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Compiling biodiversity accounts with the GLOBIO model

A case study of Mexico

Note

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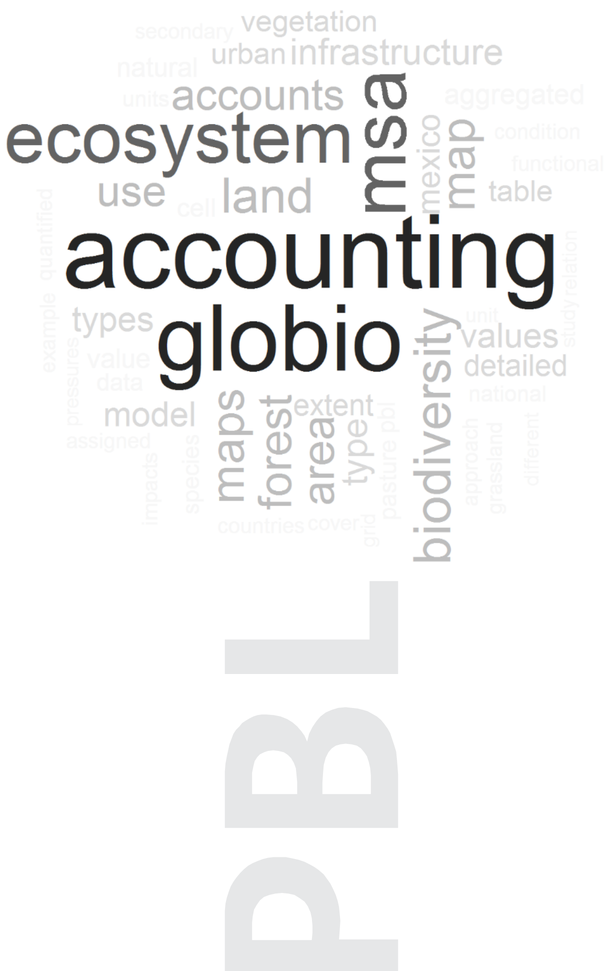
01 March 2017



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Compiling biodiversity accounts with the GLOBIO model: a case study of Mexico

PBL Netherlands Environmental Assessment Agency

The Hague, 2017

PBL publication number: 2607

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PBL Netherlands Environmental Assessment Agency is the national institute for strategic policy analysis in the field of environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and scientifically sound.

Contents

EXECUTIVE SUMMARY

Although ecosystems and biodiversity are highly important to mankind, their value is not yet included in national accounts. The United Nations Statistics Division (UNSD) developed a conceptual method to establish ecosystem accounts (Experimental Ecosystem Accounting or EEA) as part of the System of Environmental Economic Accounts (SEEA). However, concrete guidelines are lacking and actual experiences with national ecosystem accounting are very limited. In the present study, we aimed to evaluate the applicability of the GLOBIO modelling approach (version 3.5) to establish biodiversity accounts. The GLOBIO model is designed to assess past, present and future human-induced changes in terrestrial biodiversity at regional to global scales. GLOBIO is built upon a set of quantitative relationships that describe biodiversity responses to anthropogenic pressures. In GLOBIO 3.5, biodiversity responses are quantified as the mean species abundance (MSA), which expresses the mean abundance of original species in disturbed conditions relative to their abundance in undisturbed habitat, as an indicator of the degree to which an ecosystem is intact.

To test the applicability of the GLOBIO modelling approach for accounting purposes, we compiled biodiversity accounts for the country of Mexico, which is known for its high biodiversity and high quality of geographical data. We quantified the accounts based on two indicators: ecosystem extent, quantified as the total area of each ecosystem type within the country, and ecosystem condition, quantified as the area-weighted MSA per ecosystem type, as function of both land use and infrastructure. We compiled and compared the accounts based on three different land-use maps. The first map was a 0.5° by 0.5° raster land-use map for the year 2010, as produced by the GLOBIO model (version 3.5). In this map land use is represented as the fractions of the different land use type present per grid cell. The other two were vector-based maps (i.e., each polygon representing a single land-use type) that included, respectively, 19 aggregated and 178 detailed land-use types specific to Mexico. These maps were provided by Mexico's National Statistical and Geographical Institute (INEGI) and represented the years 2011-2013.

The accounts showed that either shrubland or forest comprised the most abundant ecosystem type in Mexico, depending on the land-use map used. Overall MSA values were 0.65, 0.72 and 0.75 for the detailed vector-based, aggregated vector-based and GLOBIO land-use maps, respectively. These differences were mainly due to differences in the land-use classifications and allocation of MSA values to land-use types. For example, the detailed vector-based map included considerable amounts of secondary vegetation (i.e., relatively low MSA value), whereas the aggregated map and the GLOBIO land-use map did not distinguish this land-use type. Infrastructure impacts were subordinate and highly similar between the three maps.

Based on the case study results we conclude that the MSA values and cause-effect relationships from the GLOBIO model provide a transparent, flexible and relatively time- and cost-efficient approach to compile national biodiversity accounts. Further, we found clear trade-offs between the generic global-scale land-use map from the GLOBIO model and the country-specific vector-based maps. Compiling accounts based on the GLOBIO land-use map ensures compatibility with the MSA cause-effect relationships in GLOBIO and enhances comparability among countries. Yet, the coarse resolution and model uncertainties in the land-use allocation module in the current version of GLOBIO raise questions as to the representativeness of this map in an accounting context. The country-specific land-use maps were much more detailed, which is a clear advantage at least for compiling extent accounts. Moreover, using country-specific land-use data may stimulate stakeholder engagement and hence legitimacy and uptake of the results in decision-making. However, the MSA-based biodiversity accounts require an MSA value to be

assigned to each ecosystem unit or land-use type, which may require additional data and analysis. Moreover, as land-use classifications may differ (slightly) among countries, the use of country-specific land-use maps may reduce comparability of the accounts among countries.

Given the trade-offs among the different land-use maps, it might be worth using and comparing multiple land-use input maps when compiling national ecosystem accounts, including a generic, global-scale land-use (or land cover) map as well as more detailed country-specific maps. In addition, further experimental ecosystem accounting may benefit from incorporating other biodiversity metrics that are complementary to MSA. For example, species-habitat indices (SHIs) quantify (changes in) the amount of suitable habitats of single species by combining land cover or land-use maps with literature- and expert-based judgment on the occurrence ranges and habitat preferences of single species. Thus, SHIs could be used in addition to MSA in order to account for differences in species pools among countries.

1 Introduction

Ecosystems are providing various goods and services that contribute to human existence or wellbeing (Costanza *et al.*, 1997). Examples include the provisioning of drinking water and timber, sequestration of carbon, and pollination of food crops (MA, 2005). The worldwide degradation of ecosystems and biodiversity and the increasing recognition of their values have prompted increasing calls for better protection and more systematic consideration of 'natural capital' in decision making (CBD, 2010). In particular, there have been frequent calls to better integrate ecosystem values into national accounting systems (Obst *et al.*, 2016). The System of Environmental Economic Accounts – Experimental Ecosystem Accounting (SEEA-EEA) was developed as a general framework to achieve this (United Nations, 2014). The aim of ecosystem accounting is to quantify (changes in) ecosystem assets (i.e., stocks) and services (i.e., flows) in a way that is aligned with the approaches prescribed for economic accounting (Edens and Hein, 2013; United Nations, 2014).

In general, the accounting model proposes to measure the (changes in) ecosystem assets by considering the extent and condition of given ecosystem functional units (see Table 1.1 for the corresponding definitions). Extent and condition are quantified based on, respectively, area indicators and characteristics pertaining to for example water, soil, carbon, vegetation or biodiversity (United Nations, 2014; De Jong *et al.*, 2015). The extent and condition of a given ecosystem functional unit determine its capacity to deliver certain ecosystem services, which in turn contribute to so-called ecosystem benefits (i.e., the part of the service that is actually being used). These benefits can be quantified either in biophysical terms (for example, the amount of carbon emissions sequestered per year) or in monetary values (for example, the amount of fish supplied to the market expressed in terms of the market price). Finally, the assets, services and benefits provided by the ecosystem functional units can be aggregated and reported over so-called accounting units. Accounting units combine multiple ecosystem functional units into larger units based on administrative boundaries, with the country level typically representing the highest level of aggregation (United Nations, 2014)

Despite the launch of the SEEA-EEA framework and the increasing interest in ecosystem accounting, there is only limited practical experience, and there remain various challenges in the integration of measures of ecosystem assets and services into the standard national accounts. Apart from the challenges involved in the monetary valuation of ecosystems (Obst *et al.*, 2016), the quantification of the biophysical stocks and flows is not straightforward either, as this requires clear definitions of concepts, system boundaries, and measures of stock and flow that can be quantified and aggregated in a way that is meaningful in an accounting context (Edens and Hein, 2013; Schröter *et al.*, 2014; United Nations, 2014). One particular challenge is involved in including biodiversity in ecosystem condition accounts. Although the species diversity of an ecosystem is highly relevant for both its functioning and its resilience (Hooper *et al.*, 2005; Hooper *et al.*, 2012), accounting for species diversity is complex and experiences with biodiversity accounting are much less advanced than with for example water or carbon accounting (UNEP-WCMC, 2015).

In the present study, we compiled biodiversity accounts for the country of Mexico, which is known for its high diversity of ecosystems and endemic species (González-Abraham *et al.*, 2015). We had the following specific aims:

1) to test the applicability of the GLOBIO modelling approach for establishing biodiversity accounts, by combining maps of biodiversity pressures with cause-effect relationships expressing corresponding impacts on biodiversity;

2) to compare biodiversity accounts based on ecosystem functional units established at different levels of detail.

