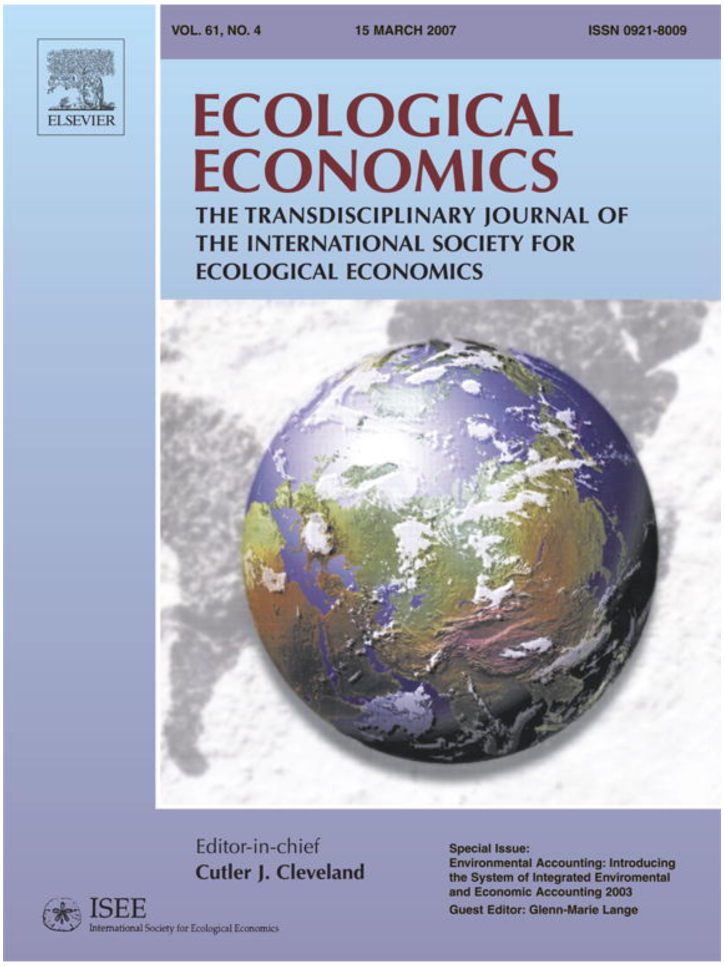
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Implementation of land and ecosystem accounts at the European Environment Agency

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ABSTRACT

The European Environment Agency has started the implementation of a programme of land use and ecosystem accounts, following the System of Environmental and Economic Accounts (SEEA) guidelines of the United Nations. The purpose is to integrate information across the various ecosystem components and to support further assessments and modelling of these components and their interactions with economic and social developments. This programme reflects the increasing demand for environmental policy integration in Europe, both vertically through thematic policies as well as horizontally across policies in those sectors that contribute most to environmental impacts. The construction of land and ecosystem accounts is now feasible due to continuous improvements in monitoring, collecting and processing data and progress with the development of statistical methods that facilitate data assimilation and integration. The accounts are based on explicit spatial patterns provided by comprehensive land cover accounts that can be scaled up and down using a 1 km^2 grid to any type of administrative region or ecosystem zone (e.g., river basin catchments, coastal zones or bio-geographic areas). Land cover accounts have been produced for 24 countries in Europe and first results published in the European Environment State and Outlook2005 report of the EEA. [1]

1. Introduction

Environmental–economic accounting is a response to the need for integrating environmental policies into the overall system of decision making. It aims first at clarifying and quantifying the use of the environment in the broader sense, marketed resources as well as services not presently internalized by the economy. The purpose is to assess public and private benefits and costs and to optimize the use of environmental resources taking into account a longer time frame and future options. Direct benefits and costs have to be assessed together with indirect – sometimes "hidden" – ones, in order to supply private and public decision makers with adequate information about the trade-offs they face. This means addressing in clear terms the possible impacts of environmental degradation on the economy, on population as well as on the ecosystems themselves.

Because ecosystem stress is subject to threshold values, aggregate statistics are not sufficient; the spatial distribution of risks and conflicts is essential. Monitoring programmes have been launched to collect this information, making use of earth observation satellites as well as technologies of ground positioning, automated monitoring and data transmission. In Europe, a special effort has been made to monitor land cover

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[1] European Environment Agency, 2005. *The European Environment State and Outlook 2005*. Copenhagen. Detailed methodology and results are to be published in forthcoming EEA, 2006, *Land Accounts for Europe, 1990–2000, Towards integrated land and ecosystem accounting*. Copenhagen.

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change in a standardised way. The so-called Corine Land Cover (CLC or "Corine") inventory has been created from satellite imagery in the early 1990s and a second time in 2000 using the same methodology. This common database used by a large number of organisations in Europe and co-financed by the European Commission and the Member States has been processed by the European Environment Agency (EEA) for producing land cover accounts, following the SEEA guidelines for "land and ecosystem accounts". Beyond the immediate results of CLC and land cover accounts, the database is now the core element for the integration of the EEA's information system, as a basic module that structures ecosystem accounts and bridges the realms of land use, biodiversity and water.

1.1. *Policy background*

During the early years of EU environmental policies, specific directives were elaborated for a broad range of issues. The purpose was to protect European citizens against air and water pollution, to regulate waste flows, to protect nature and landscapes as well as to avoid distortions in the economic competition due to uneven national emission standards. A fuller understanding of sustainability issues followed and led to a redefinition of environmental strategies. This development culminated in the 1998 launch of the integration process,[2] a process with the joint objectives of streamlining environmental legislation, improving the efficiency of policies, and, in 2001, the European sustainable development strategy.[3] The latter, also known as the Gothenburg Strategy, from the name of the city where it was approved, is an attempt to coordinate a range of issues concerning climate change, congestion of transport, threats to public health, the challenge of an ageing population, poverty and social exclusion as well as the loss of natural resources and biodiversity. It contained a commitment to halt the loss of biodiversity by 2010.

Some of the notable achievements include the following:

- The Water Framework Directive, which is based on the concept of river basin management, targets the ecological quality of water bodies, and the full recovery of the costs of water protection and management.
- Agri-environmental policies, initially seen as a way to support farmers' income, is moving towards greater integration with ecological goals. One such programme, called "high nature-value farmland areas,"[4] promotes cultivation practices (e.g. extensive grazing) that best maintain ecological potential.
- Nature conservation has progressively moved from species protection towards habitat conservation, arguably the key to halting biodiversity loss in Europe.
- The Environmental Liability Directive (ELD), adopted in April 2005, is an attempt to apply the "polluter pays principle", whereby polluters bear the cost of cleaning up the environmental damage that they cause. Ecosystem integrity and ecosystem services are fully considered in the assessment of damage and the choice of remedial actions.

Despite these positive changes, the way in which the 2010 objective to halt the loss of biodiversity will be met is uncertain. Urban sprawl is increasing and affects both agricultural and natural land in many regions. The continuous development of transport infrastructure and its acceleration in the new EU countries increase the fragmentation of landscapes (and rivers) that would otherwise guarantee some connectivity to the core areas of the ecological network. Though European rivers are on average less polluted than in the past, they are highly fragmented by dams. Dams block the routes of migratory species and isolate spawning areas. Recent climate change is accompanied by northward extension in the distribution areas of some species, like butterflies, a warning of possibly undesired modifications of ecosystems.

