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Chapter 13

Solutions for Sustainable Coastal Lagoon Management: From Conflict to the Implementation of a Consensual Decision Tree for Artificial Opening

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Chapter Outline

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INTRODUCTION

Coastal Lagoons and Sandbar Dynamics

Coastal lagoons are among the most productive ecosystems in the world (Knoppers, 1994; Duck and da Silva, 2012), sustaining important environmental services such as fisheries (Pauly and Yáñez-Arancibia, 1994; Cañedo-Argüelles et al., 2012). Coastal lagoons represent over 12% of the South America coastline and coincide with densely populated areas (Gönenç and Wolflin, 2004; Esteves et al., 2008). Their importance for biodiversity conservation has been recognized extensively (Barbosa et al., 2004; Isacch, 2008; Soutullo et al., 2010). Particularly, choked coastal lagoons are inland shallow waters periodically connected with the ocean by a narrow channel that opens through a sand barrier. These lagoons are physically dominated systems with large salinity and hydrodynamic fluctuations driven by the intermittent connection with the ocean through the sandbar (Kjerfve, 1994). The connection with the ocean is probably the single most important factor governing the structure and functioning of the resident biotic communities (Smakhtin, 2004).

Despite their relevance for conservation, coastal lagoons are seriously threatened by eutrophication, pollution, urbanization, and diverse forms of modification in their watersheds, caused by human activity in the coastal zones of all continents (Esteves et al., 2008). Worldwide, one of the most common threats to coastal lagoons is the modification of their natural hydrology, particularly the artificial connection with the ocean. Among 60 intermittently open estuaries along the southeastern coastline of Australia (Pollard, 1994), more than 72% are artificially opened (Gale et al., 2007). A similar situation is observed in South Africa, Brazil, and other countries with large numbers of coastal lagoons or intermittently opens estuaries. Artificial openings are performed to manage these coastal systems for a variety of reasons, such as improving fisheries, lowering water level to avoid floods in urban or private lands, raising oxygen concentration, removing algal blooms, or reducing nutrient level (Sei et al., 1996; Griffiths, 1999; Palma-Silva et al., 2000; Thomas et al., 2005; Esteves et al., 2008).

In many coastal lagoons, the artificial opening is a cultural artisanal tradition, generally associated with fisheries (Bertotti Crippa et al., 2013), although currently most of the openings are performed mechanically and endorsed by national and local governments (Suzuki et al., 1998; Griffiths, 1999; Young and Potter, 2002).

According to ecologists, local people, and academic groups, this practice represents an inadequate short-term solution to address a long-term complex socioeconomic problem. Despite the fact that artificial openings are widely practiced in coastal lagoons (Bally, 1987; Pollard, 1994; Griffiths and West, 1999; Schallenberg et al., 2010), relatively little is known about the impact on their biological communities and ecosystem dynamics.

Ecological and Ecosystem Impacts of Artificial Openings

Most authors who have analyzed the impacts of artificial openings of coastal lagoons and intermittent open estuaries recommend strong caution concerning this management practice (Suzuki et al., 1998; Griffiths, 1999; Saad et al., 2002; dos Santos et al., 2006; Santangelo et al., 2007; Rodríguez-Gallego et al., 2010; Bertotti Crippa et al., 2013). Besides the already demonstrated impacts on hydrology and some natural communities, a major reason calling for cautiousness is the unknown and complex effects that may probably occur on other ecosystem components. The most evident effects of artificial openings are observed on water abiotic variables. Generally, sandbar breaching promotes a freshwater discharge into the ocean and a reduction of the water level, followed by the entrance of marine waters into the lagoon. This discharge is then followed by marine intrusion and the creation of steep salinity gradients, as well as nutrients and chlorophyll changes (Suzuki et al., 1998; Conde et al., 2000). In Brazilian eutrophic lagoons, the reduction of nutrients after water discharge into the ocean can be compensated by the resuspension of bottom sediments caused by water motion and by advective transport of sediment pore waters after the marine intrusion (Suzuki et al., 2002).

Macrophytes and benthic algae mortality driven by salinity and water level changes can also cause nutrient release, promoting a shift of plant-dominated lagoons to a phytoplankton prevalence and causing dystrophic crises, as observed in Brazilian and Portuguese systems (Suzuki et al., 1998; Duarte et al., 2002). Light climate in the water column is also altered due to the connection with the ocean. Marine intrusions with low organic content exhibit higher UV penetration and therefore reduction in photosynthetic rates of phytoplankton can be observed, as reported for many lagoons around the globe, including Uruguayan coastal lagoons (Conde et al., 2000, 2002). dos Santos et al. (2006) found strong impacts on macrophyte stands (*Typha dominguensis*) in a Brazilian coastal lagoon after artificial openings and the decrease of water level caused the mortality of this species in the lagoon. Nutrients were released to the water column through plant decomposition, so the expected nutrient decrease after the lagoon opening, allegedly implemented to mitigate eutrophication from urban discharges, was compensated, and a further increase in the phosphorus concentration occurred. Rodríguez-Gallego et al. (2010) showed that artificial openings of a coastal lagoon in Uruguay (Laguna de Rocha) could cause sudden submerged aquatic vegetation (SAV) decrease in biomass and richness, affecting other processes like solid particles and nutrient resuspension by wind. Moreover, sudden salinity changes driven by frequent sandbar openings may promote a highly fluctuating SAV community, with plants and macroalgae proliferation that could also alternate with phytobenthos and phytoplankton blooms (Rodríguez-Gallego et al., 2015).

Artificial openings of Brazilian lagoons have been reported to cause severe changes in zooplankton, as well as in aquatic and floodplain macroinvertebrate assemblages (Santangelo et al., 2007). A replace of typical freshwater species by brackish and marine zooplankton taxa was observed. After sandbar breaching, the main factor driving the zooplankton community was salinity, even overcoming the eutrophication effects on this assemblage. Two years after this episode, the previous zooplankton community had not yet been reestablished, denoting low resilience to this disturbance. Macroinvertebrate richness and abundance were negatively associated with salinity and were also affected by changes in the hydroperiod after artificial sandbar openings (Bertotti Crippa et al., 2013).

Effects of artificial openings of coastal lagoons on fish assemblages are dual, some being beneficial for some coastal species but detrimental for others. Generally, this practice has negative impacts on freshwater species that must migrate to less saline areas or streams, while it can have positive effects on marine and brackish species. Higher richness and recruitment of marine and estuarine fish species were observed in Australian (Griffiths, 1999), Brazilian (Saad et al., 2002), and North American (Reese et al., 2008) coastal lagoons after artificial openings. However, effects can be different depending on species life cycles, spawning, and dispersion timing, and how they synchronize with the frequency, duration, and time of year when the system is connected to the sea. Studies do not recommend artificial openings based only on fish effects until consequences on other biological communities and ecosystem processes are assessed (Santangelo et al., 2007; Bertotti Crippa et al., 2013).

Other factors, such as the location or the time of the year of the sandbar breaching, the sort of opening (manmade or mechanical), and frequency and duration can drive different and complex effects on ecological, chemical, and physical processes, but these factors have not yet been explicitly evaluated (Yañez-Arancibia et al., 2014). Moreover, effects on the flood plain vegetation, soil maintenance, sedimentation, and aquifer dynamics may also be expected. Flooding duration and frequency, and the salinity regime, may promote changes in the wetlands vegetation and therefore on the habitat and forage production for cattle-raising.

Active participation of local stakeholders (particularly fishermen and neighbors) in the decision-making process concerning the artificial control of lagoons' sandbars has been described as essential for successful and sustainable management, especially in protected areas (Pomeroy and Douvere, 2008). Although more complex, long-term processes to involve an eclectic array of stakeholders to discuss and make consensual decisions offer numerous benefits for a successful practice, based on the best available technical information

(Whitfield et al., 2008). This approach will help to improve and democratize actions concerning relevant ecosystem services, like those associated with sandbars of coastal lagoons, where dominant interests still prevail over less influential stakeholders in the decision-making process. For example, opening of lagoons with the exclusive purpose of avoiding floods in private farms could be avoided by an active participation of other stakeholders, for example, by establishing specific intersectoral committees and by scientifically designing multicriteria decision models that take into account other local interests and needs.

The ecological relevance of the connectivity of coastal lagoons and intermittent open estuaries with the ocean is not under discussion. Nevertheless, the global impact of the artificial manipulation of this natural dynamic is still not satisfactorily known, although most of the evidence suggests strong effects on communities and processes. Although this is a historical and common management practice, an increasing institutionalization and mechanization of the practice seems to be occurring worldwide.

In this chapter we analyze (1) the institutional and social demands and conflicts for the artificial opening of the sandbar of a legally protected lagoon on the Atlantic coast of Uruguay (Laguna de Rocha), (2) the hydrodynamics that drives the lagoon opening and the extent of flooding in the floodplain, (3) the natural opening and closing dynamics of the sandbar, and (4) the geological and geomorphological processes taking place at the sandbar in relation to its fragility and evolution over time. The goal of this transdisciplinary research was to implement a consensual multidimensional decision model for the sandbar management of this coastal lagoon, aimed at reducing conflicts among stakeholders and improving the long-term environmental quality of the lagoon.

A LONG CONFLICT IN A PROTECTED AREA

Laguna de Rocha is a subtropical choked lagoon located on the Atlantic coast of Uruguay (34° 35′ S–54° 17′ W), included in a series of lagoons along the Uruguayan and the Brazilian coast (Bonilla et al., 2006). This is a very shallow system with an average depth of 0.6 m, a surface area of 72 km^2, and a watershed of 1214 km^2. The population of the watershed is over 30,000 people, although only a few hundred live close to the lagoon. Among other relevant ecosystem services, the lagoon supports the most important inland fisheries of Uruguay's Atlantic coast (Fabiano and Santana, 2006). The northern area is influenced by freshwater discharge, while the southern area is influenced by the Atlantic Ocean due to the periodically breaching of the sandbar (Figure 13.1); thus salinity ranges from freshwater to marine conditions due to the intermittent connection with the sea. After freshwater discharge, the marine intrusion determines a steep salinity gradient in the lagoon, decreasing from south to north, while turbidity (Conde et al., 2000), sediment nutrients, organic matter, and granulometry (Sommaruga and Conde, 1990; Rodríguez-Gallego et al., 2010) follow the inverse pattern. Hydrology is the main driving force for

