

# Land Use Change and Urban Ecosystem Services: A Case Study of Urban Wetlands in a Rapidly Sprawling City in the Highlands of Chiapas, Mexico

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## Abstract

Urban wetlands provide a wide range of ecosystem services that are important for human-well-being. Despite their social and environmental importance, the degradation of urban wetlands continues mainly due to land use changes induced by rapid urbanization. Estimating the impact of these changes on ecosystem services is crucial to support the decision-making process of city planners at different levels. In this study, the spatial extents of the urban wetlands of San Cristobal de Las Casas, Chiapas, Mexico were determined for the years 2001 and 2018 in order to relate the spatial changes between these years with the provision and economic value of ecosystem services. Google Earth and SPOT imagery were used to evaluate land use/land cover changes while international coefficients were used to assess the value of the ecosystem services by category. Findings reveal a 7.3% decrease in the urban wetland area and a 12.5% increase of urban areas during the study period. The ecosystem service valuation shows that the total value flow decreased around \$5 million (2007 USD) during the 17-year period, mainly due to decreases in the potential for regulating and cultural services. The use of freely available land use/land cover data together with global ecosystem service estimates reduce the cost of ground data collection and provides quick and reliable information that could help decision makers with land use planning in the context of data-scarce regions.

**Keywords:** urban wetlands, ecosystem services, land use change, freely available data

## 1. Introduction

In 2016, an estimated 54.5 per cent of the world's population lived in urban settlements. By 2030, urban areas are projected to house 60 per cent of people globally and one in every three people will live in cities with at least half a million inhabitants (United Nations, 2016). Although developing countries started the process of urbanization more recently, they are now experiencing a higher level of urbanization than in developed countries (Montgomery, 2008). This rapid urbanization implies massive investment in urban infrastructure and profound changes in urban ecosystems and landscapes (Green et al., 2016) that has many negative environmental effects, and subsequently effects in the benefits people obtain directly or indirectly from ecosystems, known as "ecosystem services" (ES) (Costanza et al., 1997; MEA, 2005). The environmental dimension impacts include the loss of biodiversity (Grimm et al., 2008; Atu et al., 2013), air and water pollution (Wilson et al., 2003), noise (Derkzen et al., 2015), higher GHG emissions (Glaeser & Kahn, 2004) and increasing runoff and flood potential (Poelmans et al., 2009). These impacts are particularly important in developing countries where there is limited capacity to cope with the environmental and social consequences of rapid urban expansion (Cohen, 2006). This unprecedented urbanization emphasizes the need for innovative approaches to generating knowledge before, during and after the process of urbanization in an adaptive mode (Ahern et al., 2014).

### 1.1 Valuation of Urban Wetland Ecosystem Services

In recent years, the study of urban ecosystem services (UES) is emerging as an important research frontier for

the incorporation of the benefits of ecosystems for urban health and well-being (Gómez-Baggethun & Barton, 2013; Kremer et al., 2016; Derkzen et al., 2015), security (Whitford et al., 2001), economy (TEEB, 2011), and as a tool for improving urban sustainability (Elmqvist et al., 2013) and resilience (McPhearson et al., 2013). Urban ecosystems provide vital ecosystem services for urban dwellers (McDonald & Marcotullio, 2011) and these UES are generated by a diverse set of land use/land covers (LULC), comprising of wetlands, parks, golf courses, gardens and yards, sports fields, among others (Haase et al., 2014). Urban wetlands are considered one of the most important ecosystems in urban areas because they provide a variety of valuable ecosystem services, including water purification, filtration, retention of nutrients, flood control, ground-water recharge, and providing habitat for a variety of species. Wetlands are also valued for recreational and aesthetic reasons (Boyer & Polasky, 2004). Despite their social importance in the support of human well-being, the degradation and loss of wetlands continues. Urbanization has become a major cause of the loss of wetland area. Wetland destruction in urban areas occurs mainly due to the conversion of LULC to commercial and residential development and establishment of road infrastructure (Azous & Horner, 2000), thereby resulting in negative impacts on biodiversity as well as in the alteration of functional processes, thus diminishing the provision of ecosystem services to local society.

The estimation of a monetary value for wetland ecosystem services is increasingly recognized as a valuable tool that facilitates better social decision-making in wetland protection versus land-use development conflict situations, and represents a foundation for the rational and sustainable utilization of environmental resources (Mitsch & Gosselink, 2000; Boyer & Polasky, 2004; Barbier, 2007; Turner et al., 2008; Gómez-Baggethun & Barton, 2013). In this sense, notable studies have estimated the changes in ecosystem service values (ESV) provided by wetlands in response to land use changes during urbanization (Kreuter et al., 2001; Zhao et al., 2004; Tong et al., 2007; Li et al., 2010; Su et al., 2012; Haase et al., 2014; Yirsaw et al., 2016; Chuai et al., 2016). In these studies, Geographical Information Systems (GIS) and remote sensing techniques have been used to examine the impacts of LULC changes in ESV identify the points of intervention and direct growth away from sensitive ecological areas (Mosammam et al., 2016). Recent advances in remote-sensing data with improved spatial accuracy and availability of free to less expensive satellite images coupled with GIS allow quantitative analyses of the rate and pattern of LULC with reasonable cost and better accuracy (Haack & Rafter, 2006). The results of these studies provide useful information to land managers and policy makers because they can recognize the relationships among urban ecosystems and the services which they provide to local inhabitants.

