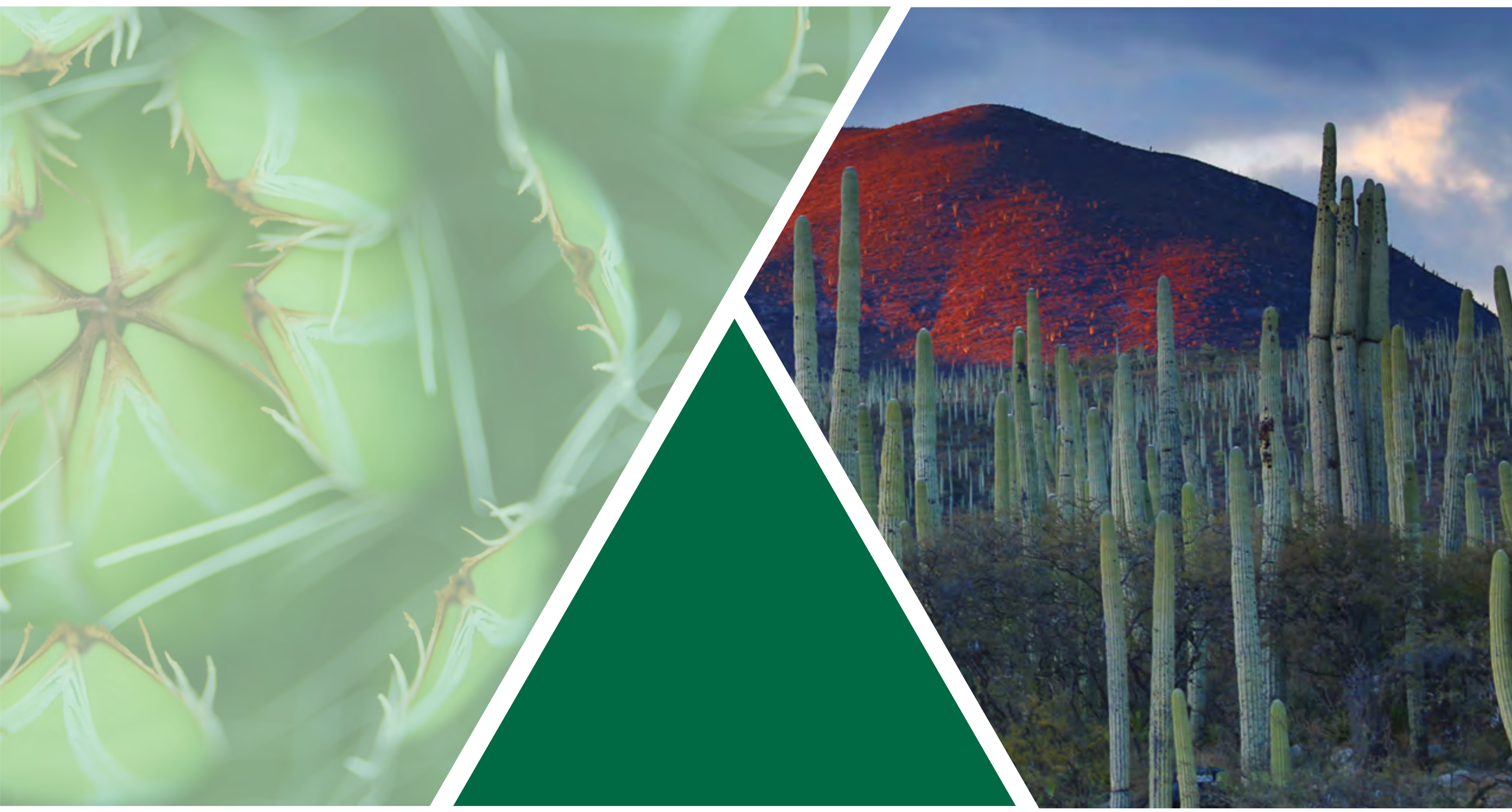
ECOSYSTEM ACCOUNTS OF MEXICO

Report of the NCAVES Project



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FOREWORD

This report presents the main results of the project Natural Capital Accounting and Ecosystem Services Valuation (NCAVES) derived from the development of a pilot study for the compilation of ecosystem accounts in Mexico following the System of Environmental Economic Accounting – Ecosystem Accounting (SEEA EA)

The project NCAVES aims to contribute to the advancement of the knowledge on ecosystem accounting and to mainstream biodiversity and ecosystem accounting to support the formulation and evaluation of public policies that incorporate the value of nature in decision-making. The project was implemented in Mexico under the leadership of the National Institute of Statistics and Geography (INEGI), in collaboration with the Secretariat of Environment and Natural Resources (SEMARNAT), with the support of the United Nations Statistics Division (UNSD) and the United Nations Environment Programme (UNEP), funded by the European Union (EU).

Mexico, along with Brazil, China, India, and South Africa, were selected as strategic partners to the European Union, on account of the importance of their natural capital, their diverse ecosystems and biodiversity, along with their adherence to the commitments to the Convention on Biological Diversity (CBD).

The work carried out as part of this project contributed to the advancement of the research agenda at the global level and supported the multilateral process for the revision of the SEEA EA framework which culminated in March 2021 when the 52nd United Nations Statistical Commission adopted chapters 1-7 describing the accounting framework and the physical accounts as an international statistical standard, and recognized that chapters 8-11 of the SEEA Ecosystem Accounting describe internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets in a context that is coherent with the concepts of the System of National Accounts.

The SEEA EA is a coherent statistical framework that takes an ecosystem perspective, using a spatial approach, to integrate data about characteristics and functions of ecosystems, to measure the ecosystem services they provide, to track changes in ecosystems, and to linki this information to economic and other human activity.

This report is intended to present a general overview of the methods used, challenges faced, solutions implemented, and a description of the results obtained as well as a first attempt to insert the ecosystem accounts in the national institutional context and generate interest for policymakers.

The structure of this report follows the process carried out during the compilation of the pilot ecosystem accounts in Mexico: extent and condition accounts and monetary valuation of ecosystem services.

The extent account provides information on the extent, location, and configuration of the terrestrial ecosystems in Mexico. The changes in the extent of ecosystems over time are presented in accounting tables and in maps. These accounts were compiled using geospatial information produced by INEGI in its land use and vegetation series and grouped the vegetation types as a proxy for ecosystems using the available Conafor-IPCC classification.

The condition account assesses the composition, structure, and function of ecosystems, which support their ecological integrity using a data-driven approach. This was done through the Ecosystem Integrity Index (IIE), which uses information related to the biophysical context in which ecosystems develop, the degree of human intervention and structural and functional attributes of the organisms that live in them. The IIE developed in Mexico draws on the information generated in the National Forest and Soil Inventory (INFyS) and the Holdridge life zones. This approach constitutes a solid proposal to contribute to the international discussions on how to measure the condition of ecosystems.

The valuation of ecosystem services makes visible nature's contributions to economic activities and to human wellbeing. Different valuation methods that approximate the exchange values of the ecosystem services considered in this project were considered. The ecosystem services considered in this pilot study are: 1) Provisioning service for selected agricultural crops; 2) Regulating service through carbon storage and sequestration 3) Regulating service through pollination in agricultural crops; 4) Provisioning and regulating service for residential water supply; and 5) Cultural services in the nature tourism economy. One of Mexico's contributions to the international discussion for the monetary valuation of ecosystem services was the estimation of the value of carbon storage and sequestration as two differentiated components.

The results obtained at the national level allow to conclude that it is feasible to implement ecosystem accounting in accordance with the accounting and methodological principles proposed in the SEEA EA, considering the availability of information and technical capacities in Mexico.

It is important to highlight that this work lays the foundations for a broader deliberative process among the relevant sectors at the national level, which should be reinforced by establishing coordination mechanisms that allow active, transversal, institutional and formal participation of the sectors. Including research institutions, through collegiate bodies within the National System of Statistical and Geographic Information (SNIEG) that INEGI is mandated to coordinate.

This ongoing process should be accompanied by capacity building, the integration and harmonization of existing data, the regular generation of statistical and geographic data that serve as input for the compilation of ecosystem accounts. These accounts allow the derivation of indicators to monitor sectoral programs and international agreements, such as the Sustainable Development Goals and the Post-2020 Global Biodiversity Framework.

Finally, the work done as part of this project is considered as a starting point to continue analyzing and expanding the issues identified in this document. In this context, a roadmap is being developed for the institutionalization of ecosystem accounts in different sectors, in accordance with the new demands that a system of this nature requires.

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Special thanks are due to the European Union for funding this project, and to UNSD and UNEP for leading the NCAVES project globally and supporting its implementation in Mexico.

The Directorates of National Accounts and Natural Resources and Environment of INEGI are recognized for their support in coordinating this project.

The present report integrates the specific technical reports developed by a team of consultants commissioned by UNSD and UNEP, namely: Octavio Pérez Maqueo, Miguel Equihua Zamora and María Luisa Martínez of the Instituto de Ecologia, A.C (INECOL); Julián Equihua from CONABIO; Melanie Kolb from the Institute of Geography of the National Autonomous University of Mexico (UNAM), Luis Miguel Galindo Paliza and Saúl Basurto Hernández (UNAM); and María Zorrilla Ramos (Universidad Iberoamericana).

At various stages of the project, other leading consultants were also involved namely, Fernando Tudela Abad and Salvador Sánchez Colón, their participation is gratefully acknowledged.

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ACRONYMS AND ABBREVIATIONS

NPA
Natural Protected Areas

ANVCC
National Atlas of Vulnerability to Climate Change

FPA
Federal Public Administration

F4B
Finance for Biodiversity Initiative

CBD
Convention on Biological Diversity

EC
Economic Census

CENAPRED
National Center for Prevention of Disasters

CICC
Inter-secretarial Commission on Climate Change

CIDR
Inter-secretarial Commission on Sustainable Development

UNFCCC
United Nations Framework Convention on Climate Change

UNCCD
United Nations Convention to Combat Desertification

COBIOCOM
Biocultural Corridor of the Center and Western Mexico

CONABIO
National Commission for the Knowledge and Use of Biodiversity

CONAFOR
National Forestry Commission

CONAGUA
National Water Commission

CONANP
National Commission of Natural Protected Areas

CONAPO
National Population Council

CONEVAL
National Council for the Evaluation of Social Development Policy

COP
Conference of the Parties

COTECOCA
Technical Advisory Committee for Determining Rangeland Coefficients

PCUMS
Political Constitution of the United Mexican States

TCEDD
Total Costs for Depletion and Environmental

DGACN
Degradation

DGARNMA
Deputy Directorate General of National Accounts

DGEE
Directorate General of Economic Statistics of INEGI

DGGMA
Directorate General of Geography and Environment of INEGI

DOF
Official Gazette of the Federation

ENA
National Agricultural Survey

ENBIOMEX
National Biodiversity Strategy of Mexico

ENCC
National Climate Change Strategy

EU
European Union

FONDEN
Fund for Natural Disasters

GIZ
Deutsche Gesellschaft für Internationale Zusammenarbeit (German Corporation for International Cooperation)

EPE
Environmental Protection Expenditure

INECC
National Institute for Ecology and Climate Change

INEGI
National Institute of Statistics and Geography

IPBES
Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

IPCC
Intergovernmental Panel on Climate Change

LAN
National Water Law

LDRS
Law on Sustainable Rural Development

LFRA
Federal Law on Environmental Liability

LGAHOTDU
General Law on Human Settlements, Land Use Management and Urban Development

LGCC
General Law of Climate Change

LGDFS
General Law for Sustainable Forestry Development

LGEEPA
General Law of Ecological Balance and Environmental Protection

LGVS
General Law for Wildlife

NCAVES
Natural Capital Accounting and Valuation of Ecosystem Services

NDC
Nationally Determined Contribution

SDG
Sustainable Development Goals

ELP
Ecological Land-Use Planning

UN
United Nations Organization

GDP
Gross Domestic Product

NDP
National Development Plan

UNDP
United Nations Development Programme

UNEP
United Nations Environment Programme

PROCAMPO
Programme of Direct Support to the Rural Areas

PROFEPA
Federal Attorney's Office for Environmental Protection

PES
Payment for Environmental Services

HAR
Hydrologic-Administrative Region

SADER
Ministry of Agriculture and Rural Development

NAICS
North American Industry Classification System

SNA
System of National Accounts

SCUSV
Land use and Vegetation Classification System of INEGI

ES
Ecosystem services

SECTUR
Secretariat of Tourism

SEDATU
Secretariat of Rural, Territorial and Urban Development

SEEA CF
System of Environmental-Economic Accounting 2012 Central Framework

SEEA EA
System of Environmental-Economic Accounting Ecosystem Accounting

SEMARNAT
Secretariat of Environment and Natural Resources

SIAP
AgriFood and Fisheries Information Service

SINA
National Water Information System

SINAREFI
National System of Phytogenetic Resources for Food and Agriculture

SIODS
Information System of Sustainable Development Goals

SMN
National Weather System

SNA
System of National Accounts

SNIARN
Information System of National Environmental and Natural Resources

SNIB
National Information System of Biodiversity

SNIEG
National System of Statistical and Geographic Information

SNIGF
National Forest Information and Management System

SUN
National Urban System

TEEB
The Economics of Ecosystems and Biodiversity

WCMU
Wildlife Conservation Management Units

UN
United Nations

UNSD
United Nations Statistics Division

Section 1
Introduction

Mexico, like many countries in the world, has the challenge of addressing numerous environment-related problems, which could, in the immediate future, constitute a serious constraint to the country's further economic development and sustainability. Among the most important issues affecting the well-being of the population are the loss and degradation of ecosystems and biodiversity, water availability and quality, environmental pollution, and the need to adapt to the effects of climate change (SEMARNAT, 2019).

Economic development, measured through Gross Domestic Product (GDP), has dominated the public policy discussion for several decades. The focus on economic growth, as an indicator of a country's progress, has resulted in limited focus on capturing the contributions of nature to economic well-being. Moreover, decision makers do not always have access to integrated information to ensure the effective and sustainable management of a country's natural resources. To bring this dilemma to the public agenda and put economic and environmental policy discussions on the same level, an approach is needed to integrate economic and environmental information, and to answer questions such as: What is the contribution of ecosystems and their services to the economy, social well-being, employment, and livelihoods? How is the condition, health, and integrity of ecosystems and biodiversity changing over time? Where are the main areas of degradation and recovery? Can natural resources and ecosystems be better managed to ensure continued services and benefits, such as food supply, water provision, flood control, carbon storage, and recreational opportunities? What are the trade-offs among different land uses (e.g. for agriculture, mining, housing development, habitat conservation, recreation) and how can a balance be struck to achieve long-term sustainability and equity?

By using standardized accounting principles and accounts, ecosystem accounting seeks to answer these questions by integrating complex biophysical data and organizing them so as to understand changes and transformations in ecosystems and their relationship to human and economic activities. Ecosystem accounts are inherently spatial as an ecosystem's contribution to human well-being is dependent on its location. Ecosystem accounts, therefore, are intended to provide more information for the design, adoption, and monitoring of public policies to address the environmental crisis that threatens our present and compromises our future.

1.1 About the project NCAVES

The United Nations Statistics Division, the United Nations Environment Programme, the Secretariat of the Convention on Biological Diversity, and the European Union have launched the project "Natural Capital Accounting and Valuation of Ecosystem Services" (NCAVES).

The project, which is funded by the European Union through its Partnership Instrument (PI), aims to assist the five participating partner countries, namely Brazil, China, India, Mexico and South

Africa, to advance the knowledge agenda on environmental-economic accounting, in particular ecosystem accounting. The project-initiated pilot testing of SEEA Experimental Ecosystem Accounting (SEEA EEA) with a view to:

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

The project was organized along several workstreams:

- **Compilation of ecosystem accounts** in physical and monetary terms in the project countries;
- Application of the accounts in **scenario analysis** based on national policy priorities;
- Development of **guidelines and methodology** that contribute to national and global implementation of NCA;
- Development and testing of a set of **indicators** in the context of the post 2020 Biodiversity Agenda and other international initiatives;
- **Contribution of business accounts** to the alignment between SEEA and corporate sustainability reporting;
- **Communications** that increase awareness of natural capital accounting both in project countries and beyond through developing a range of products;
- Enhanced **capacity building and knowledge sharing** by way of enlarging the community of practitioners on natural capital accounting by e-Learnings and training workshops (in country and regional).

In parallel, the project aims to strengthen inter-institutional mechanisms in order to foster the development and use of natural capital accounting in the project countries. This has been done through a country assessment that feeds into the development of a national roadmap for the implementation of ecosystem accounts.

1.2 National Implementation of the NCAVES Project

In Mexico, the NCAVES project was launched during the inception mission that took place in June 2017. The NCAVES project implementation in Mexico has been led by the National Institute of Statistics and Geography (INEGI), in collaboration with the Ministry of Environment and Natural Resources (SEMARNAT) and other agencies in both the environment sector and academia. This project aims to build on the progress and results of the preceding project (2014-2016), funded by the Norwegian government, called Advancing Natural Capital Accounting (ANCA), in which Mexico also participated as a pilot country.

In Mexico, INEGI is well suited as the leading institution of the NCAVES project as it is the institution responsible for coordinating the National System of Statistical and Geographic Information (SNIEG) and for generating statistical and geographic information in the country. Within INEGI, the NCAVES project is coordinated and implemented under the leadership of the Directorate General of Economic Statistics (DGEE), in collaboration with the General Directorate of Geography and Environment (DGGyMA).

The mandate of the DGEE includes the organization, processing, integration, and compilation of the annual System of National

Accounts and satellite accounts. The mandate of the DGGyMA involves the production and updating of digital geographic information on natural resources and the environment, as well as the creation of the inventory of national natural resources. The NCAVES project is coordinated by the Vice-Presidency of Economic Information (VPIE) and the Vice-Presidency of Geographic Information and Environment, Territorial, and Urban Planning (VPIGMAOTU).

A multidisciplinary project such as NCAVES requires the coordination of different actors to achieve the integration of geographic, economic, ecological and environmental information necessary for the elaboration of ecosystem accounts. In Mexico, SEMARNAT has a leading role in the development of the NCAVES project, as it is the federal government entity that is responsible for the creation of national environmental policies that enable the protection, preservation and restoration of ecosystems and that foster sustainable development in the country.

The Mexican environmental federal public sector, headed by the SEMARNAT, is composed of the National Commission for the Knowledge and Use of Biodiversity (CONABIO); the National Commission of Natural Protected Areas (CONANP); the National Forestry Commission (CONAFOR); the National Water Commission (CONAGUA); the National Institute for Ecology and Climate Change (INECC); the Mexican Institute of Water Technology (IMTA); and the Agency for Safety, Energy and Environment (ASEA).

The participation of SEMARNAT in this project is conducted via the Directorate General of Statistics and Environmental Information (DGEIA) and the Directorate General of Planning and Evaluation, both of the Under-Secretariat of Planning and Environmental Policy (DGPE). The DGEIA is in charge of the development and maintenance of the Information System of National Environmental and Natural Resources (SNIARN), a system that integrates environmental statistics and indicators, as well as geospatial information, which are not only the basis of information used by the environmental sector for monitoring, planning and evaluation activities, but also for reporting on the state of the environment. The DGPE is responsible for establishing and coordinating policies and guidelines for institutional planning and improvement, as well as monitoring compliance with the objectives, policies, strategies, and goals of the government programme for the environmental sector in Mexico.

Throughout the project, SEMARNAT has supported the development of the ecosystem accounts, both as a user of the information and also by providing support and expert opinion for the elaboration of some pilot accounts. Being the main ecosystem accounting information user, the environmental sector has also supported, at a technical level, the development of this pilot project as part of the Inter-Institutional Technical Group, which was formed as part of the previous project (ANCA) to provide relevant information for the advancement of knowledge on ecosystems in Mexico, including both their measurement and valuation.

Section 2: National context

The following is an overview of: a) the geographic, environmental and socio-economic conditions that determine the state of ecosystems as well as the use of ecosystem services; b) the main drivers of ecosystem pressures that are directly related to the changes analysed in the extent and condition accounts; and c) the institutional framework and how the results of the NCAVES project provide elements for better decision-making at the national level.

2.1 Mexico's environmental, social, and economic context

Mexico has a total surface area of 1,964,375km^2 of which 1,959,248km^2 correspond to the continental surface area and 5127km^2 correspond to island territory (INEGI, 2019). The maritime area (territorial sea and the Exclusive Economic Zone) is 3,149,920km^2 while the continental shelf is extended in the western polygon of the Gulf of Mexico covering 10,570km^2, making a total area of 5,120679km^2 (INEGI, 2020). Furthermore, it is worth noting that the coastline, according to INEGI, is 11,122km long, of which 7828km correspond to the Pacific Ocean, and 3294 km to the Gulf of Mexico and the Caribbean Sea. The location, as well as diverse geography of Mexico, account for the variety of climates found within the country, which range from hot humid and sub-humid to temperate, dry, as well as cold alpine. Precipitation ranges from 100 to 300mm in the driest areas to an average of 1000 and 4000mm in the wettest areas (INECC, 2018).

Regarding biodiversity, Mexico is one of the 17 most megadiverse countries in the world. CONABIO suggests that this is due to its characteristics such as geographical position, size, evolutionary history, landscape diversity and culture. There are 96 terrestrial eco-regions (excluding islands) and 28 marine eco-regions in Mexico alone (Sarukhán 2009; Sarukhán et al., 2017; CONABIO 2020). Mexico is the fifth richest nation in terms of species diversity in the world (after Brasil, Colombia, China and Indonesia[1]). It is home to between 10 and 12 per cent of known species, a considerable figure given that it occupies only 1.4 per cent of the world's land area (Sarukhán et al., 2017). It also ranks among the five most biodiverse countries with the highest diversity in the four vertebrate groups (mammals, birds, reptiles and amphibians), as well as for the endemic species within these groups. It also ranks second in the world in reptile species diversity (after Australia) and first in marine mammal species and is also among the five countries with the highest number of vascular plants; although the loss and fragmentation of ecosystems is a risk factor for the conservation of species diversity.[2]

Regarding agrobiodiversity, Mexico is a centre of both the origin and also the domestication of species, where more than 130 species of economic and cultural importance to the world are recognized (Acevedo et al., 2009; SEMARNAT,

[1] See: https://www.biodiversidad.gob.mx/pais/quees.html

2019). Among these species, maize (Zea mays), of which 64 breeds have been identified and described in Mexico, is one of the main ones which stand out, along with beans, chilli peppers, squash, cocoa and tomatoes, among others. In terms of knowledge of genetic diversity, according to the Report on the State of the Environment in Mexico (SEMARNAT, 2019), and while further efforts are still needed in this area, around 200 species had been described up until a decade ago.

The distribution of soils is another relevant aspect. INEGI reports that Mexico has 25 of the 32 soil types listed in the World Reference Base (WRB) classification, which represents a very important soil richness that can be explained by multiple soil formation factors e.g. climate, biota, microorganisms, topography, time, etc. Based on an assessment carried out in 2002, in that year, 44.9 per cent of the soils in Mexico had been affected by some process of chemical degradation, water erosion, wind, or physical erosion. From this total degraded percentage of soils, 77.4 per cent of the surface was associated with agricultural and livestock activities, followed by deforestation and vegetation removal (16.4 per cent); the rest of the degraded surface relates to urbanization processes, overexploitation of vegetation, and industrial activities (SEMARNAT and UACh, 2003).

In terms of the hydrological conditions of the country, Mexico has an average annual precipitation of 1450.5 cubic kilometres of water (according to calculations of normal precipitation between 1981 and 2010). CONAGUA estimated in 2017 that 72.1 per cent of precipitation is evapotranspired, 21.4 per cent runs through rivers and streams and the remaining 6.4 per cent infiltrates and recharges aquifers. The renewable freshwater per capita per year is a function of both water conditions and population. Mexico has 451.6 million cubic kilometres of renewable freshwater per year, the availability per capita, in 2017, was 3 656 m^3/inhab/yr. The availability of water per capita varies considerably across the different regions of the country. Concerning consumptive uses of water in 2017, 60.9 per cent of the volume of water that was concessioned came from surface sources, while 39.1 per cent came from groundwater. Of this, 76 per cent was used for agricultural activities, 14.4 per cent for public water supply, 4.9 per cent for self-abstraction by industry, and 4.7 per cent for electricity generation (excluding hydroelectricity) (CONAGUA, 2018).

Regarding its population, according to the results of the 2020 Population and Housing Census (INEGI, 2021), there are 126.014 million people in Mexico, of which 51.2 per cent are women and 48.8 per cent are men. The population density was 64.3 inhab/km^2 in 2020. The population increased by 13.67 million people between 2010 and 2020, the average annual growth rate in this period was 1.2 per cent.

The pressure on natural resources and ecosystem services is connected to regional processes of land occupation and population growth. The central regions of the country are particularly noteworthy, the State of Mexico and Mexico City alone account for 20 per cent of the entire population in 2020 (13.5 per cent and 7.3 per cent respectively). Among the regions with the highest growth rates, the Baja California Peninsula stands out, whose growth is connected to the border city of Tijuana and the activities around the tourist resorts of La Paz and Los Cabos. Meanwhile, in the Yucatan Peninsula, the state of Quintana Roo stands out, where there is 40 per cent more population than in 2010. While Campeche and Yucatán did not grow at the same rate, the three states of the Yucatán Peninsula together accounted for one million more people in 2020 than in 2010 (INEGI, 2011; INEGI, 2021).

The National Council for the Evaluation of Social Policy (CONEVAL) calculated that, in Mexico, between 2008 and 2018, the proportion of the population living in poverty decreased from 44.9 to 41.9 per cent and extreme poverty decreased from 11.0 to 7.4 per cent in that period of time. Other relevant data is that, in 2018, 16.4 per cent of the population residing in rural localities was in a situation of extreme poverty compared to 4.5 per cent of the population living in urban areas (CONEVAL, 2018).

Poverty also has different regional expressions, in the south-south-eastern states the highest percentages of people in poverty are found, with Chiapas having the highest percentage (76.4 per cent), followed by Guerrero and Oaxaca (with 66.5 and 66.4 per cent respectively), and then Veracruz, Puebla, and Tabasco. Conversely, the northern states (including the northeast and northwest) have the lowest proportion of the population living in poverty, with Nuevo León (14.5 per cent) and Baja California Sur (18.1 per cent) standing out.

According to the National Accounts System of Mexico, in 2019 the total GDP at basic prices was 24 453 868 million current pesos, which was distributed as follows:

- Primary activities contributed 3.4 per cent towards GDP (829 860 million pesos) of which 2.2 per cent of the total was due to agriculture. Livestock breeding and exploitation contributed 1.0 per cent to GDP, forestry activities such as logging etc. contributed 0.1 per cent, and fishing, hunting, and trapping contributed 0.1%. The services related to these activities contributed 0.01% to GDP.

- Secondary activities contributed 30.9% to the total GDP at basic prices. Mining contributed 4.3 per cent, which included oil and gas extraction, mining of metallic and non-metallic minerals, except oil and gas; as well as services related to mining. The generation, transmission, and distribution of electricity, water supply, and piped gas to the final consumer contributed 2.2 per cent, construction 7.1 per cent, and manufacturing industries contributed 17.3 per cent.

- Tertiary activities, which include commerce and services, contributed 52.9 per cent of total GDP at basic prices in 2019 and of these, wholesale trade accounted for 9.2 per cent; retail trade 9.4per cent; transport, post, and storage 6.2 per cent; mass media information 1.5 per cent; financial services and insurance 4.0 per cent; real estate and rental services of movable and intangible property 9.7 per cent; professional, scientific and technical services 1.8 per cent; corporate 0. 6 per cent; business support services and waste and refuse management and remediation services 3.4 per cent; educational services 3.6 per cent; health and social work services 2.3 per cent; recreational, cultural, sporting, and other recreational services 0.4 per cent; temporary accommodation and food and beverage preparation services 2.3 per cent; other services except for governmental activities 1.99 per cent; and legislative, governmental, law enforcement, international and extraterritorial organisation activities contributed 3.6 per cent of GDP in 2019.

The Economic and Ecological Accounts of Mexico (CEEM) make it possible to estimate the impact of economic activities on the depletion of natural resources and environmental degradation. Following the 2019 calculation by INEGI, the Total Costs for Depletion and Environmental Degradation (CTADA) were equivalent to 4.5 per cent of GDP. On the other hand, the Government's General Environmental Protection Expenditures (GPA) represented 0.5 per cent of GDP at basic prices of the same year. This indicator represents the economic effort made to measure, control, reduce and abate pollution as well as effort made towards the management and conservation of the environment and natural resources (INEGI, 2020).

2.1.1 Pressure factors

2.1.1.1 Land-use change

According to SEMARNAT (2019), the main land-use change processes are deforestation, alteration or degradation, and fragmentation. Desertification has affected 53.5 per cent of the biotic resources in the national territory; 65.3 per cent of the soil resources are affected by light to extreme erosion processes, and 63 per cent of the territory with water resources have been affected with some level of degradation (SEMARNAT, 2019).

Another main process affecting ecosystem condition is related to the impacts of urbanization. As shown in chapter 4, the land use of human settlements, while representing only 1.11 per cent of the territory in 2014, increased from 12,657 km^2 in 2002 to 21,798 km^2 in 2014, which implies an increase of 72.2 per cent. In Mexico, the urbanization process continues, and in 2020, only 21.4 per cent of people lived in towns with less than 2500 inhabitants, that is, 78.6 per cent of the population lives in urban areas, and specifically almost half of the population lives in towns with more than 100,000 inhabitants. Human settlement expansion not only affects ecosystems in terms of land-use change in surrounding areas, but also has an impact on the demand for ecosystem services, and on the impact of pollution and infrastructure construction (SEMARNAT, 2019; SEMARNAT, SEDATU and GIZ, 2016).

2.1.1.2 Climate change and extreme events

In the Sixth National Communication on Climate Change[3], the National Institute of Ecology and Climate Change (INECC) points out that due to its geographical conditions, the country is affected in a particular way by the impacts of climate change, and estimates that for the period from 2015 to 2039 (taking 1961-2000 as a reference period), climate scenarios (RCP 8.5) project temperature increases of up to 2°C in the north of the country, whereas in the majority these increases range from 1 to 1.5°C. In addition, precipitation could decrease by 10-20 per cent. More than 60 per cent of the national territory is affected by hydrometeorological phenomena and tropical cyclones, for example, between 1970 and 2017, the coasts of Mexico were hit by 269 cyclones.

Similarly, periods of severe drought have also increased during recent decades; for instance, in May 2011 more than 90 per cent of the territory was affected. The recurrence of such droughts can aggravate conditions of environmental stress and affect the social and economic activities of the drought affected regions (INECC, 2018). In terms of forest fires, and according to data from CONAFOR, between 1991 and 2017, the annual average number of fires totalled 8094, with an average burnt area of 284 thousand hectares (SEMARNAT, 2019). The main cause of fires mainly comes from agricultural activities (39 per cent). Concerning forest pests and diseases, between 1990 and 2017 the average annual area affected was 56,227 hectares. To summarize, and as SEMARNAT (2019) indicates, the impact of climate change and extreme weather events is associated with the modification of distribution, replacement of ecosystems, degradation, and modification in species composition, as well as the presence of pests and diseases. All of these changes also affect species necessary for food security, including agricultural and fisheries production.

2.2 Institutional Context

2.2.1 Legal instruments

The most important instrument in Mexico's institutional hierarchy is the Political Constitution

[3] The Sixth National Communication on Climate Change was prepared in 2018 by the Government of Mexico, through SERMARNAT and INECC, and presented to the United Nations Framework Convention on Climate Change (UNFCCC). The document includes the country's progress in the transition towards a low-carbon economy, the estimation of the costs of implementing the Nationally Determined Contributions of Mexico, the relationship between climate change, pollution, health, the co-benefits of mitigating the short-lived climate forces and the Evaluation of the National Climate Change Policy, among others. The document is available online at: http://cambioclimatico.gob.mx:8080/xmlui/handle/publicaciones/117

of the United Mexican States (Mexico, DOF, 1917) and its fourth article establishes that "All people have the right to a healthy environment for their development and well-being. The State shall guarantee the compliance of this right. Environmental damage and deterioration shall entail liability for whoever causes it in terms of the law").[4] Aside from this right, article 4 of the Constitution identifies other rights that require biodiversity and the services it renders for their fulfilment, such as the right to health, water, and sanitation, as well as the right to food, among others.

Article 27 of the Constitution lays down the regime of ownership of natural resources and is the basis for all laws regulating the use of the territory and its resources: "The ownership of the lands and waters within the limits of the national territory originally corresponds to the Nation, who had and has the right to transfer ownership of them to private individuals, constituting private property"[5] This article sets out all provisions relating to land, forests, water, seas, and national territory.

The next level of analysis is that of federal and general laws. Definitions and policy instruments directly related to information from accounts of the extent, condition, and valuation of ecosystem services were assessed. Table 2-1 shows these results.

Table 2-1: Definitions of environmental services contained in Federal and General Laws

Law and year of publication in the Official Gazette of the Federation (DOF)	Definition of Environmental Services
General Law of Ecological Balance and Environmental Protection (LGEEPA, 1998)	Ecosystem services: tangible and intangible benefits produced by ecosystems that are necessary for the survival of the natural and biological systems as a whole as well as for providing benefits to humans.
National Water Law (LAN, 1992)	Environmental Services: social benefits arising or derived from watersheds and their components, such as climate regulation, conservation of hydrological cycles, erosion control, flood control, aquifer recharge, maintenance of run-off in quality and quantity, soil formation, carbon sequestration, water body purification, as well as conservation and protection of biodiversity; for the application of this concept in this Law, water resources and their connection with forestry resources are considered first and foremost.
General Law for Sustainable Forestry Development (LGDFS, 2018)	Environmental services: the benefits of forest ecosystem services provided either naturally or through sustainable forest management, which can be provisioning, regulating, supporting, or cultural services, and which are necessary for the survival of the natural and biological systems as a whole, and which also provide benefit to humans.

[4] Secretariat of the Interior, "Decree declaring the addition of a fifth paragraph to article 4 of the Political constitution of the United Mexican States". Official Gazette. 28 June 1999."
[5] Secretary of the Interior, "Decree amending the article 27 of the Political Constitution of the United Mexican States". Official Gazette 10 January 1934

Law on Sustainable Rural Development (LDRS, 2001)	Environmental services (synonym: environmental benefits): society's benefits from natural resources, including water provision and quality, pollutant capture, mitigation of the effect of adverse natural phenomena, landscape, and recreation, among others.
General Law for Wildlife (LGVS, 2000)	Environmental services: the social benefits deriving from wildlife and its habitats, such as climate regulation, conservation of hydrological cycles, nitrogen fixation, soil formation, carbon sequestration, erosion control, plant pollination, biological pest control, or degradation of organic waste.
Federal Law on Environmental Liability (LFRA, 2013)	Environmental services: the functions performed by one natural element or resource for the benefit of another natural element or resource, habitat, ecosystem, or society.

It is important to emphasise the relation with environmental accounts, since article 15, section XIX of the LGEEPA establishes as one of the principles of Environmental Policy that "The Ecological Net Domestic Product will be calculated through the quantification of the cost of environmental pollution and the depletion of natural resources caused by economic activities in a given year. The National Institute of Statistics, Geography, and Informatics will integrate the Ecological Net Domestic Product to the National Accounts System" (DOF, 1988).

2.2.2. International commitments

The results of the NCAVES project contribute elements for compliance with the three conventions derived from the 1992 Environment and Development Summit, as ratified in the Senate, and further published in the Official Gazette of the Federation.

The Convention on Biological Diversity (CBD): in 2010, Parties to the CBD adopted the Strategic Plan for Biodiversity 2011-2020 which provided the 10-year framework for action for all countries and stakeholders to safeguard biodiversity and the benefits it provides to people. The post-2020 Global Biodiversity Framework that will replace this is now under development and the Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) has developed recommendations for a set of indicators to measure progress towards the targets. Pursuant to Article 6 of the CBD, Mexico published the National Biodiversity Strategy of Mexico (ENBioMex) and its Action Plan in 2016. This instrument was developed within the framework of a broad participatory process. As a result, the document includes six axes, 24 lines of action, and 169 lines of action. Based on the knowledge axis, throughout its objectives and actions, it highlights the importance of valuing biodiversity and ecosystem services as a key element in decision-making.

The United Nations Framework Convention on Climate Change (UNFCCC): among the most important commitments to which Mexico is committed under the framework of this convention, is the elaboration of National Communications and Biennial Update Reports, as well as the intended Nationally Determined Contributions (NDCs), all of which were updated in December 2020 (Government of Mexico, 2020). In updating the NDC, the relevance of ecosystem services in adaptation commitments are made visible and relevant information is identified to "facilitate clarity, transparency, and understanding of the NDC update for the 2020 period in accordance with the Katowice rules" (Government of Mexico, 2020).

The United Nations Convention to Combat Desertification (UNCCD): CONAFOR is a focal point for this convention. It is worth noting that the Law on Sustainable Rural Development establishes, within the framework of the Inter-secretarial Commission for Sustainable Rural Development, the formation of a "National System for Combating Desertification and Drought" (SINADES) as well as the existence of state committees.

Within the framework of the 2030 Agenda for Sustainable Development and its 17 goals, the implementation and monitoring of eight of its goals will benefit from the information generated in the framework of the NCAVES project. Goals 2, 3, 6, and 8 are closely related to article 4 of the Constitution, and as noted above, preserving biodiversity and the services it provides is fundamental to their long-term fulfilment. Goals 11, 13, 14, and 15 are not only fundamental for guaranteeing the right to a healthy environment, but also to ensure that ecosystems have the conditions and integrity to guarantee the provision of ecosystem services.

Lastly, the Regional Agreement on Access to Information, Public Participation and Justice in Environmental Matters in Latin America and the Caribbean, also known as the Escazú agreement, is also worthy of highlighting (DOF, 2021). The purpose of this agreement is to guarantee the full and effective implementation of the rights to environmental information in Latin America and the Caribbean. In particular, article 5 addresses access to environmental information, while article 6 covers the generation and dissemination of such information.

2.2.3 Policy instruments of the Federal Public Administration

Below is a description of the public policy instruments for which the results of the NCAVES project are intended to contribute towards the improvement of their design, implementation, and evaluation.

According to the Law on Planning, the National Development Plan (NDP) is the document that establishes the national objectives, strategies, and priorities of the federal government in the current administration. The NDP 2019-2024 recognizes that "The government of Mexico is committed to promoting sustainable development, which in the present era has become evident as an indispensable factor of well-being". The NDP defines sustainable development as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs" (DOF, 2019)

Various sectoral programmes are derived from the National Development Plan, for example, the Sectoral Programme for the Environment and Natural Resources (PROMARNAT) 2020-2024, managed by SEMARNAT, is one of the most prominent instruments for the institutional positioning of the NCAVES project in the current administration from two perspectives: 1) its strategic objectives (see Box 1 below) and 2) the recognition of the importance of measuring the Programme's progress, which is contained in the section entitled "Goals and parameters for well-being".

Box 1: Priority objectives of PROMARNAT (DOF, 2020d)
1. Promoting the conservation, protection, restoration, and sustainable use of ecosystems and their biodiversity with a territorial and human rights approach, considering biocultural regions, to maintain functional ecosystems that are the basis for the well-being of the population.

2. Strengthening climate action to transition to a low-carbon economy and a resilient population, ecosystems, productive systems, and strategic infrastructure, with the support of available scientific, traditional, and technological knowledge.

3. Promoting water as a cornerstone of well-being, operated by transparent, reliable, efficient, and effective institutions that ensure a healthy environment and where a participatory society is involved in its management.

4. Promoting an environment free of water, air, and soil pollution that contributes to the full exercise of the right to a healthy environment.

5. Strengthening environmental governance through free, effective, meaningful, and co-responsible citizen participation in public policy decisions, ensuring access to environmental justice with a territorial and human rights approach, and promoting environmental education and culture.

Also relevant to the NCAVES project is the Institutional Programme of the National Forestry Commission 2020-2024 (DOF 2020c) as well as the National Water Programme 2020-2024 of the National Water Commission. Both programmes are particularly relevant for the institutional anchoring of this project, since they recognize the importance of ecosystem services because they frame concrete actions for their conservation and also because they contain criteria for their measurement and evaluation. In the case of the National Forestry Program (PRONAFOR), a priority strategy has been established "to promote the implementation of the National Strategy for the Reduction of Emissions from Deforestation and Forest Degradation (ENAREDD+) to move to a zero net deforestation rate and promote the capacity to adapt to the effects of climate change" (DOF 2020e). Besides the planning instruments, it is worth highlighting the policies implemented by the environmental sector, which have been central for containing the pressure factors on biodiversity for decades. Such instruments found their foundations in the different legislations, mainly the LGEEPA, the LGVS, and the LGDFS (see table 2-1 above).

Natural Protected Areas (NPAs) stand out as one of the main conservation instruments at both global and nation al levels. The first natural protected area in Mexico was decreed in 1917, and according to SEMARNAT (2019), as of 2018, 182 NPAs under federal jurisdiction had been decreed. The results of the NCAVES project will contribute information for this protection scheme. Among other relevant instruments for the conservation of ecosystem services are wetlands of international importance derived from the Ramsar Convention (there are 142 Ramsar sites in Mexico) and the Payment for Environmental Services Programme (PES), which has been implemented since 2003 by the National Forestry Commission. As of 2017, the area benefited by PES in its different modalities was 2.68 million hectares (SEMARNAT, 2019). At present this programme is contained in the Support Programme for Sustainable Forestry Development of CONAFOR.

Information from this project can be useful for other environmental policy instruments, some of them are:

1. The ecological planning of the national territory being an instrument that aims towards "regulating or inducing land use and productive activities to achieve the protection of the environment; the preservation and sustainable use of natural resources, based on the analysis of deterioration trends and the potential for their use" (DOF 1988).

2. The environmental impact assessment is "an environmental policy instrument aimed at the detailed analysis of various development projects and the site where they are intended to take place. The purpose of this analysis is to identify and quantify the impacts that the implementation of a given project may cause to the environment" (SEMARNAT, 2019).

3. Also noteworthy is the concept of compensation as one of the possible resolutions for environmental impact authorisations (LGEEPA), as well as that referred to in the Federal Law on Environmental Liability and the Law for Sustainable Forestry Development.

4. Another relevant instrument that both the LGEEPA and the LGCC contemplate for carbon is the establishment of taxes. At present, the Law on the Special Tax on Production and Services (LIEPS), which as of 2013 establishes the so-called "Carbon Tax", which is a tax on fossil fuels per tonne of carbon.

The most relevant planning instrument for the economic sector (which includes mining, agriculture and commerce etc.) is the Sectoral Programme for Agriculture and Rural Development 2020-2024, which is under the responsibility of the Ministry of Agriculture and Rural Development (SADER) and has, among its objectives and strategies, actions that benefit from the valuation of ecosystem services such as for carbon (in soils), water and services used in agriculture. In 2021, SADER in conjunction with SEMARNAT published the National Strategy for the Conservation and Sustainable Use of Pollinators (ENCUSP), which aims to guide the policies and work of the economic and environmental sectors about the conservation of the ecosystem services provided by pollinators, that contribute to the sustainable development and food security of the country.

Lastly, it is worth mentioning the Sembrando Vida (Sowing Life) programme, implemented in 20 of the states of the country and which offers economic support for agroforestry production and technical assistance for the implementation of agroforestry systems. Only areas used predominantly for agricultural use are within the scope of this programme (forest areas, protected natural areas, land with environmental management units areas affected by natural or induced fire) are not eligible). In this context, the use of the information generated under the NCAVES project (mainly the extension and condition accounts) can be seen as providing substantive information for the implementation of this policy instrument.

2.2.4 Information systems and key actors in the framework of the NCAVES project

INEGI is the agency responsible for regulating and coordinating the SNIEG (DOF, 2008). According to the Law of the National System of Statistical and Geographic Information (SNIEG), the purpose of this system is to produce quality, relevant, accurate, and timely information that contributes to the Mexico's development. Its guiding principles are accessibility, transparency, objectivity, and independence.

The objectives of the SNIEG include producing information; disseminating the information promptly through mechanisms that facilitate its consultation; promoting knowledge and use of the information; as well as preserving the information (see Box 2 below).

Box 2. Information of national interest pursuant to the Law of the National System of Statistical and Geographic Information (SNIEG) (DOF, 2008)

The Law of the SNIEG further establishes that for this Law, the only information that meets the following four criteria may be considered information of national interest:

i. It concerns the following topics, groups of data or indicators: population and demographic dynamics; health; education; employment; income distribution and poverty; government, public security, and justice administration; housing; system of national accounts; financial information; prices; labour; science and technology; telecommunications and broadcasting; atmosphere; biodiversity; water; soil; flora; fauna; hazardous waste and solid waste; geodetic reference frame; coastal, international, state and municipal boundaries; continental, insular and submarine relief data; cadastral, topographic, natural resources and climate data, and geographical names, including those that should be known by the Subsystems referred to in the last paragraph of Article 17 of this Law:
   a) It is necessary to support the design and evaluation of public policies with a national scope.
   b) To be generated on a regular and periodic basis, and
   c) To be developed based on a scientifically supported methodology.

Moreover, "Notwithstanding the above, information of national interest may also be considered to be that necessary to prevent and, where appropriate, attend to emergencies or catastrophes caused by natural disasters, and that which should be generated pursuant to a commitment established in an international treaty" (DOF, 2008).

In addition to the SNIEG, other relevant information systems have been identified within the framework of the project, including:

- The Information System of National Environmental and Natural Resources (SNIARN), in charge of SEMARNAT and based on the LGEEPA. Its objectives are "to record, organize, update and disseminate national environmental information, which will be available for consultation and coordinated and complemented with the National Accounts System in charge of the National Institute of Statistics, Geography, and Informatics" (DOF, 1988).
- The National Forest Information and Management System (SNIGF), in charge of CONAFOR and based on the LGDFS. This system incorporates other policy instruments as the National Forest and Soil Inventory (INFyS), the National Forest Monitoring System, the National Forest Zoning, and the National Forest Register.
- The Mexican National Biodiversity Information System (SNIB), which is managed by CONABIO, has its foundation in the LGEEPA and its objective is to compile, organize and distribute information on the biodiversity of Mexico, in order to establish a national inventory of species and provide assistance in regard to biological diversity to the government and the social and private sectors.

Based on the analysis of laws and policy instruments, as well as information generated by different institutions of the federal public administration, Table 2-2 provides a synthesis of the main information providers and users of this project.

Table 2-2: Federal government agencies providing and using information from the NCAVES project

	Institution	Objectives of the institution linked to ecosystem services	Supplier	User
Environmental Sector Agencies	Secretariat of Environment and Natural Resources (SEMARNAT)	The lead agency of the environmental sector, responsible for the design, implementation, and evaluation of environmental policies such as the Ecological Land-use Planning, the Environmental Impact and Wildlife Policy, and the Federal Maritime-Terrestrial Zone policy. SEMARNAT is also in charge of the SNIARN.	X	X
	National Commission of Natural Protected Areas (CONANP)	Among its main attributions, CONANP promotes and develops activities aimed at the conservation of ecosystems and biodiversity in NPAs, aquatic species and other species that are considered a national priority for conservation. CONANP is responsible for the National System of Natural Protected Areas (SINAP).	X	X
	National Institute for Ecology and Climate Change (INECC)	INECC coordinates and conducts scientific and technological research projects with academia, public or private, national, or foreign institutions on climate change, environmental protection and preservation, as well as ecological restoration. It is in charge of the Evaluation of the Climate Change Policy, the preparation of the National Communications on Climate Change, as well as the development and updating of the National Atlas of Vulnerability to Climate Change (ANVCC).	X	X
	National Forestry Commission (CONAFOR)	CONAFOR develops, promotes and encourages productive, conservation and restoration activities in forestry. It also participates in the formulation of plans and programmes and in the implementation of forestry development policy. From 2003 it has instrumented the programmes of payment for environmental services and Payment for Hydrological Environmental Services (PES and PSAH) from the federal government. It is also in charge of the SNIGF.	X	X
	National Water Commission (CONAGUA)	A decentralised agency whose mission is to manage and preserve national waters and their inherent assets to achieve their sustainable use with the joint responsibility of the three levels of government and society in general. It has authority over inland water bodies. It is responsible for the National Water Information System (SINA), the Geographic Water Information System (SIGA), and the Hydrological Information System (SIH).	X	X
	Federal Attorney's Office for Environmental Protection (PROFEPA)	PROFEPA is a decentralised organisation in charge of, among other things, monitoring and evaluating compliance with the applicable legal provisions regarding biodiversity.	X	
Agencies in other sectors	Ministry of Agriculture and Rural Development (SADER)	SADER is in charge of all powers related to agricultural, fisheries, and aquaculture production, as well as the promotion of rural development. Its actions have a direct impact on biodiversity, both in ecosystems and in species and genetic diversity.	X	X
	Secretariat of Welfare (BIENESTAR)	BIENESTAR's responsibilities include participating in the coordination and implementation of rural development policies to raise the level of well-being of families, communities, and ejidos[6], and to contribute to the design and implementation of public policies oriented to promote agroforestry, productivity, social economy, and employment in rural areas, and to prevent migration from rural areas;		X

[6] Ejidos are a system of communal land used for agriculture.

	Secretariat of Rural, Territorial and Urban Development (SEDATU)	SEDATU is responsible for the elaboration and implementation of housing, land-use planning, agrarian, and urban development policies in coordination with the federal entities, municipalities, and, where appropriate, the mayor's offices of Mexico City.		X
	National Center for Prevention of Disasters (CENAPRED)	CENAPRED is responsible for supporting the National Civil Protection System (SINAPROC) in the technical requirements of its operation. It conducts research, training, instrumentation, and dissemination activities regarding natural and anthropogenic phenomena that can cause disaster situations, including actions to reduce and mitigate the negative effects of such phenomena.		X
	Secretary of the Navy (SEMAR)	SEMAR fulfils various strategic functions for national security, including for the Mexican navy. Among its attributions in the area of biodiversity are those of protecting national maritime, river, and lake resources, acting and intervening in the prevention and control of maritime pollution, as well as monitoring and protecting the marine environment that are within its area of responsibility.	X	X
Inter-secretariat commissions	National Commission for the Knowledge and Use of Biodiversity (CONABIO)	CONABIO's mission is to coordinate actions and studies related to the knowledge and preservation of biological species, and to promote and encourage scientific research activities for the exploration, study, protection, and use of biological resources to conserve the ecosystems of the country and generate criteria for their sustainable management. It is also in charge of the SNIB.	X	X
	Intersecretarial Commission on Climate Change (CICC)	CICC is the commission responsible for promoting the coordination of actions of the agencies of the federal public administration and entities on climate change, and for formulating and implementing national policies for mitigating and adapting to climate change, as well as incorporating them into the relevant sectoral programmes and actions.		X
	Intersecretarial Commission for the Sustainable Management of Seas and Coasts (CIMARES)	CIMARES aims to coordinate, in the area of their respective competencies, the actions of the agencies and entities of the APF related to the formulation and implementation of national policies for the planning, management, and sustainable development of the seas and coasts of the national territory. It is headed by the SEMAR and coordinates the National Policy on Seas and Coasts.		X
	Intersecretarial Commission for Sustainable Rural Development (CIDRS)	CIDRS is responsible for integrating the National Research Policy for Sustainable Rural Development, whose multidisciplinary and inter-institutional character consider account national, state, and regional priorities; it will also carry out national programming and coordination in this area.		X

Concerning the role played by different actors within the framework of the project, it should be noted that the users and providers of the information form a broad and diverse spectrum that includes: a) government actors: ministries and agencies of the federal public administration; autonomous agencies; inter-ministerial commissions, state governments, and municipal governments, and b) other actors such as the Congress of the Union, universities and research centres, cooperation agencies and civil society organisations, and individuals, communities, and society in general, among others.

To conclude, it is worth noting that there are various elements, both in the legal framework and policy instruments that contribute positively to the conservation and sustainable use of ecosystems.

Section 3:
The System of Environmental and Economic Accounting (SEEA)

The System of Environmental and Economic Accounting (SEEA) is an internationally accepted statistical standard that, through the provision of a reliable accounting framework, enables a thorough understanding of the connections between economic activities and the environment. The SEEA integrates economic and environmental information, in physical and monetary terms, into a common framework measuring the contributions of the environment to the economy and the impact of the economy on the environment, using accounting principles that allow comparability and integration with the System of National Accounts (SNA).

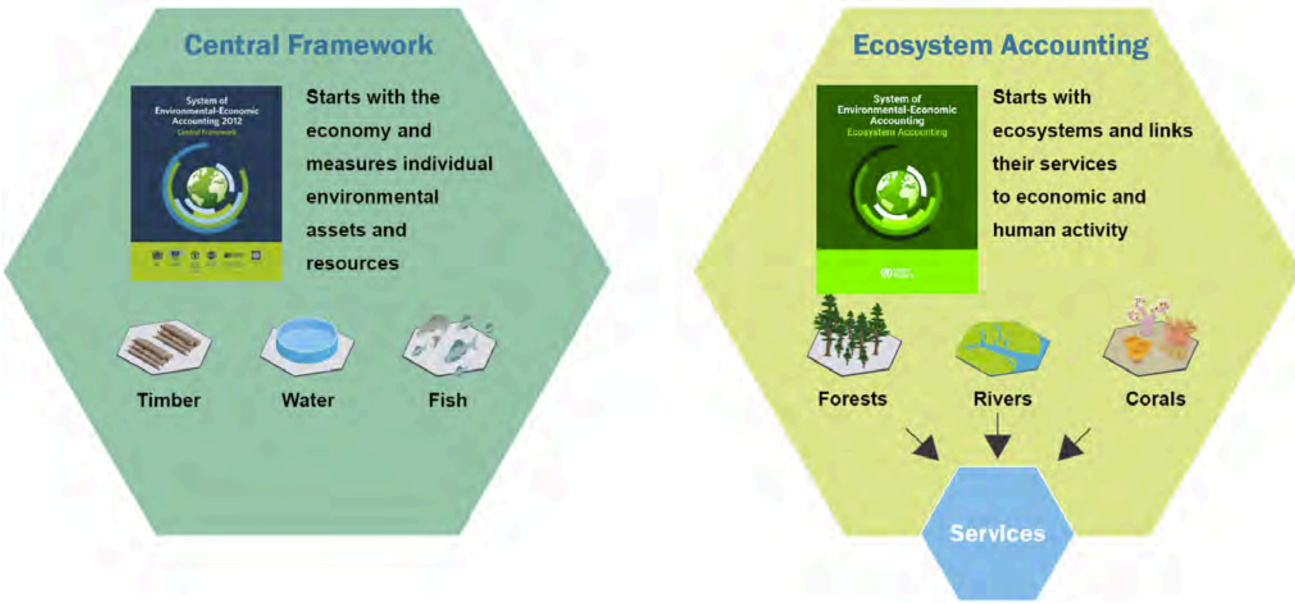
Owing to its integrated approach, the SEEA is well positioned to support decision-making, policy formulation, and review, analysis, and research, as well as to support progress in measuring a number of global initiatives, in particular the 2030 Agenda, the Post-2020 Global Biodiversity Framework, and climate change policy.

The SEEA is composed of the:

1. The System of Environmental and Economic Accounting 2012 - Central Framework (SEEA CF) which analyses environmental assets, including water, energy, forestry, fisheries, and other resources; their changes in stocks due to extraction and other causes; and their uses in the economy and returns to the economy, in the form of emissions and discharges, into the environment. The SEEA CF was adopted by the United Nations Statistical Commission in 2012 as the first international standard for environmental and economic accounting.
2. The System of Environmental-Economic Accounting- Ecosystem Accounting (SEEA EA) is a coherent framework for integrating measures of ecosystems and the flows of services from them with measures of economic and other human activity. Ecosystem Accounting complements, and builds on, the accounting for environmental assets as described in the SEEA CF (e.g. water resources, soil resources). In ecosystem accounting, as described in the SEEA EA, the accounting approach recognizes that all these individual resources function together within a broader system and within a given spatial area (see below).

The SEEA EA framework has been updated through an interdisciplinary and interagency review process that included more than 600 experts from various countries and culminated in March 2021 when the 52nd United Nations Statistical Commission in March 2021 adopted chapters 1-7 describing the accounting framework and the physical accounts as an international statistical standard, and recognized that chapters 8-11 of the SEEA Ecosystem Accounting describe internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets in a context that is coherent with the concepts of System of National Accounts.

Figure 3-1 The SEEA approach: SEEA CF and SEEA EA

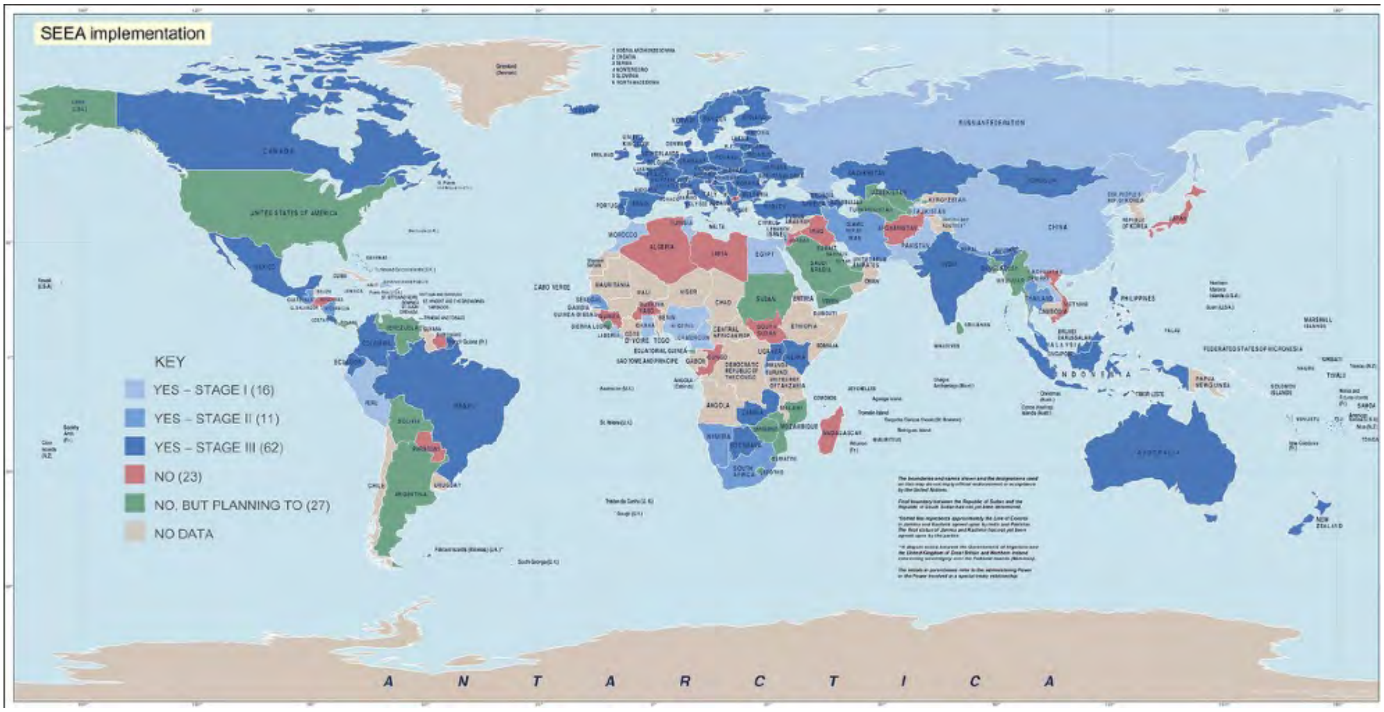


3.1 The implementation of the SEEA across the world

According to the 2020 Global Assessment of Environmental-Economic Accounting undertaken by UNSD under the auspices of the UN Committee of Experts on Environmental-Economic Accounting (UNCEEA), 89 countries have implemented the SEEA CF and 34 the SEEA EA. Furthermore, 25 countries indicated that they plan to implement the SEEA CF, and 13 countries indicated that they plan to implement the SEEA EA.

Since the last assessment in 2017, there has been a significant increase in the number of countries implementing the SEEA. In 2020, this number increased by 29 per cent compared to 2017. A higher increase was observed for developing countries, which exhibited a 47 per cent increase, while developed countries showed a 14 per cent increase between the 2017 and 2020 Assessments.

Figure 3-2 Status of the implementation of the SEEA in the world



Source: UNSD (2020)

Note: The countries shown in different shades of blue are implementing the SEEA

Regarding the SEEA EA, the most commonly compiled accounts in countries (both developed and developing) were extent, condition, and ecosystem services accounts. In terms of expanding or compiling new SEEA EA accounts, both developed and developing countries prioritized monetary asset, extent, and condition accounts. However, developed countries also gave priority to land, water, and urban accounts, while developing countries prioritized ecosystem services and carbon-related stocks/flow accounts.

3.1.1 State of environmental - economic accounting in Mexico

The natural capital accounting and environmental-economic valuation in Mexico has closely followed developments taking place at the international level. Starting in the early 1990s, the Government of Mexico, specifically through INEGI and the then Ministry of Environment, Natural Resources and Fisheries, later transformed into SEMARNAT, in conjunction with the academic sector of the country and international and local environmental NGOs, have been committed to compiling and disseminating integrated environmental and economic accounts, as well as researching and proposing methodology for environmental-economic valuation.

The development of the integrated economic and environmental accounting scheme in Mexico has implied extensions to the traditional national accounting scheme, highlighting the expansion of the asset boundary to include non-produced assets, i.e., natural resources and the environment. The results are presented in the Economic and Ecological Accounts of Mexico (CEEM), developed by INEGI as one of the satellite accounts of Mexico's System of National Accounts.

3.2 SEEA Ecosystem Accounting

The SEEA EA framework[7] (UN, 2021) provides an integrated information system for accounting: (a) ecosystem assets, including their extent, condition, capacity, and ecosystem services, and the corresponding monetary values; and (b) economic and human activities and their associated beneficiaries (governments, businesses, and households). The integration of economic and ecosystem information is intended to mainstream information on ecosystems in decision-making.

The implementation of the SEEA EA at the national level aims to achieve the integration of information on multiple ecosystem types and ecosystem services with macro-level economic information.

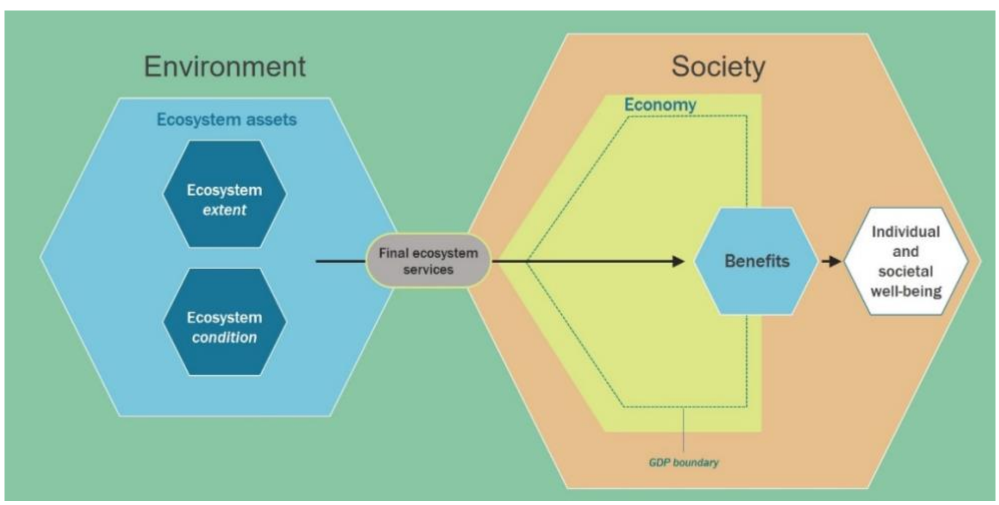
Considering the scale of the analysis, available data, and information and policy needs, the SEEA EA framework can also be used at the subnational level, for example, for the delimitation of geopolitical or administrative areas (regions, states, municipalities or cities), as well as other types of environmental areas (watersheds or natural protected areas).

3.2.1 Conceptual approach to Ecosystem Accounting of the SEEA

The essence of ecosystem accounting lies in its potential to represent the biophysical environment in terms of distinct spatial areas that each represent different ecosystem assets, such as forests, wetlands, agricultural areas, and others.

Under the logic of ecosystem accounting, each ecosystem asset produces a basket (bundle) of associated ecosystem services. Service flows, within a defined time period, will depend on the extent and condition of the ecosystem asset (Figure 3-3). As such, ecosystem accounting records (i) the stock and changes in stock of each ecosystem asset; and (ii) the supply of all ecosystem services, during the accounting period, for each ecosystem asset within an ecosystem accounting area, as well as the users of ecosystem services.

Figure 3-3 Conceptual framework of ecosystem accounting



Source: UNSD (2021)

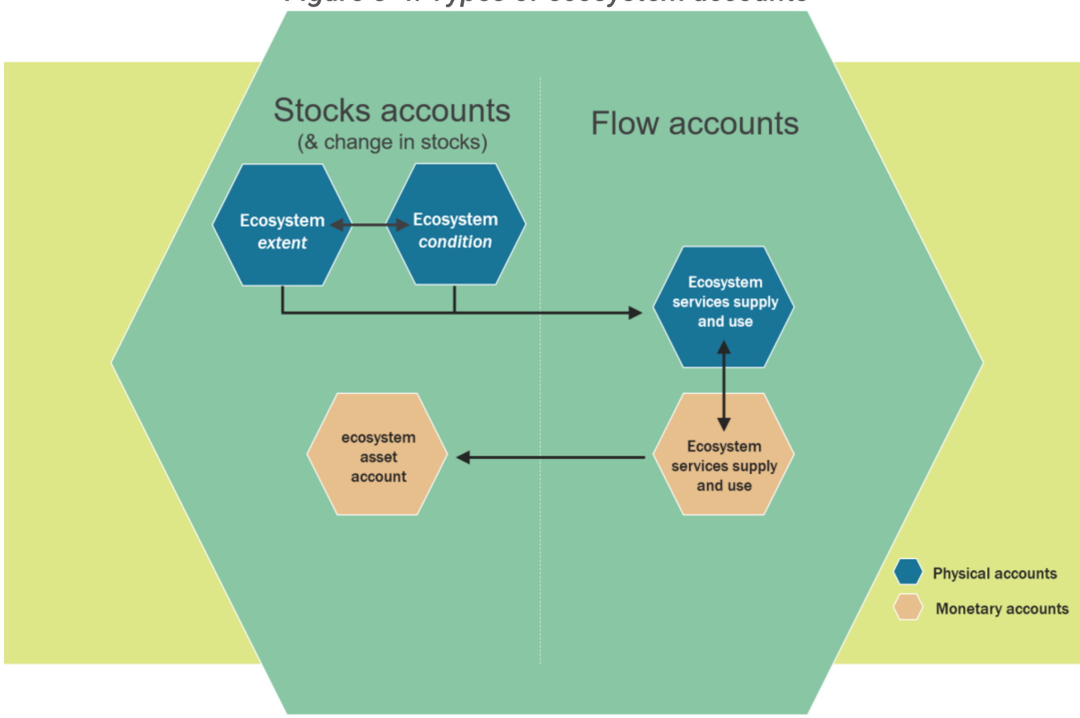
[7] "System of Environmental-Economic Accounting — Ecosystem Accounting: Final Draft", a paper prepared by the Committee of Experts on Environmental-Economic Accounting and submitted to the fifty-second United Nations Statistical Commission, Statistics Division of the United Nations Department of Economic and Social Affairs. March 2021. This document can be found at: https://unstats.un.org/unsd/statcom/52nd-session/documents/BG-3f-SEEA-EA_Final_draft-E.pdf.

Ecosystem service flows differ from flows of ecosystem benefits. The term "benefits", as used in the SEEA EA, encompasses: (a) SNA-benefits, i.e., the products (goods and services) produced by economic units registered in the national accounts; and (b) non-SNA benefits that are generated by ecosystems and consumed directly by individuals and societies. Measuring well-being is not the objective of ecosystem accounting; however, the data that are integrated through the ecosystem accounting framework can support such measurement.

3.2.2 Ecosystem accounts

The SEEA EA is an integrated statistical framework that organizes biophysical data, measures ecosystem services, examines changes in ecosystem assets and links this information to economic and human activity. It comprises a set of accounts that collectively present a coherent and comprehensive view of ecosystems. The accounts that comprise the SEEA EA are illustrated in Figure 3-4 and described below.

Figure 3-4: Types of ecosystem accounts



Source: UNSD (2021)

1. The **ecosystem extent account** records, using geospatial data, the area of each of the ecosystem types within a country or region. This account constitutes the starting point for ecosystem accounting and the foundation for the construction of the condition account and the quantification of flows of ecosystem services.

2. The **ecosystem condition account** measures the quality of an ecosystem concerning its ecological integrity over time. This account is organized from biophysical data that are structured according to the abiotic and biotic characteristics of the ecosystem.

3. The **ecosystem services flow accounts** measure the flows of final services that ecosystems provide and their use by economic units (households, businesses, and government). Such flows are quantified in physical and monetary terms. The valuation of

ecosystem service flows requires the use of valuation concepts aligned with the SNA.

4. The **ecosystem assets monetary account** records the monetary value of the opening and closing stock of all ecosystem assets within the accounting area, as well as additions and reductions to the stock during the accounting period.

Ecosystem asset values can be calculated from monetary estimates of ecosystem service flows during the lifetime of the ecosystem. Such an approach implies that the value of the ecosystem asset correlates with its capacity to deliver ecosystem services and how this capacity is expected to change in the future.

Collectively, these accounts allow for the measurement of ecosystems and their services, as well as the integration of ecosystem data with economic data, as the first step towards their incorporation into the SNA. Given the spatial nature of ecosystem accounting, the information is presented in maps. The connections between ecosystems and the economy can be presented in both physical and monetary terms. Notably, monetary valuation is an optional element in the compilation of the accounts.

In a complementary way, the SEEA EA also includes the so-called thematic accounts, obtained by combining data from the ecosystem accounts with data from other SEEA CF and SNA accounts, and other sources. Said independent accounts are compiled to support analysis and discussion in terms of public policy from a thematic perspective, for instance, on carbon, climate change, biodiversity, oceans, urban areas, protected areas, among others.

The development process of the accounts involves the integration of a range of geospatial, biophysical and economic data sources. Multiple iterations throughout the accounting process are necessary to present a coherent and consistent view of ecosystems through the five accounts that together constitute the SEEA EA. The pilot terrestrial ecosystem accounts developed as part of this project are the extent account, the terrestrial ecosystem condition account, and the ecosystem service flow accounts in physical and monetary units for selected services, namely, crop provisioning, surface water provisioning, carbon sequestration and storage, pollination, nature tourism. The ecosystem services are summarized in ecosystem services supply and use tables. These ecosystem accounts, compiled at the national level, constitute the basic structure of this report.

Section 4:
Terrestrial Ecosystem Extent Accounts in Mexico

KEY MESSAGES:

The extent of the different ecosystems that are found within Mexico, including both natural and anthropic ecosystems, varies widely.

In 2014, the natural ecosystems with the largest extent were ranked in descending order, Non-woody xeric shrubland (19 per cent), Grassland (15 per cent), Woody xeric shrubland (11 per cent), Deciduous tropical forest (9 per cent), Coniferous forest and Oak forest (8 per cent each) and Evergreen tropical forest (5 per cent). The anthropic ecosystem with the largest extent is Annual cropland (16 per cent).

Almost all of the natural vegetation categories show negative net changes and negative rates of change during 2002 to 2014.

The largest negative net change occurred in the Semi-deciduous tropical forest category (-7 741 km) followed by Grassland (-7 038 km^2) and Woody xeric shrubland (-5 810 km^2). Other categories with important regressions are the Evergreen tropical forest (-5 786 km^2) and Non-woody xeric shrubland (-3 719 km^2). In forest ecosystem types, a high dynamism between additions and reductions is observed, resulting in a balance close to zero, with the exception of Montane-cloud forest, which experienced a significant regression.

Between 2002 and 2014, the largest negative change rate is observed for the Semi-deciduous tropical forest followed by the Evergreen tropical forest which have decreased at a rate of 1.47 per cent and 0.47 per cent per year, respectively. Other categories with notable negative rates of change are Special Other types of vegetation and Xeric shrubland.

Land-use categories show net positive changes and positive rates of change.

Annual cropland is the category with the largest additions in absolute terms between 2002-2014, followed by Human settlements. However, as these categories have a large extent, the rates of change are relatively small (below 1 per cent). The category with the highest rate of change overall is Planted forest, although absolute areas are small. Another category with high rates of change is Aquaculture.

The ecosystems that have lost the greatest historical extent are the Evergreen tropical forest and Deciduous tropical forest, preserving about 50 per cent of their original extent, whereas Grassland is now almost twice as large as its original extent.

Major transitions (changes from one category in 2002 to another category in 2014).

The change process affecting the largest extent is the conversion of natural ecosystems to anthropic areas, accounting for around 3 per cent of the entire territory.

The most affected ecosystem type is Grassland, which was converted mainly to agriculture. The most significant conversions (in absolute terms) of natural ecosystems into land-use categories occurred in the Tropical Forests category, followed by Shrublands, and Forests. These areas are predominantly converted into Annual agriculture.

Transitions to Human settlements are dominated by the conversion of Annual cropland followed by Grasslands and Shrublands.

4.1 Introduction

The common starting point for ecosystem accounting is the organization of spatial information on the extent and location of different ecosystems assets, within a country or other accounting area, and how that extent is changing over time. Such information is displayed in a spatially explicit manner and is recorded in tabular form showing the opening and closing extent for each ecosystem type.

Extent accounts provide the underlying infrastructure for the measurement of the condition of ecosystems. The accounts also support the measuring and modelling of a wide range of ecosystem services, in physical and monetary terms, for subsequent integration into national accounts. Extent accounts also form part of the foundation for deriving indicators of conversion, fragmentation, urbanization, and other change processes.

Human land use and the impacts of this land use on natural ecosystems and ecosystem services has been acknowledged as the major contributing factor for the alarming loss of biodiversity that is occurring at the present time (Newbold et al. 2016; IPBES, 2019).

