Chapter 1
Distribution and Conservation of Coastal Wetlands: A Geographic Perspective

Pablo A. Marquet, Sebastián Abades, and Iván Barría

Abstract This chapter provides a synoptic view of the distribution, conservation and importance of the connectivity of coastal wetlands of central Chile. For this, a methodology was developed to identify coastal wetlands present in central Chile (30 °S and 41 °40'S), through the analysis of 13 multispectral images Landsat ETM + for the spring-summer seasons of 2000 and 2001. Furthermore, we analyzed the degree in which the identified wetlands are contained within the Chilean protected area network, and carried out a connectivity analysis using graph theory. This analysis, despite being preliminary, allow us to draw a number of simple conclusions, of great importance for the management and protection of these ecosystems. On one hand, the latitudinal tendencies in distribution and area of these ecosystems suggest that their average number and extension increase in the north-south direction, and that the degree of protection these sites have is relatively acceptable, but that this would greatly increase if the Priority Sites were included in the analysis. On the other hand, the connectivity analysis suggests that those organisms whose movement distances are below 10–20 km, perceive the landscape as highly fragmented and slightly heterogeneous. Finally, the analysis of the contribution of different coastal wetlands to the connectivity of the system allows us to highlight that, in general, most of the wetlands are important for maintaining connectivity of species with movement capacity below the critical limit of 10–20 km.

P.A. Marquet (✉)
Departmento de Ecología, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Alameda 340, Santiago, Chile

Instituto de Ecología y Biodiversidad (IEB), Casilla 653, Santiago, Chile

Laboratorio Internacional en Cambio Global (LINCGlobal) y Centro de Cambio Global UC. Pontificia, Universidad Católica de Chile, Alameda 340, Santiago, Chile
e-mail: pmarquet@bio.puc.cl

I. Barría
Departmento de Ecología, Facultad de Ciencias Biológicas, Pontificia Universidad Católica de Chile, Alameda 340, Santiago, Chile

S. Abades
Centro de Genómica y Bioinformática, Facultad de Ciencias, Universidad Mayor, Camino La Pirámide 5750, Huechuraba, Chile

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Introduction

Coastal wetlands are the environment interface between land and marine ecosystems highly sensitive to the characteristics of the water masses moving in and out of them (Niering 1985). Not only do they represent unique and important habitat for many species of vertebrates and invertebrates (eg, Vilina and Cofré 2000, 2006; Valdovinos 2004; Gonzalez and Victoriano 2005; Vila et al. 2006; Estades et al. 2009), but they also provide a number of beneficial ecosystem services, among which stand out (see Zedler and Kercher 2005; Engle 2011) the retention and removal of nutrients, stabilizing the shoreline, carbon sequestration, sediment containment, provision and quality improvement of water and lessening the effect of storms, floods and other natural disasters; the latter for the role they play in mitigating the intensity and wave height (e.g., Kirwan et al. 2011). It is to be noted as well that its distribution along the coastline represents a linear array of habitats that serve as a corridor for the migratory movement of large numbers of species (e.g., Aparicio 2006), so keeping its connectivity is essential.

The unique ecological character of coastal wetlands, combined with their high degree of vulnerability and threat from human activities - more than 10% of the human population lives within 10 m of sea level (McGranahan et al. 2007)-, have made them the focus of conservation efforts to ensure the sustainability of the services they provide (e.g., Engle 2011), especially in a context where a number of aspects that make them particularly sensitive are combined, such as: (1) the outlook for these ecosystems in a climate change scenario is not encouraging (e.g., Nicholls et al. 1999; Craft et al. 2009); (2) they have a high degree of deterioration, and (3) these are relatively rare ecosystems, as they represent less than 9% of the overall global area.

Zedler and Kercher (2005) proposed that one of the challenges for the conservation of coastal wetlands is the lack of inventories that are regularly updated on their distribution and status. This is undoubtedly a major challenge, however, it is necessary to undertake actions that would correct this important information gap. In this chapter, a geographical analysis of the distribution and conservation of coastal wetlands in central Chile is presented, with the aim of providing a synoptic view of their distribution, connectivity and importance in an geographic area where these ecosystems are little known and highly vulnerable to the human actions (e.g., Stuardo and Valdovinos 1989), because most of the country's population is concentrated in this area, and where threats arising from the increasing use of the coastal area foresee an uncertain future for its persistence.