In all these domains, policies require coherent and comparable information on the baseline situation, on past and likely future trends, on causes and effects, interactions, costs and benefits, risk or priority areas. Land and ecosystem based assessments can contribute to providing at least part of the information needed.

1.2. *Ecosystems and accounting*

The ecosystem concept is certainly not new in ecological economics, and has existed within environmental accounting since the very beginning of the formal developments that resulted in the SEEA 2003. Examples include the work done in Canada,[5] France,[6] United Kingdom,[7] Germany,[8] Spain[9] as well as the pioneering work on land accounting initiated by UNECE[10] and continued by Eurostat.[11]

[2] The Cardiff Process is the name given to the process launched by European heads of state and government (The European Council) at their meeting in Cardiff, in June 1998, requiring different Council formations to integrate environmental considerations into their respective activities.

[3] A sustainable Europe for a better world: a European Union Strategy for sustainable development — Communication from the European Commission 2001.

[4] High nature value farmland — characteristics, trends and policy challenges — EEA Report No 1/2004.

[5] Rapport, D. and A. Friend: 1979, Towards a comprehensive framework for environmental statistics: a stress-response approach. Statistics Canada Catalogue 11–510 (Minister of Supply and Services Canada, Ottawa).

[6] Commission interministérielle des comptes du patrimoine naturel, Les comptes du patrimoine naturel, Collections de l'INSEE, C137–138, Paris, 1986.

[7] Haines-Young R. et alii, Countryside Survey 2000 — Accounting for nature: assessing habitats in the UK countryside. DETR, 2000. ISBN 1 85112 460.

[8] Seibel, S., Hoffmann-Kroll, R., Schäfer, D.: Land use and biodiversity indicators from ecological area sampling — results of a pilot study in Germany, Statistical Journal of the United Nations ECE 14 (1997), IOS Press, p. 379–395.

[9] Naredo, J. M. and Parra, F. Eds. Hacia una ciencia de los recursos naturales, Siglo Veintiuno Eitores, Madrid, 1993.

[10] UNECE task force — Physical environmental accounting: land use/land cover, nutrients and the environment — Etudes et travaux n°4, IFEN, Orléans 1995.

[11] See proceedings of the International Symposium on Integrated Environmental and Economic Accounting, March 5–8, 1996, Tokyo, Japan edited also in Uno K. and Bartelmus P. eds. Environmental Accounting in Theory and Practice. Dordrecht: Kluwer Academic Publishers. (1998) 450 pages.

Historically, the reflection on ecosystem accounting has accompanied the development of spatially distributed land accounts. The reason is that such accounts monitor landscape units which can be used as a proxy for defining statistical populations of ecosystems. Research on land and ecosystem accounting has benefited from a large range of case studies at various scales and in various contexts. They introduced new concepts to the national accounts community, such as natural productivity and metabolism, feedback, species patterns, spatial patterns, health, resistance and resilience or ecosystem disturbance and stress.

However, land and ecosystem accounting sensu stricto was not a high priority for environmental accounting at the time of the first SEEA in 1993. The situation started to change with the 2003 revision of the handbook which explicitly recognised ecosystems, providing an important hook for further development.[12]

Recently, the importance of assessing ecosystems because of their contribution to the economy and human well-being has been popularised by the Millennium Ecosystem Assessment (MEA). Beyond its intrinsic value, the success of the MEA is that it addresses a range of growing concerns about the future of the planet. These concerns include the continuing loss of biodiversity, risks from climate change and a new perception of natural resource scarcity linked to the rapid growth of emerging economies. The MEA also introduces a broad concept of ecosystem goods and services beyond the natural resources (often marketed) used directly by the economy. There is therefore room for accounts where natural assets are not just inventories of material available for extraction but productive and reproductive potentials – a fixed capital – that might turn out to be of vital importance in an uncertain future context. From that perspective, biodiversity is one of the conditions for maintaining future options, and ecosystems places where conflicts in land use are formed and solved.

2. Land and ecosystem accounting at the European Environment Agency

Land and ecosystem accounting at the EEA is an attempt to answer in a coordinated way the demands for information to support environmental policies in many fields and facilitate integrated assessments and analytical modelling. It helps the EEA integrate its own information system and improve its capacity to assimilate data and information produced by its own network of national organisations as well as it institutional partners. These partners are, first, European institutions in charge of policies, which collect official data from member states related to their compliance with European legislation. Accurate due to their legal dimension, these data are not in all cases representative. From an environmental assessment perspective they can even be extremely biased (e.g. the data on designated areas for nature conservation refer only to these areas, not to nature in general or an entire country). Another group of partners includes Eurostat, the statistical office of the European Community, and the Joint Research Centre (JRC). Eurostat coordinates national statistical institutes for the collection of basic economic and social statistics, in particular for updating the European system of national accounts. Eurostat is also active in the collection of environmental statistics, mainly from national statistical offices. The Joint Research Centre develops novel methodologies of observation and modelling for the needs of the European Commission and runs data collection in areas where its network of research institutes is on the forefront, such as for soil data. Annual crops assessment from satellite images is their responsibility as well. On a less regular basis, research programmes funded by the European Commission are also part of the information system.

In the past decade, sets of standard indicators have been defined as an effort to integrate these multiple sources of information. In Europe, several sets of indicators have been defined approved at the highest political level, such as the Structural Indicators (Europe's development), the Sustainable Development Indicators, the EEA Core Set of environmental indicators or the IRENA set of agri-environmental indicators. This represents major progress but limitations are faced as long as these indicators are not integrated in a formal analytical framework (as are the economic indicators with the national accounts) that could guide integrated *quantitative analysis*.

The EEA has started the implementation of the land and ecosystem accounts by adapting the framework proposed in the SEEA. A particular emphasis has been put on the spatial dimension of the accounts, indispensable both for assessing complex interactions and delivering useful information to potential users, policy makers at the higher levels as well as decision makers at the various levels of implementation of policies.

The framework of Land and Ecosystem Accounting is presented as a platform of *core land cover accounts*, interconnected with two sets of accounts which address the *use of land* and the *ecosystem* dimension of the territory. *Land use accounts* target economic and social functions and assess the services used – in particular supplied by the ecosystems – as well as the change in artificiality of land and intensity of its use. Land use accounts are populated with geographical information as well as with socio-economic statistics for production, consumption, natural assets, infrastructures, technologies and population. *Ecosystem accounts* target measurement of the supply of ecosystem goods and services, assessing the ecosystem potentials and their integrity, health and viability. Ecosystem accounts are populated with geographical information as well as with monitoring data on atmosphere and climate, the water systems, fauna and flora, and soils.

2.1. *Land cover accounts*

Land cover accounts have been produced by the EEA for the years 1990 and 2000, based on Corine land cover. Land cover accounts were tested in two feasibility studies steered by the

[12] UN, EC, IMF, WB, OECD: Integrated Environmental and Economic Accounting 2003, Chapter 8 Specific resource accounts, Section F Land and Ecosystem Accounts, pp. 372–389, Final draft, UNSD, 2003, to be issued as Series F, No.61, Rev.1 (ST/ESA/STAT/SER.F/61/Rev.1).