Before beginning the development of ecosystem accounts, a spatial delineation of ecosystems based on a classification suitable for this purpose is required.

4.2 Classification of Ecosystems in Mexico

The SEEA EA framework recognizes that the Ecosystem Accounting Area (EAA) can be a country, a region, a state, a river basin, and so on. Furthermore, it also identifies and characterizes ecosystem assets (EAs), which are spatial units that represent ecosystems. Hence, ecosystem assets constitute part of the total EAA and are grouped by ecosystem type in accordance with a categorization of ecosystems from an ecological perspective.

At the national level, the EAA encompasses all terrestrial, aquatic, and marine ecosystems within the country's borders and its exclusive economic zone. For the purposes of this project, the EAA comprises only terrestrial ecosystems at the national level.

Ecosystems are areas that constitute a dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (CBD, 1992). According to this definition, it becomes clear that land-cover data alone is insufficient to adequately delineate ecosystem assets. It is therefore necessary for ecosystem mapping to consider a wider range of ecological attributes (biotic and abiotic) and other characteristics such as physical structure and vegetation type, species composition, ecological processes, climate, hydrology, and soil type, among others.

In view of the great biological diversity found within Mexico, coupled with the difficulty of identifying and characterizing ecosystems throughout the national territory, no national ecosystem classification system currently exists.

Dominant vegetation cover is usually a good starting point for delineating and classifying terrestrial ecosystems. A country-specific classification system is a better approximation, particularly if such a system is already in operation. Although such a system is likely to reflect local conditions there is also a risk that it will be too specific and thus make it difficult to compare results at the international level.

4.2.1 Mexico's Vegetation Classification System

Different vegetation classification systems have been formulated in Mexico over the course of several decades and provide a good starting point for recognizing the arrangement of ecosystem in the national territory (Sánchez-Colón, 2019). This system evolved into the Vegetation and Land Use Classification System developed by INEGI. Following those proposed by Miranda and Hernández-Xolocotzi (1963) and Rzedowsky (1978), the classification system of INEGI currently represents the most complete and detailed system of natural and induced vegetation and land use in the country, and is frequently used to describe the environmental context and the Mexican terrestrial ecosystems.

In this system, classes are organized based on the characteristics of the various vegetation types so as to define, in first order, the major vegetation groups, in turn comprising vegetation types with ecological and physiognomic affinity. In its latest version, this system includes 12 vegetation formations subdivided into 58 vegetation types organized in a hierarchical system. For each vegetation type, this classification also distinguishes various stages of vegetation development: primary (undisturbed vegetation) and secondary (vegetation emerging after disturbance by natural or anthropic causes and in an herbaceous, shrubby, or arboreal stage of development). The different systems that are managed, and which constitute a land-use cover per activity (agriculture, livestock, forestry, and aquaculture) and grouped by type of agro-ecosystem, are also included. This system also differentiates areas devoid of vegetation, human settlements, and water bodies (INEGI, 2017c). Altogether, the Vegetation and Land Use Classification System of INEGI results in a combination of more than 200 vegetation classes and 24 land-use classes. Such a system, cartographically represented at the national level, provides the starting point for the representation of terrestrial ecosystem types for this project.

In an attempt to use a classification that grouped ecosystems into a smaller number of classes, a more simplified version was used, which was developed by CONAFOR to enable reporting on the national emissions inventory according to the guidelines of the Intergovernmental Panel on Climate Change (IPCC, 2003). This classification, hereafter referred to as CONAFOR-IPCC-N3, includes 14 vegetation types (12 of which are segregated into primary and secondary vegetation), five land-use classes and one class for water bodies. Vegetation types were segregated into subcategories corresponding to the dominance of woody (arboreal and shrub) and non-woody (herbaceous) elements in their different developmental stages. Thus, the CONAFOR-IPCC-N3 classification results in 32 classes (see Annex 9.1).

4.2.2 Correspondence among Ecosystem Classification Systems

Numerous cartographic representations of environmental units that capture ecological aspects in different ways have been generated in Mexico, each one responding to the diverse interests and conceptions of their authors. In the process of analysing the data sources, a number of potentially useful options for the identification and characterization of ecosystems were found, such as the spatial coverage of the Holdridge Life Zones produced by CONABIO.

There was also interest in the proposal developed by the International Union for Conservation of Nature (IUCN) to integrate a "Global Ecosystem Typology" (IUCN GET), which the SEEA EA considers to be the reference system for classifying and mapping all of the Earth's ecosystems, including aquatic and marine ecosystems, based on their functions and composition. As the IUCN GET product is not mapped for Mexico, developing a correspondence with the national Vegetation and Land Use classification was not possible. Nevertheless, a conceptual cross-walk was made between the

IUCN GET ecosystem categories and the classification used for this pilot project.

In Mexico, one of the most widely used classifications is the Ecological Regions of North America (also called Ecoregions of North America) developed by the North American Commission for Environmental Cooperation (CEC) with the objective of having a region-wide ecosystem classification, including maps, of the ecological regions of Mexico, Canada, and the United States (CEC, 1997). These ecological regions represent 4 Ecoregions levels within a hierarchical system. The cartographic product of the Ecoregions classification for Mexico, developed by INEGI, CONABIO and INE, is available at a 1:1 000 000 scale, using the four levels of regionalisation proposed by the CEC (INEGI-CONABIO-INE, 2008). Level 2 of the Ecoregions is estimated to approximate the IUCN GET criteria.

4.2.2.1 Interoperability between different classification systems

In view of the growing need of users to have different representations of ecosystems depending upon the purpose of analysis, and taking into account the relative merits of each product, the conclusion was reached that it is important to generate means to incorporate the diverse spatial representations of ecosystems. Therefore, it was proposed to develop a calculation device to favour the interoperability of the available ecological information using artificial intelligence tools (See Annex 9.2).

4.3 Methodology

The general procedure for the development of the extent accounts consists of three methodological steps:

i) Identifying the ecosystems or "ecosystem assets" in Mexico. For this pilot, as described in section 0, an abridged representation of vegetation called CONAFOR-IPCCN3 was agreed upon;

ii) Compiling the extent accounts of the different ecosystems at each point in time based on the segmentation of the national geographical space, and;

iii) Developing a change analysis to obtain detailed information on additions and reductions in the extent of ecosystems by comparing two maps of the country at different times, following established best practices for land-cover and land-use change analysis (LCLUA) in Mexico (Más et al. 2004). Geometric correspondence of the charts was verified as a quality control for the change analysis.

4.3.1 Cartographic inputs

In Mexico, there are six cartographic series of land use and vegetation that have been developed by INEGI at the national level at a 1:250 000 scale. Such Land Use and Vegetation Charts (LUVC) "represent(s) the location and extent of different types of vegetation and agriculture. They also include symbols that indicate livestock and forestry use activities, and codes for crops and various plant species. They include additional field information about agricultural practices and crops, as well as structure, composition, use and dynamics of vegetation" (INEGI, 2007).

The digital version consists of a Vector Data Model and "a classification system of the different types of agriculture and vegetation in Mexico" (INEGI 2007). As a result of methodological differences between the first two versions and later versions, only maps from 2002 (Series III, INEGI, 2005), 2007 (Series IV; INEGI, 2008), 2011 (Series V; INEGI, 2013) and 2014 (Series VI; INEGI, 2016) were used, forming four periods of analysis (2002-2007, 2007-2011, 2011-2014 and 2002-2014).

4.3.1.1 Adjustments to input data

In order to have a fixed accounting area over time, it was necessary to make geometric adjustments to the polygons to correct slight differences in the coastline and coastal bodies. As a result, the total variation in the national territory between the different years in raster format was 0.001 per cent (1 964 382.99 km^2 /1 964 353.74 km^2), ensuring that the observed differences are due to changes in the extent of ecosystems and not cartographic artefacts.

A further step consisted in applying a water mask to each of the periods of the analysis to ensure that changes in extent were not influenced by inter-annual variability of epicontinental water bodies, which is recognized as a recurrent accuracy problem of such objects in satellite image interpretations. This procedure consisted of generating a map - considering all four input maps - of the maximum extent of water bodies, by adding up the pixels that were classified as water on at least one of the maps. By doing so, it is ensured that there were no changes between water bodies and the other categories (see also impossible changes in Section 4.3.3).

4.3.1.2 Basic spatial and accounting area units

To ensure spatially congruent inputs for the analysis of changes between different years, a pixel grid covering the whole study area was used as the basis for any spatial operation in the accounting system (also referred to as the primary grid). This primary grid consists of equally-sized pixels of 250m which represent the basic spatial unit corresponding to the original scale of the inputs (1:250,000). The Albers Equal-area projection depicts the national territory in its entirety as a whole with no distortions and allows to calculate the area reliably, regardless of other aspects, such as shape, distance, etc.

4.3.2 Accounting for ecosystem extent and its changes

On the basis of the classification adopted for the extent accounts, the extent of each of the ecosystem types was calculated for each of the periods of analysis. Based on these data, and with the help of the change matrices, ecosystem extent accounts were produced for each of the accounting periods, including the variables: opening extent, additions or reductions (gains or losses) and closing extent (Table 4-2).

Depending on the nature of the changes in extent, both the additions and reductions in extent are disaggregated into managed (caused by direct human action) or unmanaged (caused by natural processes or in an indirect manner by humans). All additions or reductions are considered ecosystem conversions which imply a change in ecosystem type. As a water body mask was applied to the inputs, water bodies do not show changes in extent within the periods of analysis.

For the purpose of the change analysis, the primary and secondary vegetation of all vegetation types were grouped, resulting in a reduction of the total number of classes reported from the original 32 to 20. It was therefore possible to achieve a clearer ecological interpretation of the results and their changes, in terms of the extent itself, since the designation primary or secondary refers to the condition. According to the SEEA EA, the resulting changes in condition are not indicative of ecosystem conversion and should not be considered as additions or reductions.

Three indicators of extent and their changes are reported:

1. Absolute extent in km^2
2. Annual rate of change (FAO 1996)[8]
3. Remaining proportion of the original potential extent (Rzedowski,1990).

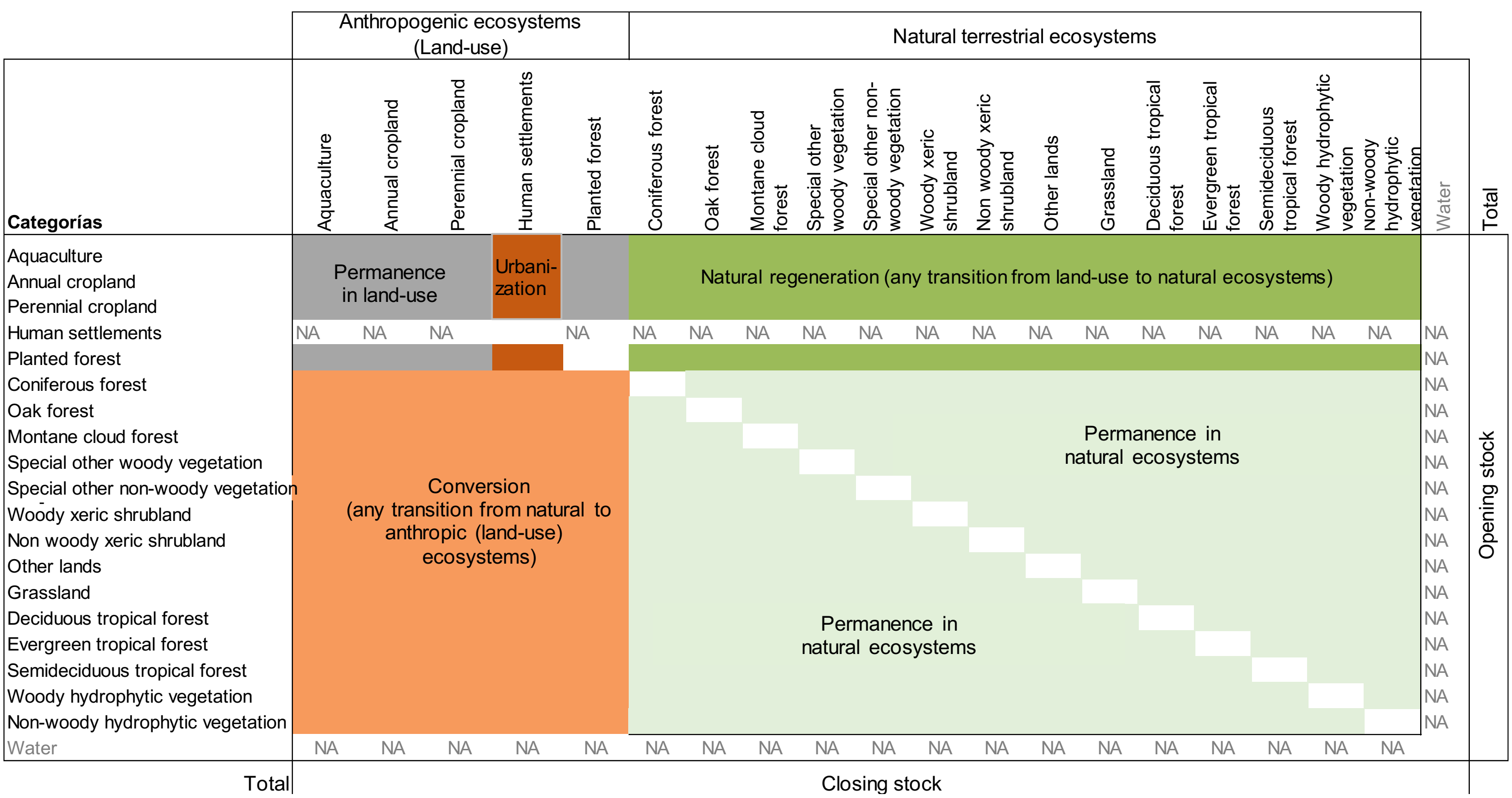
[8] The annual rate of change is calculated with the formula r = (((s2/s1) (1/t)) x 100)-100, where r is the rate, s2 and s1 are the surfaces (extent areas) for the end and start of the period, respectively, and t is the time elapsed between the dates.

4.3.3 Change matrices

In the SEEA EA approach, the aim is not only to measure changes over time on the extent of ecosystems, but also to provide additional detail on the nature of additions and reductions in ecosystems. To achieve the latter, "change matrices"[9] are compiled by intersecting the maps from two periods. Change matrices show the transitions or changes between ecosystem types, i.e. where additions came from and where reductions are converted into. They can also provide some indication of the direct drivers responsible for the observed changes.

Figure 4-1 depicts the change matrix structure with representation of changes or transitions between different ecosystem categories at two points in time. Rows represent data from the opening of the accounting period and columns the data from the end of the accounting period, so that each cell contains the area of the unit (km^2) that transitioned from the category at the beginning (row) to the category at the end of the period (column). White diagonal cells represent the area of the units (km^2) in each category that have remained unchanged while additions or reductions are shown in the other cells. The total opening extent is recorded in the last column on the right and the total closing extent in the bottom row.

Figure 4-1: Example of a change matrix structure



[9] It is also known as a transition matrix.

The following categories were defined for the change analysis to describe transitions and permanence, which are illustrated in Figure 4-1.

- **Conversion**[10] (loss of natural ecosystems): any transformation of natural vegetation to one of the land-use categories.
- **Urbanization**: the transformation of agricultural land use into human settlements.
- **Natural regeneration:** any transition from any category of land use to natural vegetation, in addition to permanence, which are:
  - **Land-use permanence:** refers to transitions between land-use categories (ecosystems of anthropic origin);
  - **Natural-vegetation permanence**: refers to transitions between natural ecosystem categories.

An important point to note is that a comparison of map series, as was done in this case, is prone to detect what are called "impossible"[11] changes (e.g. the appearance of mature forests and tropical forests in less than five years, in a place where there were none before). This type of change results from confusions between inputs and different vegetation types and are interpreted as artefacts derived from the satellite sensors themselves or from inconsistencies that are inevitable in the comparison of maps due to cartographic and thematic intrinsic variations, including in the interpretation of the data. As such, ecologically illogical and highly unlikely changes are considered as impossible changes for this analysis. In the change matrix, changes from urban areas to any other category are also indicated as impossible. For water bodies, due to the application of a maximum extent water mask, these changes cannot occur and are therefore labelled Not Applicable (NA) in Figure 4-1.

Change matrices were compiled by intersecting maps for the beginning and the end of each analysis period. In this manner, the extent of the transitions between categories was explored between map editions, as well as for the period 2002-2014. Spatial overlaying by pairs of "raster" maps was carried out to generate these data. The raster of transitions between categories or permanence resulted in a data table with which the extent of each change was finally quantified.[12]

4.4 Results

4.4.1 Extent of terrestrial ecosystems in Mexico

According to the data of the LUVC Series VI (Map 4-1), the natural ecosystem with the largest extent in the country is Non-woody xeric shrubland (366 598 km^2, 19 per cent of the total area), followed by Grasslands (308 219 km^2, 16 per cent) and Woody xeric shrubland (205 651 km^2, 10 per cent). Deciduous tropical forest has the fourth place in extent in the country (178037 km^2, 9 per cent), followed by Coniferous forests (167 826 km^2, 9 per cent) and Oak forests (158 295 km^2, 8 per cent).

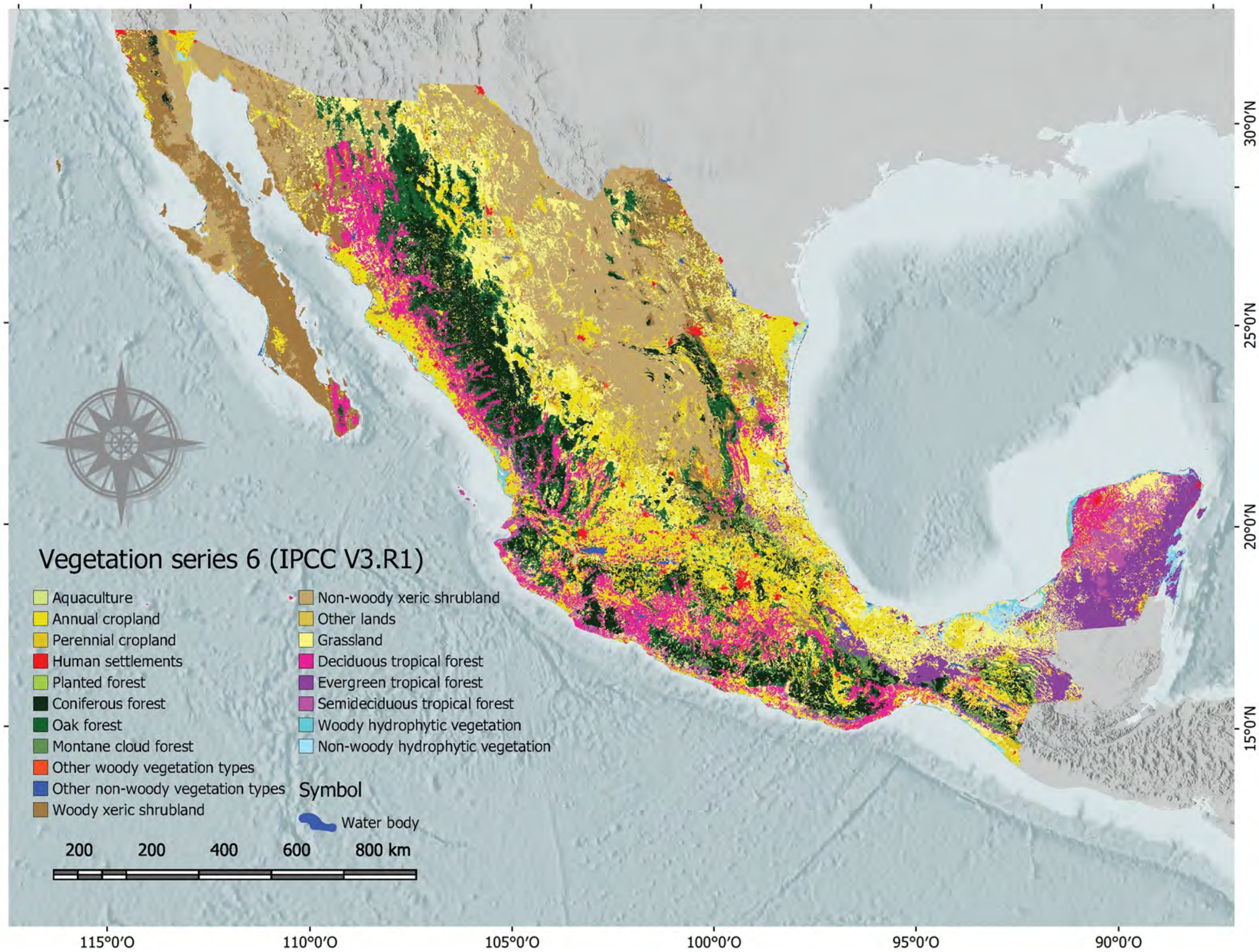
Among the ecosystems of anthropic origin (land use categories), the most extensive is Annual cropland (310 955 km^2, 16 per cent), followed by Perennial cropland (18 273 km^2, 1 per cent) and Human settlements (21 798 km^2, 1 per cent).

[10] According to the SEEA EA (UN, 2021), the changes in ecosystem type are called conversions: 'Ecosystem conversions refer to situations in which, for a given location, there is a change in ecosystem type involving a distinct and persistent change in the ecological structure, composition and function which, in turn, is reflected in the supply of a different set of ecosystem services' ((SEEA EA, p. 74). In this report, we are using the term 'conversion only for the purposes of naming the process of change that implies the loss of natural ecosystems
[11] Such changes are also known as spurious, false, unlikely, improbable or non-plausible changes.
[12] The code to repeat this process, from raster products to change matrices, is available at the following publicly accessible link: https://github.com/jequihua/SEEA-Mx

Table 4-1: Extent of terrestrial ecosystems based on CONAFOR-IPCC-N3 classification aggregated into 20 categories in 2002, 2007, 2011 and 2014 (in km^2)

	Category	Series III (2002)	Series IV (2007)	Series V (2011)	Series VI (2014)	Percentage of total (2014)	Net change (2002-2014)	Percentage change (2002-2014)	Annual rate of change (2002-2014)
Anthropogenic ecosystems (land use) Use	Annual cropland	293 268	306 675	309 811	310 955	16%	17 687	6%	0.49
	Human settlements	12 657	16 045	21 400	21 798	1%	9 142	72%	4.63
	Perennial cropland	16 239	16 840	17 671	18 273	1%	2 034	13%	0.99
	Aquaculture	683	909	1 085	1 156	0%	473	69%	4.48
	Planted forest	322	374	655	753	0%	432	134%	7.34
Natural ecosystems	Non-woody xeric shrubland	370 318	367 585	366 041	366 598	19%	-3 719	-1%	-0.08
	Grassland	315 257	310 759	306 952	308 219	16%	-7 038	-2%	-0.19
	Woody xeric shrubland	211 462	209 323	206 175	205 651	10%	-5 811	-3%	-0.23
	Deciduous tropical forest	179 643	176 845	178 802	178 037	9%	-1 606	-1%	-0.07
	Coniferous forest	168 673	168 358	167 905	167 826	9%	-847	-1%	-0.04
	Oak forest	156 366	156 248	158 350	158 295	8%	1 929	1%	0.10
	Evergreen tropical forest	105 222	102 838	101 422	99 436	5%	-5 786	-5%	-0.47
	Semi-deciduous tropical forest	47 599	44 420	40 458	39 855	2%	-7 744	-16%	-1.47
	Montane-cloud forest	18 252	18 430	18 105	17 966	1%	-286	-2%	-0.13
	Non-woody hydrophytic vegetation	14 278	13 964	14 345	14 276	1%	-2	0%	0.00
	Woody hydrophytic vegetation	11 290	11 680	11 752	11 737	1%	447	4%	0.32
	Other lands	9 493	9 742	10 165	10 279	1%	785	8%	0.66
	Special other woody vegetation types	4 279	4 276	4 189	4 171	0%	-108	-3%	-0.21
	Special other no-woody vegetation types	1 562	1 544	1 541	1 537	0%	-25	-2%	-0.14
	Water bodies	27 548	27 548	27 548	27 548	1%	0	0%	0.00
	Total	1 964 409	1 964 402	1 964 369	1 964 368				

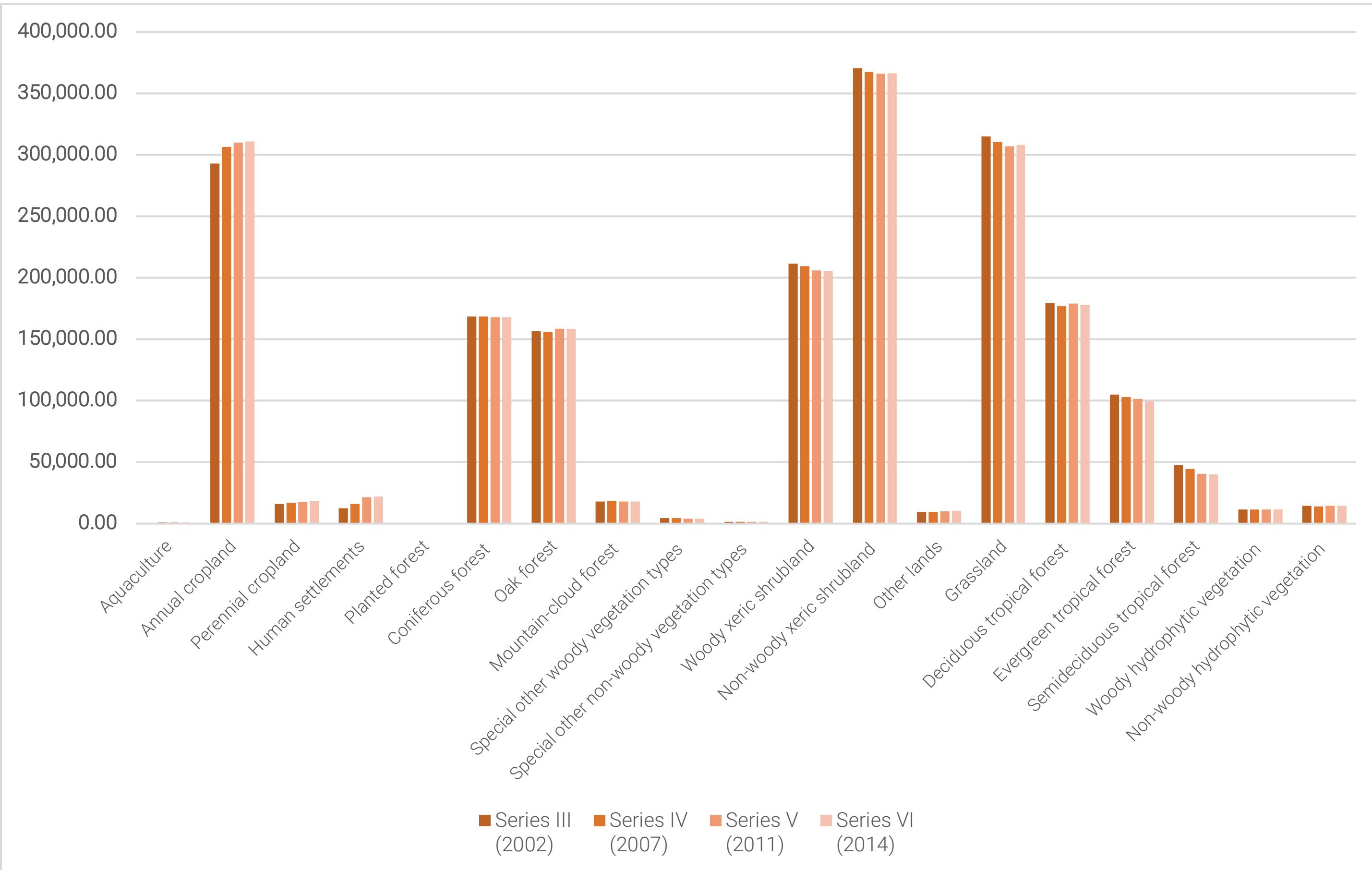
Map 4-1: Extent of terrestrial ecosystems in Mexico in 2014



Source: INEGI (2016)

In general, the extent of the anthropic ecosystem categories, such as Aquaculture, Annual cropland and Perennial cropland, Human settlements and Planted forest, has been increasing over time. By contrast, there has been a reduction in the extent of natural ecosystems (see Figure 4-2).

Figure 4-2: Extent of natural and anthropic ecosystems in km^2 during the 12-year-period between 2002 and 2014



Source: prepared by the authors based on the Land Use and Vegetation Series of INEGI (2005, 2008,2014, 2016)

4.4.2 Changes in ecosystems extent

During the 2002-2014 period, all categories corresponding to anthropic origin ecosystems (or land-use categories) showed net increases in extent and sustained positive rates of change (Table 4-2, Figure 4-2). The category Annual cropland had the largest increase in extent in the period 2002-2014, showing a net increase of 17,687 km^2 and an annual rate of change of 0.49 per cent.

The category Human settlements follows with a net increase of 9 142 km^2 and an annual rate of change of 4.63 per cent. Other categories that stand out for their high rates of change, despite their small extent, are Planted forest and the Aquaculture category, with annual rates of change of 7.34 per cent and 4.48 per cent, respectively.

On the other hand, almost all natural vegetation categories showed net reductions and negative rates of change during 2002-2014, with the exception of Other lands, Woody hydrophytic vegetation and Non-woody vegetation types (Table 4-2, Figure 4-4,). Notably, the net change and the rate of change of Oak forests is practically zero. The largest negative net change in the period occurred in the category Grassland, showing a net reduction of 7 038 km^2, which corresponds to more than 2 per cent of the initial extent, with a clear tendency to decrease over time (Figure 4-3). Other ecosystem types that showed net negative changes are Semi-deciduous tropical forest (-7,744 km², or 16 per cent reduction of the initial extent), Woody xeric shrubland (-5811 km², or 3 per cent reduction of the initial extent) and Evergreen tropical forest (-5786 km² or 6 per cent reduction of the opening extent). The Deciduous tropical forest also experienced significant reductions (in total 1606 km², or 1 per cent of the initial extent). There is however no specific pattern over time, as this ecosystem type showed significant additions in the 2007-2011 period (Figure 4-3). During the period between 2002 and 2014, the largest negative rate of change can be found in Semi-deciduous tropical forest (-1.47 per cent) followed by the Evergreen tropical forest (-0.47 per cent) (Table 4-2, Figure 4-4). Other categories with considerable negative rates of change are Special and Other woody and Non-woody (-0.22 per cent, -0.27 per cent), as well as Xeric shrubland (-0.24 per cent). A high dynamism is observed in forests, which results in a balance close to zero, with the exception of Montane-cloud forest, which exhibits a slightly higher reduction (total rate of change -0.13 per cent). Generally, a decrease in additions and reductions over time can be observed, especially for the 2011-2014 period. Nonetheless, a strong downward trend in tropical forests becomes evident during this period, especially in Deciduous tropical forest and Semi-deciduous tropical forest, compared to other types of ecosystems.

Figure 4-3: Net change in ecosystem extent for the 2002-2007; 2007-2011; 2011-2014; and 2002-2014 periods

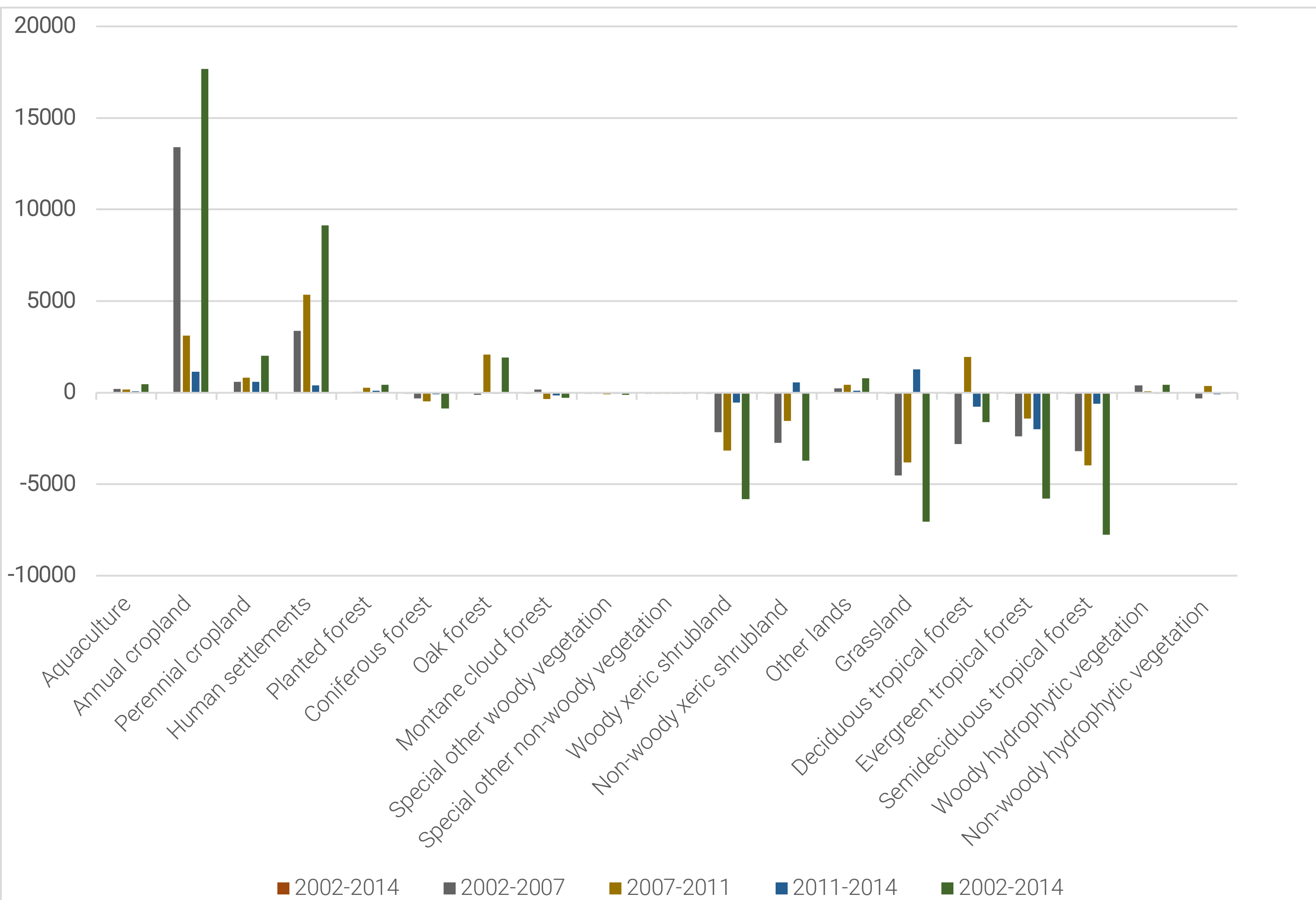


Table 4-2: Terrestrial ecosystem extent accounts for the 2002-2014 period, using the aggregated CONAFOR-IPCC-N3 Vegetation categories (km^2)

	Anthropic ecosystems (Land use)				Natural Ecosystems																
Series III -VI	Aquaculture	Annual cropland	Perrenial cropland	Human Settlements	Planted forest	Coniferous forest	Oak forest	Montane loud forest	Special other woody vegetation types	Special other non-woody vegetation types	Woody xeric shrubland	Non-woody xeric shrubland	Other lands	Grassland	Deciduous tropical forest	Evergreen tropical forest	Semideciduous tropical forest	Woody hydrophytic vegetation	Non-woody hydrophytic vegetation	Water bodies	Total
Opening extent, 2002 (Serie III)	683	293 268	16 239	12 657	322	168 673	156 366	18 252	4 279	1 562	211 462	370 318	9 493	315 257	179 643	105 222	47 599	11 290	14 278	27 548	1 964 409
Additions to extent																					
Managed expansion	536	52 999	5 227	9 376	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68 233
Natural expansion	0	0	0	0	389	9 485	14 158	1 430	668	80	4 734	7 594	1 477	45 897	19 902	8 855	3 292	1 414	1 785	0	121 161
Other additions	0	129	10	2	5	4	4	0	0	10	11	15	11	39	6	9	2	7	5	0	267
Total additions to extent	536	53 127	5 238	9 378	489	9 489	14 162	1 431	668	90	4 745	7 609	1 487	45 936	19 908	8 864	3 294	1 421	1 790	0	189 662
Reductions in extent																					
Managed reduction	11	7 062	1 351	0	30	3 495	2 830	807	280	57	4 095	6 312	196	23 723	8 838	4 563	4 229	231	512	0	68 622
Natural reduction	52	28 376	1 845	0	27	6 841	9 403	909	496	50	6 458	5 011	482	29 247	12 674	10 086	6 810	731	1 274	0	120 772
Other reductions	0	3	7	236	0	0	0	0	0	8	3	5	24	4	1	0	0	11	6	0	308
Total reductions to extent	63	35 440	3 203	236	57	10 336	12 233	1 716	775	115	10 555	11 328	702	52 974	21 514	14 649	11 039	973	1 792	0	189 703
Adjustments	0	126	3	- 234	5	4	4	0	-0	2	8	9	-13	35	5	9	2	-4	-1	0	-41
Closing extent, 2014 (Serie VI)	1 156	310 955	18 273	21 798	753	167 826	158 295	17 966	4 171	1 537	205 651	366 598	10 279	308 219	178 037	99 436	39 855	11 737	14 276	27 548	1 964 368
Net change in extent	473	17 687	2 034	9 142	432	- 847	1 929	- 286	- 108	-25	-5 811	-3 719	785	-7 038	-1 606	-5 786	-7 744	447	-2	0	-41
Percentual change	69%	6%	13%	72%	134%	-1%	1%	-2%	-3%	-2%	-3%	-1%	8%	-2%	-1%	-5%	-16%	4%	-0%	0%	
Annual rate of change	4.48%	0.49%	0.99%	4.63%	7.34%	-0.04%	0.10%	-0.13%	-0.21%	-0.14%	-0.23%	-0.08%	0.66%	-0.19%	-0.07%	-0.47%	-1.47%	0.32%	-0.00%	0.00%	

Negative annual change rate in extent denote a loss in the extent of ecosystems during the accounting period. On the other hand, positive change rates show the annual rate of expansion of ecosystems during the accounting period.

Figure 4-4: Annual rate of ecosystem change between 2002 and 2014 (%)

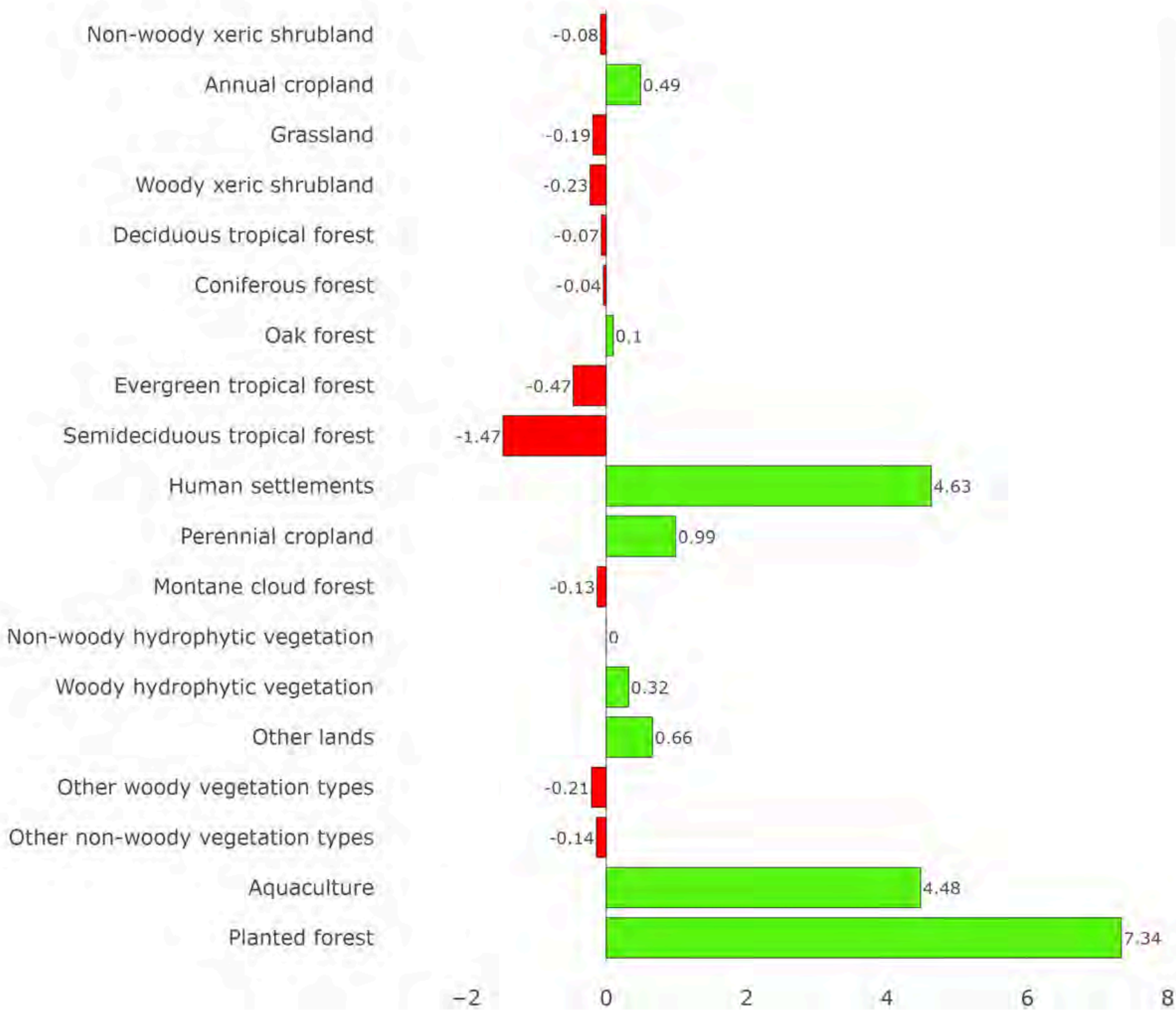
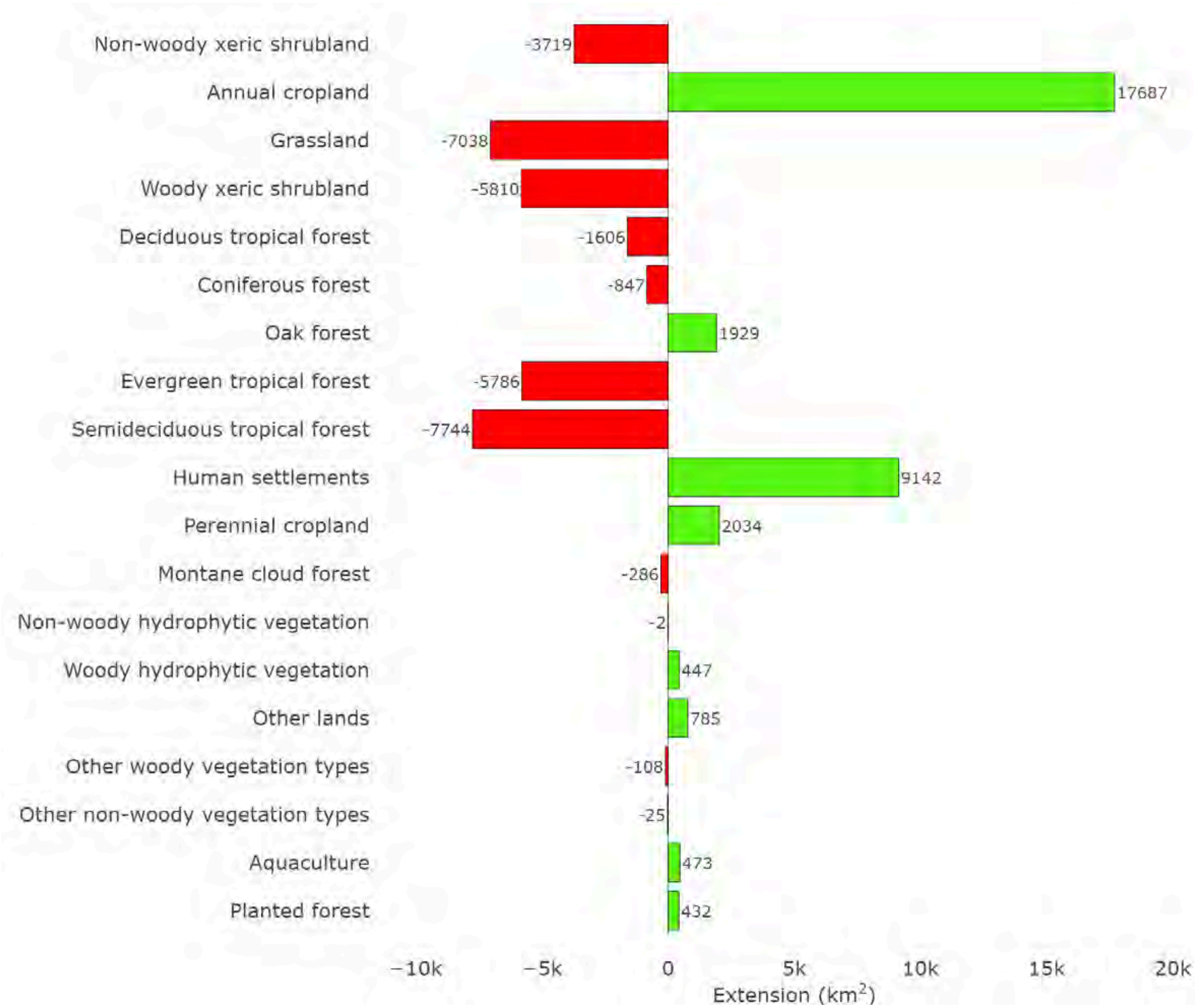


Figure 4-5: Net change in ecosystem extent between 2002 and 2014 (km²)



4.4.3 Potential vegetation

In order to have a historical baseline for the extent accounts, estimates of the remaining proportion of each ecosystem type were calculated considering the hypothetical reference condition of potential vegetation of Mexico (Rzedowski, 1990). The potential vegetation describes the vegetation which probably covered the national territory before being transformed by human activities. The scale and classification of this map diverge from those associated with the Vegetation and Land Use maps used in the INEGI Series and discussed in the previous sections. Despite these limitations, a hypothetical comparison between them is possible for the purpose of having a rough estimate of the changes in national ecosystems based on a reference map (Table 4-3).

Figures suggest that Mexican tropical forests, collectively, represent the ecosystems that have shrunk the most with respect to their original extent.

In 2014, Deciduous tropical forest would have been the most reduced ecosystem type, retaining only 47 per cent of its original area. This is followed by Evergreen and Semi-deciduous tropical forests, which preserve 53 per cent and 73 per cent of their original surface area, respectively. Coniferous and Oak forests maintain 86 per cent of their original surface. In the case of the Montane-cloud forest, while there is documented evidence of its declining extent in Mexico, no losses were observed in this study with respect to the potential vegetation representation; nevertheless, it should be considered that, given the scale of the inputs, this ecosystem occurs in relatively small areas and in close proximity to other forest types and is most likely not adequately represented. The same applies to Hydrophytic vegetation which shows an increase of 29 per cent. In the case of Grassland, the growth is likely to be due to the opening-up of natural ecosystems and their transformation into grasslands for the development of agricultural and livestock activities, primarily for keeping livestock. Regrettably, the CONAFOR-IPCC-N3 vegetation classification does not allow for a comparison in terms of the natural or anthropic origin of grasslands. Therefore, these figures should be taken with caution.

Table 4-3: Remaining vegetation in 2014 relative to the potential ecosystem's extent, in km^2 - (CONAFOR-IPCC-N3, aggregated to 8 classes)

Vegetation categories		Extent (km^2)		Percentage
Potential vegetation	CONAFOR-IPCC-N3	Potential vegetation	Vegetation Series VI-2014	Remaining vegetation
Deciduous tropical forest/ Thorn forest	Deciduous tropical forest	381 580	178 037	47
Evergreen tropical forest	Evergreen tropical forest	189 234	99 436	53
Semi-evergreen tropical forest	Semi-deciduous tropical fores	54 667	39 855	73
Xeric shrubland	Xeric shrubland	727 848	572 283	79
Coniferous and oak forest	Coniferous forest and Oak forest	377 347	326 121	86
Montane-cloud forest	Montane-cloud forest	17 836	17 966	101
Aquatic and subaquatic vegetation	Hydrophytic vegetation	20 336	26 013	128
Grassland	Grassland	157 075	308 219	196

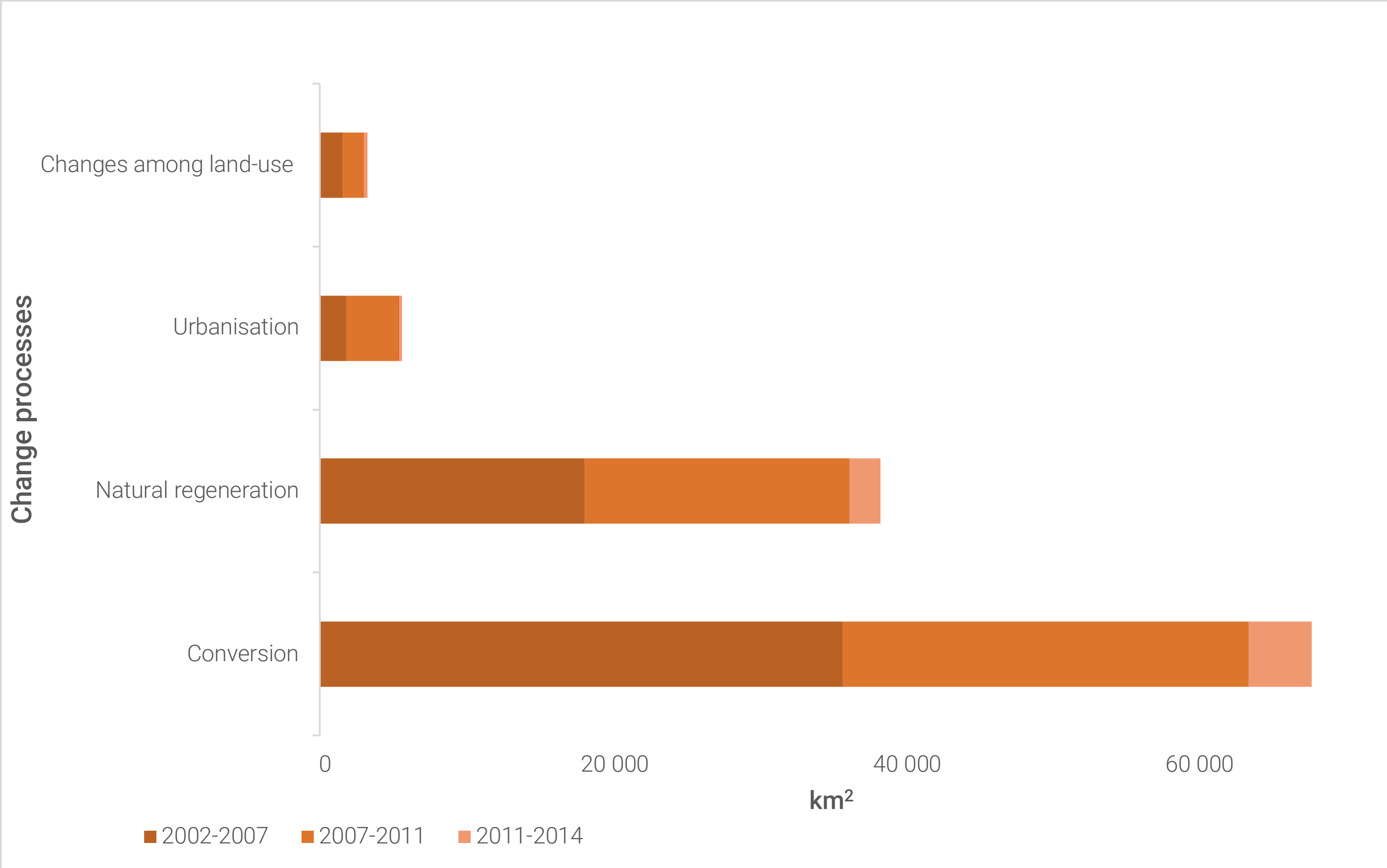
Source: Prepared by the authors based on the data of potential vegetation at a 1:4,000,000 scale (Rzedowski, 1990) and the vegetation chart of INEGI Series VI at a 1:250 000 scale.

Note: Because potential vegetation does not include land use, the corresponding categories were not considered, as well as the Special woody and Special non-woody vegetation types and Other lands classes, since they do not correspond to potential vegetation. Moreover, these categories represent a very small portion of the territory.

4.4.4 Change matrices

As was already observed in general terms, in the change matrices a decrease in the rate of change is noted. This reduced dynamics of change affects all change processes, such as land-use change, urbanization, natural regeneration, and conversion (Figure 4-6) This overall pattern does not contradict the opposite development for some vegetation types mentioned above

Figure 4-6: Extent of major change processes during the periods 2002-2007, 2007-2011 and 2011-2014



The conversion of natural ecosystems to a land-use category was the most extensive process of change, covering over 3 per cent of the territory, while natural regeneration comprises half of that extent (Table 4-5). This indicates a significant loss of natural ecosystems even though there is also a constant exchange between deforested and restored areas.

4.4.4.1 Dynamics of change, 2002-2014

In the 12-year period from 2002-2014, aside from Grassland which was converted mainly to agriculture, the most significant conversions (in absolute terms) of vegetation into land-use categories occurred in the Tropical Forests category, followed by Shrublands and Forests. These areas are predominantly converted into Annual agriculture (Table 4-4).

For Hydrophytic vegetation, the conversion of Non-woody hydrophytic vegetation amounts to double the area of Woody hydrophytic vegetation (Table 4-4). Natural regeneration is generally much lower than conversion, causing a reduction of natural ecosystems. In the Forests category, Coniferous and Montane-cloud forests are transformed to areas for perennial agriculture to a greater extent than Oak forests. In turn, Coniferous forests are transformed into urban areas to a greater extent than Other forest types. Woody xeric shrubland has a higher conversion to Human settlements, while Non-woody shrubland has a higher conversion to Annual agriculture. Tropical forests, particularly Evergreen tropical forests, have undergone most changes due to the expansion of the agricultural frontier but also due to urbanization. Transitions to Human settlements are dominated by the change from Annual cropland followed by Grasslands and Shrublands. Transitions corresponding to changes within land use categories are also noted, showing an important dynamic between annual and perennial crops (Table 4-4).

4.4.4.1.1 Dynamics of change in intermediate periods

To further analyse the changes, change matrices were prepared for each of the intermediate accounting periods using the information from the series described in the input section of this chapter. This type of analysis is important to identify trends in changes over time, given that various types of ecosystems show oscillatory behaviour between each of the periods.

Looking at the different periods of analysis, for most ecosystems there is no clear pattern, as there are considerable losses and gains over the years. For instance, Deciduous tropical forest presents significant reductions during 2002-2014; however, it also presents significant additions during 2007-2011. In general, the greatest inconsistencies in extent trends are found in the 2007-2011 period, pending review of the comparability of data for those years. The change analysis and change matrices for the periods 2002-2007, 2007-2011 and 2011-2014 can be found in Annex 10.

Table 4-4: Matrix of change for the 2002-2014 period in km²

	Anthropic ecosystems (land use)					**Natural terrestrial ecosystems**															
2014 Series VI / 2002 Series III	Aquaculture	Annual cropland	Perrenial cropland	Human Settlements	Planted forest	Coniferous forest	Oak forest	Montane cloud forest	Special other woody vegetation types	Special other non-woody vegetation types	Woody xeric shrubland	Non-woody xeric shrubland	Other lands	Grassland	Deciduous tropical forest	Evergreen tropical forest	Semideciduous tropical forest	Woody hydrophytic vegetation	Non-woody hydrophytic vegetation	Water bodies	Adjustments	Opening extent, 2002 (Serie III)
Aquaculture	620	10	0	1	0	0	0	0	0	0	0	47	0	0	0	0	0	4	1	NA	0	683
Annual cropland	20	257 828	1 810	5 161	71	2 972	2 557	265	128	2	2 005	3 143	131	8 305	6 833	1 012	638	204	180	NA	3	293 268
Perennial cropland	1	995	13 036	331	24	134	27	52	1	2	39	8	19	840	388	257	30	35	14	NA	7	16 239
Human settlements	0	128	6	12 421	5	4	4	0	0	1	10	14	5	36	6	8	2	6	1	NA	2	12 657
Planted forest	0	16	0	14	265	7	6	0	0	0	2	0	0	5	0	6	0	0	0	NA	0	322
Coniferous forest	0	3 059	268	83	85	158 337	3 363	338	2	0	30	8	16	2 666	358	10	51	1	0	NA	0	168 673
Oak forest	0	2 701	48	49	31	2 766	144 133	139	33	0	89	26	84	3 565	2 444	87	164	8	0	NA	0	156 366
Montane cloud forest	0	588	196	24	0	301	38	16 535	0	0	2	0	2	473	3	83	7	0	0	NA	0	18 252
Special other woody vegetation types	0	267	2	9	1	8	110	0	3 503	0	130	57	3	108	66	5	3	3	3	NA	0	4 279
Special other non-woody vegetation types	10	12	3	32	0	0	0	0	0	1 447	5	4	11	6	2	1	0	21	1	NA	8	1 562
Woody xeric shrubland	86	3 309	96	604	0	286	184	0	25	8	200 907	784	167	4 723	172	0	24	64	21	NA	3	211 462
Non-woody xeric shrubland	200	5 647	60	404	1	48	251	0	160	5	696	358 989	494	3 106	1	0	0	160	91	NA	5	370 318
Other lands	57	82	19	37	1	39	3	0	0	16	13	138	8 791	128	11	10	1	89	35	NA	24	9 493
Grassland	28	20 099	1 695	1 685	216	2 533	5 404	332	215	13	1 594	3 148	287	262 283	7 926	5 521	1 253	271	751	NA	4	315 257
Deciduous tropical forest	13	8 039	345	437	3	304	1 827	3	63	1	88	195	153	9 202	158 129	106	617	91	25	NA	1	179 643
Evergreen tropical forest	0	3 656	509	356	42	18	113	158	1	0	0	0	27	8 734	175	90 573	471	85	306	NA	0	105 222
Semideciduous tropical forest	0	4 010	125	85	10	69	272	143	2	0	0	0	6	3 376	1 453	1 426	36 561	31	32	NA	0	47 599
Woody hydrophytic vegetation	16	166	17	34	0	0	2	0	1	30	34	21	47	96	29	114	31	10 316	327	NA	11	11 290
Non-woody hydrophytic vegetation	106	342	35	30	0	0	2	0	38	2	7	17	30	565	42	218	4	349	12 486	NA	6	14 278
Water bodies	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	27 548	0	27 548
Adjustments	0	1	5	2	0	0	0	0	0	10	1	0	6	3	0	0	0	2	4	0		
Closing extent, 2014 (Serie VI)	**1 156**	**310 955**	**18 273**	**21 798**	**753**	**167 826**	**158 295**	**17 966**	**4 171**	**1 537**	**205 651**	**366 598**	**10 279**	**308 219**	**178 037**	**99 436**	**39 855**	**11 737**	**14 276**	**27 548**		**1 964 368**

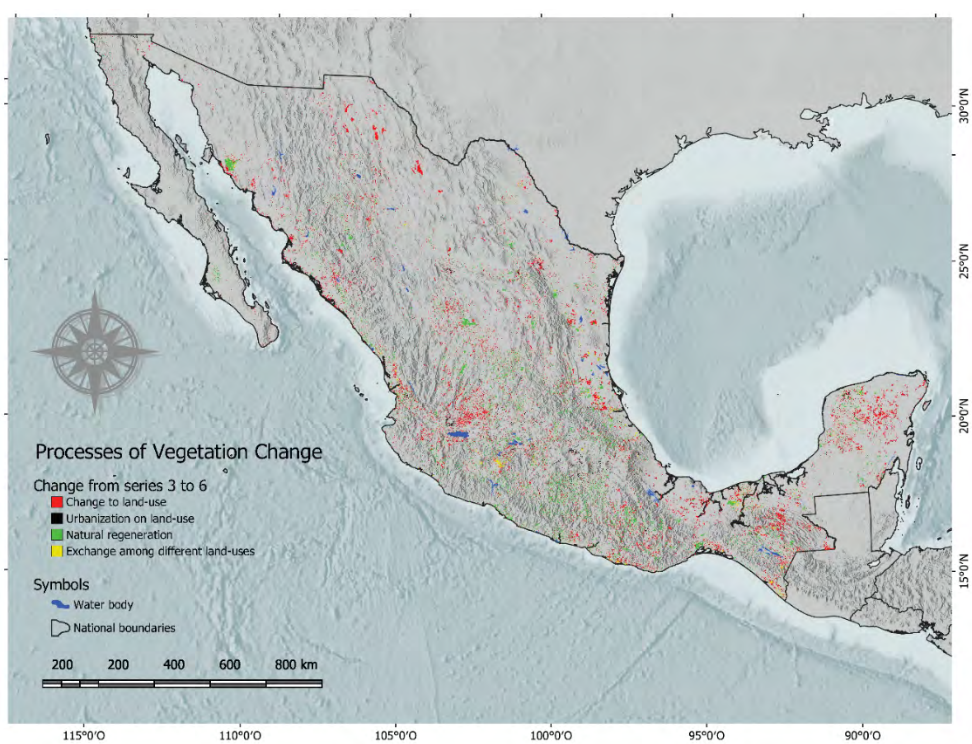
Note: Figures in light green represent impossible changes. Rows represent initial time, columns, final time, such that the quantity in each cell represents the quantity that moved from one category at initial time (row) to another category at final time (column). White diagonal cells represent the permanence of each category.

Table 4-5: Ratio of territory covered by change processes and impossible changes

Processes of change (2002-2014)	Area (km^2)	% Total
Conversion: Loss of natural vegetation	60 168	3.1%
Natural regeneration	30 300	1.5%
Urbanization	5 507	0.3%
Land use exchange	2 963	0.2%
Impossible changes		
Vegetation exchange	90 471	4.6%
Human settlements	234	0.0%

At the national level, the processes of change (Map 4-2) correspond to a little more than 5 per cent of the entire territory in the 2002-2014 period. The process of change with the largest extent is due to the conversion of natural ecosystems to ecosystems of anthropic use, mainly to Annual cropland (Table 4-5). Natural regeneration comprises almost half of the conversion extent, suggesting a significant loss of natural ecosystems, although there is also a constant exchange between converted and restored areas. It can also be noted that the extent of urbanization extent is almost twice as large as the exchanges between different land uses (Table 4-5). At this point it is important to highlight the need to control for impossible changes due to errors in the maps, as in this case the set of impossible changes represents 4.6 per cent of the total area of the country.

Map 4-2: Map of changes in ecosystem extent between 2002 and 2014



4.5 Discussion

4.5.1 Conclusions

Ecosystem asset extent accounts provide relevant information by integrating several layers of geospatial information and constitute the statistical and spatial basis for compiling other ecosystem accounts. The extent account allows to visualize the size and distribution of the different types of ecosystems throughout the territory and the changes and transitions during the period of analysis 2002-2014. The ecosystems with the largest extent in 2014 are the categories Non-woody xeric shrub followed by Grasslands, the Woody xeric shrub, Deciduous forest, the Coniferous forest and the Oak forest (19, 16, 10, 9, 9 and 8 per cent of the total area of the country, respectively). The Mexican tropical forests are the ecosystem types that have decreased the most in their original extent (approximately 53%).The analysis, based on the use of change matrices, allowed for the identification of processes and indicators of conversion and regeneration. In general, anthropogenic ecosystem classes, such as Aquaculture, Annual agriculture, Perennial agriculture, Cultivated plantations and Human settlements. The main results of these processes are particularly useful for prioritising the areas in which these changes are occurring, providing further information for decision-making at different levels, which may be translated into the formulation of landscape management for the conservation of natural heritage.

4.5.2 Areas of opportunity and recommendations

A. The classification CONAFOR-IPCC-N3 was used as a proxy for ecosystem classification for this project, which allowed to have an already-built synthesis of INEGI's classification of vegetation types to be used for the delineation of ecosystems for the pilot extent account. Nonetheless, the purpose of this IPCC's classification is not fully aligned with ecosystem accounting. For that reason, it is recommended to work towards a national ecosystem classification in coordination with different stakeholders, such as CONABIO, CONAFOR, CONANP, SEMARNAT, INECOL and other experts. Such a classification should be aligned with the global ecosystems typology (GET) proposed by the IUCN.

   It is recommended developing a classification where the natural ecosystem types can be differentiated from those that are not. In this regard, it is advisable to develop separate cartographies where natural ecosystems can be clearly distinguished from land use classes (anthropic ecosystems) as well as to have information on the natural ecosystem that preceded the land use areas. For Grasslands, it is essential to disaggregate natural from planted and induced ecosystems since it hinders the analysis of natural processes and pastoral and livestock activities.

B. The reliability of the input data should be determined to achieve greater certainty in the change analysis. In this respect, it is advisable to deepen the discussion on impossible changes based on expert knowledge and with the aim of improving the identification of the cause of the origin of the changes in order to classify them as anthropogenic or natural.

C. For the production of extent accounts, avoiding mixing condition and extent characteristics of ecosystems is recommended. As changes from primary to secondary vegetation in an ecosystem are not considered a change in extent but rather a change in condition, the status of secondary vegetation should not be considered as a separate ecosystem type from that of primary vegetation.

D. Improving the reliability of input data is important to have a better analysis of changes of ecosystems. It is suggested to deepen the analysis on impossible changes in a more systematic way and with expert knowledge in order to identify better the nature of the changes in ecosystems.

E. Ecosystem accounting requires very detailed spatial information for which it is required to ensure and strengthen the updating of the data necessary for the preparation of the accounts, with both standardised geospatial information and greater temporal coverage. Furthermore, it is advisable to continue with a representation of the information in cell format (raster) which facilitates its organisation and management.

F. It is recommended to develop a national ecosystem classification. The foundation for classification is provided by the hierarchical vegetation classification system of INEGI, an excellent starting point for classifying ecosystems; however, it is recommended to explore the possibility of incorporating biotic and abiotic elements providing more ecological information to achieve an identification and characterisation of the country's ecosystems, as well as to develop a national classification of ecosystems that takes into account not only vegetation structure but other ecological and biophysical characteristics as well.

G. Extent accounts (and ecosystem accounts in general) could be developed at the sub-national level to improve the level of analysis for decision-making.

Finally, it is highly recommended to develop a program of work to address the gaps and areas of opportunity found during this pilot within a solid coordination mechanism to develop a joint program of work that will take into account the information available and the technical capacities of other national experts, researchers and foster data exchange with different institutions and academia, such as CONABIO, CONAFOR, CONANP, SEMARNAT, INECOL and INEGI within collegiate bodies of the SNIEG.

Section 5:
Condition accounts of the terrestrial ecosystems of Mexico

Ecosystem condition accounts offer a structured approach for recording and aggregating data that describe the characteristics of ecosystem assets and their change. For Mexico, ecosystem condition accounts quantify ecosystem condition based on features of the structural and functional state of ecosystems and also on an aggregate measure through the Ecosystem Integrity Index. Furthermore, a measure of effective extent is estimated, which weights the extent of each ecosystem type, calculated in Chapter 4, with its condition and also a Natural Capital Index is compiled. The "Natural Capital Index" represents, on a scale of 0 to 1, the remaining natural capital in an area of interest (Ecosystem Accounting area) taking into account both the remaining extent and condition of the ecosystems.

KEY MESSAGES

Accounting for the condition of ecosystems provides a new reference frame for driving the development of the country. *With this accounting, decision-making can be conducted by considering not only the economic and social benefits and the provision of ecosystem services provided by ecosystem assets, but also their capacity to remain functional.*

The methodology used for this project in Mexico, which is based on the combination of a conceptual model and artificial intelligence techniques, is an excellent opportunity to take advantage of the vast amount of data generated by different institutions under a holistic approach.

The possibility of incorporating new variables or indicators into the Ecosystem Integrity Index should be evaluated. *A critical evaluation of the viability of these variables and indicators, so that they meet the criteria established by the SEEA EA, is proposed. It is recommended that this evaluation includes the participation of the institutions responsible for the production of variables and indicators to ensure the collection of data over time. Among these variables, the variables that measure physical, wildlife and landscape-level characteristics need to also be considered and integrated in a causal manner with pressure variables and change interventions that favour integrity.*

Relevant results

The accounting of variables for each ecosystem type suggests that between 2004 and 2018 there were major changes in some structural (percentage of tropical arboreal and shrub growth), functional (net photosynthesis) and pressure (percentage covered by human settlements) variables.

The condition of ecosystems in Mexico is heterogeneous throughout the territory *- As of 2018, the regions with the highest ecosystem integrity are found in the north of the country, excluding the coasts of Sonora, Sinaloa, and Nayarit, as well as one region in the arid zone of northern Mexico. The Yucatan Peninsula, though to a lesser degree, also has a high integrity status. The areas with the lowest ecosystem integrity are found in the Gulf of Mexico Coastal Plain, and the Bajío, located in the central region of the country. The northern Pacific coasts (Sonora, Sinaloa and Nayarit) also present exceptionally low* *ecosystem integrity. The central zone presents levels of degradation and low ecosystem integrity, and the Pacific Coast has some areas with high integrity and others with low integrity.*

Mexico's terrestrial ecosystems have lost a large extent (Chapter 4). The remnant of this extent is still considerable and in some natural ecosystems its condition is high - Non-woody xeric shrubland is the most extensive natural ecosystem (366,598 km^2) and one of the ecosystems in Mexico in the best condition. Grasslands are very extensive but have a low condition The Woody xeric shrubland is the fourth largest in regard to extent, and is also, for the most part, found in good integrity. Coniferous and Oak forests also have a significant extent and relatively high ecosystem integrity. The Montane-cloud forest currently occupies a reduced extent, and its integrity is between medium and extremely high.

Anthropic land uses can be naturally extensive, and the areas where they occur have extremely low integrities - The Annual cropland class has the greatest extent within the land uses with extremely low integrity. The Human settlements extent is already larger than that of some ecosystems (such as the Montane-cloud forest) and has the lowest integrity values.

The standardized distribution of aggregated ecosystem integrity according to the CONAFOR-IPCC-N3 Vegetation categories allows making different comparisons - Between 40 and 60 per cent of the extent of Non-woody xeric shrubland and Woody xeric shrubland; Woody hydrophytic vegetation, Non-woody hydrophytic vegetation; Coniferous forest; Evergreen tropical forest; Oak forest, Montane-cloud forest, Woody and Non-woody hydrophytic vegetation have a high integrity. Approximately 25 per cent of the deciduous tropical forest area and about 10 per cent of the semi-deciduous tropical forest are found with high integrity values. Seventy per cent of the extent of human settlements has exceptionally low ecosystem integrity. About 20 per cent of annual and perennial agricultural areas have extremely low and 50 per cent have low ecosystem integrity. The ecosystem integrity of planted forests is heterogeneous, at moderate levels for the most part.

Effective extent – This is defined as the product of the extent times the condition (integrity) of an ecosystem. In some vegetation types this leads to a significant reduction due to a loss of integrity. For instance, if integrity is considered, Grassland extent presented a reduction of a 50 per cent from 308 219 km^2 (extent) to 160 753 km^2 (effective extent) by 2018.

At the national level, Mexico preserves 65 per cent[13] of its original terrestrial natural capital. Percentage-wise, the natural ecosystems that maintain the greatest natural capital are Non-woody xeric shrubland (87 per cent); Woody xeric shrubland (85 per cent) and Coniferous forest (83 per cent). The Deciduous tropical forest, the Oak forest, the Evergreen tropical forest, the Semi-deciduous tropical forest, the Montane-cloud forest, and the Woody and Non-woody hydrophytic vegetation maintain between 70 and 80 per cent of their natural capital. Nevertheless, considering the reduced national extent of the Montane-cloud forest and the Woody and Non-woody hydrophytic vegetation, they are especially important ecosystems. The natural ecosystems that conserve the least natural capital are: Other lands (64% per cent); Special other Non-woody vegetation types (65 per cent); Semi-deciduous tropical forest (71 per cent) and Deciduous tropical forest (73 per cent). The natural capital contained in the grassland is 52 per cent (see footnote 1). The Land Uses that conserve the most natural capital within them are Planted forest (55 per cent); Aquaculture (51 per cent) and Perennial cropland (41 per cent). Human settlements only retain within them 9 per cent of the natural capital, Annual cropland 35 per cent, and Perennial cropland 41 per cent.

[13] $(\mathbf{19 - \sum \acute{I}ndice\ de\ Capital\ Natural * 100})$. Where 19 corresponds to the total number of ecosystems (not including water bodies).

5.1. Introduction

There is a growing global interest in stopping and trying to reverse not only the conversion (change in extent) but also the degradation of ecosystems (change in condition). Therefore, measuring the condition of ecosystems is critical for designing environmental policies and for guiding decision-making that is increasingly directed towards protecting, maintaining, and restoring natural capital. Furthermore, condition changes clearly influence the capacity of ecosystems to deliver the services that society values. Generating comprehensive and comparable accounts of the condition of ecosystems is therefore of great importance (UN, 2020a).

The ecosystem condition accounts offer a structured approach to record and aggregate data which describe the characteristics of ecosystem assets and their changes.[14] As defined by the SEEA EA, the ecosystem condition is the quality of the ecosystem measured in terms of its biotic and abiotic characteristics. The ecosystem quality is assessed in terms of the structure, function, and composition of the ecosystem, which in turn underpins the ecological integrity of the ecosystem and supports its capacity to deliver ecosystem services (UN, 2021).

The objective of this Chapter is to show the results that have been achieved in accounting for the condition of Mexico's ecosystems. This was done through the Ecosystem Integrity Index for 2004 and 2018[15] in order to document two points in time and also the changes that occurred during this period.

5.2. Background

In 2019, several variables (soil organic carbon, biodiversity, vegetation conservation status), indicators (water erosion), and indices (Ecosystem Integrity Index, Human Footprint Index and Index of Ecological Integrity) were analysed within the NCAVES project (Box 5.1), as well as independent proxies with which the condition of ecosystems could potentially be measured (see Table 5-1) and Sanchez-Colon (2019) for a more detailed analysis).