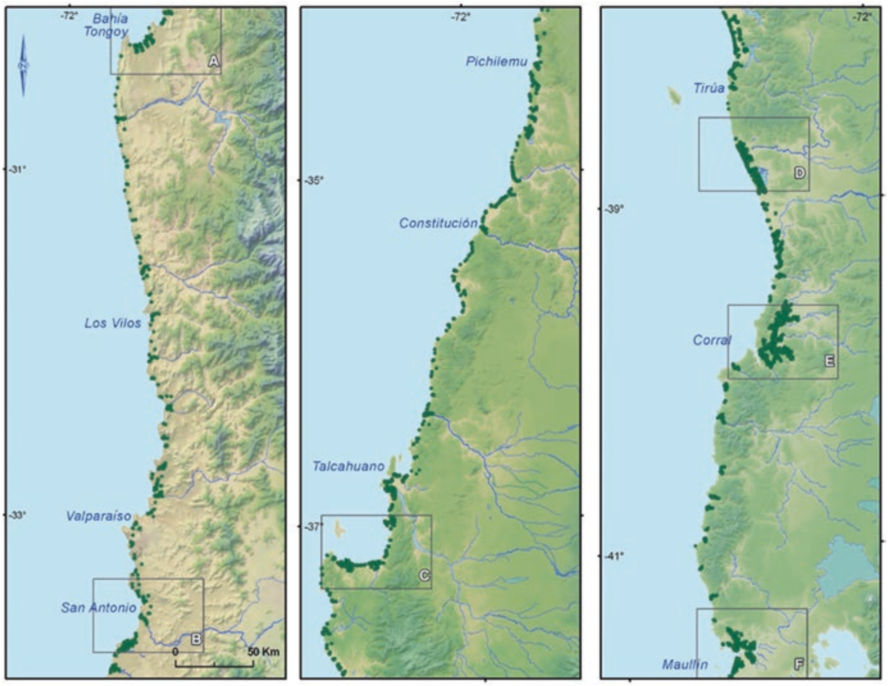

Fig. 1.1 Distribution of coastal wetlands identified in this study. The *boxes* identify wetlands presented in Fig. 1.2

Materials and Methods

The geographic area studied includes a strip of 5 km from the coastline, which stretches between parallels 30 °S and 41 °40'S (Fig. 1.1). Within this area the analysis of the distribution of coastal wetlands and their identification was based on the interpretation of a set of satellite images in order to evaluate the spectral behavior of elements characteristic to this landscape.

Identification of Coastal Wetlands

The identification of wetlands was carried out by digital processing of a total of 13 multispectral images Landsat ETM + in 2000 and 2001, during the spring-summer season. Previous to their analysis images were radiometry as well as atmospherically corrected. The identification of bodies of water by remote sensing, requires that the calibration significantly reduces atmospheric effects on the image data. The data used in this occasion were corrected by the atmospheric correction method used in the model COST (Chavez 1996). Georeferencing of images was based on the regular cartography 1: 50.000 IGM (Military Geographical Institute). Positioning errors were less than 30 m.

The process of spectral discrimination included the use of the Normalized Vegetation Index (NDVI), which is used for discrimination of vegetation from bare soil. In addition, we have used the Normalized Water Index (NDWI), in its various expressions. This index identifies bodies of water and the moisture content of the vegetation or soil. The results of each of these indexes were integrated to the set of bands for each of the corresponding images, and then we carried out a supervised classification through the ISODATA algorithm (Iterative Self-Organizing Data Analysis Technique). For the final delimitation of each of the coastal wetlands, the result of the supervised classification was used. The class corresponding to the water bodies was later modified according to the patterns extracted from the NDVI and NDWI indexes. The settings and cutoff levels were done independently for each one of the images. To validate it, the results of the polygons of the bodies of water generated were compared with the existing cartographic information.

Connectivity Between Coastal Wetlands

The description of the pattern of the coastal wetlands connectivity was done using a graph representation. A graph corresponds to a topological characterization, linking landscape elements (e.g., habitat patches) through connections (i.e. corridors), in order to provide a parsimonious description of landscape connectivity (Cantwell and Forman 1993; Urban and Keitt 2001). Formally, a graph G consists of a set of nodes or vertices V (G) connected by edges or arcs G (E), such an edge $e_{ij} = v_i v_j$ joins the nodes v_i and v_j (Harary 1969; Chartrand 1977). The existence of a connection between a pair of nodes implies a certain degree of potential ecological flow between them (e.g., dispersion of individuals, flow of materials and energy, migration). Depending on the research context, the estimated connections between the nodes are based on a distance matrices of different nature. In this analysis Euclidean geographical distance matrices were used, in order to explore simple spatial relationships and its effects on potential connectivity patterns for the complete system of habitat patches. However, more sophisticated approaches may include aspects of the biology of species of interest, degree of hostility matrix surrounding habitat patches, etc. (Schumaker 1996; Hanski 1999; Bunn et al. 2000; Urban and Keitt 2001; Vos et al. 2001; D'Eon et al. 2002; Jordan 2003).