To compile the biodiversity accounts, we used two indicators. First, we quantified the extent of different ecosystem functional types, which is considered the foundation of a biodiversity account in the broadest sense as it provides information on ecosystem diversity (UNEP-WCMC, 2015). Second, we quantified biodiversity as function two anthropogenic pressures that are generally considered to have high impacts on terrestrial biodiversity, namely land use and infrastructure (Benítez-López *et al.*, 2010; Newbold *et al.*, 2015). To that end, we used the Mean Species Abundance (MSA) indicator and underlying cause-effect relationships from the GLOBIO model (Alkemade *et al.,* 2009; PBL, 2016). The MSA indicator represents the mean abundance of original species in the current situation compared to their mean abundance in an undisturbed reference situation. It ranges between 0 and 1, where 1 indicates that there is no difference in mean abundance between the current and undisturbed state of the ecosystem. As MSA includes an inherent baseline (i.e., the undisturbed reference situation) and is easily aggregated across scales (PBL, 2016), it has high potential for ecosystem accounting purposes (UNEP-WCMC, 2015). Moreover, as MSA can be quantified based on easily retrievable pressure data and existing cause-effect relationships, the approach had the potential to be readily applied to any country.

Table 1.1 Explanation of terms used in ecosystem accounting, based on the SEEA-EEA framework description (United Nations, 2014).

Term	Description
Ecosystem functional unit	A spatial unit containing a combination of biotic and abiotic components and other characteristics that function together. Conceptually similar to the definition of an ecosystem as 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit', as used by the Convention on Biological Diversity.
Ecosystem type	Broad categorization of ecosystems made for accounting purposes (e.g., forest, grassland, shrubland, wetland).
Ecosystem accounting unit	A relatively stable (mostly administrative) area relevant for analysis and reporting purposes.
Ecosystem asset	A spatial area containing a combination of biotic and abiotic components and other characteristics that function together (note that this is in fact similar to an ecosystem functional unit). Ecosystem assets are described in terms of extent, condition (which may include biodiversity) and services.
Ecosystem extent	The total area of a given ecosystem type within a given ecosystem accounting unit.
Ecosystem condition	The overall quality of an ecosystem asset.
Ecosystem service	The contribution of the ecosystem asset to benefits used in economic and other human activities.
Ecosystem benefit	The share of the ecosystem service that is actually being used.

2 Methods

2.1 Ecosystem functional units

We used land-use maps as basis to distinguish ecosystem functional units. In order to evaluate the sensitivity of the biodiversity accounts to the level of (spatial) detail in the underlying ecosystem units, we established and compared accounts based on three land-use maps:

- A land-use map from the GLOBIO model, version 3.5 (PBL, 2016). In GLOBIO, land-use maps are compiled from the GLC2000 map combined with regional land-use data from the IMAGE model. GLC2000 which is a global land cover map with a resolution of 30 arc seconds (about 1 km at the equator) including 23 different land cover classes. To include information on anthropogenic land use, the GLC2000 map is combined with land-use data from the IMAGE model, resulting in a 0.5° by 0.5° land-use map with the fraction of each unique combination of land cover and use type per grid cell (PBL, 2016). For the present study, we used a GLOBIO land-use map for the year 2010, using land-use input data and assumptions in accordance with the baseline scenario as used in the fourth Global Biodiversity Outlook (PBL, 2014). For Mexico, this map includes 36 distinct combinations of a given GLC2000 land cover class and land-use type/intensity (see Table S1 in the Supplementary Material).
- A vector-based land-use map provided by Mexico's National Institute of Statistics and Geography (INEGI). This map is based on data from the period 2011 – 2013 and includes two hierarchic thematic classifications: 19 aggregated land-use types (Table S2) and 178 detailed classes (see Table S3).

2.2 Quantifying ecosystem extent

To quantify ecosystem extent based on the fractional GLOBIO land-use map, we used the fractions of each land-use type per grid cell multiplied with the land surface area (km^2) of the corresponding cell. We aggregated this per land-use type over the cells, resulting in the total area per land-use type. To quantify ecosystem extent based on the detailed land-use maps (vector), we first reprojected the maps into Mexican Albers Equal-Area Conic projection (centered on Mexico), using ArcGIS (10.3.1, ESRI 2015). We then calculated the area of each polygon using the "Calculate Geometry" function and used the "Summary Statistics" function to sum the polygon areas per land-use type.

2.3 Quantifying biodiversity

We quantified the biodiversity of each ecosystem functional unit by quantifying MSA in relation to two pressures, i.e., land use and infrastructure. We did this for each pressure separately as well as the two pressures combined.

2.3.1 MSA in relation to land use

To quantify MSA in relation to land use, we used the land-use type specific MSA values as included in the GLOBIO model (version 3.5) (PBL, 2016). These MSA_{LU} values have been quantified based on a meta-analysis of literature studies that reported on the abundance of species in a given land-use type and intensity in comparison to their abundance in an undisturbed reference situation (Alkemade *et al.*, 2009; PBL, 2016). The GLOBIO land-use map of Mexico consisted of 36 unique combinations of land-cover and land use (Table S1), corresponding with 12 GLOBIO LU classes and corresponding MSA values (Table 2.1).

Table 2.1 The GLOBIO land-use classes occurring in Mexico, with corresponding MSA_{LU} values.

GLOBIO land use class	MSA_{LU}
Forest - Natural	1
Forest - Reduced impact logging	0.85
Forest - Selective logging	0.70
Forest - Clear-cut harvesting	0.5
Forest - Plantation	0.3
Grassland - Natural	1
Pasture - moderately to intensively used	0.6
Pasture - man-made	0.3
Extensive cropland	0.3
Intensive cropland	0.1
Irrigated cropland	0.05
Urban area	0.05

For the vector maps, we quantify MSA in relation to land use by assigning an MSA_{LU} value to each land-use type. For the aggregated land-use types (Table 2.2), we made the following assumptions:

- We interpreted rainfed agriculture (agricultura de temporal) and groundwater-fed agriculture (agriculture de humedad) as extensive cropland (MSA = 0.3), under the assumption that the absence of irrigation is indicative of extensive use.
- We interpreted cultivated grassland (pastizal cultivado) as original grasslands used for livestock grazing (MSA = 0.6).
- We assumed that undefined vegetation (especial - otros tipos) is in natural, undisturbed state (MSA = 1)
- We interpreted man-made vegetation (vegetación inducida) as plantation, using the MSA value for both forest plantation and man-made pasture (MSA = 0.3).

For the detailed land-use types (Table 2.3), the following assumptions were made:

- We interpreted cultivated forest (bosque cultivado), man-made forest (bosque inducido) and palm plantation (palmar inducido) as forest plantation (MSA = 0.3), because they are dominated by introduced tree species (INEGI, 2015).
- We interpreted cultivated grassland (pastizal cultivado) as original grasslands used for livestock grazing (MSA = 0.6) and man-made grassland (pastizal inducido) as man-made pasture (MSA = 0.3), where succession back to natural forest vegetation is prevented due to intensive use (including grazing) (INEGI, 2015).
- The MSA value of secondary vegetation is strongly dependent on the succession stage (age) of the vegetation (Newbold *et al.*, 2015; PBL, 2016). However, because we could not retrieve the age of the secondary vegetation from the classification, we assigned a general MSA value of 0.5 to all secondary vegetation (Alkemade *et al.*, 2009).

Table 2.2 Reclassification of the aggregated land-use types into GLOBIO land-use classes with corresponding MSA_{LU} values.

Land-use type [a]	GLOBIO land use classification	MSA_{LU} [b]
Bare area	Bare area	1
Irrigated cropland	Irrigated cropland	0.05
Groundwater-fed cropland	Extensive cropland	0.3
Rainfed cropland	Extensive cropland	0.3
Forest plantation	Forest - Plantation	0.3
Coniferous forest	Forest - Natural	1
Oak forest	Forest - Natural	1
Mountain cloud forest	Forest - Natural	1
Deciduous tropical forest	Forest - Natural	1
Thornbush tropical forest	Forest - Natural	1
Evergreen tropical forest	Forest - Natural	1
Semi-deciduous tropical forest	Forest - Natural	1
Grassland	Grassland - Natural	1
Pasture	Pasture - Moderately to intensively used	0.6
Matorral	Natural vegetation	1
Undefined	Natural vegetation	1
Man-made vegetation (undefined)	Forest – Plantation/Pasture - Man-made	0.3
Urban area	Urban area	0.05
Bare area	Bare area	1

[a] The original Spanish name can be found in Table S2. [b] See PBL (2016)

Table 2.3 Reclassification of the detailed land-use types into GLOBIO land-use classes with corresponding MSA_{LU} values.

Land-use type [a]	GLOBIO land use classification [b]	MSA_{LU}
BA, BB, BG, BJ, BM, BP, BPQ, BQ, BQP, BS, SAP, SAQ, SBC, SBK, SBP, SBQ, SBQP, SBS, SG, SMC, SMQ, SMS, VPN	Forest – Natural	1
BC, BI, VPI	Forest – Plantation	0.3
PH, PN, PY, VH, VS, VSI, VW	Grassland - Natural	1
PC	Pasture – Moderately to intensively used	0.6
PI	Pasture – Man-made	0.3
MC, MDM, MDR, MET, MK, MKE, MKX, ML, MRC, MSC, MSCC, MSN, MST, PT, VA, VD, VG, VHH, VM, VT, VU	Natural vegetation	1
VSA, VSa, VSh (including all subtypes)	Secondary vegetation	0.5
RA, RAP, RAS, RP, RS, RSP,	Irrigated cropland	0.05
HA, HAP, HAS, HP, HS, HSP, TA, TAP, TAS, TP, TS, TSP	Extensive cropland	0.3
AH, ZU	Urban area	0.05
ADV, DV	Bare area	1

[a] The full names (Spanish) can be found in Table S3.