### *1.2 Study Site Context*

Previous research on urban ecosystems, including urban wetlands, has focused on cities in North America, Europe and Asia (Beninde et al., 2015), which are among the most highly urbanized continents (United Nations, 2016). In contrast, there is a lack of urban and wetland ecosystem services research in less urbanized and less economically developed regions (Luederitz et al., 2015). It is increasingly recognized that ecosystem services must be incorporated into urban planning (Colding, 2011). Therefore, effective governance and planning to achieve a more sustainable urban form are crucial and one of the major challenges for urban planners and policy makers in these countries.

Mexico is considered a country with a considerable urban growth. The urban population has been increasing steadily and has gone from 47.9 million in 1990 to 81.2 million in 2010 and is projected to have an additional increase of 13.1 million by 2030 (INEGI, 2010a). This urbanization process is being carried out in accordance with a model of disconnected land occupation characterized by a fragmented expansion of the urban area (Libertun & Guerrero, 2017) which has generated enormous pressure on natural resources.

The city of San Cristobal de Las Casas (SCC), located in southeastern Mexico and selected as our case study, has experienced a rapid urbanization especially over the past few decades following the rise of tourism activity, with an annual growth rate of 6.3% (INEGI, 2010b; Figueroa-Jáuregui et al., 2011; Figure 1). The concentration of the population and the need for housing, together with the lack of municipal regulation and economic interests has caused the degradation of important urban wetlands (Calderon-Cisneros et al., 2012). In fact, urbanization has been reported as the most influential anthropic impact on the reduction of these wetlands (Merino, 2013). In general, fragmentation of wetlands due to increases in urban encroachment and road development alter and hinder the movement of water and migration of plants and animals in these areas (Boyer & Polasky, 2004). Overall, this situation has had a direct impact on the capacity of urban wetlands to provide ecosystem services to local people; for example, the capacity of recharging the aquifer is reduced, causing water scarcity, particularly in the periphery neighborhoods, which are the most marginalized areas of the city (Cruz-Morales & Hernández-Pérez, 2010). Therefore, in order to reverse this situation and enhance local decision-making processes, it is necessary to generate information about the links between urbanization and the consequent

impact on the provision of a range of ecosystem services provided by wetlands (Boyer & Polasky, 2004).

Although in Mexico, studies on the measurement of wetland ecosystem service value variations as a consequence of land use changes have been carried out, most of them have focused on coastal wetlands (Mendoza-González et al., 2012; Camacho-Valdez et al., 2014) or some ecosystem services derived from them (Perez-Verdin et al., 2016). The main finding of these studies has been the significant loss of the ecosystem service values in mangroves ecosystems mainly caused by an increase in urban areas. On the other hand, for urban wetlands few studies have been performed and most of them have carried out in big cities (Jujnovsky et al., 2012; Merlin-Urbe et al., 2013), even when these ecosystems are considered as one of the most valuable ecosystems because they supply a number of ecosystem services in cities (Ibarra et al., 2013). In fact, according to Chaikumbung et al. (2016) urban wetlands are more valuable than other wetlands (e.g., rural wetlands).

In our case study, few studies published as journal articles have been directly related to the local urban wetlands even when urban developments have increased in the city, worsening the degradation and loss of natural ecosystems (Calderon-Cisneros et al., 2012). In one example, a report by Pronatura Sur A.C., an environmental non-governmental organization (ENGO), showed maps of the location and level of degradation of urban wetlands in San Cristobal from 2006 to 2011 (Rojas & Alba, 2011). Other studies relevant to this area have included descriptions of the conservation situation of an endemic species of fish, the San Cristobal pupfish (*Profundulus hildebrandi*) (Velázquez-Velázquez & Schmitter Soto, 2004; Velázquez-Velázquez et al., 2009), land use implications for agricultural areas within San Cristobal (Vásquez-Moreno & Córdova, 2013, Nahed-Toral et al., 2011), flood risks in the city (Gómez et al., 2008) and land use changes and carbon flux of the highland region forests of Chiapas (De Jong et al., 1999). In this sense, it is necessary to analyze the particular dynamic of LULC and their effect on wetland ecosystems services in a medium size city, since these cities will be where the greatest urban growth will be concentrated in the future.

### *1.3 Study Objective*

The aims of this paper were to: i) identify potential UES to urban dwellers from wetlands as the most appreciated natural element in cities; ii) calculate urban wetland ecosystem service values based on global references; and iii) characterize LULC changes and the effect on urban wetland ecosystem service values. This study would be helpful for the city planners and policy makers to direct future developments and for environmental management.

