System of Environmental Economic Accounting

Assessing ecosystem extent and condition in Mexico

Report of the NCAVES project

September, 2019

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1. Preamble

The *Natural Capital Accounting and Valuation of Ecosystem Services Project* is a three-year (2017-2019), global project launched jointly by United Nations Statistics Division (UNSD), United Nations Environment Programme, and the United Nations Convention on Biological Diversity (CBD), with financial support from the European Union. Brazil, China, India, Mexico, and South Africa were chosen as the initial countries to pilot test the project.

The project aims to advance the knowledge agenda on environmental-economic accounting, particularly ecosystem accounting, by initiating pilot testing of the UN System of Environmental Economic Accounts-Experimental Ecosystem Accounting (SEEA-EEA) framework in select countries where biodiversity is at stake, with a view to:

- Improving the measurement of ecosystems and their services (both in physical and monetary terms) at the national/subnational level;
- Mainstreaming biodiversity and ecosystems in national/subnational level policy-planning and implementation; and
- Contribute to the development of internationally agreed methodology and its use in partner countries.

The Mexico project was officially launched in June 2017 and implementation began in September 2017 when the project consultant was contracted. One product of the Mexico project shall be a compilation of selected ecosystem services accounts in physical and —whenever possible— monetary terms. Based on the country's policy priorities, data availability, and on their sensitivity to environmental changes and socio-economic importance (see UN, 2014), the following four ecosystem services were chosen for pilot testing the SEEA-EEA framework in Mexico both, at the State- and the countrywide level:

- Carbon capture and storage services
- Surface water supply services
- Food crop production services provided by agroecosystems
- Coastal protection by mangrove ecosystems

Given the still experimental nature of the SEEA-EEA framework, its strict methodological requirements, as well as its very recent —and, therefore, limited— application in real-world cases, it is not surprising that challenges are found in various stages of the implementation process. In this document I discuss, in particular, the issues faced when trying to map and assess the extent and condition of Mexico's ecosystems, the rationale underlying the decisions made, as well as the gaps that need to be filled in order to make further progress in ecosystem services accounting in Mexico.

Work referred to in this and other accompanying reports was carried out during 2018 and early 2019, during which period a revision process of the SEEA-EEA conceptual and methodological framework was also being conducted (UN, 2018). Early results from the revision process were released very recently (May-June, 2019) and, while they do provide further guidance and clarification on these topics, timing precluded incorporating these new developments into the Mexico pilot studies. Nevertheless, in this document I try to frame —as much as feasible— the issues found and the decisions made in relation to the results from the revision process.

2. The SEEA-Experimental Ecosystem Accounting framework

Economic and other human activities have been causing an overall degradation of ecosystems, thus reducing the ecosystems' capacity to provide the services on which people depend. Ecosystem accounts can provide valuable information for tracking changes in ecosystems and for linking those changes to human activities.

The SEEA-EEA is an integrated statistical framework to organize biophysical data, assess ecosystem services, track changes in ecosystems and link that information with economic activities, using a spatially explicit approach. However, the SEEA-EEA does not yet constitute an international statistical standard. At this stage, it only provides an accounting framework for research and testing on ecosystems and their relationship to economic and other human activity; work in this field is still deemed as experimental (UN, 2014). The *SEEA-Experimental Ecosystem Accounting* document (UN, 2014) and the *Technical recommendations in support of the SEEA-EEA* (UN, 2017) provide methodological guidelines and recommendations to test and experiment on ecosystem accounting issues. The overall workflow for valuing ecosystem services within the SEEA-EEA framework is schematically described in Figure 1 below.

In the SEEA-EEA framework, the capacity of a given ecosystem to supply a given service is considered to be a function of both, the area it covers (*i.e.*, its extent) and its condition (*i.e.*, its quality):

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Supply of ecosystem service = f(Ecosystem extent, Ecosystem condition)
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Accordingly, in the workflow (Fig.1) ecosystems are first characterized in terms of both, quantitative (ecosystem extent) and qualitative (ecosystem condition) descriptors. Then, the supply and use of the services the ecosystem provides are measured in physical terms (green boxes in Fig.1) and, finally, valued in monetary terms (grey boxes) (see UN, 2017). First accounting for ecosystems in physical terms is a key feature of the SEEA-EEA framework, as the monetary valuation of the supply and use of ecosystem services is necessarily dependent on the availability of information in physical terms, since there are few observable market values for ecosystems and their services (UN, 2014).

The *SEEA-Experimental Ecosystem Accounting* document (UN, 2014) and the *Technical recommendations in support of the SEEA-EEA* (UN, 2017) do not yet provide definitive advice on how to address the several conceptual and methodological challenges faced when compiling ecosystem accounts in practice. Early experiences with the SEEA-EEA framework have shown (UN, 2017; Bogaart *et al.*, 2019) that, in a number of areas, further conceptual advancement is still necessary and that, in all areas, better measurement methods still need to be developed and/or tested. The on-the-ground, pilot-tests of the SEEA-EEA framework being currently carried out in various countries are expected to provide valuable lessons to make further progress in these topics. Because of this, in 2018 a revision process of the SEEA-EEA framework was launched (UN, 2018), topics demanding specific attention (*viz*., spatial units, ecosystem condition, ecosystem services and valuation) were identified, and working groups established accordingly. As an early result from the revision process, a series of discussion papers providing further guidance on these themes were developed and recently released. Particularly relevant for this analysis are the discussion papers dealing with spatial units (Bogaart *et al*., 2019) and ecosystem condition (Keith *et al*., 2019; Maes *et al*., 2019; Czúcz *et al*., 2019).

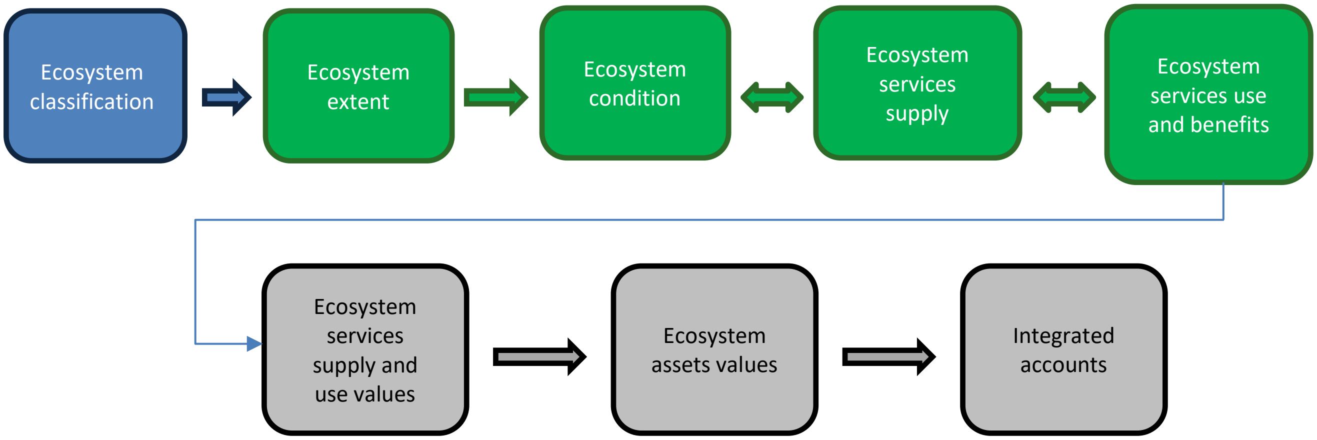

Fig.1 Diagram showing the general workflow for valuing ecosystem services within the SEEA-EEA framework; steps shown in green colour are carried out in physical terms, whereas the ones shown in grey are formulated in monetary terms (modified from UN, 2017).

3. General considerations on data and methods

Applying the SEEA-EEA framework requires of various types of statistical and geographic data from different sources, as well as the use of a range of analytical and spatial modelling methods. Given its experimental nature, as well as its still limited application in real-world cases, no officially approved nor generally adopted data sources and methods are yet available for most of the stages of the process (Maes *et al.*, 2019). This leaves the way open for potentially using any of a wide range of data sources and/or methodological approaches that could, in principle, seem useful or suitable for each stage of the workflow.

One of the main findings of the Mexico's country assessment conducted as part of the NCAVES-Mexico project was that, in general terms, there is in Mexico insufficient data/information on ecosystem services that is solid, readily available, easily accessible, and of sufficient temporal and spatial resolution. The assessment also showed that the only information currently available specifically dealing with the volume, flow and value of ecosystem services in Mexico is that compiled or produced by the many local-level study cases of ecosystem services valuation that have been conducted in the country over the las 25 yr. Such studies, however, are affected by several issues that prevent their results from being more generally useful and easily accessible. On the other hand, the assessment also showed that, as part of their operation, various government agencies regularly collect statistical and geographical data and information which are fully relevant and potentially useable for ecosystem accounting purposes. However, having those data been collected for specific purposes other than ecosystem services accounting, they need to be first reformatted, adapted, reformulated or used as inputs for biophysical models/analyses prior to use them for analysing ecosystem services stocks and flows, etc.

For these reasons, the selection of inputs (statistical and geographic data) and analytical and modelling methods to be used in the pilot tests of the NCAVES-Mexico project was based on the following principles:

- Use local, official data/information or, at least, data/information that is produced or used by official entities in the country;
- Use data with country-wide coverage;

- Use spatially explicit data of adequate resolution; given the explicit purpose of the NCAVES-Mexico project to conduct pilot tests both at the State- and countrywide level, suitable data should have a moderate to high spatial resolution (*i.e.*, 1:250,000 scale or higher; pixel size 250m or smaller);
- Use data sets encompassing a consistent time-series or that, at least, provide comparable data for various points in time (a few years);
- Use data that are freely, openly available;
- Use explicit, transparent and repeatable methods for analysis and modelling;
- Avoid using "black-box" methods or models.

4. Ecosystem classification

The first step in the SEEA-EEA framework (see Fig.1) involves delineating the ecosystems (*ecosystem assets,* as per UN, 2017) present in the study area (*ecosystem accounting area*, as per UN, 2017). The rationale is that for ecosystem accounting purposes, the biophysical environment can/should be partitioned into a set of contiguous, mutually exclusive units, each covered by a specific ecosystem that supplies ecosystem services and about which relevant information is to be collected as the basis for accounting.

In principle, a range of characteristics can be used to delineate the ecosystems present in the study area, including ecological (*e.g.*, vegetation type, soil type, hydrology, land management, etc.) and non-ecological (*e.g.*, land use, ownership, site features, etc.) features. Accordingly, many different approaches and systems for classifying ecosystems have been proposed and are in use worldwide. Ecosystem classification systems commonly differ from each other in the characteristics or attributes of ecosystems that they use (or emphasize) as classification criteria, depending on the scope (local, national, regional or global) and specific purpose for which the classification is to be used.

However, the UN-SEEA ecosystem accounting concept demands ecosystem classifications that are suitable for statistical analysis and accounting and —given the UN's essence— that also allow for the results to be compared across countries. The SEEA-EEA document (UN, 2014) and its technical recommendations (UN, 2017) focused very much on terrestrial ecosystems and suggested a simple land-cover classification (based on version 3 of the UN-FAO's Land Cover Classification System) as a starting point for classifying ecosystems. Early experiences with the SEEA-EEA framework have evidenced some shortcomings in such classification (Bogaart *et al*., 2019), including the lack of detail with regard to marine ecosystems. Thus, although the general approach for classifying ecosystems in the SEEA-EEA context is now relatively well established, there are still several important issues that need to be addressed; definite approaches and methods for delineating ecosystem assets for ecosystem accounting purposes are still under development (UN, 2017; Bogaart *et al*., 2019).

It has been now recognized that, for ecosystem accounting purposes, land cover is, by itself, insufficient for properly delineating ecosystem assets and a wider range of ecological (biotic and abiotic) and non-ecological characteristics needs to be considered (Bogaart *et al*., 2019). Ecological characteristics are usually chosen as the key criteria for delineating ecosystem assets; for terrestrial ecosystems these include (Bogaart *et al.*, 2019):

- Biotic characteristics.- Vegetation structure, type, and species composition; fauna; ecological processes, etc.
- Abiotic characteristics.- Climate, topography and geomorphology, lithology and soil, hydrology, etc.

