Wetlands of the Coast of Lima: Patterns of Plant Diversity and Challenges for their Conservation

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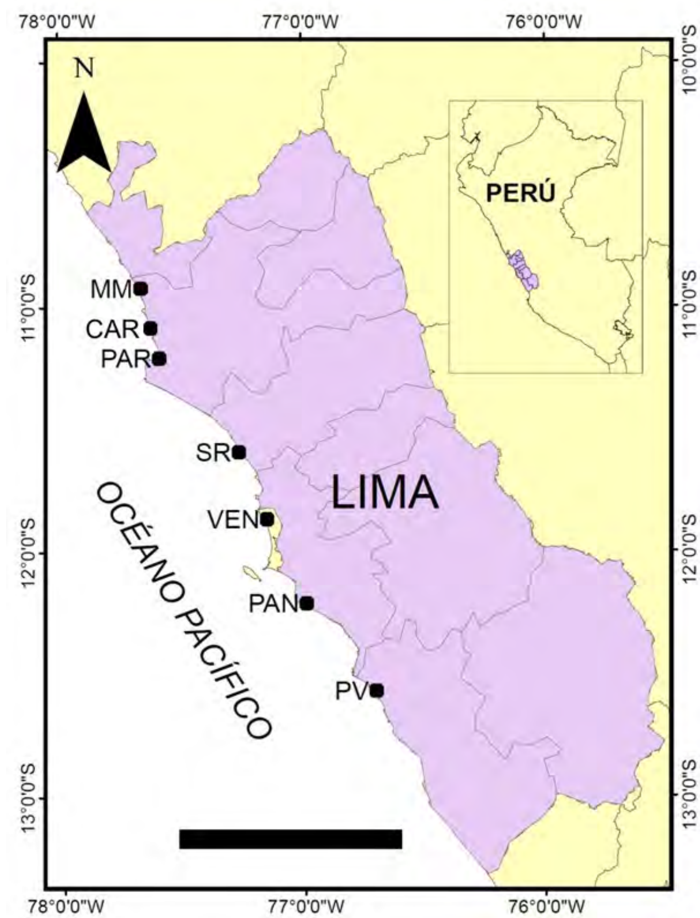
ABSTRACT

The wetlands of the coast of Lima are ecosystems very close to the city. This makes them particularly important wetlands in composition and function. In recent years, multiple investigations have been carried out on plant diversity of these wetlands. This allows us to know various aspects of their composition and structure. This article compiles the most important information on these ecosystems (mainly at the vegetation level), trying to establish some patterns regarding their diversity at the alpha, beta and gamma levels. As a result, we found that alpha and gamma diversity is intimately related to human activities, which triggers, for example, the presence of invasive species that now represent approximately 50% of the plants. Plant richness is independent of the state of conservation of the areas (having protected areas of high and low diversity compared to the non-protected) and size (the smallest wetland is the one with the highest values of richness per area unit). At the regional level, no patterns of beta diversity have been found, which suggests that we should conserve each wetland along the corridor. Some of the challenges for the conservation of these ecosystems are raised.

INTRODUCTION

Peru is rich in wetlands including coastal, Andean, and Amazonian types. The country has more than 12,000 lagoons: 3,896 in the Pacific basin, 7,441 in the Atlantic basin, 841 in the Titicaca basin and 23 in the closed basin of the Huarmicocha System that contribute to this diversity (Ministerio de Agricultura, INRENA 1996). On the coast of Peru, wetlands are part of the migratory route of birds along the Pacific Corridor and as such are especially important for the conservation of biodiversity. To date, 91 coastal wetlands, 56 natural, 11 artificial, and 14 river mouths are known and of these, 25 are in Lima: 16 natural, 4 artificial and 5 river mouths (Pronaturaleza 2010). More than 80 species of vascular plants and 180 species of birds been recorded in these wetlands by preliminary studies (Pronaturaleza 2010). More detailed work of the different biological groups produce more accurate figures of the diversity that is housed in these ecosystems. For example, the work of Aponte and Cano (2013) for just six coastal wetlands of Lima reported the presence of 123 vascular plant species. When we add birds (Tello and Engblom 2010), mammals (Pacheco et al. 2015), reptiles (Icochea 1998), spiders (Paredes 2010) and protozoa (Guillén et al 2013; Guillén et al. 2015) to the plant species, more than 300 species of organisms occur in Lima's wetlands. This diversity alone testifies to the importance of these ecosystems as shelters for the diversity of life on the desertlike coast of Peru. How much do we know about the patterns that diversity of species follows in this region? And, if known, can this help us make better conservation decisions?