A path within a graph corresponds to a sequence of interconnected nodes, in such way so that each node is unique along its route, that is, each node and edge are visited only once. A closed path including three nodes forms a cycle. A graph with paths that do not include cycles forms a tree. A tree that includes all available nodes forms a connected tree (Bunn et al. 2000; Urban and Keitt 2001). Obviously, if we define d_{max} as the maximum distance allowed to connect two patches of habitat, the topology of the resulting graph will be affected as d_{max} changes and so will be the landscape perceived by a species whose potential dispersion is approaching d_{max}.

Therefore, the simulation of graphs with different values of d_{max} can be used to assess the potential fragmentation that a species could perceive given the landscape provided. This approach is especially useful when you want to know the critical distance at which the landscape losses it connectivity for a wide range of organisms with different capacities and dispersal strategies.

Results and Discussion

Distribution

In total we have identified 412 coastal wetlands, with a total area of 38,167 ha (Fig. 1.1). The same as the distribution of wealth in our country, the distribution of the coastal wetlands areas is highly biased to small sizes, so much so that 63% (n = 260) of wetlands have an estimated area lower than 10 ha, and the 10 wetlands covering larger areas (among which are: Río Cruces, the Bío Bío river mouth, Puerto Saavedra; see Fig. 1.2) represent 66% of the total area of wetlands in the study area.

Latitudinally, the area of wetlands per degree of latitude does not exceed 2000 ha, except from 37 °S (Fig. 1.3). It is also noted in this figure that the average area of wetlands follows a similar trend, with a maximum around 700 ha at 40 °S.

Unlike what happens with other conservation targets, such as species or vegetation formations, coastal wetlands better represented within Protected Areas reaching a percentage close to 20%. This result includes considering the wetland area that overlaps with the SNASPE (National System of Protected Areas), PPP (Private Protected Areas) and Ramsar sites (Fig. 1.4) sites. Although this percentage appears high and above the threshold recommended by international bodies, it is necessary to know if we are protecting what really is the most important, in terms of the connectivity they provide, and ecosystem processes and services they are supporting, and considering the degree of threat to which they are being subjected to.

Regarding the latter, the particularly important ones are the coastal wetlands located in areas with high population density, such as Viña del Mar, Valparaíso, Talcahuano, Coquimbo and Valdivia, each of which has more than 140,000 inhabitants (near a million in total) and where about 25% of the total area of wetlands, present in the study, is concentrated (see section on the relative importance of coastal wetlands below). These, presumably, would be highly threatened as a product of human activities, especially if one takes into account the non-resident population using the coastal zone in these areas. Finally, it should be noted that, considering the priority sites for conservation proposed by the Ministry of Environment, the percentage of protection would increase by an additional 43.9%. This indicates a greatly important increase of protection for this types of ecosystems, to the extent that these sites would become part of the National Network of Protected Areas.