Box 5-1: Main variables and indices evaluated during the NCAVES project

State of conservation of the vegetation – This is based on the Vegetation and Land Use series of INEGI for six different points in time (circa 1976, 1993, 2002, 2007, 2011 and 2014). As a condition measure, a distinction is made between the successional stage or conservation status of the vegetation: primary (or relatively well-preserved) and secondary (or degraded).

Ecosystem Integrity Index – This index, developed under the project Integralidad Gamma (i-Gamma)[16], evaluates the ecosystems condition based on information from INFyS and satellite images on a 0 to 100 scale. Assessments are currently available for 2004 and 2018 but can be estimated for other dates. The evaluation method integrates a conceptual model (called three-layer) with machine learning techniques.

[14] The SEEA EA accounting framework document, Chapter 5, establishes the purpose of ecosystem condition accounting, indicating its key components, the structure, the steps for its implementation, and provides a set of considerations for its estimation.

[16] The project Integralidad Gamma was financed by the Institutional Regional Development Fund for Scientific, Technologic and Innovation Development (FORDECYT) of the National Council of Science and Technology (CONACYT) of Mexico through the project FORDECYT 296842.

Human Footprint Index – This is a pressure indicator denoting, in relative terms, the extent to which natural environments have been modified or transformed by human activities. It is calculated by estimating and/or evaluating both the transformation extent and intensity caused by various human activities. Assessments are currently available for 2011 and 2014 but can be estimated for other dates.

Index of Ecological Integrity – This characterizes "the potential of natural landscapes to support ecological integrity in maintaining biotic and abiotic apex predator interactions". It is based on a hierarchical ecological network to describe changes occurring at various levels. The approach includes: "(a) the construction of spatially-explicit indicators for ecological integrity as the basis of the assessment system; (b) the application of structural equation models to derive a set of latent indicators that construct the two-level notion of ecological integrity; and (c) an overall indicator that summarizes integrity in ecological condition." (Sanchez Colon, 2019).

Table 5-1: Initial appraisal of the variables, indicators and indices considered for assessing the condition of Mexico's terrestrial ecosystems as proposed by the SEEA EA framework (Modified from Sánchez-Colón, 2019)

	SEEA-EA typology class						
	Biotic characteristics				Abiotic characteristics		Landscape
	I. Compositional indicator		II. Vegetation and biomass		III. Physical and chemical state		IV. Landscape pattern
SEEA EA criterion	Biodiversity	Ecological Integrity Index	Conservation status of vegetation	Ecosystem Integrity Index	Soil Organic Carbon	Water caused erosion	Human footprint
Relevance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Orientation Status	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	Yes	No	No	Yes
Feasibility	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Quantitative	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

Each of these Indicators and indices has advantages and disadvantages, and provides valuable elements for accounting for ecosystem condition. In particular, the "Ecosystem Integrity

Index" or EII benefits from the large amount of environmental data used for environmental monitoring in the country e.g. from the National Forest and Soil Inventory (INFyS for its acronym in Spanish) and the National Biodiversity Monitoring System (SNMB, for its acronym in Spanish), as well as information on Vegetation and Land Use (i.e. INEGI) and satellite images of the Earth's surface using Landsat. For the current pilot, and thanks to the experience gained within the NCAVES project and the discussion and collaboration with various institutions (INEGI, SEMARNAT, INECOL, CONABIO, CONAFOR, CONANP and IG, UNAM), it was decided to carry out the accounting of ecosystem condition using the EII as a basis. This index meets the criteria, objectives and considerations established by the SEEA EA and allows for the integration of information generated through previous approaches to measure ecosystem condition (See Box 5-1 above).

However, it should be noted that the compilation of the Ecosystem Integrity Index partially differs in some conceptual and methodological respects from SEEA EA recommendations for calculating an aggregate measure of ecosystem condition" (UN, 2021, pp 96-98). Nevertheless, it is not considered a deficiency, but rather an opportunity to present an alternative that addresses some of the challenges detected when constructing the aggregate measures proposed in the SEEA EA. This chapter discusses the differences between the compilation of the EII and the SEEA EA and identifies the links between the SEEA EA guidelines and the conceptual and methodological aspects that are associated with the EII. Section 0 presents a first proposal to consolidate the ecosystem condition accounting process by integrating additional variables, such as vegetation conservation status and the Human Footprint Index.

5.3. Method

5.3.1 Steps for the Assessment of the Condition of Ecosystems

The condition account was compiled by ecosystem type based on the CONAFOR-IPCC-N3 classification used in the extent analysis (Chapter 4). For the condition assessment, the SEEA EA proposes a three-stage process. In the first stage, the measurement approach is established and the ecosystem characteristics as well as the associated variables are defined and selected. Ecosystem condition characteristics are those features of the ecosystem that are relevant to the assessment of its condition. Ecosystem condition variables are quantitative metrics that describe individual characteristics of an ecosystem asset. A single characteristic may have different variables associated with it, which may be complementary or overlapping. Variables differ from characteristics (even if the same descriptor is applied to them) since they have a clear and unambiguous definition (measurement instructions, formulae, etc.) and well-defined measurement units indicating the quantity or quality they measure. This first stage of identifying characteristics and variables is important to underpin the compilation of indicators in the second stage and to derive aggregate condition measures in the third stage (UN, 2021).

5.3.1.1 Step 1 Selection of ecosystem condition variables

For each of the ecosystem types, variables were selected to evaluate their biophysical characteristics, in addition to other auxiliary variables[17] (Table 5-2). For each ecosystem type, ten state variables (seven structural state and three functional state) and three pressure variables were selected according to the typology specified in the guide (Table 5-2). Such variables reflect

[17] These variables are not accounted for but are indicated given their importance in calculating the Ecosystem Integrity Index.

changes over time in the key characteristics of each ecosystem asset (SEEA EA, paragraph 5.15). It is worth noting that some of the classes suggested by the SEEA EA have not been considered for the time being due to lack of suitable data or the need to do further research in implementing methods of analysis or are in the process of being included in the model (see Table 5-2). Both the characteristics and the variables and their metrics were evaluated according to the conceptual, feasibility, optimization and set criteria suggested by the SEEA EA. The variables correspond to those that make up the EII in the so-called three-layer model (explained in greater detail in section 0 of this report where stage three is described).

Table 5-2: Typology of ecosystem condition proposed by the SEEA EA and relationship to variables in the three-layer model[18]

Groups	Classes according to SEEA EA	Variables of the three-layer model
Abiotic characteristics of the ecosystem	1. Physical condition characteristics (including soil structure, water availability)	Soil and water bodies, not yet considered, Anthropic noise is under preparation
	2. Chemical status characteristics (including soil nutrient levels, water quality, air pollutant concentrations)	Not yet considered
Biotic characteristics of the ecosystem	3. Compositional characteristics (including species-based indicators)	Not yet considered
	4. Characteristics of the structural state (including vegetation, biomass, food chains)	*Sign detection layer* - Number of trees and shrubs per ha. - Tree height (average and standard deviation) - Diameter at breast height (DBH; average and standard deviation) - Crown diameter (average and standard deviation) - Shaft height (average and standard deviation) - Probability of presence of standing dead trees. - Percentage of pixels covered with arboreal, tropical arboreal, shrub and herbaceous growth
	5. Characteristics of functional state (including ecosystem processes, disturbance regimes)	*Sign detection layer* - Probability of pest presence in trees - Net annual photosynthesis, dry and rainy seasons (annual average and standard deviation) - Faunistic functional groups under preparation (data collection through camera traps and recorders)
Features at landscape level	6. Landscape and seascape characteristics (including landscape diversity, connectivity, fragmentation, semi-natural features embedded in crops)	- Fragmentation and connectivity in the terrestrial landscape under preparation

[18] A technical description of how each of these variables were obtained and measured can be found in Annex 6.1, Sheet "Description of variables".

Groups	Classes according to SEEA EA	Variables of the three-layer model
Ancillary features	Relevant ecosystem features that for any given reason do not fit within the scope of the SEEA EA condition accounts. Ancillary data also include variables relating to stable environmental characteristics which are unlikely to change due to human activities, such as elevation or slope, but are still relevant, in measuring condition.	*Contextual layer* - Elevation - Biotemperature, precipitation, evapotranspiration (Holdridge Life Zones) *Human intervention*[19] - Percentage of pixels covered by bare soil*, artificial grassland or agriculture and human settlements. - Human footprint (several variables) **

* NB: the percentage of bare soil is the result of a disturbance, such as overgrazing, deforestation, change of land use to agricultural activities, among others.

**Although the variables in the Human Footprint Index are not part of the Ecosystem Integrity Index, they are included in this table because of the causal relationship made between the two indices in section 0 of this report. Such variables are: Urban layout; Localities with 500 to 2500 inhabitants; Localities < 500 inhabitants; Temporary, humid or irrigated agriculture; Aquaculture; Induced and planted forests; Induced and planted grassland; Paved road; Dirt road; Road covered with a thin layer of asphalt; Road covered with dirt or gravel; Power transmission lines; Railroads; Industry; Water treatment plants; Artificial saltworks; Archaeological features; Final disposal of solid waste in open landfill; Final disposal of solid waste in closed landfill Mines, primary zone; Mines, secondary zone; Mines, tertiary zone.

5.3.1.2 Step 2 Ecosystem Condition Indicators

In the second stage, the SEEA EA suggests deriving ecosystem condition indicators from the re-scaling of the variables that are accounted for in stage 1 leading to the Ecosystem Condition Indicator Account.[20] Re-scaling of the second stage is performed as a function of reference levels (maxima and minima) determined with regard to ecosystem integrity.

The methodology that has been developed around the EII and the use of Bayesian networks[21] has the potential and advantage of inferring what might be expected under different integrity levels. Bayesian networks are mathematical devices capable of processing data with different "reasoning approaches" (Pourret, 2008). One such approach is "deductive" reasoning, which would process data fed into "effect" nodes (Ecosystem Integrity) and the network would calculate the values that would be expected at the "cause" nodes (variables). Thanks to this capacity of the network, it is possible to infer the reference levels for each type of ecosystem and for each of the variables included in the network. For instance, the value of the reference level for the number of trees in a forested area will be different from that in an arid area, and so on. Identifying such minimum and maximum thresholds for different integrity levels may be more feasible to detect for some variables and in some vegetation types, but this would require further analysis.

According to the SEEA EA, in a third step, these indicators would be aggregated to obtain indices on the overall condition of the ecosystem. Conversely, the EII approach used in Mexico combines steps 2 and 3 in a single step with the

[19] The SEEA-EA considers this variable within its typology as an indicator variable that can be used in the absence of other status indicators and makes a series of observations on its use (section 5.4.3) (SEEA EA, UN 2021). For Mexico, such characteristics are not considered as indicators but as actions that modify the ecosystems condition.
[20] According to the SEEA EA the data in the indicator account allows descriptions of trends in condition to be interpreted relative to an agreed reference level based on ecological integrity. The indicator account can be used to monitor, and report change in values over time (UN, 2021, p. 94).
[21] See Step 3 Aggregate measure of ecosystem condition.

strength of being able to compile a spatially-explicit aggregate condition measure that is ecologically meaningful. For this reason, no results are presented for stage 2.

5.3.1.3 Step 3 Aggregate measurement of ecosystem condition

According to the SEEA EA, the aggregation of ecosystem condition indicators aims to generate summary information from a large number of observation points as data sources; it suggests a hierarchical approach to aggregation reflecting the structure of the typology of indicator classification, with sub-indices of the indicators first and then an aggregated index of the sub-indices (SEEA EA, paragraph 5.77; UN, 2021). For terrestrial ecosystem condition accounting in Mexico, the EII represents an aggregation measure and adds the different stage 1 variables through a primarily data-driven approach. Here, variables are normally classified as structural and functional (Table 5-1). However, and for the compilation of this index, an aggregation of sub-indices based on these classes is not followed. Considering the high number of interactions that can occur with the chosen variables, it is complicated to aggregate them even when incorporating experts in this task, as suggested in the guide. For instance, from the number of variables chosen in the previous section (considering average values and standard deviation in some of them), the set of combinations of relationships between interventions (4 variables) and the sign detection layer (19 variables) of each life zone (28 zones) would have to be established. A second option would be to use multivariate methods that allow the definition of composite variables to reduce the dimensionality of the variable complex or data-driven approaches (e.g. neural networks) that look for patterns of correlation between variables. Nevertheless, in both cases, the interpretability of the model is sacrificed.

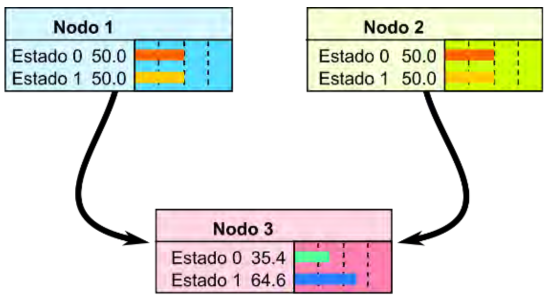
In this work we have chosen another option based on Bayesian networks. This type of statistical model is built from a directed acyclic graph, with variables as nodes linked by arrows pointing in the direction of influence (ideally a known causal relationship, or a hypothesis about that relationship), forming the network structure. This structure can be done on the basis of expert opinion. The structure can also be discovered with a data-driven approach, or a combination of both, with the goal of representing the main relationships between the elements of the model. The Bayesian network structure used for the EII was constructed by using a combined strategy where first a causal relationship was constructed between: a) physical and chemical conditions that determine the different types of ecosystems that can be established, b) human intervention (pressure) modifying these ecosystems and the data-driven strategy where an algorithm suggests the interrelationship that exists in the structural and functional measures. This is explained in more detail in the following section.[22] The other component of the network is a conditional distribution matrix $p\left(x_{ij} \middle| pa(x_i)\right)$ for each variable x_i given the parent nodes in the graph, denoted as $pa(x_i)$.

[22] A technical description of the method used can be found in the white paper (Annex 6.2) and at Garcia Alaniz et al. (2015) (Equihua et al. (2020).

Figure 5-1: Bayesian Network

Multivariate statistical model for a set of random variables which is specified on the basis of two components: **a)** Qualitative component: directed acyclic graph where a node is a variable, and the arc or arrow indicates the existence of a dependence between the variables. Because of the type of relationship they present, Nodes 1 and 2 are usually called parent nodes and Node 3 is usually called a child node; **b)** Quantitative component constituted by a conditional probability matrix.

a)



b)

Nodo 3			
Estado 0	Estado 1	Nodo 1	Nodo 2
0.7692	0.2308	Estado 0	Estado 0
0.5000	0.5000	Estado 0	Estado 1
0.1250	0.8750	Estado 1	Estado 0
0.0217	0.9783	Estado 1	Estado 1

5.3.2 Ecosystem Integrity Index

The Ecosystem Integrity Index (EII) is based on the concept of ecosystem integrity which is defined as a state of the ecosystem that arises from its capacity to self-organize in accordance with local physio-chemical factors and biological processes. Ecosystem integrity reaches full development (and maximum value) when there is no human disturbance. It is recognised that the supply of ecosystem goods and services depends on both the type of ecosystem and its state of integrity.[23] The interest in maximizing one or more ecosystem services and the ecological processes of the ecosystem themselves cause the condition of an ecosystem to be inherently dynamic. Moreover, it is worth noting that their management depends on social agreements seeking to produce desirable states that channel material and energy flows towards human interests.

The EII establishes, through a three-layer model, the relationship between abiotic and biotic characteristics and the condition of the ecosystem (Figure 5-2).

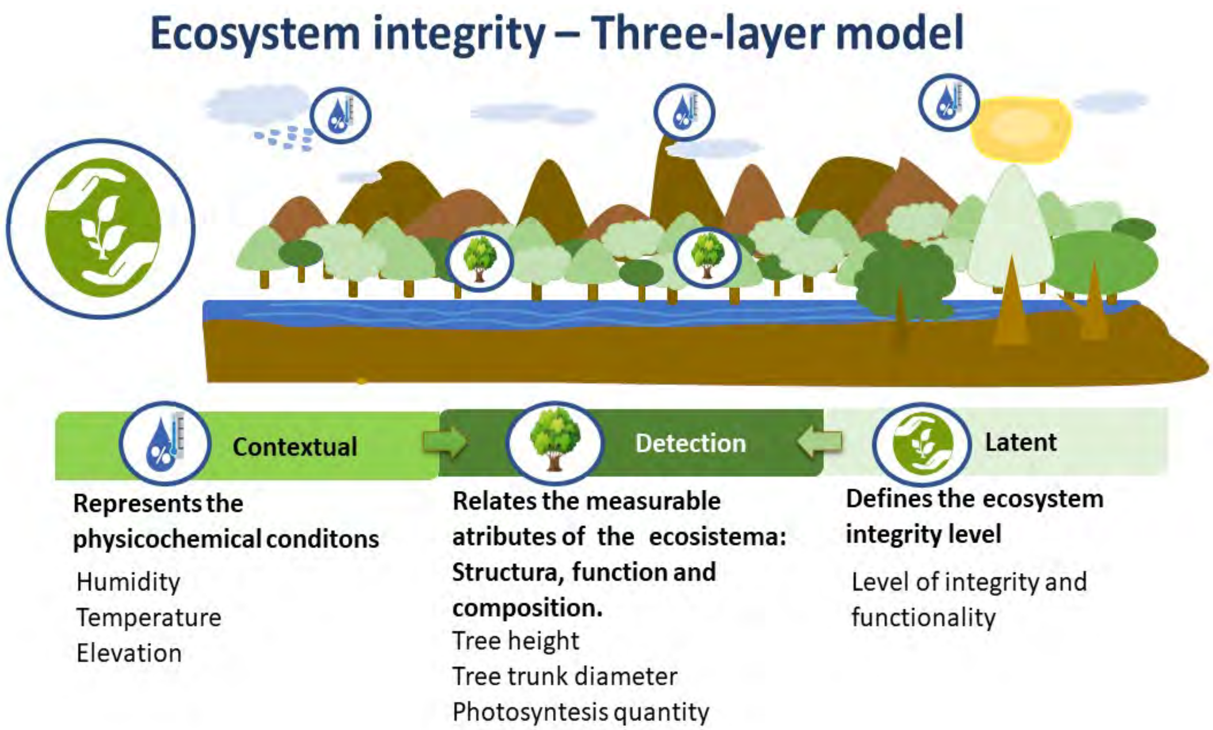
Based on this model and on a reference of optimal integrity that assumes the absence of human interventions, the condition in each 250 x 250m grid along the country's surface is estimated. The model presented here was trained[24] with 2018 data and once the model is parameterized, ecosystem integrity was then calculated for 2004 and 2018 using the set of variables for each year. It should be clarified that estimations can be made for any year where there is available information on the variables that have been used in the model.

[23] This definition is in line with the SEEA EA definition of condition which states that "Ecosystem condition is the quality of an ecosystem measured in terms of its abiotic and biotic characteristics. Quality is assessed with regard to the structure, function and composition of the ecosystem which, in turn, underpins the ecological integrity of the ecosystem and supports its capacity to provide ecosystem services" (SEEA, 2020).

[24] NB: Machine learning is the process of determining the structure, the conditional probability tables, or both, of a Bayesian network. To do this, computational algorithms and data are used that characterize the variability of situations that occur in the operating context proposed for the network. As in the case of human learning, the data constitute "sample cases" that summarize concrete experiences. The automated learning consists in that through them, the algorithms can identify solutions to the model, such that they reproduce the identifiable patterns in the cases shown.

Figure 5-2: Three-layer model

The observable characteristics of an ecosystem (sign detection layer) emerge from natural (contextual layer) and anthropic processes operating concurrently on it (pressures). The top layer of the model (latent layer) represents the ecosystem condition, which is inferred from the other two layers.

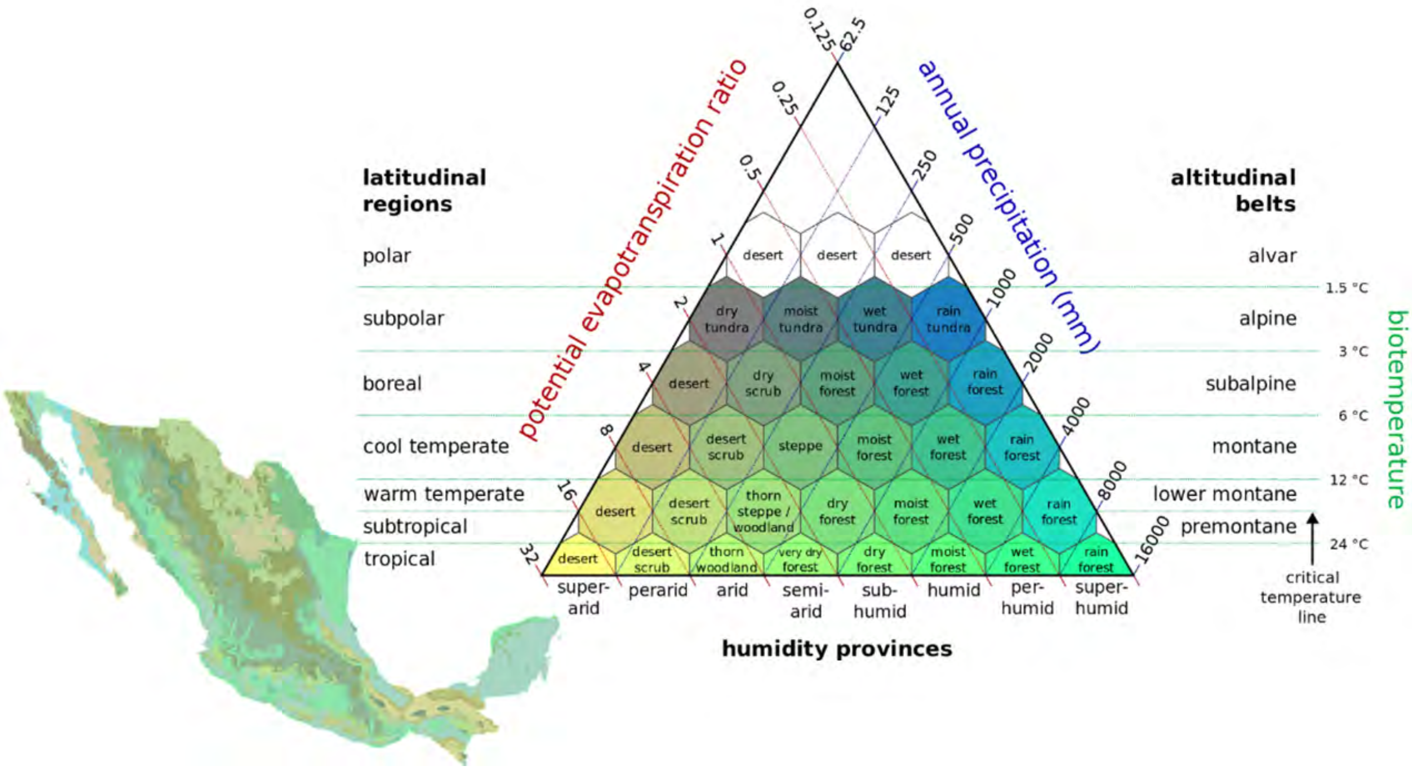


5.3.2.1 Contextual layer

The "contextual layer" represents the range of natural variability of the physio-chemical conditions in which a given ecosystem type is possible. To include this component in the analysis we have chosen the characterization of life zones proposed by Holdridge (1967)[25] that uses variables such as precipitation and bio-temperature (measurement of heat that is effective for plant growth) and their relationship with evapotranspiration.[26] Based on these variables and criteria, the country was classified into 28 life zones (Figure 5-3) Furthermore, elevation and terrain roughness were included as additional variables in this contextual layer.

[25] Another type of classification could have been selected but using Holdridge life zones is attractive considering the possibility to assess ecosystem condition in any country or terrestrial region except coasts.
[26] The variables of the contextual layer correspond to the ancillary variables according to the suggestions of the SEEA-EA (see Table 6.1).

Figure 5-3: Holdridge Life Zones



Holdridge bioclimatic classification (Holdridge, 1967)

Leslie Holdridge's system of life zones classifies the different ecological areas of the world. It is a simultaneously bioclimatic and physiographic classification. The factors considered by this classification are:

- Biotemperature.
- Average annual precipitation (in mm).
- Potential evapotranspiration (in mm).
- Altitudinal and latitudinal floors.

The first three factors are represented on a logarithmic scale on the sides of a triangle. Within the figure the latitudinal regions and altitudinal floors are delimited. The crossing of these values originates cells that correspond to up to 30 **provinces of humidity** and 38 **life zones** identified by Holdridge (different colours in the triangle figure, see: http://bit.ly/2ZXprrW or http://bit.ly/ej-holdridge). It is important to note that Holdridge's proposal defines, as the boundary between the warm and subtropical temperate belts, the **critical** temperature at which frost usually occurs (less than 18°C of average annual temperature).

Note: Triangle figure by Peter Halasz (http://commons.wikimedia.org/w/index.php?curid=1737503). Under Creative Commons Attribution: Share Alike 2.5 Generic (CC BY-SA 2.5

According to the above, it is assumed that, in the absence of human intervention, the characteristics of an ecosystem, and therefore the values of the variables of the "sign detection layer", will only be affected by the physicochemical conditions (precipitation, bio-temperature and evapotranspiration) of each zone and would tend to show values congruent with a condition of maximum integrity. The dissimilarity of the values of the variables of the sign detection layer, with regard to what is considered its optimal condition, will allow us to have a measure of the condition of each grid of each ecosystem.

5.3.2.2 Sign detection layer

The variables in the sign detection layer have been subdivided into functional, structural and species composition characteristics. These three elements provide relevant information about the condition of an ecosystem (SEEA EA, UN, 2021). The analysis was conducted using only structural and functional trait variables, as the collection and processing of data for compositional monitoring of species at national level was considered impractical due to its high economic cost. However, the possibility of monitoring groups of species, that play a key role in the functional processes within the ecosystem, with acoustic and photo-trapping methods, is being explored as part of CONABIO's National Biodiversity Monitoring System (SNMB).[27]

Currently ecosystem functionality is monitored through the use of variables to identify the presence of tree pests as these, can alter ecosystem functionality. In the future other functional groups will be included to monitor dispersal, pollination and predation functions. In order to do this, data on the presence of these groups is already being obtained through autonomous sound recorders and camera traps, thanks to collaboration with national institutions such as CONAFOR and CONANP. Meanwhile, for the evaluation of the condition, INECOL is working on the inclusion of variables that would allow for estimates of fragmentation and connectivity at the landscape level to be made. Combining these variables with the grid-level analysis will enrich the condition assessment of fragmented ecosystems at different scales.

5.3.2.3 Latent layer

In the above, the top layer of the three-layer model represents the ecosystem condition. The condition of an ecosystem is a latent or hidden variable, which unlike the other variables is not easily observed directly, or impossible to observe, but can be inferred from the other layers (sign detection and contextual) by using a probabilistic mathematical or computational model with appropriate algorithms. To infer the conditional probability tables for this latent variable, as well as for the rest of the nodes, the expectation-maximization (EM) algorithm implemented in Netica®[28] was used.

Bayesian networks have the characteristic of making use of all available information to generate estimates, which optimizes the reliability of the predictions. In this regard, it was decided to enrich the three-layer model with two more information sources: environmental pressures (as an additional layer) and hemeroby

[27] The National Biodiversity Monitoring System (SNMB) began in 2015 with the purpose of monitoring in situ the health status of Mexico's ecosystems. The SNMB is carried out in coordination with the National Commission for the Knowledge and Use of Biodiversity (CONABIO), the National Forestry Commission (CONAFOR) and the National Commission for Protected Natural Areas (CONANP), with the support of civil society organizations such as the Global Fund for the Conservation of Nature. Information available at: https://www.biodiversidad.gob.mx/monitoreo/monitoreo-biodiversidad

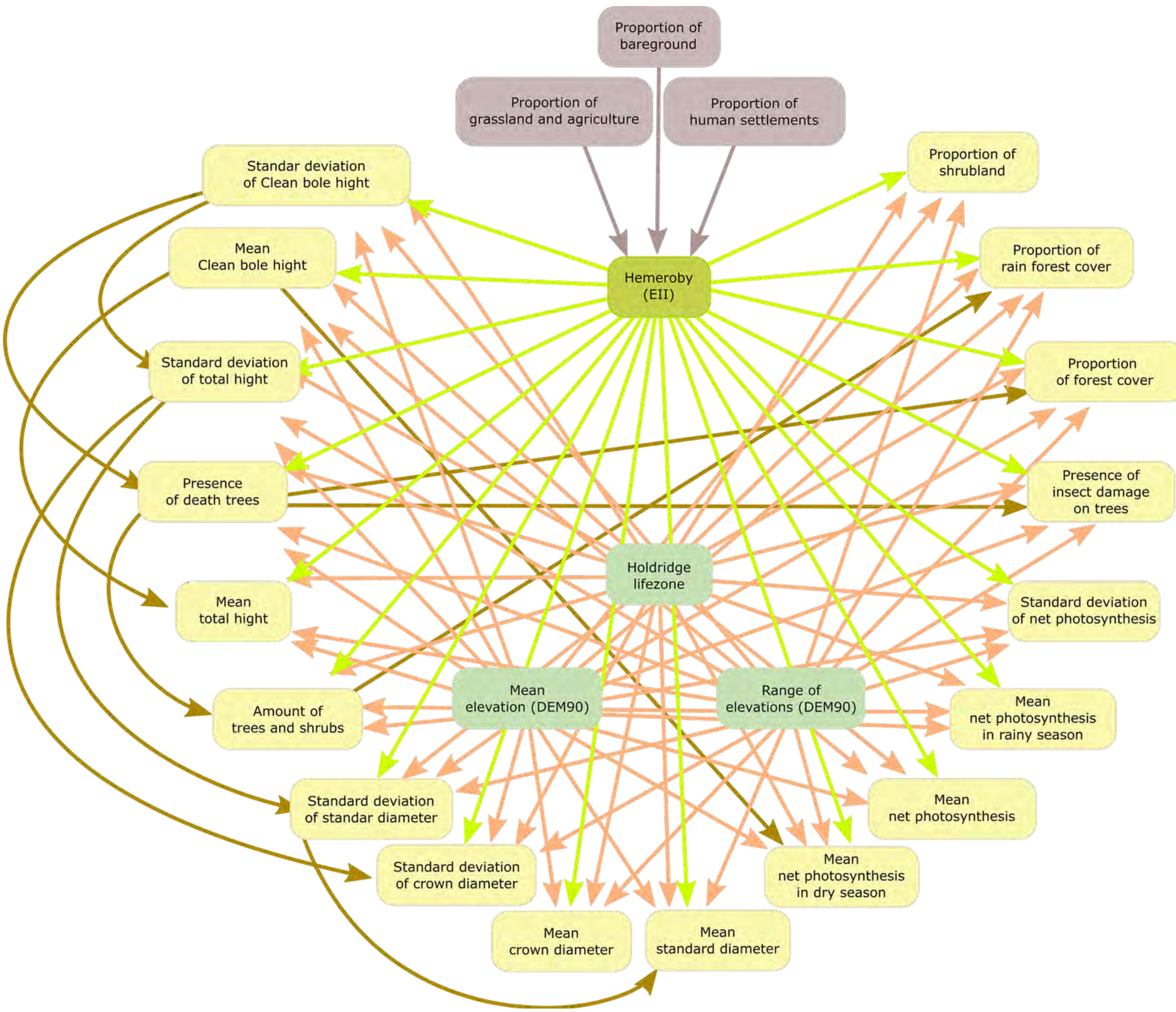
[28] Commercial software for Bayesian network development.

index (see next section) (as data to train the model).

5.3.2.4 Environmental pressures

The condition assessment also includes the effect of human intervention or pressures as understood by the SEEA EA.[29] Within the pressure variables, the percentage of each pixel that was covered by bare soil, crops and herbaceous growth and human settlements was considered (Figure 4-4).

Figure 5-4: Bayesian network of the three-layer model and human intervention variables (drivers).



[29] The idea of human intervention is preferred rather than the concept of pressure suggested by SEEA, which often has a negative connotation. Conversely, the idea of human intervention includes both the negative and positive effects of policies and practices affecting the condition of the ecosystem.

The network structure constructed to estimate the condition of Mexico's terrestrial ecosystems is shown in Figure 5-4 above. Moreover, two elements are added to the layers corresponding to the EII (sign detection and contextual): a drivers (or pressure) layer in grey and the EII node in green, which indicates that previous information on ecosystem status was incorporated into the network through the hemeroby index.

5.3.2.5 Hemeroby Index

The Hemeroby Index can be understood as an integrative measure of the impact of all human intervention on ecosystems (Walz and Stein, 2014). The index estimates the assumed degree of transformation shown by the "primary vegetation" (INEGI, 2003) with regard to the current land cover obtained from the 2014 classified satellite images, Land Use and Vegetation, INEGI series VI (INEGI, 2016). The index was calculated in order to provide a reference or baseline data to train the Bayesian network, as it is of interest to make an assessment that approximates human judgement in assessing the degree of alteration that can be seen in ecosystems[30] (Maeda, 2013; Roche and Campagne, 2017). The change magnitude was assessed using the criteria shown in Table 5-3.

Table 5-3: Hemeroby index - Transformation of change between primary vegetation and land use and vegetation in 2014

Hemeroby (ΔVP)	STATUS	DESCRIPTION
0	STASIS	No change in vegetation type or primary state of vegetation
1	PSEUDOSTASIS inferior	No change in primary state, but there is change in vegetation type within the same ecovariant
2	PSEUDOSTASIS inferior	No change in primary state, there is a change of type of vegetation to another ecovariant yet the dominant class moves up in stature (e.g. from shrubs to forest)
3	PSEUDOSTASIS superior	No change in primary state, but there is change in vegetation type to other ecovariant yet the stature of the dominant stratum is maintained (e.g. From Oak forest to Tropical forest)
4	DEGRADATION very SLIGHT	No change in primary state, but there is change in vegetation type to other ecovariant, the dominant category descends in stature (e.g. From Shrubland to Grassland)
5	DEGRADATION SLIGHT inferior	Change from primary forests or tropical forests to arboreal secondary vegetation
6	DEGRADATION SLIGHT superior	Change from any type of primary vegetation to forest plantation
7	DEGRADATION MODERATE inferior	Change from primary temperate forests, tropical forests or shrubland to shrub secondary vegetation.
8	DEGRADATION MODERATE media inferior	Change from any type of primary vegetation to a sabanoid vegetation

[30] It is important to note that the Grassland category includes grasslands of natural and anthropic origin.

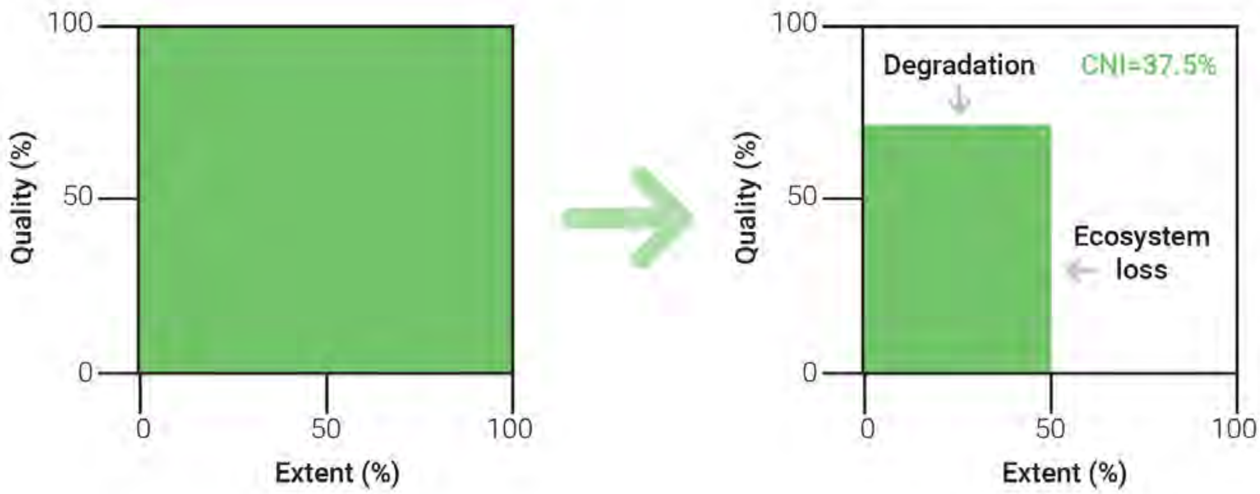
9	DEGRADATION MODERATE media superior	Change from primary temperate forests, tropical forests, shrubland, or grassland to herbaceous secondary vegetation .
10	DEGRADATION MODERATE superior	Change from any type of primary vegetation to induced palm grove or induced or cultivated grassland
11	DEGRADATION SEVERE inferior	Change from water body to aquaculture
12	DEGRADATION SEVERE media inferior	Change from any type of primary vegetation to rainfed agriculture
13	DEGRADATION SEVERE media superior	Change from any type of primary vegetation to irrigated agriculture
14	DEGRADATION SEVERE superior	Change from any type of primary vegetation to wetland agriculture
15	DEGRADATION VERY SEVERE inferior	Change from any type of primary vegetation to a water body
16	DEGRADATION VERY SEVERE media inferior	Change from any type of primary vegetation to barren areas or areas withouth apparent vegetation
17	DEGRADATION VERY SEVERE media superior	Change from any type primary vegetation to human settlements
18	DEGRADATION VERY SEVERE superior	Change from any type of primary vegetation to urban area
-9999	NO DATA	

Note: The column Hemeroby ΔVP indicates the value assigned to each grid based on the change that occurred between the primary vegetation and the INEGI VI series, referred to as States.

5.3.3 Effective extent and Natural Capital Index

From the results obtained with the EII and the extent data (Chapter 4), the effective extent and the Natural Capital Index (NCI) (Czúcz et al., 2012) were calculated. The effective extent is the area of each vegetation type weighted by its condition while NCI is defined as the "effective extent" relative to an area of interest in percentage terms. Therefore, it is always a number between 0 and 100 per cent (Figure 5-5).

Figure 5-5: Example of natural capital calculation



The graph on the left illustrates the case where an ecosystem has full extent and full integrity (NCI = 1). The graph on the right side presents the result when an ecosystem decreased by 50 per cent and lost 25 per cent of its quality (Ecosystem Integrity Index = 0.75), therefore, NCI = 0.5 x 0.75 = 0.375 (modified from Czúcz et al., 2012).

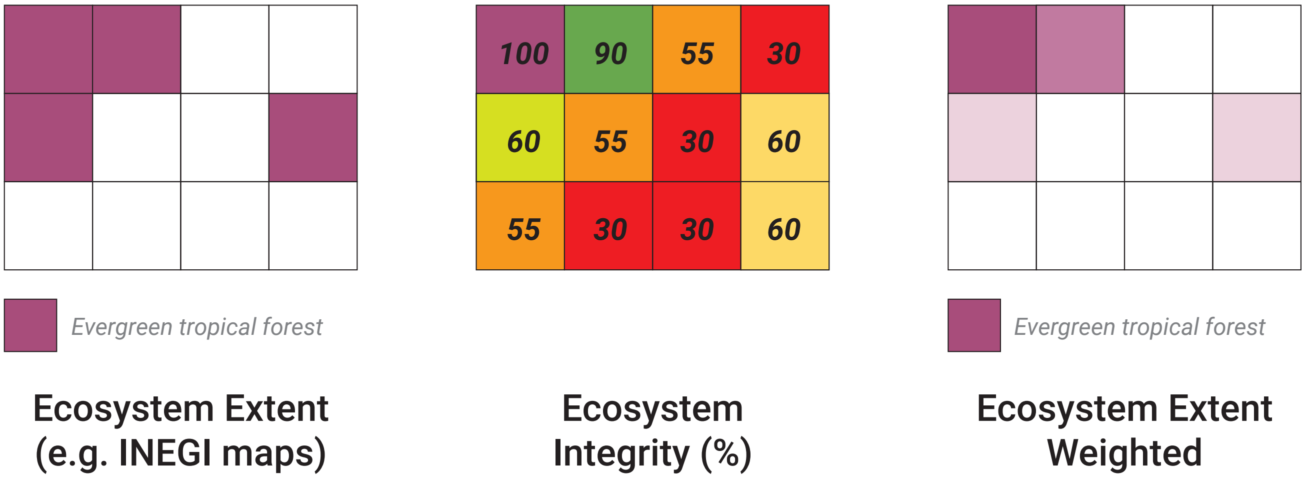
In order to calculate the NCI of an area of interest (state, municipality, basin, region, etc.) based on spatial data the following mathematical expression can be used (Czúcz et al., 2012).

$$\mathrm{NCI_r} = \frac{1}{\mathrm{A_r}} \sum_{\mathrm{i \epsilon S_r}} \mathrm{q_i A_i}$$

Where: $\mathbf{A_r}$ is the total area of the region of interest r, measured (in spatial units e.g. km^2), $\mathbf{S_r}$ is the set of all patches considered natural in the region $\mathbf{A_r}$ $\mathrm{A_i}$ is the area of each ecosystem patch i and $\mathbf{q_i}$ its corresponding quality. In this case, the set of all individual ecosystem patches ($\mathbf{S_r}$) is made up of each of the 250m grids that cover the national territory, since this is the resolution with which the vegetation map (INEGI) and the Ecosystem Integrity Index were integrated. Considering the raster format of the spatial products, the value of $\mathbf{A_i = \frac{1}{16} = 0.0625}$ of km^2 for each pixel.

This equation was applied for each separate ecosystem that in this pilot study constituted the region of interest. An illustrative example of this calculation is shown at (Figure 5-6).

Figure 5-6: Example of Natural Capital Index calculation for evergreen tropical forest



The extent is 4*0.0625 = 0.25km^2. The effective extent is: 0.0625(1) + 0.0625(0.9) + 0.0625(0.6) + 0.0625(0.6) = 0.19km^2.
Finally, the Natural Capital Index is 0.19/0.25 = 0.76 or 76 per cent of the ideal state.

5.4 Results

5.4.1 Step 1. - Accounting for ecosystem condition variables

The ecosystem condition variables which account for each ecosystem type (vegetation) can be found in Annexes 5.3 and 5.3B. The following is a summary of the variables which account for the condition of all terrestrial ecosystems in Mexico (Annex 5.3 sheet "All Ecosystems"). Table 5- indicates that most of the variables show minimal changes between the two dates analysed. Nevertheless, the table also shows significant changes in the structural, functional and pressure variables between 2004 and 2018.

Table 5-4: Summary of relative change (in percentage) between 2004 and 2018 of ecosystem condition variables, considering structural, functional and pressure variables

State	Structural														Functional					Pressure	
Ecosystem type	Number of trees and shrubs per ha	Average tree height	Standard deviation tree height	Diameter at breast height (DBH)	Standard deviation of DBHs	Average tree crown diameter	Standard deviation of tree crown diameters	Average shaft height	Standard deviation shaft height	Probability of presence of standing dead trees.	% of Pixel covered with tropical arboreal growth	% of Pixel covered with arboreal growth	% of Pixel covered with shrub growth	Probability of presence of tree pests	Average net annual photosyntesis	Standard deviation net annual photosyntesis	Average net photosynthesis in dry season	Average net photosynthesis in rainy season	% of Pixel covered with herbaceous growth	% of Pixel covered with settlements	% of Pixel covered with barren land
Aquaculture	-23%	-17%	-14%	-11%	2%	10%	-22%	13%	93%	-2%	527%	0%	-99%	-8%	7%	4%	4%	8%	27%	334%	-34%
Annual cropland	14%	7%	3%	4%	-2%	0%	2%	9%	6%	-3%	67%	44%	-9%	-2%	-2%	-1%	1%	-4%	-3%	38%	37%
Perennial cropland	4%	2%	4%	2%	2%	1%	1%	3%	5%	-4%	103%	86%	31%	-2%	-6%	6%	-2%	-11%	-5%	94%	83%
Human settlements	40%	27%	14%	20%	8%	19%	22%	32%	21%	-4%	80%	117%	-46%	-2%	33%	37%	34%	33%	0%	3%	-23%
Planted forest	5%	11%	8%	3%	10%	-1%	-1%	19%	17%	-4%	194%	-67%	-49%	-3%	-28%	15%	-22%	-35%	46%	-34%	249%
Coniferous forest	1%	0%	0%	0%	0%	0%	0%	0%	1%	-1%	8%	6%	6%	-3%	-1%	7%	-3%	1%	-29%	426%	172%
Oak forest	0%	-1%	-2%	-1%	-1%	0%	-1%	-1%	-2%	-1%	32%	2%	19%	-2%	-2%	8%	-8%	2%	-14%	308%	319%
Montane cloud forest	1%	1%	2%	2%	3%	1%	1%	1%	1%	-2%	48%	13%	-15%	-2%	0%	9%	4%	-4%	-2%	916%	35%
Special other woody vegetation types	-2%	-2%	-2%	0%	-2%	1%	0%	2%	1%	0%	1%	53%	-5%	0%	-4%	0%	-3%	-4%	1%	276%	203%
Special other non-woody vegetation types	-6%	7%	11%	1%	6%	1%	3%	11%	15%	-1%	366%	-15%	-54%	-2%	-3%	8%	3%	-9%	22%	180%	-25%
Woody xeric shrubland	-1%	0%	2%	1%	4%	1%	2%	2%	0%	0%	100%	132%	-4%	0%	-13%	-4%	-17%	-10%	6%	187%	19%
Non-woody xeric shrubland	-15%	-13%	-7%	-14%	-5%	-10%	-3%	-6%	-6%	0%	7378%	314%	-10%	0%	-2%	13%	-9%	4%	48%	487%	16%
Other lands	-5%	19%	18%	6%	3%	14%	23%	17%	13%	-2%	311%	109%	-24%	-3%	24%	35%	17%	30%	4%	483%	-20%
Grassland	10%	5%	5%	2%	1%	1%	3%	6%	5%	-2%	66%	99%	56%	-1%	-7%	3%	-5%	-8%	-16%	199%	154%
Deciduous tropical forest	1%	1%	1%	1%	0%	1%	1%	1%	0%	-2%	0%	74%	34%	-3%	-2%	10%	-11%	3%	-18%	72%	114%
Evergreen tropical forest	3%	0%	0%	0%	0%	0%	0%	1%	0%	-4%	2%	12%	-92%	-2%	-9%	3%	-8%	-11%	1%	95%	-1%
Semideciduous tropical forest	2%	1%	1%	0%	0%	0%	0%	1%	0%	-2%	4%	48%	527%	-2%	-9%	0%	-7%	-10%	-27%	7%	167%
Woody hydrophytic vegetation	-1%	-1%	1%	-1%	0%	-1%	0%	-2%	2%	-1%	10%	-1%	-23%	-2%	-8%	6%	-6%	-12%	-5%	75%	-21%
Non-woody hydrophytic vegetation	8%	3%	18%	5%	8%	3%	8%	5%	6%	-4%	29%	-18%	-98%	-3%	-19%	9%	-11%	-28%	10%	9%	11%

The relative change summary (in percentage) between 2004 and 2018 of ecosystem condition variables (Table 5-4), considering structural, functional and pressure variables, presents some relevant trends. Most of the forest ecosystems show structural increases, which are manifested in the "% of Pixel covered with tree and tropical tree growth". Meanwhile, the "% of Pixel covered with shrub growth" show negative trends in most cases. Functionally, a negative trend is observed in most ecosystems, although with intensities fluctuating between moderate and low. There is also an increase in pressures by human settlements, an increase in the percentage of bare soil and a negative trend in the "% of Pixel covered by herbaceous growth".

The results show important structural changes in Non-woody xeric shrublands, as well as some important functional changes in Woody xeric shrublands. It is also noticeable from the results that most ecosystems are exposed to pressure in terms of "% Pixel covered by human settlements" and to a lesser extent, by bare soil.

In half of the ecosystem types, there were increases in the "% of Pixel covered with tropical arboreal growth" and the "% of Pixel covered with arboreal growth", especially in anthropogenic ecosystems, Woody ecosystems (in the case of tropical arboreal growth), Grasslands and also in Deciduous tropical forests (in the case of arboreal growth). Contrary to the above, in most of the ecosystems, the "% of Pixel covered with shrub growth" had an important decrease, except in the Deciduous tropical forest, where it increased. It is also important to note that the number of trees and shrubs per hectare, the average tree height and the average diameter at breast height show significant reductions in the Non-woody xeric shrubland. Other structural variables with a moderate decrease in their values were "standard deviation of DBH" and "probability of presence of standing dead trees". The first variable is related to the age profile of the trees and the second is related, on the one hand, to the presence of pests and the incidence of forest fires that induce the mortality of tree species, and on the other hand, to human intervention to harvest firewood or charcoal. Accordingly, they are interpreted as indicators of disturbance by natural causes or by human action that influence the structural diversity of the ecosystem.

None of the functional variables increased in their values during the observed period. About half show minimal or no change in most ecosystems, while the rest show a decrease. The "probability of pest presence in trees", "average annual net photosynthesis", "net photosynthesis in dry season" and "average net photosynthesis in rainy season" show reductions in most ecosystems, both natural and anthropic. The highest decay values were recorded in Permanent agriculture, Woody xeric shrubland, Grassland, Deciduous tropical forest, and Hydrophytic vegetation. It is possible that this generalized decline in photosynthetic rates is due to changes in the plant species composition of ecosystems, which is also an indicator of disturbance.

In accordance with the above, the pressure variables showed notable increases in most cases. The "% Pixel covered by Human settlements" and "% Pixel with bare soil" increased in most ecosystems. In contrast, the "% of Pixel covered by herbaceous growth" decreased, particularly in Oak forest, Coniferous forest, Grassland, Deciduous tropical forest and Semi-deciduous tropical forest. It is likely that these reductions are the result of changes in land use towards Human settlements. The abandonment of planted fields and natural regeneration processes could also occur owing to trends of increasing areas of planted forest for timber production during the last decade (PRONAFOR, 2018).

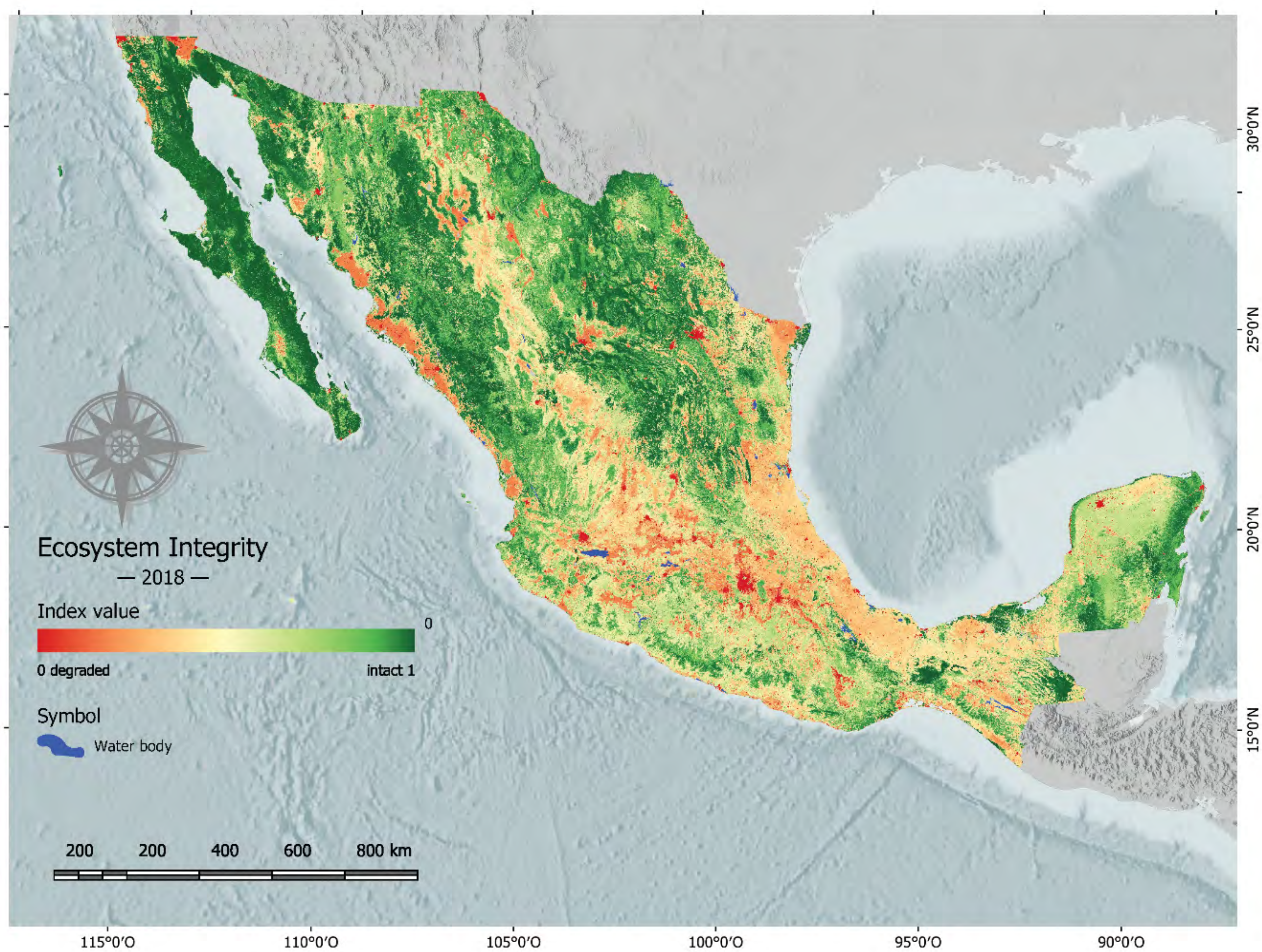
The ecosystems showing the most extreme changes were anthropic (Aquaculture, Annual cropland, Perennial cropland, Human settlements, and Planted forest), and also some natural ecosystems (Non-woody xeric shrubland, Evergreen tropical forest, and Hydrophytic vegetation).

5.4.2 Stage 3. Aggregate measure of ecosystem condition

5.4.2.1 Ecosystem Integrity Index

The Ecosystem Integrity Index at the national level (Map 5-1) shows that, in general, the northern and north-western regions have high ecosystem integrity, as well as the ecosystems of the mountainous area of the southern Pacific and the eastern part of the Yucatan Peninsula. Integrity fluctuates between moderate and high (Map 5-1) in the centre and north of the Yucatan Peninsula. Finally, the index highlights the moderate to low integrity in the central region of the country, as well as the coastal plain of the Gulf of Mexico. Similarly, the coasts of Sonora, Sinaloa and Nayarit tend to have extremely low integrity values.

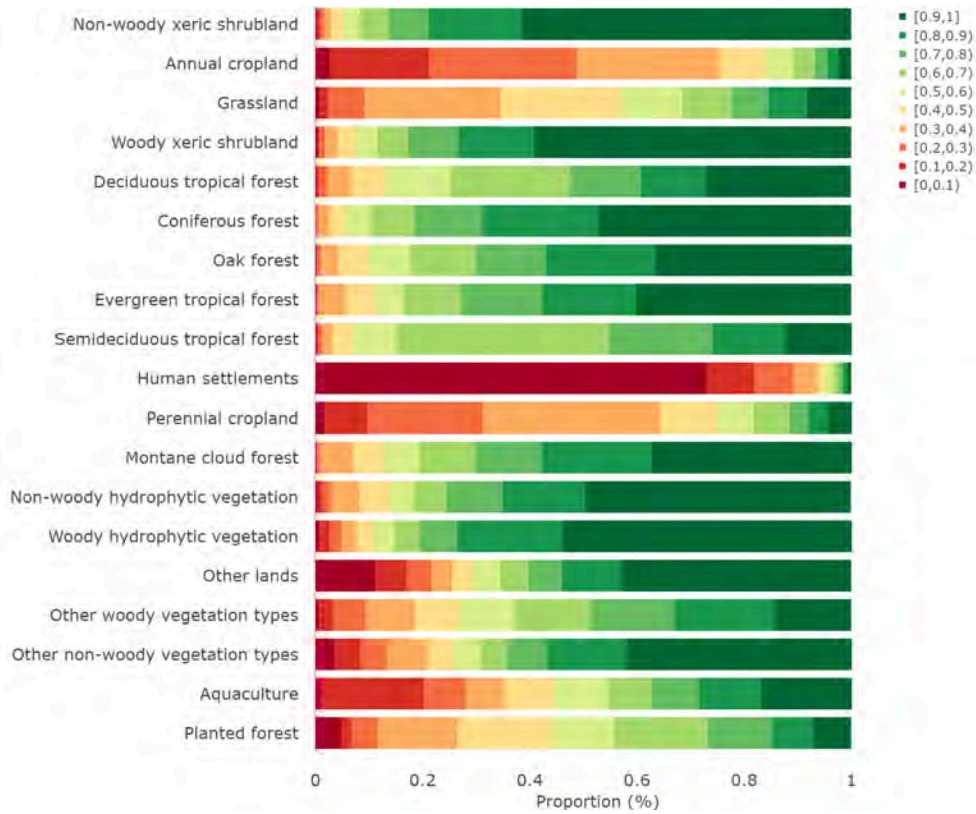
Map 5-1: Ecosystem Integrity Index for the terrestrial ecosystems of Mexico in 2018 (250 X 250 m or 6.25 ha grids)



Large urban centres such as Mexico City, Monterrey, Guadalajara, Mexicali, Tijuana, Mérida and Cancún have exceptionally low integrity values. The reasons for the low integrity levels are congruent with what is happening globally, the conversion of ecosystems into other land uses such as agriculture, pasture and urban infrastructure. For instance, in the case of the coastal plain of the Gulf of Mexico, most of the natural ecosystems have been transformed into agricultural land uses and also for cattle ranching activities. Furthermore, the Bajío area (central Mexico) also has low ecosystem integrity, which coincides with the change in land use since colonial times and the various economic activities that are currently being carried out. Whilst these changes have generated economic gains, they have also caused a lot of environmental degradation. Similarly, the Pacific coast, between Sinaloa, Sonora, and Nayarit, presents a strong degradation scenario, due to the intense agricultural activities that are occurring in the region.

Approximately 25 per cent of the Deciduous tropical forest and 10 per cent of the Semi-deciduous tropical forest have high integrity values. Between 40 per cent and 60 per cent of the extent of the Non-woody xeric shrubland and Woody xeric shrubland; Woody hydrophytic vegetation, Non-woody hydrophytic vegetation; Coniferous forest; Evergreen Tropical forest; Oak forest, Montane-cloud forest, Woody hydrophytic vegetation and Non-woody vegetation have high integrity. And approximately 70 per cent of the extent of human settlements has very low ecosystem integrity. About 20 per cent of annual and perennial agricultural areas have extremely low ecosystem integrity (values between 0 and 0.2) and 50 per cent have low ecosystem integrity (values between 0.3 and 0.5). The ecosystem integrity of planted forests is heterogeneous, and at moderate levels for the most part (Figure 5-7).

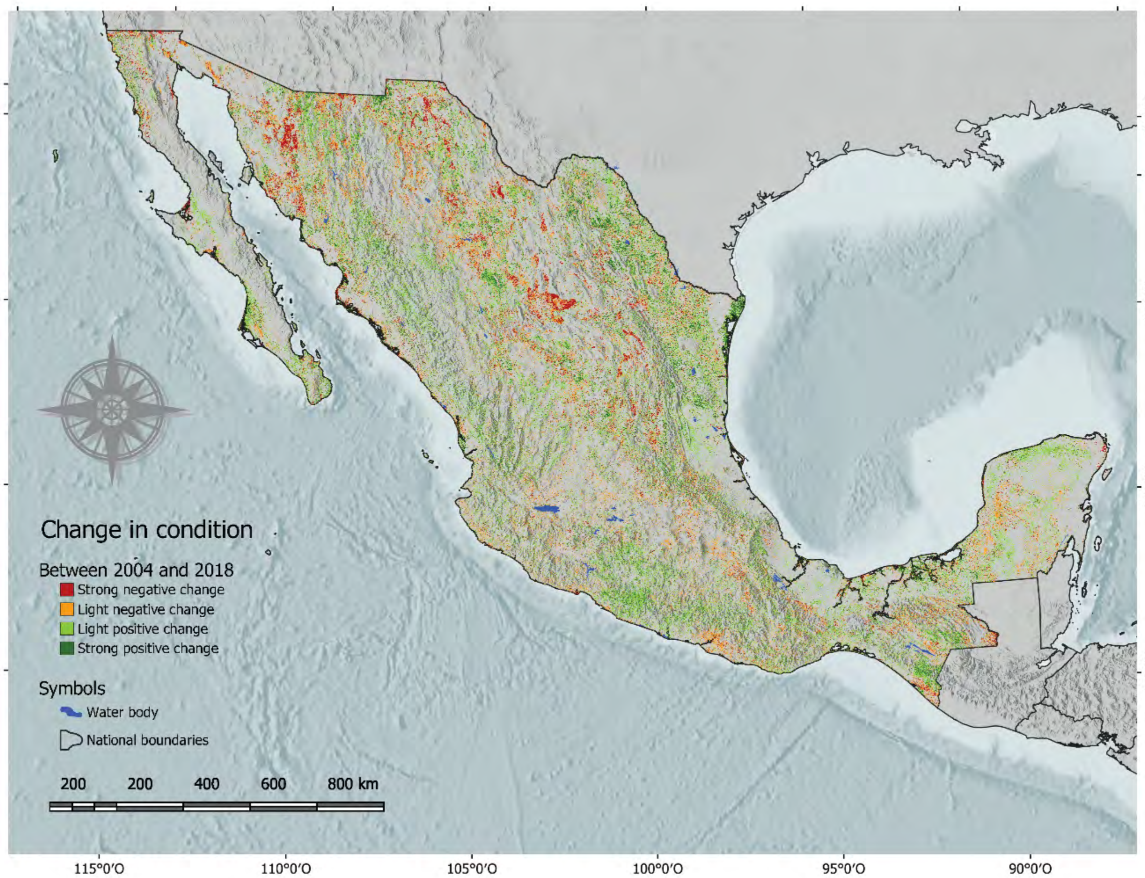
Figure 5-7: Proportional distribution of aggregated ecosystem integrity according to ecosystem type for 2018



Based on the methodology, preliminary comparisons have been made between the Ecosystem Integrity Index in 2004 and 2018 (Table 5-5, Map 5-2, Annex 6.4 Condition sheet). Most of the changes in the value of the index are observed in the central-northern part of the country, which coincides, in general, with the region with the highest Integrity indices. Extensive areas of negative change can be seen in the Sonora Desert and the Chihuahua Desert regions, which coincides with the observed reduction of Xeric shrubland. On the other hand, in Coahuila and Nuevo León there are patches with positive changes.

In the rest of the country the changes are mostly minor. It is important to note that some areas show no or minimal changes in the integrity of ecosystems, such as the coastal plain of the Gulf of Mexico and the Bajío area in central Mexico. This can be attributed to the fact that these areas already had low integrity at the beginning of the analysis period as a result of important process of alteration (expansion of the agricultural frontier, urbanization, overgrazing) of the original ecosystems. The environmental cost of economic development in these areas has been high and extensive.

Map 5-2: Map of changes in the value of the Ecosystem Integrity Index between 2004 and 2018



Differences in the value of the EII between the two years greater than 0.33 (strong positive changes); between 0.17 and 0.33 (slight positive changes); less than -0.33 (strong negative changes); between -0.17 and -0.33 (slight negative changes) are reported as changes. This corresponds to one and two standard deviations respectively to the right and left of the difference of the means of the two compared years.

In 2004, the ecosystems that showed the highest condition values and consequently showed the best integrity were Woody and Non-woody xeric shrubland, Coniferous forest and Woody hydrophytic vegetation Table 5-5).

The lowest integrity values were found in the classes Perennial Agricultural, Annual cropland and lastly Human settlements. The same trends were found in 2018, with Non-woody and Woody xeric shrubland ranking highest in integrity, and Human settlements along with the Perennial and Annual cropland classes at the bottom.

Table 5-5: Changes in condition of different ecosystem types

Ecosystems resulting from human activities are highlighted in yellow. It is important to note that the Grassland category includes grasslands of natural and anthropic origin. Red indicates decrease and green indicates increase in ecosystem integrity.

Ecosystem type	Opening value 2004	Opening value 2018	Change
Aquaculture	0.78	0.55	-0.23
Annual cropland	0.34	0.35	0.00
Perennial cropland	0.41	0.41	0.00
Human settlements	0.12	0.10	-0.03
Planted forest	0.55	0.55	0.00
Coniferous forest	0.81	0.83	0.02
Oak forest	0.77	0.78	0.02
Montane cloud forest	0.76	0.78	0.02
Special other woody vegetation types	0.65	0.65	0.00
Special other non-woody vegetation types	0.74	0.72	-0.02
Woody xeric shrubland	0.84	0.85	0.01
Non-woody xeric shrubland	0.88	0.87	-0.01
Other lands	0.81	0.68	-0.13
Grassland	0.47	0.52	0.05
Deciduous tropical forest	0.70	0.73	0.02
Evergreen tropical forest	0.78	0.79	0.01
Semideciduous tropical forest	0.69	0.71	0.01
Woody hydrophytic vegetation	0.81	0.83	0.01
Non-woody hydrophytic vegetation	0.74	0.81	0.07

The analysis of changes in integrity between 2004 and 2018 shows an increase in the ecological integrity of Grassland, Deciduous tropical forest, Montane-cloud forest, Coniferous forest, Oak forest, Woody hydrophytic vegetation, Non-woody hydrophytic vegetation, Woody xeric shrubland, Semideciduous tropical forest and Evergreen tropical forest. In contrast, the integrity of Aquaculture decreased markedly, while the degradation of Human settlements also increased. The only natural ecosystems in which a decrease in integrity was recorded were Special other non-woody types, Non-woody xeric shrubland, and above all, Other lands.

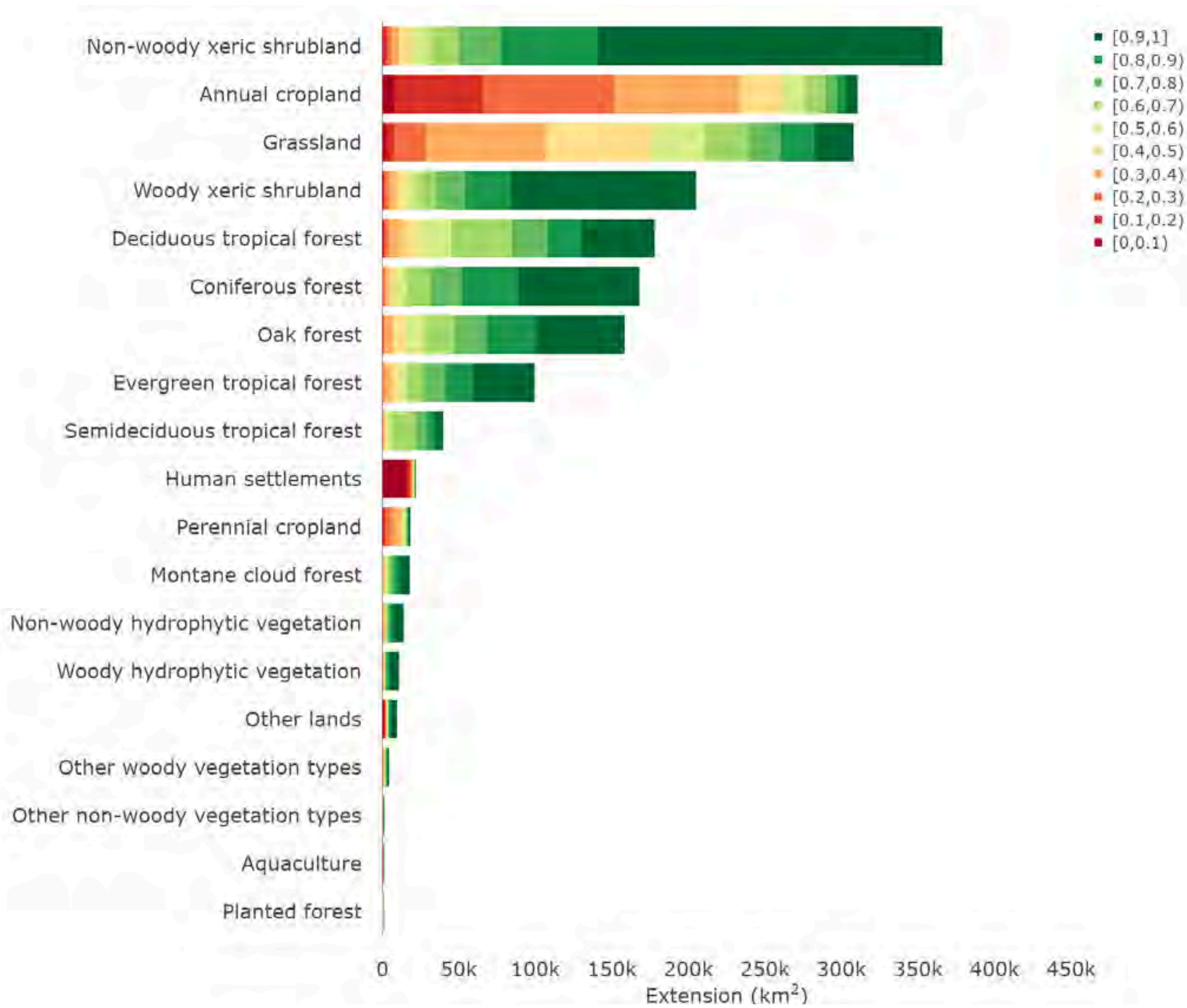
An interesting trend identified, despite the reduction in the extent of Deciduous tropical forest, Grassland, Woody xeric shrubland, Evergreen tropical forest and Non-woody xeric shrubland, was that the integrity values of these ecosystem types increased. Contrary to the above, the increase in the extent of aquaculture crops resulted in a notable decrease in their integrity.

5.4.3 Effective Extent

The integrity of some natural ecosystems is high and covers a significant extent (Figure 5-8). Non-woody xeric shrubland is the most extensive ecosystem (366,598 km²) and it is also the one in the best condition. Grasslands are very extensive but have a low condition.[31] Woody xeric shrubland is fourth in terms of extent, and is also, for the most part, in good integrity. Although to a lesser extent, Coniferous and Oak forests also have a significant extent and relatively high ecosystem integrity. Montane-cloud forest has very little extent and its integrity is between medium and very high. Forests are the third largest ecosystem type, and their condition is highly variable. The Semi-deciduous tropical forest is the one that occupies the smallest extent, and its integrity is low.

Anthropogenic land uses can be extensive and have exceptionally low integrities (Figure 5-8). The Annual cropland class has the greatest extent among the anthropic ecosystems (land use) with exceptionally low integrity. Human settlements extent is already larger than that of some ecosystems (such as the Montane-cloud forest) and has the lowest integrity values.

Figure 5-8: Aggregate ecosystem extent and integrity for 2018



[31] It is important to note that the Grassland category includes grasslands of natural and anthropic origin.

The effective extent of some vegetation types has been significantly reduced due to loss of integrity. For instance, the Grassland extent in 2014 covers 308 219 km^2 (Chapter 4) but would be equivalent to an effective extent almost 50 per cent less (160 753 km^2) if the degree of integrity with which it remains is considered (Table 5-6; Figure 5-9).

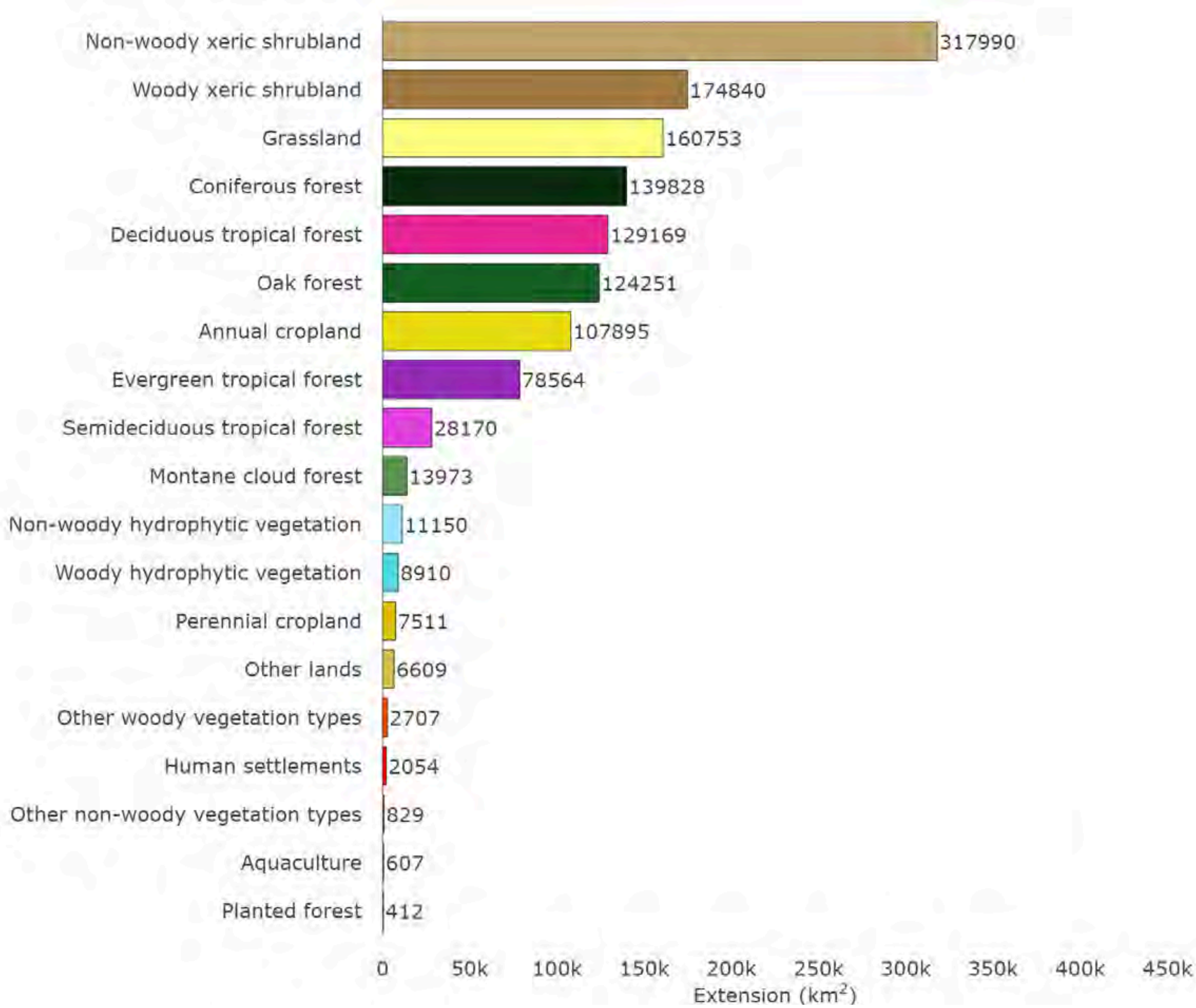
Table 5-6: Accounting of the extent and effective extent of the different ecosystems

	Extent (km2)			Effective extent (km2)		
Ecosystem type	Opening value 2002	Opening value 2014	Change	Opening value 2002-2004*	Opening value 2014-2018*	Change
Coniferous forest	168,673	167,826	-847	137,184	139,828	2,644
Oak forest	156,366	158,295	1,929	120,105	124,251	4,146
Montane cloud forest	18,252	17,966	-286	13,786	13,973	187
Special other woody vegetation	4,279	4,171	-108	2,778	2,707	-71
Special other non-woody vegetation	1,562	1,537	-25	872	829	-43
Woody xeric shrubland	211,462	205,651	-5,811	176,842	174,840	-2,002
Non-woody xeric shrubland	370,318	366,598	-3,719	326,549	317,990	-8,559
Other lands	9,493	10,279	785	7,269	6,609	-660
Grassland	315,257	308,219	-7,038	148,576	160,753	12,177
Deciduous tropical forest	179,643	178,037	-1,606	125,979	129,169	3,190
Evergreen tropical forest	105,222	99,436	-5,786	81,734	78,564	-3,170
Semideciduous tropical forest	47,599	39,855	-7,744	32,995	28,170	-4,825
Woody hydrophytic vegetation	11,290	11,737	447	8,446	8,910	464
Non-woody hydrophytic vegetation	14,278	14,276	-2	10,410	11,150	740

The extent values, reported in Chapter 4, correspond to the area covered by each ecosystem type regardless of its condition. The effective extent values for each vegetation type are the sum of the products obtained from the coverage of each grid of that vegetation type multiplied by its condition (see section 5.3.2). That is, the effective extent corresponds to the extent of the ecosystems weighted by their condition. Red indicates decrease and green indicates increase.