EEA, supported by Eurostat,[13] they are now produced for 24 EEA member countries[14] from Corine land cover. Using a scale of 1/100,000 and 44 different land cover classes, Corine is a database and a map which delivers information on the use of land, and the natural or modified ecosystems that cover it, and its change over time. The coverage is comprehensive and the data comparable among countries and over time. Moreover, the CLC can be used in conjunction with other statistical sources such as sampling surveys, censuses or administrative registers as well as with satellite or in situ monitoring data.

In the land cover accounts, the 1892 possible changes from class to class computed in the basic Corine matrix are grouped according to the processes that have generated them. These processes, called *land cover flows*, result not only from land use but also from natural factors. Land cover accounts describe the stocks at two dates as well as the flows of consumption (of initial land cover) and formation (of new land cover). These flows are presented according to drivers such as urban development (urban residential sprawl, sprawl of economic activities), agriculture (conversion from forested & natural land to agriculture, agriculture internal conversions, withdrawal of farming with or without forest creation), forestry (forest creation and management), water bodies creation and management. A final item then registers the changes due to natural and multiple causes (natural rotations, coastal erosion, fires, melting of glaciers) (Table 1).

Based on spatial information, land cover accounts can be as detailed as permitted by the resolution of the satellite data[15] input. They can be aggregated by countries, regions, river catchments, coastal zones or any appropriate spatial breakdown. The most detailed working level is currently the standard European 1 km^2 grid, which means that a land cover account can be computed for each individual grid cell.[16] Land accounts are currently used at the EEA as a convenient way of computing standard indicators of land cover change. Examples include the land uptake indicator of official EEA core set of indicators and two agri-environmental indicators of the IRENA set. Land accounts have also recently been used for the environmental assessment of Europe's coasts.

An overall assessment of land cover change in Europe based on Corine and land cover accounts has been published in the State and Outlook Environment Report 2005 of the EEA.[17] The main findings concern the magnitude of change, the uneven distribution over countries and the development patterns. The development of artificial land cover for urban fabric and industry, trade and transport infrastructure is the main concern. Although the total amount compared to Europe's surface may seem small (0.25%) it represents an increase of 5.5% of artificial surfaces in 10 years, a rate corresponding to a doubling in a little more than a century. Moreover, when looking at the country distribution, several countries which have accessed the EU in the 1970s/80s (e.g. Ireland, Portugal, Spain) show a much higher rate of artificial land formation than the average; by contrast, new member countries had very low levels of artificial land formation during the period. This trend suggests that an acceleration is likely to happen, because of the combination of economic growth and European cohesion policies which aim at minimising economic and social disparities between the EU member states and their regions (Fig. 1).

Regarding the progression of urban sprawl, the growth of large metropolis seems balanced by smaller cities', and there is a trend towards increased settlement in the neighbouring countryside. This move, linked to land and housing prices in towns as well as to the development of road transport, makes agricultural land the main direct source of consumption by urban sprawl. However, in some areas, especially the coastal zones of the Mediterranean and the Atlantic, farmers tend to replace the fields that they have sold for construction and commercial development by conversion of natural land, making natural land the main, ultimate source of development.

Regarding agricultural land cover, in some regions cropland is expanding and in others withdrawal from farming dominates. The two phenomena can coexist in some regions as the result of agriculture restructuring and modernisation. Trends of intensification can also coexist with the extension of pastures and set asides. For assessing these situations, geographically based information presents a considerable advantage over conventional aggregated statistics as long as it does not introduce a priori any artificial compensation between the + and the −.

Forests are relatively stable in Europe and, in the aggregate, tend to increase because of farmland abandonment in some regions as well as afforestation policies. Cases of afforestation over natural land have also been observed. In 2006, a special publication with both country results and a comprehensive presentation of the methodology will be issued.

The core land cover accounts will be developed further in order to:

- increase the periodicity, probably using medium resolution satellite images for simplified monitoring between two CLC;
- increase the resolution for specific areas such as urban zones, coastal zones or designated areas for conservation. Here, high

[13] Weber, J.-L., Paramo, F., Breton F., Haines-Young R., Integration of environmental accounts in coastal zones; case study of tourism, Report of the European Topic Centre on Terrestrial Environment for Eurostat and the EEA, Barcelona-Bellaterra, March 2003 and Soukup, T., Kupková, L., Weber, J.-L., Paramo, F., Accounts of the impacts on Forest and Biodiversity of Land Cover/Land Use changes; case from the land cover changes 1975–90 in 4 Central and Eastern European countries. Report of the European Topic Centre on Terrestrial Environment for Eurostat and the EEA — Prague, June 2003. Both reports available on the website of the EEA at http://eea.eionet.europa.eu:8980/Public/irc/eionet-circle/leac/library.

[14] 24 countries with both 1990 and 2000 data are presently covered. Several other countries having started the Corine programme in 2000 only, this number is expected to rise up to 30 with the next update of Corine, currently under preparation.

[15] In the case of CLC, the smallest geographical objects mapped are of 25 hectares and change and the smallest pixel are of respectively 5 and 1 hectares. For convenience, accounts (stocks and flows) are computed with a 1 km × 1 km grid, which facilitates a large range of geographical aggregations. Detailed methodology and results are to be published in a forthcoming EEA 2006 report on land accounts.

[16] Complete results are publicly available from the web site of the EEA http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=884.

[17] European Environment Agency, The European environment — State and outlook 2005, Part A: integrated assessment, setting the scene/2. The Changing Face of Europe, pp. 36–61, OPOCE, Luxembourg, November 2005 http://reports.eea.europa.eu/state_of_environment_report_2005_1/en. Detailed methodology and results are to be published in forthcoming EEA, 2006, *Land Accounts for Europe, 1990–2000, Towards integrated land and ecosystem accounting*. Copenhagen.

resolution satellite images are used as well as other sources, such as sampling survey results or specific databases;

– improve the description of linear elements, mainly transport infrastructures and rivers (imperfectly observed with the satellites used for CLC), on the basis of new geographical databases;
– integrate small ecosystems using different sources and methodologies.

2.2. *Challenges in ecosystem accounting*

Land cover changes are just the beginning of the story. They present ex-post the consequences of human driven and artificial processes without telling very much about them. The land cover image reflects many aspects of reality and can be used for stratification, but generally not alone, e.g., nitrogen surplus from animal husbandry can be correlated with pasture

Table 1 – Land cover account during 1990, 2000 and change – sum of 23 EEA member countries – (km^2)