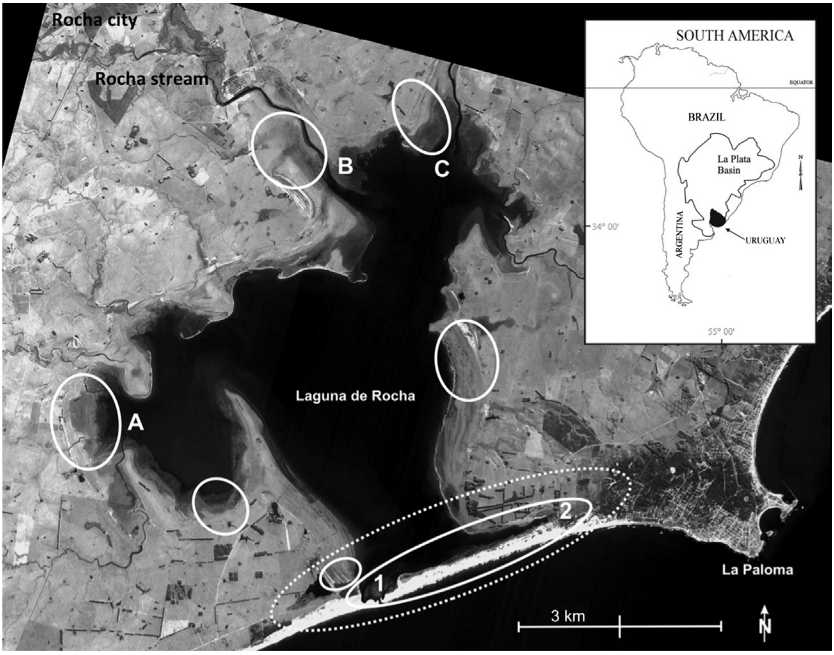

FIGURE 13.1 Overview of Laguna de Rocha and its low basin. La Paloma city is shown on the lower right margin. The provincial capital, Rocha city, is located just outside the image, on the upper left corner, where the main tributary of the lagoon (Rocha steam) can be seen. The dotted zone indicates the sandbar subsystem, where our research is focused. 1. Current opening site of the sandbar. 2. Zone called "barra vieja" (old sandbar) by local people. The circled zones indicate where the flooding areas were specifically studied. A, B, and C are the three areas referred to in Table 13.2 (Satellite image CBERS-2B-HRC 03/05/2009.)

the whole ecosystem functioning (Conde et al., 2000), and its effects on salinity gradients determine phytoplankton (Bonilla et al., 2005), phytobenthos (Conde et al., 1999), bacteria (Piccini et al., 2006), benthos (Pintos et al., 1991), and SAV (Rodríguez-Gallego et al., 2010) abundance and composition.

Phosphorus enrichment seems to be occurring in Laguna de Rocha (Aubriot et al., 2005), possibly due to land use intensification (Rodríguez-Gallego et al., 2013) during the last two decades. Concomitantly, SAV proliferation was recorded (Rodríguez-Gallego et al., 2010) and cyanobacteria blooms were observed twice (V. Hein and D. Calliari, personal communication). Afforestation with exotic trees was almost nonexistent in 1997 and increased to 8.5% of the catchment area in 2005, while agriculture increased 3% during the same time period (Rodríguez-Gallego, 2010). Agriculture is located at short distances from the lagoon and its affluents, and is changing to fertilizer-demanding crops (e.g., soybean). These quantitative and qualitative changes represent a significant increase in the input of nutrients from the catchment area to the lagoon. Moreover, the higher pressure to expand agricultural lands is restricting cattle-raising to marginal, less productive areas; therefore saline wetlands of the lagoon are now more intensively used for cattle, which in turn increases the interest of farmers to decrease the lagoon water level at the onset of flooding. On the margins of the main tributary of the lagoon (Rocha stream), Rocha city is located (about 22 km from the sandbar). This is the provincial capital, with 26,000 inhabitants, partially located on flatlands with poor pluvial evacuation and suffering frequent and short-term flooding events. In this city, there is a generalized incorrect belief that the artificial opening of the lagoon avoids or alleviates flooding; therefore during intense precipitation events, there is high pressure from people (e.g., on the media and by authorities) to accelerate the sandbar breaching process.

Laguna de Rocha constitutes a feeding and reproductive area for important fish resources (Vizziano et al., 2002; Norbis and Galli, 2004) and for resident and migratory aquatic birds (Aldabe et al., 2009; Sarroca, 2008). Therefore, it is included in the MAB-UNESCO Reserve "Bañados del Este" and since 2010 belongs to the National System of Protected Areas (SNAP) under the Protected Landscape category. Since its inclusion into SNAP, the area is co-administered by the local provincial government of Rocha (IDR) and the National Environmental Agency (DINAMA). A Director working with four rangers heads the management of the area. An Advisory Local Committee (CAE) has been installed, according to the mandate of the Protected Areas National Law, which is constituted by local and national governmental institutions, landowners, farmers, fishermen, and other local stakeholders (e.g., tourism sector). Although the CAE was formally installed in 2010, its members have been meeting for more than a decade to discuss and bring diverse environmental problems of the area to advising authorities, which represents a major advantage in the process of building consensus on the artificial opening of the sandbar. Presently, the Management Plan of the protected area is being considered for legal approval by national authorities, which includes a system for decision making for the sustainable management of the sandbar, derived from this research.

The breaching of the sandbar is performed by the local government (in coordination with DINAMA) to (1) avoid flooding of cattle-raising fields, (2) avoid floods in urban zones located on the floodplain of the lagoon and streams and in Rocha city, and (3) favor fisheries in the lagoon, which depends on the entrance of larvae and juveniles of several species from the sea. Nevertheless, there is no long-term assessment of the benefits of this management practice both on mitigating these problems and on the impact of the hydrological modification on ecosystem health. The sandbar manipulation has always been under discussion by stakeholders, but especially between two main groups: one group made up of landowners and local authorities (landowners raise cattle on the floodplain and exert pressure on authorities to open the sandbar); and the other group made up of conservationists, researchers, and some fishermen, who understand that the flooding process is part of the lagoon ecosystem dynamics and are therefore concerned about the ecological impact. Several artificial openings had apparently positive effects on fisheries (e.g., shrimp; N. Norbis, personal communication), while others had negative consequences, mainly when conducted close to summer, when the refilling of the lagoon is slower and the sediments and wetlands are exposed for several months. In many cases fishermen and researchers questioned the site selected to dig the channel on the sandbar, while on other occasions the opening was mechanically performed but insufficient water level or weather conditions closed the sandbar immediately.

More recently, discrepancy on the opening decision mechanism surfaced between both administrators of the protected area (IDR and DINAMA). Rangers pointed out that the water level to proceed to open the sandbar must lie above a certain threshold to ensure that the artificial channel dug by the machine effectively allows the discharge of water and sediments to the ocean. In other cases, the machine operator, depending on IDR, started the breaching processes without consulting the protected area director. In many cases the artificial opening was not discussed among the local and national authorities that administrate the protected area, adding confusion and tension to the management process. Furthermore, predictions of increasing risks driven by climate change adds more uncertainty to the whole discussion about the sandbar manipulation, mainly considering the potential expansion of coastal urbanization close to the sandbar of the lagoon.

DEVELOPING SOCIAL, HYDROLOGICAL, AND GEOMORPHOLOGICAL INFORMATION FOR DECISION MAKING

Sandbar Management and Stakeholder Perceptions on Sandbar Vulnerability

Laguna de Rocha is recognized for its natural and cultural values. Predominantly, its sandbar plays a central role in the socioecological balance of this environment, safeguarding its natural and cultural heritage. The intrinsic value of this fragile subsystem is crucial both from an ecological and social perspective, for example, for the sustainability of traditional fishermen communities established in the bar for many decades. The social perception of the environment is a complex mosaic of seeing, interpreting, and interacting with the environment, influenced by the particular links of people with coastal resources, the life history and permanence of these relationships, and the new knowledge they generate (Larson and Edsall, 2010). Understanding these perceptions as well as the diachronic and synchronic aspects of influential geo-historical processes, and their inclusion in management proposals for the area, will allow actions to be legitimized by local people (Shackeroff et al., 2011).

Management is an inherently human process and therefore it is essential, particularly in protected areas with a stable human population, to properly understand key socio-institutional processes and their impact on the socioecological system (Christensen and Krogman, 2012). Based on this perspective, local ecological knowledge is relevant, especially in situations where information gaps or lack of information do not allow researchers to reconstruct environmental changes (Berkes, 2009; Espinoza-Tenorio et al., 2013).

In this study, blending fishermen's ecological knowledge with the dynamics of the academic interdisciplinary work posed several challenges. For example, it was necessary to incorporate interpersonal skills that enabled a climate of communication and an open dialog to transcend disciplinary approaches and the dichotomy of academic versus local knowledge, with the aim of constructing a common knowledge focused on sustainable management (Armitage et al., 2009; Buizer et al., 2011; Hopkins et al., 2012). This approach provided higher robustness to our management proposals, which grew from diversity and cooperative reflections concerning the management of the sandbar.

Historical Strategies of Sandbar Use and Management

Given the relevance of social participation in biodiversity conservation and adaptation to climate change, especially in an area with a long history of stakeholder involvement, a systematization of sectoral interests that promote the artificial opening of the sandbar was primarily made at Laguna de Rocha, in an attempt to understand the decision process from a long-term perspective. For this, historical information on the traditional management of the sandbar made by local communities was collected, and an analysis of the current institutional mechanism of decision making was also performed. Criteria and attributes informed by stakeholders to consent to the artificial opening were also registered.

The methodological strategy consisted of a historical and documentary review on the management of the sandbar, its potential socioecological impact, and the identification of the main institutional stakeholders associated with the process. A representative sample of stakeholders was selected and 26 semistructured and structured interviews were conducted, which included most of the representatives on the CAE of the Protected Area. Field observations and open interviews with selected stakeholders were also performed. Based on this information, an analysis of the perceptions of the artificial opening was carried out, as well as geo-historical timeline analysis from 1920 to the present, describing major milestones and distinguishing transformations in the sandbar management process. We also identified diverse types of social networking between stakeholders, regarding their affinity with the opening of the sandbar and their influence on the decision-making process.

Human occupation in Laguna de Rocha area can be characterized by three stages, the first of which corresponds to the original settlement process (3000 years ago) until the colonial expansion (seventeenth century). The occupation pattern of the original colonizers corresponded to semipermanent and seasonal settlements on the paleoshore, medium and low hills, streams and coastal edge of the lagoon. Later, the colonial process imposed a clearance of the region, transforming the lagoon into an area of circulation. A second stage occurred between 1890 and 1950, when the modern settlement occurred. It was not until the early twentieth century that the permanent settlement of fishermen occurred in Los Botes port (northern area of the lagoon, on the main tributary) and in the sandbar of the lagoon. This period is characterized by the onset of agricultural and fisheries exploitation. A third stage (1950–present) is defined by the consolidation of the permanent settlement of the fishing communities and a more intense productive exploitation and housing development for tourism, mainly close to the sandbar area. A gradual process of institutionalization of the environmental management in the area started to occur later in this stage (Thompson, 2008).