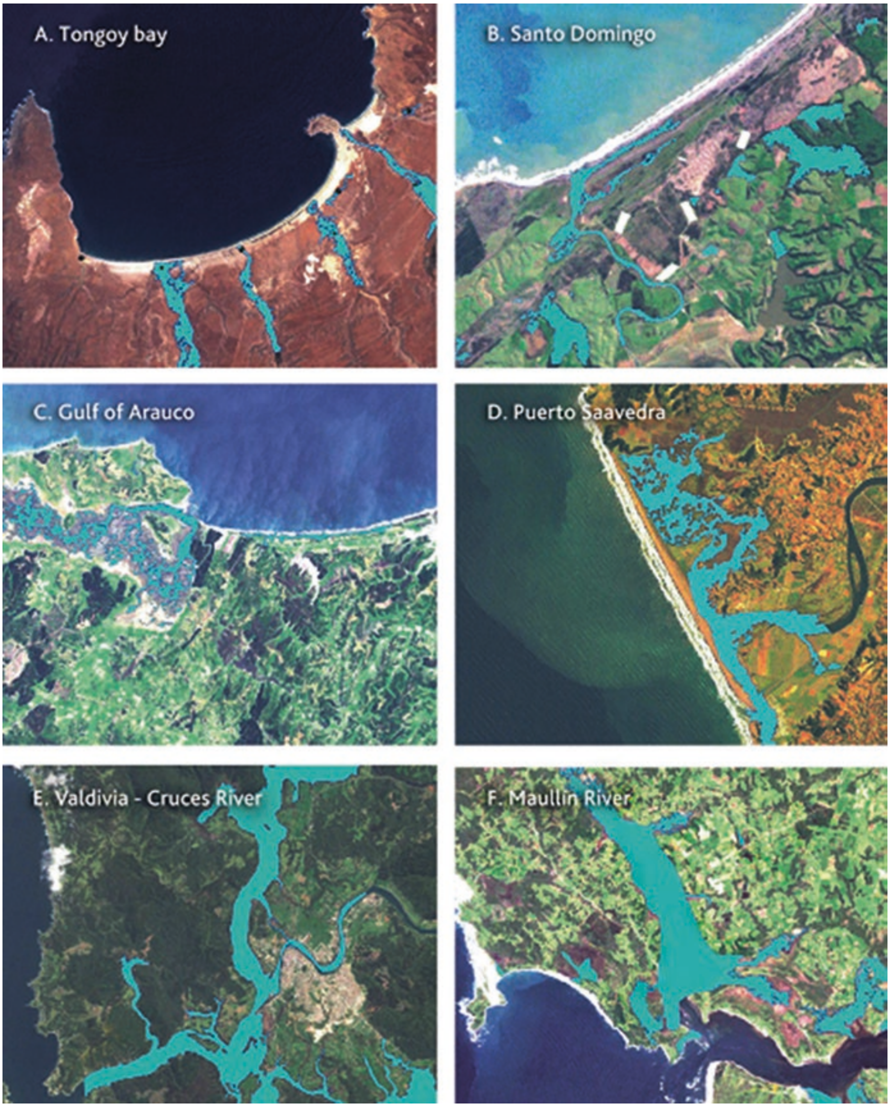

Fig. 1.2 Coastal wetlands identified (in *boxes*) in Fig. 1.1

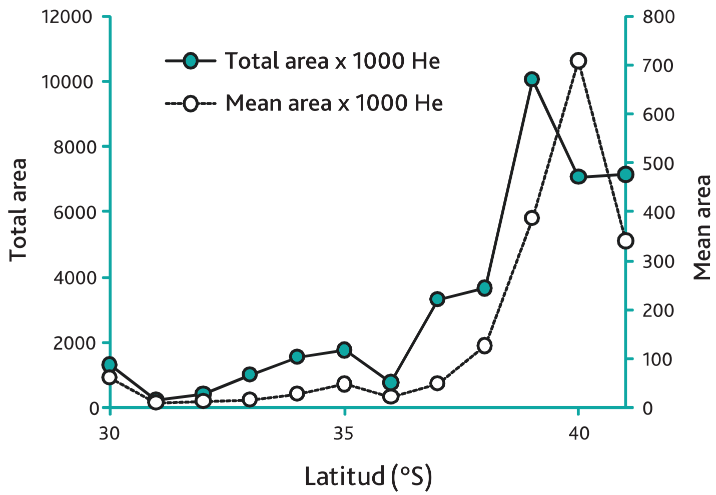

Fig. 1.3 Latitudinal tendency in the total accumulated area (*solid symbol*) and average area (*empty symbol*) of coastal wetlands present in each latitudinal band identified in this study

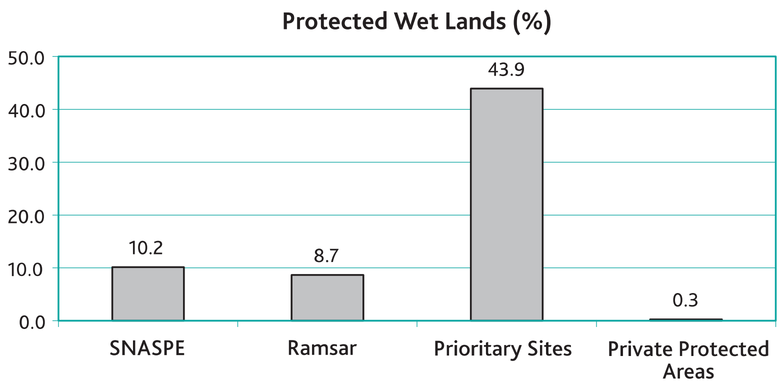

Fig. 1.4 Level of protection (as percentage) of coastal wetlands in the different types of protected areas established in the country

Connectivity

Regarding the connectivity of the system composed of the 412 identified coastal wetlands, Fig. 1.5 shows the connectivity variation obtained simulating different values of d_{max}, defined as the perceived distance by a theoretical species whose maximum dispersion oscillates around this value.

It is recognized that given the current topology of wetlands, there would be a rapid loss of connectivity for species whose dispersion does not exceed 10 km. Specifically, species with low dispersal capacity perceive the landscape as a set of