## **2. Methods**

### *2.1 Study Area*

San Cristobal de Las Casas (SCC) is a medium-sized city which has a population of 185,917 inhabitants, counted in the last census of 2010, and since the 1970s has experienced rapid urban sprawl (INEGI, 2010b; Figure 1). Currently, San Cristobal contains 85% of the municipal population (Figure 2), of which 30% belongs to indigenous groups of the region (predominantly Tsotsiles) with a high degree of marginalization, as well as numerous inhabitants from other states of the country and abroad (Calderon-Cisneros et al., 2012). The city of San Cristobal is located in Chiapas, Mexico, in a closed or endorheic basin at 2200 meters above sea level, surrounded by forest and mountain wetlands that are a priority for conservation (Arriaga et al., 2000). Overall, the wetlands present in SCC are considered as areas of connection and transition between land and water systems and play a fundamental role in flood control. They are also important reservoirs of groundwater that guarantee the permanent supply of water for the local population, since they influence the supply and protection of 10 springs (Rojas-Garcia & Alba-Lopez, 2011). These mountain wetlands are considered by the Ramsar Convention as unique and rare. Despite this, their fragility has been accentuated due to urban development, deforestation and agricultural practices that drain and eutrophize the waters (Ramsar Information Sheet, 2007).

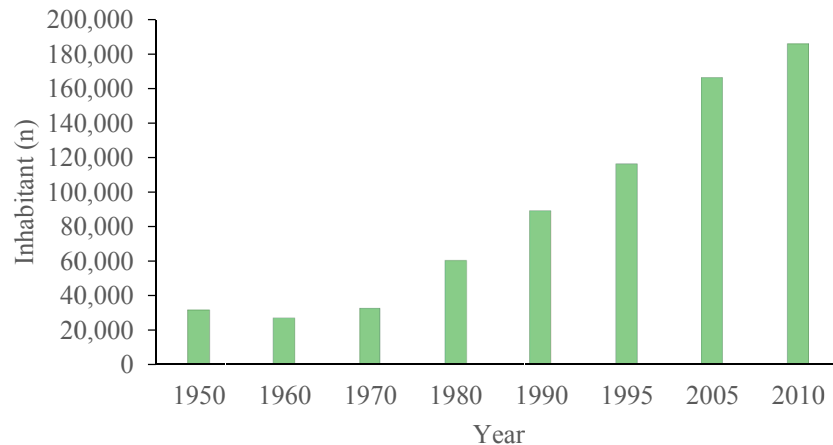


Figure 1. Population profile in San Cristobal de Las Casas city (SCC)

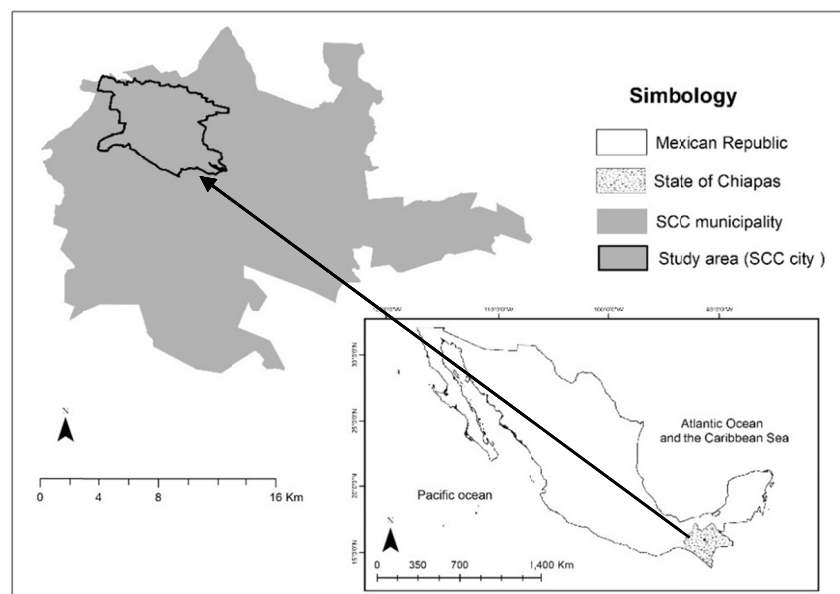


Figure 2. Study area. San Cristobal de Las Casas city (SCC), southern Mexico

The study area is mostly characterized by a warm, subhumid climate with an extensive dry season (from December to April) and 700 mm rainfall during the summer with an average annual temperature of 15°C and an annual mean rainfall of 880 mm (Bencala et al., 2006).

## 2.2 Land Use and Land Cover Analysis

The data used to identify the spatio-temporal distribution of LULC present in the study area were derived from SPOT 6 and Google Earth images acquired in 2001 and 2018, respectively. SPOT 6 images have four spectral bands and a resolution of 6 meters. Unfortunately, considering the high cost of data acquisition, we were not able to use high-resolution images such as SPOT for the 2018 image analysis. Even though the Landsat Thematic Mapper (TM) images are free and represented a good alternative, the images found for our study area (<https://glovis.usgs.gov/>) were cloudy and of very low quality to carry out the LULC analysis. Therefore, for 2018 we used Google Earth images as an alternative solution, which provides open, highly spatially resolved images suitable for assessing moderate-resolution remote sensing products across most of the world's urban and peri-urban areas (Guo et al., 2016). The Google Earth image was download at the highest resolution (4800x2701) synchronizing Google Earth Pro (GEP) with ArcMap 10.2.1 through ArcBruTile 0.2.2 tool. The advantage of this tool is that it loads Google Earth satellite images directly into ArcGIS, and offers a good resolution and updated

images.