FIGURE 1. Map showing the location of the seven wetlands studied. MM=Albufera de Medio Mundo, CAR=Humedal de Carquín – Hualmay; PAR=Laguna El Paraíso; SR=Humedales de Santa Rosa; VEN=Humedales de Ventanilla; PAN=Pantanos de Villa; PV=Humedales de Puerto Viejo. Scale bar =100km.



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STUDY AREA

In the present study, we worked with data from seven wetlands of the central coast of Peru: Wetlands of Puerto Viejo, Pantanos de Villa, Ventanilla Wetlands, Wetlands of Santa Rosa, El Paraíso Lagoon, Carquín-Hualmay Wetland and Albuferas de Medio Mundo. They are located between 10°58`05.15 "S and 12°34`16.77" S, and occur from sea level to altitudes no higher than 25m (Figures 1 and 2). Most of these wetlands are associated with coastal lagoons. While most of the water of these wetlands comes from the Andes, some water enters the subsoil in the highlands and flows into coastal lagoons. In many cases, this water crosses urban, livestock or agricultural areas before entering the subsoil and upon reaching the coast results in euthrophic ecosystems. In some other cases, it enters through temporary connections (directly or by the underground) between the lagoons and the sea.

METHODS

To answer the questions raised about diversity patterns, several sources of vascular plant richness data were examined: Aponte and Cano (2013) for the wetlands of Paraíso (not protected), Santa Rosa (not protected), Medio Mundo (protected by the regional government) and Puerto Viejo (not protected); Aponte and Ramirez (2014) for the Ventanilla wetlands (protected by the regional government); Ramirez and Cano (2010) for Los Pantanos de Villa (protected, Ramsar site and a National Protected Area) and Aponte and Cano (2018) for Carquín-Hualmay Wetland (not protected). Complementary to the species richness of each wetland (which can be an estimator of gamma diversity) are other measures of diversity on a different scale. For example, the alpha diversity indices (such as Shannon-Wiener Index) indicate diversity at the habitat level, while beta diversity estimators (such as Whittaker and similarity indices) allow us to evaluate the exchange of species between sites (Halffter and Moreno 2005). Available information on alpha diversity (mean Shannon-Wiener value from different habitats from Aponte and Ramírez 2011) and beta diversity (Whittaker and Cody indices from Aponte 2017a, 2017b) for these wetlands was added. To evaluate the correlation between beta diversity and distance between wetlands, the similarity between plant composition in these wetlands was calculated using the Jaccard index. The equations and detailed interpretation of all the mentioned indices can be found in Moreno (2001). The distance between the wetlands was measured using Google Earth.

FIGURE 2. The lagoon and wetlands of Paraíso (Huacho, Lima). Wetlands of the coast of Lima are ecosystems formed by the runoff from the water that comes from the Andes frequently interacting with salt water brought in underground from the ocean. The freshwater entering these wetlands often crosses agricultural fields and urban areas.

RESULTS AND DISCUSSION

Alpha and Gamma Diversity: Their Relationship with Anthropic Processes

The data obtained to date show that alpha (habitat level) and gamma (wetland level) diversity is high in both protected wetlands and non-protected wetlands (Table 1). For example, Los Pantanos de Villa (a protected wetland) has the greatest historical richness reported to date while the Santa Rosa wetland (non-protected) is the second-ranked wetland with the highest number of plant species and alpha diversity, despite receiving minimal protection and being located where human activities have considerably intervened the landscape. In the latter case, livestock seems to play an important role in increasing diversity at the alpha level (with high-value plant communities where this activity is practiced). Finding an adequate level of human activity is essential to achieve an adequate use of space and the consequent conservation of the ecosystem.

One of the key challenges for the conservation of biodiversity has been the need to conserve the "natural" diversity of ecosystems, so that not only the species found in ecosystems are conserved, but also those that historically have a role in that place (Santana 2019). To achieve this in the wetlands of the Peruvian coast, it is essential to carry out historical studies that allow us to understand the temporal composition of these ecosystems, in order to identify the natural diversity of plants while maintaining the ecosystem processes and services that these species provide. Likewise, it is important to identify the level of contribution that non-native species have in the ecosystem and in the ecosystem services they provide in order to adequately decide what steps to follow in their management. It has been suggested that non-native species should be considered part of the diversity of ecosystems, at least initially (Schlaepfer 2018). So we must consider their distribution in ecosystems such as Peruvian coastal wetlands where non-native plants represent a considerable percentage of the species in the plant community.

