

## Chapter 31

# Socio-ecological Transformations in Coastal Wetlands: An Approach from the South-Central Zone of Chile



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**Significance Statement** The increase in the world population has generated high pressures on the different ecosystems, mainly due to the expansion of urban areas and productive activities such as agriculture. Coastal wetlands are among the most affected ecosystems, which due to their geographical location are highly fragile and susceptible to changes and pressures. The aims of this research are focus on (1) Making a comparison regarding to the changes experienced in two similar coastal wetlands with actual protection measures (one Ramsar site and national reserve since 1996 and another declared a nature sanctuary in 2017). (2) evaluating the main transformations in both wetlands, as socio-ecological systems, from human activity and the extent of public policies that can be generated that go around the protection of these ecosystems.

**Keywords** Coastal wetlands · Land cover change · South-Central Chile · Human pressure

## 1 Introduction

The planet is currently facing a new era called Anthropocene, where most of the environmental changes are caused by human activity, these changes are coupled to new scientific evidence suggesting that worldwide landscapes are facing an unstable trajectory (Wu, 2013). It is estimated that one of the most affected ecosystems by these changes are coastal wetlands (Zhang et al., 2019).

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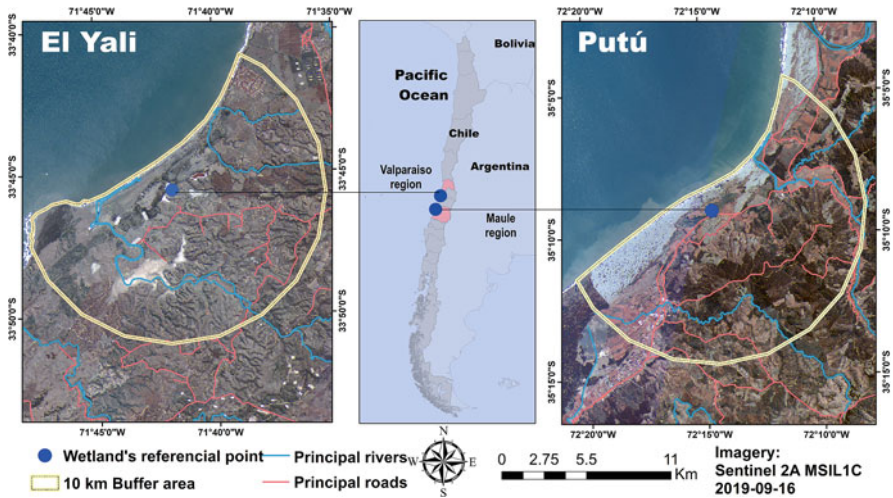
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Historically, wetland ecosystems are controversial components in the socioecological system since they have been considered for many years, as objects of low value that require treatments to be useful for development (e.g. urbanization). They have been modified to urban uses, garbage dumps, landfills, they receive runoff of liquid waste and are also fragmented by the construction of roads (Mishra, 2014). Only in the twentieth century the loss of wetlands ranged between 64 and 71% highlighting those located in Asia, where the loss was even larger. Furthermore, the current global rate of loss of coastal wetlands is 4.2 times faster than in recent decades (Davidson, 2014).

The role of wetlands in the socio-ecological system has changed quickly during the last years and they are gaining appreciation due to the significant amount of ecosystem services they can provide to people. Coastal ecosystems also provide ecosystem services that have socio-economic benefits to humans, including provision of oil, forage, building materials, wood, fish, among others tangible products, but also other benefits can be included like tourism or savings caused by disaster prevention (Zhang et al., 2019). In this regard, coastal wetlands protect the coastline against the loss of infrastructure and human lives caused by disasters (Wolanski et al., 2009). However, these ecosystems continue to be threatened by anthropic activities that generate high levels of degradation such as: (a) urbanization; (b) water pollution; (c) diversion of riverbed and (d) deforestation (Rivillas-Ospina et al., 2017). In addition, we must also consider the effects of the increase of natural disturbances due to environmental and climate changes as the differences in rainfall, rise or fall of temperature, sea level, increases of flood during rain seasons and larger periods of drought.