	Artificial areas	Arable land and permanent crops	Pastures and mosaics	Forested land	Semi-natural vegetation	Open spaces and bare soils	Wetlands	Water bodies	Total
Land cover 1990	161,860	1,174,325	820,109	1,030,635	264,932	52,593	46,915	45,854	3,597,223
Consumption of initial cover									
Icf1 Urban land management	737	15	19	0	8	0	0		780
Icf2 Urban residential sprawl		1923	1867	200	145	8	3	2	4149
Icf3 Sprawl of economic sites and infrastructures	77	2728	1595	665	451	35	22	53	5627
Icf4 Agriculture internal conversions		17,252	10,062						27,314
Icf5 Conversion from forested & natural land to agriculture	273		935	1796	1734	155	96	50	5039
Icf6 withdrawal of farming		2393	2860						5253
Icf7 Forests creation and management	254			35,803	5166	1048	1063	3	43,337
Icf8 Water bodies creation and management	191	252	253	117	190	17		21	1042
Icf9 Change due to natural and multiple causes	311	44	15	1317	1323	1041	229	252	4534
Total consumption of initial land cover	1843	24,608	17,607	39,899	9018	2304	1413	381	97,074
Formation of new land cover									
Icf1 Urban land management	780								780
Icf2 Urban residential sprawl	4149								4149
Icf3 Sprawl of economic sites and infrastructures	5627								5627
Icf4 Agriculture internal conversions		15,695	11,619						27,314
Icf5 Conversion from forested & natural land to agriculture		2450	2590						5039
Icf6 withdrawal of farming			1124	2792	1244	23	70	0	5253
Icf7 Forests creation and management				42,547	766	24			43,337
Icf8 Water bodies creation and management						21		1021	1042
Icf9 Change due to natural and multiple causes				4	2167	1790	313	260	4534
Total formation of new land cover	10,556	18,144	15,333	45,343	4177	1858	383	1280	97,074
Land cover 2000	170,572	1,167,861	817,835	1,036,079	260,090	52,147	45,885	46,754	3,597,223
Net formation of land cover (formation – consumption)	8712	−6463	−2275	5444	−4842	−446	−1030	899	
Net formation as % of initial year	5.4	−0.6	−0.3	0.5	−1.8	−0.8	−2.2	2.0	
Total turnover of land cover (consumption + formation)	12,399	42,752	32,940	85,242	13,195	4162	1796	1661	194,148
Total turnover as % of initial year	7.7	3.6	4.0	8.3	5.0	7.9	3.8	3.6	5.4

Source: EEA.

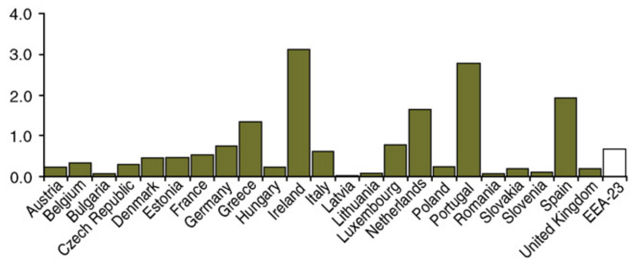

Fig. 1 – Mean annual urban and infrastructures land take as % of artificial land cover 1990. (Source: EEA 2005).

and forage cropland and cattle stocks; wildlife species can be correlated with land cover types and climate and geological conditions and agricultural use of pesticides, etc. Outlooks based on land cover accounts alone would give a very linear picture of our future. Therefore, land cover monitoring must be linked to other datasets which provide information about the processes themselves, their effects and their importance for policy issues and trade-offs. Land cover accounts have set the scene; they need now to be supplemented with accounts on land use and ecosystems.

Accounting methods have proved to be an efficient tool for organising a large range of environmental datasets including land cover. When addressing the question of describing complex systems – and their interaction with human activities – one must reflect on the limits of accounting, or, in positive terms, on the way of taking stock of complex questions – generally called "qualitative", to underline difficulties in quantification – within the accounting framework.

One issue relates to the adequacy of the double-entry bookkeeping rule used for national accounts. It is broadly considered an acceptable method for describing the economic system, but the technique cannot provide a proper account of the connections between the economic system and the environment (Naredo, 1986).[18] The national accounts describe the economic system as:

– a fundamental balance of real economic objects between production (current or previously accumulated into inventories and fixed capital) and consumption (current or postponed to another period via new accumulation).
– a theoretical equality between the balance of non-financial accounts and the balance of assets and liabilities.

The system is balanced (double-entry accounting), complete (for a given territory and a given period), self-sufficient (everything is solved in the field of exchange values) and closed (only the economic objects can be represented). Even when it takes into consideration changes in natural values which do not originate in either production or consumption, the recording takes place on the edge of the system as a gain or loss in capital. Changes in natural values can result from a change in prices as well as from 'other change in volume of non-financial assets'. Typical categories are 'economic appearance' (discoveries), 'economic disappearance' (depletion, degradation), 'catastrophic losses' and 'natural growth of non-cultivated biological resources'. All these elements come at the bottom of the table: the calculation of the fundamental accounting balances of production, consumption, income, and savings doesn't depend on them. Mirroring monetary flows by their physical counterparts can only produce useful but fragmented information. It is not sufficient for describing the ecological system which is characterised by being open and dependant on energy and material exchanged with its environment.

In fact, double-entry balances work for individual variables of the ecosystems, such as biomass, water, nutrients, individual species and the basic measures of surface, length and volume. However, ecosystems require special attention because of interactions between variables.

Firstly, there are natural limitations to sustainable extraction; only the surplus of ecoproducts[19] created by ecosystems can be used by the economy without degrading their capacity for renewal. Harvesting becomes unsustainable beyond thresholds.

Secondly, multiple space and time length scales are necessary for understanding their dynamics. When accounting for ecosystems, specific dimensions need to be represented that are not captured by conventional statistics and the linear models based on them, in particular:

– the importance of extreme events, and their distribution over the year. Extreme events matter as much as average conditions.
– the multiplicity of time frames that coexist from very short to long term, as opposed to only the short to medium term horizon of most economic analysis.
– the multiplicity of geographic scales.
– the general effect of multiple causes and sector interactions, as opposed to the focus on particular (single) determinants.[20]

[18] Naredo, J-M, L'axiomatique de l'enregistrement comptable du système économique et les limites de l'intégration d'une comptabilité nationale de patrimoine, in « Études de Comptabilité Nationale » — E. Archambault et O. Arkhipoff éditeurs, Economica Paris 1986, 394 p., FRF 125, ISBN: 2–7178–0987–2.

[19] Friend, A M, Ecological and economic pricing of circulating natural capital: a dual valuation method, 2004, invited paper to the ISEE 8th Biennial Scientific Conference, Montréal.

[20] Walker, B. 2005, A resilience approach to integrated assessment, The Integrated Assessment Journal, Vol. 5, Iss. 1 (2005), pp. 77–97. "Many of the failures in natural resource-use systems are due to failure of the ruling management paradigm. This command-and-control approach to management is underlain by four flawed assumptions: i) a focus on average conditions and particular time and space scales; ii) a belief that problems from different sectors in these systems do not interact; iii) an expectation that change will be incremental and linear, and iv) an assumption that keeping the system in some particular state will maximise yield, indefinitely. An alternative approach, based on resilience, assumes instead that social–ecological systems behave as complex adaptive systems with alternate attractors (alternate system regimes)."

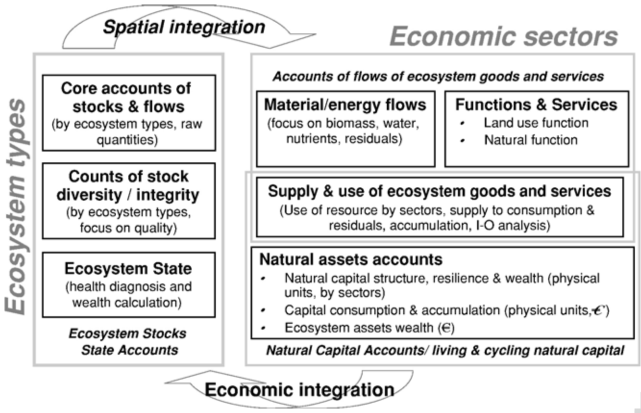

Fig. 2 – Building blocks of a tentative framework of ecosystem accounts.