The specific characteristics to use in a particular case should be chosen based on their relevance for the ecosystems involved and the availability of data. Habitat/biotope and vegetation are usually the most suitable basis for delineating and classifying terrestrial ecosystems, based on ecological criteria (Bogaart *et al*., 2019). If available, a country-specific classification system would also be strongly preferable as this will neatly reflect the local conditions; however, a highly specialized classification might limit the possibilities of comparing the results with those from other countries (UN, 2017).

In Mexico, several, progressively more refined, systems for describing and characterizing the country's vegetation have been formulated over the course of the last 60 years (Sánchez-Colón *et al.*, 2009). The first country-wide classification and description of Mexico's vegetation types was proposed by A.S. Leopold in 1950. This was followed, several years later, by Miranda and Hernández-Xolocotzi (1963) who published *Los tipos de vegetación de México y su clasificación* (Classification of Mexico's vegetation types). Several studies were completed in the 1970's, including the *Mapa y descripción de los tipos de vegetación de la República Mexicana* (A map and description of the vegetation types of the Mexican Republic) by Flores Mata *et al*. (1971), the *Tipos de vegetación de México* (Vegetation types of Mexico) by González Quintero (1974) and *Vegetación de México* (Mexico's vegetation) by Rzedowski (1978). These seminal studies provided, for the first time, an overall picture of the country's vegetation and the different plant communities that it comprises, their main and dominant species, ecological and geographical distribution and even provided information on the anthropic pressures affecting them. In addition, those first studies set up a general framework for the further description and analysis of the plant communities, vegetation and terrestrial ecosystems of Mexico.

As part of their long-standing work to periodically map the country's vegetation and land cover, the National Institute for Statistics and Geography (INEGI) has formulated a comprehensive classification system of the vegetation and land-use types present in Mexico. INEGI's classification system is based on those proposed by Miranda and Hernández-Xolocotzi (1963) and Rzedowsky (1978), and is nowadays the most comprehensive, highly-detailed, country-wide level classification of the main types of natural vegetation and land use occurring in the country. The system has been progressively refined over the last 40 years and is now consistently used as a framework for describing Mexican terrestrial ecosystems in all environmental planning and management instruments (*e.g*., National Forest and Soil Inventory, land-use planning schemes, environmental impact assessment of development projects, etc.) and national reports and indicators (Mexico's *State of the Environment Report*, *National System of Environmental Indicators*, etc.) produced in Mexico, as well as in country reports to multilateral organizations and conventions (*e.g*., FAO-*Forest Resource Assessment*, National Communications to the United Nations Framework Convention on Climate Change, National Reports before the Convention on Biological Diversity, etc.). In its latest version, the INEGI classification encompasses 12 plant formations (including conifer forests, oak forests, mountain cloud forest, xerophytic shrubland, natural grassland, evergreen tropical forest, deciduous tropical forest, semi-deciduous tropical forest, thorny tropical forest, hydrophytic vegetation, and others) subdivided into 59 vegetation types (differentiated based on physiognomy, dominant species and environmental conditions) plus 24 land-use classes (including agroecosystems, human settlements and water bodies); a detailed description of INEGI classification system is provided elsewhere (INEGI, 2017).

More recently, González Medrano (2003) made an effort to synthesize and unify the different classification systems of Mexico's vegetation. Velázquez *et al*. (2016) proposed a standardized hierarchical classification system for Mexico's vegetation. However, these more recently proposed classification systems have not been widely adopted or used so far.

Based on the above, and taking into account the general considerations described in section 3, the ecosystem classification chosen for the pilot tests of the NCAVES-Mexico project was based, first, on INEGI's vegetation and land use classification system (INEGI, 2014, 2017). The level of detail of INEGI's classification system, however, surpasses the data available on ecosystem services and, for this reason, a simplified version of the INEGI classification was used instead. Specifically, I chose the aggregated version that the National Forestry Commission (CONAFOR) utilizes as framework for compiling the national greenhouse gas emissions inventory from the land use, land use change and forestry sectors. In such simplified scheme, the 59 vegetation types and 24 land use classes of the original INEGI classification are aggregated into 14 vegetation classes, five land-use classes (annual or permanent crops, aquaculture, forest plantations, human settlements) and ancillary classes (water bodies). Table 1 shows the correspondence between INEGI's full classification and the aggregated classes included in CONAFOR's simplified version.

Table 1. Correspondence between the vegetation and land-use classes encompassed in INEGI's full classification and the aggregated classes included in CONAFOR's simplified classification; their approximate correspondence with IUCN's Global Ecosystem Typology is also shown. Cells shaded in pink colour denote land-use or ancillary classes; cells shaded in green colour denote natural vegetation classes.

INEGI class	CONAFOR class	IUCN Global Ecosystem Typology
Aquaculture	Aquaculture	F3 Artificial wetlands
Water bodies	Water bodies	F1 Rivers and streams/F2 Lakes/F3 Artificial wetlands
Annual crops dependent on residual moisture	Annual crops	T7.1 Croplands
Annual + perennial crops dependent on residual moisture		
Annual + semi-permanent crops dependent on residual moisture		
Annual, irrigated crops		
Perennial, irrigated crops		
Annual +semi-permanent, irrigated crops		
Semi-permanent, irrigated crops		
Semi-permanent + perennial, irrigated crops		
Annual, rain-fed crops		
Annual + perennial rain-fed crops		
Annual + semi-permanent rain-fed crops		
Semi-permanent rain-fed crops		
Semi-permanent + perennial rain-fed crops		
Perennial crops dependent on residual moisture	Perennial crops	
Semi-permanent crops dependent on residual moisture		
Semi-permanent + perennial crops dependent on residual moisture		
Perennial, irrigated crops		
Perennial, rain-fed crops		
Urban/constructions	Human settlements	T7.4 Urban and infrastructure lands
Urban zones		
Forest plantation	Forest plantation	T7.3 Plantations
Fir forest	Coniferous forest	T2.1 Boreal and montane needle-leaved forest and woodlands
Cypress forest		
Juniper forest		

Pine forest		
Pine-oak mixed forest		
Douglas fir forest		
Coniferous shrubland		
Oak forest	Oak forest	T2.2 Temperate deciduous forests and shrubland
Oak-pine mixed forest		
Mountain cloud forest	Mountain cloud forest	T2.4 Warm temperate rainforests
Tropical mezquital	Deciduous tropical forest	T1.2 Tropical/subtropical dry forests and scrubs
Subtropical shrubland		
Low-stature, deciduous tropical forest		
Low-stature, deciduous, thorny tropical forest		
Mid-stature, deciduous tropical forest		
Low-stature, semi-deciduous tropical forest	Semi-deciduous tropical forest	
Mid-stature, semi-deciduous tropical forest		
High-stature, evergreen tropical forest	Evergreen tropical forest	T1.1 Tropical/subtropical lowland rainforests
High-stature, semi-evergreen tropical forest		
Low-stature, evergreen tropical forest		
Low-stature, thorny, semi-evergreen tropical forest		
Low-stature, semi-evergreen tropical forest		
Mid-stature, evergreen tropical forest		
Mid-stature, semi-evergreen tropical forest		
Crassicaulescent desert shrubland	Woody xerophytic shrubland	T3.1 Seasonally dry tropical shrublands
Tamaulipan thorny shrubland		
Xerophytic mezquital		
Chaparral		
Coastal rosetophyllous shrubland		
Sarcocaulescent shrubland		
Sarco-crassicaulescent shrubland		
Submontane shrubland		
Foggy sarco-crassicaulescent shrubland		
Microphyllous xerophytic scrubland	Non-woody xerophytic scrubland	T5 Deserts and semideserts
Rosetophyllous xerophytic scrubland		
Sandy desert vegetation		
Halophytic xerophytic vegetation		
Gallery forest	Woody hydrophylous vegetation	FT1 Palustrine wetlands
Gallery tropical forest		
Gallery vegetation		
Petén vegetation		MFT1 Brackish tidal systems
Mangrove forest		
Mezquite woodland	Other woody vegetation types	T1 Tropical-subtropical forests
Natural palm-dominated vegetation		
Induced palm-dominated vegetation		
Induced forest		

Cultivated pastureland	Grassland	T7.1 Sown pastures and old fields
Halophytic grassland		T4 Savannahs and grasslands
Induced pastureland		
Natural grassland		
Gypsophylous grassland		
Savannah		
Savannah-like vegetation		
High-mountain meadow		T6.5 Tropical alpine meadows and shrublands
Popal vegetation	Non-woody hydrophylous vegetation	FT1 Palustrine wetlands
Hydrophytic, halophytic vegetation		
Tular		
Sand-dune vegetation	Other non-woody vegetation	TM2.1 Coastal shrublands and grasslands
Area devoid of vegetation	Other lands	N/A
Areas without apparent vegetation		

On the other hand, in order to integrate ecosystem information with socio-economic data, and better understand the flow of ecosystem services supplied by different ecosystems, it is also convenient to include non-ecological characteristics (*e.g*., land use, land ownership, land management, etc.) in the delineation of ecosystem assets (UN, 2017; Bogaart *et al*., 2019). The cross-classification of ecosystem and socio-economic information is key for assessing the relationship between ecosystem services, ecosystem assets and land management and ecosystem degradation. The link to socio-economic information can be better introduced during the process of delineating ecosystem assets by, for example, using information on land use or landownership, management regimes (*e.g.*, protected areas), etc.

Thus, a second set of criteria used for classifying Mexico's ecosystems aims to take into account differences in land management and use of natural resources stemming from the property regime (public, private or communal [including *ejido* or indigenous communities] property), as well as from restrictions imposed by the presence of (federal) natural protected areas. The classification of the country's ecosystems for the pilot tests of the NCAVES-Mexico project is, therefore, based on the intersection of three criteria:

- vegetation type or land use class, as *per* the CONAFOR's simplified version of INEGI's classification system
- land tenure (private *vs*. communal, including ejidos and indigenous communities), as *per* the registry kept by the National Agrarian Reform office, and
- presence of (federal) protected natural areas, as *per* the registry of the National Commission for Protected Areas.

Very recently, the SEEA-EEA revision process identified six design criteria that an ecosystem classification to be used in the SEEA-EEA framework should meet (Bogaart *et al*., 2019), as follows:

1. The classification should be **based on ecological principles**.
2. The classification units should be **mappable**.
3. The classification should be **conceptually and geographically exhaustive**, able to describe and account for the entire surface of the study area.
4. Classification types should be **conceptually and geographically mutually exclusive**.

5. The classification should be **practicable**, having a hierarchical structure with a rather small number of universally understandable, high-order classes that allow for comparisons across countries to be made.
6. The classification should be **linkable** to other established classification systems.

The first four criteria should be met by any ecosystem classification that is to be used for ecosystem accounting at the national level; the other two criteria are rather necessary for standardizing country-level reports and between-countries comparisons (Bogaart *et al.*, 2019). As can be seen from the description above (pp. 5-6), the INEGI's classification system —as well as CONAFOR's simplified version of it— does neatly meet criterion 1 and its classes are defined (see Table 1 above and detailed descriptions in INEGI, 2014, 2017) in such a way that they are also conceptually exhaustive (criterion 3) and mutually exclusive (criterion 4). INEGI's classification system also neatly meets criterion 2: As discussed in section 5 below, using this classification system, INEGI regularly produces and updates 1:250,000 scale, wall-to-wall, country-wide charts portraying the geographic distribution of the different types of vegetation and land-use occurring in Mexico. Table 1 above also makes a first attempt to link (criterion 6) INEGI's and CONAFOR's classification systems with the corresponding high-order classes in IUCN's Global Ecosystem Typology (as described in Bogaart *et al*., 2019).

Adopting INEGI's classification system as the basis for delineating Mexico's ecosystems for the pilot tests of the NCAVES-Mexico project is also in agreement with most of the guidelines derived from the SEEA-EEA revision process (Bogaart *et al*., 2019). For example, INEGI's classification system does represent ecosystems defined with basis on —and characterized by— ecological properties and that are spatially delineable; it does encompass all the terrestrial ecosystems occurring in the country; the classes are mutually exclusive and exhaustive; and the classification has a well-defined hierarchical structure. Also, CONAFOR's simplified version of INEGI's classification provides a manageable ecosystem typology that does not have too many classes, thus reaching a balance between the number of different ecosystem types that are identified and the availability of information. In addition, while this classification is based on ecological principles, I am also explicitly including anthropogenic factors, such as land use and land ownership.