The Chilean coast presents a large variety of wetlands, ranging from the most arid regions in the north of the country 18°S to the Patagonian fjords in the extreme south at 54°S This geographical range offers a high diversity of ecological and socio-environmental characteristics according to its latitude, geomorphology, tidal regimes, recent geological history, the degree of fresh water supply, but especially according to the degree of anthropic intervention (Valdovinos, 2004). The aim of this research is comparing two similar coastal wetlands as socio-ecological systems which present protection measures and are nevertheless highly degraded, and then determining their current dynamics of change. The first case is El Yali wetland located at the south of Valparaiso region at 33°S, and the second case selected was the Putú wetland which is in Maule region, at the south of El Yali at 35°S. Both areas are located in the central zone of Chile where there is a high concentration of coastal wetlands in the central area due to the tectonic activity that has been forming the coast more than 3000 years ago (Contreras-López et al., 2014). The central zone of Chile is the region with major anthropic influence, which has been shaping these landscapes through extensive agricultural activity, urban expansion and facing the incessant expansion of the forestry industry in the Coastal range (McFadden & Dirzo, 2018).



**Fig. 31.1** Study area of both cases. In blue: the centroid of the location of both wetlands that were used to make the buffer for the analysis

## 2 Methods

### 2.1 Study Area

To select the two cases different and comparable factors were contemplated. Both ecosystems can be considered coastal wetland mainly because they are located near the sea and the beach area (less than 6 km) and are located within the Mediterranean ecoregion of central Chile. In addition, both wetlands are under similar anthropic pressures such as the forestry industry and agriculture. For the delimitation of the areas, a centroid point was generated in the water mirror of each wetland, to which a 10-km buffer was generated, eliminating the area located in the sea (Fig. 31.1).

Since 1996 the El Yali wetland is part of the officially protected area that bears the same name, it is located in the district of Santo Domingo to the southwest of the Valparaíso region, near to the river mouth of the El Yali river. In addition, it is a Ramsar site (N°878) and is recognized as one of the 56 sites with a priority for the conservation of biodiversity, since in this wetland about 28% of the total bird species can be found in Chile (Victoriano et al., 2006). However, this wetland has a strong anthropic pressure derived mainly from the illegal extraction of underground water, diversion of channels for agriculture or industry, livestock and the pressure driven by the expansion of the forest industry in the territory (Fariña & Camaño, 2012; Contreras-López et al., 2017).

The Putu wetland is in the district of Constitución, located in Maule region. This wetland was declared a protected area in 2017 thanks to the participation of citizens and the local government (BCN, 2018). It runs parallel to the coastal road that

connects the cities of Constitución with Iloca. This wetland is located between a dune system and, as in the El Yali wetland, it is possible to see many endemic birds, and migratory birds during season.

## 2.2 Image Classification

For this research we decided to use satellite imagery due to their spatial-temporal scale, and also because Landsat imagery is free for download in comparison to aerial photography and can also provide a lot of useful information at landscape level. In this case the resolution of Landsat is 30 m, which allows to detect land cover changes associated with human intervention. The temporal scale is 16 days which allows to have a set of imagery to choose according to the different requirements, in this case it was necessary to find images with less than 5% of cloud cover in order to avoid noises in the imagery. Another important aspect that was considered in the selection is that Landsat has different bands in the infra-red spectrum, which allows to identify more accurately the vegetation and also the wetland area.

For image classification we used 10 classes of land cover. The selection of land cover classes was based on two major land classifications: first, the classification made by Zhao et al. (2016) who made a classification of the entire country and where the categories were grouped into three levels of specificity. In that study, they used Landsat imagery, so the spatial resolution is 30 m. The second classification scheme checked over was the official land cover classification provided by the National Forest Corporation (CONAF). The decision of the final classes used in this work were also verified in the field and in order to be comparable, the same categories were used (Table 31.1).