One consequence is that ecosystem accounting at the macro- or meso-scales should try to avoid the dilemma of "variable-oriented" analysis vs. "case-study" research.[21]

Variable-oriented analyses are based on extensive surveys of large numbers of instances and focussed on general processes. Causations are assumed to be (linear) relations between independent variables. In the case of complex systems, the addition of linear relations leads often to unacceptable simplifications that distort reality. When compiling ecosystem accounts from statistics of the basic variables (land, biomass, water, etc.) the interpretation of the positive or negative accounting balances needs to be done according to threshold values which reflect the interactions within the systems and of the systems with their environment.

In contrast, case studies aim to embrace all the details required for sound analysis within a specific context. Each ecosystem is considered as an individual entity, which makes it difficult to generalise findings, especially when the number of cases is low. Ecological monitoring networks generally deliver large amounts of data which can be used for more advanced assessments. However, their density of sampling is often insufficient to comply with the criteria of representativeness required for integration in ecosystem accounts at the appropriate scale. Additional statistical treatment is often necessary.

In the "diversity-oriented" approach, McGlade recommends: "ecosystem health assessments must provide (i) an understanding of instances or case studies as configurations, i.e. changing one important aspect can alter the whole ecosystem (ii) a framework where sets can be flexible, manipulable constructions (…);(iii) an emphasis on outcome-oriented investigations (i.e. able to address specific qualitative change in specific contexts…); and (iv) a view that causation is conjectural and heterogeneous (i.e. based on combinations of causal conditions with no presumption that the same causal factors operate in the same way in all contexts and all cases)".

For ecosystem accounts to play a role in connecting economic and environmental assessments at the macro/meso-levels and in providing indicators for framing and assessing efficient policies, they need to take stock of the requirements presented above. At the same time, they must remain, "Just Complex Enough for Understanding; Just Simple Enough for Communication", (Holling, 1999). We may add, simple enough for being feasible.

2.3. *Current development of ecosystem accounting at the EEA*

Ecosystem accounts are in no way a substitute for ecological or economic modelling. Instead, they aim to organise and present data in a way that facilitates their assimilation and use by researchers and decision makers.

This is recognised by the SEEA which states: "In general the degree to which quality indicators are combined with the accounts depends on the objectives of the analysis; in environmental accounting a more limited use of quality indicators than in natural science reporting systems on the state of environment is normally adequate" (SEEA 2003, 8.371). Technically, the specific and complex descriptors of ecosystem state are addressed in the so-called "supplementary accounts" connected to the "basic accounts" of land cover. The purpose of supplementary accounts is to integrate quality aspects on the basis of indicators attached to the basic balance of ecosystems (SEEA 2003, 8.369); a quality being expressed by (complex) indicators which cannot be directly added in all cases. "If suitable non-additive quality indicators are defined for the classes used for describing land use, land cover or biotopes in the corresponding accounts, the quality indicators can be added to the surface values as separate columns in stock matrices." (SEEA 2003, 8.368). The SEEA specifies as well (8.364) that "In general, the surface area accounts for landscapes and ecosystems or biotopes that are required to reflect biodiversity can be linked not only to diversity indicators but also to the relevant material (for example degradation by residuals) or functional indicators for describing the state of the environment."

The EEA is currently undertaking case studies related to wetlands and natural grassland:

Wetlands. A special focus is put on coastal zones where urban sprawl as well as pressure from upstream river basins are important drivers. The geo-statistical approach will be supported by a limited number of case studies on large wetlands such as the Danube Delta in Romania or Doñana in

[21] McGlade, J.: A diversity based fuzzy systems approach to ecosystem health assessment, *Aquatic Ecosystem Health & Management*, 6(2):205–216, 2003.

Spain. The main data issues will be producing representative indicators from currents data sets of habitats and species mainly restricted to designated areas (namely from the Natura 2000 regulation and the RAMSAR Convention) and merging the land cover map with monitoring data for the Net Primary Production and photosynthesis anomalies produced on a 10 days basis from satellite images.
Natural grassland is under threat in Europe because of changes in agriculture, nitrogen atmospheric deposition (which leads to changes in plant species distribution) and increasing fragmentation by transport infrastructures (not to mention possible effects of climate change). A particular emphasis will be put on the role of grassland in the connectivity of ecological networks (in particular the designated conservation areas) and on their functions as high nature-value farmland.

The basic framework for organising these case studies combines the distinctions between basic and supplementary accounts (SEEA land and ecosystem accounts) and the distinction between a natural system and a use system. In ecosystem accounting, in situ uses (the ecosystem services) are as important as the flows of material extracted from them; therefore the linkage between the natural and use system is not limited to material flows.

Currently, the framework is made of connected building blocks (Fig. 2). On the ecosystem side, the blocks relate to:

- the stocks of ecosystems and the related flows of land cover, biomass, water as well as the flows of Nitrogen and other variables;
- the counts of indicators of integrity and/or diversity of the ecosystems;
- the diagnosis of state (health, resilience etc.) and the final assessment of ecosystem assets.

On the economic sectors side, the blocks describe:

- the material (and energy) flows
- the goods and services assessed on the basis of the land use and natural functions of the ecosystems, as well as the potential stress resulting from land use;
- a supply and use table for those elements (materials or services related to materials) which are relevant for such an approach;
- the living/cyclical components of natural capital.

The connections between blocks are provided by classifications of natural systems, of the economic system (as from the SEEA) and by common spatial and temporal references. The core tables are in physical terms but aim to support monetary evaluation, where relevant and possible. Data are available for each of the building blocks, although these tend to be incomplete and heterogeneous in most cases. Ways to use such data for accounting will be discussed in the last section of this paper.

2.4. *Ecosystem stocks and state accounts*

There are three accounts of ecosystem stocks and states: the core stock account, the counts of stocks diversity and integrity and the account of ecosystem state. The first account corresponds to the "basic account" concept of the SEEA, the two others to "supplementary accounts". The term "*account*" is used when the linear relation stock-flows-stock is described in full. "*Count*" is used when the change is not analysed in the same unit as the stocks. Counts are minimal accounts which present qualitative indicators that are essential for producing accounts of the state of the ecosystems.

2.4.1. *Core accounts of ecosystem stocks and material flows*

The core (or basic) account corresponds to what is proposed in the SEEA, albeit with some extensions to the land cover accounts. It comprises the following accounts:

- Terrestrial ecosystems:
  - land cover (km^2, number of land units)
  - rivers (standard-river-km, number of reaches)
  - small features (number of units)
- Marine ecosystem (km^2)
- Biomass (dry matter, C, energy…)
  - soil biomass
  - vegetation (non soil)
  - fauna
- Water quantity (m^3)
- Nitrogen (t)
- Phosphorus (t)

and, in principle fauna and flora (number of units, of groups, volumes, tons).[22]

The starting point is land cover accounts as presented in the previous section. The choice of geographical data to feed the core accounts (instead of area sampling surveys,[23] for example) depends on how to address the meso-scale for framing ecosystem accounts. Macro-indicators are important for indicating the general trends but are sometimes difficult to connect to the local perception of the actors — or the findings of case studies. Meso-scale indicators are interesting in the sense that they can be part of a dynamic query strategy where local users (environmental actors) have a chance to insert their own perception (representation, data, knowledge) into the broader picture and associate their own indicators to the more general ones expressing the collective trends. This is particularly important when addressing ecosystems.