**Due to the mismatch of dates between the products that were used to calculate extent and condition, the effective extent value is referenced to these periods.*

Figure5-9: Effective extent of the terrestrial ecosystems of Mexico by 2018

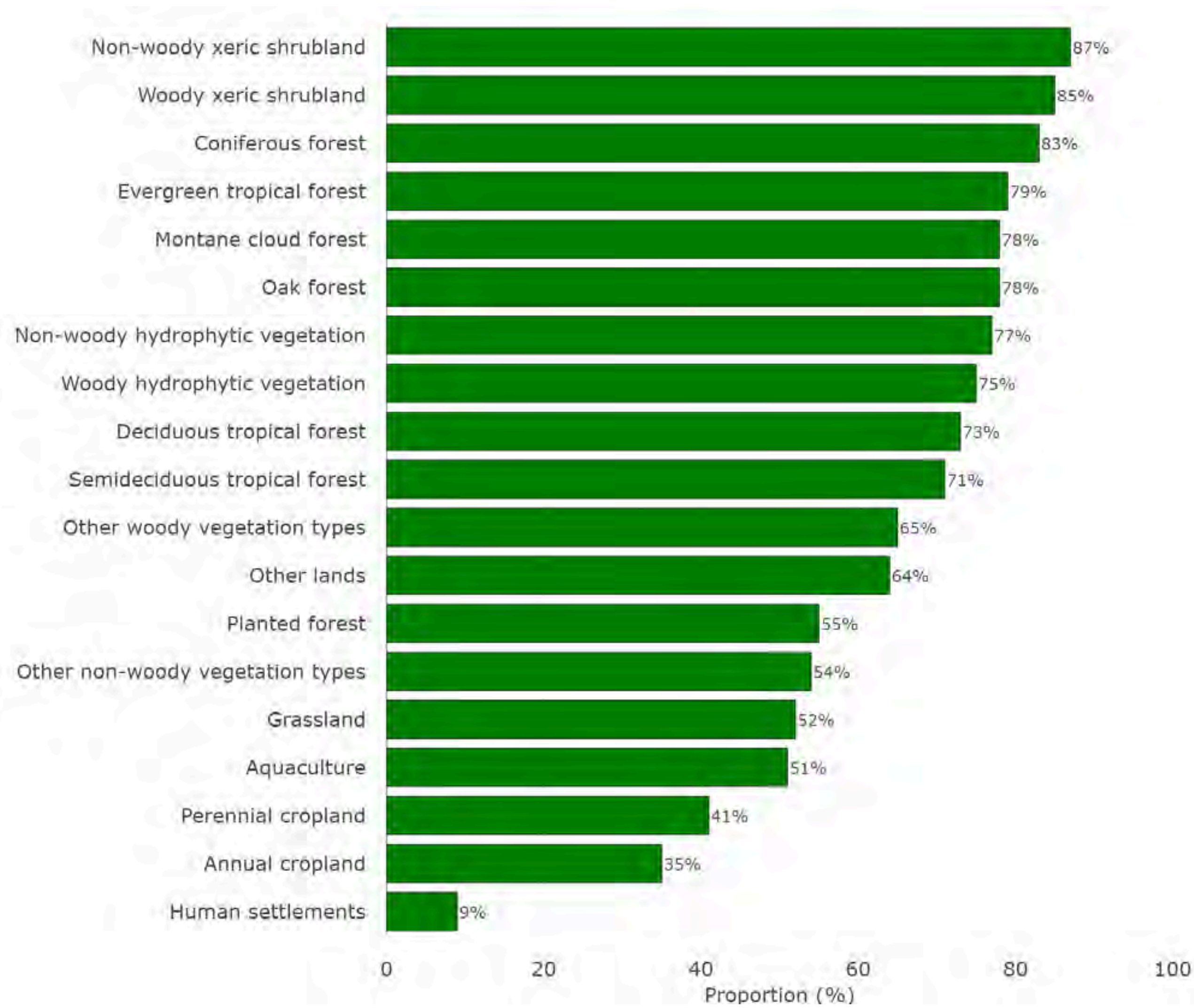


5.4.4 Natural Capital Index

Under a scenario of no human intervention, an ecosystem would express the maximum natural capital value by maintaining the entirety of its original extent with full integrity (the index would be 100 per cent). This condition can be represented, as mentioned above, in physical terms of extent ($\text{extensión} \times \text{integridad}$, (Figure 5-9) or relative (effective extent) referred to the territorial unit of interest (Ecosystem type, watershed, State, Municipality, etc.).

In relative terms, it is possible to point out that Mexico still maintains around 65 per cent of the original natural capital (Figure 5-10). Percentage wise, the natural ecosystems that maintain the greatest natural capital are the Non-woody xeric shrubland (87 per cent); the Woody xeric shrubland (85 per cent) and the Coniferous forest (83 per cent). The Deciduous tropical forest, the Oak forest, the Evergreen tropical forest, the Semi-deciduous tropical forest, the Montane-cloud forest, and the Woody and Non-woody hydrophytic vegetation maintain between 70 and 80 per cent of their natural capital. However, the Montane-cloud forest and the Woody and Non-woody hydrophytic vegetation contribute little to the natural capital of the country due to their low extent. The natural ecosystems that conserve the least natural capital are: Other lands (64 per cent); Special other non-woody vegetation types (65 per cent); Semi-deciduous tropical forest (71 per cent) and Deciduous tropical forest (73 per cent). The natural capital contained in the Grassland is 52 per cent (see footnote 13). The Land Uses that conserve the most natural capital within them are Planted forest (55 per cent); Aquaculture (51 per cent) and Perennial agriculture (41 per cent). Settlements only retain within them 9 per cent of the Natural Capital, the Annual cropland class 35 per cent, and the Perennial cropland 41 per cent.

Figure 5-10: Natural Capital (in percentage) for Terrestrial Ecosystems of Mexico in 2018.



The value corresponding to the effective area in the 2002-2004 period was higher in natural ecosystems such as Non-woody and Woody xeric shrubland, Coniferous forest and Deciduous tropical forest. In this case, it is worth noting that the most relevant decrease in natural capital occurred in Non-woody and Woody xeric shrubland, Evergreen tropical forest and Deciduous tropical forest ecosystems. For Non-woody xeric shrubland, the decrease in natural capital is due to the loss in extent and the reduction in condition. In contrast, in the case of Woody xeric shrubland, Evergreen tropical forest and Semi-deciduous tropical forest, the decrease in the value of natural capital is associated with the reduction in extent. It was also observed that the natural capital value of Woody and Non-woody hydrophytic vegetation had a slight increase between 2002 and 2018, mainly due to an increase in condition.

5.4.5 Relationship between the Ecosystem Integrity Index, the Human Footprint Index and the primary and secondary vegetation categories

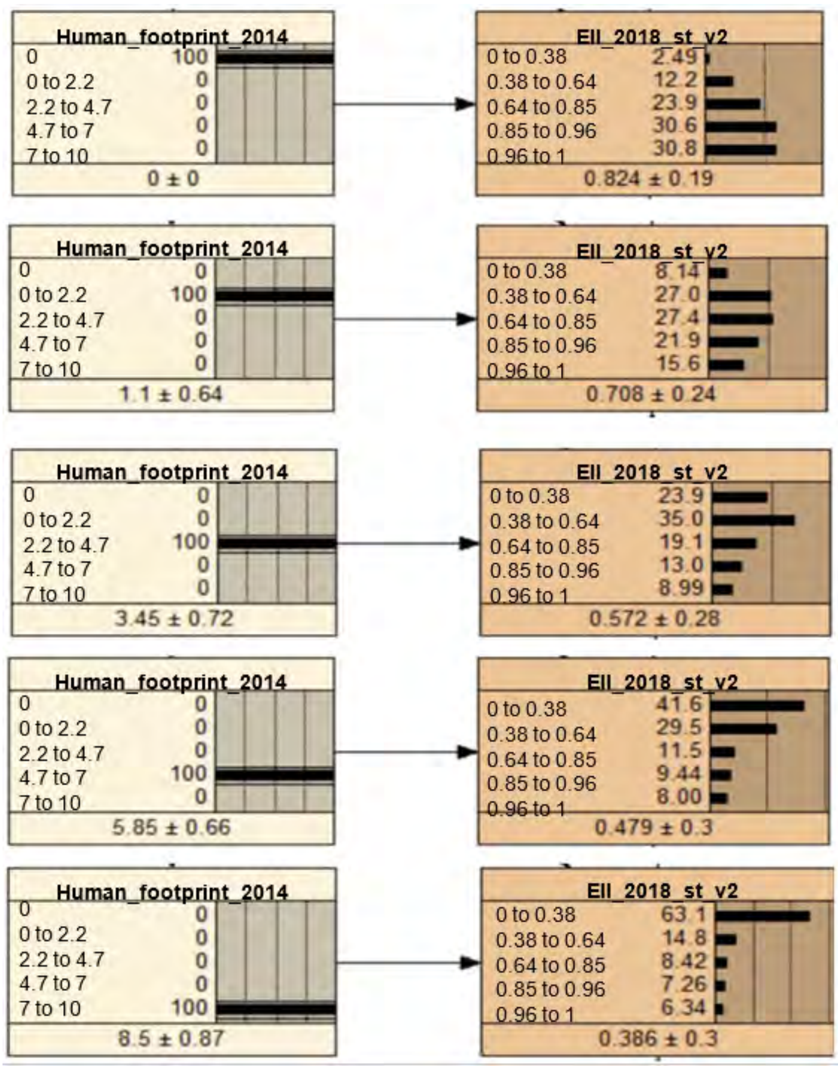
As described in Annex 9.2 of this report, an interoperability tool has been constructed as a proposal to facilitate the transition between the different classifications and cartographic representations of ecosystem extent and condition that are used in Mexico. In this regard, and for the condition account, it is particularly interesting to carry out this exercise in order to understand the relationship between the Ecosystem Integrity Index, the Human Footprint Index, and the primary and secondary vegetation. This last characterization of vegetation, although difficult to specify numerically, is used quite extensively in Mexico. Thus, it was considered pertinent to explore these two concepts in focus and to frame it in the context of the convenience of building computational mechanisms that facilitate interoperability. An important notion to assess is that multiple ecosystem representations maintain different levels of correlation (association or statistical dependence), so that probabilistic graphical models, especially Bayesian network models, are suitable for this purpose.

5.4.6 Relationship between the Ecosystem Integrity and Human Footprint Index

Initially, the Ecosystem Integrity Index and the Human Footprint Index were evaluated as alternatives for measuring ecosystem condition (Sánchez Colón, 2019). The Human Footprint Index is a pressure indicator that denotes, in relative terms, the extent to which human pressures may modify natural environments, and therefore does not directly measure ecosystem condition. This type of indirect analysis is often performed when there is little data available on the state of an ecosystem and therefore using pressure variable data can be a way of estimating the condition the ecosystem (UN, 2021). In this regard, the identification and documentation of pressures is a useful proxy, as long as the relationship between pressure and state is well understood and justified (Bland et al., 2018). However, sometimes the relationship is not direct. Considerable delays may occur between the evidence of a pressure and the evident manifestation of the changes it induced. One way of assessing the association between the two indices can be obtained through their correlation. In case of being exceedingly high, it could even be considered that they are equivalent and that they could be really used interchangeably. This section presents preliminary results of the analysis of this relationship measured between 2014 and 2018, which is the time interval for which data is available for both indices.

The results obtained showed that there is a correlation between the Human Footprint and Ecosystem Integrity indices of about 0.59, which is positive but not exceedingly high. Consequently, in general, the Bayesian network constructed to interoperate between different ecosystem characterizations and human pressure on them, presents a good agreement between human footprint and ecological integrity (Figure 5-11). For instance, when the human footprint is non-existent (zero value), the integrity values show a tendency to reach high or exceedingly high values, indicating the presence of well-conserved ecosystems. As the human footprint value increases, the distribution of integrity values also changes, which increases the frequency of lower integrity values. Finally, when the human footprint has the highest values, ecosystem integrity is predominantly low or very low, with very low frequency of high integrity values, suggesting the presence of clearly degraded ecosystems.

Figure 5-11: Relationship between Human Footprint (2014) and Ecosystem Integrity Index (2018) nodes



The bars indicate the probability (in percentage) that each of the indices falls into the five categories into which the values of each index were subdivided. Values near zero for the Human Footprint Index indicate little impact and values near zero for the Ecosystem Integrity Index indicate a very low condition.

Considering the importance of ecosystem management for detecting the causes of changes in ecosystem condition, it is necessary to explore the possibility of establishing the relationship between the two indicators from this causal approach. Moreover, some of the human activities are directly "harvesting" actions of ecosystem services that generate economic flows while degrading the condition of the impacted ecosystems. It should be recalled that the Ecosystem Integrity Index assesses the state of ecosystems based on biotic characteristics and may include pressure indicators. In this regard, it is recommended that an exercise be carried out by a working group specialized on condition of ecosystems to develop a model in which, in addition to the pressure variables evaluated in the current version of the index, those variables that make up the Human Footprint Index and even some others that could be affecting the condition positively or negatively are included. The network structure for interoperable computation between different ecosystem and human-appropriation classifications proposed in this pilot study opens up an attractive computational possibility that facilitates understanding and interpretation for different contexts of the effect of, for example, different policies on the state of ecosystems.

5.4.6.1 Ecosystem Integrity Index and Primary and Secondary Vegetation Ratio

INEGI cartographic series have a national scope, are spatially-explicit, are generated by an officially recognised agency, are considered as information of national interest, and also span over several years. Based on the Vegetation and Land Use Series II (INEGI, 2001), INEGI assesses ecosystem condition by separating natural vegetation types into at least two successional stages (INEGI, 2012). It considers primary vegetation to be that in which there is no evident alteration and secondary vegetation to be the successional state in which there are indications that have been eliminated or disturbed (note the broad spectrum with which it is characterized), either by natural or anthropic causes, to a degree that it has been substantially modified. The classification is based on the opinion of experts, who evaluate the tree, shrub, and herbaceous strata and also the degree of soil erosion.

It is important to emphasize that the information obtained from the experts has been invaluable for recognising the condition of the vegetation in a qualitative way for several years and will continue to be so in the future. Nevertheless, for an accounting exercise, the analysis of ecosystem condition, in terms of primary and secondary vegetation, does not allow for estimation of the condition of ecosystems within categories that are associated with land uses such as human settlements and crops, etc. Moreover, it is difficult to replicate the results, owing to the fact that they are based on expert opinion. Moreover, the distinction in primary and secondary classes is not designed to incorporate variables that would allow for the assessment of condition in terms of other important characteristics of ecosystem functioning, such as the presence of fauna. Finally, a binary classification (primary and secondary vegetation) misses the different nuances of condition that may be important in ecosystem management, especially those indicative of "early warning" of severe environmental damage.

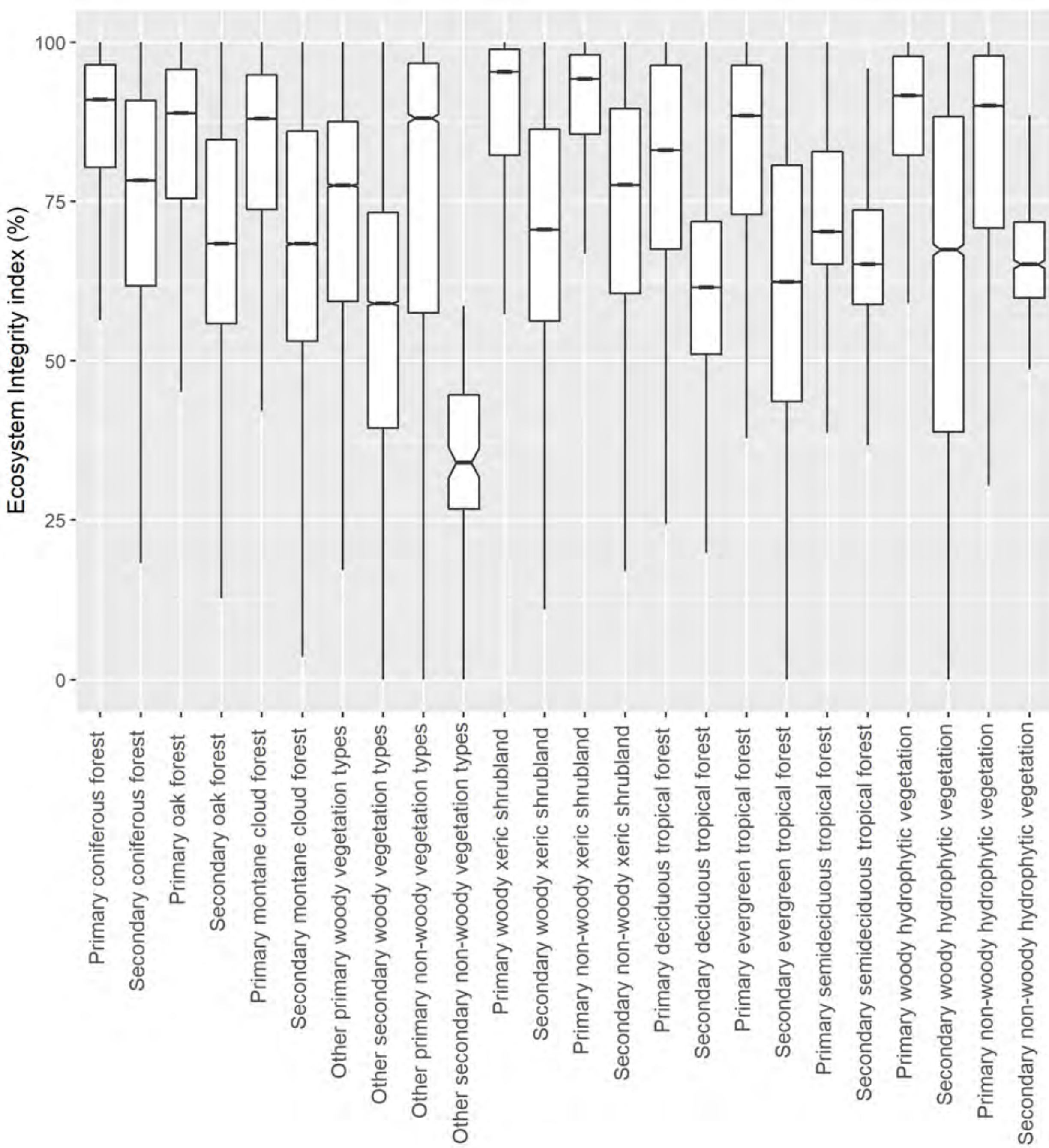
However, through the interoperability tool, it is possible to estimate with a high degree of reliability the relationship between the Ecosystem Integrity index and the distinction between primary and secondary vegetation of the INEGI classification. In this way, advantage can be taken of the existence of a clear correspondence between the two estimates. Furthermore, it also validates the approach chosen in this pilot, to opt for a continuous scale that naturally accounts for the gradation that characterizes the successional process of any ecosystem, accepting that the two INEGI categories are a coarse representation of the same process. As part of this pilot exercise, the relationship between ecosystem integrity and the dichotomy of primary and secondary vegetation was quantitatively explored. Below are results for 2018 data (Table 5-7).

Table 5-7: Ecosystem Integrity Index values (in percentage: 0% not intact, 100% fully intact) for primary and secondary vegetation)

	Ecosystem Integrity Index (2018)	
Vegetation type	Primary	Secondary
Coniferous forest	86.0%	74.8%
Oak forest	83.3%	68.4%
Montane-cloud forest	81.6%	67.8%
Special other woody vegetation types	70.9%	57.2%
Special other non-woody vegetation types	75.0%	38.8%
Woody xeric shrubland	87.5%	68.2%
Non-woody xeric shrubland	88.2%	72.7%
Deciduous tropical forest	80.0%	61.9%
Evergreen tropical forest	83.0%	63.0%
Semideciduous tropical forest	73.0%	65.7%
Woody hydrophytic vegetation	84.7%	62.9%
Non-woody hydrophytic vegetation	80.7%	68.5%

In all cases, and in any vegetation type, the integrity of primary vegetation is consistently higher compared to secondary vegetation. This means that structural and function attributes are in better condition in primary vegetation compared to its secondary counterpart.

Figure 5-12: Box plot for Ecosystem Integrity index values (2018) for terrestrial ecosystems in Mexico



The analysis also makes it evident that the Ecosystem Integrity index presents a wide variation for all vegetation types analysed. Nevertheless, the variation is greater for the case of secondary vegetation than in its primary counterpart, as would be expected from the methodological approach used to generate it, as noted above (Figure 5-12). As was seen when exploring the expected values of ecosystem integrity, it is clear from the full distribution of values that the integrity values for secondary vegetation are lower than those calculated for primary vegetation. The greater variation in secondary vegetation (especially at low integrity values) is indicative of the wide variability and heterogeneity of these vegetation types, which, by definition, are more disturbed than primary vegetation.

The distinction between primary and secondary does not allow us to appreciate this variability, as is the case with the Integrity Index. This is relevant to the management of the terrestrial ecosystems of Mexico. However, it is particularly important not to discard the information provided by the dichotomous approach for the evaluation of the condition of these ecosystems. Such information makes it possible to see over a broad time series the gross changes that have occurred in the different vegetation types. The expert opinion from which these layers were generated is invaluable and can be integrated as an input into the Ecosystem Integrity Index. In this regard, it is highly recommended that a discussion be held with those responsible for producing these layers on the possibility of integrating this information into the Index or using it as part of a process of validation or legitimisation of the Ecosystem Integrity Index.

5.5 Discussion

5.5.1 Relevance of the Condition Account for decision-making

Ecosystem condition accounting provides a new framework for driving the country's development. Through such accounting, decision-making could consider not only the economic and social benefits and the provision of ecosystem services provided by ecosystem assets, but also the capacity of ecosystem assets to remain functioning. Therefore, it is an excellent step to include ecosystem condition accounts within national statistics a measure that allows the integration of the environmental and economic dimensions. As the condition account, based on the Ecosystem Integrity Index, approximates the country's state and health of natural capital, it can guide the management of development considering the cost it may have on the natural heritage and, consequently, be a reference in national development plans. On the other hand, the high-resolution assessment that has been carried out (250 X 250m grids) and the tabular configuration that was proposed, allows the aggregation of condition values in different administrative units (nation, state, municipality, etc.); natural areas (vegetation types, watersheds, ecological regions, biomes, ecosystems, life zones) or other types of classification (economic regions, biogeographic regions, protected areas, IUCN, etc.). This level of analysis offers several advantages that can be used in decision-making and in instruments such as environmental impact assessments, ecological land-use planning, the preparation or updating of management plans for natural protected areas, or the identification of areas for the granting of support for payments for environmental services, to provide some examples. Moreover, it will be possible to associate it with global assessments and commitments such as the Nationally Determined Contributions (NDCs) or the commitments made in the context of the Post 2020 global biodiversity framework, opening the possibility of incorporating a standardized vision to assess ecosystem condition at different levels and from different approaches.

5.5.2 Areas of opportunity and limitations

During the analysis process for the elaboration of a pilot ecosystem condition account, some areas of opportunity were identified to improve the measurement of the condition of ecosystems. These areas include:

A) Vegetation classification CONAFOR-IPCC-N3: The CONAFOR-IPCC-N3 classification was found to make it difficult to present results of the Ecosystem Integrity Index. This classification combines under the label "Grasslands" those of anthropic origin and those of natural origin. Through the calculation of the Ecosystem Integrity Index, different levels of condition can be observed. However, it is difficult to identify whether this variation is due to the change in land use from some vegetation types to artificial grasslands. To improve this assessment, it is recommended to differentiate between grassland types (natural or induced/anthropic).

B) **Variables and analysis techniques.** Extensive high-resolution data generated in Mexico and machine learning-based techniques provide an efficient system for accounting for ecosystem condition. Bayesian networks make it possible to integrate different sources of knowledge and variables into a coherent model (expert opinion, data, model results, etc.) and establish their relationships in probabilistic terms. This pilot exercise mainly used functional and structural vegetation variables, but it is recommended that the Ecosystem Integrity Index be enriched with new composition variables. In particular, it would be appropriate to include variables that evaluate physical, species and other characteristics that estimate the condition at the landscape level (fragmentation and connectivity). It would be important to analyse the possibility of integrating the information from the primary and secondary vegetation charts into the index or using it as part of a process of validation or legitimisation of the Index.

C) **Human footprint and other drivers of change.** It is recommended to continue with a structure that causally represents the relationship between pressure factors and state variables. In this regard, it would be interesting to add in the drivers (pressure) layer, the variables that constitute the Human Footprint Index and other drivers that have effects on ecosystem integrity.

D) **Opportunities**. The choice of variables for the calculation of ecosystem integrity should be made on the basis of a critical assessment of their contribution to measure effectively the condition of ecosystems and their alignment with the criteria established by the SEEA EA. It is recommended that special attention be paid towards ensuring continuity in the generation of data, covering the national territory and the time frame in which it is desired to obtain an account of the ecosystems condition. Accordingly, the choice of variables should include the participation of the institutions in charge of releasing them and guarantee the periodic collection of data on a national scale, with standardized characteristics. Finally, it is recommended to take advantage of different algorithms to suggest relationships between variables. Knowledge of the relationship between several variables to form aggregation indices is a topic of interest for the SEEA EA that is still under discussion. The results obtained show that an approach based on tools such as the one used in this pilot study can be useful.

E) In a more concrete and immediate way, it is recommended to continue with the measurement of ecosystem condition starting with: i) the organization of a training for INEGI staff to be able to transfer the knowledge and details of the methodology used; ii) the integration of a geospatial database with all the economic and biophysical information used for the project; iii) the development of inter and intra-institutional workflows for the analysis of the information including the organization of a workshop or working group to explore with other institutions the use of new variables that can be used for the calculation of the ecosystem integrity index.

Section 6
Accounting and valuation of ecosystem services

KEY MESSAGES:

- *Ecosystem services (ES) contribute to the generation of value in economic activities as well as to society's well-being. Nevertheless, the value of ES is often not recognized in markets, which results into their inefficient use and exploitation, and their limited inclusion in the decision-making process of private agents and public policy. Therefore, it is important to undertake a monetary valuation of the contribution of ES to economic and human activities.*
- *Several methods exist for the monetary valuation of ES. Their application requires making various assumptions and inferences; thus, these valuations should be approached with caution and should recognize their significant level of uncertainty.*
- *This study uses an accounting approach for the monetary valuation, focusing on the identification of the exchange values of ES, thereby differing from other valuation approaches that may include other services and benefits.*

6.1 Introduction to ecosystem services

The monetary valuation of ES seeks to recognize their contribution to economic and human activities. In this regard, the preservation of ecosystems and their services is fundamental in order to promote sustainable development.

The monetary valuation analysis of ES and assets involves a large number of assumptions (i.e., there is sustainable use of resources) as well as inferences. This means that the results should be considered preliminary as the intention of this pilot is to advance the knowledge of the importance of ecosystems in the total supply of goods and services, and in particular for human wellbeing. In this regard, this study does not incorporate the full range of ES, their potential future values, and the intrinsic ecosystem value.

This analysis includes only the monetary valuation of some of the final ES (i.e., intermediate exchanges within ecosystems are excluded) and the valuation is carried out with actual or imputed exchange values without considering the values associated with welfare. Notably, experimental monetary valuations are made for:

1. Crop provisioning service (rice, beans, maize, wheat, sorghum, and soy)
2. Regulating service for carbon capture and sequestration (in biomass and soil)
3. Pollination regulating service for agricultural crops
4. Provisioning and regulating service for residential and municipal water supply
5. Cultural services for the nature tourism economy

The SEEA EA identifies ES as being the contributions of ecosystems to benefits used for economic and human activities and divides them into three broad categories: provisioning, regulating, and cultural services (Figure 6.1).

The approach for measuring (quantification and valuation) is centred on the so-called final ES, i.e., ecosystem service flows between ecosystem assets and economic units. The framework of ecosystem accounting further supports the registration of intermediate ecosystem service flows, defined as service flows between ecosystem assets, such as nursery services or pollination services. It is assumed for accounting purposes that it is possible to attribute the provision of ES to the relevant individual ecosystem assets (e.g. timber provision attributable to a forest) or, for more complex services, to estimate a contribution of each ecosystem asset to the total provision. There should be a corresponding use for each measure of ecosystem service provision. The attribution of the final ES use to different economic units is a critical element of accounting. Depending on the ecosystem service, the user (e.g. households, businesses, or government) might receive that service, while in the ecosystem asset that provides the service (e.g. when catching fish from a lake) or elsewhere (e.g. when receiving air filtration services from a neighbouring forest).

The basic valuation concept applied in the SNA and used also in ecosystem accounting is **exchange value,** i.e., the value at which goods, services, labour, or assets are in fact exchanged, or else could be exchanged for cash. Such valuation approaches adopted for ecosystem accounting exclude the consumer surplus that may be attached to transactions in ES.

Under most circumstances, ES values are not disclosed as they are not represented or traded in the market. Several techniques have been developed for the valuation of non-market transactions that can be applied to provide estimates of the value of the supply and use of ES in monetary terms. Nevertheless, it is worth noting that there are a number of challenges concerning the application of these techniques and the interpretation of the values they generate. Therefore the results of the valuation of ES as reported in this report should be considered experimental.

6.1.1 Classification of ecosystem services

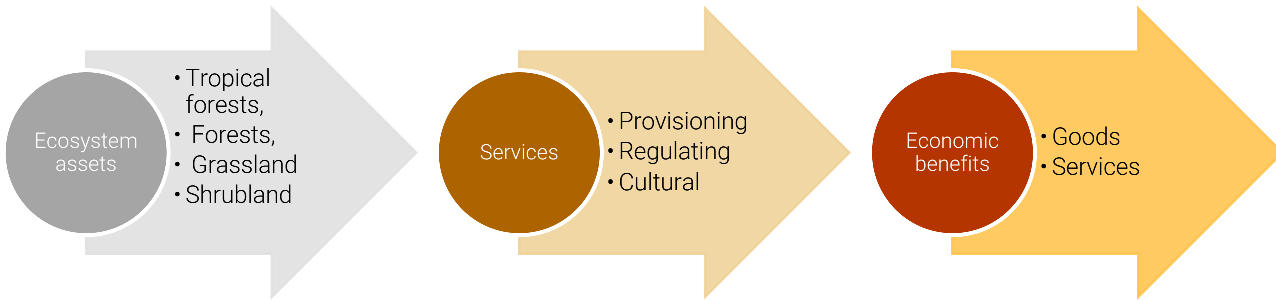
Notwithstanding progress in the development of ES classifications, most notably the Common International Classification of Ecosystem Services (CICES) and the National Ecosystem Services Classification System (NESCS), there is still no internationally agreed classification of ES. In this regard, and in a pragmatic and non-exhaustive way, the SEEA EA proposes a reference list of selected ES (UN, 2021, pp. 126-129), grouped at the highest level as follows:

Provisioning services. These services represent the material and energetic contributions that are generated by or in an ecosystem to economic and human activities (UN, 2014, pp. 42).

Regulating services. Such services include, for instance, the contribution of ecosystems to the regulation of climate, the hydrological cycle, or air quality (UN, 2014, pp. 42). Certain regulating services represent inputs for the generation of other ES, which may lead to double counting (UN, 2014, pp. 107).

Cultural services. Cultural services are typically created at specific sites with recreational, cultural, aesthetic and scientific development value.

Figure 6-1: Diagram of ecosystem services and assets

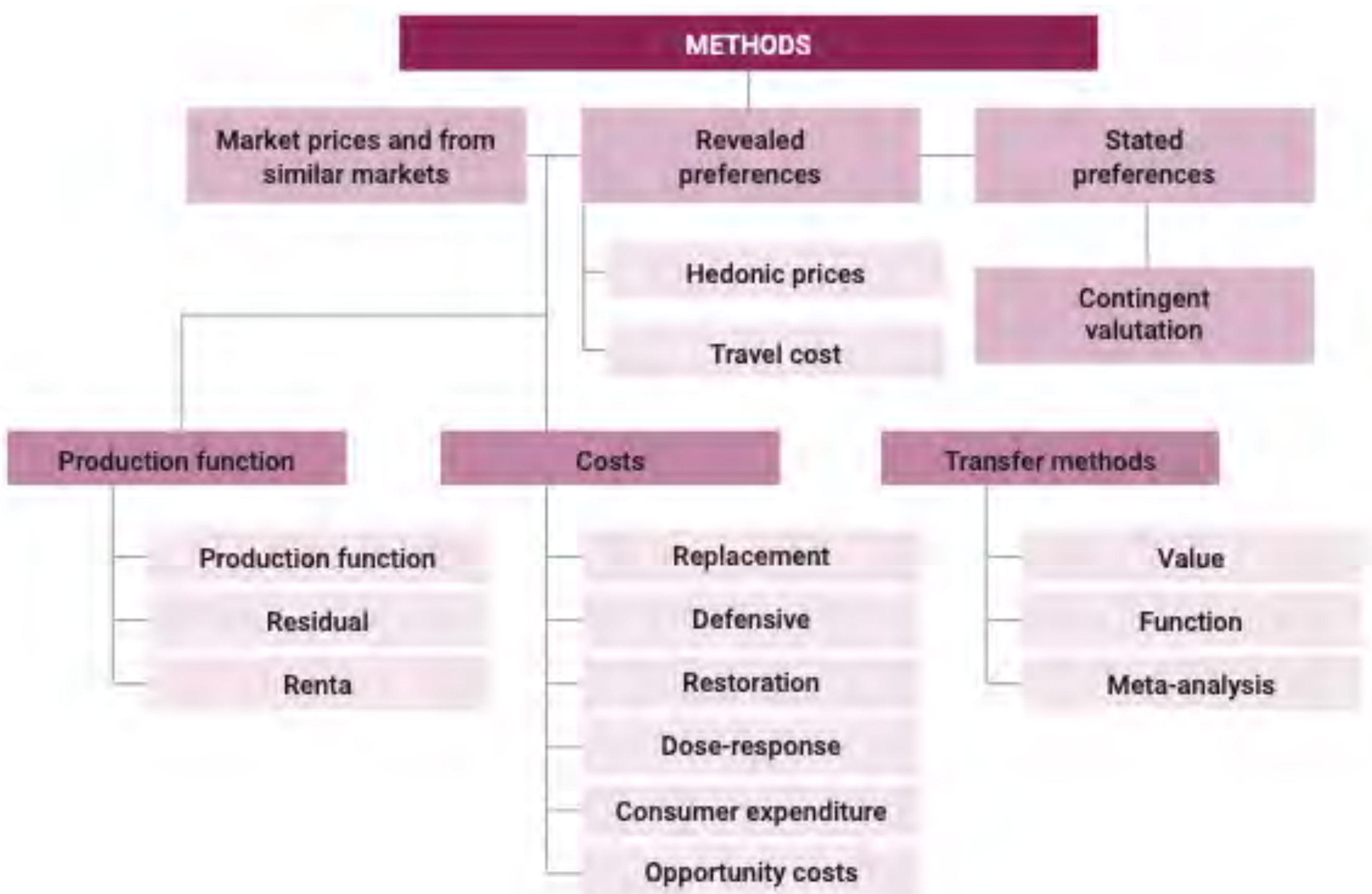


Source: Prepared based on Horlings, et al. (2019a; pp. 16)

6.1.2 Methods of monetary valuation of ecosystem services and assets

The main methods for the valuation of ES are shown in Figure 6-2 below, with further specifications in Table 6.1.

Figure 6-2: Monetary value of ecosystem services



Source: Prepared by the authors (based on Chapter9: Accounting for ecosystem services in monetary terms, UN, 2021)

Table 6-1: Methods for monetary valuation of ecosystem services

Method	Comments
Preferences revealed	
Production function approach	Physical values Used for specific products
Resource rent approach	Monetary values are associated with the difference between revenues and costs (residual) Challenges: market structure and property rights
Use cost or rent price method.	Enables the incorporation of specifications related to climate change
Hedonic pricing	Attribute-based Goods purchases and labour choice
Travel cost method	Supplementary goods Requires identifying the specific contribution
Replacement cost method	Substitute goods Health, mortality, and morbidity Requires knowledge of ecosystem functions
Defensive cost methods	Damage avoidance behaviour Improves Monetary valuation by considering that benefits outweigh costs Consumer production function based (dose-response functions) Requires damage to reflect ecosystem services
Restoration cost method	Requires defining the baseline ecosystem services basket
Dose-response function method	Requires identifying the damage effects
Consumer expenditure method	Requires identifying the specific expenditure Utilises demand functions derived from travel cost, avoidance of harm, or revealed preferences
Value transfer method	
Stated preferences	
Contingent valuation (includes choice experiments).	Pivotal survey design and estimation considering substitute goods, budget constraint, and feedback between options Estimates consumer surplus and welfare Valuations begin to converge with revealed preference valuations
Asset valuation	
GVA/NVA method	Utilises 25-year horizon and discount rates between 2% and 3%
Additional (direct market)	
Payment for ecosystem services	Commonly used for regulating services such as carbon sequestration Such payments correspond, in many cases, to heavily regulated markets

Source: Based on Horlings, et al. (2019a; pp. 27-28,); Champ, et al. (2017); OECD (2018; pp. 56); Markandya, (2019 and 2020)

6.2 Provision of ecosystem services to agricultural production and selected crops

KEY MESSAGES:

- *The valuation study for selected agricultural crops showed that the contribution of ES to agriculture production and selected crops is significant, although it requires subsequent analysis to explain the volatility and heterogeneity of the valued obtained for the different crops. This is of particular relevance since agricultural activities contribute to the national GDP, employment, exports, well-being of rural population, input supply and food security of the country.*
- *The gross monetary valuation of the contribution of ES to agricultural production in 2013 has a value of 163 667 million in current pesos corresponding with 39.23 per cent of the value of agricultural production in that year (sub-sector 111) and 1.01 per cent of the 2013 GDP. It has an average annual value, for the period 1993-2018, of 37.78 per cent of the agricultural production value and 0.99 per cent of national GDP. Meanwhile, the estimated net return of ES in the agricultural sector (incorporating soil degradation) amounts to 110 723 million pesos in 2013 in current prices, corresponding with 26.54 per cent of the value of agricultural production and 0.68 per cent of GDP in 2013 and an annual average contribution between 1993-2018 that corresponds to 22.64 per cent of the value of agricultural production and 0.59 per cent of GDP.*
- *The estimated monetary value of the contribution to the selected crops (maize, wheat, soy, sorghum, beans and rice) remains consistent with the aggregate contribution and demonstrates significant heterogeneity per product. Thus, it suggests that the contribution of ES is heterogeneous across crop type.*
- *The volatility of the monetary valuation of ES points to the presence of additional factors to be analysed such as non-competitive market structures, land speculation processes, production process differences (irrigation and rainfed), socioeconomic producer differences (e.g. education level), food price impacts or extreme weather events.*
- *The monetary value of the contribution of the bundle of ES to agricultural production reveals important regional differences. For instance, maize and beans are distributed across the country while other crops tend to be concentrated in the north and centre of the country.*
- *ES estimates, using microdata, demonstrate that the use and appropriation of ES differs by producer and crop type. In this respect, the loss of ES will have distinct consequences for risk management and/or income maximisation for different types of agricultural producers.*
- *The econometric estimation of a Neo-Ricardian model reveals that the estimated resource rent partially reflects ES, but also additional factors such as climate, machinery and equipment use, and socioeconomic factors such as education level. This suggests that the use and appropriation of ES are influenced by the characteristics of the producer, the production process, and the type of product. Similarly, it is found that shorter distance from natural areas has a positive effect on the residual suggesting the presence of the pollination regulating*

service. Therefore, it is relevant to formulate public policies that are differentiated per socioeconomic groups, types of agricultural producers, and regions.

6.2.1 Introduction

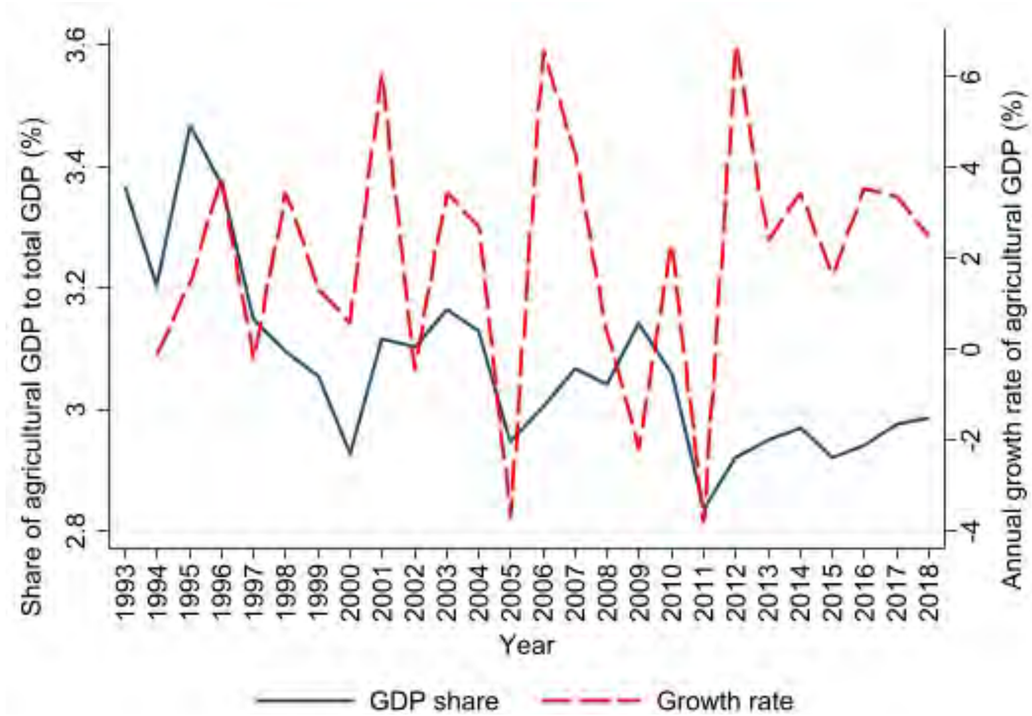
Agricultural activities are essential for economic dynamics, employment and income generation for the rural population, the trade balance, social welfare, and food security. As such, the contribution of ES to agricultural production is of particular relevance to the economic, social, and environmental developments in Mexico.

Therefore, the purpose of this chapter is to estimate the gross monetary value of a basket of provisioning (i.e., nutrient and soil moisture cycling and structure, biomass, genetic diversity, pest control, water supply and soil erosion) and end-regulating (e.g. pollination) ES to total agricultural production and selected crops.

6.2.2 Stylised facts

The agriculture and livestock sector[32] accounted for about 2.99 per cent of GDP in 2018, with an annual average growth rate of 1.94 per cent between 1993-2018 (Figure 6-3). The sector contributes to rural employment, rural incomes the evolution of rural poverty, as well as provides key inputs to other economic activities such as food supply, and represents an important part of the country's exports and is a key factor in risk management and consumption for own use of low-income producers. The agricultural area in 2018 was 21.16 million hectares in 2018 with an annual average growth rate of 0.48 per cent during the period 1993-2018, where 6.17 million hectares correspond to irrigated land and 14.99 million hectares to rainfed land.[33]

Figure 6-3: Growth rate of agricultural production and share of agriculture and livestock in total GDP



Source: Prepared by the authors (using data over several years from the National Accounts System of Mexico, INEGI)

[32] Subsectors 111 and 112 according to the North American Industry Classification System (NAICS).
[33] These figures may vary seasonally.

The production of crops selected[34] for this study because of their economic importance (i.e. rice, beans, maize, wheat, sorghum, and soy) amounted to about 23.36 per cent of total agricultural production in 2018.

Therefore, the purpose of this chapter is to estimate the gross monetary value of a basket of provisioning (i.e., nutrient and soil moisture cycling and structure, biomass, genetic diversity, pest control, water supply, and soil erosion) and regulating (e.g. pollination) ES as inputs to total agricultural production and selected crops.

6.2.3 Data sources and methods

6.2.3.1 Data sources:

Analysis and estimates were made based on three main sources of information:

- National-level information based on INEGI's System of National Accounts (SNA) (various years);
- Geo-referenced information based on the Agri-Food and Fisheries Information System (or SIAP using the Spanish acronym) for the selected crops based on the Land Use and Vegetation Charts (LUVC) of INEGI for the years 2007, 2011 and 2014;
- Microdata from the National Agricultural Survey (or ENA using its Spanish acronym) 2014 containing the information for 66 398 agricultural production units (farms) for the agricultural year from October 2013 to September 2014.

6.2.3.1.1 System of National Accounts (SNA) of INEGI (various years)

The following data were obtained:

- VBP_{it}: Gross production or Gross production value measured at basic prices, that is market production plus production for own use plus other non-market production (INEGI, 2013).
- CI_{it}: Intermediate consumption: the purchase of materials and supplies deducting changes in inventories of materials and supplies (INEGI, 2013).
- RA_{it}: Workers' compensation: the wages and salaries plus social contributions payable by employers (INEGI, 2013).
- CTN_{it}: Unpaid labour cost: imputation based on the assumption that unpaid family labour represents 16.2 per cent of total labour employed in production (INEGI, 2013).
- ISP_{it}: Production taxes: compulsory unrequited payments paid by the units producing goods and services to government units (per-unit or *ad valorem* payments) (INEGI, 2013).
- $SSPx_{it}$: Subsidies on production: current unrequited payments made by the government to economic units based on their production activity levels, quantities, or values of the goods and services they produce, sell, or import (payments per unit or *ad valorem*) (INEGI, 2013).
- EO_{it}: Operating surplus: defined as $VBP_{it} - CI_{it} - RA_{it} - TN_{it} - (ISP_{it} - SSP_{it})$ (estimated by the authors).
- CKF_{it}: Consumption of fixed capital: the depreciation experienced during the accounting period for the current value of the stock of fixed assets that a producer owns and uses, as a result of physical deterioration, normal obsolescence, or normal accidental damage (INEGI, 2013).
- CDG_{it}: Degradation cost: based on the cost of soil degradation[35] (INEGI, 2013).

34 See Sanchez Colon (2019) for the criteria to select these crops.

[35] The concept of degradation costs refers to the costs that society as a whole would have to incur to remedy or prevent the deterioration of the quality of environmental assets, a deterioration that is a product of various economic activities. The economic valuation of land degradation is based on the

6.2.3.1.2 Geo-referenced information

The following geo-referencing method is used throughout the study:

1. The LUVC's for each of the years are merged with the Municipal Geo-statistical Framework 2014. The procedure is carried out using the geo-processing operation called "intersection" of the ArcGIS software. This results in the LUVC per municipality, allowing the specific identification of the types of land use and vegetation for each municipality.[36]
2. The total area of each land use and vegetation type at the municipal level is estimated. That is done by adding the area of the polygons of the same land use and the same municipality reported in the attribute table obtained in the previous step.
3. The proportional area of each polygon with the same type of land use and vegetation in the municipality is estimated. For this purpose, the area of each polygon is divided by the total area obtained in the previous step (step 2). This ratio is considered as the allocation weight of production and production value, e.g. a factor of 0.3 means that the polygon at hand represents 30 per cent of the total agricultural land in the municipality, therefore 30 per cent of the total production and production value is attributed to that polygon.
4. The production volume and/or production value reported in SIAP for the selected crops in irrigated and rainfed modalities is assigned. Such values are assigned only to the polygons of the LUVCs designated as "annual irrigated agriculture" and "annual rainfed agriculture", correspondingly. Nevertheless, the SIAP data may not correspond to the LUVC data. For instance, for the year 2014, the municipality of Mexicali, Baja California, reports production of wheat in its rainfed mode of 254 302.36 tons, and for wheat in its irrigation mode of 265 992.19 tons the SIAP. However, the LUVC does not report any polygon assigned to the land use of "annual rainfed agriculture" in that municipality, and therefore, the 254 302.36 tonnes of wheat in its rainfed modality for that municipality are not being geo-referenced in the previous step.
5. In this regard, an allocation of the production volume and/or the production value that could not be allocated in the previous step is made. For this purpose, other types of land use and vegetation are selected depending on the crop and municipality at hand. For instance, in the case of rice, these values can be assigned to the soil types "annual wet agriculture" and "permanent annual wet agriculture".
6. The table obtained in step 5 on production volume and/or production value allocation is merged with the LUVC Table of Attributes obtained from step 1. This allows geo-referencing, on a value scale, both the production volume and the production value of selected crops.
7. Using information from the National Agricultural Survey (ENA) (2014), the average rent value (as a percentage of production value) is calculated for different return levels per product and by state. This information is merged with the table of attributes of the LUVCs using the state code, the product code, and the return level as "key" variables in the association of both databases (and matching).

remediation costs required to maintain land productivity (INEGI, 2013). The method of estimation is to derive cost and damage functions that relate to different levels of emissions and waste and hence degradation. Most methods for valuing degradation involve combining information on the level of waste and emissions to be removed with costs per unit of improvement. These costs are not linear. Often, large initial improvements can be made at a much lower cost per unit than the cost required to clean the last emission unit. It should be noted that this approach towards measuring degradation is not aligned with the proposals of the SEEA EA.

[36] The attribute tables of these new maps are exported to Excel for handling.

8. Based on the average rent values as a production value proportion, the total rent value for each of the LUVC polygons is calculated and graphed.
9. This geo-referencing method is used throughout the study.

6.2.3.1.3 Microdata

The database used corresponds to information from the National Agricultural Survey (ENA 2014), which contains information for 66 398 agricultural production units (farms) for the agricultural year October 2013-September 2014. This sample has national representativeness for the 34 main products in Mexico. Using the location of the 202 000 lands, for which there is information in the ENA 2014, it is possible to link the ENA information with Geographic Information Systems (GIS) databases, such as climate, soil characteristics, proximity to water bodies, proximity to vegetation, proximity to markets, etc. The ENA reports that the area planted in Mexico in 2014 was 22.4 million hectares, of which 20.3 per cent have some irrigation system, while the remaining 79.7 per cent depends on rain levels.

6.2.3.2 Method

Agricultural production is a consequence of a productive process combining various production factors (capital and labour), inputs (energy, fertilizers, pesticides and irrigation), with a set of provisioning services (nutrient and soil moisture cycling and structure, soil erosion, biomass and water retention and supply) and regulating services (pollination) of ecosystems, that depend on some exogenous factors such as climatic or soil conditions (Figure 6-4) (UN, 2014, pp. 46, 62, Horlings, et al., 2019a, pp. 30).

Figure 6-4: Role of production and contribution of ecosystem services to agricultural production

Source: Prepared by the authors

For monetary valuation, the residual value or resource[37] rent method38 is applied which is estimated as the return deriving from a non-monetary transaction, corresponding to the difference between the product total value39 and the total sum of production costs which includes the sum of intermediate consumption, employee compensation, fixed capital consumption (depreciation) (e.g. produced assets), taxes minus subsidies and net return on capital (UN, 2014, pp. 113) (Table 6-2). Thus, the difference between the price and the unit costs of labour, produced assets and intermediate inputs constitutes the unit resource rent price which represents the estimated price of the ES (UN, 2014, pp. 118). This is feasible where there is only one service that is not accounted for (the ES) and the price of the remaining inputs reflects their contribution to total production.

In this regard, the method of the unit resource rent price reflects the potential of ES, such as soil fertility, hydrological properties (soil moisture), and local pollination to contribute to producing various crops40 (UN, 2014, pp. 116). Nevertheless, it should be considered that the resource rent may also reflect other factors such as the structure and access to markets, location, speculation processes and alternative land uses (UN, 2019, pp. 109) and the presence of productive processes (irrigation or rainfed) with different inputs and technologies levels, so the specific production conditions should be considered.

Table 6-2: Method of the unit resource rent price

Output (value of crop production)
Minus intermediate consumption (e.g. fertilizers)
Minus workers' salaries (RA).
Minus taxes (Tx) on production plus subsidies (S) on production
Equals the gross operating surplus
Minus fixed capital consumption (depreciation)
Minus return on produced assets
Minus income of self-employed persons
Equals resource rent
= degradation + net return on environmental assets

Notes: The methods for calculating intermediate inputs, labour, fixed capital and profit rate can be found in OECD (2009).
Source: Horlings, et al. (2019a, pp. 25)

[37] The System of National Accounts considers this method as the 'second best option' and it is broadly used to calculate the economic contribution of certain public services as education and health services (UN, 2014, pp. 113)
[38] Rents are generally associated with scarcity and the presence of monopolistic structures as competition drives rents to zero (Harvey, 1994, Torvick, 2002).
[39] This method considers a joint production where multiple inputs contribute.
[40] No distinction is made between "produced and natural crops" in this study (UN, 2019, pp. 83).

This method has as assumptions (UN, 2014, pp. 119):

- The ecosystem is used sustainably.[41]
- Producers seek to maximize economic benefit.
- Markets are competitive and therefore there are no extraordinary rents.

Estimates of the monetary value of the contribution of ES in the agricultural sector using the unit rent price method are subject to several biases and challenges:

1. **Potential misspecification bias or exclusion of relevant variables.** The omission of relevant variables includes, for instance, perfectly competitive or monopolistic market structures, land speculation processes, climatic impacts, modifications in administrative or productive processes, national or international macroeconomic impacts, irrigated areas, price or agricultural production level changes.
2. **Potential risk of misattribution of the rent or residual.** That is, the processes within ecosystems and interactions of ES with economic activities and human well-being are extremely complex. This is reflected in the fact that there remains significant uncertainty regarding the specific contributions of each of these individual ES.
3. **Risk of bias in inferences due to unrealistic or incorrect assumptions** as (SEEA-EEA, 2014):
   - The exploitation of the resource is done sustainably.
   - Relative prices are consistent with sustainable exploitation.
   - Economic activities and prices in the rest of the markets correspond to competitive markets.
   - The agricultural sector is in balance and input payments reflect their marginal contribution to the product.

The conceptual framework for estimating the contribution of an ES basket in the agricultural sector, which is based on the resource rent unit price, are summarized in equations (1), (2), and (3).[42]

(1) $EO_{it} = VBP_{it} - CI_{it} - RA_{it} - CTN_{it} - (ISP_{it} - SSPx_{it})$

(2) $R_{it} = EO_{it} - CKF_{it} - REN_{it}$

(3) $RN_{it} = R_{it} - CDG_{it} \text{ or } R_{it} = RN_{it} + CDG_{it}$

where, EO_{it} is the operating surplus in year t and the subindex i represents the sector or crop type; VBP_{it} is the Gross Value of Agricultural Production, CI_t is the sum of intermediate consumption (input costs of goods and services, at the price of the purchaser, including taxes on products), RA_{it} is workers' compensation, CTN_{it} is the cost of unpaid labour, $(ISP_{it} - SSPx_{it})$ is net production taxes (taxes (ISP_{it}) minus subsidies ($SSPx_{it}$), R_t is the value of the resource rent (or resource residual), CKF_{it} is the fixed capital consumption, REN_t is the net return on fixed assets approximated by a value of 4% average per year (Table 2), RN_{it} is the net return on environmental assets[43] (degradation-adjusted environmental assets)[44] (UN, 2014, pp. 144) and CDG_t is the cost of soil degradation.

6.2.4 Results

The geo-referenced information on agricultural production and crops selected for ES analysis is summarized in Maps 6-1, 6-2, 6-6 below[45].

[41] That is, when degradation is not taken into account.

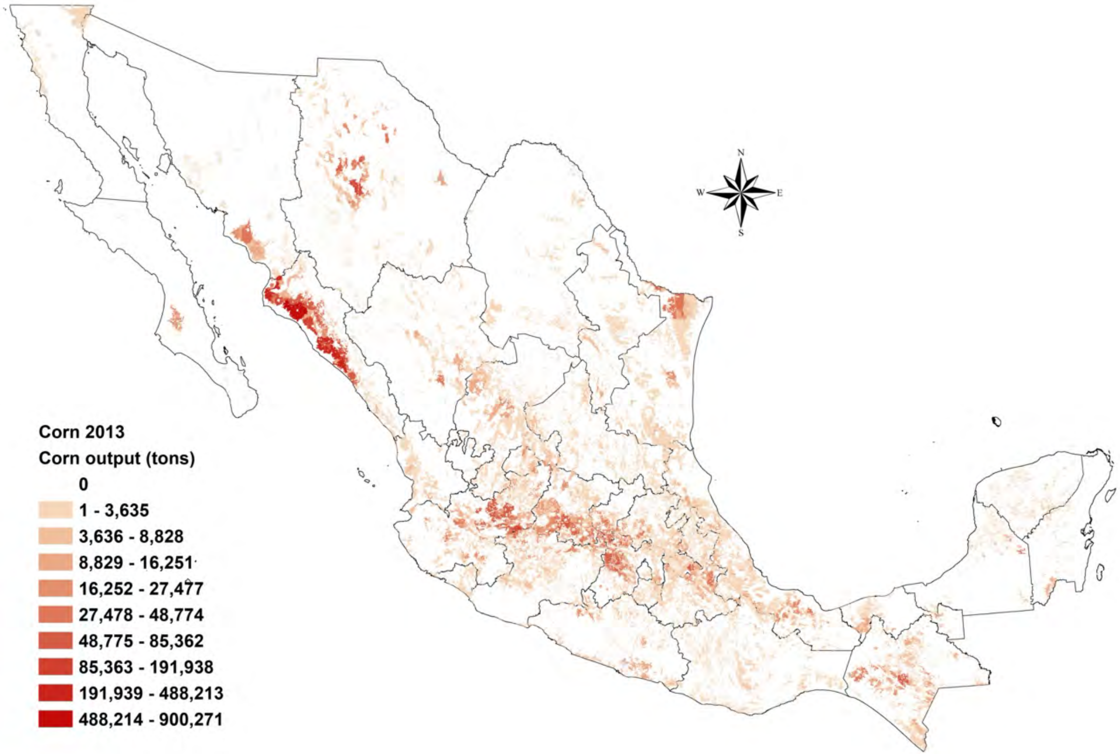
[42] The rate of return on assets was chosen as 4% per annum.

[43] See UN (2019), pp. 25 for its definition as an equation.

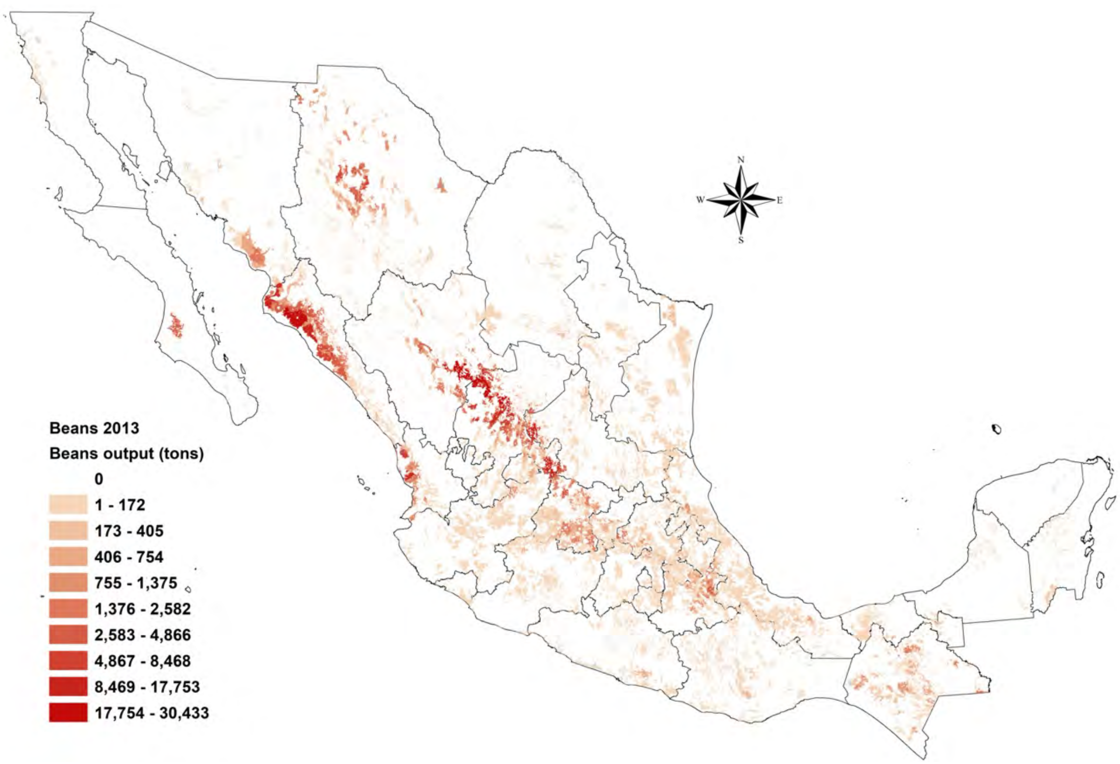
[44] These measurements are made, for example, to GDP adjusted for degradation and fixed capital, i.e., the Degradation Adjusted Net Value (UN, 2014, pp. 143, pp. 123 and pp. 135). The inclusion of adjustment for degradation is also suggested by Bateman, et al., 2011 in UN, 2014, pp. 108).

[45] The georeferentiation of the agricultural production in Mexico was done with data from the Service of Information on Fisheries and Agriculture (SIAP) at the municipal level and the Series VI maps of land use and vegetation cover of INEGI. Upon intersecting both data sets, polygons were obtained depicting the agricultural use in each municipality. By pondering the proportions by area, the production to each of the polygons was assigned as agricultural land use. Hence, the maps depicted in this chapter show the total agricultural production volume and the total rent by agricultural area.

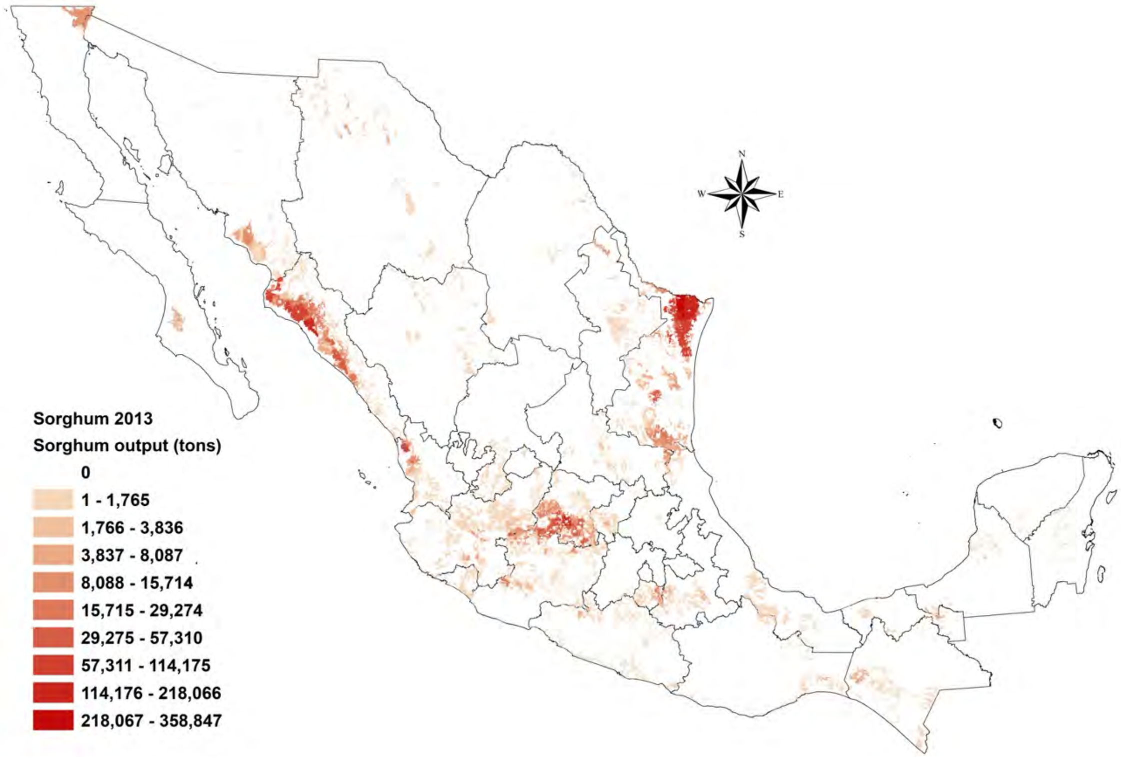
Map 6-1: Maize production in 2013 (tons)



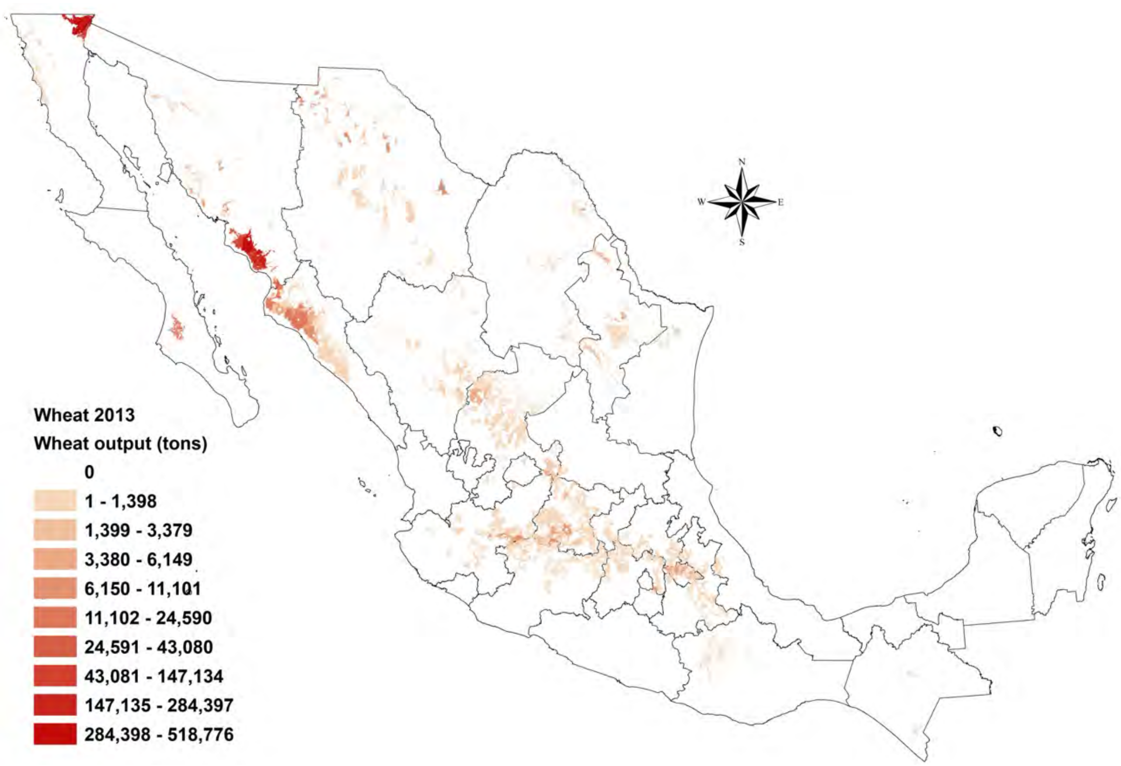
Map 6-2: Bean production 2013 (tons)



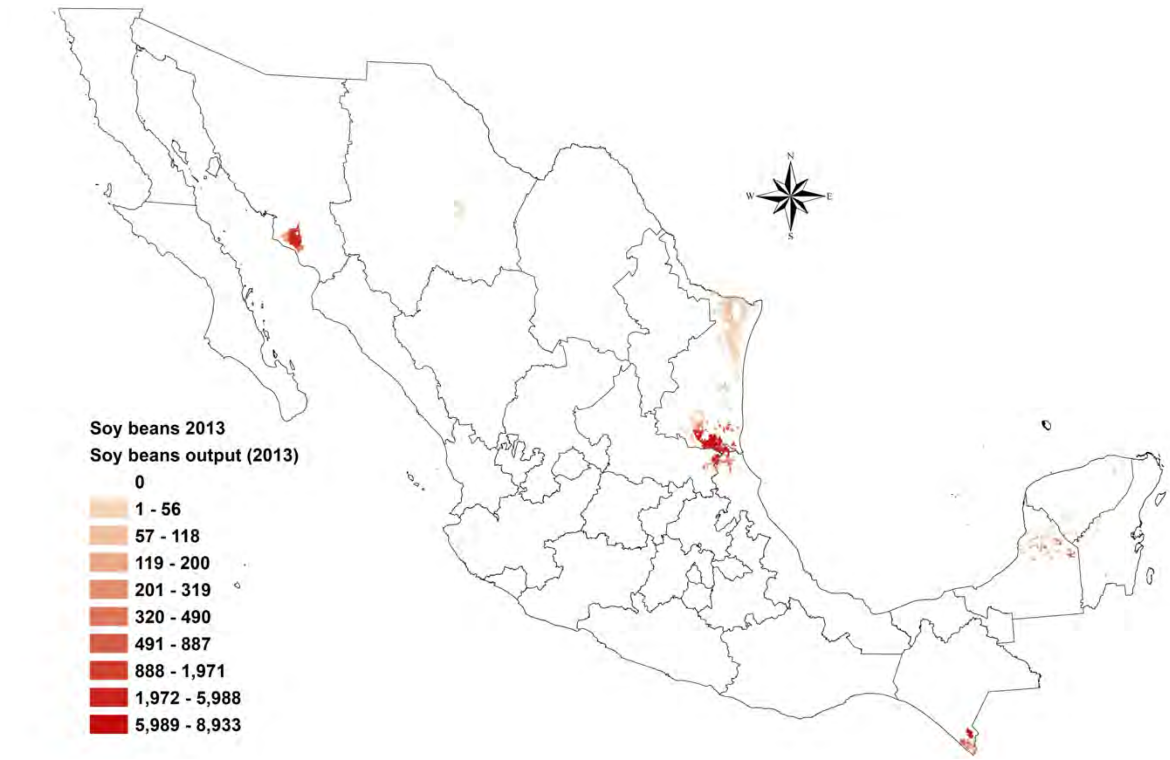
Map 6-3: Sorghum production in 2013 (tons)



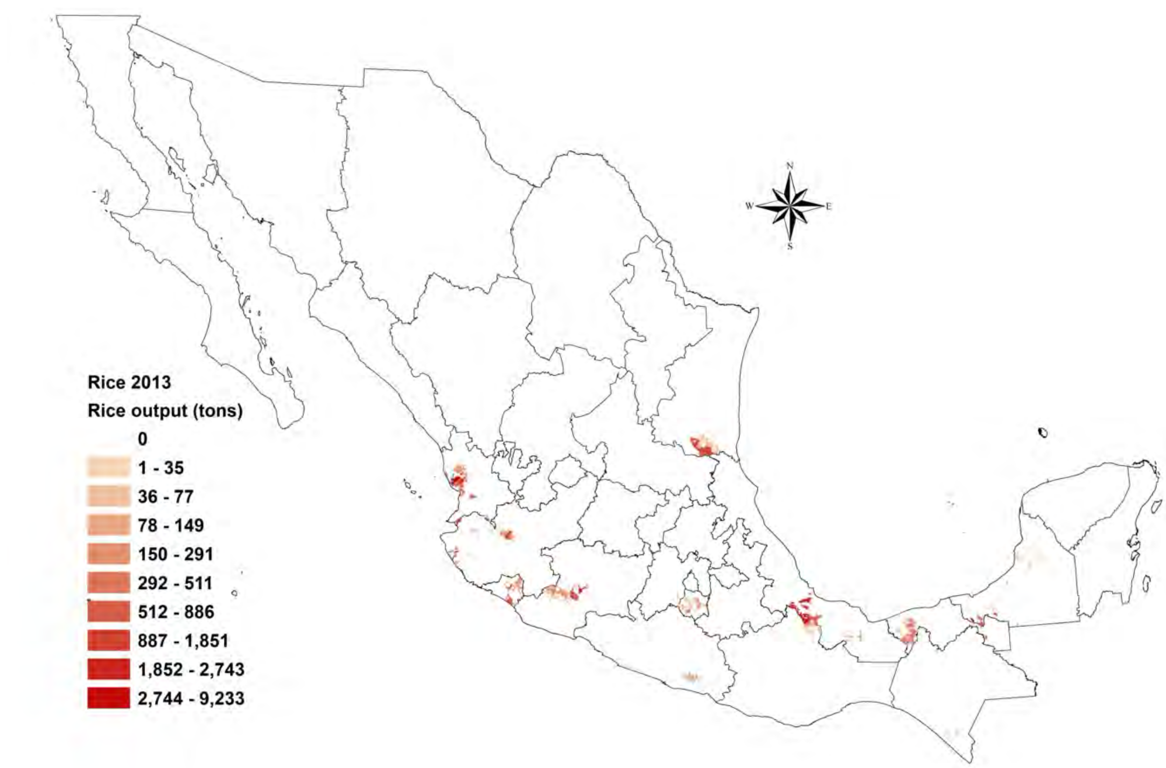
Map 6-4: Wheat production in 2013 (tons)



Map 6-5: Soy production in 2013 (tons)



Map 6-6: Rice production 2013 (thousands of tons)



Source: Prepared by the authors (based on data from SIAP and LUVC (INEGI))

6.2.4.2 Monetary valuation

6.2.4.2.1 Monetary valuation at the national level

The estimation of the method for unit resource unit price based on equation (2), indicates that the contribution of the basket[46] of the ES[47] to the production of the agricultural sector has a value of 163 667 million current pesos in 2013 representing 39.23 per cent of the value of agricultural production in the same year (subsector 111) and 1.01 per cent of the 2013 GDP (Table 6-3, Figure 6-5) When deducting the cost of soil degradation, based on equation (3), a contribution of 110 723 million current pesos in 2013 is obtained, corresponding with 26.54 per cent of the value of agricultural production and 0.68 per cent of GDP in 2013.