The approach followed for classifying Mexico's ecosystems in the NCAVES-Mexico project also coincides with one of the approaches suggested in the SEEA-EEA revision process for the construction of a national/regional ecosystem classification, namely, "…using as a starting point an existing national classification scheme, preferably, a classification that represents ecosystems or habitats, and that can be bridged to [a] reference…classification. This allows efficient use of available data, facilitates the integration of datasets and avoids producing partially overlapping datasets..." (Bogaart *et al*., 2019).

5. Ecosystem extent

The second step in the SEEA-EEA framework is estimating the ecosystems' extent at different points in time. The ecosystem extent account provides the basis for the subsequent assessment of ecosystem condition and the flow of ecosystem services from each ecosystem type and asset. For most terrestrial ecosystems, extent is commonly measured in terms of surface area covered.

Using its own comprehensive classification system (see description in section 4 above), over the last 40 years INEGI has being producing and regularly updating 1:250,000 scale, country-wide, wall-to-wall charts portraying the geographic distribution and extent of the different types of vegetation and land-use occurring in Mexico. The charts also identify the areas without apparent vegetation and provide general information on soil type and erosion, agricultural practices and crops, vegetation physiognomy, successional aspects and the use of plant communities, etc. The charts are produced by visual interpretation —by expert photo-interpreters— of satellite imagery (aerial photographs in the earliest versions), followed by on-the-ground verification. INEGI updates the 1: 250,000 scale Land use and Vegetation Charts every 4-5 years; six editions (known as *series*) have been published to date: Series I was produced based on the interpretation of aerial photographs recorded in the 1970's; Series II was based on satellite images (Landsat ETM 5) recorded in 1993; Series III was based on Landsat ETM7+ images recorded in 2002; Series IV on Spot images recorded in 2007; for the Series V, Landsat 5 images recorded in 2011 were used; and for the series VI, Landsat 8 images recorded in 2014.

Even though the various editions of INEGI's vegetation and land-use chart were made with different inputs and technologies, in all of them essentially the same vegetation classification scheme was used (with only a few minor differences between Series I and subsequent ones). Also important, the charts also provide information on the successional stage or conservation status (primary or relatively well preserved *vs*. second-growth or degraded) of vegetation, based on the presence of secondary species and the degree of soil erosion. Additionally, the charts include specific categories for anthropic (agriculture, livestock ranching, forestry, human settlements, etc.) or other land uses (*e.g.*, water bodies, areas devoid of vegetation, etc.). These features make INEGI's charts fully comparable with each other and allow examining, in a consistent manner, the extent and geographical distribution of Mexico's terrestrial ecosystems at different points in time (1970's, 1993, 2002, 2007, 2011 and 2014) with a spatial resolution (scale 1: 250 000) adequate for a reasonably detailed analysis of the whole country and of particular areas of it.

INEGI's vegetation and land-use charts have been recently criticized (see, for example, Gebhardt *et al*., 2014) for their relatively coarse spatial resolution —their minimum mappable area is 25ha— and low update frequency (every 4-5 years), which are considered insufficient for a large country, with rapid vegetation dynamics, such as Mexico. Several efforts to construct more timely, wall-to-wall monitoring systems for the entire country have been carried out. To date, the most promising of these efforts is the Monitoring Activity Data for the Mexican REDD+ programme (MAD-MEX) system developed by CONABIO (Gebhardt *et al*., 2014).

MAD-MEX is a fully automatized system for the classification of high-resolution satellite imagery (LANDSAT, Sentinel, and Rapid-Eye) based on field data from the National Forest Inventory, INEGI's vegetation and land-use charts and other ancillary data. The system produces land cover charts (scale 1:100,000, 1:50,000 and 1:20,000 respectively) annually, with a minimum mappable area of 1 ha or 0.1 ha respectively. The following products are currently available:

a. Land cover 2015, scale 1:20,000 (5m resolution), based on Rapid-Eye imagery
b. Land cover 2017, scale 1:50,000 (10m resolution), based on Sentinel imagery
c. Land cover 2018, scale 1:50,000 (10m resolution), based on Sentinel imagery
d. Land cover 2017, scale 1:100,000 (30m resolution), based on Landsat imagery
e. Land cover 2018, scale 1:100,000 (30m resolution), based on Landsat imagery

The MAD-MEX 2015 1:20,000 chart (based on Rapid-Eye imagery) was independently reviewed and validated by experts and fine-tuned accordingly; this chart is known as the reference map. The other classification products (for 2017 and 2018) have not been similarly post-processed but were calibrated against the 2015 reference map; therefore, their reliability has not been actually assessed.

The MAD-MEX classification distinguishes, with decreasing degrees of accuracy, 8, 17, or 31 different land-cover classes, which partially correspond with some classes (or groups of classes) of INEGI's vegetation and land-use classification. While the temporal and spatial resolution of the MAD-MEX products make them very useful for various applications, it has been now recognized that, for ecosystem accounting purposes, land cover is insufficient for properly delineating ecosystem assets (Bogaart *et al*., 2019).

For these reasons, and taking into account the general considerations described in section 3, the extent of Mexico's ecosystems and its changes over time (as of 2002, 2007, 2011 and 2014) for the NCAVES-Mexico pilot projects were estimated based on INEGI's Vegetation and land use charts.

6. Ecosystem condition

6.1 Context

As described in UN (2017), and illustrated in Fig.1 above, the third step in the SEEA-EEA framework consists in compiling information about the ecosystems' condition. Ecosystem condition is a fundamental component in the ecosystem accounting framework as it allows examining how the quality of ecosystems in the study area changes —due to natural or anthropogenic causes— over time (past trends and current state) and how those changes affect —in conjunction with the changes in ecosystem extent— their ability to supply ecosystem services. Such information can then be used to try to predict potential changes in the future. Together, the two accounts (*viz*., ecosystem extent and ecosystem condition) help to identify ecosystem degradation or improvement, establish the link between ecosystem assets and the flow of ecosystem services, and can be used to support estimates of the monetary value of ecosystems and the services they supply (Keith *et al.*, 2019).

However, as of today there is no unique, widely accepted definition of ecosystem condition. The Millennium Ecosystem Assessment defined ecosystem condition in relation to its ability to provide ecosystem services (MEA, 2003). The OpenNESS Glossary defines ecosystem condition as the overall quality of an ecosystem, in terms of its main characteristics underpinning its capacity to generate ecosystem services (Potschin-Young *et al*., 2016). A straightforward definition has been adopted by the working group on Mapping and Assessment of Ecosystems and their Services of the European Commission: Ecosystem condition refers to the physical, chemical and biological condition or quality of an ecosystem at a given point in time (Maes *et al*., 2014, 2018). In the SEEA-EEA framework (UN, 2014, 2017) ecosystem condition is defined as the overall quality of an ecosystem asset in terms of its characteristics such as water, soil, carbon, vegetation and biodiversity. More recently, the SEEA-EEA revision has proposed a broader —albeit entirely pragmatic— definition: The condition of an ecosystem is interpreted as the ensemble of multiple relevant ecosystem characteristics, which are measured by sets of variables and indicators that, in turn, are used to compile the accounts (Keith *et al*., 2019).

Not surprisingly, the measurement of ecosystem condition is still a matter of debate as well (Rendon *et al*., 2019). The SEEA EEA framework has adopted a straightforward, general two-stage approach to assess the condition of ecosystem assets (UN, 2014, 2017; Keith *et al*., 2019): In the first stage, a set of relevant ecosystem characteristics are selected and a set of measurements able to reflect changes in those characteristics are identified. In the second stage, the measurements are related to a corresponding reference condition to construct indicators. In order to apply, in practice, the general two-stage approach adopted by the SEEA EEA framework, it is necessary to identify:

a) the relevant ecosystem characteristics;
b) the measurements to be used for each of those; and
c) a reference condition for each measurement.

However, the SEEA-EEA framework (UN, 2014) and its technical recommendations (UN, 2017) provide only general recommendations on how to identify these elements in practice. First, with regard to the ecosystem characteristics to measure, these documents provide indicative examples of key ecosystem characteristics (water, soil, carbon, vegetation, and biodiversity); point out that the choice of characteristics will depend on the ecosystem types present in the study area and the ecosystem services being considered and that condition accounts should be compiled separately by ecosystem type; and recommend that ecosystem characteristics be selected on a sound scientific basis, to ensure that they reflect the ongoing functioning, resilience and integrity of the ecosystem.

Secondly, with regard to the measurements that should be used to describe changes in the ecosystem characteristics, the SEEA-EEA framework (UN, 2014) and its technical recommendations (UN, 2017) also provided only general recommendations: Measurements of ecosystem condition should be selected so that they reflect the general ecological state of an ecosystem, its capacity to supply ecosystem services and the relevant trends; variations in these measurements should be responsive to changes in the ecosystem's functioning and integrity. For each ecosystem characteristic, there will usually be more than one relevant indicator and, generally, different indicators will be necessary for different ecosystem types and for different ecosystem services. Ecosystem condition indicators may describe aspects such as the occurrence of species, soil characteristics, water quality, biodiversity, and ecological processes (*e.g.* net primary production) but the indicators selected should be relevant for policy and decision making, for instance because they reflect policy priorities, pressures on ecosystems, or the capacity of ecosystems to generate one or more services.

On the practical side, the technical recommendations (UN, 2017) also recognize that data availability (or the possibility to obtain additional data) is an important consideration in selecting condition indicators. Generally, condition indicators related to characteristics such as vegetation, water, soil, biomass, habitat and biodiversity for different ecosystem types, as well as indicators of relevant pressures and drivers of ecosystem change, will be appropriate. In some cases, composite indicators (combining the effect of different elements/aspects of ecosystem condition) may be useful. Five considerations to be used in selecting condition indicators are "…(i) the degree to which the indicator reflects the overall ecological condition of the ecosystem or key processes within it and is able to signal changes in this condition; (ii) the degree to which the indicator can be linked to measures of potential ecosystem services supply; (iii) how easy it is for policy makers and the general public to understand and correctly interpret the indicator; (iv) data availability and scientific validity of measurement approaches for the indicator; and (v) the possibility to generate new data cost effectively…" (UN, 2017).

Third, while the use of reference or benchmark conditions (and baselines) for indicators is well known and widely used, determining an appropriate reference condition for each indicator is not straightforward either (UN, 2014, 2017). At least two alternative approaches for determining the reference condition can be considered. One possibility is to assume the condition at the beginning of the accounting period as the reference condition and express changes in relation to that point in time. While this approach does suffice for accounting purposes, it entails the important shortcoming that it automatically assigns the same (best) condition to all the ecosystems at the beginning of the accounting period. An alternative approach is choosing as a reference condition that of a pristine, undisturbed ecosystem and then express changes in terms of the deviation from such condition. This approach allows different ecosystems to be compared fairly and its results can be readily interpreted. However, defining what a natural ecosystem looks like and what its conditions are is far from trivial.

In summary, although the general approach to assess the condition of ecosystems —in the context of the SEEA EEA framework— is well established and straightforward, a number of measurement issues and challenges in the compilation of ecosystem condition accounts still persists. As a result, early experiences with the SEEA-EEA framework have shown that different approaches to ecosystem condition accounting have been used in practice, leading to uncertainty about how these accounts should be compiled and used (Maes *et al*., 2019). Selecting appropriate measures of ecosystem condition is a highly challenging task as this is an inherently multidimensional (and, as described above, not entirely well-defined) concept that, on the one hand, is expressed out in various different ecosystem characteristics and is, at the same time, the result of a number of external, ecological and non-ecological, factors affecting the ecosystem. Thus, assessing ecosystem condition involves examining several different characteristics related to the functioning and integrity of the ecosystem. In addition, different ecosystem condition measurements (*e.g.*, water pH, soil nutrients, etc.) are relevant for different types of ecosystems and for different ecosystem services (*e.g*., soil fertility is directly relevant for food provision services, but less so for water supply, etc.). Other issues include the potential to aggregate across different characteristics to derive an overall index of condition, the level of spatial detail required, the selection of adequate reference conditions, and how to record changes in ecosystem condition over time (UN, 2017).

