Urban Wetland Trends in Three Latin American Cities during the Latest Decades (2002-2019): Concón (Chile), Barranquilla (Colombia), and Lima (Peru)

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ABSTRACT

Wetlands are valuable but threatened natural resources worldwide. While providing a wealth of environmental benefits, wetlands play a vital role in temporarily storing flood waters and thereby reducing the risk of damaging floods. This is important given the predicted impacts of climate change, especially along the world's coastline and coastal cities. The continued expansion of urban areas is posing a risk to wetlands in and around metropolitan areas. In this article we examine wetland trends in urban areas in three Latin American countries – Chile, Colombia, and Peru.

INTRODUCTION

Wetlands, including their associated vegetation and the water bodies, cover at least 10% of the planet (Davidson et al. 2018). They are disappearing, even though they are relevant ecosystems for ecological balance and for mitigating the effects of climate change. It is estimated that since 1900, the world has lost more than 50% of these ecosystems, and the increase in urbanization has been identified as one of the main causes for this loss (Boyer and Polasky 2004; Faulkner 2004; Bishop et al. 2006; González et al. 2014). In fact, more than 55% of the world's population lives in cities, and it is expected that by 2050, this figure will reach 68% (United Nations 2018). As urban growth increases, wetland area decreases. Unfortunately, Latin America leads this worldwide tendency, reporting a loss of 59% of wetlands over the last decades (1970-2015) (Darrah et al. 2019). This loss is combined with the fact that it is one of the poorest and most economically unequal regions on the planet (Cepal 2019).

Wetlands are particularly relevant for cities because: 1) most large cities are located on the coast, 2) world urban growth has been concentrated in low-elevation coastal zones, and 3) the assistance of wetlands when facing frequent urban disasters has not been considered. It is a fact that wetlands mitigate the impact of flooding, which helps make cities more resilient (Ramsar 2019). In relation to this, according to the United Nations (2014), 233 of the world's cities are located in zones that are high at risk for flooding, affecting approximately 663 million people. These urban areas require precaution and more resilient infrastructure. The importance of wetlands could be even greater when facing extreme events, such as the flooding that occurred in Phoenix, USA in 2014 (Kim et al. 2017). In fact, in the northeastern USA, wetlands helped save $625 million dollars in direct damage from the floods caused by Hurricane Sandy in 2012 (Narayan et al. 2017).

One of the main ecosystem services of wetlands is protecting the coast. They are also important for cities, as they act as carbon sequestering systems, purify water, and maintain biodiversity and ecological processes. They even provide a place for recreation and relaxation for urban residents (Maltby and Acreman 2011; McInnes 2014). Without a doubt, the loss of wetlands is affecting the sustainability and resilience of our Latin American cities. This is especially true for coastal cities that face the challenge of being prepared for the increase in frequency of natural disasters, such as urban flooding. Ramsar (2018) also highlights the role of wetlands in cities by decreasing the impact of urban flooding caused by strong rainfall, as well as providing a buffer from swells and tsunamis. However, Latin America is dealing with a loss of wetlands, despite being one of the regions most exposed to flooding (UN 2011). Evidently, this tendency also increases the region's vulnerability to climate change (Seto et al. 2011; Hallegatte et al. 2013).

We are facing an alarming scenario, where sustained urban growth is the generalized trend in Latin American cities (UN 2018) which in many cases occurs at the expense of natural spaces (Rojas et al. 2013; Aldana-Domínguez et al. 2019). Facing pressure to expand, cities have converted wetlands to developable land by legal and illegal landfills as is the case in Chile and Argentina (Rojas 2018; Pintos and Sgroi 2012). Legal clearing is protected by urban laws that do not incorporate factors such as ecological connectivity, integration with the coast, or geomorphological

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TABLE 1. Selected images per wetland study area.

Study Area	Collection Year	Image Source	Error (RMS)
Aconcagua	2004 – 2019	Google Earth Pro – ArcGIS Pro	0.45 – 0.32
Ciénaga de Mallorquín	2002 – 2019	Google Earth Pro – ArcGIS Pro	0.69 – 0.62
Pantanos de Villa	2002 – 2019	Google Earth Pro	0.98 – 0.73

processes (Rojas et al. 2019). As for the illegal clearing, in addition to the environmental impact, high risk situations are generated, caused by ground instability. This progressive growth of Latin American cities has altered and fragmented wetlands, whether it be for housing or transportation infrastructure, creating coastal zones with degraded and devalued ecosystems that are marginalized from the territory.

Because of this situation in Latin America, the study of urban wetlands is highly relevant,

FIGURE 1: Location of the studied wetlands.

as it can contribute to our base of knowledge and support conservation initiatives. Urban wetlands have been little studied and defined, to the point that the Ramsar Convention (Secretary of the Ramsar Convention) or global treaty for the conservation of wetlands recognizes this debt, admitting that urban wetlands have been forgotten (Hettiarachchi et al. 2015). Because of this, these authorities have highlighted the relevance of urban wetlands, and in 2018, they declared that they were key sites for making cities healthy and habitable. On the other hand, the lack of information on the boundaries of urban wetlands has further complicated their recognition in the planning of cities. They are in fact a unique ecosystem. It is very challenging to physically define them with remote sensing techniques and geographic information systems, especially when they coexist in a heterogeneous landscape and are located in coastal cities (Adam et al. 2014; Gibril et al. 2020). Furthermore, they do not have a uniform plant coverage, are highly dynamic and their spectral reflectance is easily disrupted. Additionally, land use has further increased their variability, causing modifications in their vegetation and water levels (Gallant 2015).

The objective of this study is to carry out a spatial and multi-temporal analysis with remote sensors, to determine wetland surfaces and changes in three cities in Chile, Colombia and Peru. It seeks to analyze changes in land use that have led to loss and gain in urban wetlands during the period (2002-2019) when the greatest loss of these ecosystems has been reported (Darrah et al. 2019). Land changes are analyzed with high-resolution satellite images, which offset problems of definition by other sensors such as Landsat, as they have only been available for the last two decades in the wetlands situated in the Latin American coastal cities of Barranquilla, Lima, and Concón. These data will allow for discovering the main spatial dynamics related to the reduction and alteration of these ecosystems, thereby taking a first step towards the recognition of the status of these ecosystems. The chosen cities are part of the "Urban Wetlands in Latin America: a solution for sustainable cities SDG 11" Project (2019 -2021); cities that have experienced rapid urbanization and are vulnerable to climate change.