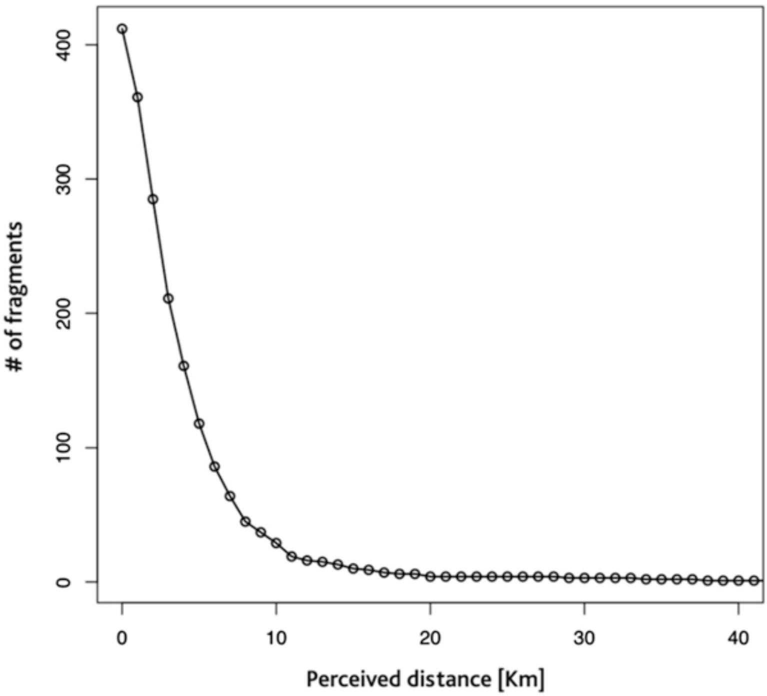

Fig. 1.5 Level of fragmentation of coastal wetlands based on the maximum distance perceived by a species. A higher number of fragments imply that species whose dispersion is below the distance perceived, experience the high degree of partition of the total landscape as isolated habitats. A low number of fragments entail the ability to perceive the wetland system as a highly connected set

multiple isolated wetlands, that is, a highly fragmented landscape and thus, the likely confinement of these species in small areas disconnected from the global system. In this case, these species would have little chance of recovery from local extinctions. Over 10 km long, the perceived landscape would essentially be unitary, because the high local connectivity between neighboring wetlands provide potential access to the entire network of habitats available in the existing system of coastal wetlands. Note that the decay curve is steep, which is expected, since the spatial arrangement of the system of coastal wetlands is essentially linear.

Figure 1.6 shows the effects of d_{max} in an average area of perceived clusters at this scale of connection, that is the amount of available habitat for the species. Leading up to a distance of approximately 20 km, the area of connected wetland clusters shows a continuous gain. Above this distance, a step-wise pattern in mean fragment area or increase in connectivity is observed. This pattern is attributed to the specific characteristics of the geographical distribution of coastal wetlands, and implies the existence of a significant degree of risk against potential losses of patches of habitat that may cause spatial gap by about 35 km, given that the species that exploit the landscape at this scale would perceive a loss of potentially available area by approximately 50%.

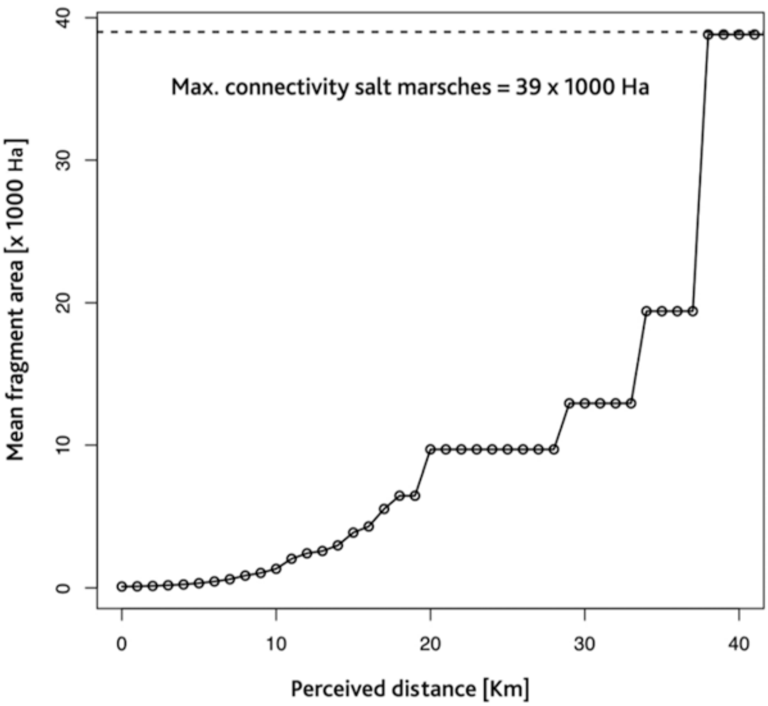

Fig. 1.6 Loss of area for species that perceive the landscape at a scale lower than the distance indicated in abscissa

In the case of the analysis presented in Fig. 1.6, it is important to consider that the available area could be made up of fragments whose areas are very heterogeneous, which could be a relevant factor to take into account, because the heterogeneity in the area is associated with diversity of environmental resources and situations which, usually in a positive way, impact the persistence of the metapopulations that inhabit them (reducing the risk of extinction, Hanski 1991). Figure 1.7 shows the heterogeneity in area of the connected coastal wetlands that are generated at distances less than d_{max}, simply defined as the standard deviation of the average values obtained for the graph, and for different scales of perception. Interestingly enough, it is noted that at 20 km is verified the highest degree of heterogeneity, which implies a connected landscape composed of coastal wetlands of widely different sizes. Above this distance, a rapid loss of variability is observed as a product of the coalescence of differents clusters of connected wetlands in a large geographical extent.