Both images (SPOT 6 and Google Earth) were geographically projected to the UTM zone 15 North (WGS84) and limited to the boundaries of the administrative limit of the city of SCC (INEGI, 2014). We work in WGS84 because doing so avoids displacements or deformations that often occur when Arc Map is synchronized with Google Earth in other reference systems. Finally, both images could be compared directly because the coordinate reference system and resolution used in each image was consistent for our purpose.

Thematic layers were digitized in vector format from the images using ArcGis 10.2.1. The use of a -classification processes was ruled out because it would not offer better results than digitization since there was a high level of knowledge by experts about the study area and the boundaries of the land covers included in our study were easily identified (urban settlement, wetlands and other land covers).

The classification of the 2001 SPOT 6 image was digitized using ArcGis 10.2.1 for the categories of settlements, urban wetlands and other land cover. To digitize the urban wetlands, technical documents and a spatial layer that simulates the flood and infiltration zones were used as a basis to define the most relevant water bodies in the study area. For settlements and other land covers, the criteria defined in table 1 were used. The SPOT 6 2001 image allowed us to digitize vector layers at a scale of 1:2,500. The minimum digitization area was 0.033172 ha/ 331.72 square meters. This level of detail was chosen according to the areas where dispersed urbanization existed (e.g., not agglomerated houses).

For the Google Earth 2018 image, settlements areas were digitized following the same criteria as with the 2001 image and using as reference the 2001 settlements layer. To obtain the urban wetlands and other land covers remaining in 2018, an extraction geo-processing was carried out in ArcMap (clip). The layer of settlements 2018 (clip) was subtracted from the layers of urban wetlands and others land covers in 2001. This extraction is supported because in the study period both covers were transformed to urban areas. In addition to the digitalization, a field study was carried out to verify the defined classes of the 2018 land cover analysis.

Table 1. Land-use categories in the study area, together with their definition

LULC Category	Definition and criteria for digitalization
Settlement	All land used to construct human structures, including residential, commercial and industrial buildings.
Urban wetland	Mountain continental wetlands (where there is seasonally saturated), predominant vegetation consists of grasses and tulares. Include: swamps, marshes and floodplains.
Other land cover	Cultivated land, uncultivated areas with sparse plant cover, including barren, rocky, or abandoned land, bare land, green urban areas and land under development

### 2.3 Assignment of Ecosystem Service Values

The ES derived from urban wetlands in San Cristobal were identified based on a review of references from scientific papers, reports, decrees, thesis and Ramsar information sheets, which could provide us with information about the study area. These studies were performed by local NGO's, government agencies, research institutions and universities. Of these, only those documents that gave us specific and reliable information about the ES provided by urban wetlands in San Cristobal were selected. Once we defined the urban ES, we classified them according to TEEB foundations report (2011), which describes 22 ecosystem services and divides them into four main categories: provisioning, regulating, habitat and cultural.

Given the lack of local primary valuation studies, we needed to use international estimations. Therefore, we calculated the value of urban wetland ecosystem services based in the results of the global ecosystem service values obtained by de Groot et al. (2012). We used this new data to produce a more integrative approach that will incorporate a wide range of ecosystem services and thus generate more representative values. We assigned the equivalent coefficient of ESV according to the mean value of inland wetland biome (Table 4). This biome-type included in the de Groot et al. (2012) work was used as a proxy for the urban wetlands occurring in our study area. The inland wetland biome includes: (freshwater) floodplains, swamps/marshes and peat lands. The ecosystem service types found in the reviewed reference documents were standardized with those included in de Groot et al. (2012) for inland biome. To have more reliability in the standardization, the list of all the references (included as Supporting material in de Groot et al., 2012) that had been used for the monetary values by ecosystem service of this biome (inland wetlands) was reviewed. The values of ecosystem services for each year (2001, 2018) were estimated by multiplying the mean values by the area of wetlands for each period. All the monetary values for the analyzed years (2001, 2018) were based on 2007 values.

The change in the value of the ecosystem services was estimated by calculating the differences between the estimated size of wetlands and the ecosystem service values in 2001 and 2018.

#### 2.4 Spatial Analysis of Ecosystem Service Values

Flow estimates were then mapped across San Cristobal city showing the losses of the ecosystem service values provided by urban wetlands during the study period (2001–2018). The analysis and map were generated with the GIS software ArcGis 10.2.1 using the previously created LULC transformation map of 2018.

### 3. Results

#### 3.1 Land Use and Land Cover Changes

The changes in the area of LULC from 2001 to 2018 is shown in table 2. Overall, the table displays a significant decrease in wetland areas (-7.4%) that are related with an increase of the urban land cover (12.5 %). The cumulative loss of wetlands (260.83 ha) and other land covers (179.96 ha) in this period (2001–2018) is essentially equal to the increase in urban areas (440.80 ha).