OVERVIEW OF URBAN WETLANDS IN LATIN AMERICA

Although Latin American countries have joined the Ramsar Convention (1981), and represent 11% of the world's wetlands, the region leads in wetland loss, reaching 59% (Darrah et al. 2019). Specifically, the region has observed losses of wetland surface in cities in Chile, Peru, Colombia, Argentina and Brazil. Decreases are registered on the Brazilian coast (Sousa et al. 2011; Wittmann et al. 2015), the Andes and Caribbean regions of Colombia (Patino

TABLE 2. Land use covers, definitions and reference signatures.

Land covers	Land Use	Description	Referential Photograph
Artificial and productive areas	Transportation Networks	Paved, gravel or dirt roads and tracks.	
	Urban Areas	Populated sectors, plazas, shopping centers and disperse urbanization.	
	Urban green areas	Sectors with artificial vegetation for recreation and relaxation.	
	Industrial	Industrial sectors, factories and supply zones.	
	Agriculture	Agriculture and fodder zones.	
	Plantations	Wood production zonas with plantations	
	Bare soils	Land devoid of or with very scarce vegetation, with no productive use.	
Natural	Water Bodies	Water bodies that do not belong to the wetland category, i.e., ocean.	
	Other types of vegetation	Other types of vegetation, such as scrubs, bushy areas and native woods.	
	Wetlands	Permanent wetland: Wet areas, intertidal zones, tide marshes, swamps and estuaries.	
		Semipermanent wetland: Zones covered in mangroves, specific case for la Ciénaga de Mallorquín.	
	Grasslands	Natural areas covered by low-lying vegetation, temporary or permanent meadows.	
	Dunes	Accumulations of sand stabilized by vegetation.	
	Beaches	Beach areas, without vegetation and dominated by wave action.	

Authors' elaboration, incorporating a subset of images from Google Earth Pro, 2002-2004.

and Estupinan-Suarez 2016) and the Luján River basin in Argentina (Pintos y Sgroi 2012). However, figures of each Latin American country's contribution and the distribution of most of the Latin American wetlands are still unknown, which is worrisome (Mitsch and Gosselink 2015).

Coastal cities in Latin America are vulnerable to the effects of climate change, which together with the socio-natural risks like flooding, means that more people are exposed to danger. Chile, Colombia and Peru have been chosen as example countries with wetlands that are subject to urbanization and vulnerability to climate change. The three countries have experienced significant urban growth and project further increases for 2030. Additionally, 80% of their population lives in cities, which are representative of the environmental conflicts caused by urbanization and conflicts with wetlands located in cities.

Chile

In Chile, more than 80% of the population lives in cities. There are more than 4 million ha of wetlands, but only 3% is protected. None of these protected wetlands are in urban areas. The pressure to build has led to the elimination of wetlands in cities spanning from north to south, especially in the southern-central zone, which happens to have a high recurrence of waterlogging and flooding (Rojas et al. 2014). The Aconcagua-Concón wetland is under pressure from industrial activity and from urban growth. There is evidence of an expansion in the real estate market for second homes (Hidalgo et al. 2016; Martínez et al. 2020), and a concentration of economic activities (ports, tourism and services). In addition, since 2015 this coastal zone has been seriously affected by extreme events associated with climate change, including swells, meteotsunamis, coastal erosion and tsunamis like Japan 2011 and Illapel, Chile (Martínez et al. 2011; Martínez et al. 2018; Carvajal et al. 2017, Campos-Cava 2016); all of which have caused considerable damage to the infrastructure and connectivity (Winckler et al. 2017). Additionally, the areas adjacent to the wetland (the Aconcagua River estuary) have been categorized as a low-quality landscape because of the high degree of anthropic intervention, which has led to a further loss of naturalness on the coastal landscape (Rangel-Buitrago et al. 2018).

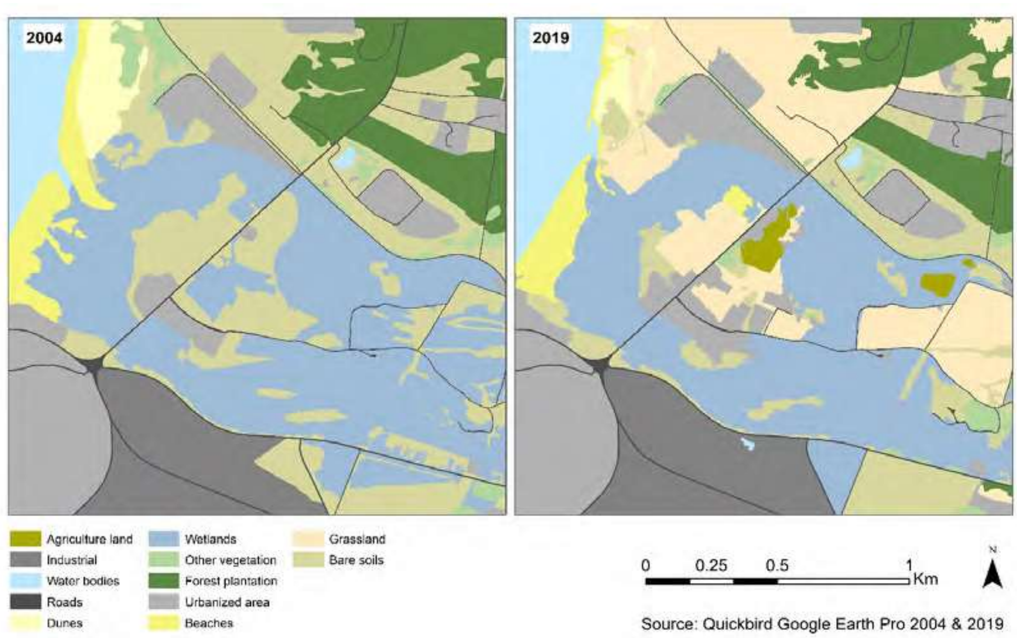
TABLE 3. Land uses changes in wetlands

Wetlands	Total Losses	Total Gains
Aconcagua	33	10
La Ciénaga de Mallorquín	224	81
Pantanos de Villa	11	2
Total	268	93