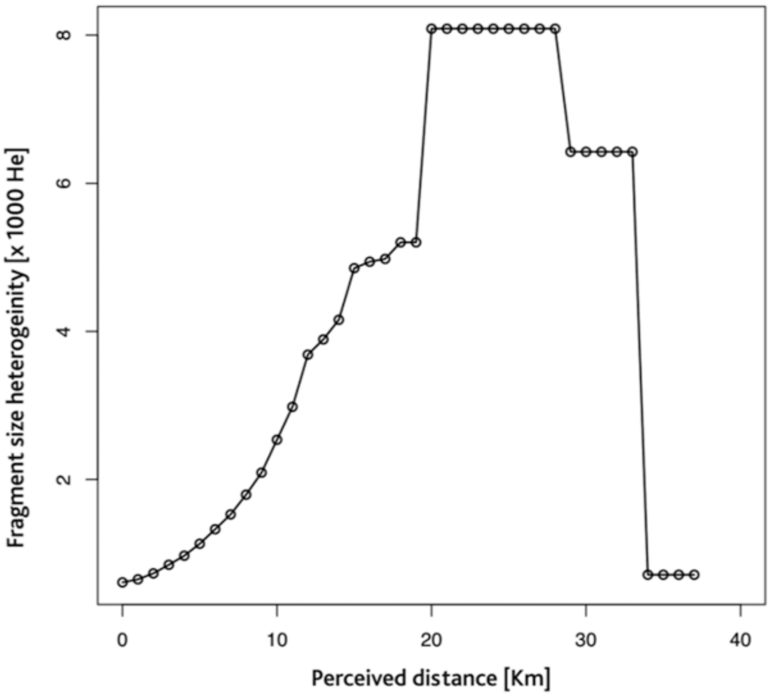

Fig. 1.7 Heterogeneity in the sizes of areas available for species that perceive the landscape at a scale lower than the distance indicated in the abscissa

Assessment of the Relative Importance of Coastal Wetlands

The relative importance of coastal wetlands was assessed by a simple procedure based on the recursive removal of neighboring wetlands: evaluating the size of the gap generated by eliminating a focal wetland and a progressive number of neighboring wetlands. Figure 1.8 shows the effect that would produce the loss of a focal wetland and its closest N neighbors, generating a distance gap. The diagram shows on the ordinate axis, each one of the coastal wetlands analyzed, sorted from north to south according to latitudinal position. The abscissa shows the number of nearest neighbors removed to the north and to the south of the disturbed wetland. The response shows on a color scale the distance gap created by removing these wetlands from the coastal network.

The impact of the removal varies depending on the latitudinal location of the wetland, which is accentuated as the number of neighbors of the focal wetland that are lost increases. The inferior diagram on the binary color scale shows the resulting pattern by examining gaps of size d_{max} <20 km. It is generally shown that for most of the wetlands, the loss of one or two close neighbors would create a large enough gap to reach a critical distance global loss of connectivity (according to the general pattern observed in Fig. 1.6).