2.3.2 MSA in relation to infrastructure

To quantify MSA in relation to infrastructure disturbance, we used the approach as implemented in the GLOBIO model. In GLOBIO, a 1 km disturbance zone is delineated along the road network, which is assigned an MSA value of 0.78 (PBL, 2016). The road network is retrieved from the Global Road Inventory Project (GRIP) database, which contains georeferenced vector data on five road types (highways, primary roads, secondary roads, tertiary roads and local roads) for 222 countries worldwide (Meijer *et al.*, in prep.).

In GLOBIO, the potential infrastructure disturbance (i.e., without accounting for any other impacts on biodiversity) is calculated based on the proportion of each 0.5° by 0.5° grid cell that is within the infrastructure impact zone, as

$$\text{if } \left(\frac{A_{I,C}}{A_C} \geq 1, MSA_{C,I} = 0.78, MSA_{C,I} = 1 - \left(\frac{A_{I,C}}{A_C} \cdot 0.22 \right) \right) \quad \text{(Eq.1)}$$

where $A_{I,C}$ is the area of the infrastructure disturbance zone in grid cell C, A_C is the area of that grid cell, and $MSA_{C,I}$ is the potential impact of infrastructure in cell C. Thus, this equation states that if the area of the infrastructure impact zone is equal or larger than the area of the grid cell, the maximum potential impact of infrastructure is obtained for that cell, and the cell gets an MSA_I value of 0.78. If the area of the infrastructure impact zone is smaller than the area of the grid cell, the maximum possible loss of biodiversity (0.22) will be reduced based on the fraction of the land use type that is within the infrastructure impact zone. In the impact calculation, it is assumed that infrastructure impacts are lower in protected areas as compared to unprotected areas, because of targeted spatial planning and regulation measures. Therefore, in protected areas the MSA_I value of 0.78 is replaced by $MSA_I = 0.90$.

To quantify the potential impact of infrastructure (MSA_I) for the discrete vector-based land use maps, a buffer of 1 km was created along each side of the roads, which was assigned an MSA_I value of 0.78. The areas outside the buffer zone were assigned an MSA_I value of 1 (i.e., no infrastructure impact).

2.3.3 MSA in relation to both land use and infrastructure

To quantify the combined impacts of land use and infrastructure, we followed the GLOBIO model approach. In GLOBIO, it is assumed that the direct land use impacts of agriculture and urban areas take precedence over any other impacts, i.e., that there is no further loss of MSA due to other anthropogenic pressures (including infrastructure). In land-use types other than cropland or urban area, impacts of multiple disturbances are assumed to interact probabilistically (response multiplication). Hence,

$$if\ (LU = cropland\ OR\ LU = urban, MSA_C = MSA_{C,LU}\ , MSA_C = MSA_{C,LU} \cdot MSA_{C,I}) \quad \text{(Eq.2)}$$

where MSA_C is the MSA value of cell C due to both land use and infrastructure disturbance, and $MSA_{C,LU}$ and $MSA_{C,I}$ are the MSA values of cell C in relation to land use and infrastructure separately.

Because the GLOBIO land-use map is fractional, the exact locations of the different land-use types in each cell are not known. Therefore, the potential infrastructure impact in each cell is distributed over the land-use types following a predefined order. According to this prioritization, the land-use classes urban area, cropland and pasture get a higher priority than for example natural forest, based on the assumption that roads will be primarily located within urban and agricultural areas. For example, assume that a certain grid cell has a total area of 1000 km^2, consisting of 50 km^2 of urban area, 500 km^2 of cropland and 450 km^2 of broadleaved deciduous forest. Assume further that the total area of the infrastructure impact zone is 700 km^2. According to the prioritization, the first 50 km^2 of the impacted area is then assigned to urban area, the next 500 km^2 to cropland, and the remaining 150 km^2 is assigned to broadleaved deciduous forest. This leaves no direct infrastructure impact for the remaining 300 km^2 of forest area. As it is assumed that infrastructure causes no (additional) MSA loss in urban areas and cropland, the MSAI value of 0.78 is then assigned only to the 150 km^2 of impacted forest area. This implies that the 450 km^2 of forest within that grid cell gets an MSAI value of 1- (150/450 · (1-0.78)) = 0.93.

To calculate the combined impacts of infrastructure and land use based on the vector maps, we used the "Union" function in ArcGIS (10.3.1, ESRI 2015), creating homogenous polygons with respect to both land use and infrastructure impact. The combined MSA per polygon was calculated according to Equation 2, using the "Field calculator" (see Text Box S1 for details). Then we used "Summary statistics" to summarize the MSA values by land-use type.

2.4 Ecosystem types and accounts

For the purposes of national level ecosystem accounting, it is considered appropriate to consider only a limited set of relatively broad ecosystems types comprising commonly understood categories like forests, wetlands, grasslands (United Nations, 2014). For the GLOBIO land use map, we considered five ecosystem types: forest, shrubland or herbaceous vegetation, cropland, pasture and urban area (see Table S1). We merged shrubland and herbaceous vegetation because two of the classes included both types (class 140 and 150). In case of mosaics, we assigned the class to the dominant type.

For the vector-based land use maps, the following assumptions were made to assign each land-use type to an ecosystem type (see Table S2, S3):

- Temporal forest (bosque), rainforest (selva) and plantation (bosque inducido, bosque cultivado) were all assigned to forest.
- Natural grassland/rangelands and pasture (pastizal inducido and pastizal cultivado) were aggregated to grassland.
- The three main secondary vegetation types as distinguished in the detailed land-use map (secondary forest (vegetación secundaria arbôrea; VSA), secondary shrubland (vegetaciôn secundaria arbustiva; VSa) and secondary grassland (vegetaciôn secundaria herbácea; VSh)) were merged with the corresponding primary types.

To create the accounts, the total extent of each ecosystem type was calculated by summing the extents of the constituent land-use types. MSA values were calculated per ecosystem type as area-weighted average over the constituent land-use types.

3 Results

3.1 Spatial patterns in MSA

Overall MSA values showed clear spatial variability across the country (Figure 3.1 – 3.3). For all three land-use maps, relatively high MSA values were found in the north, the north-west (Baja California Peninsula) and north-east (Yucatán Peninsula). Relatively low values were found in the southern part, especially in the region around Mexico City, and along the east coast of the Gulf of California, where cropland and urban area are abundant. In the vector-based map, the road impact zones could be clearly distinguished particularly in areas not affected by land use (Figure 3.2 and 3.3). The spatial patterns as found for the vector-based maps are in agreement with the findings of González-Abraham *et al*. (2015), who quantified human footprints based on land use, roads and human population density and found high footprint values particularly for the central region surrounding the capital and the eastern coast line along the Gulf of California.

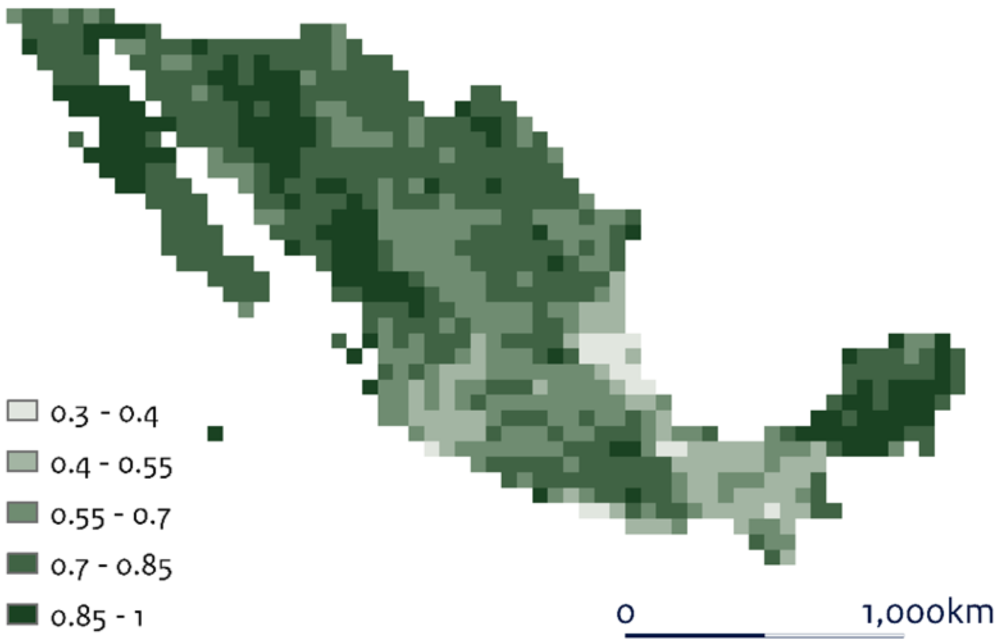

Figure 3.1 MSA in Mexico as function of land use and infrastructure (roads), based on the GLOBIO land-use map.