Colombia

In Colombia, wetlands make up more than 30 million ha, which is equivalent to 26% of its territory. Wetlands have historically been associated with the development of human cultures (Jaramillo et al. 2015). The main cause of wetland transformation has been the change in land use to pastures for raising cattle, agriculture and deforestation, and to a lesser extent, urbanization (Patino and Estupinan-Suarez 2016). These anthropic changes have led to the transformation of 24% of the country's wetlands. It is estimated that by 2025, the main factors of change in wetlands will be, in first place, the expansion of ranching, and in second place, urban and transportation development (Ricaurte et al. 2018). The Magdalena-Cauca basin (i.e., where the Metropolitan Area of Barranquilla is located) is expected to suffer the greatest changes in land use, with negative effects on wetlands. Barranquilla is a coastal city located on the Magdalena River estuary in the Caribbean Sea. This estuary creates a vast area of wetlands that have been greatly altered by anthropic

FIGURE 2. Distribution of the land uses and cover types detected in the studied wetlands and surrounding areas for the Aconcagua study area (Concón, Chile) from 2004 to 2019.



activities throughout history and is highly vulnerable to the effects of global change (Aldana-Domínguez et al. 2018; Rodríguez 2015). The transformation of these ecosystems has had a negative impact on the ecosystem services, mainly on the regulation services (Aldana-Domínguez et al. 2019), which means that new guidelines that allow for recovering and conserving the urban ecosystems must be a priority.

Peru

In Peru, the expansion of cities is one of the main causes of wetland degradation (MINAM 2015), especially in the coastal and desert strip where wetlands have a special value as nuclei of biodiversity and freshwater reserves. The wetland ecosystems cover a total surface of 6.9 million ha, which is equivalent to 5.4% of the territory (MINAM 2019). Among them, the coastal wetlands only occupy 0.04%, and are especially vulnerable to growing real estate pressure and the impact of urbanization on the aquifer. For example, the expansion of the city of Lima between 1990 and 2013 led to the loss of 203 ha of wetlands (Moschella 2018). Studies on the main wetlands in Lima show the degradation and loss of ecosystem services caused by anthropic pressure (Aponte and Cano 2013; Moschella 2012; Pulido and Bermúdez 2018). Although there is a legal framework for protecting wetlands, there are weaknesses in the instruments of protection and an adequate regulation for the application of norms is lacking (Ramírez Aponte 2018). Further studies are also required to understand the hydrology of these ecosystems and contribute to their conservation (Rodríguez 2017). In this sense, the National Wetland Strategy (MINAM 2015) has identified a lack of studies on the valuing and management of wetlands as well as a weak participation for the conservation of these ecosystems.

METHODOLOGY

Study Areas

The following urban coastal wetlands were chosen for this study: 1) Aconcagua (also known as the Concón Wetland) in the city of Concón and associated with the Andean Aconcagua River in the Valparaíso Region (Chile), 2) la Ciénaga de Mallorquín in Barranquilla (Colombia), and 3) Pantanos de Villa in Lima (Peru). They are all located in coastal areas and are subject to the different pressures of changes in use from urbanization (Figure 1).

Data Processing

Free satellite images from the last two decades (2002-2019) were selected from the collection available from the Quickbird satellite on Google Earth Pro. Then, a buffer of approximately 500 meters from the perimeter of each wetland was defined. The images were georeferenced and classified by photointerpretation at a scale of 1:2.000 in ArcGIS Pro.

TABLE 4. Land cover changes in Aconcagua study area from 2004-2019, the analyzed image included the wetland and its surrounding areas. (Note: Any difference in net change totals is due to computer round-off.)

	Aconcagua between 2004 and 2019		
Land use	**Losses (ha)**	**Gains (ha)**	**Net Change (ha)**
Water bodies	0	9	8
Roads	0	0	0
Dunes	-5	0	-5
Wetlands	-33	10	-23
Other vegetation	-6	4	-2
Plantation forest	-9	1	-7
Beaches	-10	5	-5
Bare soils	-64	12	-52
Urban	-1	15	14
Agriculture	0	3	3
Grasslands	-29	66	37
Industrial	0	31	31

TABLE 5. Land cover changes in Ciénaga de Mallorquín study area from 2002-2019, the analyzed image included the wetland and its surrounding areas. (Note: Any difference in net change totals is due to computer round-off.)

	Ciénaga de Mallorquín between 2002 and 2019		
Land use	**Losses (ha)**	**Gains (ha)**	**Net Change (ha)**
Water bodies	-14	128	114
Roads	0	7	6
Other vegetation	-77	18	-59
Beaches	-20	36	15
Bare soils	-82	39	-42
Urban	-1	70	70
Grasslands	0	17	17
Permanent wetland	-175	3	-172
Semi-permanent wetland	-49	78	29
Industrial	-6	28	22

FIGURE 3. Gains and losses in the Aconcagua Wetland (Concón, Chile) from 2004 to 2019.

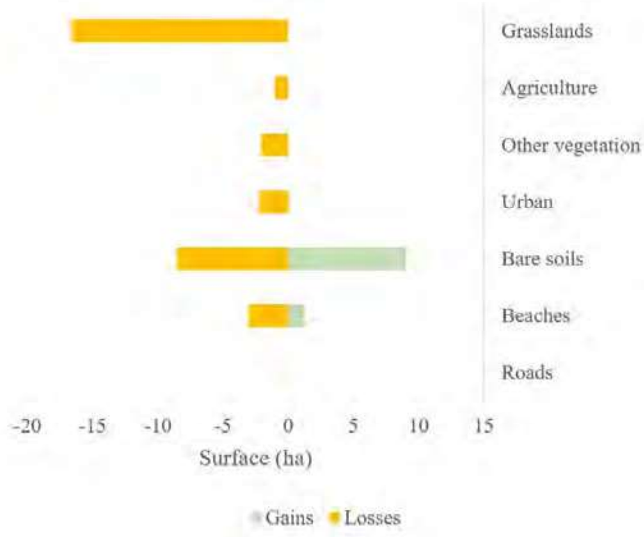


FIGURE 4. Distribution of the land uses and cover types detected in the studied wetland and surrounding area for the Ciénaga de Mallorquín study area (Barranquilla, Colombia) from 2002 to 2019.