River systems are described in the same way as in the water accounts. The source of information is generally not the satellite image but the GIS that map river basins and the arborescence of the rivers. It is accordingly possible to establish a population of river reaches, and to classify them according to their size and/or their position in the hierarchical network. The typical dimensions of river reaches are length and the amount of running water so-called "Kilometre of Standard River" (kmsr,

[22] Some elements are compiled in the accounts of fisheries and forest; in many cases, due to data gaps, only selected species will be subject to semi-quantitative accounting; therefore, fauna and flora is mainly considered at the present time in the "counts" of diversity.
[23] Data from sampling surveys are used as additional source for analysis and synthesis at the regional and national levels at which they are valid. There, they can deliver details which cannot monitored by satellite images as well as more accurate measurements of the changes in surfaces. However, spatial distribution and patterns are not addressed by these studies. Integration of geographical and sampling information is facilitated when the sampling patterns are stratified against land cover maps or rivers hydrological structure.

a standardised unit of account representing a river stretch of 1 km with a water flow of 1 m^3/s).[24] Small river streams and brooks might be accounted only as statistics of density by hydrological units. River's surface is another candidate metric, which is well correlated to biological variables.

Small ecosystems can be monitored by satellite or airborne remote sensing or sampling.[25] The value of small ecosystems is more their existence (number, density) than their total surface, so their account can be computed in number of units only.

Marine ecosystems accounts are at an early stage of reflection and have not yet been designed. The main difficulties are in the segmentation of the sea in systems — the external relations here being as important as the internal relations. Coastal ecosystems can be mapped in a realistic way when a land substrate can be defined and will probably form the basis for a first set of accounts. But even in this case, the relation to the sea with the effects of streams and heavy trends will require new, unique solutions.

2.4.1.1. Stocks of inland water and biomass. The core land cover accounts are supplemented with accounts of inland water and biomass.

Inland water stocks follow the format of the SEEA water asset account and are connected to the water supply and use table, whose flows are detailed by sectors. In an ecosystem perspective, not only the water in rivers and lakes matters but the water in the soil, one of the limiting factors of vegetation productivity, as well.

Accounting for *biomass* is important as such, and meets the demands for monitoring carbon sequestration, biodiversity or desertification and/or the factors that influence them, such as forestry or intensive agriculture practices. Biomass flows into and within the economy are part of the MFAs, the material flows accounts. HANPP,[26] the human appropriation of net primary production, is an example of a popular indicator derived from the MFAs. This expresses in an aggregated way the pressure on the natural resource from direct harvesting and indirect effects of land use that decrease natural potentials. However, MFAs are currently not fully connected with any asset account detailed by ecosystems. This is a limitation to the measurement of the natural surplus of biomass available for consumption and assessment of ecosystem impacts. Accounting for biomass stocks at the scale of an ecosystem offers the possibility to relate the material flows to the ecosystem from which they have been harvested and for defining thresholds. The stocks of biomass of ecosystems are split into three types: soil biomass, vegetation out of soil and fauna.

[24] Heldal, J. and Østdahl, T., 1984. "Synoptic monitoring of water quality and water resources. a suggestion on population and sampling approaches". *Statistical Journal of the United Nations*. Vol ECE2. pp. 393–406.

[25] following the example of the Countryside Survey of the UK; see Haines-Young, 2000.

[26] Schandl H., Grünbühel C. M., Haberl H. and Weisz H., 2002, Handbook of Physical Accounting. Measuring bio-physical dimensions of socio-economic activities MFA–EFA–HANPP, Social Ecology Working Paper 73 — ISSN 1726–3816. Martinez-Alier J., 2004, Ecological distribution conflicts and indicators of sustainability, International Journal of Political Economy, Volume 34, Number 1, pp. 13–30.

The flows of land cover, biomass and water compiled first by ecosystems in the stocks accounts are mirrored in accounts detailed by sectors, as well as by goods and services (for the material/energy flows) and the land use functions. Material flows, goods and residuals and, where relevant, services, are presented in supply and use tables, input–output (I–O) tables, PIOT (Physical I–O Tables) and as hybrid (physical–monetary) flow accounts (as named by the SEEA and so-called NAMEA[27] in Europe, Japan and other countries).

Not all flows need to be fully integrated into a stock account. This is the case for nitrogen, which is a key component of nutriment cycling, and will be accounted as a flow only.

2.4.2. Accounting for ecosystem health: counts of symptoms of distress

From an ecosystem health perspective, flow accounts tell but one, albeit important part of the story. The simple accounting balance results for land cover, nutrients or water does not deliver as such sufficient markers of ecosystem health; threshold values need to be integrated and special counts established. The counts will not consider the flows independently but possible interactions between them as well as the relative importance of flows and stocks. Flows which are not part of the core accounts (e.g. toxic substances, wildlife or plant species) are also part of the health assessment.

Therefore, ecosystem health assessments require that the core account of stocks and flows is supplemented by additional counts of diversity and integrity of the ecosystems. Diagnosis tables or check lists can then be established, based upon these assessments.

2.4.2.1. A medical approach to ecosystem health diagnosis. The framework designed for screening and presenting the indicators of state of ecosystems is inspired by the Ecosystem Distress Syndrome[28] paradigm, which recommends a medical approach focusing on the identification of symptoms.[29] The

[27] de Haan, Mark and Keuning, Steven J, 1996. "Taking the environment into account: The NAMEA Approach," Review of Income and Wealth, Blackwell Publishing, vol. 42(2), pages 131–48. or, recently, EUROSTAT, Economic activities and their pressure on the environment 1995–2001, 2006, Statistics in Focus, ISSN 1562–3106, Catalogue number: KS-NQ-06–002-EN-N.

[28] Rapport D J., Whitford Walter G.: *How Ecosystems Respond to Stress — Common properties of arid and aquatic systems* in BioScience Volume: 49 Number: 3, Page: 193–203 American Institute of Biological Sciences 1999.

[29] Because of its simple and synthetic character, the EDS diagnosis can be implemented at a rather macroscopic scale, in a summary way, as well as in the most detailed way for specific case studies. The starting point of the EDS approach is described by D. Rapport (1999) as such: *"Given that regional ecosystems are unique and thus may differ considerably in their normal range of primary and secondary productivity, species composition, diversity, and nutrient cycling, and given that each system is exposed to unique combinations of stresses, it might be expected that patterns of response to stresses will be highly variable and unpredictable. Therefore, it is surprising to discover remarkable similarities in the response of ecosystems to stress. Stressed ecosystems are characterized by a "distress syndrome" that is indicated not only by reduced biodiversity and altered primary and secondary productivity but also by increased disease prevalence, reduced efficiency of nutrient cycling, increased dominance of exotic species, and increased dominance by smaller, short-lived opportunistic species."*

Ecosystem Distress Syndrome (EDS) is common to most types of ecosystems and stress conditions.

There are a limited number of symptoms of distress:

– disruption of the pattern of nutrient cycling from a "vertical" (e.g. between biota and substrate) to a "horizontal" direction;
– adaptive strategies by opportunistic or introduced species (characterised by high reproductive rates, short life cycles and small size);
– destabilisation of substrates (loss of keystone habitats, changes in pattern and connectivity of habitat patches, loss of structural complexity, alteration of hydrologic patterns, etc.).