At the time of implementing the pilot tests of the NCAVES-Mexico project, more concrete guidance was found in the works by the working group on Mapping and Assessment of Ecosystems and their Services of the European Commission (Maes *et al*., 2018). The MAES working group proposed a reduced set of ecosystem characteristics to consider as the basis for assessing ecosystem condition either per ecosystem type or across different ecosystems (see Table 2 below). The MAES scheme distinguishes between environmental quality (which express the physical and chemical quality of ecosystems) and ecosystem attributes (biological quality of ecosystems); ecosystem attributes are further subdivided into structural and functional attributes. The ecosystem condition assessment framework proposed by the MAES working group also includes pressures on ecosystems as an important component: Given the strong causal relation between pressures and ecosystem condition, pressures can be used as approximate indicators of ecosystem condition in cases where direct indicators are not available.

Table 2. Classification of ecosystem condition and pressure indicators, as proposed by the Mapping and Assessment of Ecosystem and their Services (MAES) working group. The original classification includes one additional class (*Structural ecosystem attributes monitored under the EU nature directives*) that only pertains to the European Union.

Ecosystem condition		
Environmental quality (physical and chemical quality)		
Ecosystem attributes (biological quality)	Structural ecosystem attributes	Structural ecosystem attributes (general)
		Structural ecosystem attributes based on species diversity and abundance
		Structural soil attributes
	Functional ecosystem attributes	Functional ecosystem attributes (general)
		Functional soil attributes
Pressures		
Habitat conversion and degradation		
Introduction of invasive alien species		
Pollution and nutrient enrichment		

Over-exploitation
Climate change
Other pressures

6.2 Selecting and developing ecosystem condition indicators for the NCAVES-Mexico project

Data availability was the main and first restriction faced when selecting and developing condition indicators for Mexico's ecosystems. As mentioned in section 3 above, an important finding of the *Mexico's country assessment on natural capital accounting and valuation of ecosystem services* was that, in general, there is insufficient data/information on ecosystem services that is solid, readily available, accessible, and has the necessary coverage and temporal and spatial resolution. For this reason, the implementation of the pilot studies of the NCAVES-Mexico project had to rely, mostly, on the statistical and geographical data/information that is regularly collected by various government agencies as part of their operation and which is relevant and — after suitable reformatting, adaptation, or reformulation—potentially useable for ecosystem accounting purposes.

Based on the results of the desk study on *Data availability and sources* included in chapter 3 of the *Mexico's country assessment on natural capital accounting and valuation of ecosystem services*, data sets potentially useful for developing condition indicators relevant/applicable to all or most of the terrestrial ecosystems occurring in the country and for the different classes included in the MAES scheme (see Table 2 above) were identified. Table 3 below shows the variables and indicators that are included in (or can be derived from) the data sets thus identified. Each of these was then examined against the general criteria described in Section 3 above (*i.e.*, that the necessary data should be available for the entire country, with adequate spatial and temporal resolution, for different points in time, etc.) to finally identify those most useful for the purpose. Results from this examination are described in detail in sections 6.4 – 6.11 below.

Table 3. Variables, indicators and indices of ecosystem condition and pressure initially considered (shown in bold face) for Mexico's terrestrial ecosystems, for the four ecosystem services being assessed in the pilot studies of the NCAVES-Mexico project.

Ecosystem condition			
Environmental quality (physical and chemical quality)		**Water-caused soil erosion**	
Ecosystem attributes (biological quality)	Structural ecosystem attributes	Structural ecosystem attributes (general)	**Conservation status of vegetation** **Ecosystem Integrity Index**
		Structural ecosystem attributes based on species diversity and abundance	**Biodiversity** **Ecological Integrity Index**
		Structural soil attributes	**Soil organic carbon**
	Functional ecosystem attributes	Functional ecosystem attributes (general)	
		Functional soil attributes	
Pressures			

Habitat conversion and degradation	**Human Footprint Index**
Introduction of invasive alien species	
Pollution and nutrient enrichment	
Over-exploitation	
Climate change	
Other pressures	

6.3 Linking the ecosystem condition indicators of the NCAVES-Mexico project to the updated guidelines from the SEEA-EEA revision process

Clearly, the very definition of ecosystem condition as well as the proper way to measure it in a form suitable for ecosystem accounting are challenges still found when compiling ecosystem accounts in practice. Further conceptual work, on-the-ground testing and experimentation, and the development of better measurement approaches/methods for this purpose are still necessary (UN, 2018). UNSD recently launched a process to revise the technical recommendations for developing ecosystem accounts within the SEEA EEA framework (UN, 2018). Among other research subjects, ecosystem characteristics and indicators of ecosystem condition were identified as revision issues requiring conceptual work and specific testing and experimentation. The revision of ecosystem condition accounts aimed, in particular, at (i) developing a generalized model or structure of characteristics and indicators of condition for different ecosystem types; (ii) providing a detailed and consistent set of criteria for selecting relevant ecosystem characteristics and condition indicators; (iii) determining whether non-ecological characteristics, such as land use and management practices and pressures, should be included in condition; and (iv) providing a proposal for an indicator typology, *inter alia* (Keith *et al*., 2019; Czúcz *et al*., 2019).

Early results from the revision process have provided further clarification on the components of the condition assessment and additional detail to several key elements necessary for their practical implementation (Keith *et al*., 2019; Czúcz *et al*., 2019):

a) Definitions

- The general approach to assess the condition of ecosystem assets encompasses two stages. The first stage is to identify the most relevant ecosystem characteristics, and the second stage is to identify the appropriate quantitative measures to describe each of those characteristics
- Ecosystem characteristics describe aspects such as vegetation, water, soil, biomass, habitat and biodiversity. Ecosystems have many quantifiable characteristics not all of which should be measured but the most relevant ones should be identified, and appropriate indicators be developed. Characteristics of ecosystem condition should not be restricted to those related to the provision of the final ecosystem services used by humans; rather, they should also include aspects related to the ecosystem’s intrinsic values and the provision of intermediate ecosystem services.
- Variables, indicators, and indices are concrete quantitative measures that can be used to describe the ecosystem characteristics identified.
    - Ecosystem variables are measurable quantities describing physical, chemical or biological characteristics of an ecosystem. Variables measure individual characteristics, but a single characteristic can be described by several variables. Changes in variables do not, by themselves, convey any value judgement as to being good or bad, beneficial or detrimental, etc.

- Reference level is a value against which the current value of a variable is compared in order to derive an indicator. A reference level can reflect a natural state, a temporal baseline (the indicator value for a particular point in time), a desired value (the indicator value that a policy aims to achieve), a prescribed value (such as a legislated quality measure), or a threshold value (an indicator value above or below which there is evidence that ecosystem condition is sub-optimal).
- Indicators are variables with a normative interpretation (*e.g.* a reference level) associated, with a view to informing policy and decisions. An indicator includes the values and their comparison with the appropriate reference level.
- Indices are (thematically) aggregated indicators that, with a single figure, aim to describe broad aspects of the ecosystem. An aggregate sub-index combines several indicators describing a single characteristic of the ecosystem type. An aggregate index condenses all characteristics into a single indicator for a given ecosystem type, or one characteristic across ecosystem types.

b) Selection criteria for ecosystem characteristics and indicators

As a tool to identify the relevant characteristics, variables and indicators to use in the assessment of ecosystem condition within the SEEA-EEA framework, a set of 12 selection criteria was formulated. Criteria applicable to individual variables and their derived indicators include: relevance, state orientation, framework conformity, spatial consistency, temporal consistency, feasibility, quantitativeness, reliability, normativity and simplicity. Criteria applicable to a whole set of indicators are parsimony and data gaps. All the criteria apply to the selection of variables and indicators, but only the first three ones (*viz.*, relevance, state orientation and framework conformity) are applicable to the selection of ecosystem characteristics. The selection of ecosystem characteristics should be made upon a more conceptual basis, whereas the selection of variables and indicators involves more pragmatic criteria.

c) Typology of ecosystem condition

A general, hierarchical typology for ecosystem condition metrics is proposed, as an effort to provide a meaningful order among ecosystem condition indicators, facilitate communication, and provide a logical framework for comparisons across ecosystem types and the aggregation of different indicators into sub-indices or sub-indices into indices. The proposed typology includes:

I Compositional (species-based) indicators comprise a broad range of indicators describing the species composition of ecological communities. These include indicators based on the presence/abundance of a species or species group, or the diversity of specific species groups at a given location and time.

II Structural (vegetation and biomass) indicators describe the local amount of living and dead plant matter (vegetation, biomass) in an ecosystem, including all metrics of vegetation density and cover, either related to the whole ecosystem, or just specific compartments (aboveground, belowground, litter, etc.).

III Functional (ecosystem processes) indicators Encompass simple summary statistics (*e.g.* frequency, intensity) of relevant ecosystem functions.

IV Indicators of abiotic characteristics (physical and chemical state) Include various 'degradable environmental stocks' (*e.g.* soil organic carbon, tropospheric ozone, water table level, impervious surfaces) which directly change (deplete, accumulate) during a degradation process (*e.g.* erosion, pollution, desiccation, or soil sealing).

V Landscape-level indicators of ecosystem mosaics can describe the integrity of landscapes at broader spatial scales, including simple indicators of landscape diversity and connectivity/fragmentation.

d) Procedure

According to these new guidelines, in practice, condition accounts should be developed by first identifying —based on the selection criteria— relevant ecosystem characteristics within each class of the typology. Then, relevant variables to describe each of those characteristics are selected, also according to the selection criteria. Different combinations of these variables in association with reference levels are used to derive condition indicators. Some ecosystem condition indicators can then be combined with relevant ancillary data to derive indicators of the ecosystem's capacity to provide services

Based on the in-depth study of the data sets selected (listed in Table 3 above) for developing condition indicators for Mexico's terrestrial ecosystems, an attempt was made to link them to the SEEA-EEA typology of ecosystem condition (see Table 4 below). In addition, an initial appraisal of how well those variables and indicators meet the individual selection criteria of the SEEA-EEA framework was also attempted (see Table 5 below). These findings are justified and discussed in the detailed descriptions given in sections 6.4 – 6.9 below.

Table 4. Variables, indicators and indices initially considered for assessing the condition of Mexico's terrestrial ecosystems in relation to the new SEEA-EEA typology of ecosystem condition.

SEEA-EEA typology class	Variables	Indicators	Indices
I. Compositional (species-based) indicators	Biodiversity		Ecological integrity index
II. Structural (vegetation and biomass) indicators	Conservation status of vegetation		Ecosystem integrity index*
III. Functional (ecosystem processes) indicators			Ecosystem integrity index*
IV. Indicators of abiotic characteristics (physical and chemical state)	Soil organic carbon	Water- caused soil erosion	
V. Landscape-level indicators			Human footprint

* The Ecosystem Integrity Index aggregates both, structural and functional variables. See full description in section 6.XX below

Table 5. Initial appraisal of whether or not or how well the variables, indicators and indices initially considered for assessing the condition of Mexico's terrestrial ecosystems meet the selection criteria of the SEEA-EEA framework.

	SEEA-EEA typology class			
	I. Compositional indicators	**II. Vegetation and biomass**	**IV. Physical and chemical state**	**V. Landscape pattern**

SEEA-EEA criterion	Biodiversity	Ecological integrity index	Conservation status of vegetation	Ecosystem integrity index	Soil organic carbon	Water-caused soil erosion	Human footprint
Relevance	Yes	?	Yes	Yes	Yes	Yes	Yes
State orientation	Yes	Yes	Yes	Yes	Yes	Yes	No
Framework conformity	Yes	Yes	Partly	Yes	Yes	Yes	Partly
Spatial consistency	Yes	Yes	Yes	Yes	Partly	Yes	Yes
Temporal consistency	No	No	Yes	No	No	No	Yes
Feasibility	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quantitativeness	Yes (ratio)	Yes (ordinal)	Yes (ratio)	Yes (ordinal)	Yes (ratio)	Yes (ordinal)	Yes (ordinal)
Reliability	High	Low	High	Moderate	High	Moderate	High
Normativity	No	Yes	Partly	Yes	No	Yes	Yes
Simplicity	Yes	No	Yes	No	Yes	Yes	No

6.4 Conservation status of vegetation.- INEGI's Land Use and Vegetation 1:250,000 scale charts distinguish the successional stage or conservation status (primary or relatively well preserved *vs.* second-growth or degraded) of vegetation, recognizing three different phases (or successional stages) of second-growth vegetation:

- Tree-dominated, second-growth vegetation,
- Shrub-dominated, second-growth vegetation, and
- Predominantly herbaceous second-growth vegetation

INEGI's Vegetation and land-use charts are freely available for six different points in time (*ca.* 1976, 1993, 2002, 2007, 2011 and 2014). From the information contained in these charts, the extent of the country's terrestrial ecosystems with different conservation status and its changes over time can be readily examined both in tabular (see example in Fig.2) and in a spatially explicit manner.