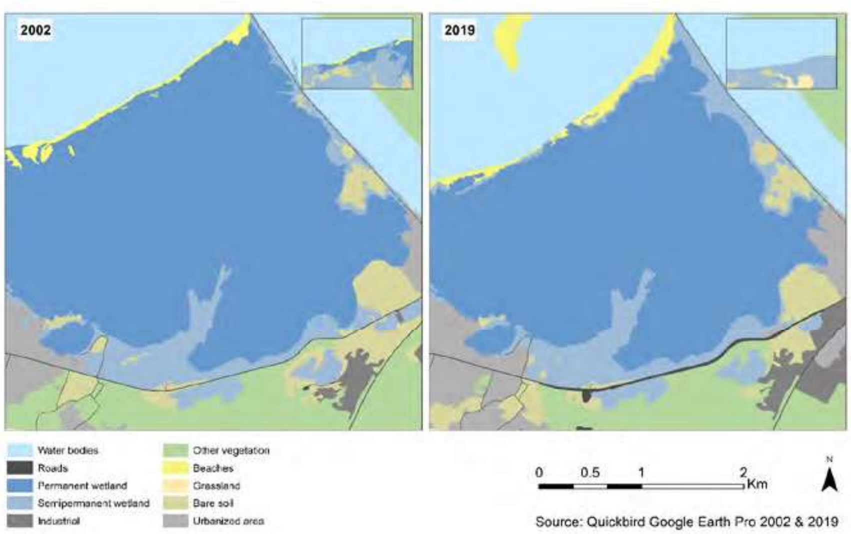
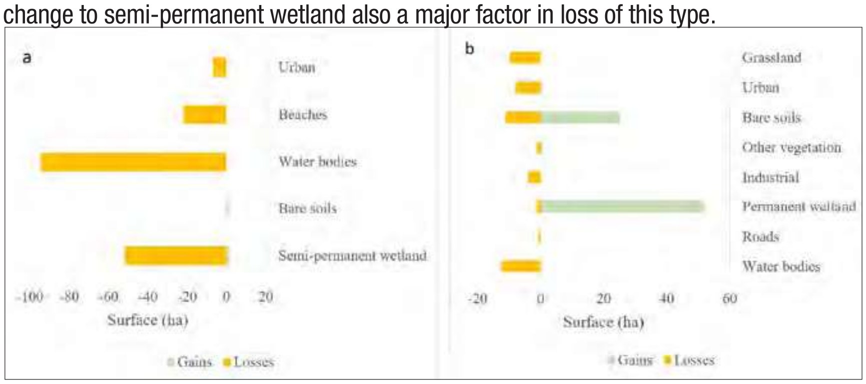


FIGURE 5. Gains and losses in the permanent wetland (a) and the semi-permanent wetland (b) at the Ciénaga de Mallorquín (Barranquilla, Colombia) from 2002 to 2019. The figures also show changes in wetland type (permanent v. semi-permanent). The conversion towards water bodies accounted for most of the permanent wetland loss, with change to semi-permanent wetland also a major factor in loss of this type.



Preparation and Selection of Satellite Images for Land Classification

Satellite images were selected from Google Earth Pro, according to the following criteria:

- Time: Search of the collections that represent changes over the last 20 years.
- Cloudiness: Determining factor for the selection of an image in its next classification as cloudiness presents one of the main problems for detection.
- Seasonality: Preference for images with similar seasonal conditions (winter – summer).

These criteria defined the studied time horizon from 2002 to 2019, and the 2.5-meter resolution Quickbird sensor (See Table 1). A priori these images also strengthen the detection of smaller surfaces like urban wetlands. The QuickBird sensor images were georeferenced by ArcGIS Pro by taking control points in KML format on Google Earth Pro. A total of 18 control points was taken in each image for each wetland, which were complemented with points on the ArcGIS Pro basemap and field work in March 2020. Once georeferencing was completed, points with an error greater than 1 meter were eliminated (Table 1).

Classification and Land Use Covers

Classification was done through a combination of photointerpretation and image tracing of the Quickbird images on ArcGIS Pro and the calculation of the Normalized Difference Vegetation Index (NDVI) that allowed for observing the different types of vegetation and separating the bodies of water and the uncovered land. The recognition of the categories was based on the definitions and reference images shown in Table 2 that allowed for distinguishing natural areas from artificial areas and using the time series of imagery to observe trends from 2002/2004=2019. Surrounding vegetation that is not part of the wetland was not classified in detail. For the Ciénaga de Mallorquín, two types of wetlands were identified following the Colombian wetland classification system (Ricaurte el al. 2019): permanent wetland (permanently flooded), and semi-permanent wetland (periodically flooded; mainly covered by mangrove forests in this area).

Validation of Land Covers

The validation of coverages was done through the capturing of 840 points of control, whose verification was optimized in GIS and with field work conducted in March of 2020. Then, the veracity of the interpreted classification was evaluated with the Kappa Statistic Index.

RESULTS

Land Covers

The results of the land cover typing for the three wetland areas are shown in Figures 2, 4, and 6; they generated kappa index values of >85% of precision. Therefore, the maps allow for making a statistically valid interpretation. The distribution and changes in land use are reported in Tables 3-5, where values from the initial year, gains, losses and net changes can be observed in the categories identified for each wetland.

A sum of 268 ha of decrease was observed totalizing the three studied wetlands, of which 175 correspond to loss (Losses – Gains). The main cause was an increase in artificial and productive covers such as urbanization and grasslands, among others. Urbanization increased by a total of 162 ha considering the three studied cases. The land use covers changes observed over the last two decades themselves confirm the general trend of wetland loss in the Latin American region reported by Darrah et al. (2019).

Of the studied wetlands, La Ciénaga de Mallorquín (Colombia) has without a doubt suffered the greatest surface loss, followed by Aconcagua (Chile) and Pantanos de Villa (Perú). Additionally, among the three wetlands, Pantanos de Villa is under the most pressure from urbanization in its surroundings (i.e., it is virtually surrounded by urban development with the exception of the "Green Area").

Aconcagua Wetland Area (Concón, Chile)

In the case of the Aconcagua wetland study area, during the period of analysis the main interactions and exchanges were between the wetland, grassland, bare soils, beaches and urban and industrial areas (Figure 2). First, the category experiencing the greatest gain was grasslands, with 37 ha of net change, closely followed by industrial area with 31 ha and then by urbanization with a net gain of 14 ha (Table 3).