Table 2. Land use/land cover dynamics and changes between 2001 and 2018

Land cover category	2001		2018		Change (2001–2018)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Settlement	1,490.5	42.1	1,931.3	54.6	440.8	12.5
Urban wetland	770.3	21.8	509.5	14.4	-260.8	-7.4
Other land cover	1,271.6	36.0	1,091.7	30.9	-179.9	-5.0
Total	3,532.5	100	3,532.5	100		

Figure 3 illustrates spatially the development of the LULC changes and highlights the transformation from wetlands to urban settlement in the northwestern zone. The changes of other land cover to settlement is more heterogeneous and are distributed in the whole study area.

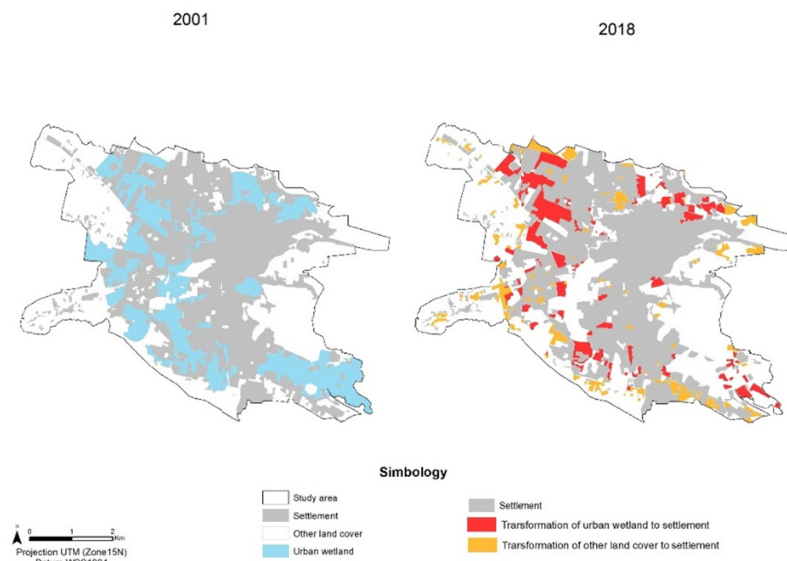


Figure 3. Land use/land cover map of San Cristobal de Las Casas city in 2001 and the transformation of urban wetland and other land cover to settlement in 2018

#### 3.2 Ecosystem Service Values

After reviewing regional references, we selected 15 documents (from 45) that mentioned specific information about the ecosystem service types of the SCC urban wetlands (Table 3). In relation to the ES categories, the most representative, in terms of frequency of appearance, were the regulating ES (46.1%) followed by cultural ES (23.1%). Less represented were provisioning (17.6%) and habitat (13.2%) categories.

Regarding the highest frequency of appearance by ES type in the total number of documents reviewed, the most important ecosystem service was “collect, store and supply fresh water” with 15 %, followed by “flood control and allow water filtration” with 14%, “maintenance of nursery populations and habitats” with 13% and “climate regulation” with 12%. Overall, cultural ecosystem service types were less important in terms of frequency (Table 3).

Table 3. Urban wetland ecosystem services derived from local reviewed documents and the total number of the documents that mention each type of service identified

SE Categories																	
Reviewed documents	<u>Provisioning services</u>	Collect, store and supply fresh water	Genetic diversity	<u>Regulating services</u>	Climate regulation	Flood control	Allow water filtration	Water purification	Soil erosion prevention	Retention of nutrients	<u>Habitat services</u>	Maintaining nursery populations and habitat	<u>Cultural services</u>	Scenic beauty	Recreation and tourism	Spirituality and religiosity	Environmental education and scientific research
1. MP of the KMW	+		+		+	+	+					+					+
2. ISRW of KW	+				+	+	+					+					+
3. KPA Decree	+				+	+	+					+					+
4. CDP					+							+		+			
5. SCDLCW: A&D	+				+	+	+					+					
6. VJBMP	+				+	+	+					+					
7. MP of the KMW	+		+		+	+	+					+		+			+
8. ISRW of MEW	+				+	+	+		+	+		+		+		+	+
9. MECCVJ	+				+	+	+					+					
10. VRF in SCDLC	+					+	+										
11. JVWSW of SCDLC	+					+	+	+				+			+	+	+
12. DDMW of SCDLC	+				+	+	+		+			+				+	
13. NRIMP in SCDLCB	+																
14. EMPT of SCDLC	+				+	+	+					+					
15. SR of JVB	+					+	+	+				+					
Total observations	16	14	2	42	11	13	13	2	2	1	12	12	21	6	6	3	6
Frequency of appearance (%)	18	15	2	46	12	14	14	2	2	1	13	13	23	7	7	3	7