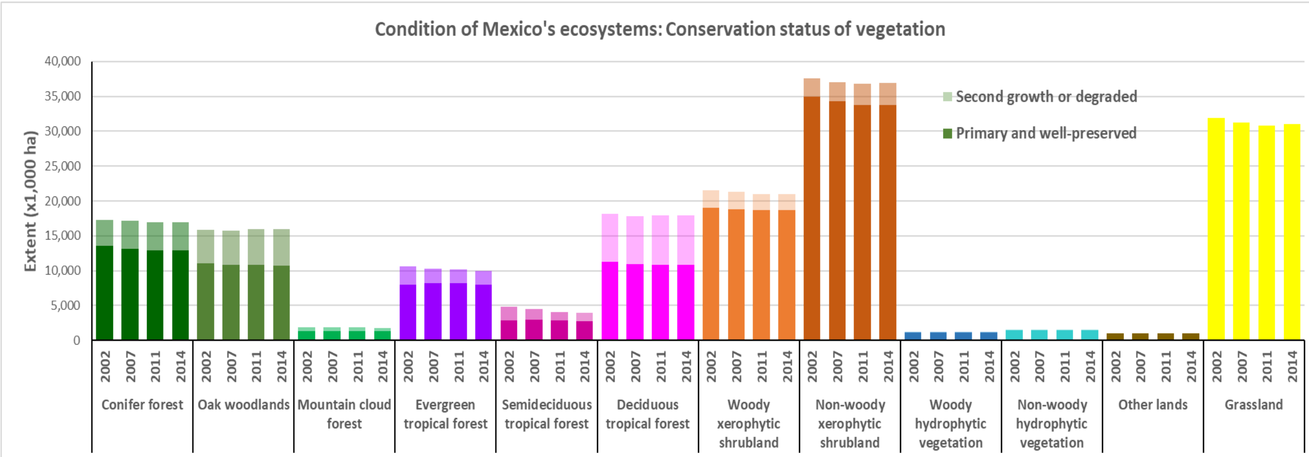

Fig.2 Changes over time in the conservation status (primary and well-preserved *vs.* degraded or second-growth) of vegetation in Mexico's terrestrial ecosystems, as estimated from INEGI's Vegetation and land-use charts for 2002, 2007, 2011 and 2014.

The conservation status of vegetation actually comprises two interlinked variables (extent of well-preserved and extent of degraded vegetation, in ha) that describe relevant structural characteristics of the natural terrestrial ecosystems occurring in Mexico (not applicable to agroecosystems or urban ecosystems). These variables clearly meet all the general criteria described in Section 3 above, as well as most of the SEEA-EEA selection criteria for individual indicators (see Table 5 above), except for normativity and framework conformity. With regard to the normativity criterion, the difficulty lies in setting an appropriate reference level. A pragmatic solution could be setting the extent of each condition (well-preserved vs. degraded) at the beginning of the accounting period as the reference level (separately for each ecosystem type). From an intrinsic point of view, however, a better approach would be setting the extent of primary vegetation (for each ecosystem type) in the absence of (or before) any anthropic impacts as the reference level —which is not easily determined. With regard to the framework conformity criterion, an important issue is that these two variables are inextricably linked to ecosystem extent, which might make it difficult to interpret changes in the levels of these variables, if not examined in relation to the concomitant changes in ecosystem extent.

<u>6.5 Soil erosion</u>.- Based on visual interpretation of satellite SPOT images, followed by on-the-ground verification, INEGI produced a hydric soil erosion, 1:250,000 scale, chart. The chart nicely depicts the extent, the degree (in relative terms), and geographical distribution of water-caused soil erosion in the country as of the period 2010-2015 (see Fig. 3). More importantly, by combining the information provided by this chart with that contained in INEGI's vegetation and land-use chart for the relevant (or closest) period of time (*e.g.*, 2011), the extent and severity (in relative terms) of soil erosion affecting Mexico's terrestrial ecosystems can be readily examined (see Fig. 4 below).

Fig.3 INEGI's water-caused soil erosion, 1:250,000 scale chart for 2010-2015. The chart depicts the relative degree (stable surface, light, moderate, strong or severe) of erosion affecting the different soil units in the country.

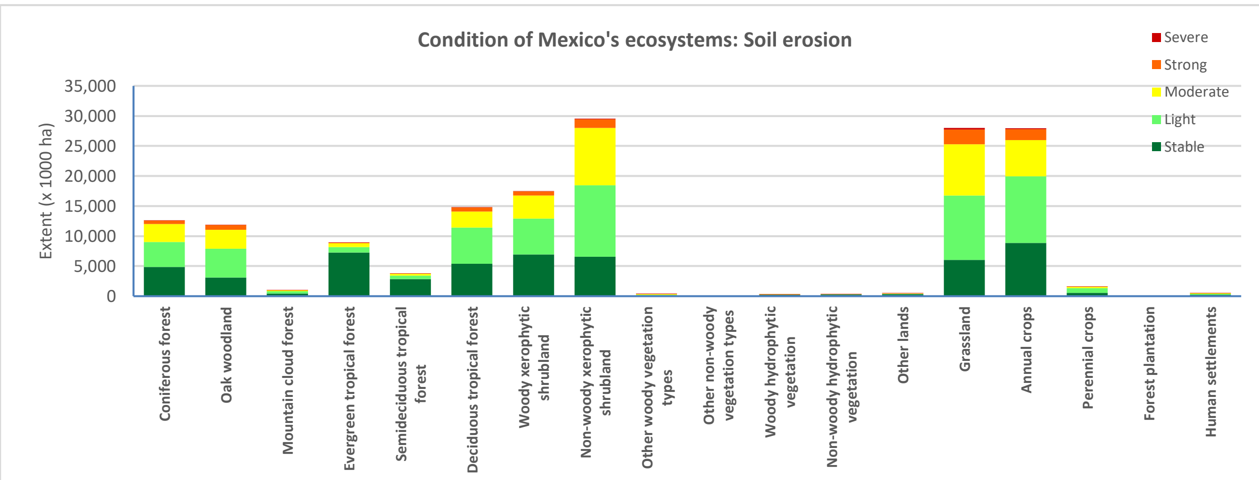

Fig.4 Relative level of soil erosion in Mexico's terrestrial ecosystems, as estimated from INEGI's Water-caused soil erosion chart (2010-2015) and INEGI's Vegetation and land-use chart for 2011.

The information contained in INEGI's hydric soil erosion chart provides a straightforward indicator of a relevant abiotic characteristic of Mexico's terrestrial ecosystems (including agroecosystems) and includes an in-built reference level (stable surface). The data available for this indicator meet most of the general criteria described in Section 3 above (except for availability of a consistent time-series), as well as most of the SEEA-EEA selection criteria for individual indicators (see Table 5 above), except for temporal consistency and, partly, for reliability. With regard to the reliability criterion, the difficulty lies in the fact that erosion severity is not actually measured but only visually assessed (using an ordinal scale) by experts, which introduces some level of subjectivity in the indicator values. At present, however, the most significant shortcoming of this indicator is that INEGI has so far only produced one edition (for the period 2010-2015) of this chart and producing a new, updated edition is not yet contemplated. Nevertheless, whenever INEGI updates this chart, the new data should be readily incorporated into Mexico's ecosystem condition accounts.

6.6 Soil organic carbon.- Information on the content of organic C in the soil's top horizon can be readily obtained from the vast archive of soil data that INEGI (as part of its national soil mapping programme) and CONAFOR (as part of its National Forest and Soils Inventory programme) have been compiling. As of today, data available come from a total of 21 806 soil profiles sampled throughout the country over a long period of time (INEGI data: since 1968 to date; CONAFOR data: 2009-2014) and using different methods (see example in Fig.5 below).

Fig.5 Geographical distribution of part of the soil profile data set collected by INEGI as part of their national soil mapping programme. The figure shows the distribution of the 4,428 soil profiles used for the construction of INEGI's soil chart series II, scale 1:250,000.

Soil organic carbon is a key abiotic characteristic of terrestrial ecosystems (including agroecosystems). From this variable, relevant indicators of the condition of Mexico's terrestrial ecosystems could, in principle, be derived. Unfortunately, as of today, the data available for this variable do not meet key selection criteria (see Table 5 above), including temporal and spatial consistency; they do not meet the normativity criterion either. With regard to the spatial consistency criterion, although all the data points are fully georeferenced, in order for them to provide a comprehensive, spatially-explicit description, they would have to be first made comparable and, then, spatially interpolated in order to produce a map of the variable (or of any derived indicator). Several efforts have been made to consolidate, make comparable and map this vast data set either directly (*e.g.*, Cruz-Gaistardo & Paz-Pellat, 2013; Paz Pellat *et al*., 2016) or through the use of advanced geostatistical modelling techniques (Guevara *et al*., accepted). However, to date, no agreed-upon, sufficiently accurate method has been produced yet. An initiative recently launched by UNSD and INEGI to implement in Mexico the S-World approach (Stoorvogel *et al*., 2017) for modelling soil properties in a spatially-explicit manner using local (tier 2) data might be able to help to fill this important data gap.

At present, however, the most significant shortcoming of the data available for this variable is that they are, in reality, a mixture of recent and legacy data collected over a long period of time, so that they cannot be referred to a specific point in time (temporal consistency criterion). Periodically updating the data in the future (availability of a time series in section 3) is a closely related issue for which no simple solution exists either, as this necessarily demands specific field-sampling efforts for monitoring the soil variables across the country.

Mexico has not yet reported on indicator *15.3.1 Proportion of land that is degraded over total land area* of *Sustainable Development Goal 15. Life on Earth* (see Gobierno de la República, 2018). This indicator encompasses three sub-indicators, namely, Land cover change, Net primary productivity, and Soil Organic Carbon Stocks. Information on land cover change are readily available in Mexico but, as shown here, not so for the sub-indicator on soil organic carbon.

6.7 Biodiversity.- CONABIO's National System of Biodiversity Information (SNIB, for its Spanish acronym) contains a vast archive of fully-georeferenced collection records of plant and animal specimens in Mexico. The SNIB contains almost one million collection records (see Fig. 6 below) that document in detail the presence of 14,424 different species of higher plants across the country, distinguishing between endemics and species at risk.

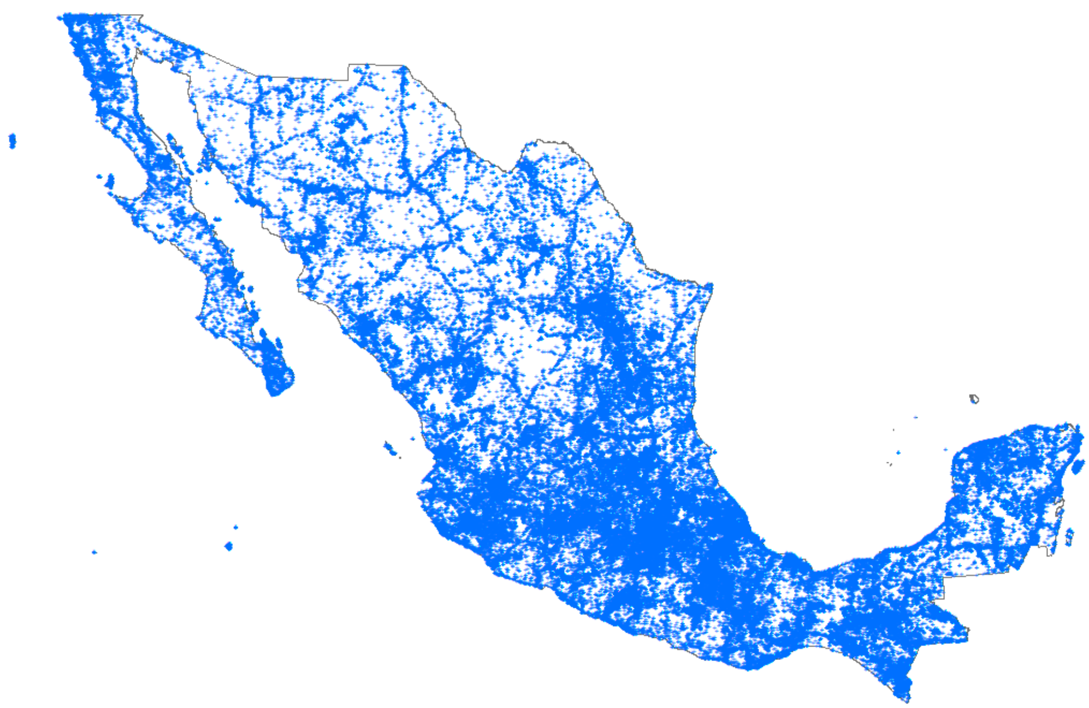

Fig.6 Geographical distribution of 887,242 unique collection records of higher plants in Mexico, as available in the National System of Information on Biodiversity. Notice the biased distribution of sampling points, strongly clustered along highways.

