurate representation of the environment and on the other hand, adequacy regarding possible and actual management practices. This last point should include an assessment of the means to act of the different stakeholders involved. The definition of good ecological status under the Water Framework Directive is a good example of such a successful process (Marchal, 2020). It has made it possible to define measurement conventions through the involvement of national experts, civil servants and political actors; and ecological thresholds combining ecological, socio-economic and technical considerations (European harmonisation, measurement and reporting constraints, etc.).

Beyond these direct uses, we may consider the other potential – though more speculative – uses which may be achieved under further developments, notably of the accounting perspective on ecological debt. If this perspective becomes a reality, the publication of individual ecological debts by economic actors could enable stakeholders to act on the basis of reliable information. This would be the case for customers and investors, who could orient their consumption and investment choices according to the level of ecological debt. Public actors could likewise establish aid or incentive policies to pay off excessive ecological debts. National accounting would make it possible to estimate the overall financial needs and to share efforts based on economic impact of such policies[13].

In the context of policy appraisal, such an information system could provide precise and reliable information for ex ante impact assessments (e.g. on ecosystem types impacted by a project). As evidenced in Germain and Lellouch (2020) for climate, such approaches could also allow deriving implicit values usable in cost-benefit valuation of projects. In an ex post perspective, such an information system would provide information needed for the assessment of integrated policy responses.

Conclusion – An agenda for research & action

An ambitious data collection effort on ecosystems is certainly be needed to ensure the transition towards sustainable societies. The approach presented in this article uses the margins left in the SEEA-EA to sketch the outline of a structured information system on Nature with a related ecological debt as a flagship indicator, with an ambition comparable to the contribution of the SNA and GDP for economic development. We specifically insist on the need to complement existing guidelines with a more direct focus on sustainable management issues, pressures, solutions and their costs. Such an information system would benefit from the rich data that already exist in support of existing policies and complement it. Such a complement to the structure of the SEEA-EA, would allow the progressive development of a broad information system on Nature meeting the actual (and critical) needs for fostering sustainable ecosystem management.

Experimental accounts of the ecological debt will be useful to explore such a perspective. Such experiments could explore how existing policy targets reflect existing knowledge on risks and could translate into a consistent set of environmental norms. Further developments in models and methodologies are also required, with specific care regarding how to deal with the multidimensionality of pressures and stakes or potential systematic bias. At last, the processes induced by such an approach may prove valuable in itself and consistent with action principles in complex systems. This calls for further reflections and studies about how the estimation of an ecological debt and underlying data could be best organized between different actors, considering all processes occurring at the frontiers

[13] e.g. reducing environmentally harmful subsidies and increasing payments for environmental services, environmental taxation, green public procurement or environmental disclosure.

between communities and perspectives. To answer these questions, lessons may be drawn from national economic accounting, but also from the long history of environmental-economic accounting.

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Grant title

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Conflicts of interest

The authors declare no conflict of interest.

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Appendix A: On the definition of natural assets

Note: hereafter, the term capital refers to liabilities and not to assets (Rambaud and Chenet, 2021; Rambaud and Feger, 2019).

- **Method and theoretical design**

The theoretical conception of assets under historical cost accounting (with which the CARE model is compatible) is included in the SNA definition, so there is no a priori risk in going outside this framework. When designing natural assets, we should therefore propose candidates consistent with the two definitions following:

> "An asset is a store of value representing a benefit or series of benefits accruing to the **economic owner from the** holding or use of an asset over a specified period of time. It is a **means of transferring value from one accounting period to another**." (Nations Unis et al., 2011, para. 3.30./10.8.)

> "An asset is a degrading use of capital that is not yet useful for value creation" (source: author, based on Rambaud and Chenet, 2021; Rambaud and Feger, 2019)

We will therefore need to check that any potential asset meets the definition given in the SNA and is consistent with accounting theory. The notions of resource and (economic) ownership must be present. The idea of reserve or not yet useful use (as opposed to direct consumption) must also be present. The CARE model also requires the idea of sacrifice, which narrows the field of possibilities but does not take us out of the definition of SNA.