*Notes.* 1. **MP of the KMW**: Management program of the Kisst mountain wetlands; 2. **ISRW of KW**: Information Sheet on Ramsar Wetlands (RIS) 2006-2008 version (Kisst wetland); 3. **KPA Decree**: Kisst protected natural area decree, 2011; 4. **CDP**: City development plan 2015-2018; 5. **SCDLCW, A&D**: San Cristobal de Las Casas Wetlands, Chiapas: actors and disputes. Cruz Morales et al, 2010. Journal of Agricultural Geography, no. 44, January-June, pp. 91-104; 6. **VJBMP**: Valley of Jovel Basin Management Plan; 7. **MP of the KMW**: Management program of the Maria Eugenia mountain wetlands; 8. **ISRW of MEW**: Information Sheet on Ramsar Wetlands (RIS). 2006-2008 version Maria Eugenia wetland; 9. **MECCVJ**: Modeling the effects of climate change in the Valley of Jovel. Santiago Lastra et al, 2016. *CaosConciencia*10 (1).1-12; 10. **(VRF in SCDLC**: Vulnerability and risk due to flooding in San Cristóbal de Las Casas, Chiapas. Montoya Gómez et al, 2008. *Estudios demográficos y urbanos*, vol. 23, núm. 1 (67), 83-122; 11. **JVWSW of SCDLC**: The Jovel Valley wetlands: source of water for the city of San Cristóbal de Las Casas, its conservation cannot be postponed. Sandra Chediack et al, Technical report, El Colegio de La Frontera Sur, Chiapas, 11 p; 12. **DDMW of SCDLC**: Diversity of dragonflies (Insecta: Odonata) in the mountain wetlands of San Cristóbal de Las Casas, Chiapas, Mexico (López Díaz: autor's Thesis, Instituto de Ciencias Biológicas, Chiapas); 13. **NRIMP in SCDLCB**: Natural resources integrated management Plan of the San Cristóbal de las Casas Basin (INIFAP-CENID RASPA, technical report, 73 p; 14. **EMPT of the SCDLC**: Ecological Management Program of The Territory of the SCDLC city; 15. **SR of JVB**: Strategy for the Restoration of the Jovel Valley Basin (Pronatura).

Table 4 shows the ecosystem services identified through the revision of local documents, and the equivalent ecosystem services derived from de Groot et al. (2012) used as proxies to estimate the mean values in urban wetlands distributed in SCC. According to the table 4, the ecosystem service category with the highest values is “regulating” with a total value of \$16,415 per hectare per year, highlighting regulation of water flow and waste treatment/water purification, with a mean value of \$5,606 per hectare per year and \$3,015 per hectare per year,

respectively. Cultural services also have been highly valued in global literature with a mean of \$3,503 per hectare per year. Provisioning and habitat services are the less valuable services (\$408 per hectare per year and \$1,287 per hectare per year, respectively) even though in our local reviewed literature are very important in relation to its representativeness, mainly “collect, store and supply fresh water” provisioning service (Table 3).

Table 4. de Groot et al. (2012) ecosystem service equivalents for the ecosystem services found in the local reviewed literature and the corresponding values per unit area (ESV in 2007 USD\$/ha/year)

ES found in the literature	Equivalent ES	No. of used estimated	Mean Value
	<u>Provisioning services</u>	17	408
Collect, store and supply fresh water	Fresh water supply	17	408
Genetic diversity	Genetic resources	-	-
	<u>Regulating services</u>	39	16,415
Climate regulation	Climate regulation	6	488
Flood control	Moderation of extreme events	11	2,986
Allow water filtration	Regulation of water flows	3	5,606
Water purification	Waste treatment/water purification	15	3,015
Soil erosion prevention	Erosion prevention	2	2,607
Retention of nutrients	Nutrient cycling/Maintenance of soil fertility	2	1,713
	<u>Habitat services</u>	2	1,287
Maintaining nursery populations and habitats	Lifecycle maintenance (nursery service)	2	1,287
	<u>Cultural services</u>	16	3,503
Scenic beauty	Aesthetic information	4	1,292
Recreation and tourism	Opportunities for recreation and tourism	12	2,211
Spirituality and religiosity	Spiritual experience	-	-
Environmental education and scientific research	Cognitive information	-	-
Total		74	21,613

Note. Modified from de Groot et al. (2012).

### 3.3 Changes in Ecosystem Service Values

Using the estimated change in the size of urban wetland together with the ecosystem service value coefficients reported by de Groot et al. (2012), we found that urban wetland changes in our study area resulted in an average net decline of \$5.63 million per year in ecosystem services between 2001 and 2018 (Table 5), which represented a significant cost for the local inhabitants. As shown in table 5, the contribution of regulating and cultural services to this decrease is significant, with around \$5 million per year.

Table 5. Values for each ecosystem service type using de Groot et al. coefficients, and the overall change and rate of change between 2001 and 2018 (ESV in US\$X10<sup>4</sup>)

Ecosystem services	Mean Value (Int\$/ha/y)	Annual flow (Int\$/y)		Change 2001–2018	
		2001	2018	(Int\$/y)	%
<u>Provisioning Services</u>	408	31.4	20.8	10.6	1.9
Fresh water supply	408	31.4	20.8	10.6	1.9
Genetic resources	-	-	-	-	-
<u>Regulating services</u>	16,415	1,264.5	836.3	428.2	75.9
Climate regulation	488	37.6	24.9	12.7	2.3
Moderation of extreme events	2,986	230	152.1	77.9	13.8
Regulation of water flows	5,606	431.8	285.6	146.2	25.9
Waste treatment/water purification	3,015	232.3	153.6	78.6	13.9
Erosion prevention	2,607	200.8	132.8	68	12.1
Nutrient cycling/maintenance of soil fertility	1,713	132	87.3	44.7	7.9
<u>Habitat services</u>	1,287	99.1	65.6	33.6	6
Lifecycle maintenance (nursery service)	1,287	99.1	65.6	33.6	6
<u>Cultural services</u>	3,503	269.8	178.5	91.4	16.2
Aesthetic information	1,292	99.5	65.8	33.7	6
Opportunities for recreation and tourism	2,211	170.3	112.7	57.7	10.2
Spiritual experience	-	-	-	-	-
Cognitive information	-	-	-	-	-
Total	21,613	1,664.8	1,101.2	563.8	

Note. Modified from de Groot et al. (2012).