From this vast data set, relevant variables and indicators (*e.g.*, species richness and number of species at risk per ecosystem type) of the condition of Mexico's terrestrial ecosystems could, in principle, be derived. Unfortunately, the SNIB data actually come from voucher specimens stored in various Mexican and international herbaria, the specimens having been collected throughout the country over a very long period of time (since the late XVI century to present). Thus, as is also the case with soil organic carbon, this legacy data cannot be referred to a particular point in time (temporal consistency criterion). Periodically updating the data in the future (availability of a time series in section 3) is another closely related issue that cannot be easily solved.

Another shortcoming in the data available for these variables is that the samples distribution is strongly biased/limited by accessibility conditions (spatial consistency criterion). Although all the sampling points are fully georeferenced, in order for them to provide a comprehensive, spatially-explicit description, they would have to be first spatially interpolated in order to produce a consistent map of the variable (or of any derived indicator). Some efforts have been made to use these data sets to map the potential distribution of species by means of geostatistical models (*e.g.*, Ceballos *et al*., 2006) but these have been limited to only some species.

In summary, the legacy collection records data currently available from CONABIO's SNIB are not suitable to construct a species-based biodiversity indicators. CONABIO (together with INECOL and other institutions) recently (as of 2014) launched an effort to set up a National System for Biodiversity Monitoring, which is now collecting observational data (by means of camera and sound-recording traps) on species occurrences at a number of sampling sites across the country (mostly located in protected areas). The data collected by the SNMB will be more suitable for this purpose.

<u>6.8 Aggregated indices of ecosystem characteristics</u>.- Recent studies have attempted to integrate several variables into composite indicators or indices that aim to provide, in a single figure, a measure of the overall condition of ecosystems. While integrating several related variables into a single index allows for easier communication and interpretation, the construction and use of indices also entails two important difficulties: Indices combine or lump together several different variables which may be independent of, or partially correlated with, each other. Thus, changes in the index value have no easily discernible meaning or interpretation without revisiting its component variables. Secondly, in most cases there is no natural or sound way to assign relative weights to the various variables contributing to the index value. Any approach undertaken to form the index involves making often untested assumptions about the relative importance of each variable and the correlations among them.

Two such indices have been recently implemented for Mexico.

<u>6.8.a The Ecosystem Integrity Index (INECOL-CONABIO)</u>.- In 2014, the National Commission for the Knowledge and Use of Biodiversity (CONABIO), together with the National Forestry Commission (CONAFOR) and the National Commission of Natural Protected Areas (CONANP) launched a coordinated effort to design and implement a National System for Biodiversity Monitoring (SNMB) in Mexico. The SNMB aims to monitor the state of the country's biological diversity and its changes over time, throughout the national territory. One of the key components of the SNMB is the Ecosystem Integrity Index (EII), a synthetic index to monitor the condition (or "health status") of the country's ecosystems. The EII was jointly designed by CONABIO and INECOL specialists (Garcia-Alaniz *et al*., 2017), as part of the activities of the *Role of Biodiversity in Climate Change Mitigation* (ROBIN) project funded by the European Union.

The EII seeks to reflect the structural integrity of ecosystems in a single figure. In this approach, ecosystem integrity is evaluated in terms of how different an actual ecosystem is from some original or desired condition. The underlying idea is that by measuring compositional, structural and functional attributes of ecosystems, Ecosystem Integrity can be inferred and assessed— in relative terms with respect to the original, unimpaired condition.

The EII is constructed from two types of information (physical-chemical conditions and structural and functional attributes) that, together, determine the condition of the ecosystem. Data from different sources are used to quantify or estimate these components. Ecosystem structure is evaluated based on field measurements of forest structure variables (*e.g.*, average tree height, average DBH, average canopy diameter, proportion of dead trees standing, tree density, etc.) that CONAFOR periodically collects throughout the country as part of its National Forest Inventory. These point data (and additional variables derived from them, such as the standard or the absolute deviation of tree height, etc.) are then spatially interpolated by building statistical models using satellite, topographic and climatic data as predictor variables.

Functional features of ecosystems (such as annual gross primary productivity, annual net photosynthesis, etc.) are evaluated using estimators derived from satellite imagery (MODIS). Holdridge life zones and site elevation are used to infer the values expected under relatively unimpaired conditions, given the physical-chemical conditions of the site. A third group of variables reflects factors that can affect the condition of ecosystems, such as the presence of human settlements, fields, pastures, etc. All the variables are rated using a single 0 to 1 score, relative to the unimpaired conditions. All the structural and functional variables are then integrated into a complex statistical model (Bayesian network) to produce the EII (see conceptual scheme in Fig. 7 below), which values can be represented in the form of maps (see example in Fig.8 below).

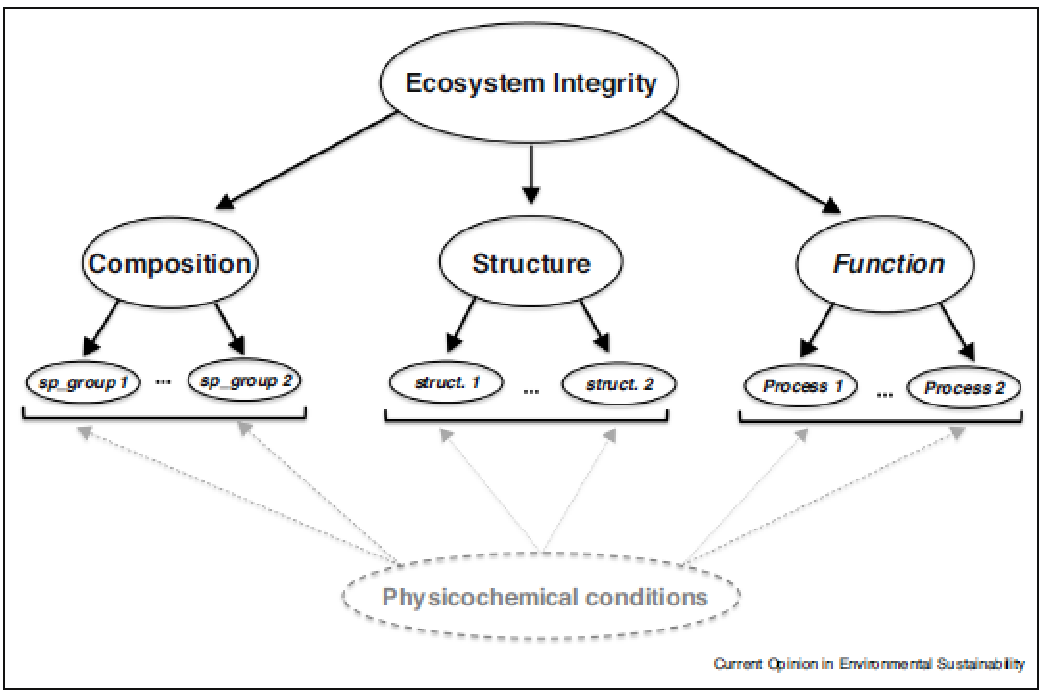

Fig.7 Conceptual model of the Ecosystem Integrity Index. The physicochemical setting present in a given area (bottom) establishes the context for the composition, structural and functional attributes (middle) of the ecosystem. These are associated with a certain ecosystem integrity condition (top) (taken from García-Alaniz *et al*. 2017).

The SNMB began monitoring the condition of the country's ecosystems using the EII in 2015. CONABIO and INECOL have produced yearly country-wide charts of the EII with a 1km spatial resolution for 2004 through 2014. More recently, a 250m spatial resolution data set for the year 2014 was also released (see Fig. 8 below). All these data sets are freely and openly available. CONABIO and INECOL are currently working on incorporating (species-based) compositional data into the IIE, using observational data recorded by camera- and sound-recording- traps. In addition, plans to produce

250m resolution data sets for other dates besides 2014 are in course.

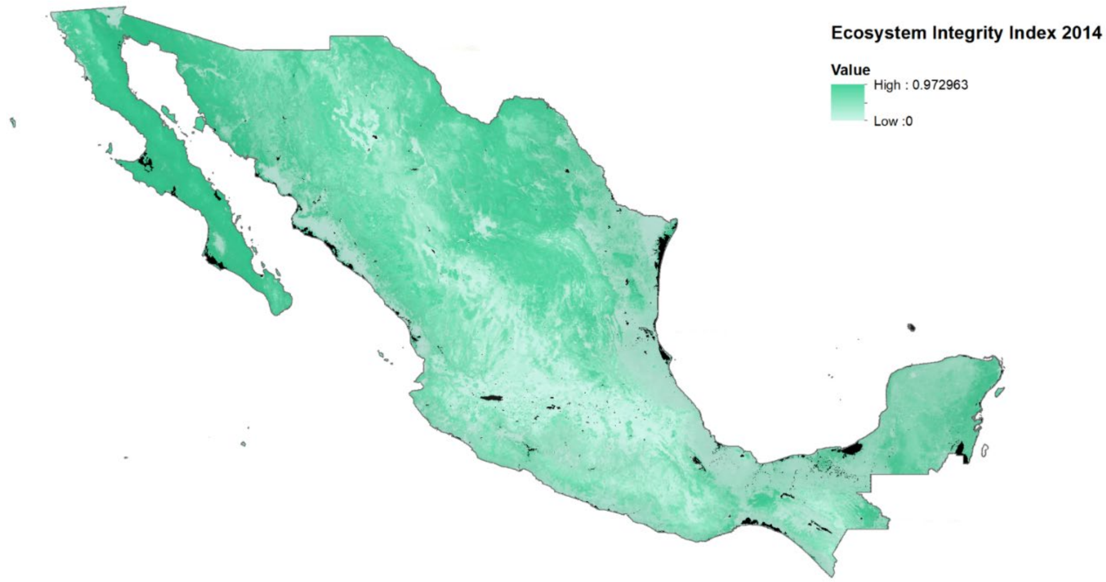

Fig.8 Ecosystem Integrity Index for 2014. The EIII aims to reflect the structural integrity of ecosystems in a single figure. Values closer to 1 denote ecosystems relatively whose structure, functioning and composition is relatively unimpaired.

The EII is an aggregated index of relevant structural and functional characteristics of Mexico's terrestrial ecosystems (including agroecosystems) and includes an in-built reference level (an unimpaired original condition). The EII meets most of the general criteria described in Section 3 above (except for availability of a consistent time-series), as well as most of the SEEA-EEA selection criteria for individual indicators (see Table 5 above), except for temporal consistency, simplicity and reliability.

With regard to the simplicity criterion, although the EII constitutes an attractive, useful communication tool, that can be easily communicated to non-specialized audiences, in reality it lumps together (by means of a complex statistical model) several different variables. Thus, the EII values (and its changes) are not easily interpretable; it is necessary to trace back the EII values/changes to the component variables in order to relate and interpret them in relation to ecosystem services.

