Land Use Policy 80 (2019) 47–56

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Urban development *versus* wetland loss in a coastal Latin American city: Lessons for sustainable land use planning

Carolina Rojas[a,*], Juan Munizaga[b], Octavio Rojas[c], Carolina Martínez[d], Joan Pino[e]

[a] *Departamento de Geografía, Facultad de Arquitectura, Urbanismo y Geografía, Centro de Desarrollo Urbano Sustentable CEDEUS, Universidad de Concepción, Chile*
[b] *Departamento de Geografía, Facultad de Arquitectura, Urbanismo y Geografía, Universidad de Concepción, Chile*
[c] *Departamento de Planificación Territorial, Facultad de Ciencias Ambientales-Centro EULA, Universidad de Concepción, Chile*
[d] *Instituto de Geografía, Facultad de Historia, Geografía y Ciencia Política, Pontificia Universidad Católica de Chile, Chile*
[e] *CREAF Center for Ecological Research and Forestry Applications, Universidad Autónoma de Barcelona, E-08193 Bellaterra, Spain*

ARTICLE INFO

Keywords:
SEA
Urban planning
Coastal wetland
Land use change
Flooding
Metropolitan area

ABSTRACT

Urbanization is a primary cause of wetland loss in coastal metropolitan regions. Therefore, it challenges the preservation of biodiversity and the provision of key ecosystem services for urban settlements. These services include leisure and recreation, climate and water regulation, water purification, and especially alleviation of natural hazards. Tsunami flood mitigation is a particularly valuable regulating service provided by these wetlands, as recently evidenced during the 2010 tsunami that hit the central coast of Chile.

The Concepción Metropolitan Area (CMA), located on the central coast of Chile, has experienced noticeable wetland loss in recent decades. Our study focused on the Rocuant-Andalién wetland, which has been particularly affected by urbanization. This wetland strongly contributes to flood control, and has provided effective protection against the CMA's latest tsunamis (1835 and 2010). Based on Strategic Environmental Assessment (SEA), we have quantified urban growth over the wetland, both executed and projected under the Metropolitan Urban Plan of Concepción (MUPC). Recent loss in wetland area by urban growth has been quantified using land use and cover change (LUCC) maps from 2004 to 2014, obtained from the classification of Landsat images. Prospective changes (considering the complete MUPC deployment) have been inferred by combining the MUPC with the 2014 land cover map. In addition, we quantified the observed effect and planned urban growth on the wetland protected area, geoforms and potential flooding based on the area affected by the last Tsunami. Results show that urban areas have increased by 28% between 2004 and 2014, while future increase is expected to reach 238%. In contrast, wetland area has decreased by 10% from 2004 to 2014 and is expected to decrease by up to 32 %. Thus, the MUPC is not contributing to the mitigation of wetland loss nor the preservation of its biodiversity and ecosystem services. Implications for coastal planning are discussed.

1. Introduction

Land use changes, especially urbanization, drainage and crop expansion, have become a primary cause of coastal wetland loss (Boyer and Polasky, 2004; Faulkner, 2004; Bishop et al., 2006; González et al., 2018). Therefore, coastal wetlands are increasingly threatened (Doody, 2004; CDB, 2012; Pontee, 2013), suffering general losses in range, ecological integrity, and service provision (Martins et al., 2012; Seto et al., 2013). Indeed, at least 50% of wetlands worldwide have been lost (Davidson, 2014), particularly in highly pressured areas such as the Mediterranean (Bouahim et al., 2015; Perennou et al., 2012; Zorrilla-Miras et al., 2014), the Gulf of Mexico (Turner, 1997), California (Mitsch and Gosselink, 2015), coastal Brazil (Sousa et al., 2011; Wittmann et al., 2015) and Argentina (Pintos and Sgroi, 2012). Coastal wetland loss is largely quantified in developed countries. For example, losses of more than 50% and 80% have been reported in California and in the Midwestern US States, respectively (Mitsch and Gosselink, 2015; Boyer and Polasky, 2004). Similarly, significant losses seem to occur especially fast in emerging countries, yet data for these regions is scarce (see Mitsch and Gosselink, 2015).