Regarding the process of managing the sandbar, two periods can be distinguished, corresponding to second and third stages described above. The first is characterized by collaboration between local people, farmers, and fishermen, and scarce institutional influence. These artificial openings were executed under physical and technological conditions that produced little affect on the system, both spatially and on a temporal scale, given the time required to concretize the opening process, which better accompanied the natural processes, as well as the lack of excavating machinery in the process. In the second period, by the time that local institutions—namely IDR, the National Direction of Aquatic Resources (DINARA), and the Program for Biodiversity Conservation of Eastern Wetlands (PROBIDES)—became more actively involved in the process, the participation of fishermen in the management process was largely reduced, and the relationship between farmers and fishermen also weakened.

From that institutionalization onwards, the bottom-up character of the sandbar manipulation changed into a top-down process (Zagonari, 2008), progressively leading to an increased frequency of the artificial openings. Gradually, IDR attained more control in the decision-making process, but opening practices were still carried out without a technical monitoring and evaluation of their consequences over more than three decades. In 2011, after questioning by the CAE, a rudimentary protocol for the artificial opening, based exclusively on a water level criterion, was developed. It consisted of a virtual perimeter or limit around the lagoon, indicated by four marks in the floodplain set following an agreement between fishermen, farmers, and authorities. It represents a subjective limit between the nonflooding and the flooding condition, according to the perception of the local people. The protocol simply stated that the sandbar could be opened once the water level reaches the four marks.

Environmental Perception of Sandbar Vulnerability and Management

The perceptions of different stakeholders concerning the sandbar management were established based on three main dimensions: (1) changes and impacts (both positive and negative) generated by the artificial opening, (2) causes and conditions for an artificial opening to be made, and (3) the elements of conflict—or consensus—for developing a decision-making system for the opening (Table 13.1). Each of these dimensions is conformed by subdimensions collected from the interviews with stakeholders.

Regarding the identification of changes and impacts on the biophysical components over the last 30 years in Laguna de Rocha, some of these elements are described by most stakeholders as negative changes as a direct effect of the artificial openings, such as the location of the opening channel, the clogging of channels, and the decreased floodplain area. To a lesser extent, stakeholders also mentioned negative impacts on wetlands and pastures, as well as other changes that coincide with the intensification of artificial openings, but that cannot be

TABLE 13.1 Dimensions and Subdimensions Concerning the Management of the Sandbar of Laguna de Rocha, According to Stakeholder Perceptions

Changes and Impacts Attributed to the Artificial Opening
Decreased depth of the lagoon and channels
Changes of the breaching site
"Greening" of the bottom of the lagoon
Reduction of the floodplain area
Decrease in bird abundance
Increase of extreme weather effects
Increased grasses on dunes
Reduced size and abundance of fish species
Increased abundance of siri crab
Loss of marshes
Loss of natural pastures
Main Reasons for the Artificial Opening
Flooding: human risk
Flooding: loss of productive areas for cattle-raising
Entrance of coastal shrimp larvae
Variables Influencing the Decision-Making System for the Sandbar Opening
Arbitrariness in the decision making
Excessive bureaucracy
Lack of technical and scientific information
Protection of private property

explained straightforwardly, such as decreased bird populations or increased populations of blue crab (*Callinectes sapidus*). Most fishermen and other permanent residents, except most cattle farmers, emphasize both the impact on fisheries and on the physical structure of the lagoon (e.g., soil characteristics, depth and area of discharging channels) as consequences resulting from frequent artificial openings inadequately performed.

Concerning the causes for the artificial opening to be authorized, stakeholders mainly argue productive reasons (e.g., negative impact of flooding on livestock, or reduced shrimp harvest) when the lagoon is closed), as well as the impacts of flooding on the human population around the lagoon (i.e., urban and suburban flooding). Flooding of housing was basically the most sensitive element that justifies the artificial opening among consulted people. While the causes of urban flooding are not directly or only associated with a closed sandbar condition but also with inadequate urban planning (especially in capital Rocha city), the local perception is that the cause is based on the status of the sandbar (i.e., closed) (this topic is further addressed in Section Evolution and Functioning of the Sandbar). Notably, several stakeholders showed a preference for the lagoon and the sandbar to behave naturally from a hydrological standpoint, that is, without human intervention for artificial openings. This perception is associated with an expressed need to restore a system that has been negatively impacted by the artificial openings in the long term. An argument for this, especially among fishermen and researchers, is that a ban of the artificial opening, even partial, would facilitate the restoration of natural processes and an understanding of how the system works without intervention.

Finally, several elements were identified as key factors that promote consensus for the artificial opening decision-making system (e.g., sound information) or those that generate conflict to reach agreements (e.g., arbitrary decisions, bureaucracy in the decision process, or respect for private property). Arbitrariness is still perceived as a problematic factor in the sandbar management. On the other hand, there is full consensus that the opening decision system has to be firmly based on technical and scientific criteria. Also, it is worth noting that the CAE is unanimously recognized as the most appropriate space for building consensus and agreements to manage the artificial opening.

There was also consensus among stakeholders in supporting the initiatives of the Direction of the protected area concerning these topics. This explicit support is evident both from the interviews and from the analysis of the relationships between stakeholders and their affinity and influence concerning the artificial opening (Figure 13.2). This analysis shows that the Direction of the area has strong linkages with most of the stakeholders but particularly with all those who have less affinity for the artificial opening. Moreover, the Direction of the protected area significantly helps keeping links and permanent communication between stakeholders. On the other hand, the local government shows leadership for the artificial opening of the sandbar, both for their legal competences and for establishing stronger relationships with those stakeholders with

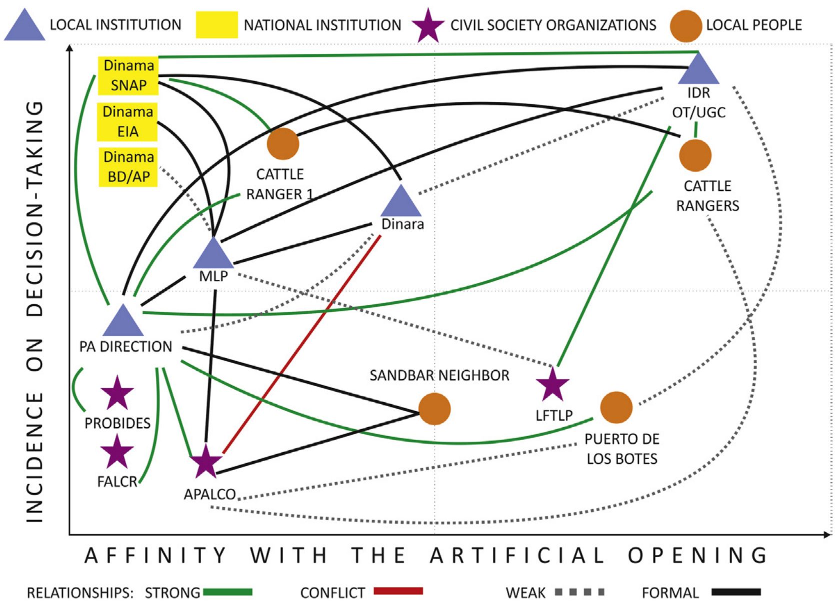

FIGURE 13.2 Laguna de Rocha stakeholder mapping, showing the individual influence on decision making (vertical axis) and affinity concerning the artificial opening of the sandbar (horizontal axis), as well as the relationships among stakeholders (indicated by different types of lines). Geometric symbols indicate stakeholder sectors. Abbreviations: DINAMA (National Environmental Agency, with three offices); SNAP (Protected Areas); EIA (Impact Assessment); BD/AP (Biodiversity); PA Direction (Laguna de Rocha protected area Director and rangers); PROBIDES (Program for Biodiversity Conservation of Eastern Wetlands); FALCR (Friends of Coastal Lagoons Foundation); MLP (Municipality of La Paloma city); APALCO (Fishermen's Association); DINARA (Aquatic Resources National Agency); LFTLP (League for Promotion and Tourism of La Paloma city); IDR OT/UGC (Rocha provincial government, with two offices; OT (Land Planning); UGC (Unit of Coastal Management). Other group stakeholders include fishermen in Puerto de los Botes settlement (PUERTO DE LOS BOTES) and cattle rangers or farmers (CATTLE RANGERS). Individuals with particular roles in the area include a cattle ranger (CATTLE RANGER 1) and neighbor (SANDBAR NEIGHBOR). (More details are given in Section Environmental Perception of the Sandbar Vulnerability and Management.)

higher affinity for the opening. This is partially balance by the role played by DINAMA, the other administrator, with low affinity for the opening but high influence on the decision making. Other stakeholders have a variety of opinions about the opening, but most of them have low influence on the decision.

Hydrological Dynamics of the Lagoon and Determination of Flooding Areas

The basin of Laguna de Rocha extends from the hilly area North of Rocha city down to the mouth in the Atlantic Ocean. The concentration time of the basin, based on the formulation of Ramser–Kirpich (Chow et al., 1994), is

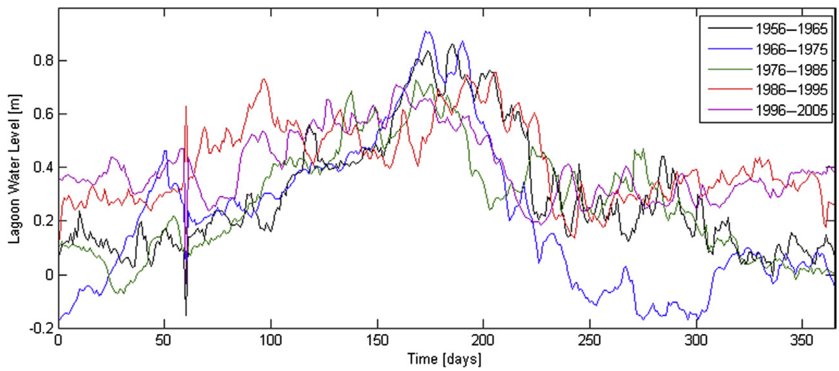

FIGURE 13.3 Mean daily water level (m) in Laguna de Rocha, estimated for five different 10-year periods from 1956 to 2005. *Data from MTOP.*

14h. Consequently, it is expected that in less than a day the lagoon receives the water runoff generated in its basin after an extreme precipitation event. In order to characterize the hydrological dynamics of the lagoon, we analyzed the available water level data from the period 1956 to 2005 (from the Ministry of Public Works, MTOP) recorded daily every 8h. Water level exhibited a significant inter- and intra-annual variability that essentially corresponds to the variability characteristics of Uruguay concerning monthly precipitation, but also due to the variability of the sandbar openings. Openings, both natural and artificial, occur at levels between 1.10 and 1.75m above the Official Zero (OZ) and produce sharp declines of the water level inside the system (Figure 13.3) (The Official Zero is an official reference defined as the average water level in the Port of Montevideo).