**Table 31.1** Land cover classes selected for the image classification and change analysis

Land cover	Description
Sea	Part of the image that contains the sea. This class was classified to reduce the percentage of error in the classification
Crops	Crop patches caused by agriculture activity including industrial and familiar agriculture.
Plantations	This class represents the forest plantation including <i>Pinus</i> and <i>Eucalyptus</i>
Vegetation	This class includes scrub and sclerophyllous forest mainly located in slopes and near riverbeds.
Continental water bodies	This category includes rivers and lagoons (natural and artificial).
Wetland	The water mirror was classified (permanently flooded area of the wetland) and part of the vegetation on the edge.
Bare soil	Soil with none or little amount of vegetation.
Grasslands	Natural or anthropic grasslands (used mostly for grazing).
Urban infrastructure	Industrial facilities, and urban areas
Sand	Sand located in the beach area and dunes.

We classified two Landsat images for the two different years: 2004 (L5 TM) and 2019 (L8 OLI-TIRS). Both sets of images were atmospheric and topographically corrected to reduce the classification error. The software used were QGIS 3.8 ZANZIBAR and EnMAP toolbox,<sup>1</sup> which is a python plugin designed to process and visualize hyperspectral remote sensing data. In this case the Support Vector Machine (SVM) classifier was selected. SVM is a distribution-free algorithm, based on the optimal separation of classes. Considering that not all classes are linearly separable, this method can get more precisely results because it is optimized to search for a non-linear hyperplane using kernel function (Karatzoglou et al., 2006; Everingham et al., 2007; Huang et al., 2002). 2000 control points were made to classify the imagery of each year and the study area was working at a scale of 1:25,000.

In order to improve the detection of wetlands and to help the classifier in detecting the natural vegetation from forest plantation and crops we included spectral indices to spectral bands of Landsat L5 and L8. They can be grouped into three categories: (i) for improving the vegetation detection we applied Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI); (ii) to improve water and wetland detection we used the Modified Normalized Difference Water Index (mNDWI), Normalized Difference Moisture Index (NDMI) and Normalized Difference Water Index (NDWI); (iii) finally, for improving the bare soil and constructed area we analysed the Normalized Difference Built-up Index (NDBI).

For the analysis of land cover changes, categories were made according to the type of change between 2004 and 2019. The groups were made according to the direction of the change: (i) those changes that occurred from a natural cover to a productive uses (e.g. crops, forest plantation, urban infrastructure); (ii) from productive use to natural cover (e.g. native vegetation, grasslands); (iii) changes associated with the area of wetlands and waterbodies (gain and loss); (iv) remains unchanged; (v) ecological succession; (vi) degradation of natural covers.

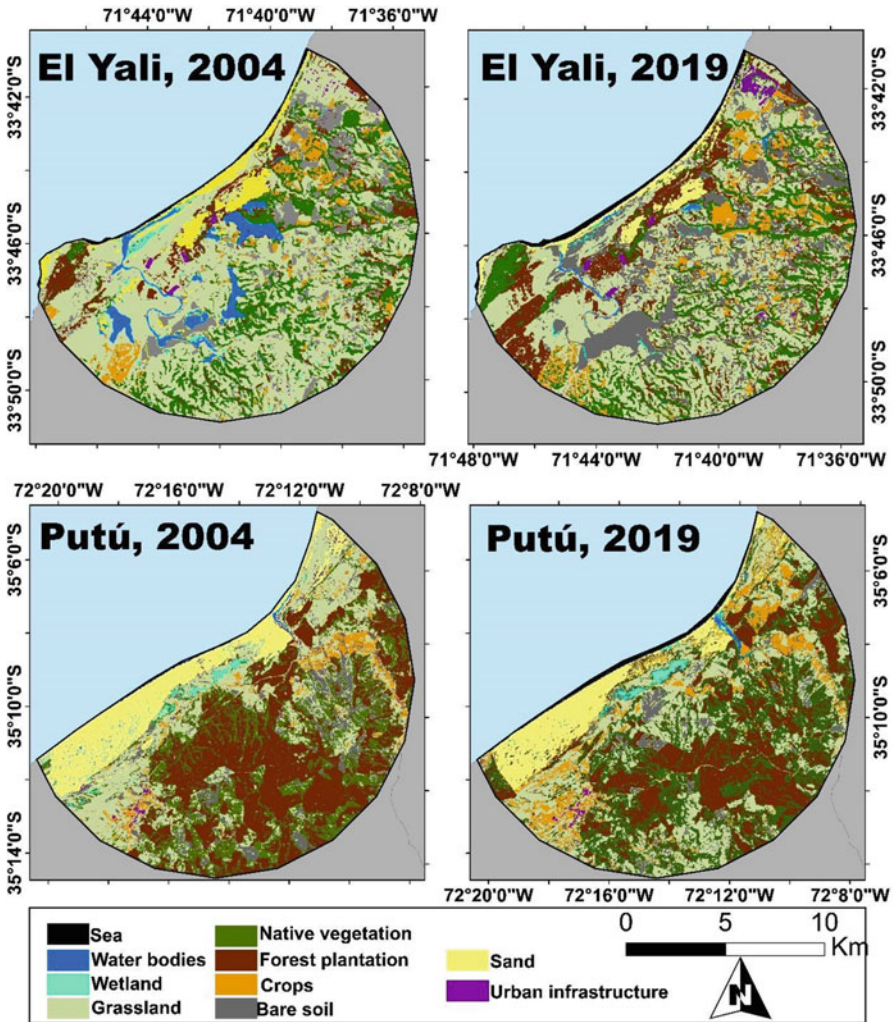
Finally, the validation of the classification was made using a Cross Validation Accuracy Assessment, method which assesses the performance of a classifier using n-fold cross-validation. This accuracy was performed on the same EnMap ToolBox as the image classification.