Since an asset is both a source of value and a source of capital degradation, we will try to see how these two notions meet and when they overlap. This will guide us towards the identification of natural assets. Ecosystem services are precisely the way in which the notion of benefit, of value derived from ecosystems, is now commonly understood. It is therefore an essential starting point. On the other hand, environmental degradation is regularly studied in public policies (particularly European directives) to estimate the efforts to be made, the actions to be taken to stop the loss of biodiversity. They constitute a good anchor point for integrating the dimension of capital degradation.

In the SEEA EA, ecosystem services are defined as follows:

> "6.9 [...] **Ecosystem services are the contributions of ecosystems to benefits that are used in economic and other human activities**. In this definition, use includes direct physical consumption, passive enjoyment and indirect reception of services. In addition, ecosystem services encompass all forms of interaction between ecosystems and people, including in situ and remote interactions. (Committee of Experts on SEEA EEA, 2021)

The typology of services distinguishes three categories:

- "6.51 [...] Provisioning services are ecosystem services representing contributions to benefits that are extracted or harvested from ecosystems.
- Regulating and maintenance services are the ecosystem services resulting from the ability of ecosystems to regulate biological processes and influence the hydrological and biochemical cycles of the climate, and thus to maintain beneficial environmental conditions for people and society.
- Cultural services are those experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contribute to a range of cultural benefits." (Committee of Experts on SEEA EEA, 2021)

If, based on the underlying ecosystem functionality, the ecosystem services are compared with the pressures listed for reporting under the Habitats, Fauna and Flora Directive, we obtain the following Table A.1. It should be noted that the "benefits" that can be derived from certain pressures are far from intuitive. For example, what is the benefit obtained by a pollution (e.g. the emission of CO_2)? The emission of CO_2 is in fact essential for the proper functioning of most thermal engines: if it is not expelled from the engine after combustion, it will suffocate the engine by taking the place of the oxidant, O_2. Thus, the benefit linked to this emission is the proper functioning of the engine. To translate this, Rambaud and Chenet (2021) call the corresponding natural asset “CO_2 warehousing”. This idea of pollutant storage can be extended to a number of emissions, for example to discharges into the aquatic environment. The case of the destruction of individuals and land for economic activities is similar: removing living things and reworking the land frees up the space and makes it usable as a physical support for building human infrastructure. Other pressures must be subject to the same scrutiny as to their actual usefulness to the business model.

Table A.1 Accounting uses at the intersection of ecosystem services and environmental pressures

Ecosystem service	Benefit without degradation	Benefit with degradation	Irreversible or not related to an activity degradation	Pressure
Provisioning	X	X	X	**Overexploitation**
Regulation (pollution, nuisance, buffer spaces)	X	X	X	**Pollution**
Regulation (pollination)	X			
Cultural (recreation)	X	X	X	**Disturbance**
Cultural (other)	X			
		X	X	**Injury**
		X	X	**Destruction of individuals**
		X	X	**Physical modification of the environment (drainage, settlement, coastal or hydrological modifications)**
		X	X	**Support for activities**
			X	**Natural dynamics**

Legend: Source: author. The categories of ecosystem services are the now classic ones (Committee of Experts on SEEA EEA, 2021; Haines-Young and Potschin, 2012) that we have broken down for our analysis. The pressures are taken from a synthesis by the author based on the typology of pressures used for the 2013-2018 reporting under the Habitat, Fauna and Flora Directive. Ecosystem services and pressures are compared when the ecosystem function underlying the service is the same as the one overexploited by the pressure in question. Some cannot be (e.g. pollination), hence the absence of a corresponding pressure. Some pressures are not based on the functioning of an ecosystem (e.g. destruction of individuals). Crosses indicate the potential existence of a benefit, employment or situations that fall outside the ecological debt accounting framework.

A priori, there are several cases that should give rise to the recording of a natural asset (the last one being debatable):

- The natural function that is overexploited is used voluntarily (e.g. overexploitation of a biological resource, disturbance due to recreational use)
- The natural function that is overused is employed involuntarily. The use is a side effect that the business model cannot avoid in its current state (e.g. unavoidable pollution such as CO_2 emissions from an internal combustion engine, disturbance caused by the passage of a road near a natural area).
- The natural function that is overused is not useful to the business model. It might not be used if the business model was more precautionary (e.g. nitrate leaching, accidental degradation). This case is more difficult because it has been specified that a use must be useful. On the other hand, it can be argued that a wasted resource is still an expense for the company, and that if the resource comes from a liability, its use does not change the amount of what needs to be paid back.