The empirical cumulative distribution function of the water level in the lagoon is presented in Figure 13.4, highlighting the value 0.87m (88% non-exceedance probability), which corresponds to the legal public demarcation of the lagoon limits, according to national regulations. The data show that in 72% of the 50-year series, the maximum water level commonly occurs in winter, a fact that is confirmed by applying a hydrological monthly balance (UNESCO, 2006) to the system, based on precipitation data, evaporation, and bathymetry of the lagoon under closed bar conditions. In Figure 13.3, the evolution of the average daily water level in decadal periods can also be observed. The general hydrological behavior of the system involves the superposition of two processes, one on a seasonal scale and another one on a daily scale. The seasonal process corresponds to the increase in water level of the lagoon toward the final months of summer and autumn, until during the winter the lagoon presents its highest water levels. Then, the opening of the sandbar occurs (data not shown), decreasing the water level of the lagoon. Superimposed with this process, if an extreme rainfall event can significantly increase the water level of the lagoon, the opening of the sandbar may also occur outside winter—even during summer. This process occurs on a daily scale. The proposed model describes the

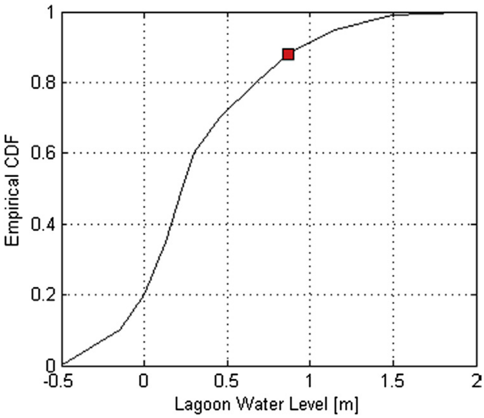

FIGURE 13.4 Empirical cumulative distribution function (CDF) of the water level (m) in Laguna de Rocha. Water level of 88% nonexceedance probability is highlighted (red square dot), corresponding to 0.87 m, that is, the limit of the legal public demarcation of the lagoon.

global behavior of the system, considering only the continental variables but not the effects of the incident sea waves on the sandbar.

In order to characterize the flooded areas surrounding the lagoon and the water retention in both public and private lands, a detailed topographic survey was conducted in selected areas (see location in Figure 13.1). With this information, a digital topography model was developed and the flooded areas were established for different water levels in the lagoon, further discriminating between public or private areas, according to the limit level of 0.87 m. The average duration of flooding in each area is given by integrating the flooded areas with the empirical cumulative distribution function of the water level in the lagoon (Figure 13.4). The results of the flooded areas for three zones of major interest are shown in Table 13.2. The result show that in all areas, the water level that can cause a natural opening floods a much higher proportion of public than private lands. For zone 1, for example, which represents one of the most critical areas because of its flatness, an opening at 1.49 m OZ floods 23% private lands, while the remaining 77% of the flooded area is public.

The effect of the water level in the lagoon on the water flow of the main tributary (Rocha stream in the Rocha city area) was preliminarily assessed based on the available hydrologic information, in particular on two bridges on the western margin of Rocha city (Estiba and Paso Real). A simplified hydrodynamic model was implemented based on the free software HEC-RAS 4.1 (U.S. Army Corps of Engineers), between the sandbar of the lagoon and a section located 5 km upstream of Rocha city. The model solves equations for free-surface flows by numerical methods based on finite differences, and in this case the modeling was performed in steady-state mode, considering the upstream flow and the level at the sandbar as the boundary conditions.

Three flow scenarios (700, 350, and 5 $m^3 s^{-1}$) were considered. These flows correspond to the maximum flow of an extreme precipitation event in the basin associated with a 100-year return period, an estimate of the base flow in the watershed, and an intermediate value of both. The selected water levels in the

TABLE 13.2 Quantification of Flooded and Nonflooded Areas for Different Water Levels in Laguna de Rocha. Results for Zones A, B, and C (Shown on Figure 13.1) Are Included, Discriminating Between Public and Private Areas, According to the Legal Public Demarcation of the Lagoon Limits (i.e., 0.87 m).

	Zone A		Zone B		Zone C	
Water Level (m)	Flooded (ha)	Nonflooded (ha)	Flooded (ha)	Nonflooded (ha)	Flooded (ha)	Nonflooded (ha)
0.35	14.78	271.6	24.4	148.5	23.0	70.6
0.87	183.8	102.6	120.9	51.9	68.6	24.9
0.93	200.7	85.6	130.8	42.0	71.7	21.9
1.15	225.7	60.6	149.1	23.65	81.6	11.8
1.49	238.8	47.5	166.8	6.0	84.6	8.9
2.0	256.2	30.1	172.8	0	87.3	6.3

TABLE 13.3 Results of the Hydrodynamic Modeling of Rocha Stream Water Levels in Two Sections (Estiba Bridge and Paso Real), According to Selected Water Levels in Laguna de Rocha (1 and 4 m). Water Levels Are Referred to the Official Zero (See Text for Explanation). Three Flow Scenarios (700, 350, and 5 $m^3 s^{-1}$) Are Modeled

Flow ($m^3 s^{-1}$)	Estiba Bridge (m)	Paso Real (m)	Lagoon Level (m)
700	10.39	9.50	1.0
700	10.39	9.50	4.0
350	9.57	8.71	1.0
350	9.57	8.71	4.0
5	6.36	5.61	1.0
5	6.36	5.61	4.0

lagoon were 1.0 and 4.0 m, the latter being a magnified value to test the hypothesis of no influence of the lagoon levels in the flooding of Rocha city. Solving the six scenarios that arise from the combination of the boundary conditions given above, the results of the water level in Estiva bridge and in Paso Real are presented in Table 13.3. Despite not having detailed cross-sectional information for this stream segment, all information led to the conclusion that there is no influence of a variation of up to 4 m of the water level of Laguna de Rocha on the water levels upstream, in both sites analyzed in the Rocha city margin.

This conclusion is relevant for sandbar management, since there is a local widespread tradition that erroneously states that when Rocha city is flooded by Rocha stream after extreme precipitation events, if the sandbar of the lagoon is closed, flooding is more intense and lengthy in the city. This has subsequently led to more intense pressure by Rocha city inhabitants on the local government to open the lagoon artificially as a way of supposedly reducing the flooding event in the city. This modeling proved that there is no reason for this conduct to be sustained in the future.

Understanding the Natural Opening and Closing Dynamics of the Sandbar

At the site of the present opening of the sandbar there are two processes that can lead to natural openings: (1) opening from the lagoon, produced when the level in the lagoon exceeds the berm crest elevation in the sandbar; and (2) opening from the ocean, caused by the combined action of high sea and heavy swell. From the available wave data based on re-analysis (Alonso, 2012) of sea level for the period 1912–2012, water levels in the lagoon (1956–2005 series from MTOP) and from DINAGUA (National Water Agency) records concerning opening and closing of the sandbar, we proceeded first to identify and characterize situations in which the opening was produced. Then, according to sea level and wave height data, we estimated the level up to which the berm at the sandbar can grow by wave effect, using the model of Horikawa and Maruo (2011). The probability distributions of the expected berm level on the short and medium term in the lagoon bar, obtained by the two above methods (DINAGUA records and Horikawa model), were very similar (Figure 13.5). In both cases the mode of the distribution lies between 1.10 and 1.49 m OZ.

Then, the effect of a wave storm over the beach profile was modeled. For this, four different berm crest elevations were used, corresponding to quantiles 10%, 50%, and 90%, and a berm crest elevation representative of a recent closure of the sandbar of the lagoon. This simulated storm event corresponds to a 72 h severe condition, with significant wave height of 4.5 m and maximum sea level of 1.1 m OZ. For the simulation, bathymetric and granulometric information of the beach area was used to construct a characteristic profile transverse to the sandbar under closed conditions. The results indicate that the sandbar can

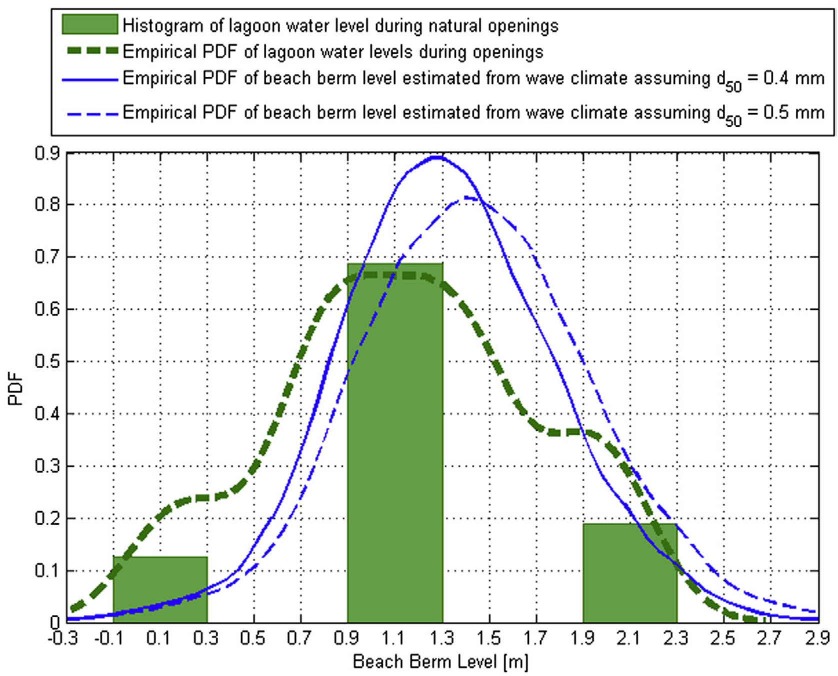

FIGURE 13.5 Empirical density function probability (PDF) estimated from berm elevation data obtained from Laguna de Rocha water level during natural openings (green) and from wave climate (blue). d_{50} is the average size of the beach sediment, used to estimate the height of the berm according to the wave climate.

be opened by sea action only if the elevation of the beach profile is very close to sea level, which is coherent with recent closing conditions.

In addition, the littoral sediment transport was estimated for the zone of the coast where the mouth of the lagoon is located. To do so, all sea states of the wave series were propagated from intermediate waters to the breaking zone, using Snell law (Dean and Dalrymple, 2002) and the breaking criteria of Thorton and Guza (1983) for irregular waves. Once the significant wave height and the breaking direction were determined, the littoral transport for each state was estimated, using the formula of CERC (U.S. Army Corps of Engineers, 2002). The net littoral transport in the sandbar area of Laguna de Rocha was zero for all practical purposes when compared to the gross longshore transport. The gross transport rate was on the order of 3 million $m^3\,year^{-1}$ (i.e., 360 $m^3\,h^{-1}$), so there is a strong potential to close the sandbar as soon as the discharge channel of the lagoon loses the capacity to clean sediments out of the system.