The EDS diagnosis can be applied to managed ecosystems in order to consider for example whether they are economically viable, self-sustaining without subsidies or excessive external input and able to sustain healthy human communities.

2.4.2.2. Current scope of the counts of ecosystem integrity/diversity. The indicators counted for in this table aim at covering the scope of what is necessary for health assessment. They are a first selection of ecosystem distress symptoms that takes into account data availability for Europe. The list below is therefore expandable with proposed items that can be monitored on a European scale:

- Disruption of nutrient cycling patterns (derived from the core accounts).
- Structure/morphology
  – Natural or artificial edges of ecosystems and ecotones between ecosystems. Edges/ecotones are places of high biodiversity; and their value is linked to their length as well as their fractal dimension. Current Corine land cover data can be used for a first sketch (length) but need to be supplemented with additional geometric details (re-processing of the satellite images) for fractal analysis.
  – Potential connectivity of ecosystems. The issue is high on the policy agenda of nature conservation. The disruption of connectivity by barriers on land (roads, railways, etc.) and rivers (dams) or by the degradation of mosaic landscapes compromises exchanges between ecosystems and the sustainability of ecological networks. Methodologies based on Corine and other GIS data exist at the meso-scale and the local level (where they integrate data on species).
  – Texture. It is an interesting proxy of diversity to overlay with the meso-scale land cover in order to capture indices of the density of micro-elements in the land cover units, and its change. Methodology based on satellite images exists.
- Fragmentation of ecosystems and partitioning of the landscape. Fragmentation metrics are well developed (e.g., edge density, patches density, proximity, contagion and interspersion, contrast,[30] effective mesh size[31]).
- Water stress (derived from the SEEA water asset accounts).
- Water quality of rivers (following the methodology introduced in SEEA 8.126–8.130). Developed and tested in France,[32] Spain and Chile, the so-called water quality accounts attach quality indexes to river reaches weighted by their value in a standard unit, kmsr,[33] and measured in the core stock account. The quality indexes can express different aspects, such as the conventional physico-chemical and biological expression of water aptitudes for uses, the osmotic power that integrates pollution and energy dimensions or the health of the river ecosystem as such.
- Chemical distress. As mentioned previously, current progress in ecotoxicology opens the way for an operational monitoring of biomarkers of ecosystem health.[34] No solution has been decided upon so far but it is important to keep options open in ecosystem accounting.
- Biodiversity. Introducing biodiversity in ecosystem accounting is mainly a statistical issue, due the huge heterogeneity of available data. These data range from very loose atlases to detailed information on protected areas, which are not, by definition, a representative sample (see below). Species diversity is considered in relation to composition, endangered or invasive species. Habitat diversity is a more complex question. As biodiversity counts, specific habitat functions of ecosystems are considered, such as refuge for particular species or spawning/nursery areas.

2.4.3. *Account of ecosystem state*

The account of ecosystem state quantifies in physical terms the amount of ecosystems (surface, volume, number…) and of their health. This, in total, determines their sustainability and their potential to deliver goods and services. The quantification will be done be by attaching diagnosis elements to ecosystems, as described in the core account.

The basic account will show the distribution of ecosystems among four health/morbidity classes:

i. Homeostasis state (no alteration foreseen).
ii. Resilience state. The disturbance that ecosystems are still able to absorb or compensate, *keeping the same functions, identity and feedbacks (Walker, 2005)*.
iii. Reversible process without compensation (degradation).
iv. Irreversible change (death).

Implementing the diagnosis grid means checking the symptoms of distress. The decision to classify an ecosystem can be taken according to one or more likely several symptoms which give the same message or suggest the same conclusion (the "weight of evidence" approach). There is therefore no

[30] McGarigal, K., and B. J. Marks. 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. USDA For. Serv. Gen. Tech. Rep. PNW-351.

[31] Jaeger, J. 2000. Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. Landscape ecology 15 (2): 115–130.

[32] Crouzet, P., Germain, C. and Le Gall, G., 1999. Les Comptes de la qualité des cours d'eau. Mise en oeuvre d'une méthode simplifiée de calcul. Développements en cours. Etudes et Travaux n° 25. Orléans. Institut français de l'environnement. 70 pages.

[33] Heldal, J. and Østdahl, T., 1984, op. cit.

[34] Tamara S. Galloway, Rebecca J. Brown, Mark A. Browne, Awantha Dissanayake, David Lowe, Malcolm B. Jones, and Michael H. Depledge, 2004, A multibiomarker approach to environmental assessment, Environmental Science & Technology; 38(6) pp 1723–1731.

requirement for any systematic computation of all possible counts.

2.5. Accounting for ecosystem from a socio-economic perspective: functions, goods, services, assets

The right part of Fig. 2 addresses ecosystem accounting from the socio-economic perspective. Focus is put on the economic classifications (commodities and sectors) but the geographical dimension, which governs the system, is still present even though not all social and economic statistics can be disaggregated down to the land cover level. In many cases, regional syntheses are acceptable.

The four blocks of accounts relate to:

- material and energy flows; they mirror, from the "industrial metabolism" perspective which has been described in the core ecosystem accounts;
- the land use accounts which assess, on a spatial basis, the goods and services (i.e. the materials and energy transformed into commodities) obtained, including services which are not presently marketed or even marketable, as well as the impact on land of land use.
- supply and use table for those flows which are relevant from conventional economic analysis, essentially, materials, goods and residuals;
- natural capital accounts.

2.5.1. Translating "ecosystem services" into accounting categories

The Millennium Ecosystem Assessment has raised awareness about the threats to ecosystems and the attractive metaphor of the ecosystem services and their importance for human well-being. It has broadened the scope of natural resources to encompass the services delivered by ecosystem functions, which are then either directly or indirectly consumed by the society. The MEA identifies four types of services: provisioning, social, support and regulating.

Support services are the basic primary inputs; they are covered to a large extent by the enlarged material/energy flow accounts described above. Provisioning services result from the intentional use of ecosystems as a source of services as well as materials transformed into goods in the economic sense, i.e. from the harvesting of non-cultivated plants to the products of intensive extraction of natural resources and transformation industries. Provisioning services are mostly goods which flow through the economy and are to a large extent covered by the national accounts. Social services are of a more non-market nature but they are used by individual and communities which can be identified. Regulating services are more complex to assess. This is due to their collective nature and their indirect yet fundamental contribution to societal development in the boarder sense.

Bridging ecosystem services in the MEA sense to the ecosystem accounting framework is possible and may facilitate further assessments. However, some precautions are necessary due to asymmetries in the so-called ecosystem services of the MEA between the goods (material and energy objects the main constituent of "provisioning services" and to a large extent the input in "support services") and other services. This makes it difficult to provide a comprehensive and homogenous flow accounting of services in the same way as for goods. The problem results in particular in the difficulty of finding direct physical units of measurement for most social and regulating services. Starting from the benefits obtained by people, monetary valuations can be considered in some cases, where markets are or could be created. However, this is often difficult, for example when ecosystem services are supplied to other agents involuntarily, with no compensation for that supply. Regulating services can be monetised in some cases (e.g. water regulation) in reference to the investments that should be made for compensating the ecosystem function. Complete supply and use tables of all the benefits from ecosystems cannot be foreseen. Assessing the importance of all these services can be done, however, indirectly, according to the potentials of the ecosystems which deliver them.