With regard to the reliability criterion, the problem lies in the fact that even though the EII uses a substantial amount of primary data (field collected by the National Forest Inventory), these have to be first spatially interpolated by means of geostatistical models. More importantly, the EII also incorporates a number of estimators of functional features of ecosystems (such as annual gross primary productivity, annual net photosynthesis, etc.) which are not actually measured but derived from satellite imagery (MODIS). These factors add to the uncertainty of the EII values.

The lack of a consistent time series for the EII seems to be only a temporary limitation for the use of this indicator, as CONABIO e INECOL are planning to produce 250m resolution data sets for other dates besides 2014 in the near future.

From a more conceptual point of view, one other shortcoming of the EII that might be worth considering is that, being based on a number of forest structure variables, the index values are naturally biased towards forested ecosystems and tend to undervalue other key ecosystems such as natural grasslands, scrublands, etc. (personal observation, data available upon request). Further, closer examination of the distribution of the EII values across different ecosystems is necessary and perhaps its use as an index of ecosystem condition be limited to only forested ecosystems.

6.8.b Ecological Integrity Index.- The Ecological Integrity Index (EII') proposed by Mora (2017) aims to characterize "…the potential of natural landscapes to support ecological integrity in maintaining biotic and abiotic apex predators' interactions…". Conceptually, the EII' is based on an ecological hierarchical network as a framework to describe changes occurring at several levels in an ecological hierarchy (see Fig. 9 below). Accordingly, the methodological approach includes: "(a) the construction of spatially explicit manifest indicators for ecological integrity as the foundation for the evaluation system; (b) the application of structural equation models for deriving a set of latent indicators that build the notion of ecological integrity at two levels (1st and 2nd order latent indicators); and finally, (c) a general indicator that summarizes the integrity in the ecological condition" (Mora, 2017).

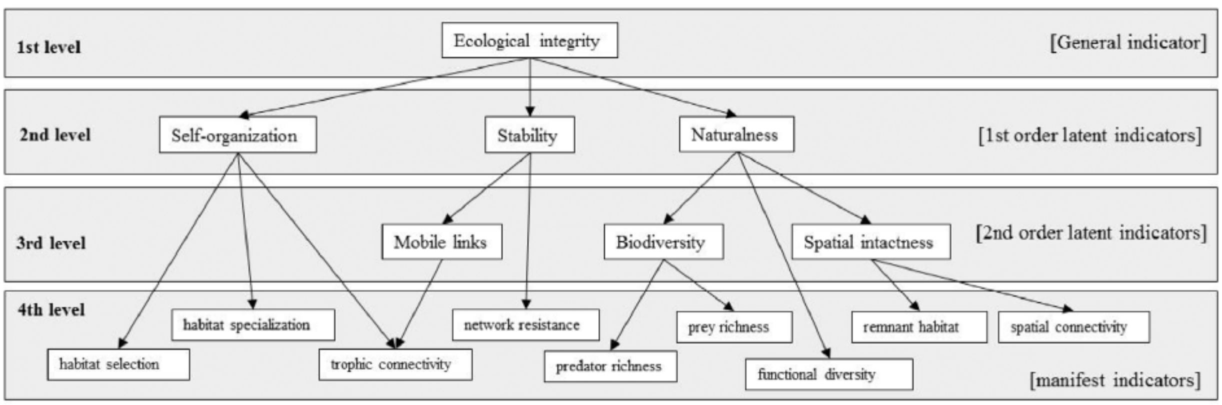

Fig.9 The Ecological Integrity hierarchy framework for evaluating the condition of natural ecosystems based on landscape characteristics that sustain predator-prey interactions (taken from Mora, 2017).

The EII' implemented by Mora (2017) was constructed based on previously constructed statistical models of the potential distribution of 232 mammal species and 7 top predators (Ceballos *et al*., 2006), along with data from INEGI's vegetation and land-use chart series IV. By overlapping and doing simple operations with the species distribution models, eight so-called "manifest ecological integrity indicators" (functional diversity, predator/prey diversity, habitat specialization, habitat selection, remnant habitat, habitat connectivity, trophic connectivity, and network resistance) were calculated. The manifest indicators were then used to build spatially-explicit Structural Equation Models for seven so-called "latent (or abstract) indicators of ecological integrity": Self-organization, Stability, Naturalness, Biodiversity, Mobile links, Spatial intactness, and Landscape heterogeneity. The latent indicators are finally aggregated into an Ecosystem Integrity Index (Mora, 2017). A country-wide chart of the EII' with a 1km spatial resolution for an un-specified date (see Fig.10 below) is available upon request.

The 1km spatial resolution of the EII' data set is relatively coarse for the purposes of the NCAVES-Mx project and no consistent time-series data are available (see general considerations in Section 3 above). The EII' meets most of the SEEA-EEA selection criteria for individual indicators (see Table 5 above), except for temporal consistency, reliability and simplicity.

With regard to the simplicity criterion, the EII' lumps together a number of different variables and synthetic indicators into a single figure, which makes its values difficult to interpret and relate to field conditions. Thus, the EII' values (and its changes) are not easily interpretable and, given the complexity of its construction process, it would be very difficult to trace back the EII' values to the underlying component variables.

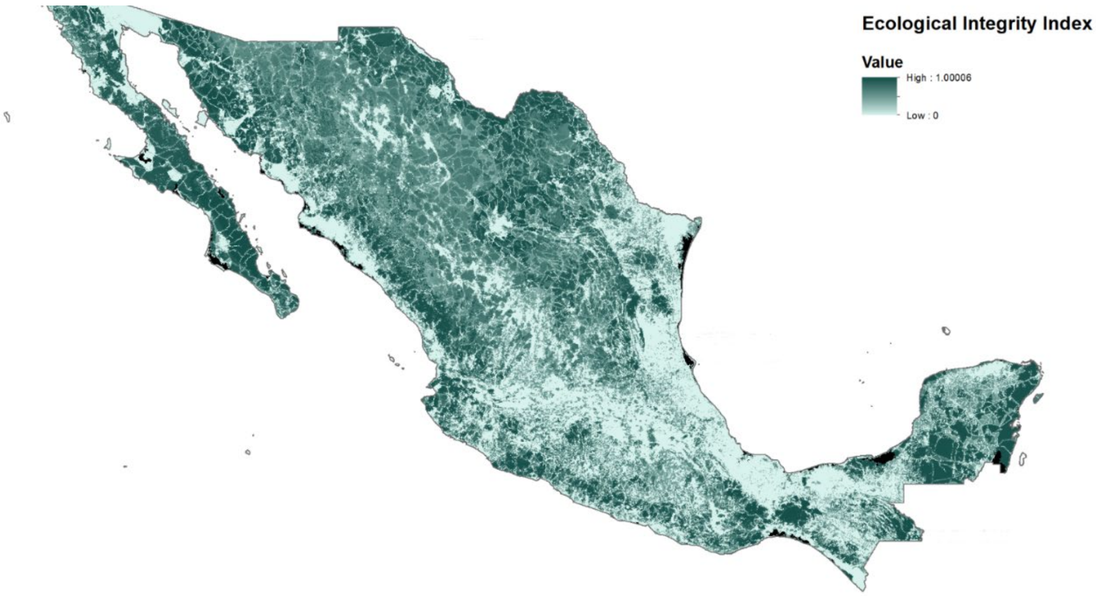

Fig.10 Ecological Integrity Index. The EII' aims to evaluate the condition of natural ecosystems based on landscape characteristics that sustain predator-prey interactions.

With regard to the reliability criterion, the problem lies in the fact that, except for the information derived from INEGI's Vegetation and Land-use chart, all the other components of the EII' are model estimates/projections and no actual measurements. The EII' is constructed by overlapping ("stacking") a number of potential distribution models for individual species and, from this, predator-prey interactions are claimed to be inferred. While the use of stacked species distribution models has been increasing lately as a modelling tool to examine biodiversity patterns and other issues, there have been repeated calls to first —as with any predictive empirical model— validate the models through an evaluation of their predictive performance prior to further use (*e.g.* Fielding and Bell, 1997; Gastón & García-Viñas, 2013). While the species distribution models used in the construction of the EII' were built from actual field collection/sighting records, they do not seem to have been properly validated (see Ceballos *et al*., 2006) nor has the EII' model itself. All these factors add to the uncertainty of the EII' values.

Finally, with regard to the spatial consistency criterion, the same fact that the EII' is constructed essentially from model projections —rather than actual measurements— implies that its values cannot be referred to a specific point in time and cannot be updated.

<u>6.9 Indicators of socio-economic pressures and drivers of change</u>.- As can be seen from the results above, the major limitation faced when compiling ecosystem condition accounts for Mexico's ecosystems is the scarcity of relevant data with the required qualities (see section 3 and Table 5 above). On this regard, the ecosystem condition assessment framework proposed by the MAES working group considers that, given the strong causal relation existent between pressures and ecosystem condition, in cases where direct indicators of ecosystem condition are not available, pressure indicators can be used as approximate indicators of ecosystem condition. Thus, the possibility of using variables and indicators of the socio-

economic pressures and drivers of change affecting Mexico's ecosystems was then explored.

Abundant data are available on a range of human activities affecting Mexican ecosystems, including infrastructure works, agriculture and livestock ranching, urban development, tourism development, mining, etc. However, some of these activities can often physically coincide, fully or partially, in some locations or times, and it is their aggregated impact what really affects the ecosystems functionality. This aggregated impact can hardly be captured if the various activities are examined separately, in isolation from each other. Thus, an integrated approach that aggregates the combined impacts of the various activities occurring in the same place into a composite index might be preferable.

Since the launching of the Ecological Footprint index in the mid 1990's (Wackernagel & Rees, 1996), there have been several initiatives to compile indices denoting the physical impact that the range of human activities have on the structure/integrity of ecosystems. Two of the best known, global-level attempts to construct spatially-explicit indices of this type were carried out by Sanderson *et al*. (2002) and, more recently, by Venter *et al*. (2016). The first implementation of a Human Footprint for Mexico was by González-Abraham *et al.* (2015), which depicts conditions as of 2011. More recently, SEMARNAT made a more comprehensive implementation of the Human Footprint for Mexico, also for the year 2011, which was included in the 2015 edition of the Mexico's State of the Environment Report. In response to an *ad hoc* request by the NCAVES-Mexico project, SEMARNAT decided to produce an updated version of the index with data for 2014-2015.

The Human Footprint index (HF) is based on previous work by Bonham-Carter (1994) and González-Abraham *et al*. (2015). The indicator denotes, in relative terms, the extent to which natural environments have been modified or transformed by human activities. It is computed by estimating/assessing both, the Extent and Intensity of the transformation caused by various human activities —for which spatially explicit information is available— including:

- Cities and towns (< 500 inhabitants, 500 - 2500 inhabitants)
- Agriculture and aquaculture; forest plantations; cultivated pastureland
- Roads (highway, dirt-road, carpeted road, gravel road), railways, electricity transmission lines
- Industry
- Wastewater treatment facilities
- Artificial salt flats
- Archaeological sites
- Solid waste final disposal sites (dump sites, sanitary landfills)
- Mines (primary, secondary, tertiary zones)

The <u>extent</u> of the transformation induced by each activity is expressed in terms of the area covered by the activity; for linear features (*e.g.*, transmission lines) 100m or 250m wide buffers were considered, for point features (*e.g*. archaeological sites) a 500x500m extent was imputed to each of them. The <u>intensity</u> of each activity was expressed in relative terms using a three-point ordinal scale (5, low; 7, medium; and 10, high intensity), depending on the perceived severity and duration of the impact (*e.g*., urban areas -> high intensity; agriculture -> medium intensity, forestry -> low intensity, etc.).

The HF index is computed based on actual, spatially explicit data (spatial scales ranging from 1:50,000 to 1:250,000) that are compiled and updated regularly or at irregular intervals by relevant government agencies including INEGI, SEMARNAT, Secretaría de Comunicaciones y Transportes, CONAGUA, Instituto Nacional de Antropología e Historia, etc. SEMARNAT has so far produced two country-wide HF maps for 2011 and 2014-2015, with a 500m spatial resolution. Based on this information, the geographical distribution, extent and severity of the impact of human activities on the country's ecosystems (and their changes over time) can be readily examined (see example in Figs. 11 and 12 below).

Fig.11 Geographic distribution of Human Footprint values in Mexico as of 2011.