The most recent study of plant diversity carried out in the Carquín-Hualmay wetland revealed the importance of small wetlands (which are often little studied) (Aponte and Cano 2018). Although this wetland was not the most diverse of those along the coast of Lima, due to its size, it hosts the greatest number of species per area. This makes it one of the most important ecosystems in the region, and by this alone, worthy of conservation. Moreover, its location at the center of the coast of Lima makes it vital as the connection in the diversity corridor along the coast.

Finally, the origin of the flora of these wetlands shows that approximately 50% of the plants are invasive species (see the tables in Aponte and Cano 2013 for more details). This situation is the result of the interaction of these ecosystems with adjacent populations and human activities (e.g., garbage disposal, livestock grazing, and agriculture; Young 1998; Ramirez et al. 2010). The presence of invasive species is now a characteristic of these ecosystems and occurs both in protected and unprotected wetlands. While the presence of these species is typically interpreted as a symbol of the deterioration of wetlands, it might be interpreted it as an integral part of surviving in a human-influenced landscape that accomplish the function as a reservoir for urban flora. So our conservation goal must reflect the reality of invasive species being a component of the diversity of these wetlands, but the challenge is how to manage them.

Regional Beta Diversity: Patterns in Plants?

The studies carried out at the beta level show that, although birds have a greater richness of species in Lima, the turnover between sites (beta diversity) is greater in plants than in birds (Figure 2). This means that the complementarity between wetlands at the regional scale is greater in the case of plants than in birds. Considering this indicator, it is very difficult to decide which wetland to conserve and which one not to conserve, or rather where do we prioritize conservation initiatives? Also, by analyzing the diversity from this second perspective (considering complementarity), we can understand the importance of each of these wetlands for the conservation of the region's flora.

When analyzing the correlation between beta diversity and distance between sites, no pattern of beta diversity at the regional scale was found. Normally, the greater the distance between localities, the greater the difference between them and as a consequence there is a greater beta diversity, but this pattern was not observed in the study area (Figure 3). This indicates that the generalization of known patterns for diversity is not the best route to make conservation decisions. In this case, the structure and composition of plant species is governed by a set of processes where human activities intervene. These interactions are often complex and little studied. Consequently, it is not possible to easily make a decision on which ecosystem to protect and makes it is necessary to study the processes that occur within and between these wetlands in order to make a good conservation decision. For example, little is known about the role of connectivity in these ecosystems and between these wetlands and coastal hills. Recently the presence of an aquatic plant has been reported in the lomas formations – *Lemna minuta* Kunth (duckweed). This plant most likely came from a nearby wetland (Aponte 2016).

The absence of patterns among these wetlands, as well as their high complementarity, is an indicator that the best way to protect them is through the creation of large-scale protected areas. There is experience of this type in Peru (i.e., the island and guano islands protection system), so these proposals are not unfamiliar to decision-makers. Currently there are initiatives to protect the wetlands of the Pacific coast (for ex-

FIGURE 3. Diversity of birds and plants in the coastal wetlands of Lima, evaluated with the beta indices of a) Whitaker and b) Cody, and c) at the richness level.

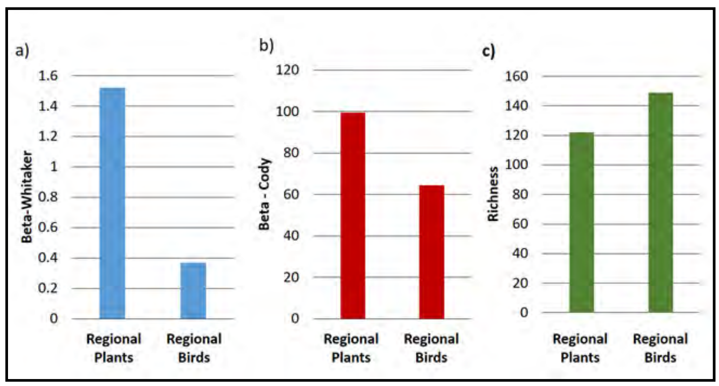
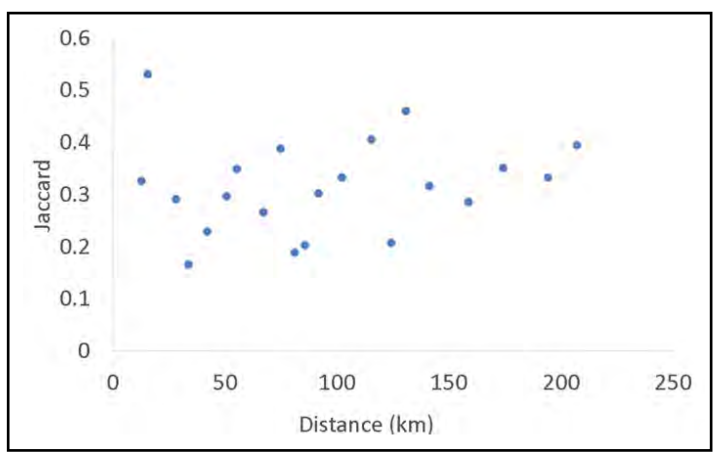