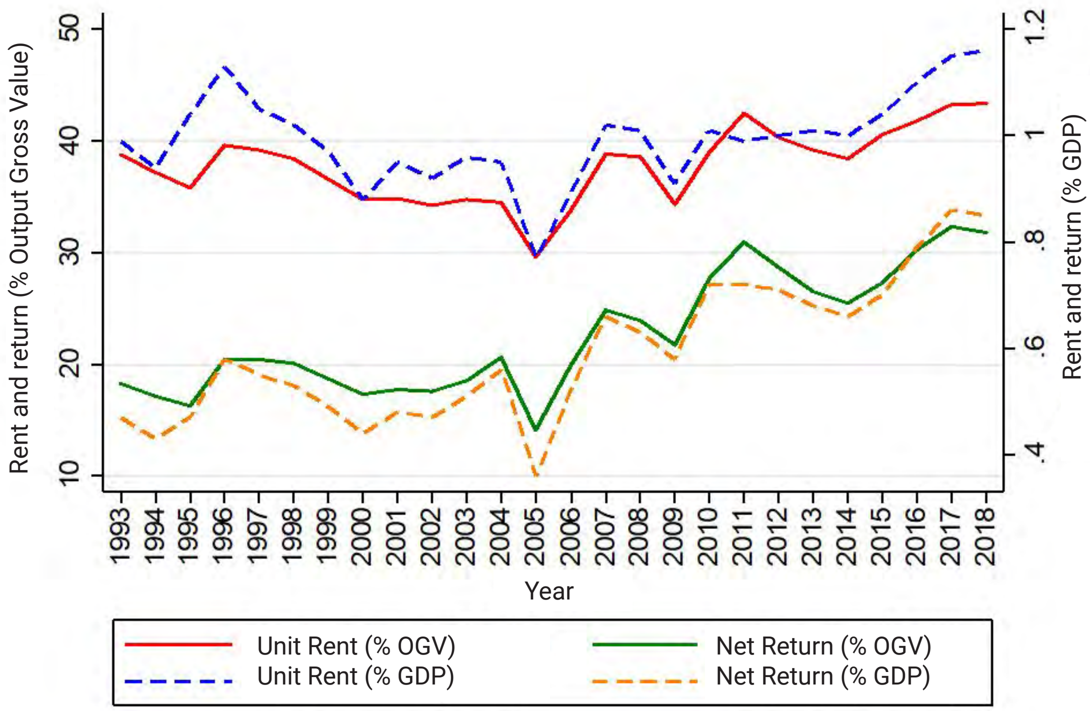
Table 6-3: Contribution of ES in the agricultural sector by the unit price method of resource rent

Item	Value (unit rent)	Value (net return)
Value of the annual contribution of ES to the production of the agricultural sector and percentage in relation to the agricultural production value and GDP: 2013	163 667 million pesos 39.23% of the Value of Agricultural Production 1.01% of GDP	110 723 million pesos 26.54% of the value of agricultural production 0.59% of GDP
Average annual value of ES contribution to agricultural sector production 1993-2018	140 723 million pesos	86 364 million pesos
% of the average annual ES of the agricultural production value 1993-2018	37.78%	22.64%
% of ES of national GDP 1993-2018	0.99%	0.59%

Source: Prepared by the authors

[46] The portfolio of services includes, at least, the services of nutrient and soil moisture provision, genetic diversity, pest control, water provision, and the ultimate regulating service of pollination and climate (Figure 1) (UN, 2014, pp. 62).
[47] In practice the unit price method of resource rent may provide results with a high uncertainty level, and it is even possible that market conditions and structure eliminate the rent giving very low or even negative values (Horlings, et. al., 2019, pp. 7).

Figure 6-5: Valuation of ecosystem provisioning services to agricultural production using the method of the unit resource unit price and net resource rent as a percentage of gross value of agricultural production and GDP: 1993-2018



Notes: The resource rent was obtained using equation (2) and an average rate of return of 4%.
Source: Prepared by the authors (using data over several years from the National Accounts System of Mexico, INEGI)

6.2.4.2.2 Monetary valuation by selected crops

The estimation of the contribution of the ES in the selected crops, using the method of the resource unit rent price (equation (2), is heterogeneous and with an annual volatility associated with factors such as the presence of non-competitive market structures, land speculative processes, different productive processes (irrigation or rainfed) and other factors (climatic) (Table 6-4, Figure 6-6).

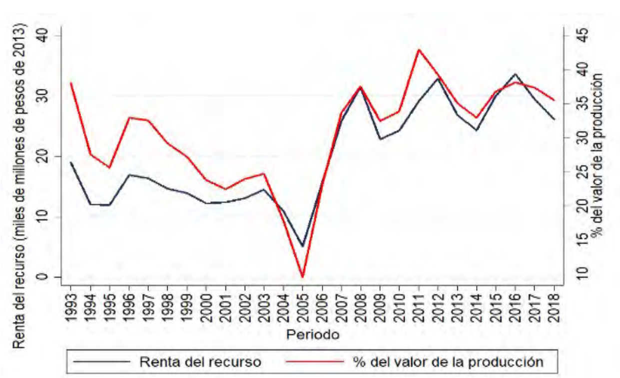
Table 6-4: Contribution of ecosystem services to agricultural production and selected crops

Ecosystem service contribution to agricultural production (annual average 1993-2018)	Value in 1993-2018 (Rent)	Value in 2013 (Rent)	Value in 1993-2018 (Net return)	Value in 2013 (Net return)
Percentage of the average annual ES of the agricultural production value 1993-2018	37.78% (0.99% of GDP) 140 723 million pesos in 2013	39.23% (1.01% of GDP) 163 667 million pesos in 2013	22.64% (0.59% of GDP) 86 364 million pesos in 2013	26.54% (0.68% of GDP) 110 724 million pesos in 2013
Rice	41.00%	38.25%	25.87%	25.56%
Corn	30.55%	35.05%	15.41%	22.36%
Wheat	35.10%	46.65%	19.96%	33.96%
Sorghum	30.78%	38.25%	15.64%	25.56%
Soy	27.54%	36.94%	12.41%	24.25%
Bean	38.51%	39.86%	23.38%	27.17%

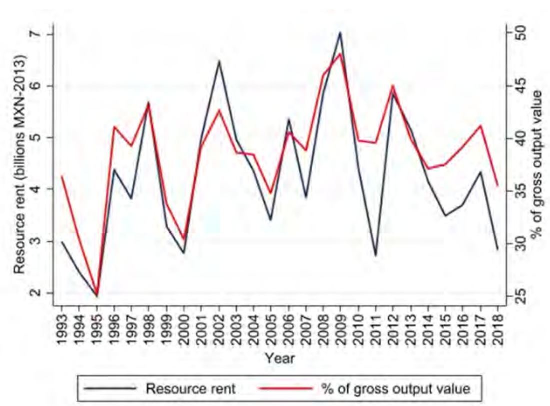
Notes: The rent value was obtained using equation (1) and an average profit rate of 4% and the Net Return Value is obtained based on equation (3) and an average profit rate of 4%.
Source: Prepared by the authors

Figure 6-6: Value of ecosystem services per crop (rice, beans, maize, wheat, sorghum, and soy) using the resource rent method (1993-2018)

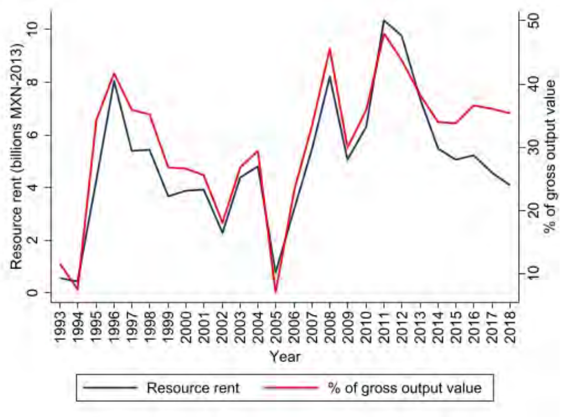
Resource rent: corn



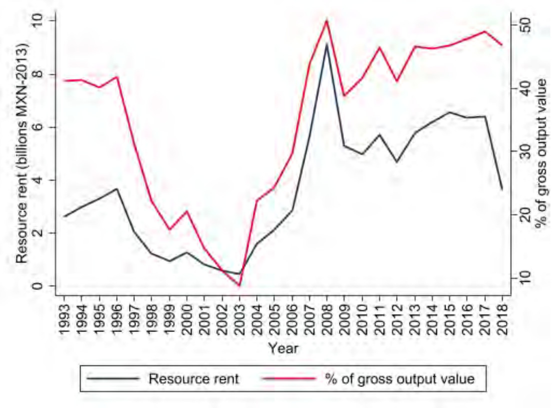
Resource rent: beans



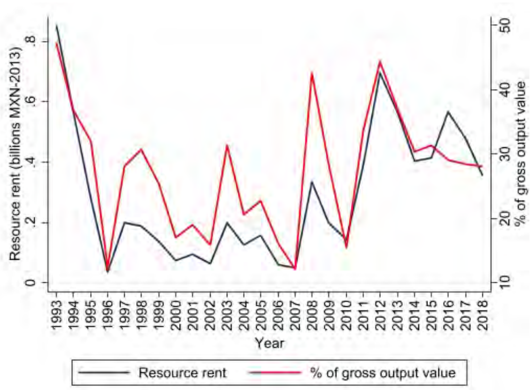
Resource rent: sorghum



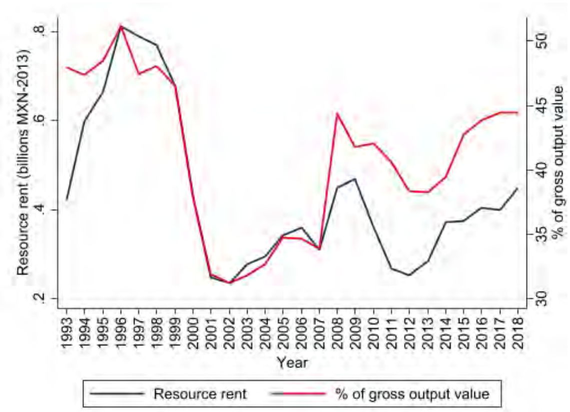
Resource rent: wheat



Resource rent: soy



Resource rent: rice



Notes: The resource rent was obtained using equation (1) and an average rate of return of 4%.
Source: Prepared by the authors (using data over several years from the National Accounts System of Mexico, INEGI)

Table 6-5: Monetary value of Ecosystem Services in agriculture per hectare

Item	Value (pesos per hectare	
	Rent	Net return
Average ES contribution	6 500	3 982
Corn	2.546	1 385
Bean	2.251	1 412
Sorghum	2.585	1 426
Wheat	5.072	3 194
Soy	1.887	907
Rice	6.976	4 491

Notes: The average contribution corresponds to the average value of all agriculture and therefore does not represent the average of the six crops selected in the Table.
Source: Prepared by the authors

6.2.4.2.3 Ecosystem services in the national agricultural sector: volatility and forecasting

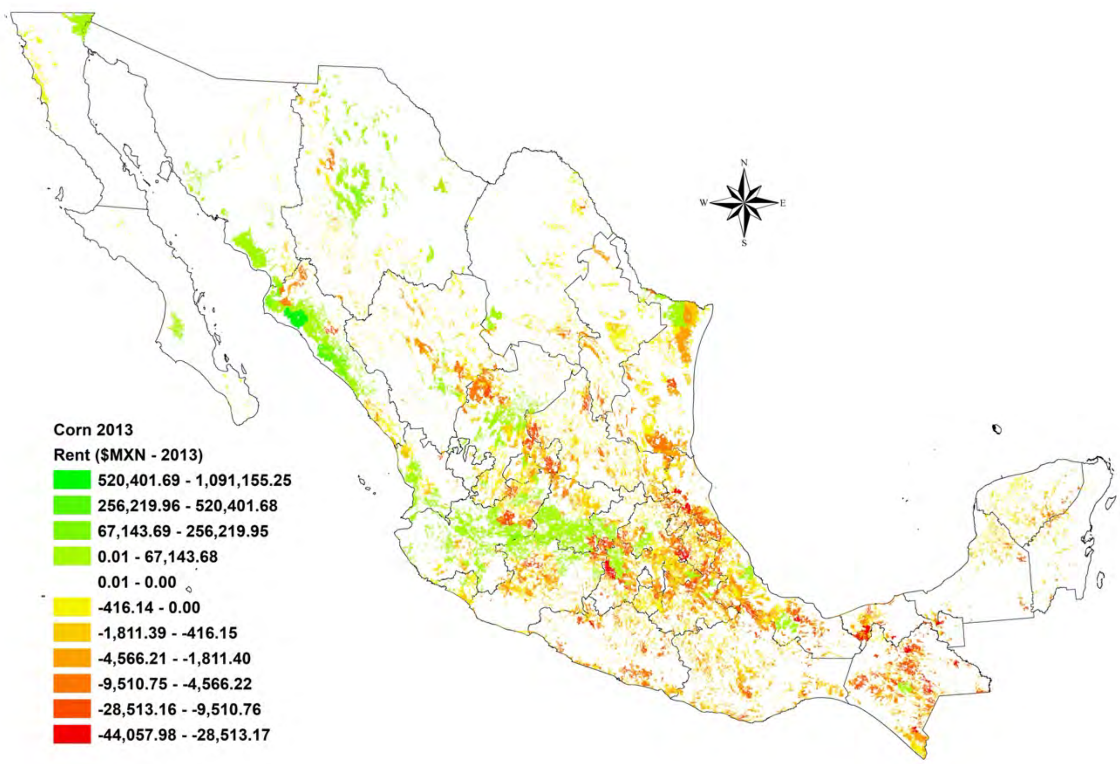
The use of Autoregressive Integrated Moving Average (ARIMA) models allows generating an inertial forward-looking scenario for the contribution of ES to agricultural production and selected crops (i.e., Business As Usual, BAU) with their corresponding fan charts (Figure 6-7.

Figure 6-7: Simulated scenarios to 2025 of the contribution of ecosystem services to agricultural production using the method of the resource unit rent

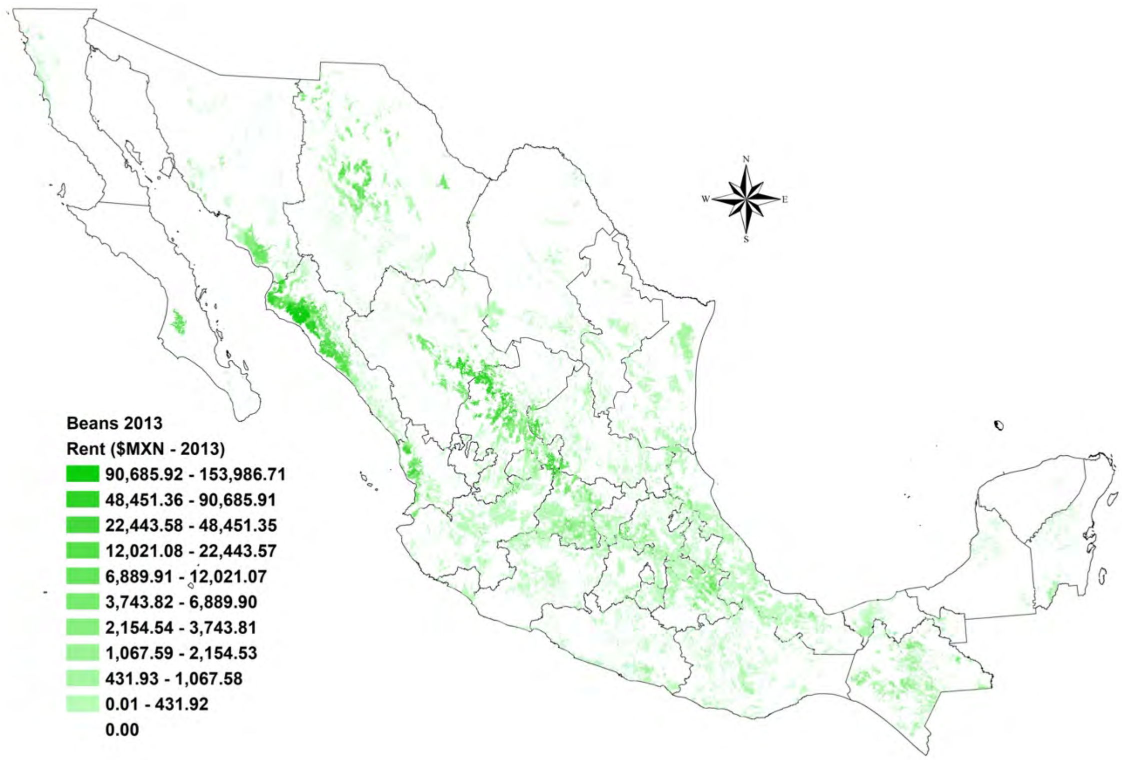
6.2.4.2.4 Monetary valuation of ecosystem services: A geo-referenced view

The geo-referenced contribution of the total value of ES shows that the agricultural production of products such as corn (Map 6-7), beans (Map 6-8) and wheat (Map 6-10) take place throughout the national territory, while rice (Map 6-12)and soy (Map 6-11)are grown in specific regions. It also shows that the estimated resource rent is heterogeneous by geographic regions of the country, where the highest levels of rent are concentrated in the north (west and east) and central Mexico. Notably, the rent level tends to be higher in those agricultural lands with irrigation systems.

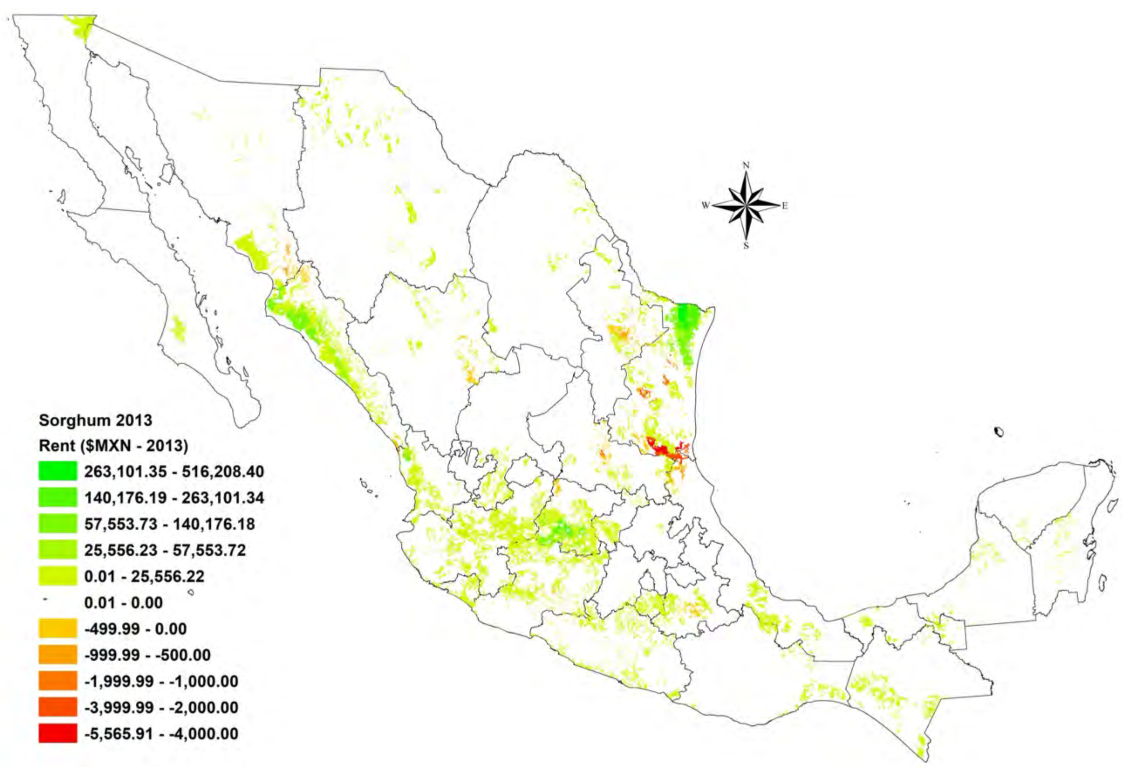
Map 6-7: Total rent value of maize 2013 (thousands of pesos)



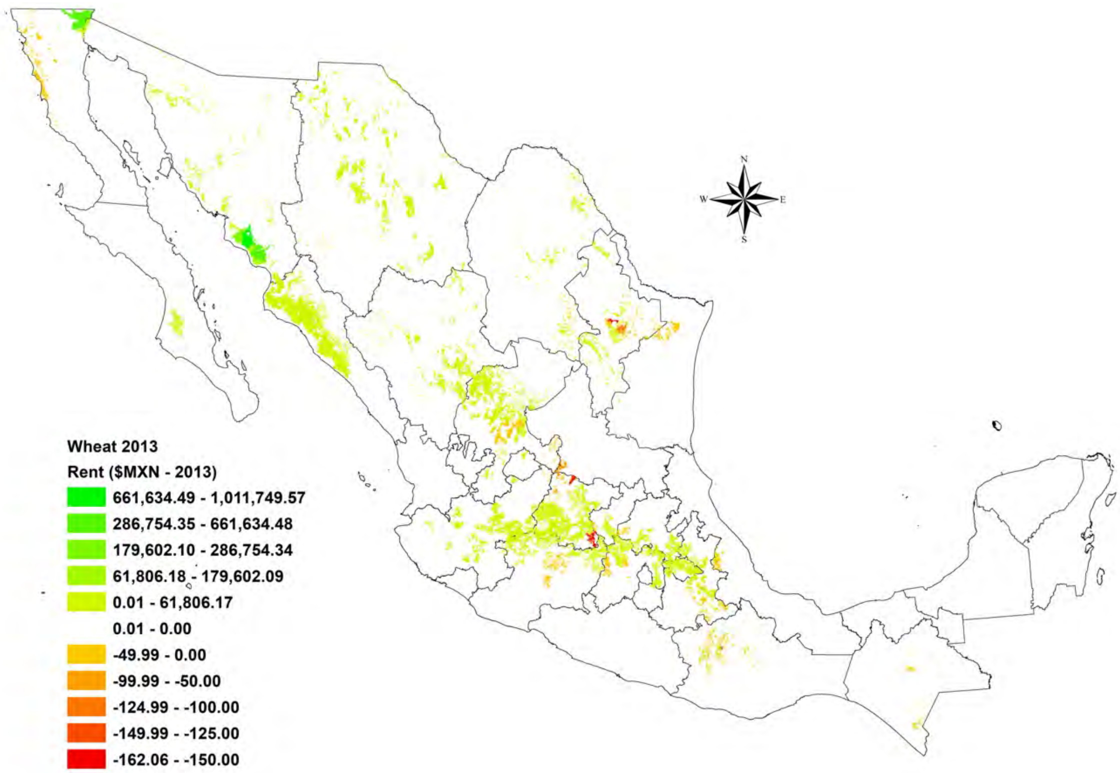
Map 6-8: Total rent value bean 2013 (thousands of pesos).



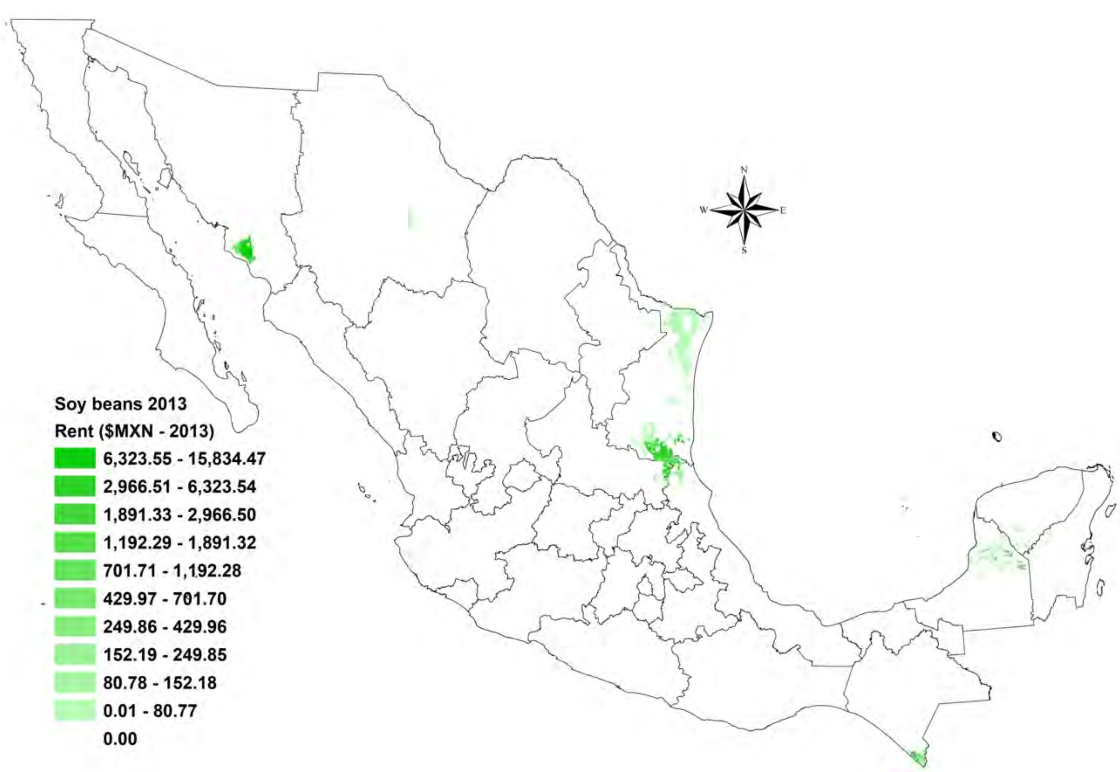
Map 6-9: Total rent value of sorghum 2013 (thousands of pesos)



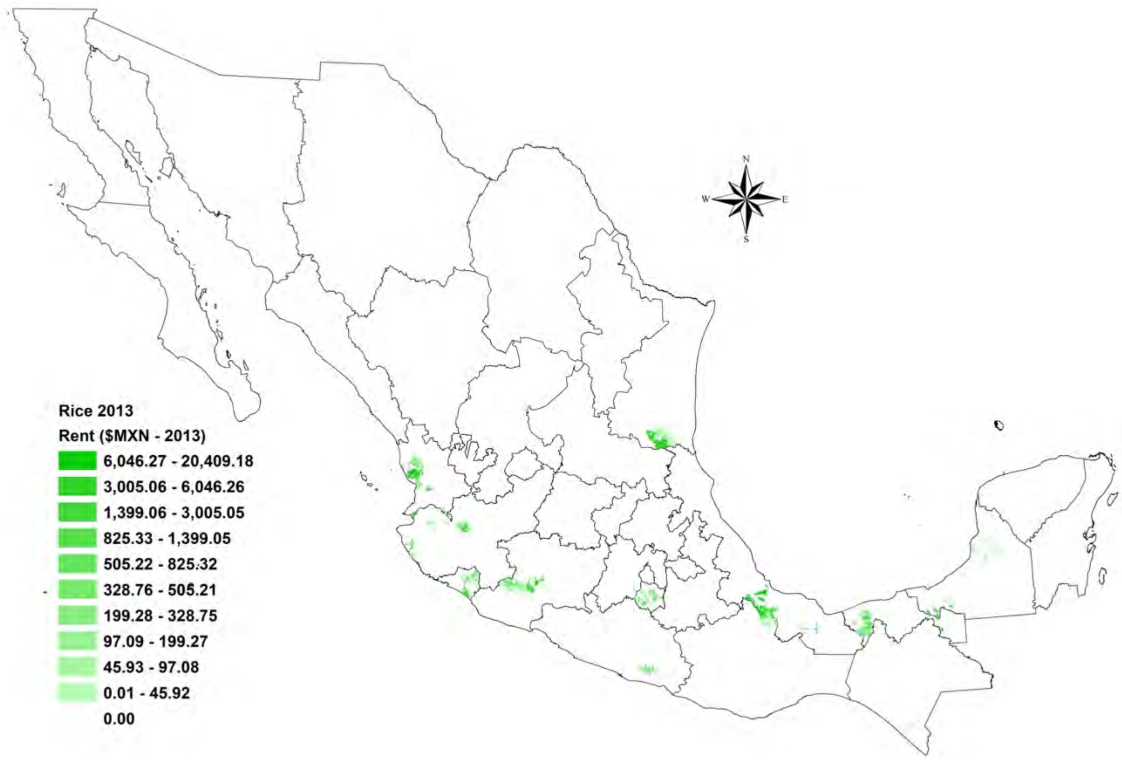
Map 6-10: Total rent value of wheat 2013 (thousands of pesos)



Map 6-11: Total rent value of soy 2013 (thousands of pesos)



Map 6-12: Total rent value of rice rent 2013 (thousands of pesos)



Source: Prepared by the authors (using data from SIAP, land use and vegetation map (INEGI), and the National Agricultural Survey (ENA) 2014)

6.2.4.2.5 Contribution of ecosystem services in the agricultural sector: A microdata view

To analyse the contribution of ES to agricultural production and selected crops in greater depth, estimates have also been done using microdata from the National Agricultural Survey, 2014 (ENA-2014) and using equation (2). The results show, by income strata (percentiles), an inverted S shape with mostly positive values. The average contribution of ES to agricultural production is found to be 8840 pesos/ha in 2013, with differences between irrigated and rainfed areas (Figure 6-8, Table 6-6).[48] The differentiated behaviour of agricultural producers regarding the use and appropriation of the residual resource rent of the agricultural sector and selected products is reflected by the fact that the residual rent is higher in irrigated crops than in rainfed crops (Figure 6-8 to Figure 6-14). The positive and negative contributions of ES reflect the behaviour of agricultural producers that simultaneously intend to maximize profits, maximize the receipt of subsidies, and appropriate the reward of the right to cultivate the land that includes the use of ES and build a risk management strategy supported by the contribution of ES differentiated between high- and low-income producers.

[48] This value is consistent with aggregate estimates.

Figure 6-8: Average rent (pesos per ha) by income strata (percentile)

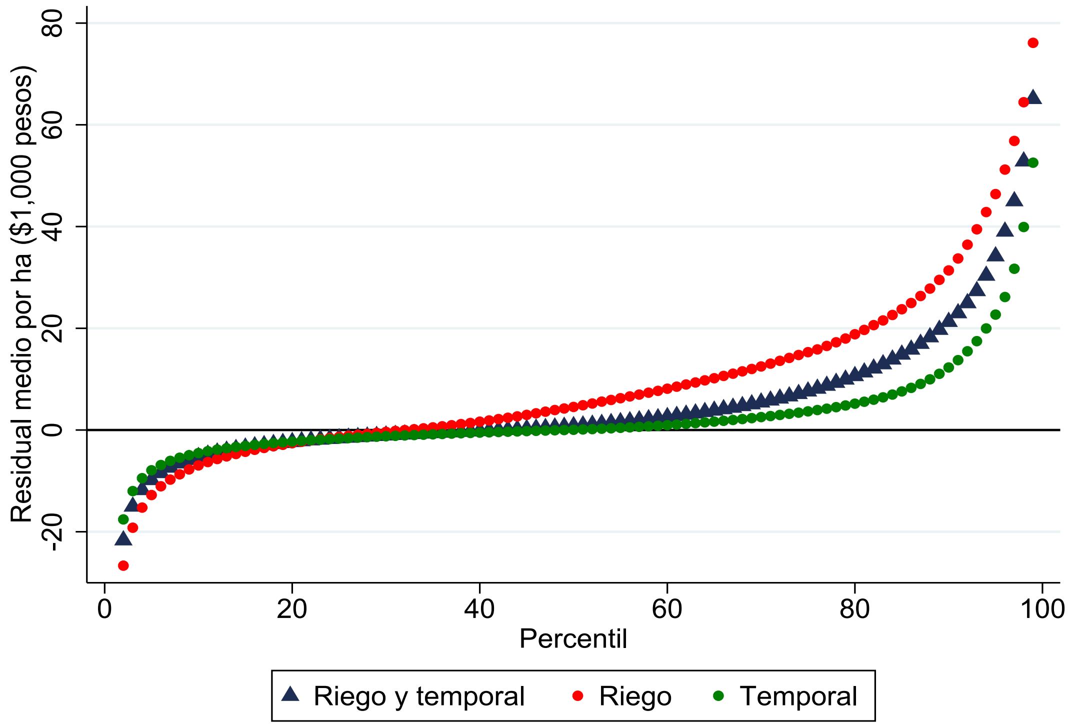


Figure 6-9: Average residual - maize (pesos per ha)

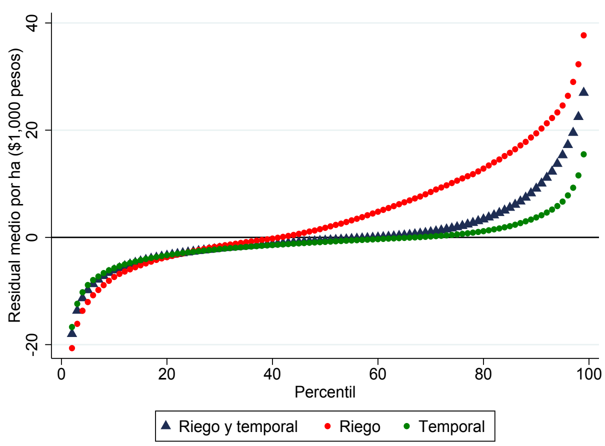


Figure 6-10: Average Residual - beans (pesos per ha)

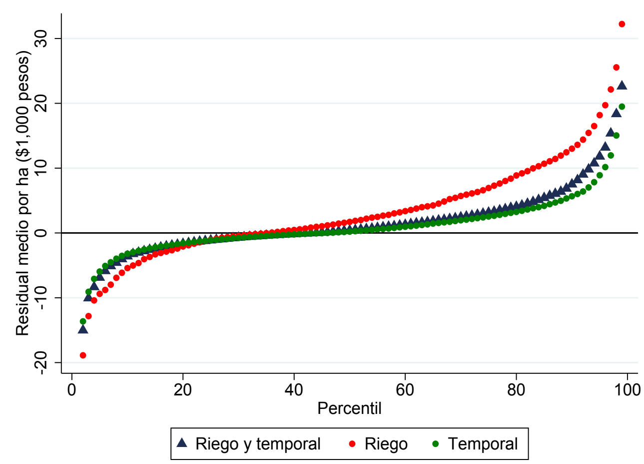


Figure 6-11: Residual Average - sorghum (pesos per ha)

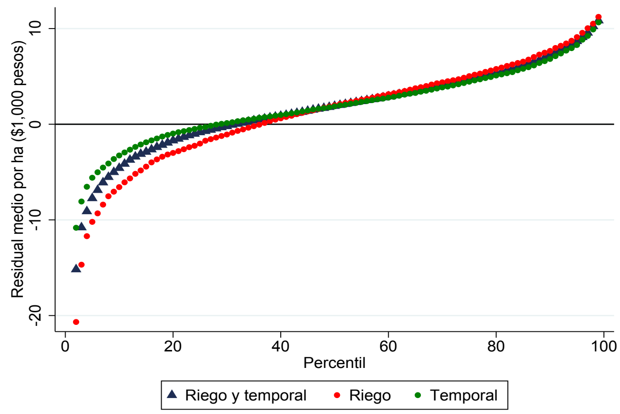


Figure 6-12: Average Residual - wheat (pesos per ha)

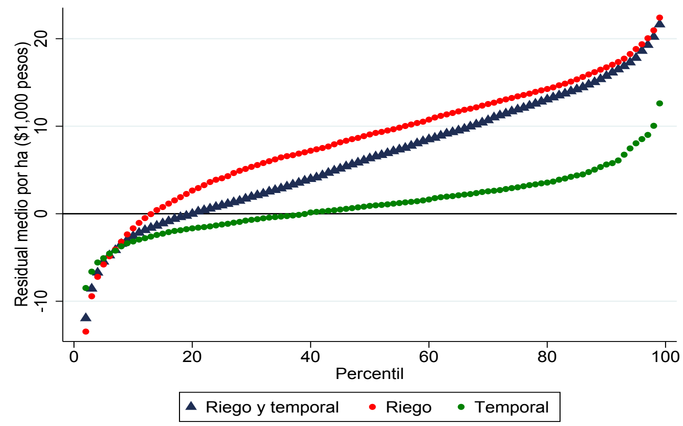


Figure 6-13: Average Residual - soy (pesos per ha)

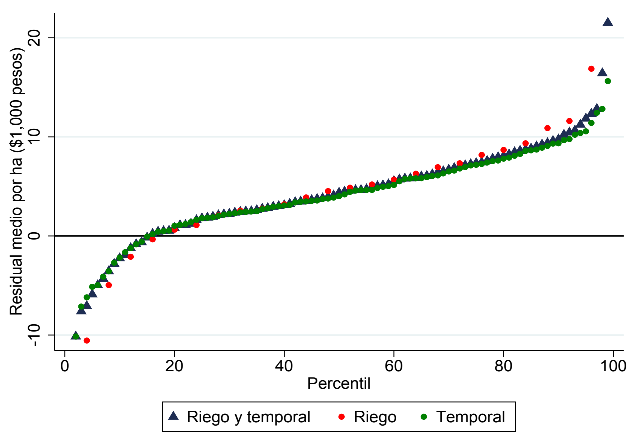
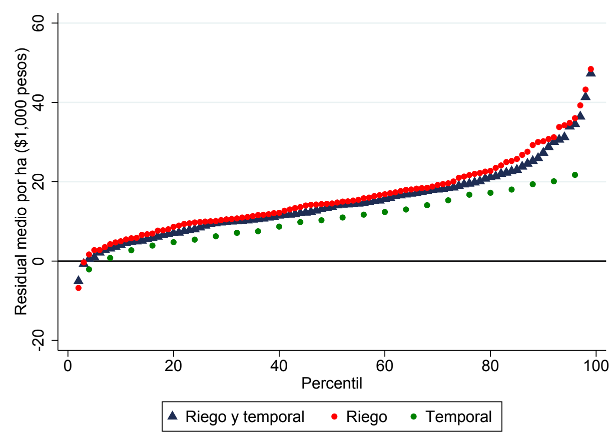


Figure 6-14: Average Residual - rice (pesos per ha)



Source: Prepared by the authors (using data from the National Agricultural Survey (ENA) 2014)

Table 6-6: Average Monetary valuation of ecosystem services per hectare per product with microdata (2013 pesos)

	Cropland	Corn	Bean	Sorghum	Wheat	Soy	Rice
Irrigation and rainfed	8 840	6 569	8 648	4 436	5 236	3 088	12 633
Irrigation	12 487	10 248	9 321	7 101	4 857	3 745	11 775
Rainfed	4 055	1 621	2 419	3 040	5 500	2 789	16 179

Source: Equation (1) based on the National Agricultural Survey (ENA) 2014)

6.2.4.2.6 Identification of the residual using econometric estimation

The estimation of a Neo-Ricardian model[49] of the contribution and identification of ES in the agricultural sector using the unit price method indicates that the ES nutrients[50], soil moisture, and pollination have a positive contribution to the evolution of the residual and that climate, and some of the control variables such as age, years of education[51] or farm subsidies programmes such as PROCAMPO affect the evolution of the residual (Table 6-7: "Neo-Ricardian" type model of the resource rent

Table 6-7: "Neo-Ricardian" type model of the resource rent

Residual (pesos)							
VARIABLES	Cropland	Corn	Bean	Sorghum	Wheat	Soy	Rice
Temperature Spring-summer (°C)	7 101.38***	7 644.52***	-1 017.50	7 044.98***	5 653.18	168 456.14	2 130.09
	(695.63)	(696.17)	(2 190.77)	(1 547.77)	(3 713.16)	(1 073 278.55)	(44 951.48)
Temperature Spring-Summer^2 (°C)	-154.55***	-155.15***	39.76	-135.64***	-82.74	-3 572.03	-468.35
	(13.73)	(13.61)	(44.37)	(29.41)	(64.39)	(20 387.92)	(869.76)
Temperature Autumn-Winter (°C)	-3 782.26***	-4 832.95***	-233.59	-3 883.99***	- 8 253.90***	-88 405.36	23 077.56
	(497.73)	(653.99)	(1 170.30)	(1 185.38)	(2 254.70)	(507 632.93)	(39 430.56)
Temperature Autumn-Winter^2 (°C)	132.73***	113.43***	-3.50	92.35***	197.48***	2 996.41	-160.20
	(13.71)	(15.24)	(30.99)	(28.50)	(63.68)	(12 737.37)	(932.77)
Price Spring-Summer (mm)	129.63*	67.66	-332.87	461.24**	-54.57	-6 759.76	260.88
	(77.61)	(84.33)	(268.58)	(186.93)	(810.36)	(9 422.18)	(2 252.02)
Price Spring-Summer^2 (mm)	-0.41***	0.38**	0.25	-0.81**	1.09	2.29	-2.98
	(0.15)	(0.17)	(0.34)	(0.40)	(3.07)	(20.92)	(2.89)
Price Autumn-Winter (mm)	205.54**	-208.21**	420.06	-108.31	-233.31	20 075.83	-3 728.88
	(99.46)	(87.12)	(288.17)	(208.34)	(1 047.04)	(22 166.76)	(4 579.94)

[49] Ricardian models, estimated with panel or cross-section data, seek to associate land rent differentials with climatic and other factors (Mendelshon, et. al., 1994). In this case, as the variables of the ecosystem services were included the model is named Neo-Ricardian.
[50] Soil nutrients can be an incomplete aggregate indicator as soil averaging does not incorporate heterogeneity and it is better, therefore, to use comparisons with reference conditions (UN, 2014, pp. 65).
[51] This suggests the relevance of factors such as management practices in agricultural production and productivity (UN, 2014, pp. 63).

VARIABLES	Cropland	Corn	Bean	Sorghum	Wheat	Soy	Rice
Price Autumn-Winter^2 (mm)	1.93***	-0.08	-0.42	-1.77***	-1.49	-37.20	10.77**
	(0.33)	(0.18)	(0.67)	(0.59)	(9.13)	(175.72)	(4.30)
Temperature*Price Spring-Summer	-2.00	-4.90	12.96	-15.07**	0.28	221.12	62.09
	(3.16)	(3.72)	(10.80)	(6.98)	(28.17)	(324.80)	(100.31)
Temperature*Price Autumn-Winter	-21.62***	8.12*	-18.90	14.55	-0.77	-712.45	29.04
	(4.61)	(4.30)	(13.73)	(10.17)	(40.98)	(752.87)	(194.50)
Acrisols (% of control area)	34.43	22.90	5.89	90.70**	-595.86		156.05
	(30.70)	(22.60)	(30.89)	(43.88)	(384.32)		(98.58)
Andosol (% of control area)	131.51***	-16.03	-16.47	-9.05	132.69*		966.55
	(22.07)	(11.24)	(30.11)	(145.55)	(77.65)		(791.43)
Psamment (% of control area)	-69.95	-93.28*	-53.60	-91.54			-607 486.57
	(58.63)	(50.01)	(132.18)	(67.36)			(617 207.61)
Cambisols (% of control area)	-19.36**	-9.71	14.90	55.91***	-37.08**		-480.73***
	(8.84)	(8.99)	(22.18)	(16.31)	(18.86)		(159.21)
Kastanozems (% of control area)	24.46***	15.60	6.56	12.38	-8.64		1 125.80
	(9.29)	(14.64)	(21.19)	(9.55)	(22.34)		(758.95)
Chernozem (% of control area)	112.27	60.07	-180.50**	76.63***	-460.08*		
	(112.90)	(111.63)	(86.25)	(26.59)	(249.28)		
Feozem (% of control area)	19.35**	-12.21	-5.25	-33.23***	-20.70	410.22	8.67
	(7.87)	(11.77)	(19.41)	(8.69)	(18.83)	(856.05)	(135.79)
Fluvisols (% of the control area)	336.69***	-21.63	-222.42**	-116.07*	-209.78		1 233.94
	(78.66)	(38.57)	(112.61)	(70.32)	(176.25)		(801.98)
Gleysols (% of control area)	-2.56	-38.68*	174.73*	7.90			822.93**
	(20.68)	(22.96)	(102.16)	(39.56)			(368.42)
Lithosol (% of control area)	-8.28	-4.24	-4.14	-56.30***	71.10	286.30	331.55
	(9.50)	(14.97)	(24.47)	(13.90)	(44.10)	(520.31)	(330.63)
Luvisols (% of control area)	4.91	19.73	42.46	-87.54***	-201.11**		-351.93
	(12.27)	(18.61)	(42.29)	(29.33)	(102.04)		(304.90)
Nitosols (% of control area)	-60.06	-74.11**	115.38	328.91***			1 850 502.29
	(81.69)	(29.90)	(152.26)	(118.81)			(1 878 139.14)
Planosols (% of control area)	-5.49	-30.67***	19.69	-86.01***	-15.76		
	(9.22)	(10.93)	(21.58)	(28.56)	(48.82)		
Ranker (% of control area)	5 351.09***	150.87	2 729.72	2 149.34***	-515.27		
	(1 208.56)	(691.74)	(1 790.88)	(627.51)	(1 557.65)		
Regosol (% of control area)	-2.12	-15.72	-3.61	-36.48***	38.21	-1 118.18	-265.61***
	(8.57)	(9.77)	(17.89)	(13.38)	(27.68)	(2 212.09)	(94.64)
Rendzin (% of control area)	-41.57***	-37.61**	-36.67	-16.51	25.09	1 283.79	103.73
	(9.57)	(14.87)	(22.81)	(12.42)	(62.16)	(2 403.06)	(274.20)

VARIABLES	Cropland	Corn	Bean	Sorghum	Wheat	Soy	Rice
Solonchak (% of control area)	-39.97*	-85.28**	-48.58	20.13	-57.92		-900.98***
	(23.83)	(42.10)	(70.32)	(26.35)	(47.11)		(231.65)
Solonetz (% of control area)	-63.49	-624.45***	-106.34**	-360.29	721.05		
	(59.37)	(148.81)	(50.09)	(529.53)	(878.63)		
Xerosols (% of control area)	25.61***	-22.29**	-11.10	29.15***	-20.56	353.45	
	(7.31)	(10.99)	(20.99)	(8.24)	(22.62)	(710.44)	
Yermosol (% of control area)	53.82	297.38***	196.52*	-96.61	26.50		
	(38.82)	(65.25)	(103.42)	(68.46)	(89.04)		
Years of education	80.48***	149.48***	68.88	-22.83	7.00	298.98	343.81*
	(29.23)	(38.20)	(51.48)	(18.63)	(51.61)	(284.44)	(199.31)
Age	-45.64	111.87	-12.17	-6.76	-33.04	359.20	175.68
	(75.46)	(74.90)	(88.43)	(38.79)	(108.44)	(291.24)	(480.58)
Age^2	0.28	-1.02	0.08	-0.06	0.22	-3.27	-1.26
	(0.63)	(0.64)	(0.77)	(0.34)	(0.98)	(2.61)	(4.17)
Procampo (1 = receives Procampo)	-3 369.92***	-459.34	-1 560.60*	-186.01	614.52	98.55	86.46
	(288.68)	(342.15)	(869.42)	(286.58)	(648.84)	(2 032.12)	(1 554.52)
Distance to the forest (km)	14.98**	27.60***	-3.92	-30.75***	-17.25	-640.85	-358.63*
	(6.25)	(9.33)	(18.88)	(7.67)	(28.78)	(1 600.03)	(186.73)
Distance to the tropical forest (km)	1.30	-10.05*	-1.72	-4.63	-13.38*	344.44	-387.21*
	(2.29)	(5.20)	(12.68)	(6.56)	(8.05)	(1 073.05)	(224.90)
Distance to arboreous secondary vegetation (km)	13.86**	-16.04*	18.22	13.02	-1.62	626.24*	1 356.37**
	(6.43)	(9.63)	(22.18)	(9.82)	(16.01)	(339.70)	(554.04)
Distance to herbaceous secondary vegetation (km)	9.73***	24.08***	8.99	8.70**	-18.38*	-318.47	80.57
	(2.73)	(4.67)	(9.00)	(3.46)	(9.40)	(656.27)	(138.54)
Distance to shrub secondary vegetation (km)	194.24***	173.33***	-322.07**	54.44	-83.00	604.54	1 452.51
	(41.77)	(65.22)	(132.25)	(38.85)	(169.96)	(4 550.67)	(900.72)
Tractors (1 = own tractors)	2 169.13***	1 540.97***	580.66	16.12	214.20	4 298.88**	1 885.13
	(397.93)	(346.08)	(581.45)	(241.96)	(552.29)	(1 945.02)	(2 400.19)
Machinery (1 = own machinery)	875.09***	1 924.83***	709.09	626.67**	548.87	137.67	-310.09
	(318.82)	(377.79)	(537.89)	(248.08)	(444.95)	(2 969.05)	(3 426.99)
Vehicles (1 = own vehicles)	1 708.59***	207.10	120.61	62.99	-668.70	-7 384.14	4 542.60
	(257.97)	(262.00)	(394.16)	(242.40)	(557.25)	(5 656.57)	(2 995.32)
Distance to nearest town (km)	-23.88	-154.33***	-93.98	-22.09	-76.26	-829.45	954.68**
	(28.59)	(28.32)	(57.99)	(21.32)	(64.30)	(2 813.20)	(378.22)
Distance to perennial body of water (km)	-15.47*	-37.86***	-15.01	30.79***	-36.84*	-655.34	-118.04
	(8.98)	(8.05)	(15.75)	(11.76)	(22.34)	(432.36)	(110.50)

VARIABLES	Cropland	Corn	Bean	Sorghum	Wheat	Soy	Rice
Distance to the nearest perennial river (km)	-21.48***	-7.20	-14.77	24.14**	24.32	-470.86	449.49***
	(5.97)	(8.29)	(13.01)	(9.86)	(27.17)	(457.61)	(132.41)
Planted area	-3.57***	13.01***	42.08***	-1.98	-6.26*	2.41	-58.92***
	(0.44)	(4.72)	(14.56)	(1.96)	(3.55)	(9.73)	(21.35)
Planted area^2	0.00***	-0.01***	-0.10***	0.00*	0.00	-0.01	0.04**
	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.01)	(0.02)
Constant	-51 675.27***	-39 735.22***	13 435.30	-55 017.00***	15 856.61	-1492761.66	-198 713.59
	(6 294.54)	(5 396.16)	(16 519.94)	(12 703.77)	(43 528.95)	(9 271 681.73)	(252 612.12)
Fixed effects per crop	Yes	No	No	No	No	No	No
Remarks	85 936	31 262	5 395	4 002	2 761	226	244
R^2	0.151	0.198	0.178	0.254	0.262	0.168	0.560

Note Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.   Source: Prepared by the authors (using data from the ENA, 2014)

6.2.5 Discussion

6.2.5.1 Conclusions

The valuation study for selected agricultural crops showed that the contribution of these ES is significant, yet it requires subsequent analysis to explain the volatility and heterogeneity of the values obtained for different crops. This suggests that ES are used in a differentiated manner in different types of crops by different types of producers. Furthermore, the monetary value of the contribution of the ES basket to agricultural production shows relevant regional differences. As an example, the contribution of ES to maize and bean crops is distributed throughout the country while other crops tend to be concentrated in the north and centre of the country. The contribution of ES to agricultural production summarized in Table 6-8 reveals that there is a close interrelation between ES and the characteristics and conditions of agricultural production (small or large producers or irrigated or rainfed crops). Therefore, it is relevant to formulate public policies that differentiate between socioeconomic groups, types of agricultural producers, and by regions.

6.2.5.2 Recommendations

It is necessary to deepen the analysis to identify the components included in the method of the unit resource rent price of ES for the provision of crops

The presence of relevant differences in the forms of use and appropriation of ES per producer type, production conditions and product type, suggests the usefulness of incorporating the monetary value of ES in public policy discussions.

Deepen the analyses of ES based on microdata to better identify the behaviours of economic agents in reference to ES.

Delve into the analyses of a non-linear relationship between physical and monetary flows, and the relative independence of the monetary valuation of ES of various economic, social and public policy factors

Table 6-8: Monetary valuation of the contribution of ecosystem services to an agricultural product and selected products as a percentage of agricultural production value, GDP, and value per hectare

	Agricultural production		Corn		Wheat		Bean		Soy		Sorghum		Rice	
AGGREGATE ESTIMATE (AVERAGE 1993-2018)	**R**	**RN**	**R**	**RN**	**R**	**RN**	**R**	**RN**	**R**	**RN**	**R**	**RN**	**R**	**RN**
Monetary contribution of ES (billions of pesos)	140.72	86.36	20.19	10.83	3.72	2.34	4.23	2.61	0.29	0.15	4.92	2.72	0.43	0.27
Share in agricultural production value (%)	37.78	22.64	30.55	15.41	35.10	19.96	38.51	23.38	27.54	12.41	30.78	15.64	41.00	25.87
Value per hectare (pesos)	6 500	3 982	2 546	1 385	5 072	3 194	2 251	1 412	1 887	907	2 585	1 426	6 976	4 491
Percentage in GDP (%)	0.994	0.594	0.141	0.072	0.026	0.015	0.031	0.018	0.002	0.001	0.035	0.019	0.003	0.002
ESTIMATION WITH MICRODATA (ENA 2014)														
Value per hectare (2013 pesos)	8 840		6 569		8 648		4 436		5 236		3 088		12 633	
Irrigation (pesos	12 487		10 248		9 321		7 101		4 857		3 745		11 775	
Without irrigation (pesos)	4 055		1 621		2 419		3 040		5 500		2 789		16 179	
Monetary contribution of ES with microdata (Billions of pesos)	187.06		46.38		4.64		11.04		1.35		13.23		0.27	
Percentage in GDP (%)	1.11		0.275		0.028		0.065		0.008		0.078		0.002	

Notes: R = unit rent and RN = net rent
Source: Prepared by the authors

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6.3 Provision of carbon storage and sequestration regulating service

KEY MESSAGES:

- *The monetary valuation of the final regulating service of carbon capture (sequestration) and storage is fundamental in Mexico and for global climate change policy as a whole.*
- *The monetary valuation of the carbon storage and sequestration service can be realized in a robust accounting framework based on the concept of monetary assets and flows. This valuation is consistent with the design of public policies on climate change, with asset accounting and the new ecosystem accounting.*
- *The monetary valuation of the carbon regulating service is sensitive to the selected values of the carbon price and interest rate. Thus, it shows that climate change negotiations can impact the monetary value of the service and can subsequently even contribute to an improvement in the physical condition of ecosystems.*
- *The estimate of the average annual monetary value of the carbon storage and sequestration service, with a price of USD25 per ton of CO2 and a 2 per cent interest rate, between 2007-2014, in biomass is 0.309 per cent of GDP in 2013 and 0.315 per cent of GDP in 2014 and in organic carbon in soils is 1.33 per cent of GDP in 2013 and 1.35 per cent of GDP in 2014. Hence, the aggregate monetary value of the annual service of carbon storage and sequestration in biomass and soils, between 2007-2014, is 1.64 per cent of GDP in 2013 and 1.67 per cent of GDP in 2014.*
- *The decomposition of the evolution of carbon sequestration in biomass and soils shows a differentiated behaviour. The study of carbon in biomass showed differentiated behaviour between primary and secondary vegetation.*
- *The geo-referencing of the monetary value of the carbon regulating service shows the highest values in the south and west of the country.*

6.3.1 Introduction

Climate change, a consequence of greenhouse gas emissions (GHG), has negative impacts on economic activities, social welfare, as well the environment and on ecosystems. In this regard, climate change is, from an economic perspective, a global negative externality that puts at risk a global public good such as climate (IPCC, 2014; Stern, 2006). In this context, vegetation, and soils capture (sequestration) and accumulate (storage) carbon stocks, through photosynthesis and other biological processes, which are expressed in tons of carbon per given area per year (tC/ha/yr).[52] Such carbon sequestration and storage are a regulating service of ecosystems to economic and human activities by reducing the negative impacts of climate change. Thus, the purpose of this chapter is to estimate the monetary value of the final regulating service of carbon capture (sequestration) and storage in Mexico.

6.3.2 Data and methods

6.3.2.1 Sources of information

The information used corresponds to:

- The information on carbon in living aerial biomass corresponds to the 2004-2009 and 2009-2014 sampling cycles and refers to the relevant area of 2007 and 2014 (CONAFOR, 2018). That is, it corresponds to the total stocks estimated

[52] The term CO_2e (CO_2 equivalent) corresponds to 0.27 (12/44) carbon units, i.e., the amount of CO_2 can be expressed in terms of carbon and the amount of carbon it contains results from multiplying the amount of CO_2 by 0.27 (12/44). For instance, 1 kg of CO_2 can be expressed as 0.27 kg of carbon, since this is the amount of carbon in CO_2 (1kg of carbon equals (44/12) kg of CO_2).

with data from the INFyS sampling cycle 2004-2009 referring to the 2007 area, reported in Series IV of the LUVC of INEGI and the total stocks made with INFyS data for the period 2009-2014 with reference to the relevant 2014 area corresponding to Series VI of the Land Use and Vegetation Chart of INEGI. To provide a more appropriate value, "a distinction is made between the primary and secondary successional vegetation phases, which reflects more accurately the productivity of ecosystems" (CONAFOR, 2018, pp. 150).

- The information on Soil Organic Carbon (SOC) corresponds to the estimates harmonized by Paz-Pellat et al. (2016) using the FAO FRA Mexico Report estimates from Series II (1993), III (2002), and IV (2007) (CONAFOR, 2010) to generate multi-temporal estimates of SOC in Mexican ecosystems, corresponding to Series V (2011) and VI (2014). To generate the estimates of this last Series (2014), the same procedures and methodologies used by INEGI for the development of Series II, III, IV, and V[53]were used. Soil Organic Carbon (SOC) at a depth of 0-30 centimetres is considered, corresponding to approximately 50 per cent of the accumulated carbon estimated for one-metre depth (Paz Pellat, et al. 2016).[54] This is consistent with IPCC Guidelines for National Greenhouse Gas Inventories (2006), which recommends using estimates for carbon storage in soils for 0 to 30 cm depth (Paz Pellat and Etchevers, 2016).

The geo-referenced information is obtained given that:

- Using the biomass and soil carbon storage and sequestration volumes reported in the National Forest Inventory and Paz-Pellat, et al. (2016, 2012, 2010) correspondingly, the average value per hectare of carbon storage and sequestration services was calculated for each of the vegetation types.
- Interest rates of 2 per cent and 4 per cent and social carbon costs of US $ 25 and US $ 30 per tonne of carbon were used to calculate the value per hectare.
- An exchange rate of 13.3 Mexican pesos to USD1 dollar was used.
- The implicit price index, or GDP deflator, was used to obtain the values in 2013 prices.
- The values obtained in the previous steps were associated with the corresponding land and vegetation uses in the Soil and Vegetation Use Chart Series VI published by INEGI.

6.3.2.2 Method

The overall ecosystem carbon service corresponds, firstly, to the carbon storage service in trees, grasses, plants, vegetation and soils corresponding to the retention or avoided flux of carbon into the atmosphere as a consequence of maintaining the sequestered carbon stock (UN, 2014, pp. 65) and, secondly, the carbon capture or sequestration service corresponding to the process where CO_2 is captured from the atmosphere and stored in forests, vegetation and soils and representing the net carbon accumulation in the ecosystem (UN, 2014, pp. 65). Therefore, carbon sequestration and storage are considered regulating services[55], final or final/intermediate ES contributing to the

[53] Inorganic Carbon in Soils (CIS) is not included (Paz Pellat and Etchvers, 2016a).
[54] The errors in the estimates between 0 and 30 cm. using the IPCC Tier 1 method, are less than 10% (Paz and Pellat, et al., 2016).
[55] The service corresponds to long-term carbon storage and sequestration and therefore does not include short carbon cycles (Horlings, et al., 2019a).

reduction of the potential negative effects of climate change (UN, 2019, pp. 79, Horlings, et al., 2019a).

The monetary valuation of the carbon storage and sequestration service has as its accounting framework that the carbon stored at $t-1$ plus the net carbon sequestered in the period between t and t-1 corresponds to the total carbon stored at t (equation (4)):

(4) $$C_t = C_{t-1} + \Delta C_t$$

Where, C_t represents the total carbon stored at t, C_{t-1} is the carbon stored at $t-1$ and ΔC_t is the net carbon sequestration between $t-1$ and t.

The monetary valuation of the carbon service, including carbon storage and sequestration, considers the annual monetary value of carbon storage in the period $t-1$ (considering the annual interest rate flow) and the monetary value of carbon sequestration in the period t (equation (5)). This intends to incorporate the adjustments corresponding to an environmental asset:

(5) $$VTC_t = VAC_{t-1} + V\Delta C_t$$

Where VTC_t represents the total monetary value of the joint carbon capture and storage service, $VAC_{t;1}$ is the monetary value of carbon storage, and $V\Delta C_t$ is the monetary value of carbon sequestration. With (Edens, *et al*., 2019):

(6) $$VAC_t = r_t * (C_t * PC)$$

Where r_t represents the interest rate. The rates used in this study correspond to:

- Social discount rate: 2 per cent per year.
- Market interest rate: per cent per year.

This method of estimating the carbon service allows:

- Consistency with public policy strategies on climate change arising, for instance, from the Paris Agreement.
- Consistency with the capital asset theory and its flows.
- Incorporating the entire ecosystem in the monetary valuation of the carbon service.

The sources of changes in carbon sequestration can furthermore be identified from equations (7.a) and (7.b):

(7.a) $$\Delta C_{Bt} = \alpha_{Bt-1}(BIO_t - BIO_{t-1}) + (\alpha_{Bt} - \alpha_{Bt-1})BIO_t$$

(7.b) $$\Delta C_{St} = \alpha_{St-1}(SUE_t - SUE_{t-1}) + (\alpha_{St} - \alpha_{St-1})SUE_t$$

Where the biomass to carbon ratios are defined as:

(8.a.) $$\alpha_{Bjt} = \left[\frac{C_{jt}}{BIO_{jt}}\right]$$

(8.b) $$\alpha_{Sjt} = \left[\frac{C_{jt}}{SUE_{jt}}\right]$$

Where BIO_{jt} represents the biomass in the different types of forests and vegetation, SUE_{jt} the soil type that is associated with different levels of organic carbon storage and α_{Bjt} and α_{Sjt} correspond to the carbon coefficients contained in each type of forest and vegetation for biomass (B) and soils (S). The sub-indexes correspond to the time t and $t-1$ and j to the type of vegetation or soils.

6.3.3. Results

6.3.3.1 Physical flows

Available information indicates that carbon stored in biomass increased from 1 299.7 million tons of carbon (tC) in the 2004-2009 cycle to 1 420.5 million tC in the 2009-2014 cycle (CONAFOR, 2018, pp. 83). As such, carbon sequestration increased by 122.4 million tC, with a net increase of 120.75 million tC in forest areas, due to a net loss in semi-arid and other forest areas of 1.6 million tC (CONAFOR, 2018, pp. 152) (Table 6-9) This increase is heterogeneous across vegetation types.

Table 6-9: Aggregate carbon stocks and sequestration in primary and secondary vegetation (million tonnes).

Cycle	Primary vegetation	Secondary vegetation	Total stock
2009-2014	802.11	618.36	1 420.47
2004-2009	766.16	533.56	1 299.72
Sequestration: 2009-2014 minus 2004-2009	**35.95**	**84.80**	**120.75**
Annual sequestration 2007-2014 (average)	**5.14**	**12.11**	**17.25**

Notes: 2004-2009 and 2009-2014 cycles use 2007 and 2014 land area and land use information, correspondingly. The annual carbon sequestration estimate is obtained by dividing the total carbon sequestration by the number of years in the period 2007-2014.[56]
Source: Prepared by the authors (based on CONAFOR, 2018; pp. 154-155)

The available information allows estimating that the total organic carbon stock (SOC) in soils in 2014 is 9 152.47 million tC and the carbon sequestration in soils is estimated at 24.46 million tC between 2007 and 2014 with a relevant heterogeneity per soil type (Table 6-10)

Table 6-10: Aggregate carbon stocks and sequestration in soils

	2007	2014	2014-2007
Total carbon stock (million tons)	9 128.01	9 152.47	
Carbon sequestration 2007-2014 (millions of tons)			24.46
Annual carbon sequestration (average millions of tons)			3.49
Total stored carbon (ton/ha)	46.97	47.10	

Source: Prepared by the authors (based on Paz Pellat, 2016)

The analysis of sequestration based on equation 7.a reveals that the increase in carbon sequestration between 2007 and 2014 is associated with an increase in biomass during the same period, whilst, at the same time a reduction in carbon sequestration capacity has taken place. This is the case in all types of forests and vegetation, with some exceptions, such as lowland forests and semi-arid areas in which the sequestration of carbon increased on account of an increment in biomass albeit a reduction in the storage capacity was observed (Table 6-11, Table 6-12) (Figure 6-15, Figure 6-16) (CONAFOR, 2018, pp. 146-151).

[56] See also SEMARNAT-INEC (2006) and (2009) and Sánchez-Colon (2019).