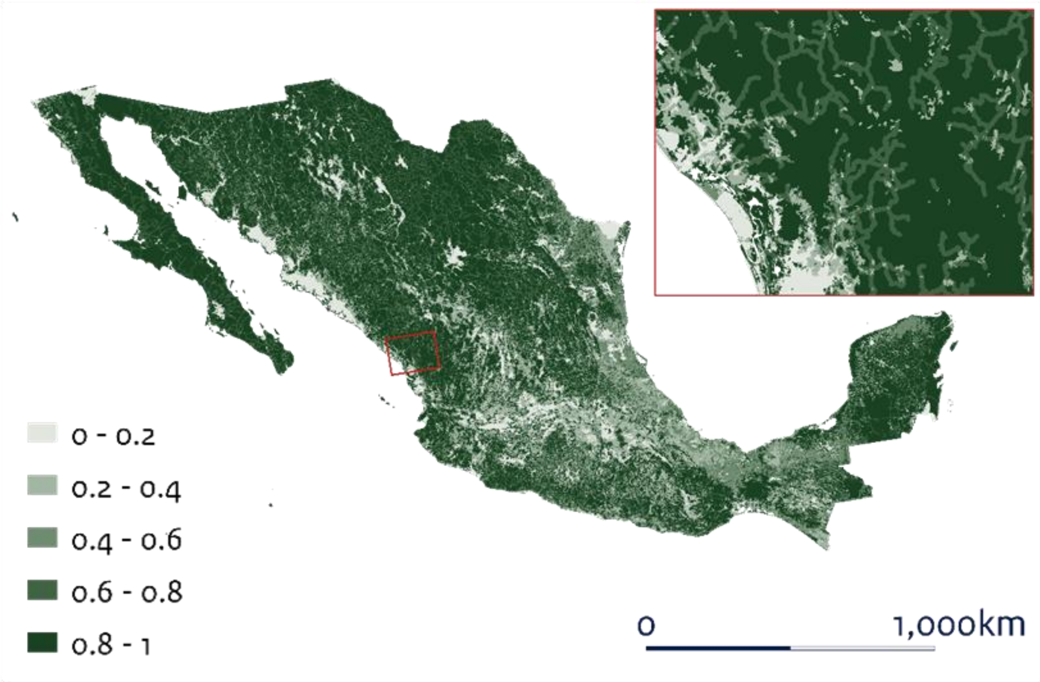

Figure 3.2 MSA in Mexico as function of land use and infrastructure (roads), based on the aggregated vector-based land-use map.

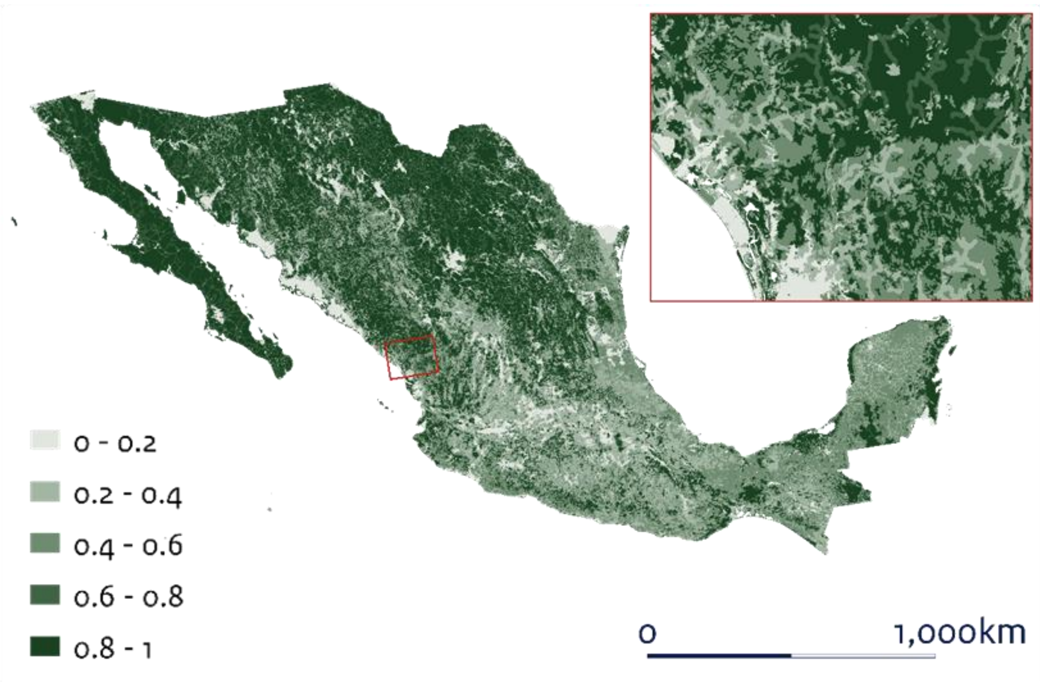

Figure 3.3 MSA in Mexico as function of land use and infrastructure (roads), based on the detailed vector-based land-use map.

3.2 Accounts

3.2.1 Extent

According to the GLOBIO land use map, the largest part of Mexico is covered by forest (Table 3.1), followed by pasture and shrubland/herbaceous vegetation. Forest is also the most extensive ecosystem type according to the aggregated vector-based land-use map, but this map contains more shrubland and cropland and less grassland/pasture than the GLOBIO map (Table 3.2). According to the detailed land-use map, the largest part of Mexico is covered by shrubland (over 40%), followed by forest and cropland (Table 3.3). Differences in ecosystem extents between the two vector-based maps can be explained by the reclassification of the land-use types from the detailed to the aggregated classification. For example, the land-use type "ADV" ("without vegetation") on the detailed map was classified as "Bare area" in the detailed classification. However, in the aggregated classification, "ADV" is included in "Urban area". Similarly, the differences in shrubland and forest extent between the aggregated and detailed vector-based maps reflect that some of the detailed shrubland types were reclassified to forest in the aggregated classification.

Urban area constitutes only a small part of the total land surface area, yet it is considerably larger according to the vector-based maps than the GLOBIO map. This might be due to differences in classification as well as explained by the fact that the GLOBIO land-use map is based on the GLC2000 land-cover map. As increases in urban area over time are not accounted for in the GLOBIO land-use allocation module, as is done for cropland and pasture (PBL, 2016), the amount of urban area in the GLOBIO land-use map is fixed at the level as observed in the year 2000.

3.2.2 Condition (biodiversity)

Overall area-weighted MSA values for Mexico as a whole were 0.65, 0.72 and 0.75 for the detailed, aggregated and GLOBIO land-use maps, respectively. Differences were mainly due to differences in land use (MSA_{LU}), which in turn reflected differences in classification. For example, classifying "ADV" as bare area yields an MSA_{LU} of 1, whereas classifying the same type as urban results in an MSA_{LU} of 0.05. The relatively low MSA value for the detailed map in particular mainly reflects the inclusion of secondary vegetation (Table S3), which was not included in the other two maps (Tables S1 and S2). According to the detailed map, a relatively large part of Mexico is covered by secondary vegetation (21.7%), which was assigned a relatively low MSA value of 0.5 (see Table 2.3). Infrastructure impacts were similar across the three maps and considerably lower (i.e., higher MSA) than the land-use impacts.

Table 3.1 Ecosystem accounts based on the GLOBIO land-use map (0.5° by 0.5°).

Ecosystem type	Extent (km^2)	Extent (%)	MSA_{LU}	MSA_I	$MSA_{LU,I}$
Forest	834,584	33.5	0.96	0.94	0.91
Pasture	544,077	27.9	0.59	0.85	0.51
Shrubland/herbaceous vegetation	346,981	14.9	1.00	0.98	0.98
Cropland	224,988	9.0	0.14	1.00	0.14
Urban area	1,794	0.1	0.05	1.00	0.05
Total	*1,952,424*	*100*	*0.77*	*0.93*	*0.72*

Table 3.2 Ecosystem accounts based on the aggregated vector-based land-use map. MSA values were not calculated for the ecosystem types 'aquaculture' and 'water and wetlands' because aquatic land-use types are not included in the terrestrial GLOBIO model.

Ecosystem type	Extent (km^2)	Extent (%)	MSA_{LU}	MSA_I	MSA
Forest	663,441	34.0	1.00	0.94	0.94
Shrubland	574,399	29.4	1.00	0.94	0.94
Cropland	327,917	16.8	0.22	0.85	0.22
Grassland	248,836	12.7	0.79	0.91	0.72
Plantation	62,872	3.2	0.30	0.89	0.27
Urban area	33,310	1.7	0.05	0.86	0.05
Water and wetlands	26,167	1.3	NA	NA	NA
Bare area	9,684	0.5	1.00	0.96	0.96
Natural vegetation - undefined	4,605	0.2	1.00	0.91	0.91
Aquaculture	1,069	0.1	NA	NA	NA
Total	*1,952,300*	*100*	*0.80*	*0.92*	*0.75*

Table 3.3 Ecosystem accounts based on the detailed vector-based land-use map. MSA values were not calculated for the ecosystem types 'aquaculture' and 'water and wetlands' because aquatic land-use types are not included in the terrestrial GLOBIO model.

Ecosystem type	Extent (km^2)	Extent (%)	MSA_{LU}	MSA_I	MSA
Shrubland	792,448	40.6	0.83	0.93	0.77
Forest	467,197	23.9	0.84	0.94	0.79
Cropland	327,917	16.8	0.22	0.85	0.22
Grassland	297,249	15.2	0.68	0.90	0.62
Water and wetlands	37,810	1.9	NA	NA	NA
Urban area	18,537	0.9	0.05	0.78	0.05
Bare area	10,073	0.5	1.00	0.96	0.96
Aquaculture	1,069	0.1	NA	NA	NA
Total	*1,952,300*	*100*	*0.70*	*0.92*	*0.65*

4 Discussion

4.1 Biodiversity accounting based on MSA

The aim of this study was to develop and test the GLOBIO modelling approach for developing ecosystem condition accounts based on biodiversity, using the mean species abundance (MSA) indicator. MSA has various properties that make it intrinsically suitable for biodiversity accounting (UNEP-WCMC, 2015):

- It can be mapped to individual ecosystem units, so stocks of biodiversity can be assigned to ecosystem assets.
- It is comparable to a common reference condition indicative of a 'balanced' state.
- It can be spatially aggregated to any ecosystem accounting unit, in order to provide an overall indicator of ecosystem condition.
- As long as the input maps on the underlying anthropogenic pressures are the same, the resulting MSA values are comparable over space and time, thus allowing direct comparison of biodiversity stocks in different ecosystem units and among different countries.