The results obtained considering the expected berm elevation, the erosion of the beach profile, and the coastal sediment transport show that the predominant opening mechanism of the sandbar occurs when the level of the lagoon exceeds the berm. A conceptual diagram of the natural opening and closing mechanism of the sandbar, based on the hydro-sedimentological behavior of the system, is presented in Figure 13.6, showing that the water level of the lagoon produces

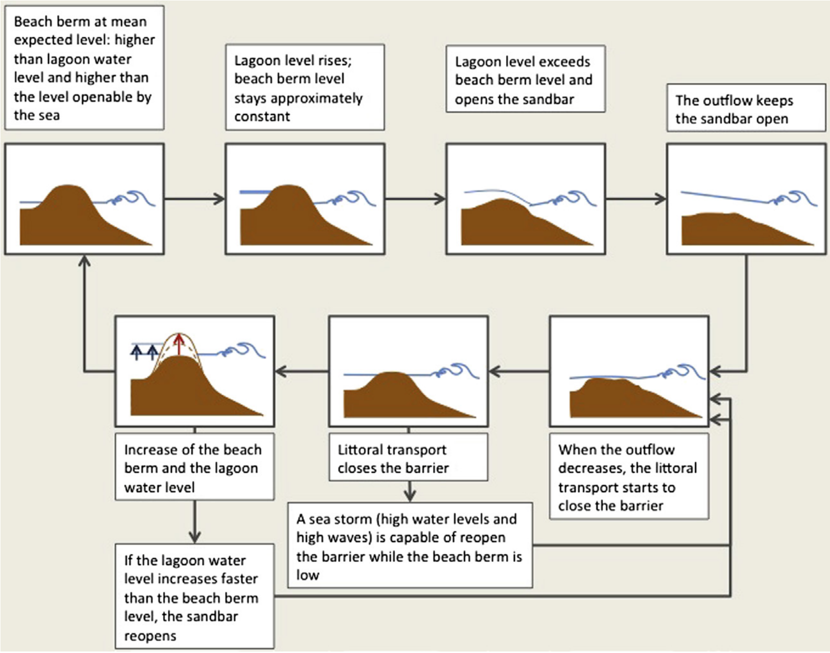

FIGURE 13.6 Conceptual diagram of the dominant opening and closing natural mechanisms operating at Laguna de Rocha sandbar (see text in Section Understanding the Natural Opening and Closing Dynamics of the Sandbar for explanation).

the breach of the berm and subsequently the water discharge to the sea occurs. After the mouth's closing by coastal sediment transport, and while the level of the berm is low, the sea can break the berm, creating temporary connections with the sea, which are again closed by the longshore transport. However, when the berm grows significantly, the sea loses its overtopping ability and under this condition only high water levels inside the lagoon can produce an opening.

Geomorphology and Vulnerability of the Sandbar

From a geological viewpoint, coastal lagoons are ephemeral environments, frequently evolving to fluvial or tidal dominated environments (Duck and da Silva, 2012), especially where human action has triggered major physical changes and deterioration. Due to their intrinsic ecological fragility, knowledge of their structure and functioning is key to facilitate risk assessments, model scenarios, and for their sustainable management. This research sought to understand the evolution of the sandbar subsystem of Laguna de Rocha (Figure 13.1) and to analyze the appropriate conditions for hypothetical artificial openings. The previous available information suggested that this sandy bar would be a relict of Pleistocene deposits shaped during the past 10,000 years (Preciozzi et al., 1985; Heinzen et al., 1986), with a relict area of closure at the Northeastern end known as "barra vieja" by local people (zone 2 in Figure 13.1). In order to confirm this hypothesis, a study including photointerpretation, detection of temporal changes, exploratory surveys, and sediment analysis was performed. The study had a transdisciplinary context by merging the expert knowledge with knowledge of local people, based on joint working sessions with key informers. Photointerpretation and digital image processing included image georeferencing and orthogonalizing, images change detection analysis (1943–2011), geomorphological and geological interpretation, digitization of thematic layers, and the design of a geological map. Satellite imagery included sensors CBERS-2B-HRC (2007–2010), QuickBird multispectral (2004, 2007, 2008, 2009), and panchromatic and multispectral WorldView I (2009–2011) and II (2010–2011). In addition, aerial photographs from the Military Geographic Service (SGM; 1943, 1967) and the Uruguayan Air Force (from 1986) were used.

Overlapping and combining spectral bands on a temporal sequence of images, we examined changes in the evolution of the sandbar. Baseline information on the stratigraphy and sedimentary sequence was complemented by conducting surveys, geological cross-sections, and interpretation of geoelectrical profiles. A mineralogical analysis of sands was also performed (600 X). Absolute and relative dating was addressed through the analysis of the relative luminescence response in 10 sand samples from the sandbar by infrared and temperature stimulation (IROSL and TL). Samples were collected in surveys ~40 cm deep, performed in the lower portions of inter-dunar areas, which are considered the oldest elements of the subaerial environment of the sandbar. Luminescence analysis was complemented by dating peat through the carbon-14 method. Bathymetric and precision altimetry data were also used. A detailed bathymetry of the lagoon and the marine area of the lagoon's mouth was also performed with centimeter accuracy.

Evolution and Functioning of the Sandbar

In general, we obtained consistent results between the remote sensing study, the mineralogy, the IROSL/TL and the carbon-14 analysis, the bathymetric and the altimetry survey, the analysis of the historical information, and the local ecological knowledge. All results indicate that the sandbar that separates the lagoon from the ocean consists of a recent sedimentary sequence formed by a series of sand ridges originated on the littoral drift and remobilized by wind above the water table. The fine sand fraction in the bar showed a more diverse mineralogy than the lacustrine samples, its luminescence was low, and its edaphic differentiation was confined to a very limited translocation of quartz silt. Survey in the sandbar also showed the presence of thin lenses of lacustrine gray muds.

We originally hypothesized that the "barra vieja" zone was a relict area where the lagoon connected with the ocean in the past. Nevertheless, this hypothesis was rejected because of the identification of areas with evidence of relatively recent ingress of sea waves into the lagoon, as well as zones of low depression (close to sea level) clearly corresponding to opening channels of the lagoon during the Holocene epoch. In particular, one depression was located about 800 m distant from the area of the current opening of the lagoon, which was registered in pictures from 1943 with evidence of hydraulic percolation (Figure 13.7(c)). Given this information, the new operating model of the sandbar system considers that while "barra vieja" served as a site of connection with the sea in the last 2660 ± 50 years (according to carbon-14), the whole connection process was governed by multiple, and probably synchronous, openings until late 1930–1940, both on the western and eastern extremes of the sandbar. This would indicate that the dynamic opening mechanism that can be observed today is very recent, that is, less than 100 years old.

Geomorphologically, the evolution of the sandbar opening mechanism can be explained by sediment transported by wind and by wave action under a regimen of multiple ocean–lagoon exchanges, where the dominance of the relationship marine/eolic energy has incremented in relation to the hydraulic lacunar energy, as major forces of change in the dynamic equilibrium of the system. This evolution toward the current situation can be explained by the interaction of three forces: eolic, marine, and hydraulic, which are described next.

The marine regression occurring during the last period of the Holocene epoch shaped large plains around Laguna de Rocha, which were frequently waterlogged. Under these conditions, the formation of peat soils by deposition of sediments and plant biomass took place. During dry periods like the one known as the "bonariensis little ice age," about 300 years ago (Rabassa et al., 1984), and probably from 3500 and 2500 years ago (Bracco et

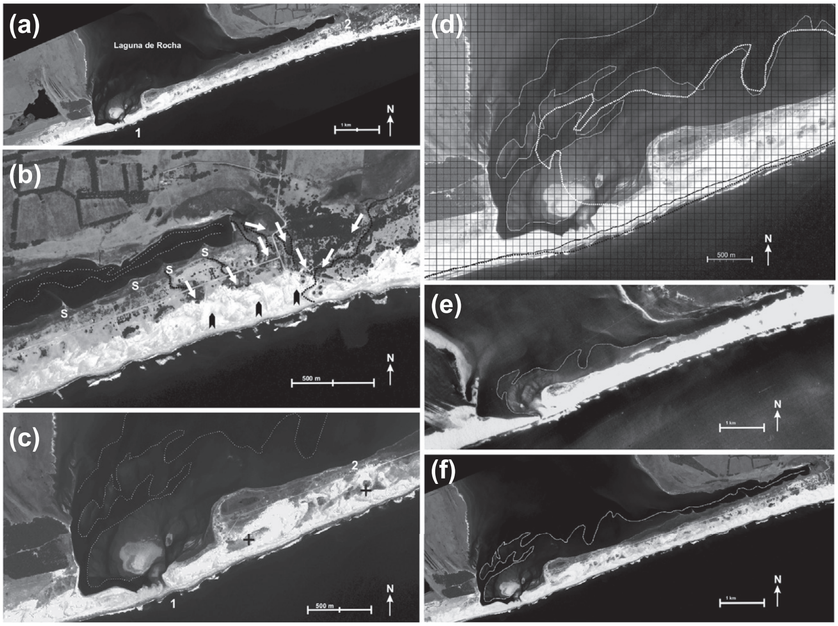

FIGURE 13.7 Details of the Laguna de Rocha sandbar system, based on satellite image WordView II (15/11/2011). Dunes with scarce vegetation (i.e., higher kinetic potential) are shown in whitish tones. (a) Numbers indicate different opening areas of the lagoon (1, current opening zone; 2, a relict area ("barra vieja"). (b) White arrows indicate slopes into streams and creeks (black dotted lines) corresponding to some of the last opening areas; black arrows indicate remnant areas with evidence of seawater intrusion (kidney-shaped forms, corresponding to flooded depressions with emerging water table); S indicates sand ridges formed by internal waves in the lagoon. (c) Soils with level similar to sea level (+ symbols), which correlate with relict openings. The first mark is situated ca. 800 m from the present opening zone. The dotted white line inside the lagoon indicates the limit of the silty-sandy bank with depth less than 1 m, limiting the deeper channels. (d) Movement of sand banks inside the lagoon toward the west are shown (1966, dotted line; 2011, continuous line). On the marine side of the sandbar, the receding shoreline is also shown (1943, dotted black line; 2011, solid black line). The grid side is 50 m (satellite image WordView II—15/11/2011). (e) A detail of the 1943 image (SGM). (f) A detail of the 2011 image (WordView II).

al., 2011), the material supplied from the sea and the existence of plains generated favorable conditions for the formation of a mobile dune system with different types of evolution, complexity (Barnes, 1980; Carter and Woodroffe, 1997), and conditions for confining water bodies. These coastal lagoons originated through this process, by damming caused by dunes, which were mobilized by wind action according to the direction of the prevailing winds. In Uruguay, the estimated age for the origin of the mobile dune systems is between 4000 and 4500 years ago (Piñeiro and Panario, 1993). For Laguna de Rocha sandbar, both the IROSL and TL analysis as well as the sediments surveyed indicate the evolution of a system of mobile bark-haan dunes across the current sandbar, generated from sands of marine origin.