The Aconcagua wetland itself experienced a net loss of 23 ha, but with the total loss of 33 ha were lost from 2004 to 2019, mainly caused by the conversion to grasslands (17 ha), followed by bare soils (8 ha), beaches (3 ha) and finishing with less pressure of urban zones (2 ha) (Figure 3). The losses were somewhat compensated for by a gain of 10 ha from bare soils (9 ha) and beaches (1 ha).

Besides the loss of wetlands, bare soils experienced a loss of 64 ha and gain of 12 ha for a net loss of 52 ha from 2004-2019. This loss accounted for some of the increase in grasslands surrounding the wetland. Some of the new grasslands also came from beaches. A similar situation has occurred with the dunes – conversion of dunes to grassland; they experienced a net loss of 5 ha (Table 4).

TABLE 6. Land cover changes in Pantanos de Villa study area from 2002-2019, the analyzed image included the wetland and its surrounding areas. (Note: Any difference in net change totals is due to computer round-off.)

	Pantanos between 2002 and 2019		
Land use	**Losses (ha)**	**Gains (ha)**	**Net Change (ha)**
Water bodies	0	9	9
Roads	-1	5	4
Wetlands	-11	2	-8
Beaches	-11	2	-9
Bare soils	-76	7	-70
Urban	-8	86	78
Agriculture	-1	0	-1
Green areas	-3	0	-3

FIGURE 6. Distribution of the land uses and cover types detected in the studied wetland and surrounding area for the Pantanos de Villa wetland (Lima, Peru) from 2002 to 2019. The larger "Green Area" is a private golf course.

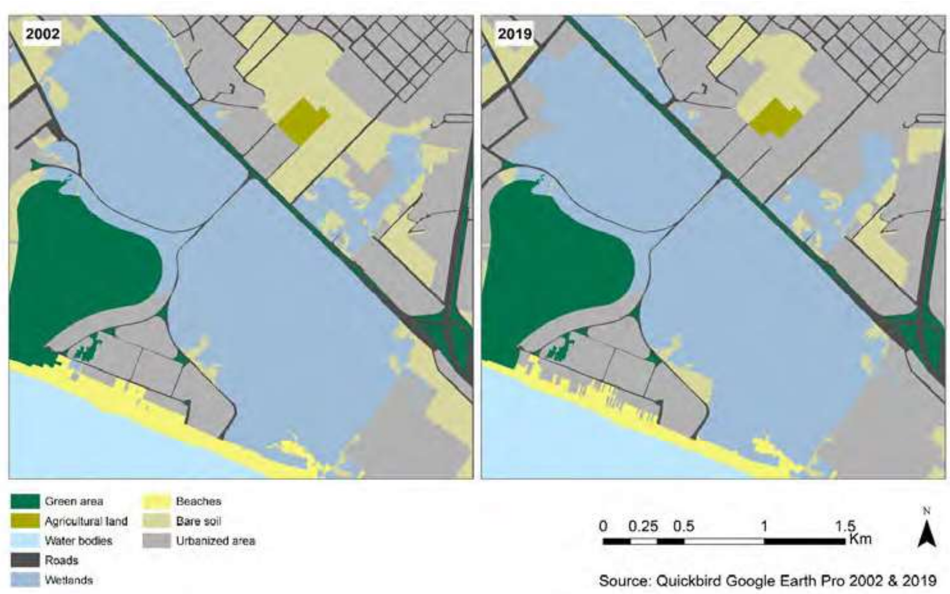
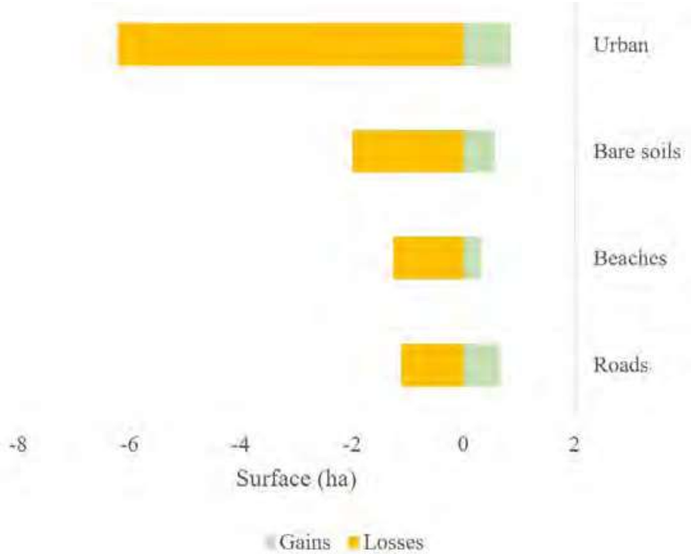


FIGURE 7. Gains and losses in the Pantanos de Villa Wetland (Lima, Perú) from 2002 to 2019. There were small changes in wetland area, mainly a few hectares of losses.



La Ciénaga de Mallorquín Wetland Area (Barranquilla, Colombia)

Both permanent and semi-permanent wetlands at La Ciénaga de Mallorquín changed during the study period (Table 5 and Figures 4 and 5). The main wetland change was the loss of permanent wetland surface (net loss of 172 ha). This loss was mainly due to coastal erosion resulting from the displacement of the sand bar that separates the wetland from the Caribbean Sea (Figure 5a). This contributed 94 ha to the overall net increase in the water bodies coverage. The water bodies are represented by the ocean and the river. The wetlands have connections to both, but are separated by a sand bar and a spur. The retraction of the sand bar was documented by Rivillas-Ospina and others (2018) who noted an erosion rate of 0.14 m/year from 1973 to 2016. The permanent wetland was also reduced by an increase in the semi-permanent wetland (52 ha), probably due to the natural formation of mangrove areas on the western side of the Ciénaga de Mallorquín and a recent mangrove reforestation effort. The formation of beaches and conversion to urban development were also responsible for the loss of 22 ha and 6.7 ha, respectively, of permanent wetland.