To test the applicability of the GLOBIO approach and MSA indicator for biodiversity accounting, we compiled biodiversity accounts for the country of Mexico. To that end, we combined existing cause-effect relationships from GLOBIO (version 3.5) with spatially explicit input data on two main anthropogenic pressures on biodiversity (land use and infrastructure). We used three land-use maps as input: the 0.5° by 0.5° raster-based land use map from the GLOBIO model (version 3.5), where land use is represented as fractions of each land-use type per grid cell, and two vector-based maps consisting of, respectively, 19 aggregated and 178 detailed land-use types specific to Mexico, provided by Mexico's National Institute for Statistics and Geography (INEGI). The vector maps represented the years 2011-2013. As GLOBIO model output is typically produced at decadal intervals, we selected the model year 2010 as closest possible to the date of the vector maps.

Our case study showed that the GLOBIO modelling approach provides a relatively quick, straightforward and transparent method to compile biodiversity accounts. The method is flexible, as it is relatively easily tailored to different input maps of anthropogenic pressures on biodiversity. We further conclude that each of the land-use maps as used in this case study has its pros and cons. The land-use maps that are produced by the GLOBIO model (version 3.5) have the advantage that they are compiled at the global level, which ensures comparability among countries, and that there is a direct link with the MSA_{LU} values from the GLOBIO model. Yet, the resolution of the map is rather coarse (0.5° by 0.5°) and the extents of anthropogenic land use (cropland and pasture) result from model simulations rather than observations. In GLOBIO, cropland and pasture 'claims' are derived from the IMAGE model, for each of 26 world regions, and then spatially allocated (downscaled) based on land cover (PBL, 2016). As Mexico represents a single world region in the IMAGE model, the cropland and pasture claims are spatially coherent and might therefore be relatively representative. However, for other (smaller) countries, this might be much less so. Further, in the current version of the GLOBIO model, increases in urban area over time are not accounted for, as the level of urbanization is fixed at the value represented in the GLC2000 land cover map (PBL, 2016). This is problematic particularly because urban land-use is expanding rapidly and has a clear impact on biodiversity (Seto *et al.*, 2012; Newbold *et al.*, 2015; Bren d'Amour *et al.*, 2016).

The country-specific land-use maps available for Mexico contain more spatial detail and are based on observations rather than model simulations. Moreover, using country-specific land-use data may stimulate stakeholder engagement and hence legitimacy and uptake of the results in decision-making (Posner *et al.*, 2016). Yet, the biodiversity accounts retrieved from these land-use maps are contingent on the allocation of MSA values to ecosystem units or land-use types. The MSA values as included in the GLOBIO model are retrieved from a global database and global meta-analyses, and the extent to which the values are representative for a specific country (Mexico) has not been tested. For example, assigning a generic MSA value of 0.5 to all secondary vegetation types resulted in a considerably lower overall MSA for the detailed land-use map as compared to the other two maps (Tables 3.1-3.3), whereas it is not known whether the generic value of 0.5 is actually representative. This might be remedied by collecting biodiversity data and defining corresponding MSA values specific to Mexico, but this would go on the expense of reduced comparability among countries.

4.2 Concluding remarks and recommendations

Based on the results obtained, we provide the following conclusions and recommendations:

- The MSA values and cause-effect relationships from the GLOBIO model provide a relatively time- and cost-efficient as well as transparent approach to compile national biodiversity accounts, provided that suitable input data are available regarding the underlying anthropogenic pressures.
- In the present study, we compiled the accounts for a single point in time. However, ultimately, biodiversity accounts should inform about changes in the stock of biodiversity between opening and closing accounting periods (UNEP-WCMC, 2015), i.e., typically from year to year. In principle, the approach presented here is easily applied to multiple subsequent years, provided that the maps of the anthropogenic pressures are updated on a yearly basis. If this is not the case, yearly changes in biodiversity stock might be obtained by dividing the changes observed between two subsequent maps by the duration of the mapping interval.
- Compiling accounts based on the global-scale GLOBIO land-use map ensures compatibility with the MSA cause-effect relationships in GLOBIO and enhances comparability among countries. Yet, the coarse spatial resolution of the map and the model uncertainties in the land-use allocation module in the current GLOBIO model (version 3.5) raise questions as to the representativeness of this map in an accounting context. For accounting purposes, it might be more adequate to rely on monitoring data, but global-scale monitoring data are not available for all land-use types. For example, the state-of-the-art discrete high-resolution (10’’) land cover maps of the Climate Change Initiative provide information on cropland and urban area, but not on use of grasslands (grazing) or forestry. In order to cover these land-use types, remote sensing imagery would need to be integrated with additional data sources on land use.
- In general, country-specific land-use maps are more detailed than global-scale maps, which is a clear advantage at least for compiling extent accounts. However, MSA-based biodiversity accounts require an MSA value to be assigned to each ecosystem unit or land-use type, which may require additional data and analysis. Currently, the MSA values and cause-effect relationships from GLOBIO are derived from a generic database and the extent to which the values are applicable to individual countries has not been evaluated. Moreover, using country-specific land-use maps reduces comparability among countries.
- Given the trade-offs among the different land-use maps, it might be worth using by default multiple maps when compiling national ecosystem accounts, including a generic, global-scale land use (or land cover) map as well as more detailed country-specific maps.

- Because biodiversity is multi-dimensional, it is generally acknowledged that it cannot be adequately represented by a single indicator or metric (Schipper *et al.*, 2016). Hence, to obtain more inclusive biodiversity accounts, it is worth including additional metrics that are complementary to MSA. For example, species-habitat indices (SHIs) could be used in addition to MSA in order to account for differences in species pools among countries. SHIs quantify (changes in) the amount of suitable habitats of single species by combining land cover or land use maps with literature- and expert-based judgment on the occurrence ranges and habitat preferences of single species (GEO BON, 2015). Like MSA, SHIs are readily spatially aggregated and comparable across space and time.
- In the current study, we focused on ecosystem condition (state) only. Future efforts are needed to quantify also ecosystem services (flows) in the context of ecosystem accounting. Over the recent years, knowledge has greatly improved on the relationships between biodiversity on the one hand and ecosystem functioning and provisioning of services on the other (Isbell *et al.*, 2011; Hooper *et al.*, 2012). However, much of this ecological knowledge is acquired at small scales (e.g. experimental plots) and is still to be incorporated into models of ecosystem services at larger scales.

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SUPPLEMENTARY INFORMATION

Table S1 GLOBIO land-use types and classes with corresponding ecosystem types, extent (km^2) MSA values in Mexico. SL = Selective Logging; RIL = Reduced Impact Logging. For a more extensive description of the GLOBIO land-use mapping, see PBL (2016).

Code	Land-use type	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
10	Tree Cover, broadleaved, evergreen, natural	Forest - Natural	Forest	157078	1.00	0.97	0.97
11	Tree Cover, broadleaved, evergreen, plantation	Forest - Plantation	Forest	96	0.30	0.97	0.29
12	Tree Cover, broadleaved, evergreen, harvest	Forest - Clear-cut harvesting	Forest	10345	0.50	0.97	0.48
13	Tree Cover, broadleaved, evergreen, SL	Forest - SL	Forest	3509	0.70	0.97	0.68
14	Tree Cover, broadleaved, evergreen, RIL	Forest - RIL	Forest	668	0.85	0.97	0.82
20	Tree Cover, broadleaved, deciduous, closed, natural	Forest - Natural	Forest	129312	1.00	0.89	0.89
21	Tree Cover, broadleaved, deciduous, closed, plantation	Forest - Plantation	Forest	88	0.30	0.88	0.26
22	Tree Cover, broadleaved, deciduous, closed, harvest	Forest - Clear-cut harvesting	Forest	9485	0.50	0.88	0.44
23	Tree Cover, broadleaved, deciduous, closed, SL	Forest - SL	Forest	3218	0.70	0.88	0.62
24	Tree Cover, broadleaved, deciduous, closed, RIL	Forest - RIL	Forest	613	0.85	0.88	0.75
40	Tree Cover, needle-leaved, evergreen, natural	Forest - Natural	Forest	418234	1.00	0.95	0.95
41	Tree Cover, needle-leaved, evergreen, plantation	Forest - Plantation	Forest	261	0.30	0.94	0.28
42	Tree Cover, needle-leaved, evergreen, harvest	Forest - Clear-cut harvesting	Forest	28119	0.50	0.94	0.47
43	Tree Cover, needle-leaved, evergreen, SL	Forest - SL	Forest	9538	0.70	0.94	0.66
44	Tree Cover, needle-leaved, evergreen, RIL	Forest - RIL	Forest	1817	0.85	0.94	0.80
60	Tree Cover, mixed leaf type, natural	Forest - Natural	Forest	56112	1.00	0.94	0.94
61	Tree Cover, mixed leaf type, plantation	Forest - Plantation	Forest	37	0.30	0.93	0.28
62	Tree Cover, mixed leaf type, harvest	Forest - Clear-cut harvesting	Forest	4005	0.50	0.93	0.47
63	Tree Cover, mixed leaf type, SL	Forest - SL	Forest	1358	0.70	0.93	0.65
64	Tree Cover, mixed leaf type, RIL	Forest - RIL	Forest	259	0.85	0.93	0.79
90	Mosaic tree cover, natural	Forest - Natural	Forest	398	1.00	0.93	0.93
91	Mosaic tree cover, plantation	Forest - Plantation	Forest	0.2	0.30	0.93	0.28
92	Mosaic tree cover, harvest	Forest - Clear-cut harvesting	Forest	25	0.50	0.92	0.46
93	Mosaic tree cover, selective logging	Forest - SL	Forest	8	0.70	0.92	0.64
94	Mosaic: Tree cover / Other natural vegetation, RIL	Forest - RIL	Forest	2	0.85	0.92	0.78
110	Shrub cover, closed-open, evergreen	Shrubland - Natural	Shrubland/Herbaceous	43346	1.00	0.99	0.99
120	Shrub cover, closed-open, deciduous	Shrubland - Natural	Shrubland/Herbaceous	240289	1.00	0.98	0.98
130	Herbaceous cover, closed-open	Herbaceous cover - Natural	Shrubland/Herbaceous	29737	1.00	0.95	0.95