FIGURE 4. Scatter plot of the distance between wetlands and the similarity (measured with the Jaccard index) between them. The figure shows no correlation between beta diversity and distance between sites which means that there is no spatial pattern of beta diversity at the regional scale. The correlation analysis for these variables resulted in p> 0.05.



ample the Initiative for the Conservation of Coastal Wetlands and Shorebirds in the Arid Coast of the South American Pacific), where these proposals would fit perfectly.

Challenges for the Conservation of the Coastal Wetlands of Lima

The study of diversity patterns identified research needs that are important to make adequate conservation decisions. There are small wetlands that have not yet been studied (e.g., Laguna la Encantada) and whose importance as shelters for diversity should not be underestimated. Likewise, the role of invasive plant species (considering that, in some cases, they represent around 50% of the species) in these wetlands is hitherto unknown, so it is necessary to study them before indicating that they are harmful species for those ecosystems. In addition to these, Lima's wetlands have several common characteristics (e.g., proximity to the city, land ownership or management problems in perimeter areas, presence of human activities for the use of its resources, absence of permanent monitoring programs for both biotic and abiotic components, and ignorance of the existence and importance of these ecosystems by the general public) that have allowed us to identify situations requiring immediate attention for conservation (Aponte 2017c; Aponte et al. 2018). At least three activities have been identified as fundamental for the protection of these ecosystems in the long term:

- **Legally recover the spaces.** Many of the areas have owners who could legally eliminate the wetland. NGOs and the state must work to reverse the land tenure processes and be able to properly manage these spaces. This will require public education and outreach and dialogue with the owners to help them understand the environmental value of the wetlands and how use of these lands can be done in a way to minimize adverse effects.
- **Media movement.** It is necessary to involve local media (radio, television) and social networks to help improve the public's understanding and appreciation of these wetlands. Surprisingly, many people who live in Lima do not know about the existence of these ecosystems. This outreach must include information (e.g., pamphlets and videos) and education through field trips by school students and encouraging universities to use wetlands as a subject for ecosystem research.
- **Working together.** It is essential that all people involved in the protection of these wetlands work together. In recent years there have been several personal and isolated initiatives, but I think it is more productive to work cooperatively on outreach activities. Environmental professionals need to work with economists, lawyers, sociologists and communicators on improving public awareness of wetlands and conservation needs. In this way, the fruits of interventions and research can be analyzed from various perspectives, considering possible gaps in the design of management and management plans that allow for solutions (Figure 5).

Along with the lomas formations where we also find hundreds of species (Dillon et al. 2011), wetlands are an important refuge for the flora and fauna of this region. Due to their proximity to human populations, both lomas formation and wetland ecosystems have suffered reductions in their extent and degradation by various impacts.

TABLE 1. Plant mean alpha diversity, historical gamma diversity, area and number of species per area for the studied wetlands. Protected wetlands are marked with a *

Wetland	Mean Alpha	Gamma	Area (ha)	Species/ area
Puerto Viejo	0.32	32	200	0.16
Pantanos de Villa*	-	72	276	0.26
Ventanilla*	-	37	265	0.14
Santa Rosa	0.72	67	60	1.12
Carquín-Hualmay	-	41	11.64	3.52
Paraíso	1.05	33	690.42	0.05
Medio Mundo*	0.48	21	261	0.08

FIGURE 5. A pelican in the coastal wetland Poza de la Arenilla (La Punta, Callao), an artificial wetland that is enriched by nutrients (probably from urban origin plus natural organic matter) causing the growth of thick mats of green algae (in the background). Controlling the growth of these algae and the sources of eutrophication is very important, and will only be achieved with research and appropriate land management. To date, no studies of the flora of this wetland have been published.

Therefore, management plans must be applied in an integral manner for the management of the coastal ecosystems of Lima and Peru. ■

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