The "profit with degradation" column can be likened to a use. It remains to rename them to fully reflect both aspects in the use name.

The Figure A.1 details the relationship that may exist between the use of ecosystem services and the resulting ecosystem degradation. Some ecosystem services may be used beyond a point that results in degradation of the state of the ecosystem that provides them. This is the case for provisioning services and some regulatory (pollutant absorption) and cultural (recreation) services. When these services are overexploited (too much extraction, too much pollution, too much recreation, etc.), degrading use can occur. Before that, the flow is only positive for the economy, we benefit from the ecosystem services without impacting the ecosystems. From such a threshold, we reach the notion of classic degradation, which is found in the typologies of pressures.

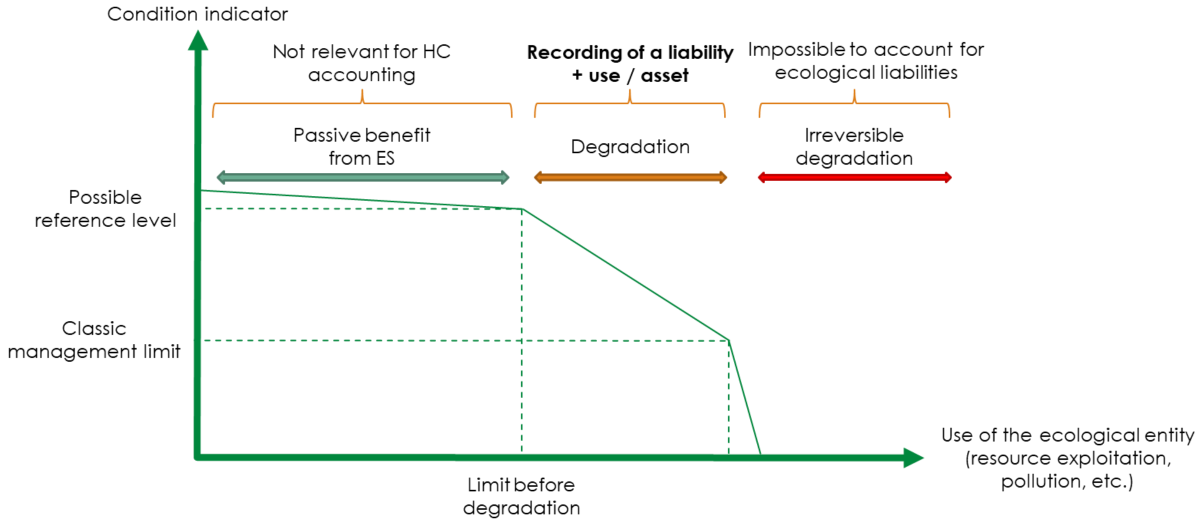

Figure A.1 Stylized relationship between the state of an ecosystem and its use (source: author). HC means historical cost. ES means ecosystem services.

This figure illustrates the boundary that could be drawn between the monetary accounts of the SEEA EA and the asset accounts that we propose. To avoid double counting, it would be necessary to stop recording profits in the SEEA EA accounts as soon as a degradation appears with the use of the service. This leaves room for other natural asset accounts, linked to the ecological debt. Their recording stops as soon as the degradation becomes irreversible. In fact, we leave the framework of ecological debts because there are no longer any means of evaluating the costs of reduction or degradation in monetary terms due to the lack of techniques for managing these impacts. We then fall into another management mode, that of regulation or fines.

The next step is to verify that these uses, these potential assets can be acquired, owned economically (possibly legally). Concerning the benefits corresponding to these potential assets, it seems that it is indeed the economic actors who use the capital that benefit from them. The case of natural resources seems obvious, and we have seen this with the examples of pollution and the destruction of ecosystems to install infrastructures. One can consider that the risks involved are the obligation to repay the capital.