Table 6-11: Changes in biomass and carbon sequestration coefficients in primary and secondary vegetation (million tons and coefficients)

Forestry formation	Changes between cycles 2004-2009 and 2009-2014		Biomass carbon sequestration coefficients		
	Change in biomass	Carbon sequestration	α_t	α_{t-1}	α_t-α_{t-1}
Primary	109.78	35.95	0.4509	0.4590	-0.0081
Secondary	187.37	84.80	0.4537	0.4539	-0.0002
Total	**297.16**	**120.75**	**0.4521**	**0.4569**	**-0.0048**

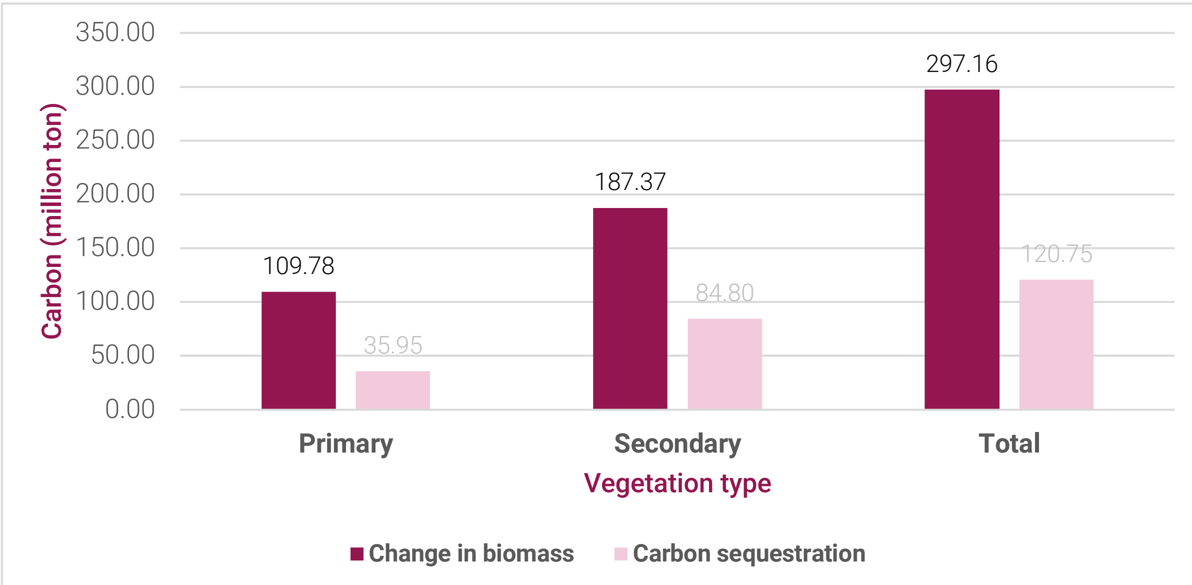
Source: Prepared by the authors (based on information from CONAFOR, 2018)

Table 6-12: Coefficients in biomass and carbon sequestration (equation (7.a)

Ecosystem	Forestry formation	Changes between 2004-2009 and 2009-2014 cycles		Carbon sequestration coefficients in biomass		
		Change in biomass (million tons)	Carbon sequestration (million tons)	α_{Bt}	α_{Bt-1}	α_{Bt}-α_{Bt-1}
Forest	Coniferous	26.32	12.41	0.4727	0.4728	-0.0001
	Coniferous and broadleaved	51.10	23.37	0.4675	0.4683	-0.0008
	Broadleaved	29.10	13.13	0.4579	0.4584	-0.0005
	Montane-cloud forest	16.80	7.66	0.4675	0.4690	-0.0015
Tropical forests	High and medium tropical forests	112.76	36.35	0.4277	0.4446	-0.0169
	Lowland tropical forests	62.61	28.16	0.4417	0.4403	0.0014
Other associations		0.00	0.00	NA	NA	NA
Mangrove		2.99	1.28	0.4356	0.4364	-0.0008
Subtotal arboreal		301.69	122.36	0.4524	0.4576	-0.0053
Xeric shrubland	Semi-arid zones	-9.74	-3.88	0.4354	0.4310	0.0044
	Arid zones					
Other forest areas		5.22	2.27	0.4576	0.4592	-0.0015
Total forestry		**297.16**	**120.75**	**0.4521**	**0.4569**	**-0.0048**

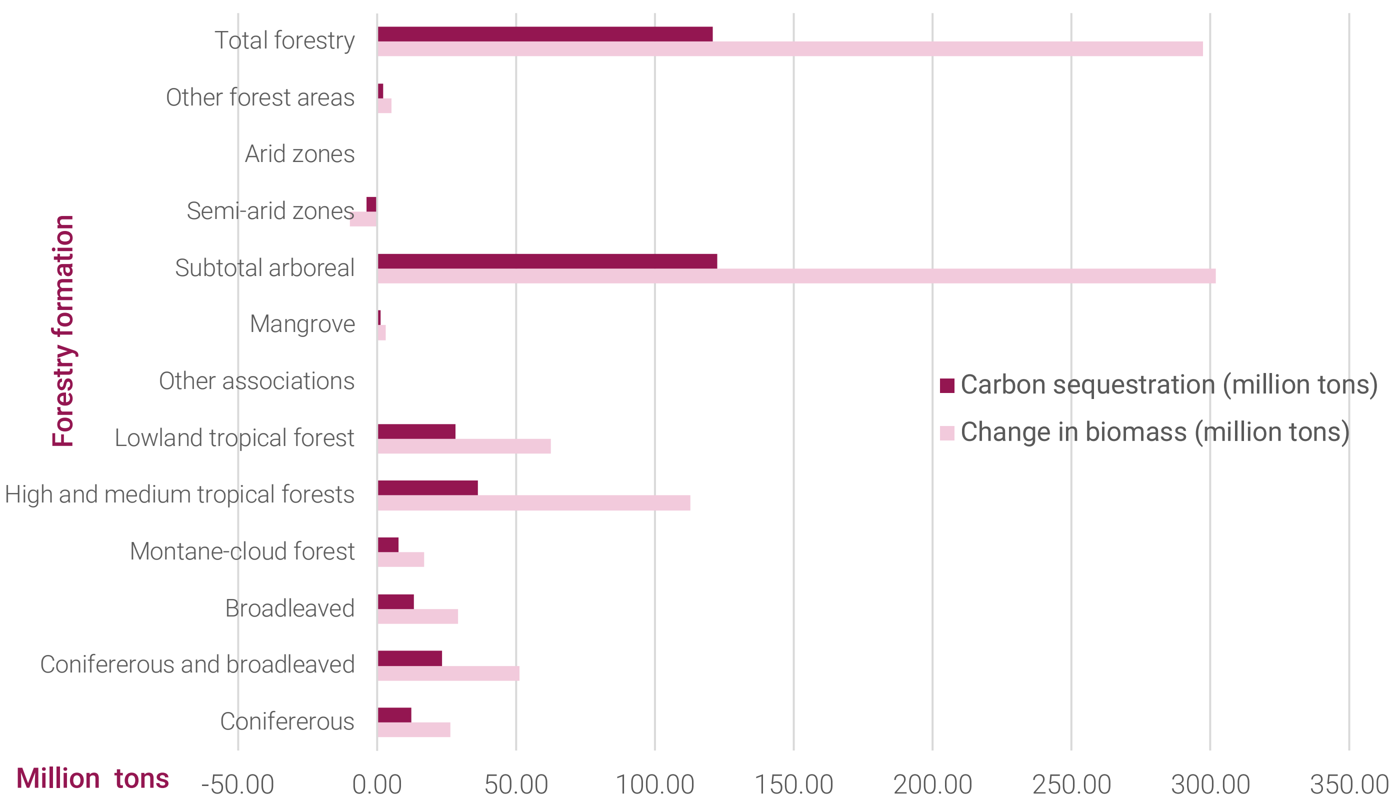
Source: Prepared by the authors (based on information from CONAFOR, 2018)

Figure 6-15: Changes in biomass and carbon sequestration coefficients by primary and secondary vegetation



Source: Prepared by the authors (based on CONAFOR, 2018)

Figure 6-16: Changes in biomass and carbon sequestration coefficients



Source: Prepared by the authors (based on information from CONAFOR, 2018)

Table 6-13: Coefficients of soil organic carbon (SOC) and carbon sequestration (equation (7.b)

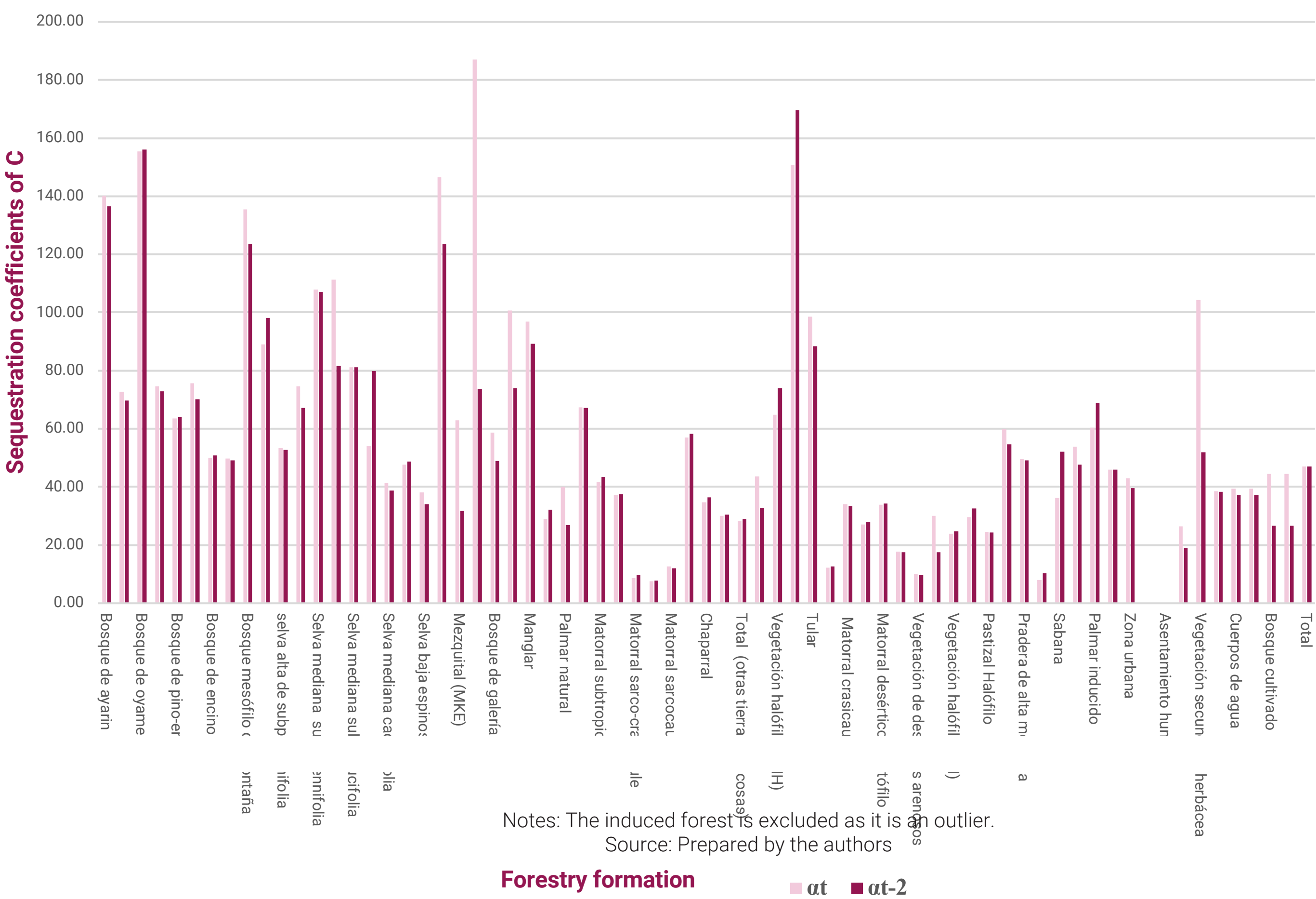
Ecosystem	Forestry formation	Carbon sequestration coefficients in soils		
		α_{St}	α_{st-1}	$(\alpha_{St} - \alpha_{st-1})$
Forests	Douglas-fir forest	140.125	136.612	3.513
	Cedar forest	72.764	69.732	3.032
	Oyamel fir forest	155.428	155.997	-0.569
	Pine forest	74.590	72.825	1.765
	Pine-oak forest	63.549	63.963	-0.415
	Juniper forest	75.599	70.104	5.494
	Oak forest	50.028	50.806	-0.778
	Oak-pine forest	49.833	49.171	0.662
	Montane-cloud forest	135.558	123.630	11.928
	High evergreen tropical forest	88.960	98.270	-9.310
	High semi-evergreen tropical forest	53.516	52.749	0.767
	Medium evergreen tropical forest	74.545	67.273	7.273
	Medium semi-evergreen tropical forest	107.890	107.058	0.833
	Low evergreen tropical forest	111.298	81.595	29.703
	Medium semi-deciduous tropical forest	81.093	81.224	-0.132
	Low semideciduous tropical forest	53.970	79.838	-25.868
	Medium deciduous tropical forest	41.368	38.673	2.696
	Low deciduous tropical forest	47.709	48.674	-0.965
	Low thorny tropical forest	38.100	34.022	4.078
	Low semi-evergreen tropical forest	146.480	123.706	22.774
	Mezquital (MKE)	62.863	31.804	31.059
	Gallery tropical forest	186.959	73.867	113.092
	Gallery forest	58.678	48.950	9.728
	Petén	100.626	74.038	26.589
	Mangrove	96.795	89.276	7.519
	Mezquital (MK)	29.071	32.153	-3.082
	Natural palm grove	40.018	26.941	13.077
	Induced forest	625.000	47.222	577.778
	Total (forests)	67.442	67.125	0.318
Other wooded lands	Coniferous shrubland	0.000	69.155	-69.155
	Subtropical shrubland	41.659	43.522	-1.863
	Tamaulipan thorny shrubland	37.356	37.539	-0.182
	Sarco-crasicaule shrubland	8.722	9.766	-1.044
	Mist sarco-crasicaule shrubland	7.501	7.834	-0.332
	Sarcocaule shrubland	12.688	12.144	0.544
	Submontane shrubland	57.093	58.286	-1.194
	Chaparral	34.765	36.342	-1.577
	Mezquital (MKX)	30.058	30.515	-0.457
	Total (other wooded lands)	28.463	28.988	-0.525

Other lands	**Gallery vegetation**	**43.572**	**32.885**	**10.688**
	Halophytic vegetation (VHH)	64.767	74.032	-9.265
	Thalia geniculata	150.837	169.634	-18.797
	Tule forest	98.630	88.399	10.232
	Coastal dunes vegetation	12.311	12.647	-0.336
	Crasicaule shrubland	34.138	33.574	0.564
	Microphyll desert shrubland	27.020	27.878	-0.858
	Desert rosette shrubland	33.803	34.220	-0.417
	Coastal rosette shrubland	17.844	17.536	0.308
	Sandy deserts vegetation	10.115	9.671	0.444
	Gypsum vegetation	29.976	17.598	12.378
	Halophytic vegetation (VH)	24.019	24.672	-0.653
	Natural grassland	29.692	32.651	-2.958
	Halophytic grassland	24.519	24.336	0.183
	Gypsum grassland	60.048	54.710	5.338
	High-mountain meadow	49.660	49.235	0.425
	Sabanoid	7.943	10.351	-2.408
	Savannah	36.161	52.135	-15.974
	Induced grassland	53.854	47.602	6.253
	Induced palm grove	60.492	68.836	-8.344
	Agricultural - livestock - forestry information	46.033	46.032	0.001
	Urban area	43.040	39.655	3.385
	Area deprived of vegetation	0.000	0.000	0.000
	Human settlement	0.000	0.000	0.000
	Area without apparent vegetation	26.536	19.029	7.506
	Secondary herbaceous vegetation	104.227	51.845	52.382
	Total (other lands)	38.480	38.378	0.102
Water bodies	Water bodies	39.350	37.269	2.082
	Total (water bodies)	39.350	37.269	2.082
Planted forest	Planted forest	44.527	26.716	17.811
	Total (planted forest)	44.527	26.716	17.811
Total	Total	47.101	46.975	0.126

Notes: The coefficients correspond to the periods 2007 and 2014.
Source: Prepared by the authors (based on information from INEGI, 2016)

The organic carbon sequestration capacity increased in most soil types, although with heterogeneous behaviour and some exceptions (equation (7.b) (Table 6-13, Figure 6-17)

Figure 6-17: Carbon sequestration coefficients in soils- 2014-2007



Notes: The induced forest is excluded as it is an outlier.
Source: Prepared by the authors

6.3.3.2 Monetary valuation

6.3.3.2.1 Monetary valuation at the national level

The monetary valuation of carbon sequestration and storage is based on a price per ton of carbon of USD25 /tCO_2 derived from the meta-analysis of Alatorre, et al. (2019) and an alternative scenario of a price per ton of CO_2 of USD30/tCO_2 reflecting the average price, in the more recent literature (Howard and Sterner, 2017).

Table 6-14: Estimates of the Social Cost of Carbon (SCC) with a meta-analysis - random effects

Parameter	Total	Rate 1	Rate 2	Rate 3	Rate 4
M	US $ 25.83	US $ 100.63	US $ 16.47	US $ 30.14	US $ 6.29
Confidence interval	[24.99-26.67]	[42.96-158.30]	[15.72-17.22]	[17.15-43.18]	[4.08-8.50]
Heterogeneity tests					
τ^2	3.25***	0.0003***	1.71***	421.7***	0.00
Q-stat	37 477***	9 914***	19 520***	2 131***	14.03
I^2	0.99***	0.99***	0.99***	0.97***	0.00
N	232	62	75	58	31

Note: *** denotes rejection of the null hypothesis with 99 per cent confidence. Q-Stat refers to the Q-statistic of the homogeneity test (Cooper, et al., 1994), I^2 measures the proportion of the total variation that is due to heterogeneity (Cooper, et al., 1994), and N represents the number of studies in the sample. H0: All studies in the sample share a common population mean. Rate 1 corresponds to discount rates between 0 and 0.3 per cent, Rate 2 corresponds to discount rates between 1 and 1.5 per cent, Rate 3 corresponds to rates between 2 per cent and 3.5 per cent, and Rate 4 corresponds to discount rates higher than 4 per cent. The results are referenced in USD. There are no identified studies in the intervals without rates.
Source: Alatorre, et al. (2019)

The monetary value of the annual biomass carbon storage and sequestration and Soil Organic Carbon (SOC) service, with US$25 and an interest rate of 2 per cent per year, is equivalent to 0.308 per cent of 2013 GDP and 0.315 per cent of 2014 GDP[57] and 1.33 per cent of 2013 GDP and 1.35 per cent of 2014 GDP, correspondingly (Table 6-15). Lastly, the aggregate monetary value of carbon storage and sequestration is 266 254 million pesos of 2013 corresponding to 1.64 per cent of 2013 GDP and 1.67 per cent of 2014 GDP at US$25 /tCO2 and 2 per cent annual interest rate (Table 6-). This indicates that the monetary value of carbon storage and sequestration is relevant to the Mexican economy. Indeed, using a price of US$30/tCO2 and a 4 per cent annual interest rate leads to a value of 3.75 per cent of 2013 GDP.

Table 6-15: Monetary value of carbon storage and sequestration service in living aboveground biomass and soil organic carbon (millions of pesos; 2014)

	Storage		Sequestration		2007-2014	
	Value (millions of pesos)	of GDP (%)	Value (millions of pesos)	of GDP (%)	Value (millions of pesos)	of GDP (%)
25 tCO2 dollars and a 2% rate						
Storage plus sequestration (annual)	254 262.92	1.52	25 290.11	0.15	279 553.03	**1.67**
25 tCO2 dollars and a 4% rate						
Storage plus sequestration (annual)	508 525.85	3.04	25 290.11	0.15	533 815.96	**3.19**
30 tCO2 dollars and a 2% rate						
Storage plus sequestration (annual)	305 115.51	1.82	30 348.13	0.18	335 463.64	**2.00**

[57] The exchange rate reported by INEGI is used to exchange from US dollars to Mexican pesos,13.3 MXN per USD.

30 tCO2 dollars and a 4% rate						
Storage plus sequestration (annual)	610 231.02	3.64	30 348.13	0.18	640 579.15	**3.83**
Values in pesos in 2013 and as a percentage of 2013 GDP						
25 tCO2 dollars and a 2% rate						
Storage plus sequestration (annual)	242 166.94	1.49	24 086.99	0.15	266 253.93	**1.64**
25 tCO2 dollars and a 4% rate						
Storage plus sequestration (annual)	484 333.88	2.98	24 086.99	0.15	508 420.87	**3.12**
30 tCO2 dollars and a 2% rate						
Storage plus sequestration (annual)	290 600.33	1.79	28 904.39	0.18	319 504.71	**1.96**
30 tCO2 dollars and a 4% rate						
Storage plus sequestration (annual)	581 200.65	3.57	28 904.39	0.18	610 105.04	**3.75**

Source: Prepared by the authors

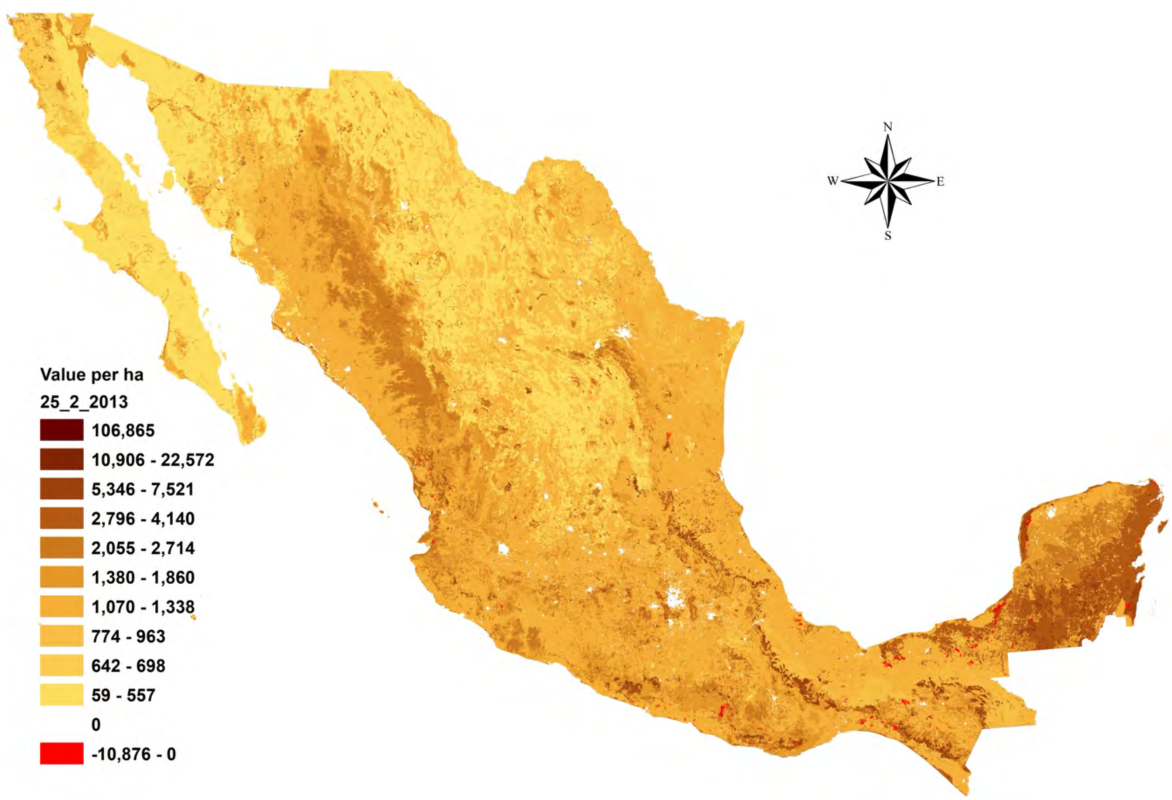
6.3.3.2.2 Monetary valuation of carbon storage and sequestration: A geo-referenced view

The geo-referenced monetary value[58] of carbon service storage and sequestration in living biomass and organic carbon in soils, with US$25 tCO_2 and 2 per cent interest rate, per vegetation and forest type for 2007 and 2014 are presented at Map 6-13 and Map6-14. The geo-referenced monetary valuation shows a high value of carbon storage and sequestration mainly in southern and western Mexico in both biomass and soils. This demonstrates the environmental and economic relevance of ecosystems in this region and the importance of their preservation for regional development.

[5858] The INEGI classification includes 58 different vegetation types that are aggregated, for comparison and management purposes, into 14 vegetation types, of which 12 can be separated into primary vegetation or secondary vegetation, five land use types and two auxiliary classes.

Map 6-13: Value of annual biomass carbon storage and sequestration service (2013 pesos per ha) US $ 25 and a 2% discount rate

Map6-14: Value of annual soil organic carbon storage and sequestration service (2013 pesos per ha) US$25 and a 2% discount rate



6.3.4 Discussion

6.3.4.1 Conclusions

Climate change is conceptualized as a global negative externality that puts a global public good such as the climate at risk. Thus, carbon storage and sequestration represent a regulating service (intermediate and/or final) of ecosystems by reducing the negative impacts of climate change.

The estimate of the annual monetary value of the carbon storage and sequestration service, at US$25 per ton of CO_2 and 2 per cent interest rate, between 2007-2014, in biomass is 0.309 per cent of 2013 GDP and 0.315 per cent of 2014 GDP and in soil organic carbon 1.33 per cent of 2013 GDP and 1.35 per cent of 2014 GDP. Hence, the joint monetary value of the annual service of carbon storage and sequestration in biomass and soils, between 2007-2014, is 1.64 per cent of GDP in 2013 and 1.67 per cent of GDP in 2014. This monetary value increases significantly using USD30/tCO_2e and a 4 per cent interest rate.

The monetary value of the annual carbon storage and sequestration service is particularly sensitive to the social cost of carbon and interest rate assumptions. This suggests the presence of non-linear, dual-channel causality between the physical and monetary flows of ecosystems, and relative independence of monetary valuation from physical conditions.

6.3.4.2 Recommendations

Incorporating carbon storage and sequestration into monetary valuation allows:

Consistency with public policy strategies on climate change arising, for instance, from the Paris Agreement.

Consistency with the capital asset theory and its flows.

Incorporation of the entire ecosystem in the carbon service in the monetary valuation.

However, the monetary value of the annual carbon storage and sequestration service is particularly sensitive to the social cost of carbon and interest rate assumptions.

6.3.4.3 Areas of opportunity

Existing evidence indicates that further work is needed on accounting for the physical flows of carbon storage and sequestration. This is essential, for instance, to develop a strategy where forests can be incorporated into a mechanism to purchase offsets for other economic activities.

6.4 Pollination services

KEY MESSAGES:

Existing evidence shows that animal pollination services and therefore their potential loss is relevant for agricultural production in Mexico. The monetary value at the municipal level of potential pollination service demand represents 12.09 per cent of the agricultural production value in 2013 and, on average, 12.73 per cent of agricultural production between 2003-2018. Estimations based on the ENA 2014 report similar results with a monetary value of the demand for animal pollination service accounting for 11.48 per cent of agricultural production in 2014. At the aggregate level the average potential provision of animal pollination, for 2013, is 7.74 per cent of agricultural production and represents, on average for the period 2003-2017, 8.15 per cent of the gross agricultural production value. Moreover, the monetary contribution of pollination service, derived from pollination provision adjusted for proximity to habitats, in 2013, is 32 277 million 2013 pesos corresponding to 7.74 per cent of the Value of Agricultural Gross Production and, on average between 2003-2018, 0.21 per cent of total GDP (Table 6-18).

Such results demonstrate that there is a persistent deficit of potential pollination supply compared with potential demand for pollination as a consequence of the current agricultural development practices

There are also forms and capacity of appropriation of the monetary contribution of animal pollination services in agricultural production differentiated per producer and/or production type. This should be considered in the development of public agricultural and social policies.

These estimates demonstrate that the monetary contribution of pollination ES shows volatility that is associated in part with changes in the agricultural production structure. For instance, the increasing economic relevance of crops such as avocado associated with events such as the Super Bowl is noteworthy. Thus, the behaviour of the monetary value of pollination services has a non-linear dependence on the evolution of the agricultural production structure and therefore has relative independence of physical flows.

6.4.1 Introduction

Animal pollination is a regulatory ecosystem service that contributes to plant fertilization by bees, insects, butterflies, birds or bats, and other animals, which increases the quantity and quality of agricultural crops and helps their preservation. The monetary valuation of animal pollination services is important in Mexico for several reasons: 1) It helps to understand their value to agricultural production, and therefore their indirect contribution to economic activities and welfare of the population; 2) It helps to identify the potential consequences and costs of the loss of pollination service; 3) It provides important information for public policy and cost-benefit analyses, for instance, around land use; and 4), It serves to highlight the importance of natural capital in the context of sustainable development. Monetary valuation is particularly relevant considering that the pollination service is considered an emblematic ecosystem service. Therefore, the purpose of this section is to estimate the monetary value of the regulation service of animal pollination in agricultural production.

6.4.2 Data and methods

6.4.2.1 Data sources

Animal pollination service use the same data sources as described in the section on crops:

The AgriFood and Fisheries Information Service (SIAP) contains information about the production value, production volume, return per hectare, average rural price, water modality and production cycle of about 310 different crops produced in the 2435 municipalities of Mexico. In doing so, it is possible to assign animal pollination dependency rates to each of the crops produced in Mexico.

The National Agricultural Survey (ENA) (2014) collects information on production volume, return per hectare, selling price, water modality, and production cycle of a wide variety of crops produced in the 2013-2014 agricultural cycle. This survey is nationally representative of the 29 most important crops in Mexico. To be consistent with the analysis at the municipal level, SIAP rural average prices are used to value the total volume of production, including that which is used for own consumption (unsold production).

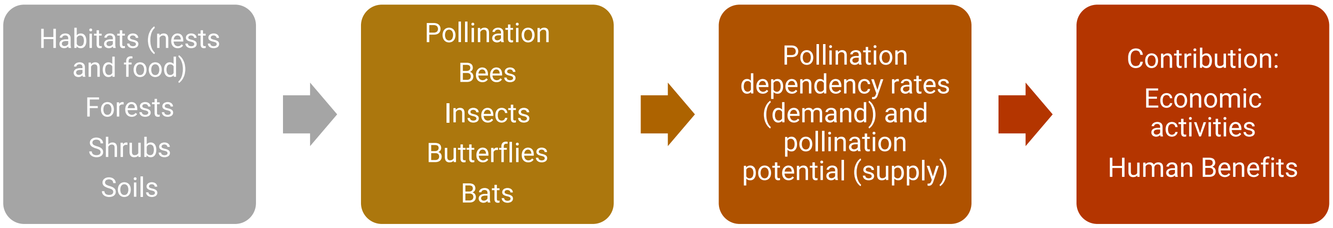
The geo-referenced information is consistent with the information in the agricultural chapter.

Potential provision information is estimated with the InVest tool available at https://naturalcapitalproject.stanford.edu/software/invest-models/crop-pollination.

6.4.2.2 Monetary valuation methods for animal pollination services

Pollination services that are provided by ecosystems consist of the fertilization of crops through the accumulation and transport of pollen by insects (bees, flies, moths, or butterflies), bats, birds, and other pollinators (Klein et al., 2007; Ricketts, et al., 2008), so suitable habitats, nests, caves, forests, shrubland, soil and flora, pollen and nectar should be available adjacent or close to agricultural production areas (Horlings, et al., 2019b, pp. 33-34 and pp. 78). This animal pollination process contributes to agricultural production and productivity, quality of agricultural products, and reducing losses and variance in agricultural production (Figure 6-18)

Figure 6-18: Animal pollination regulating service in agricultural production



Source: Prepared by the authors

The available evidence on the contribution of animal pollination service to agricultural production indicates that it is an important service, although heterogeneous, depending on crop type and other factors. As an example, Klein et al. (2007) estimate that 35 per cent of global crop production depends on animal pollination, that 60 per cent of global production comes from crops that do not depend on animal pollination, and 5 per cent is undefined. All together 87 of 124 crops (about 70 per cent) for human consumption depend on the pollination process. Gallai et al. (2009a, 2009b) estimate that the economic contribution of insect pollination59 to the total value agricultural output in Central and South America lies between 6.1 per cent and 6.6 per cent while in North America, it contributes around 11.4 per cent.

There are several methods for estimating the pollination service value, among which the following stand out:

1. **The market method** estimates the price of pollination based on existing market prices, for instance, for commercial bee hive rental rates. This is possible if an established commercial practice already exists such as in the United States, Canada, and New Zealand.
2. The **replacement cost method** estimates the price of pollination based on the costs of replacing this service in case it were to be lost. For instance, through managed pollination or other means.
3. **The total monetary value method** estimates the pollination service value as being equivalent to the total value of pollinated crops.
4. **The dependency ratio method** considers that pollination contributes a share of agricultural production, albeit differentiated per crop type.
5. **The production function method** assumes that the marginal contribution that the animal pollination service has on the product presents the monetary value of the service (Hanley, et al., 2015).

In this study, the dependency ratio method, together with an index of potential supply and demand of animal pollinators, is used (Klein, et al., 2007; Gallai, et al, 2009b; Gallai and Vaissière, 2009a; Horlings, et al., 2019a and 2019b; Smith, et al., 2011). This can be represented according to equation (10.a), which focuses on the impact of animal pollination on the production function or according to equation (10.b), which identifies the loss of pollination service (Hanley, et al., 2015; Vaissiere, et al., 2011).

(10.a) $Y_{jt} = F(X_{jt}) + A_{jt} + u_{jt}$

(10.b) $Y_{jt} = F[ins_{jt}, otro_{jt}, polin_{jt}, \in_{jt}] + u_{jt}$

Where Yjt represents the production of crop j including its pollination crop return measured in

[59] The economic contribution of animal pollination to global food production is not defined.

physical or monetary units, usually in product per hectare per year, Xjt is the pollination level, F corresponds to the ratio between the pollination level Xjt and the production Yjt, A represents the return of crop j resulting from an autonomous pollination process, insjt corresponds to total inputs, polinjt is the pollination service, otherjt are other control variables, εjt are stochastic variables such as weather, ujt is the error term and the subindexes j corresponds to crop j and t to the time period. In this manner, F(Xjt) indicates the dependence rate of crop j production on the pollination process (Vaissiere, et al., 2011) and corresponds to the production flow derived from pollination (Klein, et al., 2007).

Therefore, the potential demand for the final regulating service derived from pollination dependency rates can be estimated according to equation (11) (Gallai, et al., 2009a):

$$(11) \qquad IPEV_t = \sum_{i=1}^{i} \sum_{t=1}^{t} (P_{it} * Q_{it} * D_{it} * \rho)$$

Where IPEVt is the demand for the total economic value of pollination, Pjt is the price of crop j, Qjt is the quantity produced, Djt is the dependence ratio of crop j on pollination, ρ represents a parameter between zero and one that intends to capture the effect of the pollination deficit and the subindexes j corresponds to crops and t to time.

Evidence demonstrates, however, that agricultural intensification, land-use change, intensive use of pesticides, new species introduction, pathogens and parasites, climate change and the loss of natural habitats reduce put at risk these animal pollination processes (Hanley, et al., 2015; Guimaraes, et al., 2020; Klein, et al. 2007). As such, pollination dependency rates for different crops may present a potential pollination deficit, structural or seasonal (Vaissiere, et al., 2011).

The model of potential animal pollination supply is developed to help identify potential animal pollination deficits, whereby the potential pollination supply per crop is derived from an estimation of nests and soil nutrients and the distance between pollinator habitat and crop areas and distance-adjusted potential pollination supply. This pollination deficit can also be included through coefficient ρ in equation (11). Potential provision information is estimated with the InVest tool available at https://naturalcapitalproject.stanford.edu/software/invest-models/crop-pollination.

6.4.3 The spatial information used in this section is fully consistent with the analysis undertaken in the 6.2 on the crop provisioning service results

6.4.3.1 Stylised facts and physical flows in pollination

Available evidence on dependency rates for various crops is summarized in Table 6-16 based on the dependency ratios of Klein et al. (2007). This shows that, for instance, the production of some fruits, seeds, and nuts is reduced by up to 90 per cent without pollinators (Southwick and Southwick, 1992), that pollination is essential for the production of products such as cocoa and vanilla (Vaissiere, et al., 2011) or that animal pollination is not relevant for the production of some cereals. This suggests that the economic importance of pollination in GDP is associated with the agricultural production structure.

Table 6-16: Rates of crop dependence on pollination service based on return loss in the absence of pollinators

Dependence degree	Reduced production in the absence of pollinators	Crops
Essential	90% and 100% (95%)	Acerola, annatto, atemoya, cacao, pumpkin, cambuci, copoazu, glycydia, jurubeba, kiwi, macadamia, passion fruit, sweet passion fruit, cantaloupe, Brazil nut, watermelon, and vanilla
High	40% - 90% (65%)	Adesmia, avocado, apricot, buckwheat, almond, cranberry, araticum, carambola, cherry, plum, peach, raspberry, gabiroba, guarana, guava, jambo vermelho, mango, apple, quince, nanche, loquat, walnut, cashew nut, Barbados nut, cucumber, and pear
Modest	10% - 40% (25%)	Cotton, cottonseed, apple balsam, aubergine, coffee, chestnut, cherry, coconut, rapeseed, strawberry, sunflower, pomegranate, currant, bean, fig, mangosteen, blackberry, okra, cayenne pepper, castor bean, sesame seed, and soybean
Low	0% - 10% (5%)	palm oil, persimmon, chillies, hog plum, beans, pigeon pea, soursop, cowpea, juazeiro, lemon, linseed, lychee, mandarin, peanut, mombin, orange, papaya, malagueta pepper, pepper, rambutan, tamarind, and tomato
No increase	0%	Olive, garlic, artichoke, cotton wool, gum tree, rice, oats, sweet potato, yam, sugar cane, cassava, barley, onion, rye, Indian cha (tea), clove, cauliflower and broccoli, asparagus, ginger, jaboticaba, lettuce, maize, mallow, mate, walnut, potato, white pepper, pineapple, Chinese silk plant, banana, sisal, tobacco, wheat, triticale, grape, jute, and carrot

Notes: The value in parentheses is the average value for generating pollination maps. The dependency ratios in Klein et al. (2007) are mainly used, where no information is reported, information from Giannnini et al. (2015), and, finally, of the remaining studies.
Source: Borneck and Bricout (1984); Robinson et al. (1994); Southwick and Southwick (1992); Morse and Calderon (2000); Klein, et al. (2007); Gallai and Vaissiere (2009); Giannnini et al. (2015).

6.4.3.2 Aggregate contribution of pollination service to agricultural production and priority crops

The average potential pollination service demand, applying the pollination dependency rates of Klein et al. (2007), based upon the Mexican agricultural production structure60 amounts to 50 432 million pesos in 2013. This corresponds with 12.09 per cent of the agricultural production value and 0.31 per cent of GDP in 2013 (Table 6-17). It is also noted that the monetary contribution of the demand for animal pollination services for agricultural activities as a whole is relatively volatile due to, for instance, the high consumption of avocado and tomato for the preparation of guacamole in the United States during the Super Bowl (Figure 6-19).

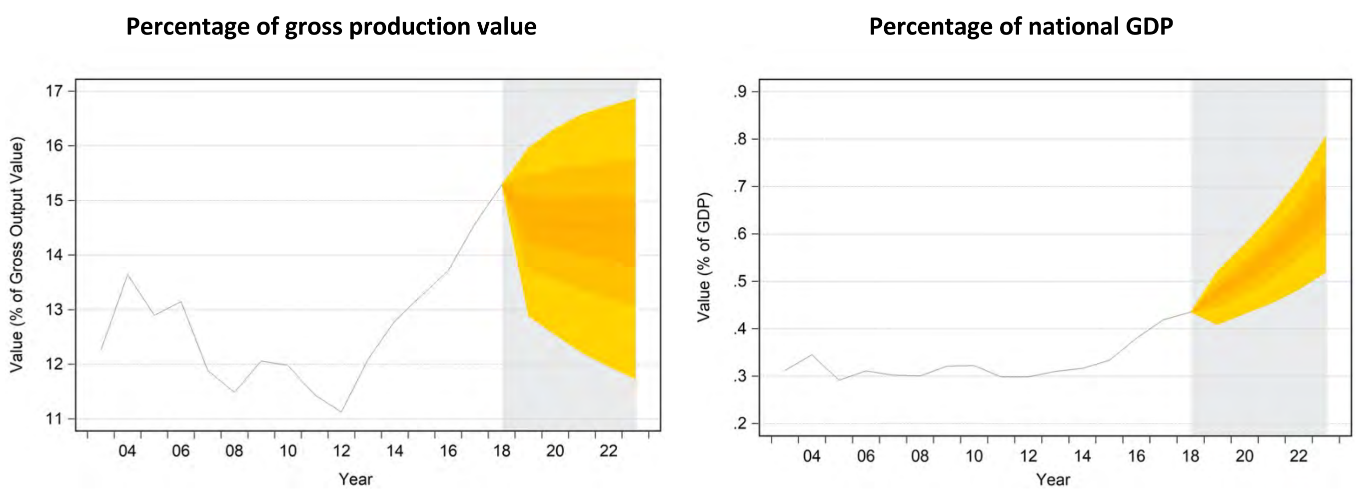
[60] For instance, Guimaraes et. al. (2020) estimate that the structure of crops in Mexico corresponds to 33.3% that depend on pollination, 33.7% that do not depend on pollination and 33% that are unknown.

Table 6-17: Economic value of potential demand for animal pollination 2003-2018 (with dependency rates)

	Economic value of pollination			
Period	**(million pesos)**	**(millions of pesos 2013=100)**	**(% of GVP)**	**(% of total GDP)**
2013	50 432.48	50 432.48	12.09	0.31
Average:	49 940.84	52 252.59	12.73	0.33

Source: Prepared by the authors (based on data from the AgriFood and Fisheries Information Service (SIAP) and Klein et al., 2015)

Figure 6-19: Economic value of potential demand for animal pollination 2003-2018

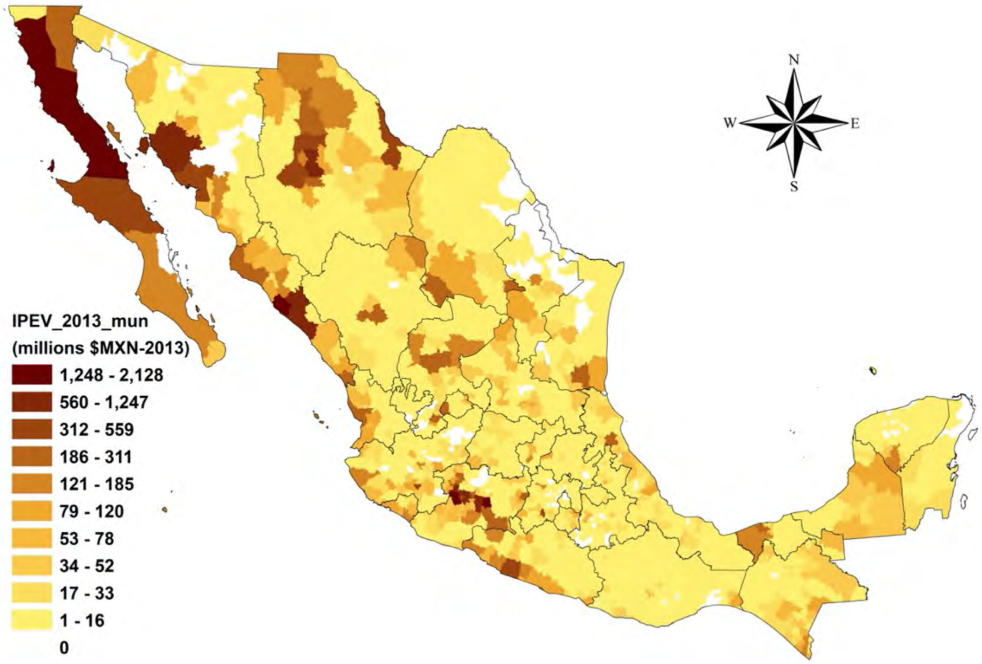


Source: Prepared by the authors (based on data from SIAP, Klein et al., 2007, and Giannini et al., 2015)

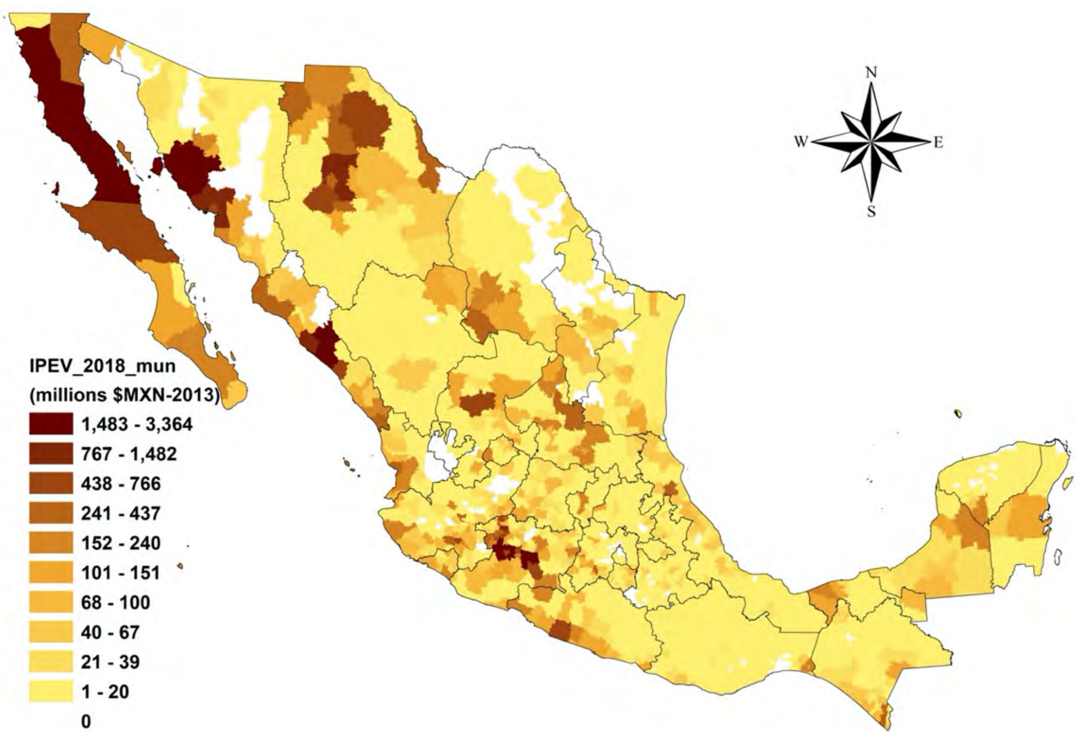
6.4.3.3 Geo-referenced contribution of potential pollination service demand for agricultural production

The geo-referenced estimates of the potential demand for pollination services are summarized in Map 6-15 and Map 6-16, where it is observed that the contribution of animal pollination services is concentrated in the municipalities of Ensenada (BC), Tancítaro (Michoacán), Uruapan (Michoacán), Peribán (Michoacán), Tacámbaro (Michoacán), Salvador Escalante (Michoacán), Hermosillo (Sonora), Ario (Michoacán), Culiacán (Sinaloa) and Navolato (Sinaloa). This is consistent with the production of some agricultural export products.

Map 6-15: Geo-referenced contributions of potential demand for animal pollination service to agricultural production for 2003 (millions of pesos)



Map 6-16: Geo-referenced contributions of potential demand for animal pollination service to agricultural production for 2018 (millions of pesos)

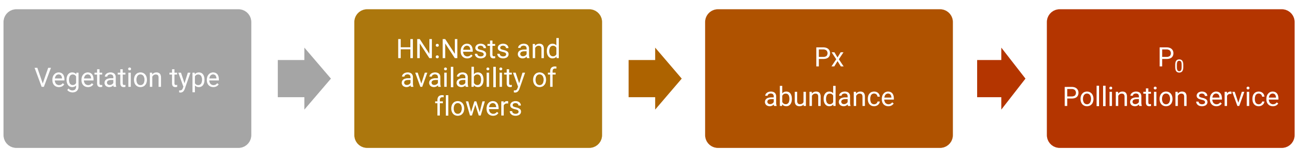


Notes: Cereals (wheat-0.00, maize-0.00, rice-0.00, sorghum-0.00 and barley-0.00); Beverage and spice crops (coffee-0.25, cocoa-0.95, dry chilli-0.05 and green chilli-0.05); Oilseed crops (soy-0.25, peanut-NA and coconut copra-0.25); Fruits and nuts (avocado-0.65, banana-0.00, mango-0.65, papaya-0.05, pineapple-0.00, lemon-0.05, orange-0.25, grape-NA, raspberry-0.65, strawberry-0.25, blackberry-0.25, apple-0.65, peach-0.65, guava-0.65 and walnut-0.00); Legumes (bean-0.05 and chickpea-NA); Other crops (agave-NA, alfalfa-NA, cotton-0.25, nopal-NA, pasture-NA, tuna-NA, sugarcane-0.00 and potato-0.00); and, Vegetables and melons (asparagus-0.00, lettuce-0.00, tomato-0.65, tomato-0.65, watermelon-0.95, melon-0.95, pumpkin-0.95, carrot-0.00, onion-0.00, broccoli-0.00 and cucumber-0.65).
Source: Prepared by the authors (based on data from SIAP, Klein et al., 2007, and Giannini et al., 2015)

6.4.3.4 Potential pollination supply[61]

There is evidence that the increasing intensification of agricultural practices and the reduction of natural habitats for animal pollinators is having an impact on their provisioning and is decreasing in specific regions which is in contrast to the overall increase in crops that actually require animal pollination (i.e., increase in structure as well as monoculture practices). The estimation of the potential supply of animal pollinators in agricultural areas is done based on the method of vegetation and abundance of animal pollinators developed by Lonsdorf et al. (2009) and Kennedy et al. (2013). This model tries to predict the abundance and diversity of pollinators in reference to soil type Figure 6-20) and through this, the model can then predict the potential pollination available in each crop area. For this purpose, the InVest crop pollination model (Sharp et al., 2018) has been is used to estimate the potential pollination indexes (pollinator provision and abundance) throughout the territory of Mexico.[62]

Figure 6-20: Logic of the vegetation cover and pollination abundance model



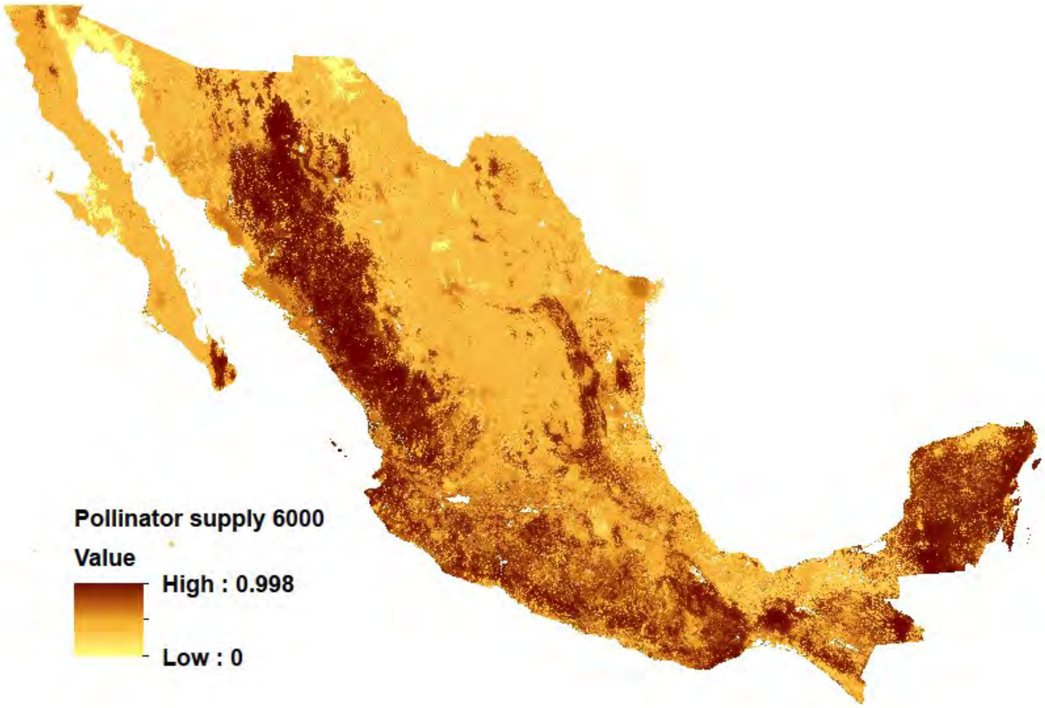
Source: Prepared by the authors

Map 6-17 shows the resulting animal pollination abundance index in Mexico. The model finds a national average of pollination abundance index value of 0.64. with respect to pollination demand (Map 6-18).

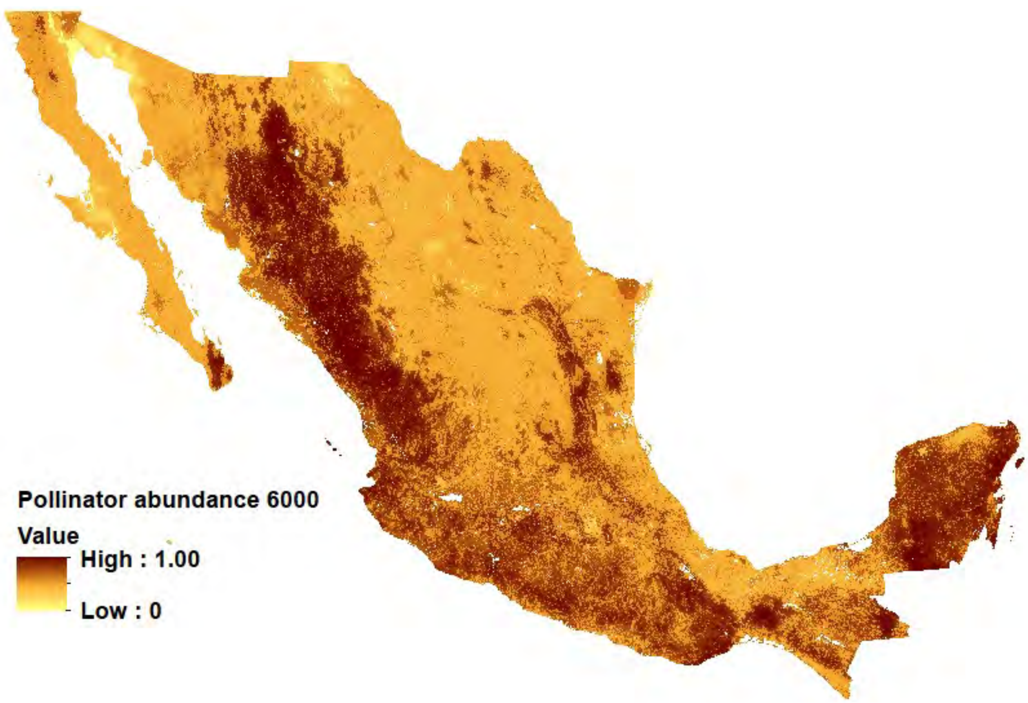
[61] Potential pollination ecosystem service.

[62] The Invest crop pollination model (Sharp et al 2018) is available at: https://naturalcapitalproject.stanford.edu/software/invest-models/crop-pollination

Map 6-17: Potential animal pollination provision index
All land uses: Average: 0.64 - SD: 0.18 - Minimum: 0.00 - Maximum: 1.00



Map 6-18: Animal Pollination Abundance Index
All land uses: Average: 0.64 - SD: 0.18 - Minimum: 0.00 - Maximum: 1.00



Source: Prepared by the authors (based on the LUVC Series VI (INEGI, 2019) and with the InVest tool available at http://releases.naturalcapitalproject.org/invest-userguide/latest/croppollination.html)

Applying the potential pollination demand dependency rates adjusted for aggregate potential provision results in a total value of the pollination service of 32 277 million pesos in 2013 corresponding to 7.74 per cent of the agricultural production value in the same year. (Table 6-18)

Table 6-18: Monetary value of the contribution of potential pollination provision to agricultural production

	Economic value of pollination		
Period	**(millions of pesos)**	**(% of GVP)**	**(% of total GDP)**
2013	32 276.79	7.74	0.20
Average: 2003-2018	31 962.14	8.15	0.21

Source: Prepared by the authors (with data from the AgriFood and Fisheries Information Service (SIAP), Klein et al. (2007), Giannini et al. (2015), and simulations of the InVest tool available at http://releases.naturalcapitalproject.org/invest-userguide/latest/croppollination.html)

The monetary contribution of the pollination service, based on the potential pollination provision adjusted for proximity to habitats is 33 510 million 2013 pesos corresponding with 0.21 per cent of GDP in 2013 and with 0.218 of GDP averaged over the 2003-2018 period (Table 6-19).

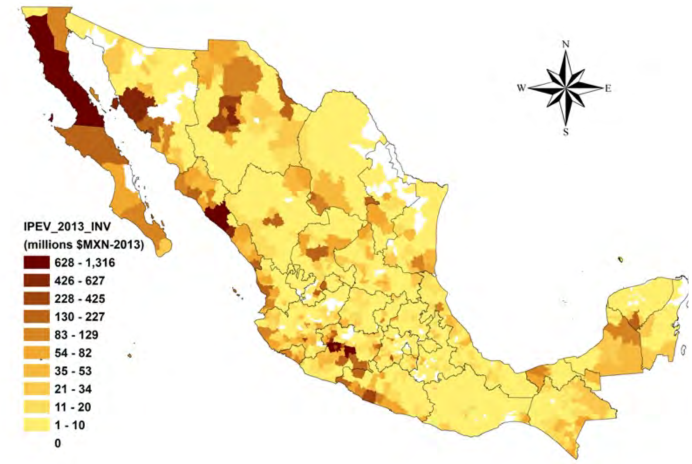
Table 6-19: Value of the monetary contribution of the pollination service, adjusted for distance, based on the potential provision 2003-2018

	Economic value of pollination		
Period	**(Millions of pesos)**	**(% of GVP)**	**(% of total GDP)**
2013	33 510	8.033	0.21
2018	67 877	10.133	0.29
Average: 2003-2018	32 980	8.388	0.22

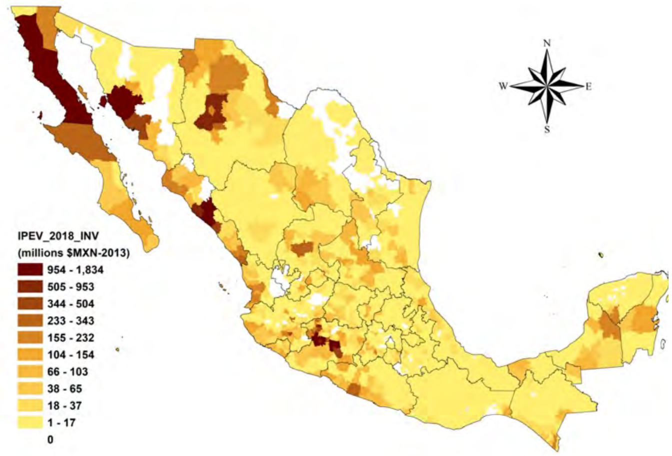
Notes: The pollinator value at the municipal level was adjusted using the average of all pixel values in Figure 4.1 for each of the municipalities in Mexico.
Source: Prepared by the authors (with data from the AgriFood and Fisheries Information Service (SIAP), Klein et al. (2007), Giannini et al. (2015), and simulations of the InVest tool available at http://releases.naturalcapitalproject.org/invest-userguide/latest/croppollination.html)

The resulting proximity adjusted animal pollination service, in geo-referenced form, for crops is presented in Map 6-19.

Map 6-19: Value of monetary contribution of pollination service based on the potential provision



Map 6.19(a). Value at municipal level 2013



Map 6.-19(b). Value at municipal level 2018

Source: Prepared by the authors (with data from the AgriFood and Fisheries Information Service (SIAP), Klein et al. (2007), Giannini et al. (2015) and simulations of the Invest tool available at http://releases.naturalcapitalproject.org/invest-userguide/latest/croppollination.html)

6.4.3.5 The distance and potential contribution of pollination service to agricultural production: A microdata consistency analysis

The contribution of pollination to agricultural production, including the distance between pollinator habitats and crop areas to meet the potential pollinator deficit, can be estimated econometrically by considering an income function (i.e., Winfree et al., 2011) or, similarly, with a Neo-Ricardian model (Mendelsohn et al., 1994). The estimation of the econometric model, based on the National Agricultural Survey 2014, shows that:

- there is a significant and non-linear association between climate and net farm income (Mendelsohn et al., 2009);
- soil characteristics maintain a significant association with net income;
- years of producer education are generally associated with higher net incomes;
- those production units that have their tractors, machinery and vehicles tend to have higher net incomes than production units that do not;
- the proximity to markets and bodies of water (e.g. a kilometre further from the market) reduces net income per hectare;
- the association between planted land and net income is sensitive to the type of crop and whether or not an irrigation system is available; and
- an additional metre of distance between the forest and agricultural land reduces net income by an average of 3.25 pesos from 2013 in the range of 0 to 1 308 metre.

On the other hand, no significant association was found between proximity to forest between 1309 and 6000 metres.

6.4.4 Conclusions and general comments

This section has estimated the potential demand for pollination services as well as the service adjusted for aggregate pollinator abundance and a distance adjusted estimate. The monetary value of the potential pollination service demand represents 12.09 per cent of the agricultural production value in 2013 and, on average, 12.73 per cent of agricultural production. Estimations based on the ENA (2014) report similar results with a monetary value of the demand for animal pollination service accounting for 11.48 per cent of agricultural production in 2014. Furthermore, by applying at the aggregate level the average potential provision of animal pollination, for 2013, is 7.74 per cent of agricultural production. Moreover, the monetary contribution of pollination service, derived from pollination provision adjusted for proximity to habitats, in 2013, is 32 277 million pesos corresponding to 7.74 per cent of the Value of Agricultural Gross Production (Table 6-20).

Table 6-20: Value of the contribution of animal pollination to agricultural production as GDP percentage

	2013 Value	2018 Value	Average value 2003-2018 as GDP percentage
Potential demand	0.31	0.43	0.33
Potential supply	0.20	0.28	0.21
Distance adjusted pollination service	0.21	0.29	0.22

Source: Prepared by the authors

The analysis highlights the difference between the potential demand and the potential provision of animal pollination which demonstrates the pollination deficits in the country as a consequence of the current style of agricultural and livestock activities and therefore suggests the potential consequences of the loss of pollination service. It is also observed that the various forms and capacity of appropriation of the monetary contribution of the animal pollination service in agricultural production are differentiated by the type of producers and/or type of production. That is, irrigated lands tend to benefit more from proximity to certain types of vegetation or animal pollinator habitats than rainfed agricultural areas. This behaviour between provision and potential demand for pollination is also observed by regions of the country where the importance of pollination in agricultural production is in the centre and west of the country.

The monetary contribution of pollination ES shows significant volatility, partly associated with changes in the agricultural production structure. For instance, it highlights the growing economic relevance of crops such as avocados, which have a high dependence on pollination, associated with the consumption of guacamole at events such as the Super Bowl. Therefore, the behaviour of the monetary value of the pollination service has a high, non-linear dependence on the evolution of the agricultural production structure and relative independence from physical flows.

This monetary value of the final regulating service of pollination can then be subtracted from the total aggregate value of the ecosystem service contribution of agricultural production. This avoids double counting and allows moving from the gross contribution of ES to the net contribution of ES (UN et al., 2014, pp. 52).

This set of results demonstrates that the loss of these animal pollination services would have significant economic costs for agriculture in Mexico, with diverse impacts per producer type and for the development of sustainable agriculture (Hanley, et al., 2015).

6.4.4.1 Recommendations

- The relevance of animal pollination to crops suggests the importance of preserving animal pollinator habitats. This requires the implementation of a pollination strategy that considers the economic, social, and environmental consequences of preserving and enhancing pollination. This will be crucial in the future of agricultural activities.
- The monetary contribution of animal pollination services in agricultural production is differentiated by the type of producers and/or type of production (e.g. irrigated or rainfed). This implies the need to consider the different economic and social consequences of animal pollination and to include, for instance, pollination services in the economic strategy of the agriculture and livestock sector and the rural social strategy.
- The monetary contribution of ecosystem pollination services is a function of the evolution of a set of economic and social variables, such as the agricultural production structure. This should be incorporated into the conceptual framework of monetary valuation of ES.
- The monetary valuation of pollination regulating services is included in the monetary valuation of the ES to crops using the method of the unit resource rent. In this regard, its independent monetary valuation makes it possible to advance in the identification and attribution of the factors included in the residual obtained using the method of the unit resource rent, and thus move from a gross monetary valuation to a net monetary valuation and avoid double accounting.
- The volatility of the animal pollination service should be incorporated when developing prospective scenarios.

6.4.2.2 Areas of opportunity

- It is necessary to further identify the relationship of individual animal pollinators to pollination dependency rates and the relationship between different pollinators and their habitats is needed.

6.5 Water services

KEY MESSAGES:

The provisioning, regulating and cultural services of water resources in ecosystems contribute, through diverse channels, to economic activities and people's well-being. Yet, the diversity of ways the service is provided, the multiple effects and feedback processes of water resources services make monetary valuation of the services provided by water resources difficult. Such estimates should therefore be considered as preliminary. Therefore, further research is necessary to reduce the bias in the results with a view to produce economic values that would improve the analysis.

The monetary value of the ecosystem service of water supply, estimated using the method of the resource unit rent price, is 1.95 pesos and 1.72 pesos per m3 derived from the System of National Accounts (SNA) and the Automated Census Information System (EC). The monetary value of the contribution of water resources for household consumption corresponds to 0.052 per cent and 0.039 per cent of GDP in 2013 and 0.044 per cent and 0.033 per cent of GDP in 2018.

The monetary value of the contribution of water resources at municipal level corresponds to 0.011 per cent and 0.014 per cent of 2013 and 0.010 per *cent and 0.012 per cent of 2018 GDP considering the two available sources of information.*

The annual replacement costs of municipal wastewater and industrial wastewater correspond to 0.28 per cent and 0.54 per cent of 2013 GDP and 0.25 per cent and 0.49 per cent of 2017 GDP, correspondingly.

The replacement costs geo-referenced by Administrative Hydrological Region, show that the greatest monetary contribution of water resources ecosystem services to economic and human activities is located in the west and centre of the country.

This set of results show the relevance of ecosystem water services for household water consumption and municipal water provision.

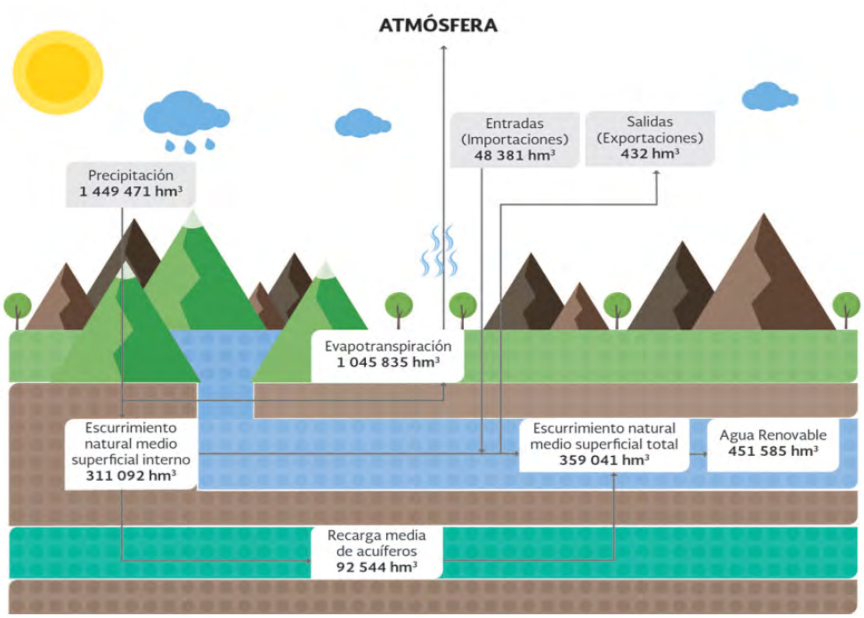
6.5.1 Introduction.

Water resources from ecosystems provide a set of provisioning, regulating, and cultural services essential for economic and human activities. Having a monetary valuation of the contribution of water resource-based ES to economic and human activities is essential to ensure their preservation and sustainable use, their economically efficient use, and their incorporation into cost-benefit analyses and public policy strategies. Nevertheless, estimating the monetary value of each of these services is extremely complex. The purpose of this chapter is to estimate the monetary value of the water supply service used by households (residential) and the municipal water supply. This monetary valuation is, of course, preliminary and requires further research.

6.5.2 Stylised facts and physical flows in water resources:

The average annual precipitation in Mexico, in 2017, is, approximately, 1 449 471 hm3 of water of which 1 045 835 hm3 return to the atmosphere by evapotranspiration, 311 092 corresponds to natural average internal surface run-off plus other filtrations to the subsoil (aquifers) cubic annual in 2017 (CONAGUA, 2018) (Figure 6-21).

Figure 6-21: Annual mean values of the hydrological cycle components in Mexico



Source: CONAGUA (2018)

Table 6-21: Consumptive and non-consumptive water use disaggregated by activities, and sources: 2017

Type of water use	Superficial (thousands of hm³)	Underground (thousands of hm³)	Total volume concessioned (hm³)	Percentage
Agriculture	42.47	24.32	66 799	76%
Water supply	5.25	7.38	12 628	14.4%
Industry	2.04	2.23	4 267	4.9%
Electricity (excluding hydropower)	3.70	0.45	4 147	4.7%
Consumptive subtotal	53.46	34.39	87 842	100%
Grouped non-consumptive use				
Hydropower			183 066	
Ecological conservation			9.46	
Non-consumptive subtotal			183 075	
Total			270 917	

Notes: Sums are approximate and rounded.
Source: CONAGUA (2018)

Mexico has an average annual rainfall of approximately 1 449 471 million cubic metre Out of this, an estimated 72.1 per cent is evapotranspiration and returned to the atmosphere, 21.4 per cent runs off through rivers or streams, and 6.4 per cent infiltrates into the subsoil and recharges aquifers (CONAGUA, 2018). Such water resources allow for a consumptive use of 87 842 hm3 of which 76 per cent is used for the agricultural sector, 14.4 per cent for public provision, 4.9 per cent for self-supplied industry, and 4.7 per cent for electric power, excluding hydroelectricity. The 60.9 per cent of this water supply comes from surface sources (rivers, streams, and lakes) and 39.1 per cent from underground sources (aquifers). This water provision is used in various economic and human activities where the total volume of water concessioned for these economic and human activities corresponds to 87 842 hm3 for consumptive uses[63] and 183 075 hm3 for non-consumptive uses[64] come from surface and groundwater sources[65] (Table 6-21)

These water resources show a heterogeneous distribution per region and socioeconomic strata.

Ecosystem water resources supply a range of provision, regulating, and cultural services for economic and human activities associated with the characteristics (i.e., extent and condition) of

[63] Consumptive uses refer to the difference between the volume deducted and the volume discharged when carrying out an activity (CONAGUA, 2018, pp. 74).
[64] This is the consumption where the activity does not modify the volume of water (CONAGUA, 2018, pp. 74).
[65] This information is available by Hydrological Regions (CONAGUA, 2018, pp. 80-81).

ecosystems and climate (UN, 2019, pp. 146; UN-SEEA-WATER, 2012a). That is, the soil cover vegetation type affects infiltration, retention and storage, evapotranspiration, and water quality patterns. Thus, ecosystem types condition the quality and magnitude of water provision coming from ecosystems.

6.5.3 Data and methods

6.5.3.1 Sources of information

The information used corresponds to:

1. National accounts (INEGI, 2013 and various years) data on gross output, intermediate consumption, net taxes, wages of the branch 2221 'Water collection, treatment, and provision'.[66] The information on the fixed capital consumption of branch 2221 is obtained from the information available for the fixed capital consumption of sub-sector 222 to which an adjustment factor is applied, according to the share of branch 2221 in the operating surplus of sub-sector 222.
2. Economic Census 2018 of branch 2221 'Water collection, treatment, and provision from which gross value added is obtained from which total compensation, gross capital formation, and fixed assets depreciation are deducted.
3. Water treatment cost estimates are obtained from the Regional Water Program - 2030 Vision per Hydrologic-Administrative Regions (HAR) (CONAGUA, 2012). These estimates, prepared by CONAGUA (2018 and 2012[67]), allow us to identify the costs of treating municipal wastewater (public and industrial) by river basin, where the cost required per additional m^3 of water is the annual sum of the required investments to achieve clean rivers by 2030, discounted at an annual 12 per cent ratebased on the ATP model (SGP-Conagua, 2010) and where the cost depends on the volume of treated water.

   Said costs for municipal and industrial water treatment are estimated[68] based on the municipal wastewater treatment cost index, which is based on cost curves estimated by the Mexican Institute of Water Technology and a cost survey on water treatment and reuse in the petrochemical industry (CONAGUA, 2018). These curves identify the average/marginal cost of municipal and industrial wastewater treatment, including the annualized investments and operating costs, and maintenance expenses required to close the municipal and industrial wastewater treatment gap until 2030 to have water in rivers that meets the minimum standard required by NOM-001 SEMARNAT-1996 (CONAGUA, 2012; Forecasting HAR III pp. 72) and where the cost of treatment corresponds to the sum of the total costs per m^3 (CONAGUA, 2012; Forecasting HAR III, pp. 69, Mantilla, et al., 2002).
4. To geo-referenced the water supply service, the InVEST platform (Sharp, et al., 2018) has been used. The InVEST water return model estimates the relative contribution of different land uses and allow for the allocation of the ES to the ecosystem types that play a role in its provision. For the simulations in the InVEST platform, the precipitation and evapotranspiration raster published in Fick and Hijmans (2017) were used. For

[66] Includes households, industry, and commerce.
[67] Regional Water Program. 2030 Vision per Hydrologic-Administrative Regions (HAR) (CONAGUA, 2012).
[68] This is due to the location of the plant or specific regional conditions.

the depth of the root restriction layer, the global soil database was used, as available in the Soil and Terrain Database (SOTER) Programme. For the available water content in vegetation, ranges per soil texture according to Sharma (2019) have been utilized. For the vegetation types of rasters, the Land Use and Vegetation Chart Series VI of INEGI were used. For the basin and sub-basin maps, the shape files published by CONAGUA were used. A parameter $Z = 13.99$ is used to simulate the seasonal distribution of precipitation.

6.5.3.2 Method of monetary valuation of the water provision service

There are, various methods for the monetary valuation of water provisioning and regulating services of ecosystem resources for economic and human activities (UN, 2012a; UN,SEEA-WATER, 2012a, pp. 134; Champ, et al. 2017; Remme et al., 2015; Horlings, et al., 2019).

In this study, various methods were applied to estimate the monetary value of water resources:

6.5.3.2.1 Method of the unit resource unit rent

The method of the unit resource rent has been used (see section 6.2). This assumes that all markets are competitive[69] except for the water market[70]. Thus, the total production value of water equals the value of water product minus gross operating surplus and minus fixed capital consumption (depreciation) and profits from produced assets and wages of self-employed (Table 6-22) (UN, 2012a; UN,SEEA-WATER, 2012b, pp. 38, 135); INEGI, 2020)).

Table 6-22: Water resource rent

Total product value
- Intermediate consumption
- Wages and salaries
- Net taxes
Equal to the operating surplus
- Fixed capital consumption (depreciation)
- Profit from assets produced
- Wages and salaries of self-employed persons
Equal to resource rent
= depletion + net income from environmental assets.

Source: Horlings, et al. (2019)

6.5.3.2.2 Defensive expenditures method

The defensive cost method is based on the preferences of individuals who are willing to modify their behaviour or spend to avoid negative consequences arising from ecosystem degradation or at least to modify the likelihood of occurrence of harmful effects (OECD, 2018; UN, 2014). In this regard, the desire to pay for better environmental conditions is analyzed. The defensive cost method estimates the value of ES based on the damages cost due to the loss of these services and calculates the willingness of

[69] Companies maximize their profits at the point where marginal net revenue equals marginal costs.
[70] Thus, the estimated value corresponds to the monetary value of water that can be adjusted by correcting for distortions in market prices of inputs or opportunity costs of all inputs (UN-SEEA-WATER, 2012a, pp. 139).

individuals to pay for improved health or avoid negative health consequences (Farber, et al., 2002).

The treatment cost method estimates the costs of repairing ES damage (UN, 2014, pp. 119). However, this option does not necessarily reflect changes in ES (Barbier, 2013) and requires the fulfilment of some conditions such as the consumer not paying more than the value of the substitute (Champ, et al., 2017).

6.5.4 Results

6.5.4.1 Aggregate monetary valuation of water services.

The estimate of the monetary value of water supply for household consumption and municipal provision (including consumption by households, industry, and services) using the unit resource rent price method is carried out based on information from the System of National Accounts (SNA) and information derived from the Economic Censuses (EC). This intends to identify a range of ecosystem water service values. The estimates, summarized in Table 6-23 show a monetary value of the water service of the operating agencies of 34.05 billion Mexican pesos with information from the System of National Accounts and 24.84 billion Mexican pesos based on information from Economic Censuses as of 2018. Said values allow the development of a range of the monetary value of the ecosystem water supply service.

Table 6-23: Estimates of the monetary value of the water service based on the method of the resource unit rent

Description (year)	**2018**
Gross Operating Surplus subsector 222	51 939.770
Fixed Capital Consumption subsector 222	16 385.374
Depreciation	1 361.843
Net rent (millions of current pesos)	34 046.080
Estimated net residential water rent with information from branch 2221 Water collection, treatment, and provision from Economic Censuses of the INEGI.	
Description (year)	2018
Gross Value Added (GVA) (millions of current pesos)	53 064.102
Total remuneration (millions of current pesos)	23 585.395
Gross capital formation (millions of current pesos)	50 073.900
Fixed assets depreciation (millions of current pesos)	4 637.023
Net or residual rent (millions of current pesos)	24 841.684

Source: Prepared by the authors (with data from the Goods and Services Account of the System of National Accounts and the Automated Census Information System)

The estimated monetary value of the ecosystem water service is 1.95 and 1.72 pesos per m3 derived from the System of National Accounts and the Automated Census Information System, respectively. In this way, the monetary value of the contribution of water resources to household consumption corresponds to 8.39 and 6.35 billion pesos in 2013, correspondingly, equivalent to 0.052 per cent and 0.039 per cent of national GDP in 2013 and 0.044 per cent and 0.033 per cent of national GDP in 2018. Furthermore, the monetary value of the contribution of water resources for municipal provision corresponds to 1.84 and 2.25 billion 2013 pesos, which is equivalent to 0.011 per cent and 0.014 per cent of national GDP in 2013 and 0.010 per cent and 0.012 per cent of national GDP in 2018 (Table 6-24). Moreover, estimates based on information from the System of National Accounts and the Automated Census Information System indicate a monetary value[71] of $1.47 and 2.5 pesos/m3 correspondingly corresponding to 0.047 per cent and 0.069 per cent of 2013 GDP for household consumption and 0.010 per cent to 0.025 per cent and municipal consumption.

Table6-24: Monetary value of water supply service (2018)

	Monetary value of operating agencies (billions of 2013 pesos)	Total water supply (millions of m^3)	Unit Resource rent price (2018 pesos)	Monetary value (billions pesos of 2013)	Value (% of 2018 national GDP)	Value (% of 2013 national GDP)
Households (SNA)	22.878	5 246	1.95	8.391	0.044	0.052
Households (EC)	15.020	4 500	1.722	6.350	0.033	0.039
Municipal provision (SNA)	5.023	1 152	1.95	1.844	0.010	0.011
Municipal provision (EC)	2.253	1598	1.722	2.253	0.012	0.014

Source: Prepared by the authors

6.5.4.2 Geo-referenced contribution of the monetary value of water services for household consumption and municipal provision

The monetary contribution of ES per Hydrologic-Administrative Region (HAR) for household consumption for 2017 are presented in Table 6-25, Map 6-20, and Map 6-21 where a significant geographical heterogeneity is observed and where the highest monetary value is concentrated in HAR VI, VIII, and IX.

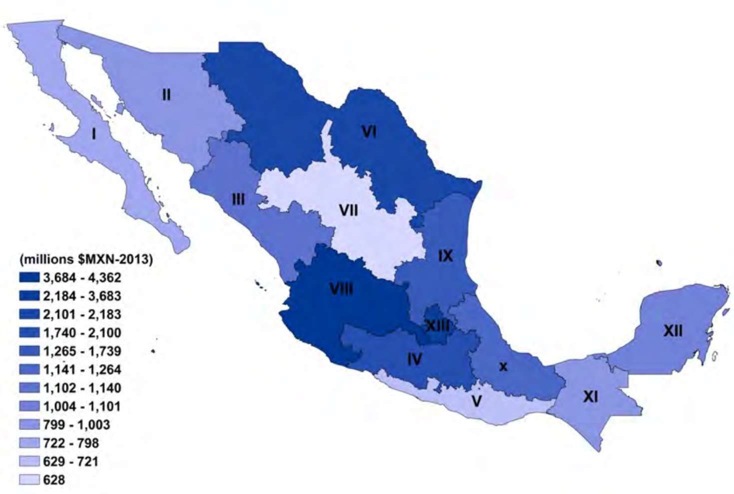
[71]The high value of $2.5/m^3 derived from the 2013 census is associated with falling wages.