### 3 Results and Discussions

The class that covers most of the land on both wetlands are grassland, other classes with a high occupancy are forest plantations and native vegetation. Before the description of land cover changes it can be noted that the high classification accuracy in all situations. In the case of the Putú area, the classification accuracy was 92% for the image of 2019 and 90% in the case of 2004. For El Yali, the results obtained were

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<sup>1</sup>For more detail information visit <https://enmap-box.readthedocs.io/en/latest/general/about.html>

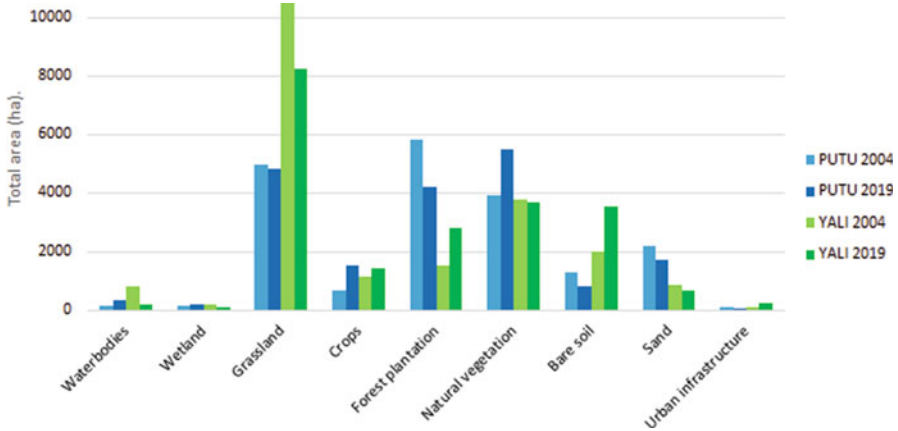


**Fig. 31.2** Land cover classification for both study areas. Yali 2004; Kappa index 90%; Yali 2019, Kappa index 91%; Putú 2004, Kappa index 90%; Putú 2019, Kappa index 92%

91% for 2019 and 90% for 2004 (Fig. 31.2). Within the error obtained, it was estimated that a large percentage is related to the confusion between the categories of natural vegetation and crops. In the case of El Yali, this error is given by fruit plantations present in the sector.