Wetland loss in urban settings is especially worrisome, as they provide many ecosystem services of great importance for human well-being (Warner and Rubec, 1997; Neiff, 2000; MEA, 2005; Iniesta et al., 2014; Andersson et al., 2015). These include water regulation and

* Corresponding author.
E-mail addresses: crojasq@udec.cl (C. Rojas), juanmunizaga@udec.cl (J. Munizaga), ocrojas@udec.cl (O. Rojas), camartinezr@uc.cl (C. Martínez), joan.pino@uab.cat (J. Pino).

https://doi.org/10.1016/j.landusepol.2018.09.036
Received 15 December 2017; Received in revised form 26 September 2018; Accepted 26 September 2018
0264-8377/

purification, mitigation of natural hazards (e.g. flooding) and recreation, among others (Boyer and Polasky, 2004; MEA, 2005; SEO, 2011). Wetlands are also acknowledged biodiversity hotspots, which has determined their priority for protection through general (e.g. UNESCO Biosphere reserves across the World; Bennett and Kalemani, 2006) and specific (e.g. the Ramsar Convention; Secretaría de la Convención de Ramsar, 2010) conservation initiatives. Coastal wetland loss alters sedimentation and hydrological regimes systems, compromising the stability of coastlines and affecting biodiversity along with a set of basic functions and services (Azous and Horner, 1997; Zedler and Leach, 1998; Ren et al., 2003; DeLuca et al., 2004).

Thus, coastal metropolitan areas must be planned from an environmentally sustainable perspective that encompasses the needs of citizens (e.g., safe, healthy, efficient and pleasant places to work and play; Girardet, 2008), while enhancing wetland protection to ensure the preservation of biodiversity and of ecosystem functions and services. The concept of ecosystem service (*sensu* MEA, 2005) has recently broken into land use planning and management with force (Basnou, 2015); however, it is not a new concept (Daily, 1997; Costanza et al., 1998). Ecosystem service provision should be ensured through nature-based solutions within the so-called green infrastructure, a strategically planned network of natural and semi-natural areas with other environmental features (European Commission, 2013). Strategic environmental assessment (SEA) is a potentially useful tool for reaching this goal. SEA is a mandatory land planning procedure in Europe, by which environmental considerations are required to be integrated into the preparation and adoption of plans and programs (Botequilha-Leitão and Ahern, 2002; Portal and Béjar, 2005; Jiricka and Pröbstl, 2008; Marull et al., 2007).

Although developed in Europe, SEA framework has been progressively implemented in South American countries like Chile, where its application to urban planning is in its early stages. The case of the Concepción Metropolitan Area (CMA hereafter) is especially relevant. Since the 1970s, more than 23% of its total wetland area has been lost (Pauchard et al., 2006; Rojas et al., 2013a), mostly due to planned urbanization (Pauchard et al., 2006; Smith and Romero, 2009; Rojas et al., 2015). The CMA is currently following the Metropolitan Urban Plan of Concepción (MUPC hereafter), which was approved in 2003. In a previous study, the sustainability of the MUPC was assessed within the framework of SEA (Rojas et al., 2013b). Based on this work, the present study aims at specifically assessing the effects of recent (2004–2014) and projected (based on the MUPC) urban development on wetland protection. It then tries to: (i) assess recent urban growth and its effects on wetland areas, geoforms and the previously designated protected areas, as well as on the mitigation of flooding hazards; and (ii) forecast the effects of the MUPC on these items, taking the SEA perspective as a framework. Implications of land zoning in coastal areas will be discussed regarding the ecosystem service provision of flood control against the frequent tsunamis that affect the Chilean coast.

2. Materials and methods

2.1. Study area

The study focuses on the Rocuant-Andalién Wetland, located in the northern CMA (Fig. 1). The CMA (ca. 2830 km^2) is located in South-Central Chile, which according to the 2017 Population and Housing Census has 985,034 inhabitants (INE, 2017). It formerly accounted for a large extension of coastal wetlands, developed from the confluence of several rivers and the Pacific Ocean. However, since 1975 (when the first survey was performed), urbanization has led to the loss of 40% of the Rocuant Andalién wetland (Smith and Romero, 2009).