Table 6-25: Monetary value of ecosystem water supply service per hydrological region

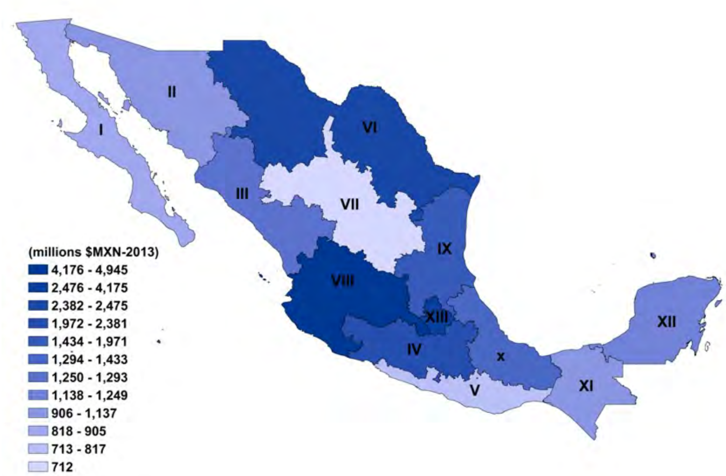
	Public provision 2017 (hm^3/year)			Value (2013 millions of pesos 1.72 pesos/m3)				Value (2013 millions of pesos 1.95 pesos/m3)			
Region	Sup	Inf	Total	Sup	Inf	Total	% of 2013 GDP	Sup	Inf	Total	% of 2013 GDP
I	123	341	464	212	587	798	0.0049	240	665	905	0.0056
II	291	292	583	501	502	1003	0.0062	567	569	1137	0.0070
III	324	339	663	557	583	1140	0.0070	632	661	1293	0.0079
IV	591	630	1221	1017	1084	2100	0.0129	1152	1229	2381	0.0146
V	188	231	419	323	397	721	0.0044	367	450	817	0.0050
VI	570	699	1269	980	1202	2183	0.0134	1112	1363	2475	0.0152
VII	12	353	365	21	607	628	0.0039	23	688	712	0.0044
VIII	1057	1479	2536	1818	2544	4362	0.0268	2061	2884	4945	0.0304
IX	854	157	1011	1469	270	1739	0.0107	1665	306	1971	0.0121
X	446	289	735	767	497	1264	0.0078	870	564	1433	0.0088
XI	437	146	583	752	251	1003	0.0062	852	285	1137	0.0070
XII	0	640	640	1	1101	1101	0.0068	1	1248	1249	0.0077
XIII	358	1783	2141	616	3067	3683	0.0226	698	3477	4175	0.0256
Total	5251	7379	12630	9032	12692	21724	0.1335	10240	14389	24629	0.1513

Source: Prepared by the authors (based on CONAGUA's report - *Water Statistics 2018*. Superior: surface water; Underground: groundwater)

Map 6-20: Monetary value of the water service for residential consumption: 2017 (millions of pesos $1.72 pesos/m^3)



Map 6-21: Monetary value of residential consumption service (millions of 2013 pesos - $1.95 pesos/m^3)



6.5.4.3 The defensive cost method

The water resource replacement or defensive cost method estimates the monetary value of the intermediate regulating service of natural groundwater filtration for residential and/or municipal consumption (Horlings, et al., 2019a and 2019b; UN, 2021). Estimates for Mexico, prepared by CONAGUA (2018 and 2012), allow for identifying the costs of treatment of municipal wastewater (public and industrial) per basin to have clean rivers by 2030 that meet the minimum standard required by NOM-001 SEMARNAT-1996 (CONAGUA, 2012; Forecasting HAR III pp. 72) and where the cost of treatment corresponds to the sum of the total costs per m3 (CONAGUA, 2012; Forecasting HAR III, pp. 69, Mantilla, et. al. 2002). The annual replacement costs of municipal wastewater in 2030 and industrial wastewater correspond to 0.28 per cent and 0.25 per cent and 0.49 per cent of 2017 GDP, correspondingly.

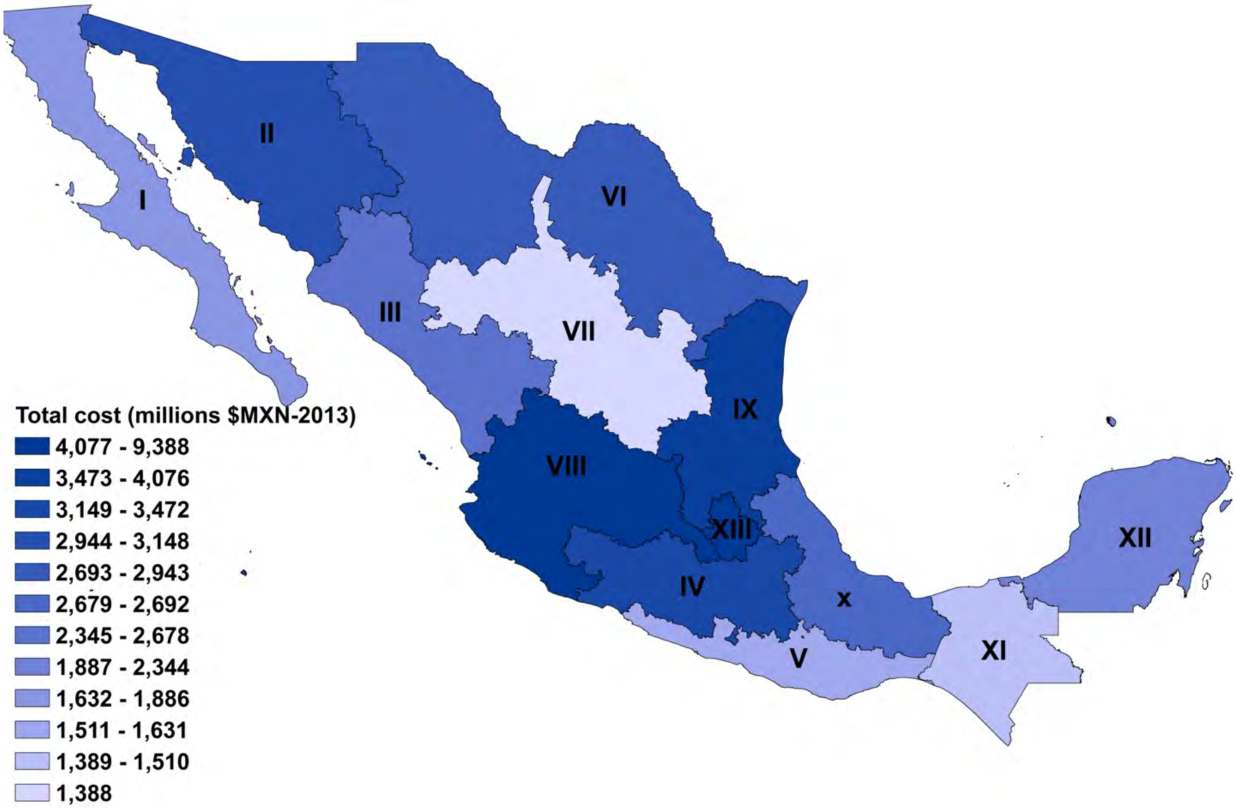
General and geo-referenced estimates of the municipal wastewater treatment costs per Hydrologic-Administrative Region (HAR) are summarized in maps Map 6-22 and Map 6-23 below. Such estimates show that the monetary value of ecosystem water services is concentrated in the central and western parts of the country.

Table 6-26: Total wastewater purification costs per hydrological region

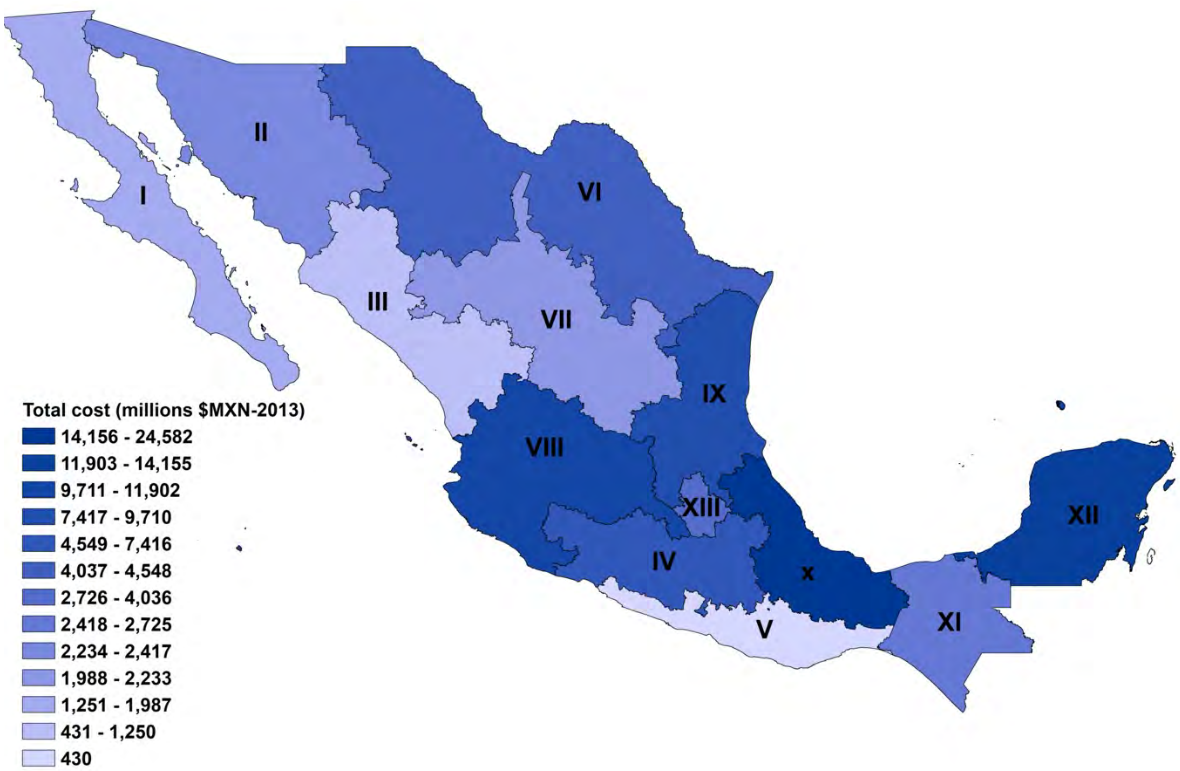
HAR	Cost of providing clean water to rivers (pesos/m^3)	Replacement cost of industrial water volume (millions pesos of 2017)			Volume replacement cost of water for industrial consumption (% of 2017 GDP)		
		Surface	Underground	Total	Surface	Underground	Total
HAR I	**25.00**	1 800.0	625.0	2 425.0	0.008	0.003	0.011
HAR II	**25.00**	200.0	2 750.0	2 950.0	0.001	0.013	0.013
HAR III	**25.00**	975.0	550.0	1 525.0	0.004	0.003	0.007
HAR IV	**25.00**	6 725.0	2 325.0	9 050.0	0.031	0.011	0.041
HAR V	**25.00**	25.0	500.0	525.0	0.000	0.002	0.002
HAR VI	**25.00**	350.0	5 200.0	5 550.0	0.002	0.024	0.025
HAR VII	**25.00**	25.0	2 700.0	2 725.0	0.000	0.012	0.012
HAR VIII	**25.00**	1 650.0	12 875.0	14 525.0	0.008	0.059	0.066
HAR IX	**25.00**	10 825.0	1 025.0	11 850.0	0.049	0.005	0.054
HAR X	**25.00**	26 100.0	3 900.0	30 000.0	0.119	0.018	0.137
HAR XI	**25.00**	1 425.0	1 900.0	3 325.0	0.006	0.009	0.015
HAR XII	**25.00**	0.0	17 275.0	17 275.0	0.000	0.079	0.079
HAR XIII	**25.00**	775.0	4 150.0	4 925.0	0.004	0.019	0.022
Total		50 875.0	55 775.0	106 650.0	0.232	0.254	0.486
Total (pesos and 2013 GDP)		41 687.3	45 702.4	87 389.8	0.256	0.281	0.537

Source: Prepared by the authors (based on the Regional Water Programmes: Vision 2030 for the 13 water regions and on the document Water Statistics in Mexico, 2018, with data for 2017)

Map 6-22: Replacement cost of residential consumption water volume (millions of pesos of 2013)



Map6-23: Water volume for residential consumption replacement cost (millions of pesos of 2013)

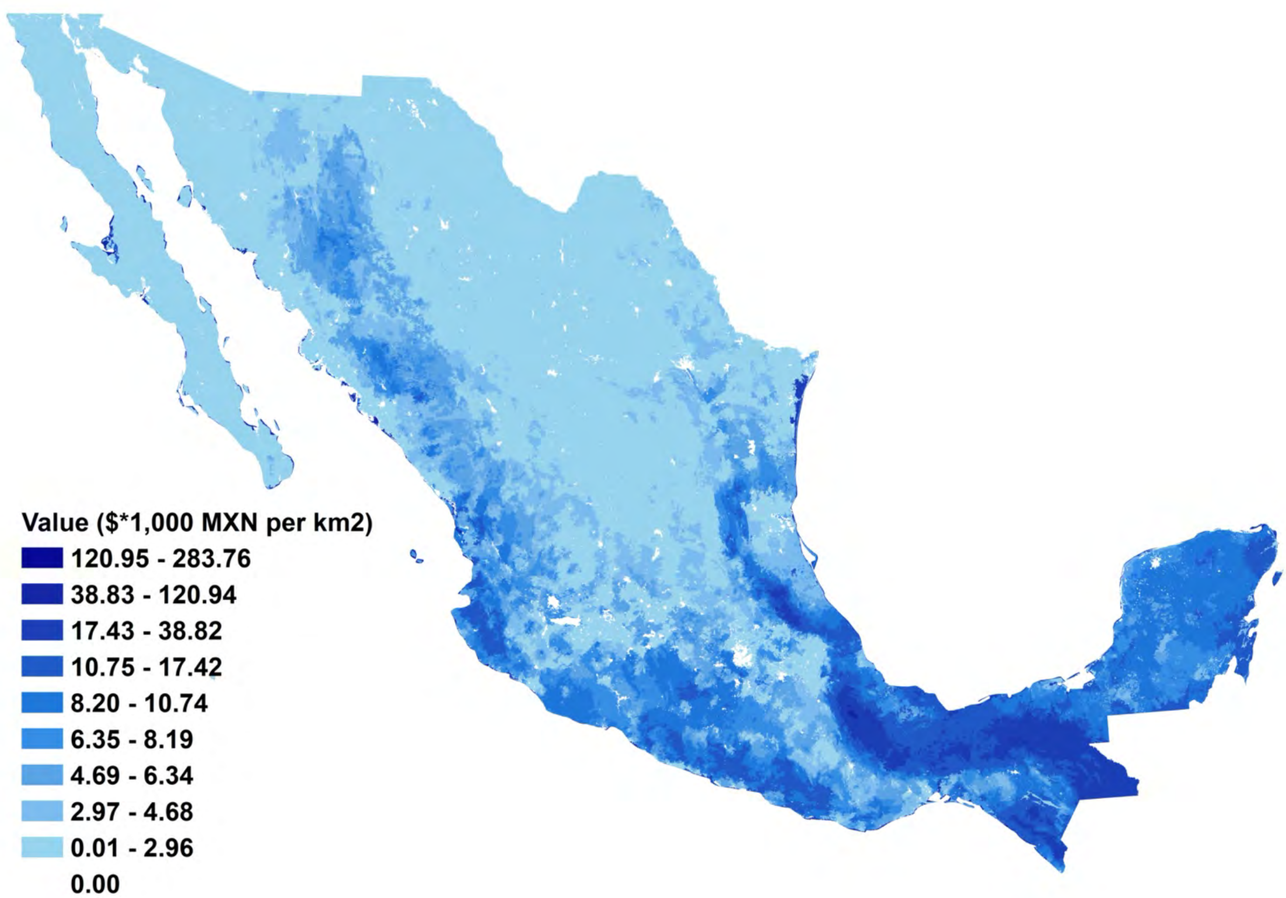


6.5.4.4 Geo-referenced water supply service

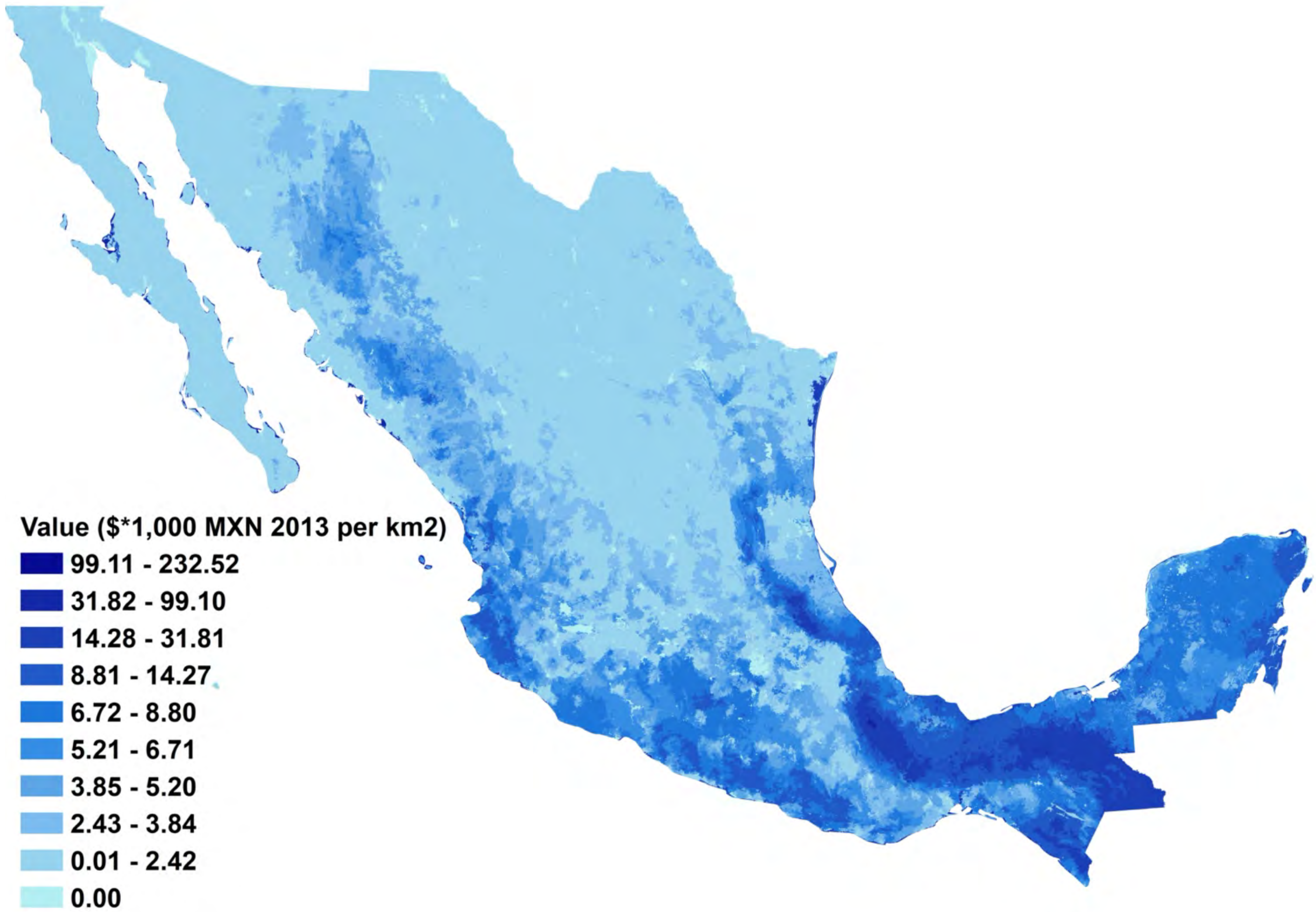
The resource rent results by water basin have been spatialized using the InVEST water model.

Water provision is conditioned by the type of land use and vegetation cover, both of which affects evapotranspiration, infiltration, and water retention patterns, altering the hydrological cycles and therefore the water provision. In this regard, the water provision associated with the different ecosystems allows for estimating the water yields of ecosystems, which is equivalent to the water from precipitation adjusted by a parameter that identifies the fraction of water that comes from precipitation and that does not return to the atmosphere by evaporation or transpiration, and that was then captured by the ecosystems associated with different types of soil (UN, 2021, Sánchez-Colón, 2019). As such, the monetary value of the ecosystem water service is adjusted to the ecosystem provision per soil and vegetation type based on the land use and vegetation chart Series VI published by INEGI (INEGI, 2020). Estimates of water return (mm) are presented at (Map 6-24 and Map 6-25).

Map 6-24: Monetary value of water service per vegetation type (thousands of pesos per km^2)



Map 6-25: Monetary value of water service per vegetation type (thousands of pesos in 2013 per km^2)



Notes: To calculate the value of the water service, a price per m3 of 1.95 pesos is used
Source: Prepared by the authors (based on information from InVEST (Sharp et al, 2018), land use and vegetation map Series VI (INEGI, 2020), climate data from Fick and Hijmans (2017).

6.5.5 Conclusions and recommendations

The provisioning, regulating and cultural services of water resources in ecosystems contribute, through diverse channels, to economic activities and people's well-being. Yet, the diversity of transmission channels, the multiple effects and feedback processes of water resources services, and the presence of an extremely complex political economy make monetary valuation of the services provided by water resources difficult. Such estimates should therefore be considered as preliminary and with a high uncertainty level.

- The monetary value of water resources ES based on the unit rent price method for household consumption and municipal provision and by the replacement cost method for municipal provision indicates that
- The monetary value of the contribution of water resources for household consumption corresponds to 0.052 per cent and 0.039 per cent of GDP in 2013 and 0.044 per cent and 0.033 per cent of GDP in 2018.
- The monetary value of the contribution of water resources to municipal provision corresponds to

0.011 per cent and 0.014 per cent of 2013 and 0.010 per cent and 0.012 per cent of 2018 GDP considering the two available sources of information.

- The annual replacement costs of municipal wastewater in 2030 and industrial wastewater correspond to 0.28 per cent and 0.54 per cent of 2013 GDP and 0.25 per cent and 0.49 per cent of 2017 GDP.
- The georeferenced replacement costs show that the greatest monetary contribution of water resources ES to economic and human activities is located in the west and centre of the country (HAR VI, VIII, and IX).

These results show the relevance of ecosystem water services for household water consumption and municipal water provision.

6.5.5.1 Recommendations

- The monetary valuation of the contribution of ES to household and municipal water provision is relevant. In this regard, it is necessary to consider the interrelationships established between the water supply, its price and cost, and its consumption and the preservation of ecosystems, and to incorporate them into the economic, social, and environmental design of water policy.
- Further estimation of the monetary value of ES with various methods is required to conduct various consistency analyses.

6.5.5.2 Areas of opportunity

- The estimation of the monetary value of ES based on the resource unit rent method has a high uncertainty because of the complexity for disaggregating the factors included in the calculated residual.
- Estimating the monetary value of ES from water resources is limited by the availability of information.

6.6 Nature tourism

KEY MESSAGES:

- Available evidence shows that nature tourism in Natural Protected Areas (NPAs) is an activity of growing importance in the economic and social dynamics in Mexico.
- Estimates of the monetary value of nature tourism considering its contribution to product for the 15 NPAs IS 36 021 million 2013 pesos representing 0.22 per cent of 2013 GDP.
- The estimates, conducted with a meta-analysis and meta-regression, indicate that the monetary nature value-based tourism in the selected NPAs is US$17 311 million, representing 1.36 per cent of the 2013 GDP. Such monetary values, derived from the meta-analysis, are higher than the accounting monetary values suggesting that there are still significant opportunities in nature tourism in Mexico and the importance of other ES in NPAs.

6.6.1 Introduction

During the last decades, tourism activities in Mexico have grown rapidly as evidenced through growing employment rates and consumption of goods and services related to leisure, and an increase in income levels in general associated with lodging, food, and recreational industries, which are carried out in the various tourism segments such as sun and beach, cultural, business, adventure, and nature or ecological tourism. In this context, there is a growing demand for information about nature tourism[72] in Mexico and the services offered by ecosystems, since it is considered that nature tourism has significant economic potential while preserving natural assets.

Estimating ES in nature-based tourism requires solid and systematized information (national surveys, censuses, or national accounts) at the national level that incorporates the environmental and ecosystem services dimension. This information is available for some flagship sites but there is no structural data collection at the national level.

In this section, we make two experimental estimates of the monetary contribution of ES to the nature tourism economy associated with natural protected areas (NPAs) at the national level. The first method is based on the estimation of the output of economic activities associated with Natural Protected Areas (NPAs). The second approach applies a benefit transfer approach using results on valuation of ES in NPAs elsewhere.

Tourism activities in Mexico have a relevant contribution to GDP and employment. They also have an impact, due to their geographic location, on regional development, where a significant and growing part of these tourism activities are associated with sustainable tourism. Thus, it is observed that the GDP of the tourism sector in 2018 accounted for 8.7 per cent of the national GDP[73] and the tourism sector generated 2.3 million paid jobs representing 6 per cent of the total paid occupations nationwide in 2018 (INEGI, 2018). Consumption expenditure, in 2018, made by tourists within the country (domestic consumption) was 3 222 433[74] million current pesos where consumption corresponding to tourism by residents in Mexico (domestic tourism) accounted for 82.7 per cent and spending by foreign visitors (inbound tourism) accounted for 17.3 per cent (Table 6-27). Domestic tourism expenditure is made for holiday reasons (30.4 per cent), excursions (12.9 per cent), business (5.6 per cent) and previous expenditure (11 per cent), and international tourism expenditure corresponds to holiday reasons (69.6 per cent), “other reasons for travel” (16.3 per cent), excursionists (7.5 per cent) and for business reasons (6.6 per cent) (INEGI, 2018). Moreover, there is an estimated number of foreign visitors of 41.4 million representing a foreign exchange income of 22 510 million dollars in 2018 (INEGI, 2018; SECTUR, 2018 and other years).

[72] The nature tourism economy refers to the income generated in locations with tourism activity where the protection of the environment is regulated, so that the environmental impact is null or minimal and the tourist economic activity can prevail, for example, it includes areas with views of the Natural Protected Areas (NPA).
[73] That is, 1 941 343 current pesos or 1 540 868 million constant pesos of 2013 (SECTUR, 2018)
[74] Representing 2 555 957 million pesos in 2013.

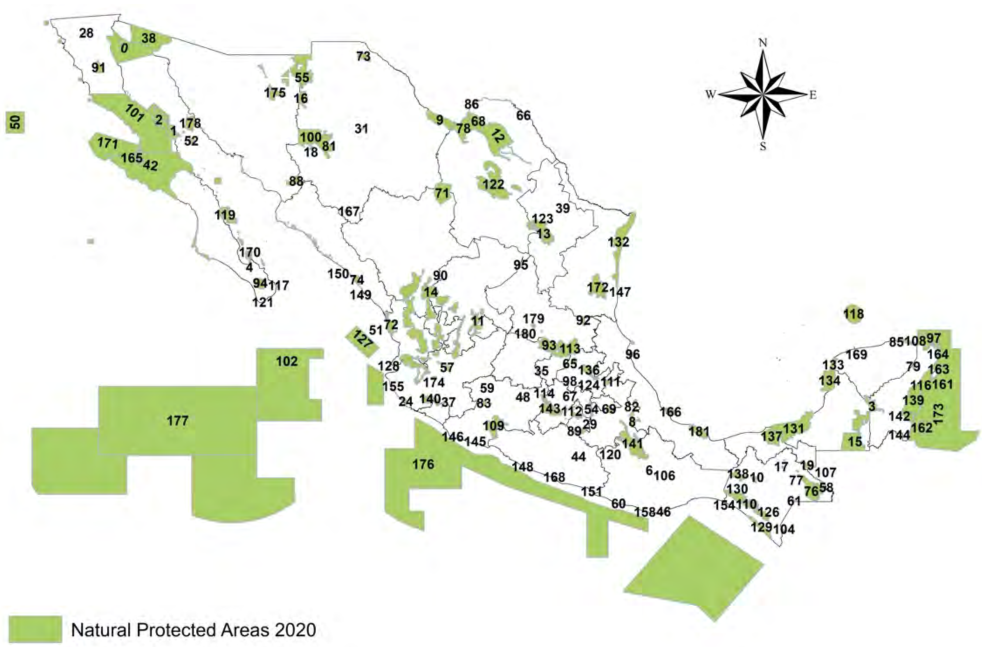
Table 6-27: Tourism expenditure by origin: 2018 [75]

Item	Amount in current pesos	Percentage	Percentage	Amount in constant 2013 prices
Total	**3 495 233**	**100**		**2 828 767**
1. Domestic expenditure	3 222 433	92.2	100	2 555 967
1.1. Domestic tourism	2 666 482	76.3	82.7	2 111 998
1.2. Inbound tourism	555 951	15.9	17.3	443 970
2. Outbound tourism	272 800	7.8		272 800

Source: INEGI, 2018.

In this context, it is noted that only a small proportion of the total expenditure of national and foreign tourists corresponds to nature tourism. One of the foundations of the nature tourism economy is natural protected areas (NPAs). Currently, there are 182 federally protected natural areas with 90 838 011 hectares consisting of 21 379 398 hectares of protected land areas (10.88 per cent of the national land surface) and 69 458 613 hectares of marine areas (22.05 per cent of the marine surface of the national territory) (CONANP page) (Map 6-26)

Map 6-26: Natural Protected Areas



Source: Prepared by the authors (based on data from CONANP, 182 NPAs)

[75] GDP of 22 191 164 million pesos (INEGI, 2018).

6.6.2 Data and methods

6.6.2.1 Sources of information

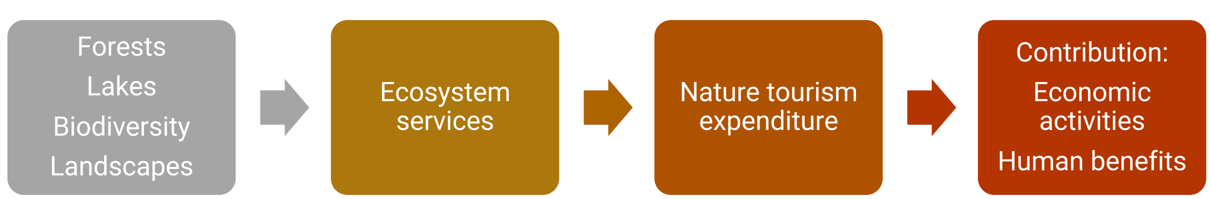
The sources of information for the analysis of the ES of nature tourism correspond to:

1. In collaboration with the Ministry of Tourism and CONANP, 15 Natural Protected Areas (NPAs) were identified at the federal level with a clear tourist function.
2. Fifteen buffer polygons have been constructed, which cover the area of influence[76] surrounding the selected NPAs with tourism potential. These polygons were estimated, based on the tourism module of the 2014 Economic Census, considering the potential tourism expenditure within and around the NPAs which is inferred from visits to the area of interest and which have been subsequently related to economic activities around the NPAs: passenger transport, restaurants, bars and nightclubs, accommodation, travel agencies and other booking services, commerce, cultural services, sports, and recreational services, and other such as professional services, currency exchange services.
3. The information used corresponding to the Natural Protected Areas (NPAs) and their area of influence, comes from the establishments of the year 2013 in current values from the "Tourism Statistics based on the results of the Economic Censuses 2014" and the polygons of influence of the NPAs of interest, are developed from the study of the characteristics of each of them, considering the tourism activities carried out and the geographical proximity of the establishments related to tourism.
4. For the benefit transfer approach, a database of relevant studies that conduct monetary valuation of ES in natural areas was developed for its use in the meta-analysis.

6.6.2.2 Methods for monetary valuation of nature tourism in Natural Protected Areas

ES contribute to nature tourism through various channels (Figure 6-22). The estimation of the overall economic value of the natural and environmental resources found in natural protected areas can serve as an input for the evaluation of projects or sectoral environmental policies.

Figure 6-22: Ecosystem services for nature tourism



Source: Prepared by the authors

[76] The extent of the area of economic influence of NPAs varies from case to case depending on the geographical distribution of economic establishments.

The estimation of the ES of nature tourism in protected natural areas is carried out, as a consequence of still fragmented information, through:

1. Expenditure method

   The expenditure approach measures the value added of economic activities that can be directly related to the presence of the selected Natural Protected Areas (NPAs). It is assumed that these economic activities would not take place without the ecosystem being present, and hence provides a proxy estimate of the ecosystem services provided. As the method measures value added the resulting estimate is consistent with exchange values.

2. Meta-analysis and meta-regression

   A preliminary analysis of the monetary value of nature -based tourism in selected Natural Protected Areas (NPAs) can be obtained based on a meta-analysis (Lipsey and Wilson, 2001). Indeed, a meta-analysis makes it possible to transfer the results from one sector or region to another area of analysis by estimating a weighted average[77] of the effects identified in various studies (Glass, et al., 1981).

6.6.3 Results

6.6.3.1 Monetary valuation of nature tourism in NPAs

The ecosystems present in protected areas have natural attributes and attractions which generate recreational, cultural and health benefits and also help to reduce noise and air pollution. Thus, ES generate economic benefits to the nature tourism economy when combined with physical human capital, labour, infrastructure, and other inputs.

6.6.3.2 Monetary valuation of NPAs per contribution to the product

The estimation of the gross value added of the activities related to the nature tourism economy, based on the information of the 15 NPAs with tourist function and the tourism module of the 2014 Economic Census, is summarized in Table 6-28

[77] The weighted average of the studies normally assigns greater weight to the more precise studies.

Table 6-28: Gross Production value (GPV) and Gross value added (GVA) of activities related to nature tourism around NPA[78]

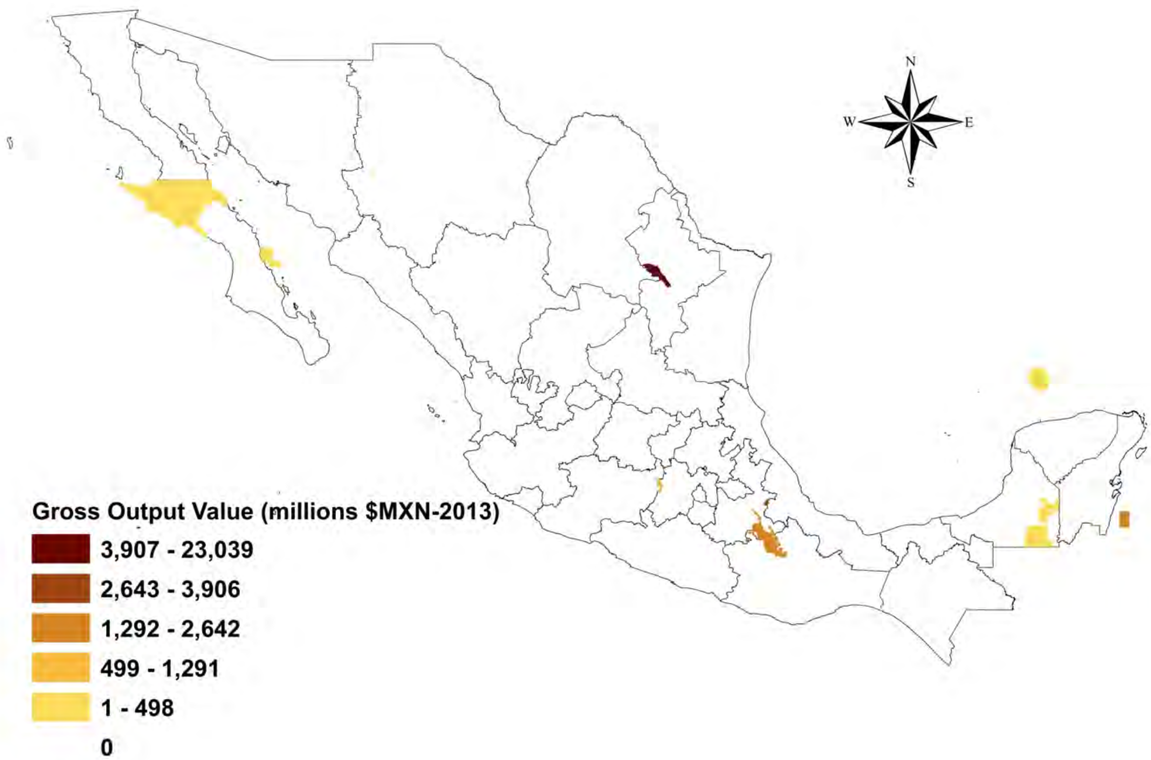
NPA	Description	GPV (thousands of pesos 2013)	GVP % of GDP 2013	GVA (thousands of pesos 2013)	GVA % of GDP 2013
1	RB El Vizcaíno	245 754	0.00151	131 222.2	0.00081
2	PN Loreto Bay	169 507	0.00104	72 285.8	0.00044
3	PN Bassaseachic Waterfall	1 420	0.00001	576.9	0.00000
4	PN Monterrey Hills	23 039 124	0.14154	10 895 520.0	0.06694
5	PN Isabel Island	0	0.00000	0.0	0.00000
6	PN Marietas Islands	497 539	0.00306	172 725.8	0.00106
7	RB Monarch Butterfly	1 291 171	0.00793	269 618.9	0.00166
8	RB Tehuacán - Cuicatlán	2 641 689	0.01623	1 358 620.4	0.00835
9	PN Orizaba Peak	3 906 343	0.02400	1 915 800.4	0.01177
10	PN Huatulco	306 540	0.00188	167 592.5	0.00103
11	PN Montebello Lagoons	745 053	0.00458	414 259.6	0.00255
12	RB Calakmul	169 003	0.00104	109 148.1	0.00067
13	RB Banco Chinchorro	1 846 549	0.01134	910 658.4	0.00559
14	PN Tulum	740 499	0.00455	187 383.5	0.00115
15	PN Alacranes Reef	420 755	0.00258	233 953.0	0.00144
	TOTAL	**36 020 943**	**0.22130**	**16 839 365.5**	**0.10345**

Note: Includes passenger transport, restaurants, bars and nightclubs, accommodation, travel agencies and other booking services, trade, cultural services, sports and recreational services, other (including professional services, and currency exchange)

Thus, the monetary value of the contribution to the product in the economy of nature in the selected NPAs is 36 020.94 million pesos of 2013 representing 0.22 per cent of the GDP of 2013.This monetary value of NPAs can also be associated with geographically (Map 6-27).

[78] Includes Passenger transport, Restaurants, bars and nightclubs, Accommodation, Travel agencies and other booking services, Trade, Cultural services, Sports and recreational services, Others - Including professional services, bureaux de change, among others).

Map 0-1: Geo-referenced monetary value of NPAs (millions of 2013 pesos)



6.6.3.3 Meta-analysis of the monetary value of tourism in Natural Protected Areas

The meta-analysis indicates that the monetary value of all ES provided per hectare is MEX $ 23 725 and the meta-regression estimates show that nature tourism increases the monetary value of natural protected areas.

The 15 Natural Protected Areas with tourist function include 4 724 637 hectares (CONANP, 2020). The meta-analysis estimates that the basic value per hectare of the NPAs lies around 3 664 dollars, increasing to 8 660 dollars when used for hunting and fishing activities[79], further increasing to 12 435 dollars when used for tourist and recreational activities. Therefore, the monetary value of the 15 NPAs with tourism function corresponds to 221.58 billion current 2013 pesos[80] corresponding with 1.36 per cent of the GDP of 2013 (Table 6-29). This value is higher than previously estimated and suggests that there are still important opportunities in environmental or nature tourism in Mexico and the importance of other ES in NPAs.

[79] This value is similar to that estimated for the Cozumel area including all ecosystem services, which partially reflects that in this case a monetary value associated with the welfare economy is estimated (ECOVALOR, 2021).

[80] Considering a value per hectare of 3 664 dollars and an average exchange rate of 12.8 Mexican pesos per US dollar in 2013.

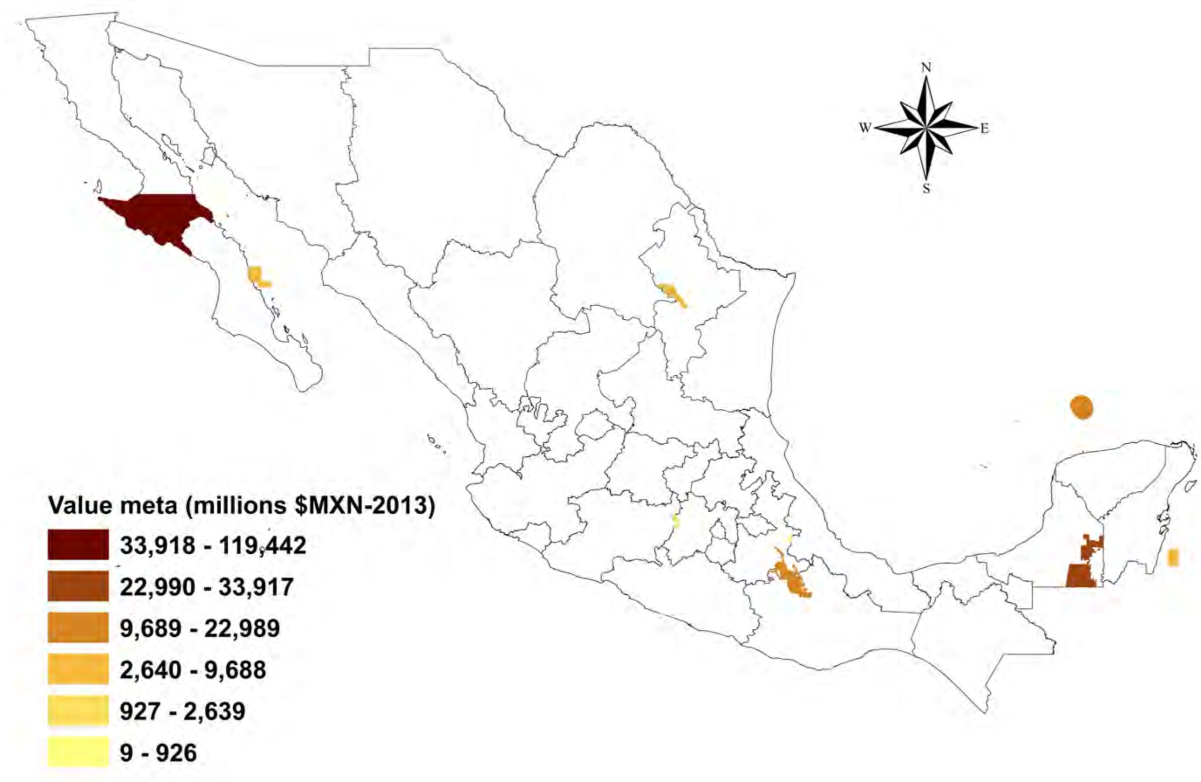
Table 6-29: Monetary value of nature tourism in natural protected areas

Number of NPAs	Area (hectares)	Value	Value
		(millions of dollars)	(% of 2013 GDP)
15 NPA	4 724 637	17 311	1.361

Source: Estimate prepared by the authors. Note: An average exchange rate of 12.8 Mexican pesos per U.S. dollar in 2013 is used.

The geographic expression of the monetary value of sustainable tourism, based on the meta-analysis, addressing the 15 NPAs with tourist vocation is presented in Map 6-28
at 2013 prices.

Map6-28: Monetary value of environmental or nature tourism in NPAs 15 (millions of 2013 pesos)



6.6.4 Conclusions and general comments

The experimental estimates in this chapter underscore that ecosystem services provided by NPAs are highly valuable nature tourism is an important activity in Mexico. These estimates have a high level of uncertainty:

- o Estimates of the monetary nature of value-based tourism using the method of contribution to the product of the 15 NPAs considered suggesting a value of 36 021 million

2013 pesos representing 0.22 per cent of 2013 GDP.

- Estimates, conducted with a meta-analysis and meta-regression, indicate that the monetary value of nature tourism in NPAs is 17 311 million dollars representing 1.36 per cent of the 2013 GDP. Such monetary values, derived from the meta-analysis, are higher than the accounting monetary values suggesting that there are still significant opportunities in nature tourism in Mexico and the importance of other ES in NPAs.

6.6.4.1 Recommendations

- It is recommended to continue collaborating with the tourism and environmental sectors to have robust and consistent national information on nature-based tourism.

6.6.4.2 Areas of opportunity

- The exercise can be complemented and updated as more sources of information are generated or as more criteria are integrated into the data collection items.

- These estimates are preliminary as other elements should be included in a more complete assessment of nature tourism.

6.7 Aggregate monetary valuation of ecosystem services

KEY MESSAGES

- *The monetary valuation of ES at the national level shows the contribution, in monetary units, of ES to economic and human activities in Mexico. In this regard, the preservation of ecosystems and their services is fundamental to promote sustainable development. Nevertheless, the monetary valuation of ES at the national level requires further research and complementary approaches. Thus, the monetary valuation results obtained should be considered preliminary. Moreover, this pilot considered a limited number of ES and it should be considered to gradually*
- *Available evidence indicates that the use and appropriation of ES are heterogeneous per product and producer type and region. That is, it is observed that lower-income groups use ES as a mechanism to maximize income and, simultaneously, as a risk management mechanism, and that profit-maximising appropriation of ES is more frequent in groups of agricultural producers with higher incomes, and who have irrigation and machinery.*
- *The evidence also shows that there is a non-linear, dual causal relationship between physical flows and monetary flows of ES, and relative independence of the monetary valuation of ecosystems about physical flows that may even influence the ecosystems condition and extent.*
- *Such results can inform decision-making and be incorporated into the design of agricultural, environmental, climate, and social policies, as well as foster discussion on mechanisms for transition to sustainable development.*

6.7.1 Introduction

ES contributes, through various channels, to economic and human activities. Nevertheless, the monetary values of such ES contributions are not assigned a real monetary market value and are therefore not accounted for in the national accounts as a whole. This lack of a recognized monetary value in the market translates into inefficient use and overexploitation of ES and degradation of ecosystems and makes it difficult to incorporate them into public policy strategies and the analyses and the behaviour of economic agents.

The purpose of this chapter is to present a synthesis of the monetary estimates of the ES contributions to crops, carbon storage and sequestration, animal pollination, water provision, and nature tourism in the selected Natural Protected Areas.

6.7.2 Results

A synthesis of the monetary valuation of ecosystem services in Mexico is presented in Table 6-30. In this way, the **gross** output of all ES (agricultural, carbon, pollination, residential water and nature tourism) of ecosystems accounts for 3.11 per cent of 2013 GDP. The **net** contribution of ES, which is obtained by subtracting the pollination service from the gross contribution as pollination is considered an intermediate ecosystem services, amounts to 2.79 per cent of 2013 GDP.

Table 6-30: Monetary value of Ecosystem Services

Type of service	Ecosystem service	Amount at 2013 prices=100 (millions of pesos)	Percentage of GDP in 2013	Average percentage of GDP 1993-2018
Provisioning services	1. Agriculture (R) 2. Agriculture (RN)	$163 667 $110 723	1.01% 0.68%	0.99% 0.59%
	1. Rice (R) 2. Rice (RN)	$285 $190	0.0017% 0.0012%	0.0033% 0.0021%
	2.1. Bean (R) 2.2. Bean (RN)	$5 147 $3 508	0.0316% 0.0216%	0.0306% 0.0184%
	3.1. Corn (R) 3.2. Corn (RN)	$26 762 $17 071	0.1644% 0.1049%	0.1407% 0.0721%
	4.1. Wheat (R) 4.2. Wheat (RN)	$5 765 $4 197	0.0354% 0.0258%	0.0255% 0.0155%
	5.1. Sorghum (R) 5.2. Sorghum (RN)	$7 313 $4 887	0.0449% 0.0300%	0.0348% 0.0185%
	6.1 Soy (R) 6.2. Soy (RN)	$561 $368	0.0034% 0.0023%	0.0021% 0.0011%
	Microdata	$187 062	1.11%	
Regulating services	7.3. Carbon in biomass area 7.2. Soil Organic Carbon (SOC) 7.3. Total carbon storage and sequestration	$50 213 $216 041 $266 254	0.3085% 1.3273% 1.636%	
	8. Pollination: 8.1. Demand 8.2. Aggregate 8.3. Distance-adjusted	$50 432 $32 277 $33 510	0.310% 0.198% 0.206%	0.331% 0.212% 0.218%
	9. Water supply 9.1. Net household rent 9.2. Net municipal rent 9.3. Replacement costs	$8 391 $1 844 $44 996	0.052% 0.011% 0.276%	

Cultural services	10. Natural Protected Areas (NPA). 10.1. Product valuation 10.2. Meta-analysis	$36 021 $221 582	0.2213% 1.361%	
Total 1: Gross value with agriculture rent	Agriculture (rent (R)) + Total carbon storage and sequestration + pollination (offer) + residential water + NPA (Product)	$506 610	3.112%	
Total 2: Gross value with net agriculture rent	Agriculture (net return (RN) + total carbon storage and sequestration + pollination (provision) + residential water + NPA (Product)	$453 666	2.787%	

Notes: The water supply for household and municipal consumption includes regulation and provision services. Totals represent a gross estimate as there is double accounting (e.g., agricultural ES and pollination). **Total 1**: ES agricultural (rent) 163 667 million pesos, carbon storage and sequestration 266 254 million pesos, Pollination (offer) 32 277 million pesos, water (residential consumption) 8 391 million pesos, nature tourism (product) 36 021 million pesos. **Total 2**: Agricultural ES (net rent) $110 723, carbon storage and sequestration $266 254, pollination (offer) $32 277, water (residential consumption) $8 391, nature tourism (product) $36 021. The household net rent is calculated with a price of 1.95 pesos per m^3 and based on information from the System of National Accounts. Source: Prepared by the authors.

The relevance of different ecosystem services is presented at Figure 6-23 and Figure 6-24.

Figure 6.23: Gross monetary contribution of provisioning, regulating and cultural ecosystem services (% of 2013 GDP)

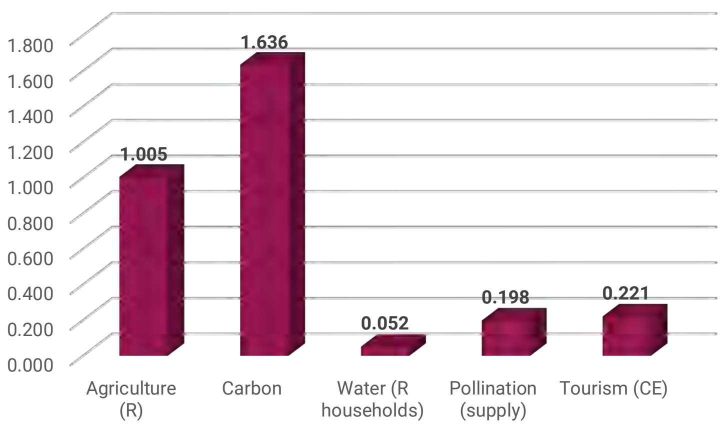


Figure (A) Agricultural rent, carbon, residential water, and tourism (% of 2013 GDP)

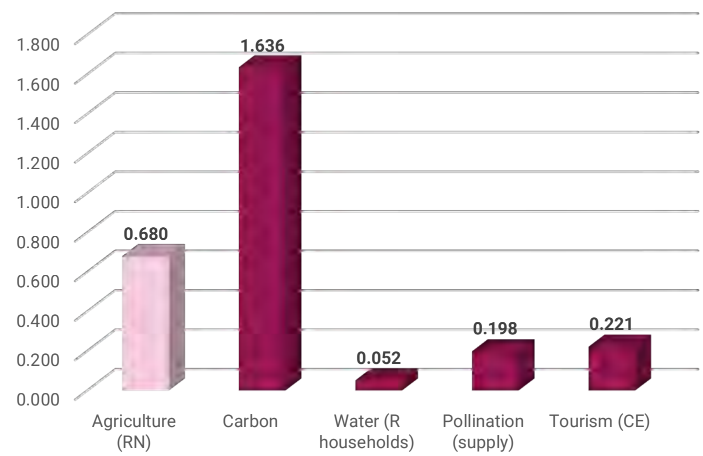


Figure (b) Net agricultural, carbon, residential water, and tourism returns (% of 2013 GDP)

Source: Prepared by the authors

Figure6-24: Percentage share of provisioning, regulating, and cultural services in the aggregate provision of ecosystem services

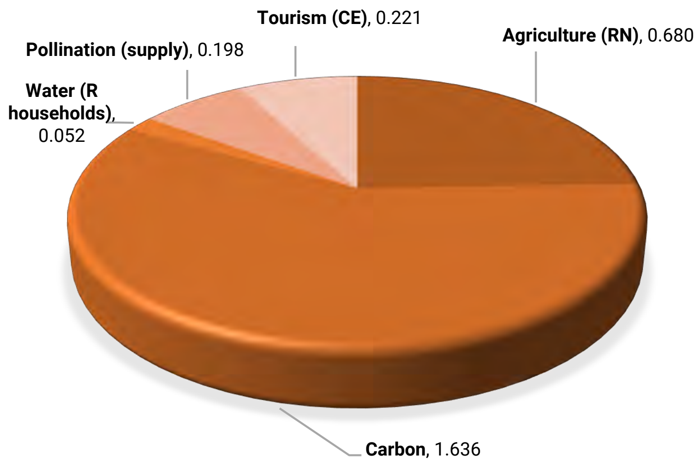


Figure 6-24 (a). Agricultural rent, carbon, residential water, and tourism (% of 2013 GDP)

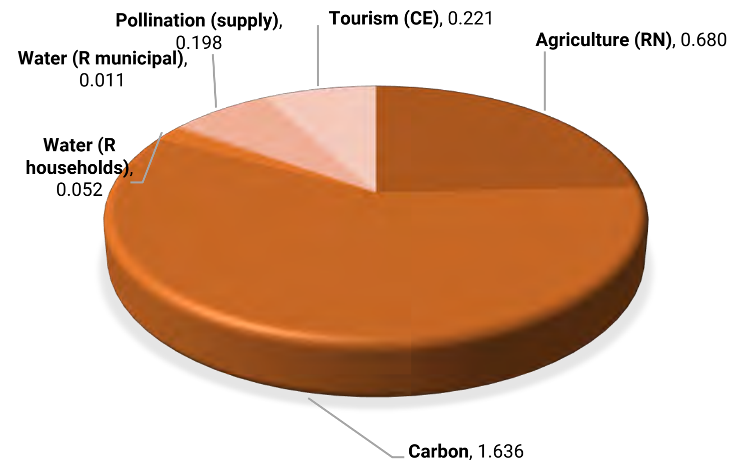


Figure 6-24 (b). Net agricultural, carbon, residential water, and tourism returns (% of 2013 GDP)

Notes: The water offer for household consumption includes regulation and provision services.
Source: Prepared by the authors

Geo-referenced analysis from ES suggests that there is heterogeneous spatial expression. That is, it is observed that: (i) provision to crops is concentrated in the centre and northwest of the country, but with differences per crop; (ii) that carbon storage and sequestration is concentrated in the south and northwest of the country; (iii) pollination in crops in the north and northwest of the country, especially, in Baja California, Baja California Sur and Sinaloa; iv) for the water service for household consumption, this is concentrated in the south and south-east of the country; and, v) in the case of tourism, the spatial distribution of the value of this service is subject to the location of the Natural Protected Areas with a tourist vocation.

6.7.3 Supply and use tables of ecosystem services.

Supply and use tables of ecosystem services in Mexico are presented at Table 6-31 and Table 6-32. These tables were developed based on the monetary value of ES.

Table 6-31 Monetary value of Ecosystem Services: Supply table.

	Economy						Environment							Total	
	Primary sector (agriculture)	Secondary sector	Tertiary sector (tourism)	Homes	Government	Rest of the world	Agriculture	Forests (primary)	Tropical forests (primary)	Shrubland (primary)	Other forest areas (primary)	Secondary vegetation	Other land uses	Total (2013 MEX $ millions)	Total (% of 2013 GDP)
Crops (total)							163 666.51							163 666.51	1.0055%
Grain corn							26 762.22							26 762.22	0.1644%
Bean							5 146.91							5 146.91	0.0316%
Wheat grain							5 765.07							5 765.07	0.0354%
Sorghum							7 312.92							7 312.92	0.0449%
Soy							560.96							560.96	0.0034%
Rice							284.50							284.50	0.0017%
Other crops							117 833.94							117 833.94	0.7239%
Carbon (total)							49 116.27	68 707.53	54 871.00	29 277.50	16 537.96	42 802.72	4 941.61	266 254.57	1.6358%
Biomass								15 277.49	7 762.95	107.73	607.42	26 457.74		50 213.33	0.3085%
Soils							49 116.27	53 430.04	47 108.04	29 169.77	15 930.54	16 344.98	4 941.61	216 041.24	1.3273%
Pollination (total)							**6 415.28**	**909.16**	**2 086.18**	**8 305.23**	**14 560.93**			**32 276.79**	**0.1983%**
Water (total)							**1 438.09**	**1 093.24**	**776.77**	**511.70**	**1 842.63**	**2 609.68**	**118.45**	**8 390.57**	**0.0515%**
Tourism (total)							**1 283.34**	**12 429.57**	**1 073.21**	**9 310.22**	**2 146.01**	**6 234.59**	**3 544.00**	**36 020.94**	**0.2213%**
Total (millions of 2013 pesos,)							**221 919.49**	**83 139.51**	**58 807.16**	**47 404.65**	**35 087.52**	**51 646.99**	**8 604.06**	**506 609.38**	**3.1124%**
Total (% of 2013 GDP,)							**1.3634%**	**0.5108%**	**0.3613%**	**0.2912%**	**0.2156%**	**0.3173%**	**0.0529%**	**3.1124%**	

Notes: The 2018 pollination value in 2013 prices is used because the geo-referencing exercise with InVEST was carried out for 2018 due to the availability of information for calibration.
Source: Prepared by the authors

Table 6-32: Monetary value of Ecosystem Services: Use table

	Economy							Environment						Total	
	Primary sector (agriculture)	**Secondary sector**	**Tertiary sector (tourism)**	**Homes**	**Government**	**Rest of the world**	**Agriculture**	**Forests (primary)**	**Tropical forest (primary)**	**Shrubland (primary)**	**Other forest (primary)**	**Secondary vegetation**	**Other land uses**	**Total (2013 MEX $ millions)**	**Total (% of 2013 GDP)**
Crops (total)	163 666.51													**163 666.51**	**1.0055%**
Grain corn	26 762.22													**26 762.22**	**0.1644%**
Bean	5 146.91													**5 146.91**	**0.0316%**
Wheat grain	5 765.07													**5 765.07**	**0.0354%**
Sorghum	7 312.92													**7 312.92**	**0.0449%**
Soy	560.96													**560.96**	**0.0034%**
Rice	284.50													**284.50**	**0.0017%**
Other crops	117 833.94													**117 833.94**	**0.7239%**
Carbon (total)					266 254.57									**266 254.57**	**1.6358%**
Biomass					50 213.33									**50 213.33**	**0.3085%**
Soils					216 041.24									**216 041.24**	**1.3273%**
Pollination (total)							32 276.79							**32 276.79**	**0.1983%**
Water (total)		**8 390.57**												**8 390.57**	**0.0515%**
Tourism (total)			**36 020.94**											**36 020.94**	**0.2213%**
	163 666.51	0.00	36 020.94	8 390.57		266 254.57	32 276.79							**506 609.38**	**3.1124%**

Notes: The 2018 pollination value in 2013 prices is used because the geo-referencing exercise with InVEST was conducted for 2018. Pollination is an intermediate ecosystem service and therefore is reported in agriculture.
Source: Prepared by the authors

6.8 Discussion

6.8.1 Conclusions

The monetary valuation of ecosystems can be seen as an instrument that allows to reflect the degree of importance that the flow of services from nature has for society, associated with its own well-being, and that, seen as a compensation mechanism, reflects the willingness of society to pay for maintaining the flow of services over time (provisioning, regulation, tourism and culture, among others). This mechanism may provide information to help in the comprehensive design of environmental policy instruments that allow efficient allocation of environmental assets and services, and that additionally enable the generation of financial resources to guarantee their sustainability over time.

The monetary valuation required the continuous analysis of proposals tested in exercises similar to the one we have developed in Mexico, which is why, at this stage of the project, good practices have been exchanged with countries such as the United Kingdom, Australia, Holland, Canada, among others within the United Nations Committee of Experts on Environmental Economic Accounting.

6.8.2 Recommendations:

The monetary valuation of ecosystem services relies on a considerable amount of physical data that serve as input for the biophysical models. Therefore, it is recommended to compile ecosystem services flow accounts, in a spatially-explicit manner, before starting with the monetary valuation in alignment with the recommendations of the SEEA EA.

Various methods to approximate the monetary valuation to exchange values were used during this pilot, It is recognized that further in-depth research must be undertaken, jointly with the relevant stakeholders with a view to obtain consensus and agree on a regular compilation of selected ecosystem services.

It is recommended to explore the relationship of ecosystem extent and condition with the provisioning of ecosystem services to obtain a measure of the capacity of ecosystem services. These relationships may not be linear and would imply further analysis. As a first step for the generation of integrated information, it is necessary to align the classifications between physical and monetary data and use the same temporal and geospatial dimensions.

This pilot on valuation of ecosystem services revealed the need to work in close coordination and collaboration with the experts in environmental economics, ecology and geospatial information within a more formal structure Although since the beginning of the project there has been an interinstitutional working group that has been accompanying the development of the accounts, it is important to improve the development of the account and a joint work programme, within the collegiate bodies of the SNIEG. In this way, the experience and knowledge of experts could also be broadened and include factors such as the SHCP, the Ministry of Economy and the Bank of Mexico, and representatives of INECC, SEMARNAT, CONAFOR, CONANP, SADER, INECOL, UNAM, U M, Colmex and INEGI, among others.

Section 7: Conclusions

The NCAVES project in Mexico achieved very important progress with the first pilot exercise at the national level for the development of the first ecosystem extent and condition accounts and the experimental valuation of some ecosystem services, following the guidelines proposed by the framework of the ecosystem accounting system, SEEA EA. The accounts were developed from national, geospatial, economic, and environmental data sets, which were integrated and compiled.

The results obtained from this project at the national level indicate that Mexico has the necessary information and analytical capacities to establish an accounting system that quantifies, values, and monitors ecosystems and the services it provides. Nevertheless, more work is needed in developing data, methodologies and classifications that are fully harmonized with the SEEA EA definitions, concepts and classifications.

Inter- and intra-institutional collaboration and data exchange have been fundamental to the development of the project. In this regard, INEGI has played an essential role in ensuring users' and producers' participation of information during the compilation stages of the ecosystem accounts. To ensure continuity to the project, these coordination efforts must be shifted to a formal coordination within the framework of the collegiate bodies of the SNIEG, in order to use the existing institutional infrastructure to establish a cross-cutting mechanism between different disciplines and sectors.

The pilot also demonstrated the importance of having a multidisciplinary team since the compilation of accounts requires a high degree, and a wide range of expertise in the areas of national accounting, geospatial information, ecosystems, biodiversity, environmental and ecological economics, so skills are needed to be able to interpret the data correctly. The contribution of the academia (scientists and researchers) was of great help to develop biophysical models and economic valuation, necessary for the generation of input data for the accounts.

It should be emphasized that for the preparation of the pilot accounts, classifications and open data were used at the national level that can be used immediately. In Mexico there is information that has potential use for accounts that could be adapted to the ecosystem accounting framework.

7.1 Main results of the pilot ecosystem account

7.1.1 Extent accounts

Ecosystem asset extent accounts provide relevant information by integrating several layers of geospatial information. The spatial distribution of ecosystems throughout the territory and ecosystem changes can be visualized at the national level, but also delineated by regions of interest such as NPAs, states, and ecoregions. The change analysis based on the use of change matrices allowed the identification of change processes and indicators of conversion and regeneration. This is extremely useful since it allows to prioritize the areas where the main processes of change are occurring, providing more useful information for decision-making.

As a result of this account, it was found that the ecosystems that have lost the greatest historical extent are the Evergreen tropical forest and Deciduous tropical forest, preserving about 50 per cent of their original extent, which results in loss of biological diversity and the structure of the ecosystem. For its part, the Grassland is now almost twice as large as its original extent. The change process affecting the greater extent is the conversion of natural ecosystems to anthropic areas, accounting for slightly over 3 per cent of the national territory. In the temporal analysis, a constant exchange between deforested and regenerated areas was observed, so that natural regeneration comprises half of the conversion area. Between 2002 and 2014, it was observed that the Coniferous forest is the ecosystem most converted to urban areas; the Coniferous and Mountain-cloud forests are the most converted to perennial agriculture; the Woody shrubland is more converted to urban areas while the Non-woody shrubland is more converted to annual agriculture and the tropical forest are more converted due to perennial agriculture (especially the Evergreen) and urban areas.

7.1.2 Condition accounts

In Mexico, as a result of discussion and collaboration with various institutions (INEGI, SEMARNAT, INECOL, CONABIO, CONAFOR, CONANP and IG, UNAM), it was decided to carry out the condition account included in the SEEA EA, using as a basis the Ecosystem Integrity Index, developed independently and in parallel by a group of researchers at the Institute of Ecology A.C. (INECOL), based on a theoretically coherent, integral and repeatable approach, as well as spatially explicit. The purpose of this index is to determine the integrity (condition) of Mexican ecosystems, taking advantage of a large amount of environmental data available for environmental monitoring in the country (the National Forest and Soil Inventory (INFyS) and the National Biodiversity Monitoring System (SNMB), the Land Use and Vegetation Charts and satellite images). Moreover, as part of the project, the information obtained by this index was compared with that obtained by considering the "vegetation conservation status" of the LUVCs and the Human Footprint Index.

The Ecosystem Integrity Index allows differentiation between structural (percentage of tree and shrub growth), functional (net photosynthesis), and pressure variables (percentage covered by human settlements), and it has the potential to generate more robust results as more variables are integrated in the Bayesian network.

Overall, between 2004 and 2018, structural variables on tree growth showed increases in most forest ecosystems, while shrub growth showed negative trends in almost all ecosystems. Functional variables exhibited an overall negative trend in most ecosystems, although with intensities fluctuating between moderate and low. Lastly, pressure variables show positive trends, especially that related to human settlements and bare soil, while herbaceous growth showed a negative trend in all ecosystems. When analysing the different ecosystems, it is observed that the most relevant changes in most of the structural variables with a negative trend, several of them relatively intense, occurred in the non-woody xeric shrubland. On the other hand, the most intense negative changes in the functional variables are registered in the woody xeric shrubland. On the other hand, the ecosystems showing the most extreme changes were anthropogenic (aquaculture, annual agriculture, permanent agriculture, human settlements, and planted forest).

7.1.3 Valuation of ecosystem services

According to the SEEA EA, this pilot used an approach that focuses on the exchange values of ecosystem services and therefore excludes other valuation approaches that may include other services and benefits. The monetary valuation analysis of ecosystem services and assets involves a large number of assumptions (i.e., there is sustainable use of resources), as well as inferences in order to analyse in detail the impact of the provision of such services in the economy. Therefore, these results should be considered as preliminary and partial since the whole ecosystem services basket, their potential future values, and the intrinsic ecosystem value have yet to be incorporated. Thus, the results obtained in this pilot only seek to identify the economic value of some of the ES in reference to their benefits to economic and human activities and leave room for improvement in later stages, and in a coordinated manner with the institutions of the environmental sector, of the work on valuation schemes for the total value of ecosystems in order to reduce or eliminate the initial assumptions and the uncertainty factors. It is noted that the approach for measuring (quantification and valuation) is centred on the so-called final ecosystem services, i.e. ecosystem service flows between ecosystem assets and economic units.

This analysis included only the monetary valuation of some of the final ecosystem services (i.e., excluding intermediate exchanges within ecosystems) with real or imputed exchange values, without considering the values associated with welfare. Notably, a monetary valuation proposal is made for:

7.1.3.1 Provisioning service for the agricultural sector and selected crops (rice, beans, maize, wheat, sorghum, and soy)

The contribution of these services is relevant, although with significant volatility and heterogeneity per crop. This is particularly important because agricultural activities contribute to national GDP, employment, exports, the well-being of the rural population, the evolution of poverty, the provision of inputs, and the food security of the country. The estimated monetary value of the contribution of these crops is consistent with the aggregate contribution and shows significant heterogeneity per product.

7.1.3.2 Regulating service for carbon capture and sequestration (in biomass and soil)

The monetary valuation of the carbon storage and sequestration service can be realized in a robust accounting framework based on the concept of monetary assets and flows. Thus, it considers the annual service of the carbon storage flux in t-1 and the carbon sequestration in period t. This valuation is sensitive to selected carbon price and interest rate values. Thus, it shows that climate change negotiations can impact the monetary value of the service and can subsequently even contribute to an improvement in the physical condition of ecosystems. Thus, transmission channels exist between physical and monetary flows with circular causality. The decomposition of the evolution of carbon sequestration in biomass and soils shows differentiated behaviours, for instance, between primary and secondary vegetation suggesting differentiated physical behaviours. The geo-referencing of the monetary value of the service shows its importance in the south and west of the country, suggesting its importance for regional development. Furthermore, this valuation is consistent with the design of public policies on climate change, with asset accounting and the new ecosystem accounting.

7.1.3.3 Pollination regulating service for agricultural crops

The information reviewed shows that animal pollination service, and therefore its loss, is relevant to agricultural production in Mexico. The monetary value at the municipal level of the potential pollination service demand represents 12.09 per cent of the agricultural production value in 2013 and, on average, 12.73 per cent of agricultural production for the period 2003-2018. Furthermore, by applying at the aggregate level the average potential provision of animal pollination, for 2013, is 7.74 per cent of agricultural production and 0.20 per cent of GDP and represents, on average for the period 2003-2017, 8.15 per cent of the gross agricultural production value.

Such results demonstrate that there is a gap between the potential supply and the demand of pollination for agricultural production. This is explained, on the one hand, to the loss of habitats for pollinators due to the expansion of the agricultural frontier that grew from 2002 to 2014 by 18.6 per cent (19,721.25 km2). In compensation for this loss, new forms of production and capacities of appropriation of the animal pollination service in agricultural production, differentiated by the type of producers and/or production, have been developed (e.g. manual pollination methods) Provision and regulating service of water supply.

The provisioning, regulating and cultural services of water resources in ecosystems contribute, through diverse channels, to economic activities and people's well-being. Yet, the diversity of provision of the service and the multiple effects and feedback processes of these services, make their monetary valuation difficult. Such estimates should therefore be considered as preliminary and require further research.

The monetary value of the ecosystem water service, estimated by the unit price method of resource rent, is 1.95 and 1.72 pesos per m3 derived from the System of National Accounts (SNA) and the Automated Census Information System (EC), respectively. The monetary value of the contribution of water resources for household consumption corresponds to 0.052 per cent and 0.039 per cent of GDP in 2013 for both data sources. In 2018 the value correspond to 0.044 per cent and 0.033 per cent of GDP. .

At municipal level, the monetary value of the contribution of water resources to water provision corresponds to 0.011 per cent and 0.014 per cent of the GDP in 2013 and 0.010 per cent and 0.012 per cent in 2018, considering the two available sources of information. The annual replacement costs of municipal wastewater and industrial wastewater correspond to 0.28 per cent and 0.54 per cent of 2013 GDP, and to 0.25 per cent and 0.49 per cent of 2017 GDP. The geo-referenced replacement costs by Hydrological Administrative Region show that the greatest monetary contribution of ES of water resources to economic and human activities is located in the west and centre of the country.

7.1.3.4 Cultural services in the nature tourism economy

Available information indicated that nature tourism in Natural Protected Areas (NPAs) is an activity of growing importance in the economic and social dynamics in Mexico.

Estimates of the monetary value show a contribution to product for the 15 NPAs, selected due to their tourist and biological interest (see chapter 6) is $36 021 million pesos representing 0.22 per cent of 2013 GDP. On the other hand, estimates made with a meta-analysis and meta-regression, indicate that the monetary value is 17 311 million dollars which represents 1.36 per cent of the 2013 GDP. Said monetary values, derived from the meta-analysis, are higher than the monetary accounting values, suggesting that there are still important opportunities in nature tourism in Mexico and the importance of other ES in NPAs.

It is expected that the conclusions and recommendations of this report will enrich the process to achieve in the future an integrated national ecosystem accounting system, with a geospatial approach, aligned with the international standard of the SEEA EA, and that it will be relevant and useful for policy and decision making (see the discussion section in chapters 4, 5, and 6 of this report).

In this first accounting exercise, great advances were made that have marked a path to follow for improving, consolidating and corroborating the results with groups of experts. However, the results are still experimental and it is necessary to gradually improve the measurements. In the case of ecosystem service valuation, the results may indicate that the value of the benefit of an ES may be related to factors outside the biophysical state of the ecosystem asset, and may be defined, perhaps, per market conditions. Therefore, it is important to deepen the analysis of the relationship between physical and monetary flows of ecosystem services and assets.

7.2 Next steps: towards the implementation of integrated accounting

Besides the lessons learned particular to each of the accounts, it was found that there are common themes that are fundamental to the implementation of an ecosystem accounting system that require future actions in order to improve and consolidate the progress made. The following are some of the issues that are considered important to improve and consolidate the progress achieved in this pilot project.

7.2.1 Data availability and interoperability

The implementation of the SEEA EA involves the identification, selection, integration and harmonization of the data available and produced in the country. For the implementation of the accounts, different environmental data Series generated by different institutions, including INEGI, were used allowing for progress to be made with the pilot in Mexico.

Mexico has an official information infrastructure at the national level that makes it possible to have the best information available. The national information system has an institutional architecture that allows specific work and the identification of available, relevant and quality information to be used for the production of accounts. INEGI has a central role in the generation of information, and in the coordination of the SNIEG with other institutions that develop other national information systems.