On the other hand, the semi-permanent wetland gained 52 ha at the expense of permanent wetland and 25 ha from bare soils, while it lost some surface area mainly to water bodies (12 ha), bare soils (11 ha), grasslands (10 ha), and urban zones (8 ha; Figure 5b). Although the Ciénaga de Mallorquin is included in the Ramsar Site "Estuarine system of the Magdalena River Ciénaga Grande de Santa Marta", anthropic pressures continue to affect it.

Another significant change in the area surrounding the wetland was the loss of other vegetation (59 ha; Table 5), which included the last few fragments of tropical dry forest in the area. The tropical dry forest is one of the most threatened ecosystems and at risk of collapse in Colombia (Etter et al. 2017), and it is also a key ecosystem for the supply of ecosystem services in Barranquilla (Aldana-Domínguez et al. 2019). It continues to lose surface area, mainly because of urbanization. For the entire study area, as expected, urbanization has increased (70 ha; Table 5), affecting both wetlands and tropical dry forest.

Pantanos de Villa Study Area (Lima, Peru)

For the Pantanos de Villa study area, the greatest change from 2002 to 2019 was the increase of urban areas (86 ha; Table 6 and Figure 6), which mostly happened on bare soils, and to a lesser extent on wetlands and beaches. Wetland coverage declined by 11 ha: 6 ha due to urbanization, 2 ha lost to bare soils, and the remainder to beaches and roads. Wetland gained only 2 ha, with the most significant corresponding to wetland expansion over an unbeaten path (Figure 7). Although the variation in the wetland's extent seems limited, it is worth mentioning that this wetland has been converted to urban land for several decades before the period of this analysis. While most of the new urban areas are registered here as conversions from bare soils without use, these bare soils are actually cleared wetland (i.e., they were mainly filled to dry the land for future plotting and building). Currently, the wetland is practically restricted to the area that is protected and recognized as a Ramsar site. Since its borders are mostly developed, it is most likely that its expanse will not vary.

Additionally, it is worth mentioning that there are significant differences between the degree of urban planning and its impact on the wetland's functioning. To the northeast of the wetland, irregular low-income settlements and filled wetlands can be found. Here, recent land-use changes affect the main springs that supply the wetland and the water channels that connect them, putting the quality and quantity of surface flow entering the wetland at risk. Specifically, there is an increase of dwellers that use the spring water as they lack piped drinking water. Also, a near and unstable landfilling might block the channels. For instance, a public sports field obstructs the water flow. Meanwhile, the southwest end presents mostly beach urbanization through construction of high-income condominiums, which have drained the wetlands and have also reduced the ecosystem's connection with the coast.

CONCLUSION

The analysis of Quickbird images from the period of 2002-2019 has allowed for the creation of valid maps that show land use cover, including wetlands during two time periods. Consequently, it has permitted spatial and temporal tracking of wetland trends in selected urban wetlands in Latin America and provided information on land cover changes over the past 20 years.

Our study shows important reduction in surface area of most of the studied urban wetlands, mainly caused by three factors: coastal erosion/creation of water bodies, expansion of grassland and growth of urban areas surrounding them.

The Ciénaga de Mallorquín wetland has suffered the greatest loss, caused by coastal dynamics and changes in the water body and vegetation. Coastal erosion is a complex phenomenon and, in this area, it is related with oceanographic processes (i.e., currents and waves generated by the wind and tides) and the anthropogenic impacts originated by the construction of infrastructures to maintain the Barranquilla port and the navigable channel (Rivillas-Ospina et al. 2018).

The spreading of grasslands could be interpreted as pre-construction activity, where grassland increase over bare soils and agricultural areas mostly in the case of Aconcagua. The Aconcagua wetland area, although located in an area under a great deal of historic pressure from industrial activity, is currently being altered by an increase of grasslands and bare soils specially when the dunes started to increase with low vegetation due to natural conditions as a precipitation, which is also affecting the losses in beaches. The Aconcagua wetland is lesser affected by urban growth and agriculture areas.

Clearly, urbanization is affecting these three areas. The Ciénaga de Mallorquin is the most urbanized wetland studied, losing 15 ha due to urban expansion. Two sectors of urban growth are recognized: the eastern side of the wetland where unplanned settlements built by displaced people from other Colombian regions, and even from other countries, come to Barranquilla seeking better life opportunities. And on the western side of the wetland, in addition to the informal settlements, there are the planned social interest urban developments to fulfil the housing deficit of the population with lower monetary resources. In a similar way, in Pantanos de Villa and its surrounding areas the urban areas have increased at a greater speed because of pressure for two type of development: 1), informal settlements or housing units constructed illegally (i.e., unplanned and with scarcity of services such as drinking water) and 2) beach condominiums or planned settlements, which were built on cleared wetlands and the area surrounding the protected zone (i.e., designated Ramsar Site). The urbanization of Aconcagua wetland is lesser than grassland growth and, in this period, impacted due to urbanization process was produced before eighty decades.

Overall, the urban wetlands have lost surface, confirming the Latin American trend. Urban expansion, mainly for housing, is the major impact but urbanization may also be responsible for a change in beaches and grassland. Pressures surrounding the wetlands that could be interpreted as an urbanization transformation process were also identified e.g., kind of settlements in Pantanos de Villa (Perú).

Latin America faces a great challenge in advancing towards urban sustainability according to the 17 Sustainable Development Goals (SDG established by the 2030 Agenda (UN, 2015) where the Goal 11 have a target to make cities and human settlements inclusive, safe, resilient and sustainable. The region also needs to improve urban planning and management regarding the identification, definition, and norms for permitted uses of urban wetlands and their surroundings. Urban wetlands should be "recognized spaces" in the city – natural habitats important for the well-being of the city residents and kept safe, resilient and sustainable facing the challenges of climate change. ■

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REFERENCES

Adam, E., O. Mutanga, J. Odindi, and E.M. Abdel-Rahman. 2014. Land-use/cover classification in a heterogeneous coastal landscape using RapidEye imagery: evaluating the performance of random forest and support vector machines classifiers. *International Journal of Remote Sensing* 35(10): 3440-3458.

Aldana-Domínguez, J., C. Montes, and J.A. González. 2018. Understanding the past to envision a sustainable future: A social-ecological history of the Barranquilla Metropolitan Area (Colombia). *Sustainability* 10: 1-18.