- **Quantification**

Monetary valuation is a thorny issue when moving to national accounting. Indeed, CARE accounting advocates allocating the amount of debt to the corresponding assets in terms of physical 'work units' (a factor) of degradation. In this way, different uses receive an appropriate proportion of the preservation costs. Can values estimated in this way be considered to inherit the characteristics of ecological debt, in particular its nature as an exchange value? Are the revaluation methods used to update asset values each year appropriate here?

In CARE, non-financial assets are valued by sharing liabilities, via a physical "unit of work" (a factor). Thus, the more an asset is used (the more the corresponding liability is degraded), the more the figure on the asset increases. Thus the amount recorded as an asset increases with its degree of transformation for human use. And the amount decreases with a more respectful use. This may seem counterintuitive. In fact, we need to look at it in a broader context: if ecological debts are to be repaid in the long term, the companies that contract them have first carried out cost-benefit analyses to find out whether the use of such environmental capital should bring sufficient value within the framework of the current business model to allow the production of a good or service that will cover the repayment of the capital. Thus, the value placed on the asset (in terms of preservation costs) must be less than the expected gains from its use, if the company has done its calculations correctly. The value of natural assets is therefore a minimum value of the expected gains.

- **Provisional conclusion**

This account presents pressures in the same terms as the state of the environment indicators. Unlike ecosystem services, which classify active or passive benefits, the use account focuses on active use that leads to ecosystem degradation. Thus, ecosystem services only appear in the use account when their use degrades the ecosystem (exceeding the absorption capacity of the pollutant, overexploitation of a provisioning service, pressures from recreational use, etc.). Other uses are also included: any degradation, intentional or not, linked to the function (production or consumption) of an institutional unit (household, company, administration, etc.) is taken into account. Thus, we can cite the storage of pollutants (including GHGs) in the environment, artificialisation, reduction in the size of the population of protected species, etc.

Compared to the SEEA EA, this results in significant shifts (ecosystems are not considered assets, assets are named differently, monetary valuation is different), but does not undermine the whole logic of the SEEA: it is possible to maintain assets based on the value of ES that are provided without environmental degradation. This requires abandoning the idea of a necessary sacrifice to obtain an asset. The two approaches are therefore complementary. We therefore propose to leave the SNA definition of assets unchanged, as it encompasses CARE's conception of natural assets. It is broader, which leaves the door open to the SEEA EA definition of assets. We need to delineate more clearly what separates the two approaches, but it seems possible to design a system that hybridizes the two approaches.

Appendix B: Possible asset variation account including environmental liabilities

Change in assets	Explanations
Capital account	
Gross fixed capital formation - operating cycle	Conventional GFCF
Consumption of fixed capital - operating cycle	Classic CCF
Gross fixed capital formation - preservation cycle	Individualisation of GFCF on capital preservation assets (e.g. sewage treatment plant, carbon capture and storage facility)
Consumption of fixed capital - preservation cycle	Corresponding CCF
Financing capacity (+) or need (-)	
Natural capital account	
Natural asset formation – uses	GFCF related to the consumption of new natural capital. Fixed assets related to the perennial degradation of a natural capital
CO2 warehousing	Current assets
Ploughed soil	Current assets
Simplified ecosystem and stable soil	Fixed assets
Consumption of natural assets – uses	Corresponding CCF
CO2 warehousing	
Ploughed soil	
Simplified ecosystem and stable soil	
Natural assets – commitments	Account used by the institutional nature sector to record the counterparts of ecological liabilities
Natural loans – Atmosphere	
Natural loans – Soil	
Natural loans – Terrestrial ecosystems	
Financial account	
Monetary gold and SDRs	
Debt securities	
Loans	
Other volume changes and adjustments	
Natural assets – uses	
Natural assets – commitments	
Revaluations	
Natural assets – uses	
Natural assets – commitments	

The place of current preservation expenditures that reduce ecological debts when the (biophysical) improvement of capital is observed is not yet determined: they can either remain in GDP by recording an additional transaction when the biophysical balance of monetary debt is observed; or they can be reclassified from the intermediate consumption account to the change in wealth account.