The studied wetland covered 767 ha in 2014, and its origin has been determined by drift processes affecting the marine platform from Eocene to Pliocene (SERNAGEOMIN, 2002). Through interpretation of recent aerial photographs, Munizaga (2015) followed the geomorphologic classification development by Verger et al. (1971) (Fig. 2), and determined that the Rocuant-Andalién Wetland includes 11 geomorphological units: beaches and dunes, estuary bar, vegetated dunes, water bodies, sand spit, Andalién river sand plain, salt marsh, swamp, wave-cut platform, the “U” hill, and the Bíobío river paleo channel. It is surrounded by urbanization (built-up area), backfills and the actual MUPC wetland protection area (Fig. 2).

The CMA is highly exposed to natural coastal disasters. The studied wetland played a key role in mitigating the flooding associated with tsunami events (Beltrán, 2012; Rojas et al., 2014). This is especially true with the last tsunami, which affected the area in 2010 (Valdivia and Lagos, 2014). This tsunami caused different levels of flooding (from 1 to 6 m; Fig. 2) as detected by the National Oceanographic and Hydrographic Service (Servicio Hidrográfico y Oceanográfico de la Armada de Chile; SHOA, 2013). A large percentage of the surrounding residential and military areas were flooded, affecting more than 180,000 people, including 23 casualties, 1805 displacements, and 56,535 injuries. In addition, 6600 houses and 24 schools were destroyed, and wide economic and environmental losses were suffered (Lara et al., 2017). After the 2010 tsunami, mitigation strategies focused on the so-called hard-infrastructure (Martínez et al., 2017; Khew et al., 2015), neglecting the natural role of wetlands in the ecosystem service of the coastal area’s increased resilience.

Urban development in the CMA is now driven by the MUPC, whose main goals are: (i) to regulate the physical development of the urban and rural areas of the intercounty system, (ii) to guarantee the integrity and continuity of different elements that structure neighbouring counties, (iii) to provide a frame of reference for evaluating projects that are of community interest, and (iv) to move towards sustainable development in the CMA (Rojas et al., 2013b). The MUPC is essentially a zoning plan that provides land preservation in some areas by restricting urbanization. Based on this plan, the urban area in the CMA is subdivided into a consolidated urban area (22,504 ha; 8.47%) and an urban extension area for future growth (31,381 ha; 11.82%). The latter is divided into: (i) mixed use residential, (ii) mixed housing, (iii) conditional urban development, and (iv) urban extension in sloped areas. The plan also designates some areas for commercial use and transport infrastructure. The MUPC is officially scheduled to be completed by around 2024, 20 years after their approved (Fig. 3). Over the last decade, it has focused on a major investment in transport infrastructure (Martínez et al., 2012).

2.2. Methodology

2.2.1. Determining wetland area along with main land use and cover categories

The wetland area and the remaining land use and land cover (LULC) categories for both 2004 and 2014 were detected using the remote sensing methods proposed by Vásquez (2013), who selects the most abundant wetland vegetation in order to improve its detection from the surrounding LULC categories. We used two Landsat images (30 m pixels): a Landsat 5 T M (Thematic Mapper) for 2004 (05/29/2004) and a Landsat 8 OLI/TIRS (Operational Land Imager / Thermal Infrared Sensor) for 2014 (08/12/2014). In both cases, we considered the entire wetland area and its surroundings (approx. 300 m around). Images were obtained from the U.S. Geological Service (www.usgs.gov) and were geometrically (UTM 18S zone, WGS84 datum) and radiometrically corrected (Chander et al., 2009).

Following previous studies, image classification was performed using the Maximum Likelihood Classifier (hereafter ML), a widely used supervised classification method for Landsat satellite imagery with satisfactory results. This method proved to be precise in separating the main LULC categories in the CMA (Rojas et al., 2013a). It is based on a set of training areas (regions of interest or ROI´s) selected for a group of pre-defined land use and cover categories, which are submitted to a statistical analysis of similarity to get discrimination of these categories.