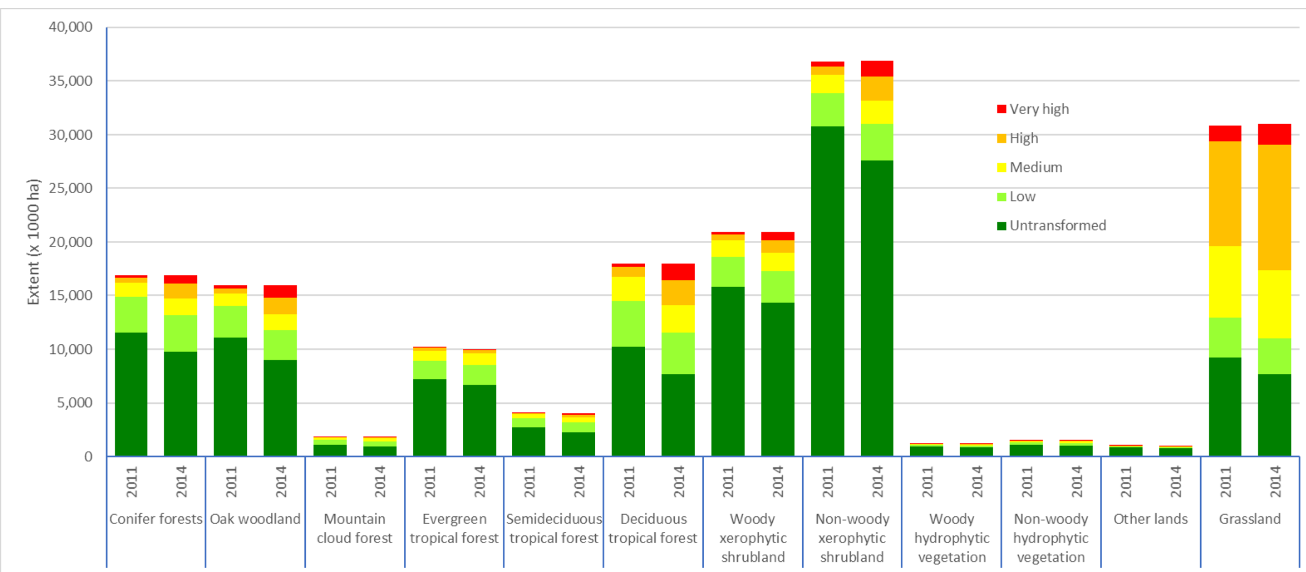

Fig.12 Changes over time (2011 to 2014/2015) in the impact of human activities on the main ecosystems in Mexico.

As can be seen, the HF index meets all the general requirements stated in section 3 above. It can be updated whenever new information on infrastructure and human activities occurring in the country becomes available. In addition, when (spatially-explicit) information on other not yet considered activities becomes available, the index can readily incorporate it. On the other hand, the HF lumps together a number of different variables denoting the influence of various human activities that impact or modify natural landscapes. Its main shortcoming is that its values (and its changes) cannot be readily interpreted (or translated into actionable terms), as a given change might be the result of changes in one or several of its component variables.

On the other hand, however, the HF index clearly violates two of the main SEEA-EEA selection criteria, namely, state orientation and framework conformity. In fact, contrary to the view adopted by the MAES working group and a rather extended practice (*e.g.*, Rendon *et al*., 2019; Maes *et al*., 2019), the SEEA-EEA criteria specifically recommends avoiding the use of pressure and other non-ecological variables (*e.g*., protection status, land management, etc.) in ecosystem condition accounts. Instead, the recommendation is to identify the underlying 'degradable stocks' affected by pressures and use these as condition indicator. While the rationale for this strict requirement holds, it overlooks some important facts both, practical and conceptual. On the one hand, the actual impact of environmental pressures on ecosystems often cannot be easily captured by one single variable, particularly when several environmental pressures act simultaneously on the same ecosystem or place. In such cases, the pressures on the ecosystem may be known, but the combined effects on the ecosystems' functioning and condition are often not well understood. As the total impact cannot be directly measured, it would, at least can be accounted for by considering the various pressures impinging on the same site. On the practical side, it is true that environmental pressures are often used in cases where data are not available but this is very often the case particularly in not so-data-rich countries. Excluding the use of environmental pressure indicators altogether might restrict severely the scope of the analyses. In addition, restricting the analysis of condition to state indicators might make its findings less relevant in practice, as policy responses cannot operate directly on state variables but they do so through regulating, eliminating or ameliorating pressures.

6.10 Conclusions and lessons learned

Data availability. Clearly, the first and major issue faced when compiling ecosystem condition accounts for Mexico's ecosystems was the availability of sound, reliable data that meet all the necessary requirements (general considerations in Section 3; SEEA-EEA selection criteria in Table 5). For example, for the pilot projects of the NCAVES-Mexico project, only seven variables/indicators/indices were initially identified based on data availability. Upon closer examination, fully suitable data (*i.e*., meeting the various requirements/criteria set in section 3 above) were only available for only two of those, namely, the conservation status of vegetation, the Human Footprint Index. Data currently unavailable for the Ecosystem Integrity Index and soil erosion might be produced or made available in the near future. However, suitable data on key variables such as soil organic carbon content and biodiversity will be more difficult to obtain.

Vast amounts of relevant data are available in Mexico, obtained through soil surveys, the national forest inventory, the national system of information on biodiversity, and other national programmes, but having been compiled for purposes other than ecosystem accounting, those data sets do not readily meet the requirements necessary to be used for this purpose. More efforts are needed to collect/compile country-wide, spatially explicit, moderate resolution, multi-date data on biophysical variables/indicators of ecosystem condition, using existent and traditional data sources (*e.g.*, field monitoring), data from other sources (*e.g.*, remote sensing), and suitable modelling tools (*e.g*. S-World).

For these reasons, the push to avoid the use of pressure indicators to assess ecosystem condition might be overly restrictive in practice in the rather common cases where suitable data on direct indicators are not available.

Variables, indicators and indices. Being measures of biophysical variables, variables/indicators of ecosystem characteristics such as soil organic carbon, soil erosion, biodiversity, etc. might not always be easily interpreted by non-specialists and need specialized knowledge for interpretation. Nevertheless, their values and changes can be more readily related to particular ecosystem services and to the ecosystem's capacity to supply them. On the other hand, indices (composite indicators) often constitute attractive, useful communication tools, as they can be easily communicated and interpreted by non-specialized audiences. However, as they lump together data from several different variables, the meaning of their values (and their changes) are not immediately clear. It is often necessary to trace back the values/changes to the component variables in order to relate and interpret them in relation to ecosystem services and translate those findings into actionable information. For example, although the two indices examined aimed to evaluate the integrity of ecosystems, they use different sets of variables, namely, forest structure and function in the case of the EII vs. predator-prey interactions in the case of the EII'. Thus, these two equally-named, equally-scaled indices in reality reflect different aspects of ecosystems. Indices lump together several different variables and there is no clear, univocal, objective way to assign weights to each component.

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Appendix
Data:

- Abundance of statistical and geographic data for country-wide analyses
- Data available collected for other specific purposes; need to adapt/recalculate/reformat for use in valuation of ecosystem services
- Spatial or temporal resolution of available data insufficient for studies at a local-level or on "specialized" services
- The experience gained through the pilot studies being carried out as part of the NCAVES-Mexico project shows that, for country-wide level studies, this information is useful and fairly sufficient, although a number of data gaps still remain, particularly with regard to information on ecosystem condition, and on the supply of ecosystem services, especially for the more complex services such as pollination and others. Also, some important data sets provide valuable information but in a non- or only partly spatially explicit manner, which limits their usefulness for ecosystem accounting purposes. More importantly, such data and information, lack the high temporal, spatial or thematic resolution that is necessary for examining specific services at a local level.
- the insufficient (or lack of) data/information on ecosystem services that is solid, readily available, easily accessible, and of sufficient temporal and spatial resolution,
- The literature review conducted for this assessment, together with the work being carried out for the pilot studies of the NCAVES-Mexico project, show that the only information currently available specifically dealing with the volume, flow and value of ecosystem services in Mexico is that produced by the many ecosystem services valuation studies that have been conducted in the country. As already discussed, while those studies have provided valuable information and insights, several of them suffer from a number of design, technical and dissemination issues that prevent their results from being more generally useful and easily accessible.
- various GOM agencies regularly collect, as part of their operation, statistical and geographical data and information which are fully relevant and potentially useable for examining different aspects of ecosystem accounting. However, having those data been collected for specific purposes other than ecosystem services accounting, they need to be first reformatted, adapted, reformulated or used as inputs for biophysical models/analyses prior to use them for analysing ecosystem services stocks and flows, etc.

- The experience gained through the pilot studies being carried out as part of the NCAVES-Mexico project shows that the data/information available from government sources is indeed useful for country-wide level ecosystem accounting studies, but a number of data gaps still remain, particularly with regard to information on ecosystem condition, and on the supply of ecosystem services, especially for the more complex services such as pollination and others. In addition, some important information is available only in a non- or partly spatially explicit manner, which limits its usefulness. Finally, data and information available often lack the high temporal, spatial or thematic resolution that is necessary for examining specific services at the local (as opposed to the countrywide-) level.

- **This set of selection criteria has important implications on other aspects that have been commonly considered in examining the ecosystem condition.** One consequence of these selection criteria is that **Concludes that** non-ecological variables, for example pressures and drivers of ecosystem change, land use and management practices are often easier to quantify but only indirectly represent ecosystem condition. Pressures can be used sometimes as a proxy for condition, but should not be combined with direct indicators of condition. The characteristics of ecosystem assets, in terms of their state or ecological stocks and their change over time, should be measured as the condition variables. These provide more direct measures than derived measures from human activities that create pressures, drivers, or land management activities, including protected areas. Relationships between indicators based on human activities and the condition of ecological stocks can be difficult to define and may vary through space or time, for example, there is no inherent relationship between protection status and ecological condition. Pressures or land management activities are often not direct explanatory variables of changes in condition of ecosystem characteristics. A single pressure may affect more than one ecosystem characteristic, or alternatively, several pressures may interact to affect the condition of a single characteristic. Further, changes in condition as a stock can be detected without knowing the pressure or driver. The conceptual criteria of state orientation and framework conformity imply that **Pressures, which are** often considered as an "indirect approach" for measuring ecosystem condition (e.g. Erhard et al., 2016, p.31). If there are little data available on state, then pressures can be considered a useful surrogate, as long as the relationship between the two is well understood and justified (Bland et al. 2018). This is clearly a compromise, as conflating pressures with state variables can compromise the credibility and salience of the resulting accounting tables. Nevertheless, this does not necessarily mean that accounting tables should be blind to the policy issues highlighted by the most relevant pressures. In the case of most pressures (*erosion*, *pollution*, *invasion…*) there is an underlying 'hidden' variable, that reflects the 'degradation' of the ecosystem with respect to that specific pressure. This underlying variable is an environmental 'stock' (e.g. the thickness of soil layer, the concentration(s) of pollutants, or the abundance of invasive species) that is gradually degraded (depleted, accumulated...) by the pressure. Typically, such stocks can meet all the criteria, so they can be more appropriate for condition accounting than their change or the connected flows (degradation / depletion rates, fluxes, flows, or other indicators of flow intensity). Using these 'degradable stocks' as condition indicators comes with multiple further advantages: they can be used to formulate very clear and pertinent policy messages on ecosystem degradation (as a change in these environmental stocks); and the degree of policy attention highlights those 'degradable stocks' that are perceived as the most valuable or most endangered.

Thirdly, condition measures should ideally be actually measured on each ecosystem asset in the study area, periodically over time. However, in many cases data for some condition indicators may not be available for all the ecosystem assets or may be only recorded at some localities or times of the year. In such conditions, it is often possible to build a statistical model linking the indicator to other more easily measured variables (*e.g.*, remote sensing data) and thus predict (estimate) values for the indicator for those ecosystems or localities where no actual measurements are available.
Comments**.-** Condition indicators that are generally applicable to all ecosystems in the country can be found and it is not always necessary to identify specific indicators por each ecosystem type **[Rendon et al., 2019]**Despite the great progress that has been made in mapping ecosystem services (Maes and Burkhard 2017), which is often based on the geographical distribution of ecosystems, more research on the relationship between ecosystem structures, processes and pressures is still needed to produce robust and reliable maps on ecosystem condition.