Code	Land-use type	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
140	Sparse herbaceous or sparse shrub cover	Herbaceous cover - Natural	Shrubland/Herbaceous	31449	1.00	0.99	0.99
150	Regularly flooded shrub and/or herbaceous cover	Herbaceous cover - Natural	Shrubland/Herbaceous	2159	1.00	0.97	0.97
160	Cropland, extensive	Cropland, extensive	Cropland	61312	0.30	1.00	0.30
161	Cropland, irrigated	Cropland, irrigated	Cropland	53872	0.05	1.00	0.05
162	Cropland, intensive	Cropland, intensive	Cropland	109803	0.10	1.00	0.10
180	Other natural vegetation	Herbaceous cover - Natural	Shrubland/Herbaceous	0.6	1.00	1.00	1.00
220	Artificial surfaces and associated areas	Urban area	Urban	1794	0.05	1.00	0.05
300	Pasture[a]	Pasture	Pasture	544077	0.59	0.85	0.51

[a] In GLOBIO, pasture is subdivided into moderately used grassland (MSA = 0.6) and man-made pasture (MSA = 0.3) based on the encompassing biome, following the biome classification and map of Olson (2001). If located in a forest biome, the pasture is considered man-made, else it is assumed to be moderately to intensively used grassland (PBL, 2016). The MSA values for pasture as provided in this table comprise area-weighted averages over the two pasture types.

Table S2 Aggregated land-use types with corresponding GLOBIO land-use classes, ecosystem types and MSA values.

Description[a]	Translation	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
ACUICOLA	Aquaculture	-	Aquaculture	1069	NA	NA	NA
AGRICULTURA DE HUMEDAD	Irrigated cropland	Irrigated cropland	Cropland	2075	0.05	0.84	0.05
AGRICULTURA DE RIEGO	Irrigated cropland	Irrigated cropland	Cropland	101031	0.05	0.84	0.05
AGRICULTURA DE TEMPORAL	Rainfed cropland	Extensive cropland	Cropland	224810	0.30	0.85	0.30
BOSQUE CULTIVADO	Forest plantation	Forest - plantation	Forest	597	0.30	0.87	0.26
BOSQUE DE CONIFERAS	Coniferous forest	Forest - natural	Forest	168597	1.00	0.93	0.93
BOSQUE DE ENCINO	Oak forest	Forest - natural	Forest	155742	1.00	0.95	0.95
BOSQUE MESOFILO DE MONTANA	Mountain cloud forest	Forest - natural	Forest	18542	1.00	0.93	0.93
ESPECIAL (OTROS TIPOS)	Undefined	Natural vegetation	Natural vegetation - undefined	4605	1.00	0.91	0.91
MATORRAL XEROFILO	Matorral	Natural vegetation	Shrubland	574399	1.00	0.94	0.94
NO APLICABLE	Urban area	Urban area	Urban area	33310	0.05	0.86	0.05
PASTIZAL	Grassland	Grassland - natural	Grassland	118815	1.00	0.93	0.93
PASTIZAL CULTIVADO	Pasture	Pasture - moderately to intensively used	Grassland	130022	0.60	0.89	0.53
SELVA CADUCIFOLIA	Deciduous tropical forest	Forest - natural	Forest	166580	1.00	0.93	0.93
SELVA ESPINOSA	Thornbush tropical forest	Forest - natural	Forest	18865	1.00	0.94	0.94
SELVA PERENNIFOLIA	Evergreen tropical forest	Forest - natural	Forest	91832	1.00	0.95	0.95
SELVA SUBCADUCIFOLIA	Semi-deciduous tropical forest	Forest - natural	Forest	42685	1.00	0.94	0.94
SIN VEGETACION APARENTE	Bare area	Bare area	Bare area	9684	1.00	0.96	0.96
VEGETACION HIDROFILA	Water and wetlands	-	Water and wetlands	26167	NA	NA	NA
VEGETACION INDUCIDA	Man-made vegetation (undefined)	Forest - plantation/man-made pasture	Plantation	62872	0.30	0.89	0.27

[a] Description according to the original map.

Table S3 Detailed land-use types with corresponding GLOBIO land-use classes, ecosystem types and MSA values.

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
ACUI	Acuìcola	-	Aquaculture	1069	NA	NA	NA
ADV	Desprovisto de vegetación	Bare area	Bare area	388	1.00	0.86	0.86
AH	A sentamientos humanos	Urban area	Urban area	6669	0.05	0.79	0.05
BA	Bosque de oyamel	Forest - natural	Forest	1250	1.00	0.92	0.92
BB	Bosque de cedro	Forest - natural	Forest	21	1.00	0.86	0.86
BC	Bosque cultivado	Forest - plantation	Forest	597	0.30	0.87	0.26
BG	Bosque de galeria	Forest - natural	Forest	204	1.00	0.86	0.86
BI	Bosque inducido	Forest - plantation	Forest	47	0.30	0.82	0.24
BJ	Bosque de táscate	Forest - natural	Forest	1481	1.00	0.92	0.92
BM	Bosque mesofilo de montaña	Forest - natural	Forest	8485	1.00	0.95	0.95
BP	Bosque de pino	Forest - natural	Forest	51664	1.00	0.93	0.93
BPQ	Bosque de pino-encino	Forest - natural	Forest	53679	1.00	0.94	0.94
BQ	Bosque de encino	Forest - natural	Forest	66340	1.00	0.96	0.96
BQP	Bosque de encino-pino	Forest - natural	Forest	29881	1.00	0.95	0.95
BS	Bosque de ayarin	Forest - natural	Forest	244	1.00	0.93	0.93
DV	Sin vegetación aparente	Bare area	Bare area	9684	1.00	0.96	0.96
H2O	Cuerpo de agua	-	Water	14384	NA	NA	NA
HA	Agricultural de humedad anual	Extensive cropland	Cropland	1324	0.30	0.85	0.30
HAP	Agricultural de humedad anual y permanente	Extensive cropland	Cropland	135	0.30	0.85	0.30
HAS	Agricultural de humedad anual y semipermanente	Extensive cropland	Cropland	278	0.30	0.83	0.30
HP	Agricultural de humedad permanente	Extensive cropland	Cropland	28	0.30	0.81	0.30
HS	Agricultural de humedad semipermanente	Extensive cropland	Cropland	171	0.30	0.85	0.30
HSP	Agricultural de humedad semipermanente y permanente	Extensive cropland	Cropland	140	0.30	0.80	0.30
MC	Matorral crasicaule	Natural vegetation	Shrubland	11504	1.00	0.92	0.92
MDM	Matorral desertico micrófilo	Natural vegetation	Shrubland	190505	1.00	0.93	0.93
MDR	Matorral desertico rosetofilo	Natural vegetation	Shrubland	103862	1.00	0.96	0.96
MET	Matorral espinoso tamaulipeco	Natural vegetation	Shrubland	24813	1.00	0.92	0.92
MK	Bosque de mezquite	Natural vegetation	Shrubland	2346	1.00	0.89	0.89
MKE	Mexquital tropical	Natural vegetation	Shrubland	1253	1.00	0.89	0.89
MKX	Mexquital xerofilo	Natural vegetation	Shrubland	20271	1.00	0.90	0.90
ML	Chaparral	Natural vegetation	Shrubland	20320	1.00	0.96	0.96
MRC	Matorral rosetófilo costero	Natural vegetation	Shrubland	4469	1.00	0.95	0.95