Simultaneously to the formation of the sand dune system during the last period of the Holocene epoch, there also occurred transport and deposition of sands in submarine banks and beach berms by longshore drift currents and waves. Until the early 1900s (after the "bonariensis little ice age," with prevailing winds from the west), the net transport probably had a northeastern direction, filling up with sand the area of "barra vieja" and making less frequent the possibility of opening in that zone. This can be revealed by direct testimonies of a higher opening frequency during the past century in the western sector (opposite to "barra vieja") but still keeping an area of less frequent opening in the northeastern sector. Over the long term, sediments carried by waves took a predominant direction westward, as evidenced by the sandbar structure (Figure 13.7), the trend of sand grain size, and the east-to-west evolution of a dissipative beach toward an intermediate reflective one. The presence until the present of a parallel channel in the interior of the lagoon along the whole sandbar indicates that this area has the potential of opening if extreme marine conditions and high hydraulic pressure from the lagoon prevail simultaneously. Marine sand spits in the interior of the lagoon associated with semipermanent small water bodies and flooded depressions on the sandbar, close to the present sea level, correlate well with local people's knowledge of marine ingressions by waves during high-energy events (overwash) until the end of the 1930s and early 1940s.

The hydraulic pressure of the lagoon water body on the sandbar, besides its relevant role in the opening mechanism, is also a significant process concerning the water soil saturation and the elevation of the water table in that zone. Water saturation of the sandy sediments of the bar reduces the dissipative capacity against sea wave action by decreasing the permeability of the substrate, facilitating the penetration of sea waves in low-lying areas, especially in depressions between dunes. Furthermore, in this latitude extreme rainfall events are associated with an increase of the sea level (i.e., storm surges), strong southern winds with extended fetch (~50 km), and high wave energy, adding up to produce a greater effect on the sandbar structure.

Impact of the Artificial Opening on the Dynamics of the Sandbar

Diverse disturbances caused by human activity act on the sandbar of Laguna de Rocha, with enormous implications for management (e.g., construction of roads and houses, afforestation with exotic species, off-road traffic). However, the deliberate artificial opening of the sandbar stands out as one of the most severe physical and ecological threats. Our results demonstrate that this disturbance has introduced during the last decades a new dynamic equilibrium to the system and has defined new attractors that could generate nonreturn points to predisturbance conditions. One of the key changes was the gradual change of opening mechanism, where the traditional manual opening (using shovels to dig a channel) done by fishermen and other local people has been replaced by excavating machinery, the current opening method. This technological change has enabled openings in conditions that would not be possible by more traditional procedures. For example, mechanized openings have been performed in inappropriate places and beyond optimum conditions, like low hydraulic potential of the lagoon, which does not allow water and sediment to flow out to the sea, favoring the development of internal banks.

There has been an extensive growth of internal banks and the gradual filling up of the lagoon channels, especially close to the opening area (Figure 13.7(c)–(f)). In the past 10 years, this area has been progressively transformed into a tidal delta type structure, where the marine energy prevails as well as the inward flow of marine sands. Since 2003, these banks have generated a threatening positive feedback that makes more difficult the evacuation of sediments due to the decreased depth of the lagoon. Probably, the long-term result is the evolution of the lagoon to a coastal wetland type of environment, as occurred elsewhere (Carter and Woodroffe, 1997). Images change detection analysis showed a correlation between growth and translation of internal banks with the regression of the coastline (Figure 13.7(d)), which reached over 80 m in the opening area between 1966 and 2011. This type of regression has been also reported in other estuaries of the Uruguayan coast (Panario and Gutiérrez, 2005). Therefore, the information on changes in the dynamics of the natural opening and the reported impacts from the 1900s to the present suggest an increase of the marine energy relative to the hydraulic energy of the lagoon, mainly attributable to the fact that over the past 30 years the lagoon has been mechanically open far from the optimal natural conditions.

A CONSENSUAL DECISION MODEL FOR THE ARTIFICIAL OPENING OF THE SANDBAR

The outcomes of this study prompted us to develop a series of technical and management recommendations, hierarchically ranging from (1) a complete ban of the artificial opening, to (2) a partial ban of the practice, and finally to (3) a multidimensional decision tree for the artificial opening.

Primarily, considering all available information on the sandbar functioning, collected or derived from this study, our research team suggested IDR and DINAMA authorities and the CAE give a central recommendation consisting of fully avoiding artificial openings of the sandbar of Laguna de Rocha, given the character of the protected area. This advice is based on the potential long-term impacts that this practice would have on the hydrology and on ecological and ecosystem processes of the lagoon (Rodríguez-Gallego et al., 2010, 2013), as well as on the international experience on this matter (see Section Introduction). In fact, we basically recommend the reestablishment of the natural connection of the system with the ocean, with the conviction that the natural hydrology is the optimal controller of the ecosystem functioning and quality (e.g., by discharging the excess of nutrients, pollutants, and sediments). It has to be emphasized that this general suggestion is not novel, since several research and conservationist groups operating in these coastal lagoons for more than two decades have been permanently informing authorities and local stakeholders about the threat that the practice represents to these highly vulnerable ecosystems (Conde and Rodriguez-Gallego, 2002).

If a complete ban of the artificial opening is not possible to implement in the short term, mainly due to the social pressure experienced by the protected area administrators, our team alternatively recommended maintaining a three-year period without artificial openings. To our understanding, this period would probably allow (through the occurrence of several natural openings) the reconstruction of the principal discharge channel along the main axis of the lagoon, the recovery of an adequate depth in the channel for the water and sediments to be released, and the sand dunes of the bar to be recovered, reestablishing the optimal conditions for a natural connection in the site where the discharge can take place with the highest energy. This partial ban would also make it possible to monitor the functioning and the evolution of the system without artificial manipulation, which has never been done until now. Moreover, researchers will be able to compare both management modes and make sounder recommendations on the best options for the artificial manipulation.

Although we do not consider the artificial opening a sustainable environmental practice, since technical advice is not always politically realistic to be implemented, in case the previous recommendations cannot be applied we have developed a multidimensional decision-making model concerning the artificial opening. The practical purpose of this model is to help those who have to make the decision about when, where, and how this can be done in the best way possible, based on the current decision procedure (the four marks indication; see Section Historical Strategies of Sandbar Use and Management) and upon relevant information obtained during this research.

The uniqueness of the new model is that it is not merely based on the water level criteria (as it has been until now), but also on geomorphological criteria as well as on weather conditions. The final aim of the model is to reduce to a minimum the number of times the lagoon is artificially open along an annual cycle, including the possibility of not opening at all if criteria are not met. Several dimensions and criteria covering various relevant aspects of the opening mechanism guarantee that the new decision system is highly restrictive in comparison to the previous one. The rationale behind the proposed model is that there is evidence of severe impacts if indiscriminate openings take place in this protected and vulnerable site; therefore they must be kept to a minimum, and approved and performed only if diverse technical criteria are fully met.

Here we only present the decision system developed to decide when an artificial opening can be authorized, given that this is the most critical and challenging aspect of the whole problem. This decision tree, and a protocol of good practices, were consulted and adjusted several times with the protected area Director and the rangers, with managers from IDR and SNAP/DINAMA, as well as with the CAE and other stakeholders. The consensus accomplished was only possible due to the already stated tradition of stakeholders of addressing environmental local issues through active and egalitarian participation.

The new model (Figure 13.8) is basically a simple decision tree designed to be easily understood by administrators, rangers, and by the local people as

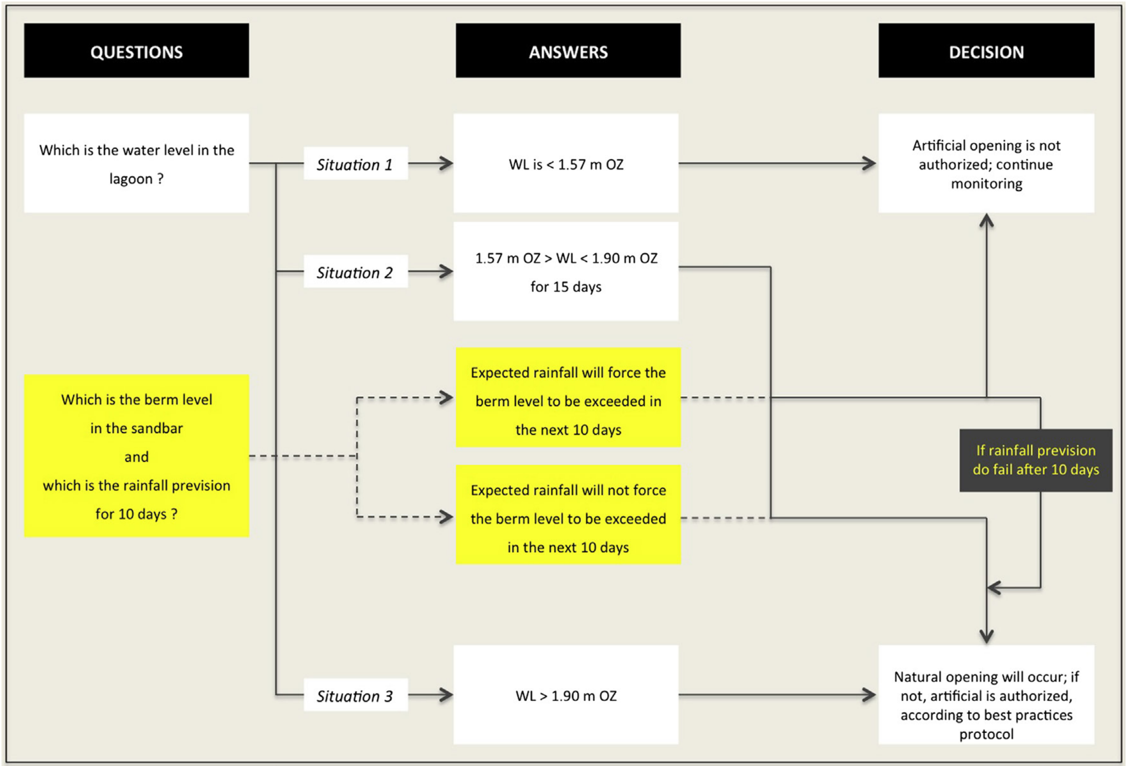

FIGURE 13.8 Proposed decision-making model for the artificial opening of Laguna de Rocha sandbar (see text in Section A Consensual Decision Model for the Artificial Opening of the Sandbar for a detailed explanation). WL, water level.

well. The tree is guided through a series of intuitive and straightforward questions, starting by assuming the lagoon is not connected with the ocean, but a progressive increase of the water level is taking place. Specifically, the first and leading question refers to the water level of the lagoon, which triggers the following steps and questions in the protocol, depending on the flooding situation observed.