Each of these systems has a defined purpose, management methods, and information generated regularly. However, one of the main challenges faced during this project was the compatibility between the available information. The information generated by each of the institutions responds to their own needs and, although they share some characteristics, it was not easy to integrate them into the accounting system of the SEEA EA. This condition meant that in all cases the information had to be reorganized or recalculated to homogenize coverage or scale. A scheme such as the SEEA EA requires a careful selection of information to achieve homogenization and thus meet the accounting purposes.

It is important to have multidisciplinary teams with the skills to distinguish and interpret the information being used at the spatial and temporal scale in which they are working. Therefore, an inter-institutional collaborative approach allows data-producing institutions, through institutional arrangements, to adapt their information for use in ecosystem accounts. This collaboration ensures, on the one hand, that the institution's information retains its purpose and, on the other hand, that it can be used in accounting. The main advantage of this collaboration is to have their experience and knowledge of the institutional information used.

Given the importance of having a spatially explicit approach to ecosystem accounting, it is necessary to ensure and improve the production of useful datasets including increasing their frequency over time. In the same way, it is very useful to have official information in cell format (raster) that favours its organization and management, as well as the linkage with a tabular configuration that facilitates the analysis and its subsequent aggregation in other units of interest (municipality, state, basin, region, etc.) in projects such as these.

The project identified that there is a need for data over time that are developed according to the definitions and classifications of the SEEA EA or can be interoperable so that there is a clear correspondence based on mapping tables between different definitions and classifications. For instance, to calculate the ecosystem extent account, the classification developed by CONAFOR according to IPCC guidelines was used. However, further research should be taken to align this classification with the SEEA EA. To this effect, it is suggested to work on a national classification of ecosystems in a consensual manner, through an inter-institutional process, that corresponds with existing classifications and with the internationally agreed reference classification (IUCN GET). Moreover, it is important to explore mechanisms for data interoperability. In this regard, an interoperability mechanism based on artificial intelligence techniques and Bayesian networks is proposed [see Annex 9.2] with a view to identify correspondence and operate through multiple concepts and categories of ecosystem classifications.

7.2.2 Consolidation and integration of accounts

Although very significant progress has been made in understanding and determining the relationship between physical and monetary valuation analyses of ES in an integrated approach, e.g., a basket of services. There is also a need to refine approaches to better understand how ecosystem assets are linked to economic activities.

Now that a first approximation of the extent and condition accounts of ecosystems has been completed, an approach linking these accounts to the provision of ES should be developed. To deepen the analysis of the relationship between ecosystem extent and condition, it is essential to estimate ES using the same spatial structure. It is particularly interesting because it is seen that this relationship is non-linear with economic performance. This nonlinearity, which is even expressed as a complex association with the decisions and policies involved in the use of natural resources, deserves a further review in the light of available data and approaches. In the same vein, it is important to delve deeper into tipping points in ecosystems.

7.2.3 Bundle of ecosystem services and other accounts

It is considered important to include a more complete set of ES that can be built up gradually and based on a prior assessment to explore data needs and availability. The need was detected to deepen not only in individual ecosystem services but also in an integrated analysis, considering the rest of the services provided by each ecosystem (baskets of ecosystem services).

During the NCAVES project, efforts were made to compile the first estimate of coastal protection services in physical terms. It is considered of great importance to continue this work because of its ecological and economic importance. It is also recommended to explore the development of other thematic accounts for soils, forests, biodiversity, mangroves, and oceans, which would be very useful to be considered in a strategy for the deployment of an ecosystem accounting system that considers terrestrial, aquatic, and marine ecosystems.

7.2.4 Expansion and strengthening of working groups

The SEEA EA has the advantage of producing new information flows and data integration processes that allow interaction between systems that are siloed or sectored. Although the accounts can be elaborated individually, it was demonstrated that analysing each one of them separately is insufficient and hence the interest in developing a broad systemic approach, such as that of the SEEA EA, arises. Transdisciplinary interaction based on integrated information resources on involved subsystems is highly recommended. The development of this approach also requires the creation of new multidisciplinary and multisectoral discussion spaces where the socio-environmental dimension is integrated with a cross-cutting perspective. INEGI, together with SEMARNAT, has a very important role here to promote discussion and debate to continue promoting the formation and strengthening of working groups according to a research agenda that allows for integrated and coherent accounting.

7.2.5 Capacity building, coordination and institutional collaboration

As mentioned throughout this report, the development of this first pilot would not have been possible without the intra-institutional and inter-institutional collaboration and the central role of INEGI as coordinator of the information The constant development of the capacities of both producers and users of information is essential to achieve the operationalization of the accounts. Given that this process has a learning curve, it is advisable to collaborate with experts from institutions, universities, and research centres that can develop innovative solutions while supporting knowledge transfer and capacity building.

It is necessary to continue promoting the strengthening of this inter-institutional cooperation and the involvement of academic institutions that can contribute to innovation and the implementation of models and data that speed up the preparation of information and the integration of accounts. As a result of this pilot, findings and areas of opportunity have been identified to improve the compilation of the accounts, including incorporating new variables or indicators into the Index of Ecosystem Integrity; revising the classification of ecosystems used for accounting, temporal, and spatial alignment of the accounts; improving estimates of ecosystem services; and linking condition to ecosystem service provision. Finally, a critical evaluation of the viability of these variables and indicators so that they meet the criteria established by the SEEA EA is proposed.

Beyond the statistical part and the improvement of biophysical models and the strengthening of technical working groups, it is essential to scale up the existing coordination mechanism, where representatives of INEGI, the environmental sector, and other sectors identified in this project, such as the agricultural and livestock sector, the economic sector, and other experts in the areas of knowledge required for ecosystem accounting, continue to participate. Having an inclusive strategy with a holistic approach makes it possible to take advantage of the full potential of the ecosystem accounts system to assess the dimensions of the sustainability paradigm and to promote the well-being to which the country aspires.

7.2.6 Institutional Integration

A system such as the new Ecosystem Accounting will have to find ways to articulate with the policy instruments operating in the country. This is the case of instruments such as land-use plans, environmental assessment plans, and others summarized below.

The analysis of the legal framework, as well as the policy instruments, demonstrates that there are sufficient elements by which the generation, updating, and use of information on the extent, condition, and valuation of ecosystem services are a fundamental contribution to compliance with the provisions contained in at least eight federal laws on the environment and natural resources, water, forestry development, sustainable rural development, climate change, and wildlife. These foundations have to do both with the explicit definition of environmental services, as well as with the contribution that the information of this project gives to the application and evaluation of the policy instruments derived from these laws. The usefulness of the information from the accounts for the environmental sector stands out as input for instruments such as the ecological land-use planning (ETO), natural protected areas and environmental impact assessment, payment for environmental services, as well as instruments for the restoration of ecosystems and environmental compensation for land-use change. In other sectors, this information can improve decision-making in agriculture and livestock sector policies, as well as in urban, territorial, and agrarian development policies and in all those that have a direct impact on land use. These sectors have been the main drivers of the pressure factors that impact both the extent and condition of ecosystems. Therefore, knowledge and use of this type of information have the potential to make their impact on the territory visible and promote its reduction in the design of these policies. Finally, the results of this project contribute to the development of indicators that allow the systematic monitoring and evaluation of public policies.

The generation of information in the framework of the NCAVES project for Mexico also supports the fulfilment of international commitments on biodiversity, climate change, combating desertification and the 2030 Agenda for sustainable development. It also highlights, at this moment, the fact that there is a process of updating the commitments at the international level (Post-2020 Global Biodiversity Framework) where the SEEA EA is supporting the derivation of indicators for the Monitoring Framework for this framework. At the national level, the "Intergovernmental Dialogue on the updating of Nationally Determined Contributions" promoted by SEMARNAT and INECC stands out. It is important to be able to incorporate the concept and uses of ecosystem accounting to support these initiatives at the national level.

Concerning the role played by different actors within the framework of the project, it should be noted that the users and providers of the information form a broad and diverse spectrum that includes: a) government actors: ministries and agencies of the federal public administration; autonomous agencies; inter-ministerial commissions, state governments, and municipal governments, and b) other actors such as the Congress of the Union, universities and research centres, cooperation agencies and civil society organizations, and individuals, communities, and society in general, among others. In this regard, it should be noted that the information generated through information systems and inventories provides elements for better use of the territory.

Although the national territory is heterogeneous, environmentally, economically and socially, the results of this project contribute to the understanding of what are and where are the main dynamics of change of ecosystems and the services they provide. This information has a high potential to support better decision-making not only in the federal context but also at the sub-national level, in states, regions and municipalities.

It should be noted that accounting for the extent and condition of ecosystems, as well as the quantification and valuation of the services they provide, offers a new frame of reference for the design of policies with territorial implications. Through such accounting, decision-making could consider not only the economic and social benefits and the provision of ecosystem services provided by ecosystem assets but also the capacity of ecosystem assets to remain to function. Lastly, the linkage between user needs and the information resulting from ecosystem accounting makes this framework useful for decision-making in the design of policies, plans and programmes.

In summary, at a conceptual and methodological level, the next steps should include:

- Expand the supply of data on physical flows of ecosystem services with a view to strengthen the possibilities of monetary valuation in the integrated scheme of the accounts;

- Link the physical data from ecosystem accounts (extent and condition accounts) with the flows of ecosystem services to reflect in the valuation of ecosystem services the state, extent and condition of ecosystems;

- Use geospatial data and Earth observations, including the use of the geospatial data cube, to integrate the spatial dimension into the analysis at national and subnational level (i.e., natural protected areas, water basins, municipalities). This is one of the main contributions that Mexico can make to ecosystem accounting, considering that it is underpinned by geospatial data

- Explore the compilation of biodiversity, climate change and ocean accounts and include coastal protection and disaster risk reduction as key ecosystem services. This would help to align with the discussions at the international level, where issues of monetary valuation and adequate measurement of biodiversity are still in process.

In terms of the institutional framework that would ensure a comprehensive implementation of ecosystem accounting in Mexico, it is particularly important to ensure that strong partnerships and a solid governance structure is established. In this regard, it is important to consider:

- The need for an institutional architecture for ecosystem accounting within the infrastructure of the SNIEG with a view to create an inter-functional, multidisciplinary cross-cutting committee.

- Consolidate and enhance the interinstitutional participation, which will be broad enough as to include not only the environmental sector, but also other key sectors such as agriculture, finance, economy, tourism, land development as well as researchers and the private sector.

- Include the relevant institutions and other stakeholders as strategic partners in the process for the development and implementation of ecosystem accounting, not only as key data users or providers, but also as key actors in the conceptual and methodological discussions, processes and information needs for the design and monitoring of public policies.

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Section 9: Annexes

9.1 Classification of terrestrial ecosystems in Mexico and their correspondence with other classifications

Table 9-1: INEGI full vegetation classification and correspondence with the aggregate classes prepared by CONAFOR for reporting to the Intergovernmental Panel on Climate Change (IPCC). The approximate correspondence with the IUCN Global Ecosystem Typology is also shown.

INEGI	CONAFOR-IPCC-N3	IUCN Global Ecosystem Typology
Aquaculture	Aquaculture	F3 Artificial wetlands
Water bodies	Water bodies	F1 Rivers and streams/F2 Lakes/F3 Artificial wetlands
Annual wet agriculture	Annual crops	T7.1 Croplands
Annual and permanent wet agriculture		
Annual and semi-permanent wet agriculture		
Annual irrigated agriculture		
Annual and permanent irrigated agriculture		
Annual and semi-permanent irrigated agriculture		
Semi-permanent irrigated agriculture		
Semi-permanent and permanent irrigated agriculture		
Annual rainfed agriculture		
Annual and permanent rainfed agriculture		
Annual and semi-permanent rainfed agriculture		
Semi-permanent rainfed agriculture		
Semi-permanent and permanent rainfed agriculture		
Permanent wet agriculture	Permanent crops	

INEGI	CONAFOR-IPCC-N3	IUCN Global Ecosystem Typology
Semi-permanent wet agriculture		
Semi-permanent and permanent wet agriculture		
Permanent irrigated agriculture		
Permanent rainfed agriculture		
Urban/built	Human settlements	T7.4 Urban and infrastructure lands
Urban areas		
Planted forest	Planted forest	T7.3 Plantations
Douglas-fir forest	Coniferous forest	T2.1 Boreal and montane needle-leaved forest and woodlands)
Cedar forest		
Juniper forest		
Pine forest		
Pine-oak forest		
Oyamel fir forest		
Coniferous shrubland		
Oak forest	Oak forest	T2.2 Temperate deciduous forests and shrubland
Oak-pine forest		
Mountain-cloud forest	Mountain-cloud forest	T2.4 Warm temperate rainforests
Tropical mesquite	Deciduous tropical forest	T1.2 Tropical/subtropical dry forests and scrubs
Subtropical shrubland		
Low deciduous tropical forest		
Low deciduous thorny tropical forest		
Medium deciduous tropical forest		
Low semideciduous tropical forest	Semideciduous tropical forest	
Medium semideciduous tropical forest		
High evergreen tropical forest	Evergreen tropical forest	T1.1 Tropical/subtropical lowland rainforests
High semievergreen tropical forest		
Low evergreen tropical forest		

INEGI	CONAFOR-IPCC-N3	IUCN Global Ecosystem Typology
Low thorny semievergreen tropical forest		
Low semievergreen tropical forest		
Medium evergreen tropical forest		
Medium semievergreen tropical forest		
Crasicaule shrubland	Woody xeric shrubland	T3.1 Seasonally dry tropical shrublands
Tamaulipan thorny shrubland		
Xeric mesquite		
Chaparral		
Coastal rosette shrubland		
Sarcocaule shrubland		
Sarco-crasicaule shrubland		
Submontane shrubland		
Mist sarco-crasicaule shrubland		
Microphyll desert shrubland	Non-woody xeric shrubland	T5 Deserts and semideserts
Desert rosette shrubland		
Sandy deserts vegetation		
Halophytic xeric vegetation		
Gallery forest	Woody hydrophytic vegetation	FT1 Palustrine wetlands
Gallery tropical forest		
Gallery vegetation		
Petén		MFT1 Brackish tidal systems
Mangrove		
Mesquite forest	Other types of woody vegetation	T1 Tropical-subtropical forests
Natural palm grove		
Induced palm grove		
Induced forest		
Planted grassland	Grassland	T7.1 Sown pastures and old fields

INEGI	CONAFOR-IPCC-N3	IUCN Global Ecosystem Typology
Halophytic grassland		T4 Savannahs and grasslands
Induced grassland		
Natural grassland		
Gypsum grassland		
Savannah		
Savannah vegetation		
High mountain meadow		T6.5 Tropical alpine meadows and shrublands
Thalia geniculata	Non-woody hydrophytic vegetation	FT1 Palustrine wetlands
Halophytic hydrophytic vegetation		
Tule forest		
Sandy dunes vegetation	Other non-woody vegetation types	TM2.1 Coastal shrublands and grasslands
Area deprived of vegetation	Other lands	N/A
Without apparent vegetation		

9.2 Proposal for the interoperability of ecological data available in Mexico in the NCAVES project framework

A positive contribution of the NCAVES project and the SEEA EA has been the creation of mechanisms enabling the interoperability required to consider the interests of different users. In this context, this proposal is a concrete contribution to this endeavour. Consequently, we have developed a computer resource focusing on the following question: How much do the different classifications share? Although we understand that a high correspondence between them is to be expected, will it be possible to directly determine what the correlation between them is, and more accurately, what are the specific patterns of correspondence between the classes represented? To address these concerns, we use tools from the field of so-called “artificial intelligence”. Our solution seeks to clarify connections and operate through the multiple concepts and intentions of use embedded in the different approaches to catalogue ecosystemic geography aspects.

This proposal relies on the family of statistical models known as "Bayesian networks" or “influence networks.” Such models have been used in the artificial intelligence field and have proved to be highly successful as computational devices that could resemble human reasoning modalities in terms of inference and deduction. Bayesian network modelling is a mathematical tool devised by Pearl (1988) as a formalism for developing intuitive, versatile, and powerful models. Bayesian networks have been successfully used in a wide range of applications involving prediction, anomaly detection, diagnosis, automated perception, reasoning, prediction over time, and decision making under uncertainty. Generally, they are beneficial for making weighted use of different data sources, to optimise the probabilistic formulation of conclusions. A final key aspect is that model building can be largely supported by the data at hand, opening up the possibility of developing “data-driven” numerical modelling approaches, complementary to “expert ruling-driven” and theoretical models.

9.2.1 Bayesian Networks

A Bayesian network is defined as a graphical model or probabilistic graphical model (there are references to this in econometrics under the concept of causal analysis and do-calculus.) A graphical model refers to models associated with structures forming a graph, that is nothing more than a depiction of the pattern of the way a set of variables influence each other. In a graph, variables are represented as “nodes” and influence by lines or “arcs”. This collection of nodes and arcs is a qualitative graphical representation of how variables are thought to influence each other (causally or by providing data or “evidence”.) Such a graphical representation is also called “the topology” of the system since it forms a qualitative map of the system. For Bayesian networks, the influence between variables is required to be directional (represented by arrows suggesting the destination of the influence) and that there are no feedback loops to any of the nodes in the network. This specific type of topological structure is called “Directed Acyclic Graph” (DAG). It is sometimes a concern that these representations do not tolerate feedback loops, but this is not always the case, given that, in a causal chain, time creates the possibility of having “copies” of the topology that may then include “repeated” nodes that influence each other over time.

Bayesian networks also include a quantitative component. This is done through a table consisting of the conditional probability values which define the node and form the conditional probability table (CPT, a kind of cross-table), of the node. Such a table will have as many entries as variables converge at a node. Each table entry corresponds to some kind of “node response” conditional on the data provided. From these two elements:

1) Qualitative through the network topology and 2: Quantitative through the conditional probability table. The model can make calculations combining the probability values generated from data (evidence) provided to some nodes, to predict the state that would be expected at other nodes of interest. A Bayesian network is

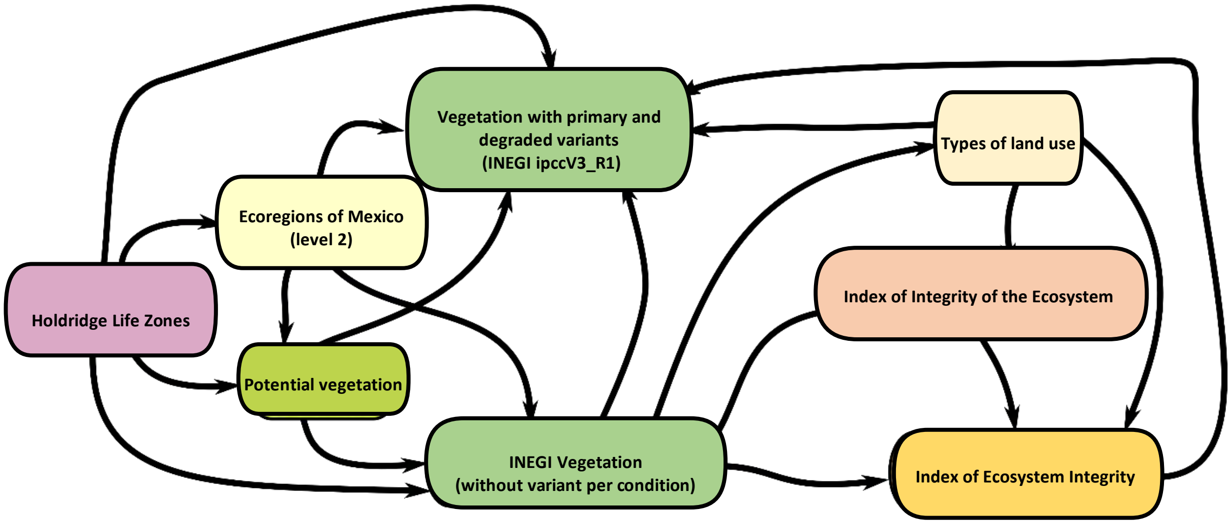
always a description of the joint probability distribution of the system being modelled. It generates “reasoning” forms in artificial intelligence terminology, which are just various ways of combining pieces of evidence to calculate the most likely state that the network as a whole would have, given the data provided. Using such a device makes available an effective means of “contextually translating” equivalences between classification.

9.2.2 Modelling interactions between social-ecological data

The Bayesian network we developed to analyse the correspondence between the different classifications, the interaction with human influence indicators, and their relationship with the index of ecosystem integrity (a measure of condition), embodied the following components as depicted in Figure 9-1.

- Ecoregions of Mexico (level 2, variable with 24 levels)
- Human Footprint Index (continuous variable between 0 and 10 discretised at 5 levels)
- Index of Ecosystem Integrity (continuous variable between 0 and 1 discretised at 5 levels)
- Type of land use (variable with 7 classes)
- INEGI Vegetation (IPCCv3R1, variable with 32 classes)
- INEGI Vegetation reduced (variable with 16 classes)
- Potential vegetation (variable with 10 classes)
- Holdridge Life Zones (variable with 28 classes).

Fig. 9-1: Network structure on interoperability of ecological and use representations.



Network training from data

All processing of the Bayesian network has been done with the NETICA application by Norsys. The network was "trained" (adjusted), by providing data for all the variables contained in the graph. The count-learning algorithm (in Netica) was applied. This method is relatively simple but follows the Bayesian probability calculus logic. Roughly speaking, this algorithm starts with an equiprobability network, i.e., in a complete state of "ignorance". This is fed in sequence with "cases", which are data collections with specific values for each of the variables (collections that may or may not be complete, depending on the data available). Each case is analysed to find which nodes it provides data for and whether it also provides data for all nodes on which these nodes depend, and in which case the necessary calculations are made to update the probabilities at the relevant nodes in the network. As can be seen, this process can be described as a "learning" process, thus the "training" terminology widely used in the Artificial Intelligence field.

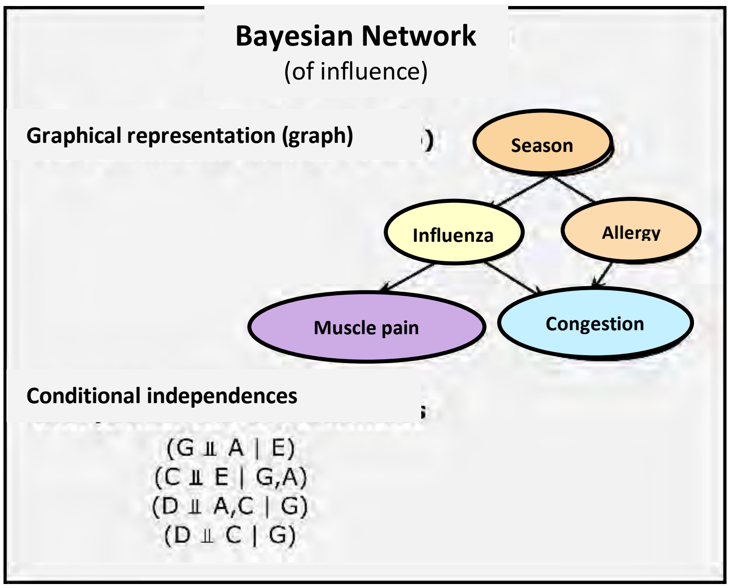
Data used for training were taken from the digital mapping that has been collected for the NCAVES project. All products are in raster format with a pixel size of 250 m per side. Thus, the databases processed are each associated with tables containing 30 470 057 records. This makes a total of 457 050 855 cases processed in the case of the proposed network. Reference vegetation used was that of Series 6, the Human Footprint index that of 2014 and the Ecosystem Integrity index of 2018. Holdridge Life Zones, Ecoregions (level 2), and Potential Vegetation coverages correspond to products that do not refer to time, but rather to context.

9.2.3 Association patterns between mapped categories

The graph structure or DAG relates to influence and data flow patterns. The DAG is expressed in structures in the network which can be characterised through the notion of "independence" in probability terms. A significant feature of the DAG structure is that, although it is built from the relationships inferred to exist in the system under analysis, it also involves the existence of independence patterns and particularly conditional independence, accounting for the absence of specific influences (by data or causality), between system components. For instance, Figure 9-2 illustrates a DAG contrasting the relationship between "influenza" and "allergy" (hay fever), linked to the season of the year and its symptoms in a person. From the relationship structure shown, it is also possible to deduce inferences or implications that cannot be made, as they relate to combinations of variables that are independent.

For instance, in the influenza-allergy DAG, the implication is that if one starts from the data on the season of the year in which one is living, “influenza” and “allergy” are independent of each other, i.e., they are conditionally independent of the data on the “season”. Moreover, it can be seen that, if a person is diagnosed with influenza and allergy, seasonal data is no longer relevant to explain the presence of nasal congestion in a patient, and conditional independence is implied between “season” and the symptom “congestion”. This potential of DAGs to analyse the inference patterns implicit in the qualitative structure is the basis for the formulation of inference mechanisms or “reasoning” from data (evidence).

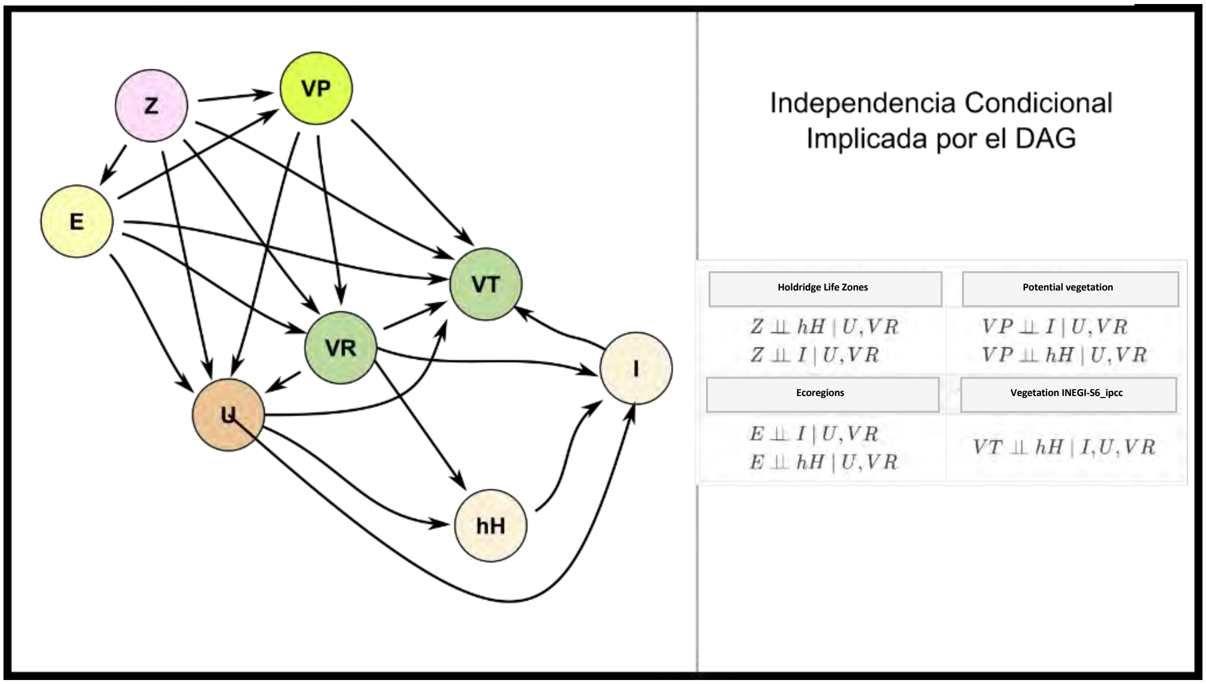
Fig. 9-1. Example of basic DAG and the independence patterns implied by the graph.



As can be seen in Figure 9-3 a conditional independence analysis for the network we have developed. We found 15 occurrences of independence implied by the pattern of influence we have identified. Examples of interpretations of what these conditional independence expressions suggest are as follows:

1. Using modified (reduced) vegetation table information and data on the type of use made of ecosystems, Life Zone and the Human Footprint Index become independent. ($Z \perp\!\!\!\perp hH | U, VR$). For instance, this suggests that combining the “Modified Vegetation” and “use type” data (the equivalent of the original INEGI-CONAFOR IPCC-Level III vegetation classification) yields enough data to characterise the anticipated state of the Human Footprint index not requiring Life Zone data. Conversely, having “modified vegetation” data, the Human Footprint Index, in particular, does not yield data for determining which Life Zone is most likely to be involved, provided the rest of the data in the network.

Figure 9-3: The conditional independence analysis implied by the graph associated with the network we have developed for the interoperability of environmental categories of the project.

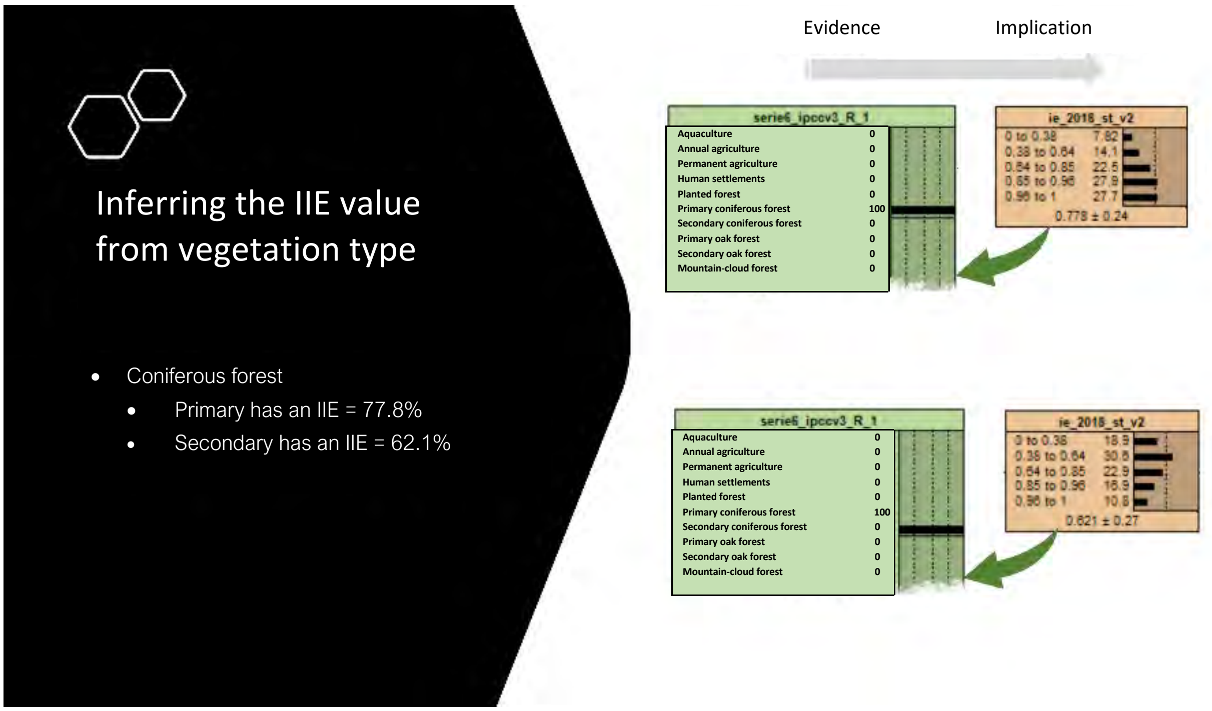


2. If integrity index, land use, and modified vegetation data are available, the Human Footprint index becomes independent of the Original Vegetation table. ($VT \perp\!\!\!\perp hH \mid I, U, VR$). That suggests that the intended configuration of the complete vegetation table would not use data from the Human Footprint Index, provided that data is simultaneously available from the integrity index and the simplified land use and modified vegetation tables we produced (in addition to data from the other nodes that may be available).

9.2.4 Inferences from the Bayesian Network

Based on the data contained in the nodes and following the data flow patterns described in the previous section, various inference processes can be performed. In the "Machine Learning" literature, the model can be used to produce different types of automated “reasoning”. For instance, Figure 9-4 shows that if the “Complete Vegetation” table is given as having Coniferous Forest secondary vegetation, then the Bayesian inference engine suggests that ecosystem integrity would be likely to have a range of values that would approximate the probability distribution as shown in the figure, where the most likely value (the average) would be 62.1%. Conversely, if the data we feed into the network is primary vegetation of the same forest type, then we find that the most likely value is 77.8%. It is important to consider that these results apply to the general distribution of vegetation type across the entire national territory, as the model was “trained” with these data.

Figure 9-4. Example of "deductive reasoning" from the proposed Bayesian model



Inference of the average integrity value that is associated with the "Coniferous forest" vegetation type in its "primary" and "secondary" variants is analysed

Table 9-2 summarises the accuracy (various indices including the percentage of correctly identified classes in the case of discrete variables), for each node, considering that data is fed to the network for all nodes (except the one of interest, naturally).

Table 9-2. Error rate is the percentage of cases erroneously classified by the network. Proximity to zero for the Logarithmic loss (0-inf) and Quadratic loss (0-2) indexes suggests better performance. For the Spherical Payment Index (0-1) the best performance is suggested by the closeness to 1. Matthews Correlation Coefficient (-1 to 1). Root Mean Squared Error in the measurement units, close to 0 suggests better performance.

Variable	Error rate	Logarithmic loss	Quadratic loss	Spherical payment	Matthew's correlation coefficient	Root mean squared error (rmse)
Ecoregions (level 2)	30.26	0.858	0.4108	0.75	0.65	
Human footprint [0-10] (2014)					0.39	2.18
Index of Ecosystem Integrity [0-1] (2018)					0.34	0.17
Types of use	0.01	0.001	0.0002	1.00	1.00	
Vegetation (S6_IPCC-V3.R1)	10.45	0.250	0.1519	0.92	0.88	

Potential vegetation	20.85	0.539	0.2973	0.83	0.73	
Reduced vegetation	0.05	0.004	0.0010	1.00	1.00	
Holdridge Life Zones	46.06	1.194	0.5826	0.63	0.49	

As expected, results reveal that there is no perfect correlation between variables and that no perfect correspondence is reached across the network for any of the variables. Correspondence values are high in general, which suggests a good performance of the model. In the search for correspondence, the worst-case turned out to be the Holdridge Life Zones node. This would be expected as it is located as an "origin" node in the network structure, so there are relatively few sources of evidence to infer its status. Nevertheless, the network predicts at least twice as well as a completely random choice. Furthermore, results also suggest that the different products are not actually interchangeable and support the idea, as we argued at the beginning, of an important complementarity between them.

9.2.5 Interoperability of socio-ecological data

In this way, the network we have developed seeks to be a support to facilitate, in the best possible way, using different ways to describe the ecological scenario and the socio-ecosystemic factors identified, which are in operation in the space. It was observed that it is possible to generate reasonable interpretations of the different variable combinations and that the computational mechanism allows for enriched interpretability of the results that the SEEA is producing. This is valuable as it facilitates the assimilation of the results and broadens their potential to generate useful information for decision-making.

The NCAVES project made it possible to build a pilot database consisting of a collection of cartographic products homogenised in terms of their attributes of projection, extent, and spatial resolution. The spatially explicit database is efficiently linked to the Bayesian network we have built and together they become an interesting source for consultation. To do so, there is the added value of being able to use the "automated reasoning" capabilities described above. This approach to the challenge posed by the SEEA has great potential for development because, as we have seen, the theoretical basis for the construction of this type of model allows the confluence of the experience of multiple disciplines, in this case from ecology to economics. Successful experiences in the use of the "Directed Acyclic Graph" approach exist in all the fields of interest of the SEEA, and the development we report here demonstrates its integrative potential.

Figure 9-5: SEEA geospatial data integration concept. This is uniform 250m raster geographic coverage with congruent projection and extent data. In this way, each pixel can be imagined as a variable "stack".

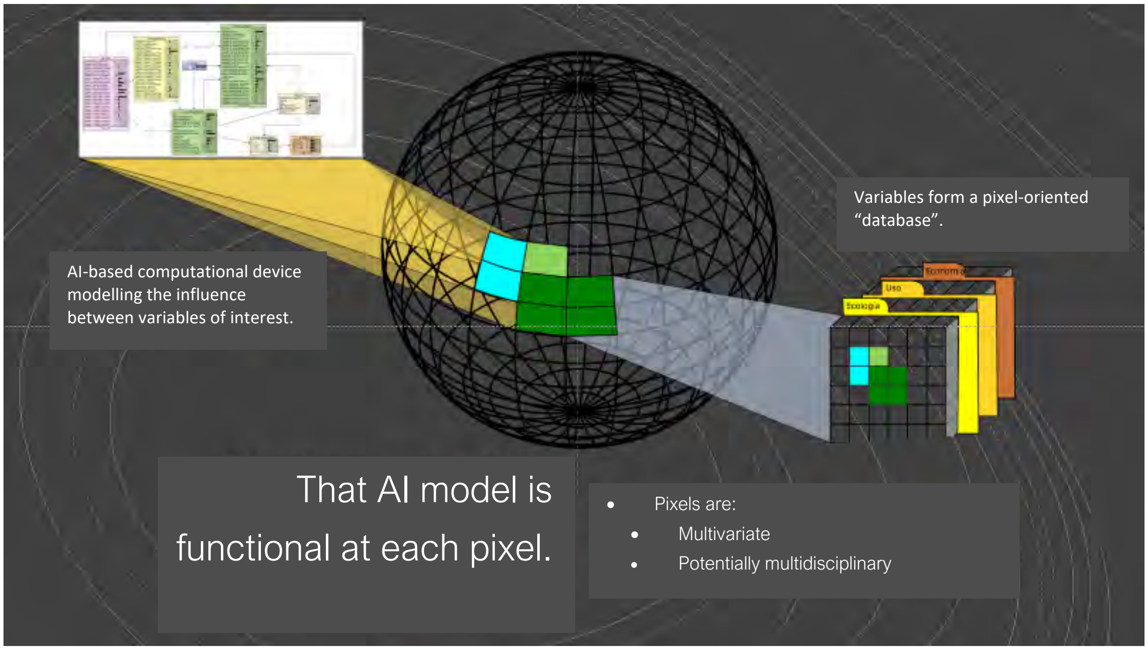
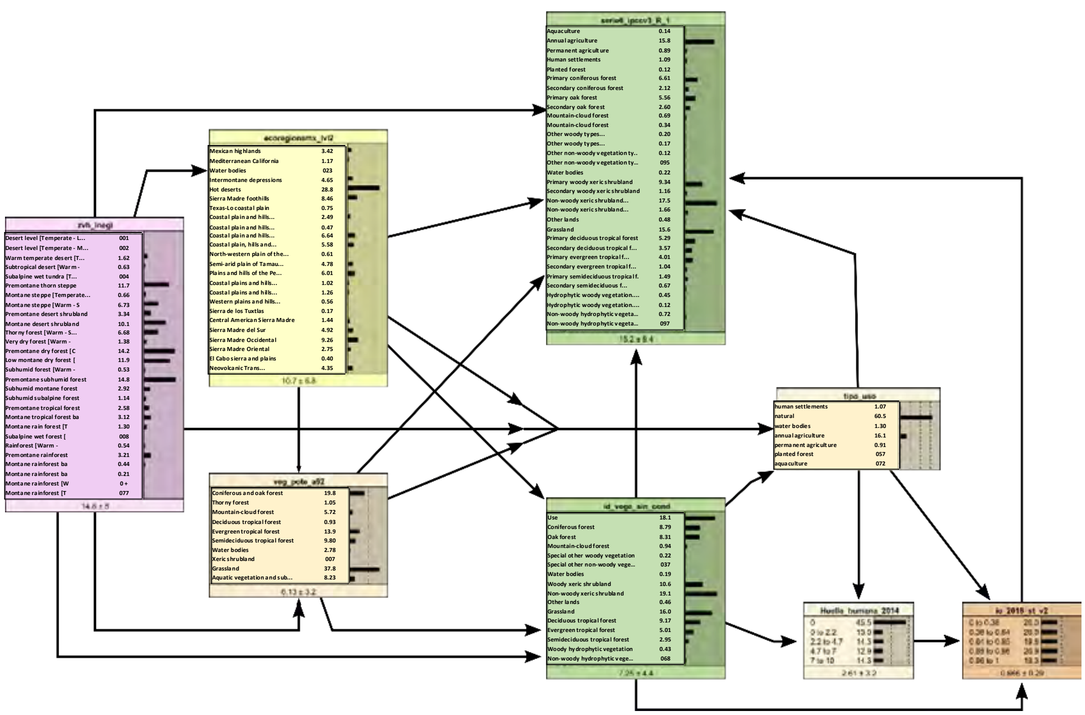


Figure 9-6: "Baseline" or "a priori" state of the proposed Bayesian network. The values that appear are basically the "pixels" ratio under each condition according to the node at hand.



An overall picture of the state of the variables and their relationships resulting from the inspection of the proposed Bayesian network of ecological and human use attributes can be seen in Figure 9-6. The first interesting picture that the network clearly shows is the distribution pattern of ecosystem attributes in Mexico, as well as the land-use variants of the national territory. That is the "baseline state" of the network and is a summary of the frequency with which each of the attributes appears in Mexico. The most frequent life zone in Mexico is the Premontane semiwet forest [Warm-Rainy] (14.8% of the land). Warm Deserts (28.8%) is the largest ecoregion. The most frequent potential vegetation is Grassland (37.8%). The most abundant vegetation type is the non-woody xeric shrubland (19.1%) and also in its primary variant (16.9%). A large percentage of the national territory has natural vegetation (80.6%), which we label as "natural" in the "land use" node. This correlates to an overall Human Footprint Index of about 26% and an Index of Ecosystem Integrity of 67%.

Another example of questions that can be posed to the network that we have built. would be, how is annual crop agriculture deployed in Mexico's ecological scenario?

This even includes the association with the ecosystem condition indicator. The result is illustrated in Figure 9-7. These lands report on average a Human Footprint Index of around 67% and an Index of Ecosystem Integrity of 45%. Ecological units in which this type of agriculture has been predominantly established in Mexico are the semiarid regions, certainly also strongly associated with tropical and temperate forest areas. The remaining types of use can be seen in Figure 9-8.

Figure 9-7: The effect of consulting on a "deductive reasoning" regarding what happens with the deployment of annual agriculture in Mexico. Each node is reconfigured based on the evidence provided in the "type of use" node.

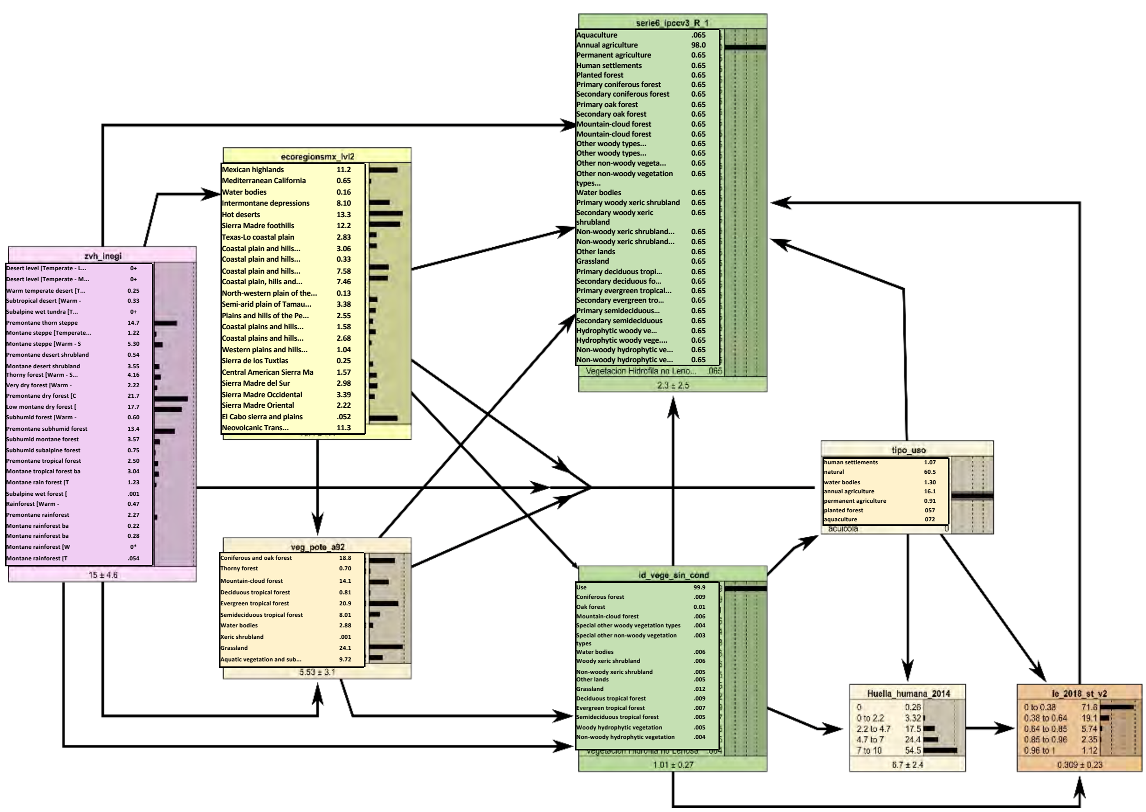
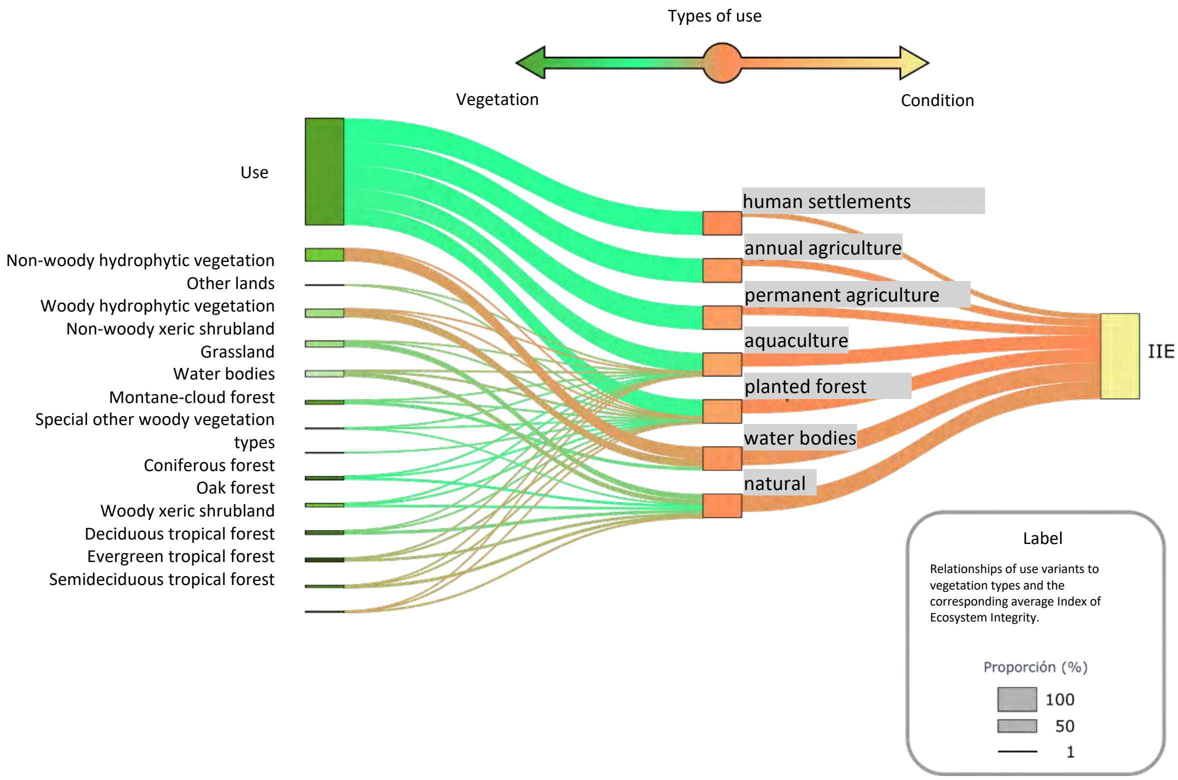


Figure 9-8: Interaction pattern between network nodes when analysing the effect of various types of use



Similar or more complex questions, involving several pieces of “evidence” can be posed to the network simultaneously. Also, queries can be made from specific pixel data of the national geography and the result can then be expressed in cartographic form. Clearly, the potential is enormous.

9.3 Analysis of changes in the ecosystem's extent at the national level by intermediate periods

In the 2002-2007 period, changes between land use show a dynamic exchange between annual and permanent crops and urbanization occurs mainly due to the conversion of Annual agriculture. Conversion mainly affects tropical forests, where the Deciduous tropical forest stands out, by Annual agriculture fields, followed by Perennial agriculture and Urbanisation. Coniferous and Oak forests, Special woody Vegetation, woody vegetation, with annual agriculture as the recipient of these regressions. In Coniferous and Mountain-cloud forests also crops are important to change drivers. The conversion of Non-woody xeric shrubland is almost 3 times more extensive than for Woody xeric shrubland. Conversion is less extensive in evergreen and semideciduous forests than in forests. For shrubland, urbanisation is more important as a driver of conversion than in forests. Grassland conversion to agricultural fields is almost 10 times larger than forest conversion. For forests, a strong exchange between conversion and natural regeneration is noted, as well as for Woody special and Woody hydrophytic vegetation. For the rest of the natural vegetation, the areas affected by conversion are at least twice as large as what could have been recovered by natural regeneration (Table 9.3).

In the following period analysed (2007-2011), changes between land use show an exchange between Annual and Perennial agriculture, although it is less intense than in the previous period. The transition from Annual to Perennial agriculture predominates. Regarding conversion, the extent for the Deciduous tropical forest is reduced to less than half, while for the Evergreen tropical forest conversion increases and also does so for the Semideciduous tropical forest. There is also a decrease in conversion affecting Oak forests, but it is minor than that in Coniferous and Special woody forests. The opposite happens in the Mountain-cloud forest, given that the conversion increases in this case. For Woody shrubland, the conversion increases, while for Non-woody shrubland, the conversion decreases. Conversion decreases four times for Woody hydrophytic vegetation and remains constant for Non-woody vegetation. Conversion of Grassland to Annual agriculture continues to occur, although is minor than that in the previous period, but Urbanization increases at the expense of Grassland (Table 9-4). Natural regeneration decreases in the Mountain-cloud forest and for Special woody vegetation, while it increases in the Woody and Non-woody xeric shrubland, Deciduous tropical forest, and Non-woody hydrophytic vegetation types. Overall, the same drivers of change remain.

During 2011-2014, changes in land use show a decrease in the exchange between annual crops, and the dominant pattern of Annual to Perennial agriculture transition is maintained. There is a decrease in the extent of conversion of Deciduous and Semideciduous tropical forest (4 times), Evergreen tropical forest (3 times), Non-woody shrubland (7 times) and Coniferous forest, Oak, Special woody vegetation types, Woody shrubland, and Woody hydrophytic vegetation (10 times, Table 9-5). In Montane-cloud forest conversion increases and Perennial agriculture gains in importance as a direct driver of change, relative to Annual agriculture. In the Non-woody hydrophytic vegetation, conversion is maintained at a high level. Grassland urbanisation decreases 10 times, but conversion to Annual agriculture remains almost at the same level as in the previous period. Natural regeneration decreases for Coniferous forest, Oak, Montane-cloud, Special woody vegetation types, and Woody and Non-woody hydrophytic vegetation, while it increases for Non-woody shrubland and Grassland. The same transformation drivers of the national landscape are retained.

Table 9-3: Change matrix for the 2002 (rows) - 2007 (columns) period with transitions area in km²

	Anthrogenic ecosystems (land use)					Natural terrestrial ecosystems																
2007 Series IV / 2002 Series III	Aquaculture	Annual cropland	Perrenial cropland	Human Settlements	Planted forest	Coniferous forest	Oak forest	Mountain-cloud forest	Special other woody vegetation types	Special other non-woody vegetation types	Woody xeric shrubland	Non-woody xeric shrubland	Other lands	Grassland	Deciduous tropical forest	Evergreen tropical forest	Semideciduous tropical forest	Woody hydrophytic vegetation	Non-woody hydrophytic vegetation	Water bodies	Adjustments	**Opening extent, 2002 (Serie III)**
Aquaculture	614	0	0	0	0	0	0	0	0	0	0	65	0	0	0	0	0	3	0	NA	0	**683**
Annual cropland	12	273 720	835	1 682	11	1 720	1 563	114	125	2	972	1 574	31	6 138	3 602	489	387	138	152	NA	1	**293 268**
Perennial cropland	1	707	14 383	149	4	109	12	25	0	2	3	3	6	564	155	71	19	19	8	NA	0	**16 239**
Human settlements	0	93	5	12 500	2	2	4	0	0	1	5	14	1	15	5	6	2	2	0	NA	0	**12 657**
Planted forest	0	10	0	1	302	0	4	0	0	0	0	0	0	3	0	1	0	0	0	NA	0	**322**
Coniferous forest	0	1 743	89	21	1	162 416	2 098	282	0	0	9	9	1	1 715	231	9	48	0	0	NA	0	**168 673**
Oak forest	0	1 744	16	13	13	2 223	147 711	121	57	0	57	9	9	2 407	1 764	57	156	8	0	NA	0	**156 366**
Mountain-cloud forest	0	98	81	1	0	220	30	17 611	0	0	0	0	0	174	3	31	2	0	0	NA	0	**18 252**
Special other woody vegetation types	0	169	0	4	0	0	44	0	3 827	0	61	29	1	74	61	0	3	2	2	NA	0	**4 279**
Special other non-woody vegetation types	4	1	3	16	0	0	0	0	0	1 507	5	4	4	4	1	0	0	13	1	NA	0	**1 562**
Woody xeric shrubland	56	1 624	28	296	0	14	47	0	21	6	207 116	589	37	1 470	97	0	0	44	17	NA	0	**211 462**
Non-woody xeric shrubland	75	4 906	29	249	0	71	214	0	72	4	346	362 337	272	1 652	0	0	0	85	5	NA	1	**370 318**
Other lands	33	36	20	12	0	1	3	0	0	8	7	60	9 150	88	4	7	1	34	22	NA	9	**9 493**
Grassland	21	12 882	794	624	32	1 311	2 667	143	115	2	635	2 664	176	285 044	3 737	3 154	646	194	416	NA	0	**315 257**
Deciduous tropical forest	7	6 053	250	221	2	201	1 500	3	54	2	75	191	36	4 637	165 863	90	363	75	20	NA	0	**179 643**
Evergreen tropical forest	0	1 304	238	184	4	16	88	44	0	0	0	0	5	4 716	139	98 028	267	55	134	NA	0	**105 222**
Semideciduous tropical forest	0	1 199	41	42	4	54	257	86	1	0	0	0	1	1 530	1 122	718	42 494	30	20	NA	0	**47 599**
Woody hydrophytic vegetation	11	114	11	11	0	0	5	0	0	10	27	21	6	45	23	34	28	10 678	265	NA	2	**11 290**
Non-woody hydrophytic vegetation	76	272	13	20	0	0	2	0	4	2	5	18	6	482	37	140	3	300	12 900	NA	0	**14 278**
Water bodies	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	27 548		
Adjustments	0	1	2	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	NA	-7	
Closing extent 2007 (Serie IV)	**909**	**306 675**	**16 840**	**16 045**	**374**	**168 358**	**156 248**	**18 430**	**4 276**	**1 544**	**209 323**	**367 585**	**9 742**	**310 759**	**176 845**	**102 838**	**44 420**	**11 680**	**13 964**	**27 548**		**1 964 402**

Figures in grey represent unlikely changes. Rows represent time 1, columns time 2, such that the quantity in each cell represents the quantity that moved from one category at time 1 (row) to another category at time 2 (column). Diagonal white cells represent the permanence of each category

Table 9-4: Change matrix for the period 2007 (rows) -2011 (columns) with the transition area in km²

	Anthrogenic ecosystems (land use)					Natural terrestrial ecosystems															
2011 Series V 2007 Serie IV	Aquaculture	Annual cropland	Perrenial cropland	Human Settlements	Planted forest	Coniferous forest	Oak forest	Mountain-cloud forest	Special other woody vegetation types	Special other non-woody vegetation types	Woody xeric shrubland	Non-woody xeric shrubland	Other lands	Grassland	Deciduous tropical forest	Evergreen tropical forest	Semideciduous tropical forest	Woody hydrophytic vegetation	Non-woody hydrophytic vegetation	Water bodies	Adjustments	**Opening extent 2007 (Serie IV)**
Aquaculture	892	9	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	3	4	NA	0	909
Annual cropland	6	285 086	1 061	3 453	39	1 377	946	162	45	4	1 057	3 790	99	4 369	3 784	884	389	66	56	NA	2	306 675
Perennial cropland	0	383	15 223	181	28	28	19	28	0	0	35	11	13	372	255	224	22	12	3	NA	1	16 840
Human settlements	0	70	4	15 858	3	1	1	0	0	0	6	6	10	39	8	24	1	6	1	NA	8	16 045
Planted forest	0	6	1	11	334	8	2	0	0	0	2	0	0	3	0	6	0	0	0	NA	0	374
Coniferous forest	0	1 319	84	52	84	164 319	1 265	67	2	0	22	50	11	937	145	1	0	0	0	NA	0	168 358
Oak forest	0	1 010	24	29	14	605	152 163	10	8	0	73	214	45	1 355	626	28	43	0	2	NA	0	156 248
Mountain-cloud forest	0	439	83	22	0	81	13	17 440	0	0	2	0	2	290	0	54	5	0	0	NA	0	18 430
Special other woody vegetation types	0	146	2	4	1	9	102	0	3 846	0	90	37	2	28	3	5	0	0	1	NA	0	4 276
Special other non-woody vegetation types	3	11	1	8	1	0	0	0	0	1 491	0	0	8	2	1	1	0	9	0	NA	8	1 544
Woody xeric shrubland	22	1 647	62	276	0	65	196	0	5	2	203 389	284	125	3 105	93	0	24	20	5	NA	2	209 323
Non-woody xeric shrubland	114	2 997	32	125	0	23	230	0	113	2	439	360 782	287	2 266	0	0	0	85	86	NA	5	367 585
Other lands	19	50	0	23	1	39	0	0	0	9	7	241	9 206	52	11	3	1	53	12	NA	14	9 742
Grassland	6	9 257	673	985	114	1 254	3 026	218	123	2	1 008	621	178	283 760	4 690	3 630	736	89	386	NA	4	310 759
Deciduous tropical forest	3	2 519	120	142	1	81	319	0	10	0	34	4	98	4 426	168 793	22	244	20	8	NA	1	176 845
Evergreen tropical forest	0	2 087	263	159	30	4	33	113	0	0	0	0	12	4 025	39	95 601	248	30	195	NA	0	102 838
Semideciduous tropical forest	0	2 640	34	38	5	9	32	67	1	0	0	0	4	1 759	318	764	38 732	3	12	NA	0	44 420
Woody hydrophytic vegetation	5	52	3	22	0	0	0	0	0	22	7	2	41	49	13	75	12	11 271	96	NA	11	11 680
Non-woody hydrophytic vegetation	13	82	1	10	0	0	0	0	35	0	2	0	19	113	22	100	1	85	13 477	NA	5	13 964
Water bodies	1 085	309 811	17 669	21 399	655	167 905	158 350	18 105	4 189	1 532	206 174	366 040	10 159	306 949	178 802	101 422	40 458	11 750	14 342	27 548		
Adjustments	0	0	2	0	0	0	0	0	0	9	1	0	6	3	0	0	0	1	3	26	-34	
Closing extent 2011 (Series V)	1 085	309 811	17 671	21 400	655	167 905	158 350	18 105	4 189	1 541	206 175	366 041	10 165	306 952	178 802	101 422	40 458	11 752	14 345	1 964 369	27 548	1 964 369

Figures in grey represent unlikely changes. Rows represent time 1, columns time 2, such that the quantity in each cell represents the quantity that moved from one category at time 1 (row) to another category at time 2 (column). Diagonal white cells represent the permanence of each category.

Table 9-5: Change matrix for the 2011 (rows) - 2014 (columns) period with transitions area in km²

	Anthrogenic ecosystems (land use)					Anthrogenic ecosystems (land use)															
Serie VI / Serie V	Aquaculture	Annual cropland	Perrenial cropland	Human Settlements	Planted forest	Coniferous forest	Oak forest	Mountain-cloud forest	Special other woody vegetation types	Special other non-woody vegetation types	Woody xeric shrubland	Non-woody xeric shrubland	Other lands	Grassland	Deciduous tropical forest	Evergreen tropical forest	Semideciduous tropical forest	Woody hydrophytic vegetation	Non-woody hydrophytic vegetation	Water bodies	Adjustments	**Opening extent, 2011 (Series V)**
Aquaculture	1 085	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0	1 085
Annual cropland	5	307 496	188	135	3	83	46	4	1	0	55	1 090	16	174	473	12	29	3	0	NA	0	309 811
Perennial cropland	0	38	17 525	14	4	0	0	0	0	0	0	0	1	75	10	5	0	0	0	NA	0	17 671
Human settlements	0	1	1	21 397	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	0	21 400
Planted forest	0	0	0	0	654	0	0	0	0	0	0	0	0	1	0	1	0	0	0	NA	0	655
Coniferous forest	0	232	64	4	0	167 310	29	0	0	0	0	0	3	263	1	0	0	0	0	NA	0	167 905
Oak forest	0	96	5	2	5	12	157 985	0	0	0	0	0	27	207	9	0	2	0	0	NA	0	158 350
Mountain-cloud forest	0	72	31	0	0	8	0	17 956	0	0	0	0	0	37	0	0	0	0	0	NA	0	18 105
Special other woody vegetation types	0	19	0	0	0	0	0	0	4 168	0	0	0	0	2	0	0	0	0	0	NA	0	4 189
Special other non-woody vegetation types	3	0	0	8	0	0	0	0	0	1 530	0	0	0	0	0	0	0	0	0	NA	0	1 541
Woody xeric shrubland	6	145	2	32	0	214	3	0	0	0	205 515	0	13	245	0	0	0	0	0	NA	0	206 175
Non-woody xeric shrubland	28	428	5	30	1	0	0	0	0	0	1	365 508	10	30	0	0	0	0	0	NA	0	366 041
Other lands	5	0	0	5	0	0	0	0	0	0	6	1	10 148	0	0	0	0	0	0	NA	1	10 165
Grassland	1	869	296	90	83	200	231	6	1	7	74	0	29	304 047	672	121	226	0	0	NA	0	306 952
Deciduous tropical forest	4	545	10	53	1	0	2	0	0	0	0	0	16	1 299	176 864	3	6	0	0	NA	0	178 802
Evergreen tropical forest	0	606	107	24	4	0	0	0	0	0	0	0	9	1 379	0	99 293	0	0	0	NA	0	101 422
Semideciduous tropical forest	0	378	27	1	0	0	0	0	0	0	0	0	1	448	9	2	39 592	0	0	NA	0	40 458
Woody hydrophytic vegetation	1	4	3	2	0	0	0	0	1	0	0	0	3	5	0	0	0	11 734	0	NA	0	11 752
Non-woody hydrophytic vegetation	18	26	12	2	0	0	0	0	1	0	0	0	4	7	0	0	0	0	14 276	NA	0	14 345
Water bodies	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27 548	0	27 548
Adjustments	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	NA	-1	
Closing extent, 2014 (Serie VI)	1 156	310 955	18 273	21 798	753	167 826	158 295	17 966	4 171	1 537	205 651	366 598	10 279	308 219	178 037	99 436	39 855	11 737	14 276	27 548		1 964 368

9.4 Accounting of the extent of terrestrial ecosystems in Mexico at the sub-national level (ecoregions, protected natural areas, states of the republic).

9.4.1 Ecosystem extent in Mexico's Natural Protected Areas

Accounting for the extent of ecosystems in protected areas (PAs) shows a wide range of situations and trends. While some show a large extent of natural vegetation, others are completely dominated by anthropogenic forms of land use. In assessing changes over the last 12 years, there are PAs with active regeneration processes, however, more show an increase in conversion due to the effect of the expansion of annual agriculture, pastures, and especially human settlements. Urbanisation in many cases is the process of change with the highest positive rates of change. It is worth noting that a large number of PAs that did not have human settlements in 2002, now have them in 2014. A more or less extensive transition from annual agriculture to grassland is also shown in some cases.

It is worth mentioning that, among the ecosystems with regressions, the Semideciduous tropical forest shows the greatest decline, even disappearing completely in several PNAs between 2002-2014 (Xcalak, Escobilla beach, and Uaymil reefs). Other vegetation types showing complete loss are Deciduous tropical forest (Mexiquillo Beach), Woody hydrophytic vegetation (Puerto Morelos Reef, Piedra de Tlacoyunque Beach, Puerto Arista Beach), Non-woody hydrophytic vegetation (Chacahua Lagoon), Oak Forest (Mohinora Hill), Special other non-woody types (Chamela-Cuixmala, Teopa Beach). In some PAs there is also complete regression of Annual agriculture (Benito Juárez, Molino de Flores Netzahualcoyotl, Maruata and Colola beach, Rayón). Other PAs with important regressions in annual agriculture are Chan-Kin, Boquerón de Tonalá, El Jabalí and Sierra del Abra Tanchipa. In terms of extent, the most important regressions are Oak forest (490 km^2, CADNR [feeding basin of national irrigation district] 043 the State of Nayarit), Grassland (362 km^2, Mapimí), Semideciduous tropical forest (265 km^2, CADNR 043 State of Nayarit), Evergreen tropical forest (259 km^2, Montes Azules), Woody Xeric Shrubland (145 km^2, Metztitlán Ravine), Grassland (138 km^2, Tehuacán-Cuicatlán), Semideciduous tropical forest (118 km^2, Calakmul).

As shown by the opposite cases, i.e., the emergence of categories that did not exist at the first date there is a need for a detailed revision of the data, since the appearance of new vegetation types in PA is practically impossible in 12 years. Vegetation types that did not exist in 2002 but did in 2014 include Deciduous tropical forest (Bala'an K'aax, El Veladero, La Encrucijada), Semideciduous tropical forest (Sierra Gorda), Montane semideciduous tropical forest (Mariposa Monarca, Garnica Hill), Other lands (Marismas Nacionales Nayarit, de Metztitlán Ravine, Tutuaca). However, the appearance of Human settlements predominate (CADNR 001 Pabellón, Sacromonte, La Sepultura, Tacaná Volcano, Huatulco, Bosencheve, Mismaloya Beach, El Triunfo, El Pinacate and the Great Altar Desert, Nahá, Agua Azul Waterfall, Marismas Nacionales Nayarit, Tulum, Sierra Huautla, El Chico, Chacahua Lagoons, Sierra de Tamaulipas, Dzibilchantún, Baranca de Metztitlán, Cañon de Usumacinta, Calakmul, Cumbre de Monterey) and Annual agriculture (Sierra de Órganos, Escobilla Beach, Las Huertas, Las Huertas, Usumacinta Canyon, Calakmul, Monterey Mountain Top), Baranca de Metzttitlán, Cañon del Usumacinta, Calakmul, Monterey Mountain Top) and Annual agriculture (Sierra de Órganos, Escobilla Beach, Las Huertas, Volcán Tacaná, El Potosí, Palenque, Nahá, El Pinacate and Gran Desierto de Altar, Lacan-Tun, Chacahua Lagoon), where in 2002 these categories are not reported. Other PAs with a strong increase in urbanization are Cabo San Lucas, Malinche or Matlalcuéyatl mountain, Zicuirán-Infiernillo, la Silla hill and Puerto Morelos reefs.

The PAs with the least increases and decreases are Valle de los Cirios, Papigochic, Cacaxtla plateau, Maderas del Carmen, Los Tuxtlas, Los Mármoles, and Zempoala, Janos, General Juan Álvarez, El Vizcaíno lagoons.

9.4.2 The extent of ecosystems in the states of the Mexican Republic

The accounting of ecosystem extent by state shows that Sonora, Nayarit, Chiapas, Campeche, Guerrero, Tabasco, Chihuahua, Durango, Coahuila, Michoacán, Puebla, Quintana Roo and Zacatecas have the greatest extent of increases and regressions (Annex 2). The increases mainly relate to land use categories, such as e.g., Perennial cropland, Aquaculture, Grassland in Baja California (South), Campeche, Chiapas, Chihuahua, Coahuila, Edo de Mexico.

Annual agriculture in Jalisco, Chihuahua, Chiapas, Chiapas, Yucatán, Quintana Roo, Veracruz, Zacatecas, Durango, Oaxaca, and Tamaulipas stand out for their larger extension (>1 000 km^2). In addition, increases are recorded for Grassland in Sonora, Yucatán, and Chiapas. Other notable increases are the Planted Forest in Campeche, Hidalgo, SLP, Tabasco, Veracruz; Urbanization in Colima, Chiapas, Baja California Sur, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, Michoacán, Morelos; Nayarit, Nuevo León, Oaxaca, Puebla, Querétaro, Quintana Roo, SLP, Sonora, Tamaulipas, Tlaxcala, Veracruz, Yucatán, Veracruz, Yucatán and Zacatecas; Annual agriculture in Jalisco, Michoacán, Nayarit, Querétaro,, Sinaloa, Sonora, Yucatán; Aquaculture in Nayarit, Sinaloa, Sonora and Tamaulipas. There are important regressions (>1 000 km^2) for the categories of natural vegetation, of which the Semideciduous tropical forest in Yucatán, Nayarit and Campeche, the Grassland in Chihuahua, Jalisco, Zacatecas, Oaxaca, Veracruz and Nayarit stand out , the Evergreen tropical forest in Chiapas and Quintana Roo, the Woody xeric shrubland and Deciduous tropical forest in Sonora, the Non-woody xeric shrubland in Chihuahua, the Woody xeric shrubland in Nuevo León and Tamaulipas and the Coniferous forest in Chiapas.

The only land use with a comparative regression is Annual agriculture in Guerrero. Taking the change rate as a criterion, Hydrophytic non-woody vegetation in Zacatecas and Non-woody xeric shrubland in Guerrero (-100% in both cases), Woody xeric shrubland in Veracruz (-16.80%), Non-woody xeric shrubland in Aguascalientes (-13.24%), Other lands in Michoacán (-6.54%) stand out. Other important increases or regressions occur in rather small categories, such as Special other (Non) woody types, Hydrophytic vegetation, or Other lands, which raises the question of the reliability of the observed changes, since, with small vegetation types, errors in the maps can cause a remarkably high change rate. The largest relative regression in land use was Annual agriculture in Guanajuato and Baja California Sur (>5%). The largest regressions for Grassland occur in Tlaxcala, Nayarit, and Mexico City (>2%). The largest relative increases in land use are Planted forest in Tabasco, Aquaculture in Baja California Sur, Tamaulipas and Campeche, Settlement in Tlaxcala and Annual agriculture in Yucatán and Quintana Roo.

States showing changes in the extent of both land use and vegetation categories are Sonora, Chiapas, and Chihuahua, while those with the least change are Mexico City, Tlaxcala, and Aguascalientes (Table 12). In those states showing significant changes, land-use change extents are similar to vegetation changes, which suggests a causal relationship between the two types of changes (Table 12).

Table 13. The extent of changes observed between 2002-2014 in each state.

	Total area of change (km^2)	Land use changes (km^2)	Vegetation changes (km^2)
Ciudad de México	181	15	-17
Tlaxcala	263	56	-59
Aguascalientes	401	112	-116
Colima	404	-36	35
Querétaro	519	123	-144
Morelos	703	-93	89
Baja California Sur	880	37	-29
Guanajuato	1181	243	-246
Baja California	1514	60	-4
Hidalgo	1583	-156	165
México	1708	208	-278
Tabasco	2015	383	-647
San Luis Potosí	2063	807	-809
Puebla	2169	-295	287
Coahuila de Zaragoza	2785	712	-739
Nuevo León	2831	636	-721
Sinaloa	2865	1228	-1182
Tamaulipas	3326	1286	-1478
Michoacán de Ocampo	3403	328	-274
Campeche	3599	1226	-1221
Durango	3679	1249	-1240
Zacatecas	3799	1287	-1276
Veracruz de Ignacio de la Llave	4136	1787	-1778
Quintana Roo	4143	1761	-1764
Nayarit	5127	748	-713
Guerrero	5238	-1043	1040
Oaxaca	5474	1606	-1630
Yucatán	7246	2158	-2163
Jalisco	8193	3997	-4143
Chihuahua	8818	3761	-3800
Chiapas	9098	3185	-3230
Sonora	9552	1506	-1546

9.4.3 Ecosystem extent in terrestrial ecoregions of Mexico

Ecosystem accounting by ecoregion (level 2) reveals that the largest regressions in terms of absolute area occur in the Semideciduous tropical forest in the Plains and hills of the Yucatán Peninsula, the Grassland in the foothill of the Sierra Madre Occidental, the Evergreen tropical forest of the Coastal plain and Humid hills of the Gulf of Mexico, and the Non-woody xeric shrubland of the Warm deserts (>3 000 km^2). Also important are the regressions of the Deciduous tropical forest of the Coastal plain, hills, and ravines of the West, and the Woody xeric shrubland of the semiarid Tamaulipas-Texas plain (>2 000 km^2). In contrast, important increases correspond to land use categories, with Annual agriculture as the most frequent category, e.g., for the Yucatán Peninsula plains and hills, the Warm deserts, the Coastal plain and Humid hills of the Gulf of Mexico, and the foothill of the Sierra Madre Occidental (> 2000 km^2). In the plains and hills of the Yucatán Peninsula, there is also an increase of Grassland and in the Intermontane depressions the Deciduous tropical forest (>2 000 km^2).

This last change is most probably due to an input error, as it is not likely that such an extensive increase as natural regeneration in 12 years is feasible in one part of the country. Taking the change rate as a criterion, the total loss of the Woody hydrophytic vegetation in the Neovolcanic Transversal System, as well as of the Non-woody xeric shrubland in the Coastal plain and hills of the South Pacific is noteworthy. The only ecoregion that records two ecosystems with significant relative regressions is the Sierra de Los Tuxtlas (Oak Forest and Non-woody hydrophytic) vegetation). Altogether, there are 17 ecosystems from different ecoregions showing a more negative change rate of -2% (Annex 3). There are 71 ecosystems in different ecoregions with a change rate above 2%, with a dominance of land use categories, mostly Human settlements, and Perennial cropland. Once again, some exceedingly small classes, such as Other Lands show extremely high rates of change, raising questions as to whether these changes are due to inconsistencies in inputs.