Regarding the main results of the classification, it can be observed in the case of Putú that there was an increase in the wetland area, ranging from 142.3 ha in 2004 to 191.4 hectares in 2019 (+35%). This can be contrasted to the case of El Yali, where a considerable decrease in this land cover was seen, passing from 811.36 ha during 2004 to only 323.6 ha in 2019 (−60%) (Fig. 31.3). It is important to notice that the





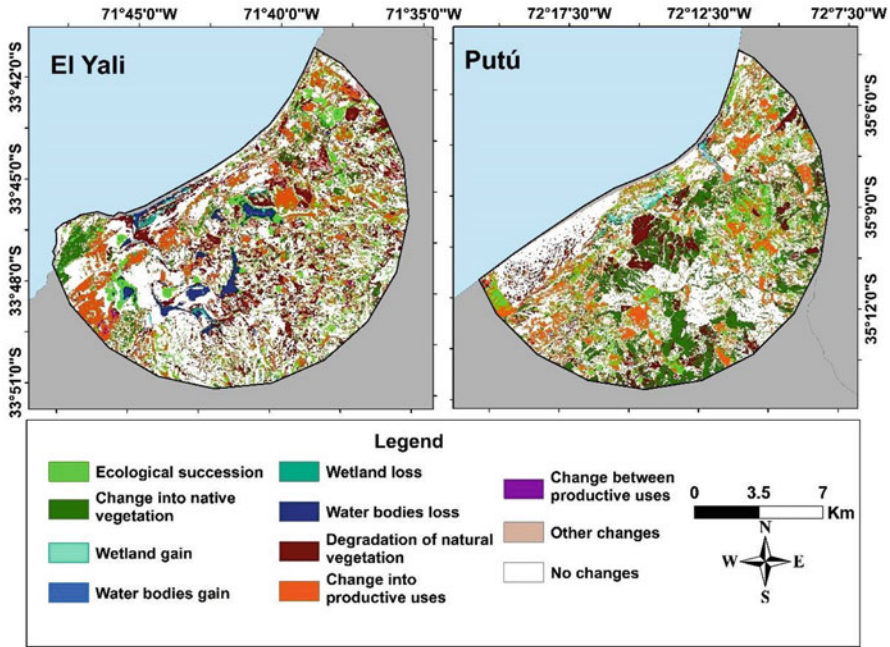
**Fig. 31.3** Total area for each category of land cover for Putú and El Yali between 2004–2019

Putú wetland was categorized as protected area (nature sanctuary) only in 2017, while Yali has been since 1996 (national reserve), so the decline in the wetland surface is quite striking.

In the same direction, the change in forest plantations stands out. In Putú wetland, it was observed a decrease from 5803.6 ha in 2004 to 4194.3 ha in 2019 (–28%). The opposite was observed in El Yali, where forest plantations increased considerably from 1517.7 to 2825.1 ha between 2004 and 2019 (+86%) (Fig. 31.4). In addition, the bare soil class increased in this same area, going from 2001.7 to 3506.8 ha respectively (+75%). This can be understood by the recently harvested areas, either corresponding to forest plantations or fruit plantations and in addition to the areas where previously were water bodies that are currently dry. In the case of Putú, the areas with bare soils decreased from 1308.1 to only 798.1 ha (–39%). Among the main changes that explain this decrease is the rise in natural vegetation from 3900.1 ha in 2004 to 5508.3 ha in 2019 (+41%) and water bodies from 141.7 to 326.6 ha respectively (+130%), which is not the case of El Yali where water bodies saw the surface drastically diminished, going from 811.35 ha in 2004 to 192.97 ha in 2019 (–76%).

In the case of urban infrastructure cover, there is an increase of this area in El Yali going from 94.1 ha in 2004 to a total of 239.9 ha in 2019 (+154%). This increase can be explained by the subdivision of land for the construction of second residence (I. Municipalidad de Santo Domingo, 2019).

Regarding the processes of land cover change, both wetlands present similar amounts of change into productive uses as well as the percentage of surface that remained unchanged. However, in the case of Putú, the change into natural vegetation stands out, while in the case of El Yali, the change associated with the degradation of vegetation was higher (Fig. 31.4). This is consistent with the reality of both areas, where in the Putú surroundings there has been intervention from the local government and citizens to protect this ecosystem, it also accounts for a decline



**Fig. 31.4** Land cover changes between 2004 and 2019 in both study areas. In the case of El Yali the most important change was the degradation of natural vegetation, Contrary to the Putú case, where the biggest change was towards natural covers

in forest plantations, while in El Yali represents the opposite scenario which despite having protection figures and being in the RAMSAR site category is highly degraded.