Situation 1

If the water level has not attained the four marks already agreed by local stakeholders (which approximately indicate the legal delimitation of the lagoon, i.e., 1.57 m OZ), then no action is taken, because it is considered that the water level is not enough to allow an artificial opening, but mainly because the volume of the lagoon is still well below the limit of private lands. Also, under this situation, the perception of people is that no flooding is still occurring. A continuous daily to hourly monitoring has to be performed by rangers, especially when the water level approaches the marks.

Situation 2

The water level of the lagoon is higher than 1.57 m OZ, but lower than 1.90 m OZ, for up to 15 days (on a continuous series or accumulated). The value 1.90 m OZ represents the maximum water level observed in one of the artificial openings in 2013 (June). Although stakeholders perceived that this artificial opening was performed with a high water level, it did not significantly affect houses or other infrastructure, and did not generate major conflicts in the decision-making process, although being a water level very close to the water level required for a natural opening.

Nevertheless, this flooding situation (range from 1.57–1.90 m OZ) can still produce persistent flooding of cattle-raising fields, some interferences with housing in the floodplain of the lagoon, and a generalized social perception of the need of an artificial opening of the lagoon, thus prompting pressure on authorities and managers to artificially manage the sandbar. Positively, this water level range will trigger an alert to managers, so they can start preparing conditions to perform the artificial opening if the water level continues to rise or keeps more than 15 days in the reported range.

Once this period of time is achieved under the same flooding situation, the second and third questions come in, concerning the rain forecast and the height of the berm. The motive to include these criteria is that if a rainfall event is expected to occur in the basin in the next 10 days, and the water level, due to the rainfall effect, is estimated to be exceeding the height of the berm in the sandbar, then there is no reason to make an anticipated artificial opening, because it is highly probable that the natural one will occur anyhow, once the berm is crowned. In contrast, if the rainfall prevision is low (or if the berm is too high), then the artificial opening makes sense, but only if the other criteria (water level higher than 1.57 m for 15 days, plus 10 days of rainfall prevision) were already achieved. A specific protocol has been designed to estimate, for a given expected rainfall in the watershed, the expected water level in the lagoon, to be able to know if the berm will be overtopped (not shown here).

If after a period of 10 days, estimations that the berm will be exceeded fail, the opening can also be performed. It is assumed that the beneficial ecological processes associated with the flooding period can be properly achieved during the potential accumulated time (from 15 to 25 days).

Situation 3

If water level in the lagoon reaches 1.9 m OZ it is assumed that the sandbar will open naturally, so no action except monitoring has to be taken.

Nevertheless, if for any reason the natural connection does not occur after a prudent time once the 1.9 m OZ is achieved (e.g., 1–2 extra days), the lagoon can be artificially opened. In this case, a rapid response has to be taken, to avoid extreme flooding of fishermen's houses or other areas, which can occur in few hours if rains are persistent and the lagoon is closed. This situation was observed during the second artificial opening conducted in 2013 (in August), where water level increased from 1.9 to 2.17 m during the night (less than 12 h). Even if no risks for human safety were observed, fishing gear and other houses located in the sandbar were partially damaged. Although the recurrent period of flooding achieving a water level of 2.17 m OZ is 5–10 years, it is suggested that correct land planning in this lagoon should strongly promote the migration of littoral houses to safer places or to promote a modification to different building typologies (e.g., pile-dwelling).

In all cases, the artificial opening is to be performed by applying a best practice protocol specifically, which includes a precisely explanation of all variables and steps to be taken for the artificial opening procedure. This includes how and where the water level of the lagoon as well as the berm height must be measured, and an explicit methodology to determine if an expected rainfall can exceed the berm or not. The protocol also determines the precise site to conduct the artificial breaching and the orientation of the excavation, how to determine the moment of the optimal wind to avoid a fast refilling of the channel with littoral sand, and the ideal steps to involve the fishermen into the process, among others features. Details on these aspects are not included in this chapter.

CONCLUSIONS AND PERSPECTIVES

From a general perspective, research is still needed to fully understand the impacts of artificial openings of coastal lagoons and intermittent estuaries on their biological, ecological, and systemic processes (Santangelo et al., 2007; Bertotti Crippa et al., 2013). There are contrasting evidences about the benefits and costs of manipulating sandbars, although results from tropical lagoons (where a major part of the research has been done) cannot be straightforwardly extrapolated to mid-latitude lagoons (Esteves et al., 2008), where less unpredictable rainfall regimes prevail. Comparative results between artificially intervened systems and undisturbed ones, as well as long-term comparisons of management with and without human interventions, may be adequate research questions to address. These studies should ideally be complemented with long-term data series, commonly not available; experimental research simulating different hydrological conditions of the lagoon dynamics and their effects on species and processes; and a modeling approach to capture and simplify the essentials of the problem.

A central characteristic of coastal lagoons and intermittent estuaries, mainly in regions of unpredictable climate path, is their permanent change, making these systems highly dynamic and complex (Haines and Thom, 2007). These features are very attractive to researchers but at the same time pose a high degree of complexity. How changes in rainfall and wind patterns, sea level rise, and temperature changes may further enhance anthropogenic effects and promote disruption and deregulation of the natural driving processes, are some of the main questions to be answered. Local information on these aspects will allow adapting new models and protocols of sustainable management of sandbars in these coastal lagoons.

To fully understand the functioning and evolution of the sandbar system in Laguna de Rocha, new variables associated with climate change should be incorporated (i.e., sea level and wave energy increase, and changes in rainfall and winds patterns). Considering these aspects, it can be projected that risk is even higher than expected. According to local prediction, future scenarios can be more complex and the consequences will significantly depend both on the response of the natural system and on the management actions to be implemented. Alterations in the hydrological regime of the lagoon, as well as the reduction of the hydraulic pressure by the development of internal banks, suggest the possibility of scenarios where ancient areas of openings could be reactivated. Nagy (2012) specifically mentions the effects of climate change for this coast, suggesting an increase in sea level between 12 and 18 cm for 2030, without considering the further increases caused by wind. This would indicate an increasing erosive impact, especially when coupled with wind tides of ca. 2 m above sea level. The regression observed in the coastline of the current opening area and the presence of many depressions in "barra vieja" close to sea level indicate a high vulnerability of the sandbar system considering the time scale of climate change. Taking into account these climatic caveats, it seems indispensable to completely avoid any urban development across the sandbar of the lagoon.

The main outcomes of this study range from ideal technical recommendations to preserve the environment (i.e., permanently banning the artificial opening) to more practical and applicable suggestions (e.g., a temporal ban or a consensus multidimensional decision tree). All of the recommendations emerged from the study are believed to be a substantial improvement concerning the decision making on the artificial opening of the sandbar of the protected area Laguna de Rocha, which could also be generalized for other neighboring systems, if proven to be successful. Suggested courses of action are considered to be adaptive schemes that need to be permanently monitored, revised, adapted, and improved, according both to the results obtained and to the natural dynamics of the local socioecological system. The effective implementation of the new decision system, the monitoring of its beneficial effects on the ecosystem processes, its readjustment following evaluation, and its social acceptance or rejection is at the same time an approach to management, a participatory process, and a research challenge.

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REFERENCES

Aldabe, J., Rocca, P., Claramunt, S., 2009. Uruguay. Bird life conservation series no. 16. In: Devenish, C., et al. (Eds.), Important Bird Areas Americas, Priority Sites for Biodiversity Conservation. Bird Life Internacional, Quito, pp. 383–392.

Alonso, R., 2012. Evolución del potencialundimotriz de Uruguay. Tesis de Maestría en Mecánica de los FluidosAplicada, Facultad de Ingeniería de la Universidad de la República, Uruguay.

Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N., Johnson, D.S., Marschke, M., McConney, P., Pinkerton, E., Wollenberg, E., 2009. Adaptive co-management for social–ecological complexity. Front. Ecol. Environ. 6, 95–102.

Aubriot, L., Conde, D., Bonilla, S., Hein, V., Britos, A., 2005. Vulnerabilidad de unalagunacostera en unaReserva de Biosfera: indiciosrecientes de eutrofización. In: Vila, I., Pizarro, J. (Eds.), Eutrofización de Lagos y Embalses, CYTEDXVIIB. Printers Patagonia, Chile, pp. 65–85.

Bally, R., 1987. Conservation problems and management options in estuaries: the Bot River estuary, South Africa, as a case-history for management of closed estuaries. Environ. Conserv. 14 (1), 45–51.

Barbosa, F.A.R., Scarano, F.R., Sabará, M.G., Esteves, F.A., 2004. Brazilian LTER: ecosystem and biodiversity of Brazilian LTER. Environ. Monit. Assess. 90 (1–3), 121–133.

Barnes, R.S.K., 1980. Coastal Lagoons: The Natural History of a Neglected Habitat. Cambridge University Press, Cambridge.

Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manage. 90, 1692–1702.

Bertotti Crippa, L., Stenert, C., Maltchik, L., 2013. Does the management of sandbar openings influence the macroinvertebrate communities in southern Brazil wetlands? A case study at Lagoa do Peixe National Park Ramsar site. Ocean Coastal Manage. 71, 26–32.

Bonilla, S., Conde, D., Aubriot, L., Perez, M.C., 2005. Influence of hydrology and nutrients on phytoplankton species composition and life strategies in a subtropical coastal lagoon. Estuaries 28 (6), 884–895.

Bonilla, S., Conde, D., Aubriot, L., Rodriguez-Gallego, L., Piccini, C., Meerhoff, E., Rodríguez-Graña, L., Calliari, D., Gómez, P., Machado, I., Britos, A., 2006. Procesos estructuradores de las comunidades biológicas en lagunas costeras de Uruguay. In: Menafra, R., et al. (Eds.), Bases para la conservación y el manejo de la costa Uruguaya. Vida Silvestre Uruguay, Montevideo, pp. 611–630.

Bracco, R., del Puerto, L., Inda, H., Panario, D., Castiñeira, C., García-Rodríguez, F., 2011. The relationship between emergence of mound builders in SE Uruguay and climate change inferred from opal phytolith records. Quat. Int. 245, 62–73.

Buizer, M., Arts, B., Kok, K., 2011. Governance, scale, and the environment: the importance of recognizing knowledge claims in transdisciplinary arenas. Ecol. Soc. 16 (1), 21. www.ecologyandsociety.org/vol16/iss1/art21.