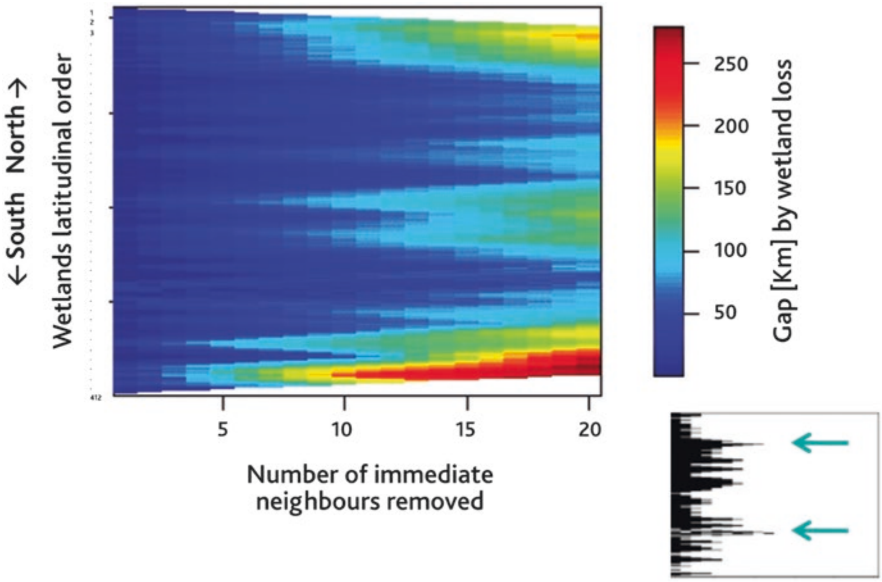

Fig. 1.8 Sensitivity diagram showing coastal wetland loss. *Y* axis shows the latitudinal ranking of the 412 coastal wetlands analyzed (without associated geographical coordinates). *X* axis shows the number of immediate neighbors removed, both to the north and to the south, of a focal wetland evaluated. *Color scale* indicates the size of the gap generated by the loss of the neighboring wetland collection. Lower diagram shows, in binary scale, the removals that imply the creation of a critical gap of 20 km. *Arrows* signal robust wetlands that require a significant loss of close neighbors to cause a notable change in the global connectivity of the wetland system. Most of the wetlands show a high sensitivity, since removing a few neighbors seems to be enough to trigger effects of global disconnection

This implies that the loss of a relatively low set of neighbors could be sufficient to cause an effect of global loss of connectivity in the current arrangement of coastal wetlands. This result is expected because of the linear arrangement of this habitat type that makes global connectivity highly sensible to the loss of local elements, which break the linearly concatenated arrangement. However, it should be noted that in some latitudes (arrows on the bottom panel) there is a significant degree of robustness, and therefore a large number of neighboring wetlands need to be lost in order to generate a critical gap in connectivity. This is possibly due to the high density of small wetlands concentrated at these latitudes. A simple and useful way to assess the priorities for conservation of coastal wetlands is to jointly consider their importance for connectivity (Fig. 1.8) and the degree of threat they are subjected to (this is assessed through evaluation of the number of inhabitants in municipality where the wetland is located). This is presented in Fig. 1.9, where you can see that the Tongoy and Maullin wetlands are of great importance, and at the same time, are under high potential threat, which render them as of high priority for conservation.

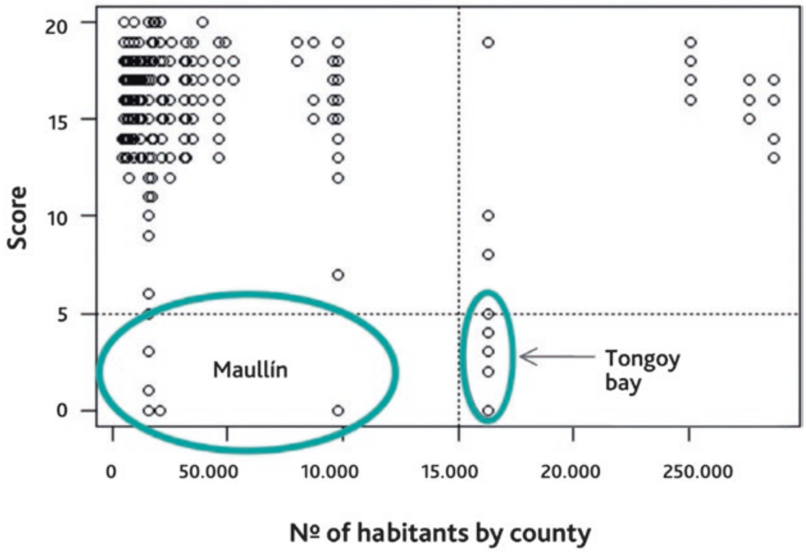

Fig. 1.9 Ordination diagram between wetland importance and the potential threat of human effects. The wetland's importance corresponds to the score value obtained in Fig. 1.8, where values close to zero would entail a high vulnerability associated to the loss of the focal wetland and its closest neighbors

Conclusions

This chapter has attempted to provide a synoptic view of the distribution, conservation and importance for the connectivity associated to the coastal wetlands of central Chile. This view, despite being preliminary, allows us to draw a number of conclusions that are of great importance for the management and protection of these ecosystems. On one hand, the latitudinal distribution trends and areas of these ecosystems, point out that their number and average size are increasing in the north south direction, that the degree of protection they have is relatively acceptable, and that this would markedly increase if Priority Sites where become part of the National Network of Protected Areas (SNASPE). On the other hand, the connectivity analysis suggests that those organisms, whose movement distances are below 10-20 km, perceive the landscape as highly fragmented and with little heterogeneity. Further, the analysis of the contribution of various coastal wetlands to the connectivity of the regional system analyzed, points out that in general, most wetlands are important to maintain connectivity for species with movement capabilities under the critical threshold of 10-20 km.

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References

Aparicio, A. 2006. Abundance, distribution and migration chronology of shorebirds on exposed sandy beaches of south central Chile. In *Waterbirds around the world*, ed. G.C. en Boere, C.A. Galbraith, and D.A. Stroud, 188. Edinburgh: The Stationery Office.

Bunn, A.G., D.L.Y. Urban, and T.H. Keitt. 2000. Landscape connectivity: a conservation application of graph theory. *Journal of Environmental Management* 59: 265–278.