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
MSC	Matorral sarcocaule	Natural vegetation	Shrubland	51990	1.00	0.96	0.96
MSCC	Matorral sarco-crasicaule	Natural vegetation	Shrubland	22945	1.00	0.96	0.96
MSM	Matorral submontano	Natural vegetation	Shrubland	23207	1.00	0.94	0.94
MSN	Matorral sarco-crasicaule de neblina	Natural vegetation	Shrubland	5667	1.00	0.94	0.94
MST	Matorral subtropical	Natural vegetation	Shrubland	9783	1.00	0.94	0.94
PC	Pastizal cultivado	Pasture - moderately to intensively used	Grassland	130022	0.60	0.89	0.53
PH	Pastizal halofilo	Natural grassland	Grassland	16906	1.00	0.93	0.93
PI	Pastizal inducido	Pasture - man-made	Grassland	60341	0.30	0.89	0.27
PN	Pastizal natural	Natural grassland	Grassland	60625	1.00	0.93	0.93
PT	Vegetación de Petén	Natural vegetation	Water and wetlands	571	1.00	0.98	0.98
PY	Pastizal gipsófilo	Natural grassland	Grassland	389	1.00	0.91	0.91
RA	Agricultural de riego anual	Irrigated cropland	Cropland	53963	0.05	0.85	0.05
RAP	Agricultural de riego anual y permanente	Irrigated cropland	Cropland	9520	0.05	0.85	0.05
RAS	Agricultural de riego anual y semipermanente	Irrigated cropland	Cropland	28350	0.05	0.84	0.05
RP	Agricultural de riego permanente	Irrigated cropland	Cropland	3104	0.05	0.84	0.05
RS	Agricultural de riego semipermanente	Irrigated cropland	Cropland	4329	0.05	0.83	0.05
RSP	Agricultural de riego semipermanente y permanente	Irrigated cropland	Cropland	1764	0.05	0.84	0.05
SAP	Selva alta perennifolia	Forest - natural	Forest	13189	1.00	0.98	0.98
SAQ	Selva alta subperennifolia	Forest - natural	Forest	577	1.00	0.99	0.99
SBC	Selva baja caducifolia	Forest - natural	Forest	62827	1.00	0.94	0.94
SBK	Selva baja espinosa caducifolia	Forest - natural	Forest	2093	1.00	0.92	0.92
SBP	Selva baja perennifolia	Forest - natural	Forest	368	1.00	0.97	0.97
SBQ	Selva baja espinosa subperennifolia	Forest - natural	Forest	4444	1.00	0.99	0.99
SBQP	Selva baja subperennifolia	Forest - natural	Forest	837	1.00	0.99	0.99
SBS	Selva baja subcaducifolia	Forest - natural	Forest	285	1.00	0.95	0.95
SG	Selva de galería	Forest - natural	Forest	43	1.00	0.89	0.89
SMC	Selva mediana caducifolia	Forest - natural	Forest	1352	1.00	0.93	0.93
SMP	Selva mediana perennifolia	Forest - natural	Forest	3	1.00	1.00	1.00
SMQ	Selva mediana subperennifolia	Forest - natural	Forest	14475	1.00	0.97	0.97
SMS	Selva mediana subcaducifolia	Forest - natural	Forest	4080	1.00	0.97	0.97
TA	Agricultural de temporal anual	Extensive cropland	Cropland	175986	0.30	0.86	0.30
TAP	Agricultural de temporal anual y permanente	Extensive cropland	Cropland	15517	0.30	0.84	0.30

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
TAS	Agricultural de temporal anual y semipermanente	Extensive cropland	Cropland	8018	0.30	0.85	0.30
TP	Agricultural de temporal permanente	Extensive cropland	Cropland	14036	0.30	0.85	0.30
TS	Agricultural de temporal semipermanente	Extensive cropland	Cropland	8140	0.30	0.84	0.30
TSP	Agricultural de temporal semipermanente y permanente	Extensive cropland	Cropland	3114	0.30	0.83	0.30
VA	Popal	Natural vegetation	Water and wetlands	1422	1.00	0.96	0.96
VD	Vegetación de desiertos arenosos	Natural vegetation	Shrubland	21386	1.00	0.97	0.97
VG	Vegetación ed galería	Natural vegetation	Shrubland	1501	1.00	0.90	0.90
VH	Vegetación halófila xerófila	Natural grassland	Grassland	23350	1.00	0.93	0.93
VHH	Vegetación halófila hidrófila	Natural vegetation	Water and wetlands	3676	1.00	0.95	0.95
VM	Manglar	Natural vegetation	Water and wetlands	8541	1.00	0.97	0.97
VPI	Palmar inducido	Forest - Plantation	Forest	965	0.30	0.93	0.28
VPN	Palmar natural	Forest - natural	Forest	178	1.00	0.94	0.94
VS	Sabana	Natural grassland	Grassland	1580	1.00	0.93	0.93
VSa/BA	Vegetación secundaria arbustiva de bosque de oyamel	Secondary vegetation	Shrubland	131	0.50	0.91	0.46
VSA/BA	Vegetación secundaria arbôrea de bosque de oyamel	Secondary vegetation	Forest	122	0.50	0.91	0.45
VSa/BB	Vegetación secundaria arbustiva de bosque de cedro	Secondary vegetation	Shrubland	1	0.50	0.87	0.44
VSA/BB	Vegetación secundaria arbôrea de bosque de cedro	Secondary vegetation	Forest	3	0.50	0.78	0.39
VSa/BG	Vegetación secundaria arbustiva de bosque de galería	Secondary vegetation	Shrubland	13	0.50	0.83	0.42
VSA/BG	Vegetación secundaria arbôrea de bosque de galería	Secondary vegetation	Forest	14	0.50	0.84	0.42
VSa/BJ	Vegetación secundaria arbustiva de bosque de táscate	Secondary vegetation	Shrubland	1620	0.50	0.90	0.45
VSA/BJ	Vegetación secundaria arbôrea de bosque de táscate	Secondary vegetation	Forest	281	0.50	0.90	0.45
VSa/BM	Vegetación secundaria arbustiva de bosque mesófilo de montaña	Secondary vegetation	Shrubland	5233	0.50	0.91	0.45
VSA/BM	Vegetación secundaria arbôrea de bosque mesófilo de montaña	Secondary vegetation	Forest	4707	0.50	0.92	0.46
VSa/BP	Vegetación secundaria arbustiva de bosque de pino	Secondary vegetation	Shrubland	16968	0.50	0.93	0.46
VSA/BP	Vegetación secundaria arbôrea de bosque de pino	Secondary vegetation	Forest	7812	0.50	0.92	0.46
VSa/BPQ	Vegetación secundaria arbustiva de bosque de pino-encino	Secondary vegetation	Shrubland	19997	0.50	0.93	0.47
VSA/BPQ	Vegetación secundaria arbôrea de bosque de pino-encino	Secondary vegetation	Forest	12898	0.50	0.93	0.46
VSa/BQ	Vegetación secundaria arbustiva de bosque de encino	Secondary vegetation	Shrubland	39014	0.50	0.94	0.47
VSA/BQ	Vegetación secundaria arbôrea de bosque de encino	Secondary vegetation	Forest	6878	0.50	0.93	0.47
VSa/BQP	Vegetación secundaria arbustiva de bosque de encino-pino	Secondary vegetation	Shrubland	9524	0.50	0.94	0.47
VSA/BQP	Vegetación secundaria arbôrea de bosque de encino-pino	Secondary vegetation	Shrubland	3799	0.50	0.94	0.47

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
VSa/BS	Vegetación secundaria arbustiva de bosque de ayarín	Secondary vegetation	Forest	147	0.50	0.96	0.48
VSA/BS	Vegetación secundaria arbôrea de bosque de ayarín	Secondary vegetation	Forest	14	0.50	0.86	0.43
VSa/MC	Vegetación secundaria arbustiva de matorral crasicaule	Secondary vegetation	Shrubland	3802	0.50	0.89	0.45
VSa/MDM	Vegetación secundaria arbustiva de matorral desértico micrófilo	Secondary vegetation	Shrubland	22314	0.50	0.91	0.45
VSa/MDR	Vegetación secundaria arbustiva de matorral desértico rosetófilo	Secondary vegetation	Shrubland	3494	0.50	0.94	0.47
VSa/MET	Vegetación secundaria arbustiva de matorral espinoso tamaulipeco	Secondary vegetation	Shrubland	8460	0.50	0.91	0.46
VSa/MK	Vegetación secundaria arbustiva de bosque de mezquite	Secondary vegetation	Shrubland	506	0.50	0.90	0.45
VSA/MK	Vegetación secundaria arbôrea de bosque de mezquite	Secondary vegetation	Forest	40	0.50	0.93	0.46
VSa/MKE	Vegetación secundaria arbustiva de mexquital tropical	Secondary vegetation	Shrubland	235	0.50	0.87	0.43
VSa/MKX	Vegetación secundaria arbustiva de mezquital xerófilo	Secondary vegetation	Shrubland	3141	0.50	0.89	0.44
VSa/ML	Vegetación secundaria arbustiva de chaparral	Secondary vegetation	Shrubland	432	0.50	0.93	0.47
VSa/MRC	Vegetación secundaria arbustiva de matorral rosetófilo costero	Secondary vegetation	Shrubland	221	0.50	0.89	0.45
VSa/MSC	Vegetación secundaria arbustiva de matorral sarcocaule	Secondary vegetation	Shrubland	886	0.50	0.92	0.46
VSa/MSCC	Vegetación secundaria arbustiva de matorral sarco-crasicaule	Secondary vegetation	Shrubland	174	0.50	0.93	0.47
VSa/MSM	Vegetación secundaria arbustiva de matorral submontano	Secondary vegetation	Shrubland	4055	0.50	0.89	0.45
VSa/MSN	Vegetación secundaria arbustiva de matorral sarco-crasicaule de nebli	Secondary vegetation	Shrubland	42	0.50	0.93	0.46
VSa/MST	Vegetación secundaria arbustiva de matorral subtropical	Secondary vegetation	Shrubland	3204	0.50	0.92	0.46
VSa/PH	Vegetación secundaria arbustiva de pastizal halófilo	Secondary vegetation	Shrubland	1533	0.50	0.91	0.45
VSa/PN	Vegetación secundaria arbustiva de pastizal natural	Secondary vegetation	Shrubland	37575	0.50	0.92	0.46
VSA/PT	Vegetación secundaria arbôrea de vegetación de Petén	Secondary vegetation	Forest	42	0.50	0.95	0.47
VSa/PY	Vegetación secundaria arbustiva de pastizal gipsófilo	Secondary vegetation	Shrubland	21	0.50	0.82	0.41
VSa/SAP	Vegetación secundaria arbustiva de selva alta perennifolia	Secondary vegetation	Shrubland	8942	0.50	0.92	0.46
VSA/SAP	Vegetación secundaria arbôrea de selva alta perennifolia	Secondary vegetation	Forest	9919	0.50	0.94	0.47
VSa/SAQ	Vegetación secundaria arbustiva de selva alta subperennifolia	Secondary vegetation	Shrubland	125	0.50	0.88	0.44
VSA/SAQ	Vegetación secundaria arbôrea de selva alta subperennifolia	Secondary vegetation	Forest	963	0.50	0.91	0.46
VSa/SBC	Vegetación secundaria arbustiva de selva baja caducifolia	Secondary vegetation	Shrubland	59126	0.50	0.91	0.46