It can also be observed that in the case of El Yali, a large part of the water bodies decreased between 2004 and 2019. During 2016 two lagoons located within the national reserve area were completely dried up because of illegal extraction (El Mostrador, 2016) (Fig. 31.5), in addition this socio-ecological system has been strongly affected by the current drought that the country is facing. In the case of Putú, on the other hand, a significant increase in the wetland area is observed, which shows that the protection plans around this ecosystem are giving results.

These results also accounted for the impact of forest plantations on the natural vegetation cover in Chile, which can be seen in the case of El Yali. The change in land covers in this study case is highly related to anthropic activities, where 16% of the changes between 2004 and 2019 were precisely from natural covers to productive uses, where the greatest changes occurred from native vegetation and grasslands to forest plantation. Today in the Anthropocene, it is crucial to understand what effects these impacts will generate at the global and local level to support planning in many sectors (Xie et al., 2019), especially in areas with biodiversity and with pressure of uses by different economic activities like the case of the coastal wetlands in central Chile, as the case of El Yali for example.





**Fig. 31.5** Example of the drought that is currently affecting El Yali wetland. (Source: Vannia Ruiz)

Nowadays we are facing the consequences of human activities that have been carried out in the last decades. The interaction and interdependence of social and ecological systems is seen as a driving link to unite understandings and guide actions towards a sustainable future (Berkes & Folke, 1998; Stone-Jovicich et al., 2018). These new concepts incorporate the dynamics of systems over time, focusing the analysis on their ability to persist and respond adaptively to disturbances or changes (Anderies et al., 2013). In this way, the example of the Putú wetland becomes relevant, where, based on the valuation of this ecosystem by society it promoted a change in pursuit of its conservation and protection, where the local government also generated measures to be able to specify social actions, thus allowing the wetland to become a nature sanctuary. These actions could serve as an example in other degraded socio-ecological systems such as El Yali, where greater local actions are urgently needed to promote governance with a clear axis of environmental sustainability.

Despite Chile has been making progress regards legal protection of wetlands through the Urban Wetlands Law (2020), where the citizenship-science and parliament trilogy was validated in the achievement of a common goal, many coastal wetlands are located in the rural area, which have high natural value, they are currently without a protection figure, so they are severely threatened by driving forces such as El Yali, despite being a RAMSAR site. For this reason, evaluations from the socioecological systems approach provide key elements such as the causal relationship between stressors and effects, as well as the interactions between them, allowing to define strategies for Ecosystem Based Management due to the high concentration of ecosystem services and the Integrated Management of Coastal Zones (IMCZ), due to the wide variety of economic interests and the need for regular uses (Barragán Muñoz & de Andrés García, 2020). In Chile, only the IMCZ

approach is recognized among public management instruments but with many limitations in terms of its results (Martínez et al., 2019; Hidalgo et al., 2019), for which it is expected that as it is recognize the functioning of these socio-ecological systems, incorporate guidelines for coastal governance capable of effectively promoting a sustainable transformation in these spaces.

## 4 Conclusions

Through this research we were able to account for how high-intensity productive activities such as the forestry and agricultural industries have generated transformations in the landscape with their consequent environmental consequences. In the case of the El Yali wetland, the high degradation of ecosystems observed despite to their importance for society and to be officially protected area since 1996 and RAMSAR site. On the other hand, the Putú wetland shows that when there is strong local governance, there is a greater awareness of society regarding environmental protection and conservation. That is why it is important to implement public policies with a strong local and environmental component and the citizen participation, capable of promoting the sustainability of the coast, as well as management plans that incorporate ecosystem restoration through nature-based solutions. Finally, for future research it will be interesting to contrast more coastal wetlands with similar conditions, because progressing in the knowledge of the state of the ecosystem and their major pressures could lead to generate better public policies and actions for environmental protection and biodiversity conservation, and at the same time, human well-being.

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