Aldana-Domínguez, J., I. Palomo, J. Gutiérrez-Angonese, C. Arnaiz-Schmitz, C. Montes, and F. Narváez. 2019. Assessing the effects of past and future land cover changes in ecosystem services, disservices and biodiversity: A case study in Barranquilla Metropolitan Area (BMA), Colombia. *Ecosystem Services* 37: 100915.

Aponte, H. and A. Cano. 2013. Estudio florístico comparativo de seis humedales de la costa de Lima (Perú): actualización y nuevos retos para su conservación. *Revista Latinoamericana de Conservación* 3(2): 15-17.

Bishop, M., S. Powers, H. Porter, and C. Peterson. 2006. Benthic biological effects of seasonal hypoxia in a eutrophic estuary predate rapid coastal development. *Estuarine Coastal Shelf Science* 70(3): 415-422.

Boyer, T. and S. Polasky. 2004. Valuing urban wetlands: A review of non-market valuation studies. *Wetlands* 24(4): 744–755.

Campos-Caba, R. 2016. Análisis de marejadas históricas y recientes en las costas de Chile. Memoria del proyecto para optar al Título de Ingeniero Civil Oceánico, Facultad de Ingeniería, Universidad de Valparaíso, Valparaíso, Chile. 136.

Carvajal, M., M. Contreras-Lopez, P. Winckler, and I. Sepúlveda. 2017. Meteotsunamis occurring along the southwest coast of South America during an intense storm. *Pure and Applied Geophysics* 174(8): 3313–3323.

Cepal Comisión Económica para América Latina y el Caribe. 2019. Informe de avance cuatrienal sobre el progreso y los desafíos regionales de la Agenda 2030 para el Desarrollo Sostenible en América Latina y el Caribe. Online https://www.cepal.org/es/publicaciones/44551-informe-avance-cuatrienal-progreso-desafios-regionales-la-agenda-2030-desarrollo

Darrah, S., Y. Shennan – Farpón, J. Loh, N. Davidson, C. Finlayson, C. Royal, M. Gardner, and M. Walpole. 2019. Improvements to the Wetland Extent Trends (WET) index as a tool for monitoring natural and human-made wetlands. *Ecological Indicators* 99: 294-298.

Davidson, N.C. 2014. How much wetland has the world lost? Long-term and recent trends in global 295 wetland area. *Marine and Freshwater Research* 65 (10): 934–941.

Davidson, N.C., E. Fluet-Chouinard, and C.M. Finlayson. 2018. Global extent and distribution of wetlands: trends and issues. *Marine and Freshwater Research* 69: 620–627.

Etter, A., A. Andrade, K. Saavedra, P. Amaya, and P. Arévalo. 2017. Estado de los ecosistemas colombianos: Una aplicación de la metodología de la Lista Roja de Ecosistemas ver. 2.0. Informe Final. Bogotá, Colombia: Pontificia Universidad Javeriana.

Faulkner, S. 2004. Urbanization impacts on the structure and function of forested wetlands. *Urban Ecosystem* 7(2): 89–106.

Gallant, A. 2015. The Challenges of Remote Monitoring of Wetlands. *Remote Sensing* 7(8): 10938-10950.

González, S., K. Yáñez-Nevea, and M. Muñoz. 2014. Effect of coastal urbanization on Sandy beach coleóptera Phaleria maculata (Kulzer, 1959) in northern Chile. Universidad Católica del Norte. Coquimbo, Chile. *Marine Pollution Bulletin* 83 (1): 265-274.

Hallegatte, S., C. Green, R.J. Nicholls, and J.Corfee-Morlot. 2013. Future flood losses in major coastal cities. *Nature Climate Change* 3: 802–806.

Hidalgo, R., F. Arenas, and D. Santana. 2016. ¿Utópolis O Distópolis? Producción Inmobiliaria y Metropolización en el litoral central de Chile (1992-2012). *Revista EURE* 42 (126): 27-54.

Jaramillo, U., J. Cortés-Duque, and C. Flórez. 2015. Colombia Anfibia, un país de humedales. Volumen 1, Instituto Alexander von Humboldt. Instituto Alexander von Humboldt, Bogotá, Colombia. Online https://doi.org/10.1007/s13398-014-0173-7.2

Hettiarachchi, M., T. H. Morrison and C. McAlpine. 2015. Forty-three years of Ramsar and urban wetlands. *Global Environmental Change* 32: 57-66.

Gibril, M. B., B. Kalantar, R, Al-Ruzouq, N. Ueda, V. Saeidi, A. Shanableh, and H.Z. Shafri. 2020. Mapping heterogeneous urban landscapes from the fusion of digital surface model and unmanned aerial vehicle-based images using adaptive multiscale image segmentation and classification. *Remote Sensing* 12(7):1081.

Kim, Y., D.A. Eisenberg, E.N. Bondank, M.V. Chester, M, G. Mascaro, and B.S. Underwood. 2017. Fail-safe and safe-to-fail adaptation: decision-making for urban flooding under climate change. *Climatic Change* 145(3–4): 397–412.

Maltby E. and M. Acreman. 2011. Ecosystem services of wetlands: pathfinder for a new paradigm. *Hydrological Sciences Journal* 56:8, 1341-1359.

McInnes, R. 2014. Recognising wetland ecosystem services within urban case studies. *Marine and Freshwater Research* 65: 575–588.

Mitsch, W. and J. Gosselink. 2015. *Wetlands*. Fifth Edition. John Wiley & Sons, New Jersey, USA.

Narayan, S., M.W. Beck, P. Wilson, C.J. Thomas, A. Guerrero, C.C. Shepard, B.G. Reguero, G. Franco, J.C. Ingram, and D. Trespalacios. 2017. The value of coastal wetlands for flood damage reduction in the northeastern USA. *Scientific Reports* 7(1): 9463 - 9462.

Martínez, C. P. López, C. Rojas, J. Quense, R. Hidalgo, and F. Arenas. 2020. A sustainability index for anthropized and urbanized coasts: the case of Concón Bay, central Chile. Applied Geography 116.

Martínez, C., M. Quezada, and P. Rubio. 2011. Historical changes in the shoreline and littoral processes in a headland bay beach in central Chile. *Geomorphology* 135: 80-96.