2.5.2. Natural functions, land use functions and ecosystem services

The solution for obtaining a comprehensive assessment is therefore to concentrate on the potential of the systems that deliver them. This can be done by analysing the functions of land and ecosystems, the demand for services as well as the land input to the generation of services.

Land use commonly designates the direct uses of land for production of goods and services as well as in the delivery of the so-called social or cultural services. Natural functions relate more generally to the background services of hydrological and climate regulation, soil formation or habitat functions for species. These services of critical importance are mostly classified as regulating services by the MEA and need to be assessed separately.

In contrast to land cover, which can only exist in one state at a moment in time, the uses of land – its functions – can be numerous. Even intensive agriculture has some habitat functions, e.g. for migratory species, hydrological functions and other land use functions such as hunting. Therefore, the starting point is to assess the multiple uses/functions within a geographical context and do so a systematic way. A classification of land use functions is tested for that purpose.

From an ecosystem services perspective, this inventory will lead at the same time to identifying clusters of potential services, of the real services requested by the actors, of trade-offs between immediate needs and the conservation of ecosystem functions and potentials as well as possible conflicts over land use between actors.

Land use functions can be assessed according to various spatial patterns. These spatial patterns range from the parcel to land cover or landscape dominant character[35] at more or less aggregated level up to urban systems, agri-ecosystems or natural systems. When the parcel level can be more directly linked to flows of products and short term outcomes, the landscape level corresponds better to the social representations that frame the vision of the world and influence decisions about future options.

[35] Haines-Young R., and Potschin M., 2005, Building landscape character indicators, in European Landscape Character Areas, Wascher D.M. (ed), Final report of the project European Landscape Character Assessment Initiative (ELCAI) of the Research 5^{th} Framework Programme of the European community.

In practice, the possible levels of disaggregation will be constrained by the detail of available statistics that can be incorporated into the land use accounts.

2.5.3. *Land use functions and ecosystem stress*

The other side of land use is the stress that it creates upon natural systems. The stress side of the Ecosystem Distress Syndrome model is the reference here and connects ecosystem and land use approaches. Four main types of anthropogenic stress are listed:

- physical restructuring which fragments or destroys critical habitats, causes substrate instability and disrupts nutrient cycling;
- introduction of exotic species, intentionally or accidentally;
- discharge of residuals and toxic substances, which contributes to eutrophication and the build up of toxic substances in food webs.
- over-harvesting.

In land use accounts, stressors are identified in relation to the previous health diagnosis of the account of ecosystem state, taking into account carrying capacities and threshold values as well as possible synergies with natural disturbances. In a second step, the observed stress is bridged to the supply and use table of the corresponding flows as well as to a range of statistics on agriculture, forestry, population, transport and others.

In DPSIR[36] terms, the framework used in Europe for presenting environmental indicators, the EDS invites reconsideration of traditional interpretations where the emphasis is put on the pressure side (P) and tends to neglect State and Impacts (S and I), supposedly linear consequences of P. Conversely, in an EDS approach, the S and I come first and are assessed on the basis of symptoms. This approach is in line with the most recent developments in ecotoxicology where the monitoring of biomarkers precedes the research of the determinants. Direct and indirect effects of low toxic doses on ecosystem health (as well as on human health) are identified using biomarkers, and the pollutants can be monitored in a very cost-effective way.

2.6. *Towards accounting for natural capital*

The ultimate ambition of land and ecosystem accounts is to support environmental policy integration by clarifying and quantifying trade-offs between environmental priorities, their costs, the benefits they bring to the society and the benefits of environment friendly policies in agriculture, land and urban planning, and economic development in general. What has been achieved so far with the implementation of land cover accounts and is continuing with the ecosystem and land use modules is the creation of an information base which supports future assessment by developing classifications and meta data, as well as identifying the main indicators that need to be considered at the relevant scales, starting from the meso-scale.

At this stage, the choice of economic valuation methods to be used for ecosystem services and assets is still open for discussion. The ambition here is to support many possible approaches in an open way. Clearly, there is a focus on the capital based approaches and the assessment of the ecosystem wealth, but this is not exclusive. As long as the market does not provide appropriate prices, alternate valuations probably make sense. Also, the approach of land and ecosystem accounts implicitly assumes that even though some elements cannot be monetised they are part of the natural capital and should be quantified in one way or another to be part of the decision making process and assessment of trade-offs.

3. Perspectives on ecosystem accounting

Once the basic data have been made available, the first steps of the implementation of land and ecosystem accounts have been quite swift, with a moderate marginal cost.[37] One may conclude that currently data are a limiting factor, but this is only partly true as long as data are relatively abundant, albeit heterogeneous.

Firstly, the space-based technologies, earth observation as well as geo-positioning systems and data transmission, not only provide large quantities of data, they contribute in structuring the whole information system with exhaustive images, continuous monitoring, precise locations and frequent access, even from remote places.

Secondly, in situ monitoring systems are producing more and more data for a wide range of purposes. However, these data are very rarely based on strict sampling patterns and need to be reprocessed. The combination of in situ and space data facilitates the establishment of correct stratifications, which reflect landscape as well as time variability.

Thirdly, conventional socio-economic statistics have (still) their space and time patterns but the rapid development of databases and open content dissemination policies is reducing the importance of this issue. Again, merging statistics with geographical information may help to fill the data gaps. It will contribute as well to the organisation of the indispensable cooperation between statistical offices, research institutions and environmental agencies.

From an analytical and methodological point of view probabilities and uncertainties are also part of the game. New approaches based on the recent progress of research (from global ocean modelling to monitoring biomarkers of the effect of toxics on the genome) and technology in the domains of sensors, geo-location, data transmission, storage and analysis will facilitate the establishment of diagnosis of ecosystem health. They will also help improve data quality as well as fill in empty boxes within the present accounting framework.

[36] Driver, Pressure, State, Impact, Response.

[37] This is confirmed by the recent production of land cover accounts in Burkina Faso on the basis of a mapping programme similar to Corine Land Cover, namely the BDOT (for Base de Données de l'Occupation des Terres) 1992–2002 — see Jaffrain G., 2006, Diachronic analysis and land cover account in Burkina Faso — Presentation to the EEA.

One important point now is the clearly understood need to integrate the satellite and in situ monitoring systems, as reflected in the acronym GEOSS, (Global Earth Observation System of Systems) — an outcome of the GEO world programme. Considering land cover monitoring itself, the combination of satellites with various resolutions facilitates a nested approach respecting both the variety of scales and the specific interest of the various communities of users. From a global perspective, the images of the medium resolution imaging satellites[38] will provide an opportunity to implement standard methodologies with comparable results. The dissemination in 2006–2007 of the Globcover 2005 data will probably stimulate this type of development.

To make further progress, best use should be made of existing datasets first, including imperfect data. The approach allows policymakers' questions to be answered, even imperfectly, while remaining prepared for using new data. The best use of data can be made only if the players have free access to data and agree to pool their databases. This is the policy of the EEA and more and more other organisations around the world.

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[38] E.g. ENVISAT-MERIS (Europe), MODIS (USA), RESURS (Russia), CBERS (China-Brazil) or IRS (India).