### 3.4 Spatial Variability of Ecosystem Service Values

Once the annual flow of ESV was determined, a map was created to illustrate the spatial distribution of the ESV losses between 2001 and 2018. Figure 4 shows the total losses. Overall, the highest losses appear to be concentrated in the northwest zone of the study area with values up to 2 million per year, which coincide with the transformation from wetland to urban settlement during the study period. The areas of the lowest losses are mainly located in the south and southeast zone, where protected wetlands are prevalent.

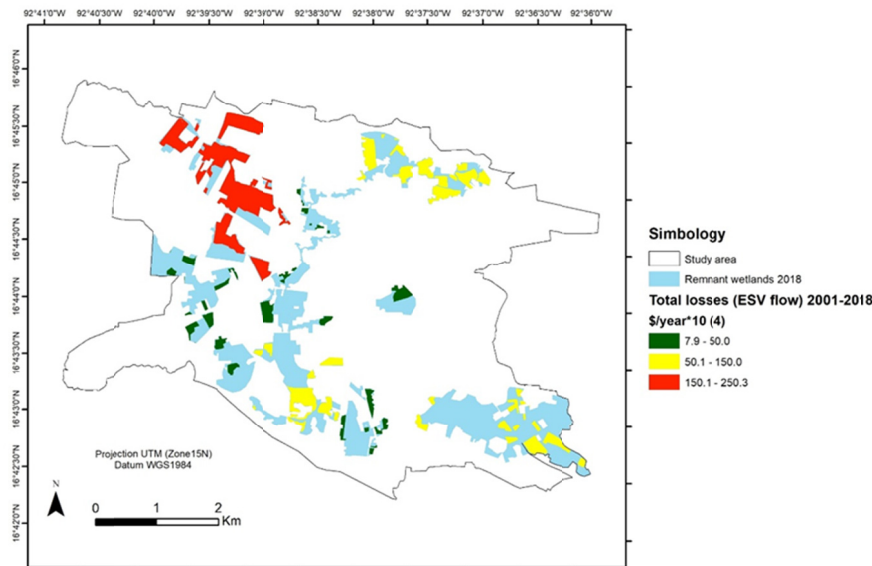


Figure 4. Total losses of ecosystem service value flow between 2001–2018 (ESV X10<sup>4</sup> in 2007USD\$/year)

## 4. Discussion

### 4.1 Advantages of the Use of Free Satellite Images and GIS

Thanks to the fast development of technology related to remote sensing and GIS, spatial data availability has increased significantly over the past decade (Hou et al., 2013). While there are debates as to the accuracy of the coverage maps and land use classification derived from satellite images (Alvarez-Martinez et al., 2010), in many cases, remote sensing from satellites, combined with GIS, may be the only economically feasible way to gather regular land cover information in developing countries like Mexico. The generation of maps from high resolution images is expensive, and even detailed maps often have discrepancies at a local level (Maes et al., 2011). Consideration of the spatial complexity in the supply and demand of ecosystem services is fundamental for the understanding of the underlying distribution of benefits and calculation of aggregated values across ecosystems and/or administrative regions. GIS have been used to map the spatial distribution of multiple ecosystem services at local (Lavorel & Grigulis, 2012), regional (Metzger et al., 2006) and global spatial scales (Ghermandi et al., 2013). Representation of the spatial variability of the provision of ecosystem services in maps is becoming an important tool for planning purposes and conservation decision-making. In this context, this research utilizes both, free satellite images provided by Google Earth platform and SPOT imagery to analyze the distribution of urban wetlands and land uses in San Cristobal and builds on such spatial information to provide a first estimate of the change in the ecosystem service value flows in the region.

### 4.2 Ecosystem Service Values

Our case study of an urban freshwater wetland is currently an underrepresented topic within the literature of Mexican wetland ecosystem services. The majority of these types of studies have focused on the current and historical provisioning services provided by the coastal wetlands of Mexico, which are important habitats for fish and other aquatic resources (Kovacs, 2000; Sardon, 2006). Urban wetlands, especially those within spatially restricted mountainous regions experience very different threats and provide different ecosystem services to those of coastal wetlands in more rural environments (Torres-Lima et al., 2018).

The few studies, which have assessed the ecosystem or socioeconomic values of urban freshwater wetlands in Mexico, have been done in the wetlands of Xochimilco, in Mexico City (Ibarra et al., 2013; Torres-Lima et al., 2018). These wetlands have a unique cultural importance in Mexico City and provide specific ecosystem services to the surrounding communities. However, the studies of the urban wetlands of Mexico City do demonstrate similarities to those of San Cristobal, of the types of services important to urban areas (especially non-market values such as water filtration and endemic species habitat) (Ibarra et al., 2013), and threats which these urban wetlands face in Mexico (e.g., contamination, urban expansion).