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km²)	MSA_{LU}	MSA_I	MSA
VSA/SBC	Vegetación secundaria arbôrea de selva baja caducifolia	Secondary vegetation	Forest	20731	0.50	0.92	0.46
VSa/SBK	Vegetación secundaria arbustiva de selva baja espinosa caducifolia	Secondary vegetation	Shrubland	2193	0.50	0.91	0.46
VSA/SBK	Vegetación secundaria arbôrea de selva baja espinosa caducifolia	Secondary vegetation	Forest	2165	0.50	0.89	0.45
VSa/SBP	Vegetación secundaria arbustiva de selva baja perennifolia	Secondary vegetation	Shrubland	46	0.50	0.94	0.47
VSA/SBP	Vegetación secundaria arbôrea de selva baja perennifolia	Secondary vegetation	Forest	5	0.50	0.94	0.47
VSa/SBQ	Vegetación secundaria arbustiva de selva baja espinosa subperennifolia	Secondary vegetation	Shrubland	2630	0.50	0.96	0.48
VSA/SBQ	Vegetación secundaria arbôrea de selva baja espinosa subperennifolia	Secondary vegetation	Forest	3840	0.50	0.97	0.48
VSA/SBQP	Vegetación secundaria arbôrea de selva baja subperennifolia	Secondary vegetation	Forest	165	0.50	0.92	0.46
VSa/SBS	Vegetación secundaria arbustiva de selva baja subcaducifolia	Secondary vegetation	Shrubland	104	0.50	0.93	0.47
VSA/SBS	Vegetación secundaria arbôrea de selva baja subcaducifolia	Secondary vegetation	Forest	115	0.50	0.96	0.48
VSA/SG	Vegetación secundaria arbôrea de selva de galería	Secondary vegetation	Forest	11	0.50	0.93	0.47
VSa/SMC	Vegetación secundaria arbustiva de selva mediana caducifolia	Secondary vegetation	Shrubland	1472	0.50	0.91	0.46
VSA/SMC	Vegetación secundaria arbôrea de selva mediana caducifolia	Secondary vegetation	Forest	7790	0.50	0.92	0.46
VSa/SMP	Vegetación secundaria arbustiva de selva mediana perennifolia	Secondary vegetation	Shrubland	4	0.50	0.90	0.45
VSa/SMQ	Vegetación secundaria arbustiva de selva mediana subperennifolia	Secondary vegetation	Shrubland	5931	0.50	0.91	0.46
VSA/SMQ	Vegetación secundaria arbôrea de selva mediana subperennifolia	Secondary vegetation	Forest	35600	0.50	0.96	0.48
VSa/SMS	Vegetación secundaria arbustiva de selva mediana subcaducifolia	Secondary vegetation	Shrubland	9160	0.50	0.93	0.46
VSA/SMS	Vegetación secundaria arbôrea de selva mediana subcaducifolia	Secondary vegetation	Forest	28893	0.50	0.95	0.47
VSa/VD	Vegetación secundaria arbustiva de vegetación de desiertos arenosos	Secondary vegetation	Shrubland	24	0.50	0.97	0.48
VSa/VG	Vegetación secundaria arbustiva de vegetación de galería	Secondary vegetation	Shrubland	3	0.50	0.78	0.39
VSa/VH	Vegetación secundaria arbustiva de vegetación halófila xerófila	Secondary vegetation	Shrubland	2463	0.50	0.92	0.46

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_{I}	MSA
VSa/VHH	Vegetación secundaria arbustiva de vegetación halófila hidrófila	Secondary vegetation	Shrubland	3	0.50	0.84	0.42
VSa/VM	Vegetación secundaria arbôrea de manglar	Secondary vegetation	Forest	772	0.50	0.93	0.46
VSA/VM	Vegetación secundaria arbustiva de manglar	Secondary vegetation	Shrubland	133	0.50	0.95	0.47
VSa/VPN	Vegetación secundaria arbôrea de palmar natural	Secondary vegetation	Forest	11	0.50	1.00	0.50
VSA/VPN	Vegetación secundaria arbustiva de palmar natural	Secondary vegetation	Shrubland	5	0.50	1.00	0.50
VSh/BJ	Vegetación secundaria herbácea de bosque de táscate	Secondary vegetation	Grassland	16	0.50	0.88	0.44
VSh/BM	Vegetación secundaria herbácea de bosque mesófilo de montaña	Secondary vegetation	Grassland	117	0.50	0.86	0.43
VSh/BP	Vegetación secundaria herbácea de bosque de pino	Secondary vegetation	Grassland	61	0.50	0.92	0.46
VSh/BPQ	Vegetación secundaria herbácea de bosque de pino-encino	Secondary vegetation	Grassland	186	0.50	0.91	0.46
VSh/BQ	Vegetación secundaria herbácea de bosque de encino	Secondary vegetation	Grassland	246	0.50	0.90	0.45
VSh/BQP	Vegetación secundaria herbácea de bosque de encino-pino	Secondary vegetation	Grassland	60	0.50	0.91	0.45
VSh/MC	Vegetación secundaria herbácea de matorral crasicaule	Secondary vegetation	Grassland	34	0.50	0.93	0.47
VSh/MDM	Vegetación secundaria herbácea de matorral des desértico micrôfilo	Secondary vegetation	Grassland	2	0.50	1.00	0.50
VSh/MDR	Vegetación secundaria herbácea de matorral desértico rosetófilo	Secondary vegetation	Grassland	30	0.50	1.00	0.50
VSh/MET	Vegetación secundaria herbácea de matorral espinoso tamaulipeco	Secondary vegetation	Grassland	24	0.50	0.84	0.42
VSh/MJ	Vegetación secundaria herbácea de matorral de coniferas	Secondary vegetation	Grassland	1	0.50	0.78	0.39
VSh/MRC	Vegetación secundaria herbácea de matorral rosetófilo costero	Secondary vegetation	Grassland	17	0.50	0.91	0.45
VSh/MSCC	Vegetación secundaria herbácea de matorral sarco-crasicaule	Secondary vegetation	Grassland	2	0.50	1.00	0.50
VSh/MSN	Vegetación secundaria herbácea de matorral sarco-crasicaule de nebli	Secondary vegetation	Grassland	8	0.50	0.86	0.43
VSh/PN	Vegetación secundaria herbácea de pastizal natural	Secondary vegetation	Grassland	19	0.50	0.90	0.45
VSh/SAP	Vegetación secundaria herbácea de selva alta perennifolia	Secondary vegetation	Grassland	525	0.50	0.90	0.45
VSh/SAQ	Vegetación secundaria herbácea de selva alta subperennifolia	Secondary vegetation	Grassland	32	0.50	0.88	0.44
VSh/SBC	Vegetación secundaria herbácea de selva baja caducifolia	Secondary vegetation	Grassland	272	0.50	0.91	0.45

Code	Name[a]	GLOBIO land-use class	Ecosystem type	Extent (km^2)	MSA_{LU}	MSA_I	MSA
VSh/SBK	Vegetación secundaria herbácea de selva baja espinosa caducifolia	Secondary vegetation	Grassland	1	0.50	0.81	0.40
VSh/SBQ	Vegetación secundaria herbácea de selva baja espinosa subperennifolia	Secondary vegetation	Grassland	12	0.50	1.00	0.50
VSh/SMC	Vegetación secundaria herbácea de selva mediana caducifolia	Secondary vegetation	Grassland	23	0.50	0.93	0.47
VSh/SMQ	Vegetación secundaria herbácea de selva mediana subperennifolia	Secondary vegetation	Grassland	128	0.50	0.90	0.45
VSh/SMS	Vegetación secundaria herbácea de selva mediana subcaducifolia	Secondary vegetation	Grassland	49	0.50	0.90	0.45
VSh/VH	Vegetación secundaria herbácea de vegetación halófila xerófila	Secondary vegetation	Grassland	8	0.50	0.93	0.46
VSh/VM	Vegetación secundaria herbácea de manglar	Secondary vegetation	Grassland	1	0.50	0.78	0.39
VSI	Sabanoide	Natural grassland	Grassland	1519	1.00	0.91	0.91
VT	Tular	Natural vegetation	Water and wetlands	9216	1.00	0.97	0.97
VU	Vegetación de dunas costeras	Natural vegetation	Shrubland	1519	1.00	0.95	0.95
VW	Pradera de alta montaña	Natural grassland	Grassland	166	1.00	0.94	0.94
VY	Vegetación gipsófila	Natural grassland	Grassland	480	1.00	0.95	0.95
ZU	Zona urbana	Urban area	Urban area	11868	0.05	0.78	0.05

[a] According to the original source.

Textbox S1 python script to calculate combined MSA values

```
cls( !Ecosystem_type!, !MSA!, !Road_factor! )
# “cls” is the name of the variable to be calculated in the MSA_c field, Ecosystem_type,
MSA and Road_factor are Field names in ArcGIS for fields with values
def cls( Ecosystem_type, MSA, Road_factor ):
  if Road_factor == 0.78:
# calculates values for areas influenced by roads
    if Ecosystem_type == "Cropland":
      return MSA
    elif Ecosystem_type == "Urban area":
      return MSA
# the  MSA for Cropland and Urban area remains the original MSA
    else:
      return  MSA * Road_factor
# calculates the combined MSA for the original MSA (not for Cropland or Urban area) and
the road factor (0.78)
  else:
    return MSA
# returns the original MSA for area’s not influenced by roads
```