Martínez, C., M. Contreras-López, P. Winckler, H. Hidalgo. E. Godoy, and R. Agredano. 2018. Coastal erosion in central Chile: a new hazard? *Ocean and Coastal Management* 156: 141-155.

MINAM - Ministerio del Ambiente, Perú. 2015. Estrategia Nacional de Humedales. Aprobada por Decreto Supremo Nº 004-2015-MINAM.

MINAM - Ministerio del Ambiente, Perú. 2019. Mapa Nacional de Ecosistemas del Perú. Online https://sinia.minam.gob.pe/mapas/mapa-nacional-ecosistemas-peru

Moschella, P. 2018. Peri-urbanization and land management sustainability in Peruvian cities. Geography. Université de Strasbourg. Online https://tel.archives-ouvertes.fr/tel-02144701

Moschella, P. 2012. Variación y protección de humedales costeros frente a procesos de urbanización: casos Ventanilla y Puerto Viejo. (Tesis) Pontificia Universidad Católica del Perú, Lima.

Patino, J.E., and L.M. Estupinan-Suarez. 2016. Hotspots of wetland area loss in Colombia. *Wetlands* 36: 935–943.

Pintos, P., and A. Sgroi. 2012. Efectos del urbanismo privado en humedales de la Cuenca baja del río Luján, provincial de Buenos Aires, Argentina. Estudio de la megaurbanización San Sebastián. *Augmdomus* 4: 25-48.

Pulido, V. M., and L. Bermúdez. 2018. Estado actual de la conservación de los hábitats de los Pantanos de Villa, Lima, Perú. *Arnaldoa* 25(2): 679-702.

Rangel-Buitrago, N., M. Contreras-López, C. Martínez, and A. William. 2018. Can coastal scenery be managed? The Valparaíso region, Chile as a case study. *Ocean and Coastal Management* 163: 383-400.

Ramírez, D. W., and H. Aponte. 2018. Por qué los Humedales de Puerto Viejo perdieron su protección legal: analizando los motivos. *Revista peruana de biología* 25(1): 49-54.

Ramsar 2018. Urban wetlands: prized land not wasteland. Online http://www.worldwetlandsday.org

Ramsar. 2019. Humedales: Una solución natural al cambio climático. Online http://www.worldwetlandsday.org

Ricaurte, L.F., M.H. Olaya-Rodríguez, J. Cepeda-Valencia, D. Lara, J. Arroyave-Suárez, C. Max Finlayson, and I. Palomo. 2017. Future impacts of drivers of change on wetland ecosystem services in Colombia. *Global Environmental Change* 44: 158–169.

Ricaurte, L.F., and others. 2019. A classification system for Colombian wetlands: an essential step forward in open environmental policy-making. *Wetlands* 39: 971-990.

Rivillas-Ospina, G.D., G. Ruiz-Martínez, R. Silva, E. Mendoza, C. Pacheco, G. Acuña, J. Rueda, A. Felix, J. Pérez, and C. Pinilla. 2018. Physical and morphological changes to wetlands induced by coastal structures. In: C.W. Finkl and C. Makowski (eds.). *Coastal Wetlands: Alteration and Remediation*. Springer, Cham, Switzerland. pp. 275-315.

Rodríguez, M. (ed.). 2015. ¿Para dónde va el Río Magdalena? Riesgos sociales, ambientales y económicos del proyecto de navegabilidad. Foro Nacional Ambiental, Bogotá, Colombia.

Rodríguez, M. 2017. Variación de humedales costeros e irrigaciones agrícolas: el caso de la Albúfera de Medio Mundo y el área agrícola de Huaura. (Tesis) Pontificia Universidad Católica del Perú, Lima.

Rojas, C., J. Pino, C. Basnou, and M. Vivanco. 2013. Assessing land use and cover changes in relation to geographic factors and urban planning in the Metropolitan Area of Concepción (Chile). *Applied Geography* 39: 93–103.

Rojas, C. 2018. Desafíos en la Planificación Territorial: Humedales Urbanos una oportunidad de gestión y participación para ciudades más sustentables y resilientes. En: Ministerio de Medio Ambiente. La Vía Medio Ambiental. Desafíos y Proyecciones para un Chile Futuro, 191-201.

Rojas, C., J. Munizaga, O. Rojas, C. Martínez, and J. Pino. 2019. Urban development versus wetland loss in a coastal Latin American city: lessons for sustainable land use planning. *Land Use Policy* 80: 47 - 56.

Rojas, O., M. Mardones., J. Arumí, and M. Aguayo. 2014. Una revisión de inundaciones fluviales en Chile, período 1574–2012: Causas, recurrencia y efectos geográficos. *Revista Geográfica Norte Grande* 57: 177–192.

Patino, J. and L. Estupinan-Suarez. 2016. Hotspots of wetland area loss in Colombia. *Wetlands* 36: 935–943.

Seto, K. C., M. Fragkias, B. Güneralp, and M.K. Reilly. 2011. A meta-analysis of global urban land expansion. *PLoS One* 6(8): e23777.

Sousa, P.T. Jr., M.T, Fernandez Piedade, and E. Candotti. 2011. Brazil's forest code puts wetlands at risk. Letter to Nature. *Nature* 478: 458.

United Nations. 2011. World Urbanization Prospects: The 2011 Revision, Highlights (ST/ESA/SER.A/322). New York, United States. http://www.un.org/en/development/desa/population/publications/pdf/urbanization/WUP2011_Report.pdf.

United Nations. 2014. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). New York, United States. http://doi.org/10.4054/DemRes.2005.12.9.

United Nations. 2018. Revision of World Urbanization Prospects. Online https://www.un.org/development/desa/publications/2018-revision-of-world-urbanization-prospects.html.

UN HABITAT. 2017. New Urban Agenda. Quito. Online http://habitat3.org/wp-content/uploads/NUA-English.pdf.

Winckler, P., M. Contreras, J. Beyá, and R. Campos-Caba., 2017. El temporal del 8 de agosto de 2015 en la región de Valparaíso, Chile Central. *Latin American Journal of Aquatic Research* 45(4): 622-648.

Wittmann, F., E. Householder, A. Lopes, A. de Oliveira, J. Wolfgang, and M. Piedade. 2015. Implementation of the Ramsar Convention on South American wetlands: an update. *Research and Reports in Biodiversity Studies* 4: 47 – 58.