The environmental and economic perceptions of urban wetlands provided as a result of these studies as well as the methods used in our analysis (spatial changes in wetland extents and determination of specific values related to the urban environment), can be used as starting point to evaluate future urban wetlands in this region. The main finding of this study is that can highlight an important aspect of their value (monetary) and demonstrate to urban managers the need to conserve these areas, which may be seen as potential areas of development with little natural value.

Although the values of ecosystem services generated by de Groot (2012) that we have used in our analysis are far from perfect and have methodological challenges (e.g., value heterogeneity or valuation methods), for our context, they represent the most comprehensive and updated set of valuation coefficients available. In fact, the estimations using LULC and established ecosystem service value coefficient, is extremely important in San Cristobal de Las Casas city where ground data collection is expensive and there is scarce data on the historical LULC of urban areas.

#### *4.3 Influence of Policy in the Degradation of Urban Wetland*

The decrease in urban wetland ESV is largely attributable to the population growth and rapid economic development in the study area that have led to the expansion of construction over urban wetland areas, accelerating the losses of the value of the services provided by these ecosystems. Such conversion of wetland to construction land is in part a result of urban policy design by government (Tovar & Crispin, 2015).

From the 1990s onwards, Latin American cities have been subject to urban policies that have been characterized by: a) the implementation of new urban planning and renewal legislation; b) the promotion of tourism competitiveness and c) facilitation to the real estate market for residential, commercial, etc., among others (Brites, 2017). Overall, an urban focus which is oriented to install a market logic that favors the real estate speculation of private capital.

Although many cities have formulated urban planning and policy that included guidelines on land development and the future direction of urban growth, rarely have these been implemented. Reasons for this include poor urban governance and poor critical assumptions. Urban population projections underpinning these plans have often been extremely weak and the inability of plans to be adjusted and refined in the light of changing conditions, such as the invasion and settling of unused public space (Cohen, 2006). San Cristobal de Las Casas, selected as our case study, is not the exception to this context, and since the 1970s has experienced rapid urban sprawl without sustainable policy of land use and urban planning (Chediack et al., 2015), causing degradation and loss of urban wetland ecosystems and therefore reducing the provision of ecosystem services to local inhabitants. One of the main environmental and health problems associated with urbanization in the study area is the high contamination of urban wetlands due to the lack of adequate treatment of wastewater (Bencala et al., 2006). In this sense, it is a priority issue to make a sustainable urban planning, which will ensure the provision and maintenance of ecosystem services for local inhabitants over the interests of real estate and commercial speculation.

While there are currently two wetland areas that are under protection (Ramsar and local protection), it is necessary to establish an effective natural protected area system, with adequate management and protection plans, which will ensure the conservation of the scarce surface area of wetlands remaining in the study area (Chediack et al., 2018).

## **5. Conclusions**

This study is the first to estimate the change in the ecosystem service values provided by urban wetlands in San Cristobal de Las Casas, Chiapas. Based on the estimated extent of urban wetland cover and the assessment of ESV through international estimates, we determined that the total annual ES values decreased by approximately 5 million (2007 USD) from 2001 to 2018, highlighting the northern zone with the highest concentration of losses, where transformations to urban commercial land are prevalent. Regulating and cultural services were the most valuable ecosystem services.

The results of this study can provide alternatives and basic information for decision-making processes at urban landscape level, recognizing the value of urban wetlands to human survival and well-being in future land-use and policy formulation in San Cristobal de Las Casas. Otherwise the area of the urban wetland will continue decreasing.

## 6. Limitations and Recommendations

Even though the use of satellite images can be a useful tool for analyze land use/land cover changes, they have some limitations. Onscreen digitizing processes could give us different results depending on the practice and knowledge of the area by the technician. It could lead to a misclassification of bare soils and therefore overestimate the impact of urban sprawl. Regarding this, it is recommended that the image user be the same throughout the digitalization process and have enough knowledge of the area.

There are uncertainties related with the valuation of ecosystem services, especially in our case that we use international data as proxy for estimate wetland values. The main causes of biases in the use of this type of information are related with the heterogeneity of the primary data. This heterogeneity is due data were obtained from different socio-economic contexts and have been estimated through different valuation methodologies, among others. Therefore, it is necessary to include criteria (e.g., take account socio-economic context) or protocols in future primary studies or data sets that help to improve the accuracy of the value coefficients. Although the values estimated have to be taken with caution they can be a useful starting point for the interactions between academic and land decision makers.

In local future studies, it is imperative to obtain data on ecosystem services that more accurately reflect local conditions (Zhao et al., 2004). One approach to achieve this is to incorporate the social perception from ecosystem services by urban dwellers. Socio-cultural valuation approaches appear to be appreciated in understanding the diversity of values emerging from the ecosystem services spectrum and in analyzing how human well-being may be affected by ecological changes (Chan et al., 2012).

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