Cantwell, M.Y., and R.T.T. Forman. 1993. Landscape graphs: ecological modeling with graph theory to detect configurations common to diverse landscape. *Landscape Ecology* 8: 239–255.

Chartrand, G. 1977. *Introductory graph theory*. New York: Dover Publications.

Chavez, P.S., Jr. 1996. Image-based atmospheric corrections- revisited and improved. *Photogrammetric Engineering and Remote Sensing* 62 (9): 1025–1036.

Craft, C., J. Clough, J. Ehman, S. Joye, R. Park, S. Pennings, H. Guo, and M. Machmuller. 2009. Forecasting the effects of accelerated sea-level rise on tidal marsh ecosystem services. *Frontiers in Ecology and the Environment* 7: 73–78.

D'eon, R.G., S.M. Glenn, I.Y. Parfitt, and M.-J. Fortin. 2002. Landscape connectivity as a function of scale and organism vagility on a real forested landscape. *Conservation Ecology* 6: 10–23.

Engle, V.D. 2011. Estimating the provision of ecosystem services by Gulf of Mexico coastal wetlands. *Wetlands* 31: 179–193.

Estades, C.F., M.A. Vukasovic, and V. López. 2009. Las aves acuáticas del río Itata. In *La cuenca hidrográfica del río Itata. Aportes científicos para su gestión sustentable*, ed. O. Parra, J.C. Castilla, H. Romero, R. Quiñones, and A. Camaño, 213–228. Concepción: Editorial Universidad de Concepción.

González, A., and P. Victoriano. 2005. Aves de los humedales costeros del Centro-Sur de Chile. Capítulo 35 En. In *Biodiversidad y Ecología de la Cordillera de la Costa*, ed. C. Smith, J. Armesto, and C. Valdovinos. Santiago: Editorial Universitaria.

Hanski, I. (1991). Single-species metapopulation dynamics: concepts, models and observations. Biological Journal of the Linnean Society 42: 17–38.

Hanski, I. 1999. *Metapopulation ecology*. Oxford: Oxford University Press.

Harary, F. 1969. *Graph theory*. Reading: Addison-Wesley.

Jordán, F. 2003. Quantifying landscape connectivity: key patches and key corridors. En. In *Ecosystemand sustainable development IV*, ed. E. Tiezzi, C.A.Y. Brebbia, and J.-L. Usó, 883–892. Southampton: WIT Press.

Kirwan, M.L., E. Wolanski, E.B. Barbier, and B.R. Silliman. 2011. The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm. *Climatic Change* 106: 7–29.

Mcgranahan, G., D. Balky, and B. Anderson. 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and Urbanization* 19: 17–37.

Nicholls, R.J., F.M.J. Hoozemans, and Y.M. Marchand. 1999. Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environment Change* 9: S69–S87.

Niering, R. 1985. Wetlands. The Audubon society nature guides, 638 p. Alfred A. Knopf Inc. New York, NY.

Schumaker, N.H. 1996. Using landscape indices to predict habitat connectivity. *Ecology* 77: 1210–1225.

Stuardo, J., and C. Valdovinos. 1989. Estuarios y lagunas costeras: Ecosistemas importantes de Chile Central. *Ambiente y Desarrollo* 5: 107–115.

Urban, D.L.Y., and T.H. Keitt. 2001. Landscape connectivity: a graph-theoretic perspective. *Ecology* 82: 1205–1218.

Valdovinos, C. 2004. Ecosistemas estuarinos. En. In *Biología marina y oceanografía: Conceptos y procesos*, ed. C. Werlinger, vol. 2, 395–414. Chile: Trama Impresores S. A.

Vila, I., A. Veloso, R. Schlatter, and C. Ramirez (Eds). 2006. Macrófitas y vertebrados de los sistemas límnicos de Chile. Editoral Universitaria, Santiago, Chile.

Vilina, Y.A., and H. Cofré. 2000. El Niñoeffectsontheabundanceandhabitatassociation patterns of four grebe species in Chilean wetlands. *Water birds* 32: 95–101.

Vilina, Y., and H. Cofré. 2006. Aves acuáticas continentales. P 270-279 en Biodiversidad de Chile: Patrimonio y Desafíos. In *Comisión Nacional del Medio Ambiente*, ed. P. Saball, M.K. Arroyo, J.C. Castilla, C.F. Estades, J.M. Ladrón de Guevara, S. Larraín, C. Moreno, F. Rivas, J. Rovira, A. Sánchez, and L. Sierralta. Santiago: Editorial Ocho Libros.

Vos, C.C., J. Verboom, P.F.M. Opdam, and C.J.F. Yter Braak. 2001. Toward ecologically scaled landscape indices. *The American Naturalist* 183: 24–41.

Zedler, J.B., and S. Kercher. 2005. Wetland resources: status, trends, ecosystem services and restorability. *Annual Review of Environment and Resources* 30: 39–74.