Cañedo-Argüelles, M., Rieradevall, M., Farrés-Corell, R., Newton, A., 2012. Annual characterisation of four Mediterranean coastal lagoons subjected to intense human activity. Estuarine, Coastal Shelf Sci. 114, 59–69.

Carter, R.W.G., Woodroffe, C.D., 1997. Coastal Evolution: Late Quaternary Shoreline Morphodynamics. Cambridge University Press, Cambridge.

Chow, V.T., Maidment, D., Mays, L., 1994. Hidrología Aplicada. McGraw-Hill Interamericana, Buenos Aires.

Christensen, L., Krogman, N., 2012. Social thresholds and their translation into social-ecological management practices. Ecol. Soc. 17 (1), 5. http://dx.doi.org/10.5751/ES-04499-170105.

Conde, D., Aubriot, L., Bonilla, S., Sommaruga, R., 2002. Marine intrusions in a coastal lagoon enhances the effects of UV radiation on the phytoplankton photosynthetic rate. Mar. Ecol. Prog. Ser. 240, 57–70.

Conde, D., Aubriot, L., Sommaruga, R., 2000. Changes in UV penetration associated with marine intrusions and fresh-water discharge in a shallow coastal lagoon of the Southern Atlantic ocean. Mar. Ecol. Prog. Ser. 207, 19–31.

Conde, D., Bonilla, S., Aubriot, L., De León, R., Pintos, W., 1999. Comparison of the areal amount of chlorophyll a of planktonic and attached microalgae in a shallow coastal lagoon. Hydrobiologia 408 (9), 285–291.

Conde, D., Rodríguez-Gallego, L., 2002. Problemática ambiental y gestión de laslagunas costeras atlánticas de Uruguay. In: Dominguez, A., Prieto, R. (Eds.), Perfil ambiental del Uruguay. Nordan-Comunidad, Montevideo.

Dean, R.G., Dalrymple, R.A., 2002. Coastal Processes with Engineering Applications. Cambridge University Press, Cambridge.

Duarte, P., Bernardo, J.M., Costa, A.M., Macedo, F., Calado, G., Cancela da Fonseca, L., 2002. Analysis of coastal lagoon metabolism as a basis for management. Aquat. Ecol. 36, 3–19.

Duck, R.W., da Silva, J.F., 2012. Coastal lagoons and their evolution: a hydromorphological perspective. Estuarine, Coastal Shelf Sci. 110, 2–14.

Espinoza-Tenorio, A., Wolff, M., Espejel, I., Montaño-Moctezuma, G., 2013. Using traditional ecological knowledge to improve holistic fisheries management: transdisciplinary modeling of a lagoon ecosystem of southern Mexico. Ecol. Soc. 18 (2), 6. http://dx.doi.org/10.5751/ES-05369-180206.

Esteves, F.A., Caliman, A., Santangelo, J.M., Guariento, R.D., Farjalla, V.F., Bozelli, R.L., 2008. Neotropical coastal lagoons: an appraisal of their biodiversity, functioning, threats and conservation management. Braz. J. Biol. 68 (4, Suppl.), 967–981.

Fabiano, G., Santana, O., 2006. Las pesquerias en laslagunassalobres de Uruguay. In: Menafra, R., et al. (Eds.), Bases para la Conservación y el Manejo de la Costa Uruguaya. Vida Silvestre Uruguay, Montevideo, pp. 557–565.

Gale, E., Pattiaratchi, C., Ranasinghe, R., 2007. Processes driving circulation, exchange and flushing within intermittently closing and opening lakes and lagoons. Mar. Freshwater Res. 58, 709–719.

Gönenç, E., Wolflin, J.P., 2004. Coastal Lagoons: Ecosystem Processes and Modeling for Sustainable Use and Development. CRC Press, New York.

Griffiths, S.P., 1999. Consequences of artificially opening coastal lagoons on their fish assemblages. Int. J. Salt Lake Res. 8, 307–327.

Griffiths, S.P., West, R.J., 1999. Preliminary assessment of shallow water fish in three small intermittently open estuaries in southeastern Australia. Fish. Manage. Ecol. 6 (4), 311–321.

Haines, P.E., Thom, B.G., 2007. Climate change impacts on entrance processes of intermittently open/closed coastal lagoons in new South Wales, Australia. J. Coastal Res. SI 50, 242–246.

Heinzen, W., Velozo, C., Carrión, R., Cardozo, L., Mandracho, H., Massa, E., 1986. Carta Hidrogeológica del Uruguay, escala 1/2.000.000 y texto explicativo. DINAMIGE, Montevideo. Uruguay.

Hopkins, T.S., Bailly, D., Elmgren, R., Glegg, G., Sandberg, A., Støttrup, J.G., 2012. A systems approach framework for the transition to sustainable development: potential value based on coastal experiments. Ecol. Soc. 17 (3), 39.

Horikawa, K., Maruo, H., 2011. Nonlinear Water Waves. Springer-Verlag, Berlin.

Isacch, J.P., 2008. Implementing the biosphere reserve concept: the case of Parque Atlántico Mar Chiquita biosphere reserve from Argentina. Biodiversity Conserv. 17, 1799–1804.

Kjerfve, B., 1994. Coastal Lagoons Processes. Elsevier Oceanography Series (60). Elsevier Science Publishers, Amsterdam.

Knoppers, B., 1994. Aquatic primary production in coastal lagoons. Elsevier oceanography series (60). In: Kjerfve, B. (Ed.), Coastal Lagoons Processes. Elsevier, Amsterdam, pp. 243–275.

Larson, K., Edsall, R., 2010. The impact of visual information on perceptions of water resource problems and management alternatives. J. Environ. Plann. Manage. 53 (3), 335–352.

Nagy, G.J., 2012. Reporte PACCC Escenarios climáticos y Diagnóstico ambiental para la adaptación en el sitio Piloto Laguna de Rocha y Adyacencias, Proyecto "Implementación de medidas piloto de adaptación al cambio climático en áreas costeras del Uruguay, URU/07/G32.

Norbis, W., Galli, O., 2004. Feeding habits of the flounder *Paralichthys orbignyanus* (Valenciennes, 1842) in a shallow coastal lagoon of the southern Atlantic Ocean: Rocha, Uruguay. Cienc. Mar. 30 (4), 619–626.

Palma-Silva, C., Albertoni, F., Esteves, F.A., 2000. *Eleocharismutata* (L.) Roem. Et Schult. subject to drawdowns in a tropical coastal lagoon, State of Rio de Janeiro, Brazil. Plant Ecol. 148 (2), 157–164.

Panario, D., Gutiérrez, O., 2005. La vegetación en la evolución de playas arenosas. El caso de la costa uruguaya. Ecosistemas 14 (2), 150–161.

Pauly, D., Yañez-Arancibia, A., 1994. Fisheries in coastal lagoons. Elsevier oceanography series (60). In: Kjerfve, B. (Ed.), Coastal Lagoons Processes. Elsevier, Amsterdam, pp. 377–396.

Piccini, C., Conde, D., Alonso, C., Sommaruga, R., Pernthaler, J., 2006. Blooms of single bacterial species in a coastal lagoon of the Southwestern Atlantic ocean. Appl. Environ. Microbiol. 72 (10), 6560–6568.

Piñeiro, G., Panario, D., 1993. Dinámicasedimentaria y geomorfológica de dunas y playas en Cabo Polonio, Rocha. Informe UNCIEP, Facultad de Ciencias, Uruguay.

Pintos, W., Conde, D., De Leon, R., Cardezo, M.J., Jorcin, A., Sommaruga, R., 1991. Some limnological characteristics of Laguna de Rocha. Revista de Biología Brasilera 51 (1), 79–84.

Pollard, D.A., 1994. Opening regimes and salinity characteristics of intermittently opening and permanently open coastal lagoons on the south coast of New South Wales. Wetlands 13, 16–35.

Pomeroy, R., Douvere, F., 2008. The engagement of stakeholders in the marine spatial planning process. Mar. Policy 32, 816–822.

Preciozzi, F., Spoturno, J., Heinzen, W., Rossi, P., 1985. MemoriaExplicativa de la CartaGeológica del Uruguay a la escala 1:500.000. DINAMIGE, Montevideo, Uruguay.

Rabassa, J., Brandani, A., Boninsegna, J.A., Cobos, D.R., 1984. Cronología de la "PequeñaEdad del Hielo" en los glaciares Río Manso y Castafio Overo, Cerro Tronador, Provincia de Rio Negro. 9no. Congreso Geológico Argentino, Actas, vol. 3, pp. 624–639.

Reese, M.M., Stunz, G.W., Bushon, A.M., 2008. Recruitment of estuarine-dependent nekton through a new tidal inlet: the opening of Packery channel in Corpus Christi, TX, USA. Estuaries Coasts 31, 1143–1157.

Rodríguez-Gallego, L., 2010. Eutrofización de laslagunascosteras de Uruguay: impacto y optimización de los usos del suelo, Tesis de doctorado, PEDECIBA, Facultad de Ciencias, Universidad de la Republica, Montevideo.

Rodríguez-Gallego, L., Meerhoff, E., Clemente, J.M., Conde, D., 2010. Can ephemeral proliferations of submerged macrophytes influence zoobenthos and water quality in coastal lagoons? Hydrobiologia 646 (1), 253–269.

Rodríguez-Gallego, L., Sabaj, V., Masciadri, S., Kruk, C., Arocena, R., Conde, D., 2015. Salinity as a major driver for submersed aquatic vegetation in coastal lagoons: a multi-year analysis in the subtropical Laguna de Rocha. Estuaries Coasts 38, 451–465.

Rodríguez-Gallego, L., Santos, C., Amado, S., Gorfinkiel, D., González, M.N., Neme, C., Tommasino, H., Conde, D., 2013. Interdisciplinary diagnosis and scenario analysis for the implementation of a coastal protected area (Laguna de Rocha, Uruguay). In: Yáñez-Arancibia, A., et al. (Eds.), Ecological Dimension for Sustainable Socio Economic Development. WIT, Southampton, pp. 389–411.

dos Santos, A.M., Amado, A.M., Minello, M., Farjalla, V.F., Esteves, F.A., 2006. Effects of the sandbar breaching on *Typha domingensis* (PERS.) in a tropical coastal lagoon. Hydrobiologia 556, 61–68.

Saad, A.M., Beaumord, A.C., Caramaschi, E.P., 2002. Effects of artificial canal openings on fish community structure of Imboassica coastal lagoon, Rio de Janeiro, Brazil. J. Coastal Res. 36, 634–639.

Santangelo, J.M., Rocha, A., Bozelli, R.L., Carneiro, L.S., Esteves, F., 2007. Zooplankton responses to sandbar opening in a tropical eutrophic coastal lagoon. Estuarine, Coastal Shelf Sci. 71, 657–668.

Sarroca, M., 2008. Relevancia de la Laguna de Rocha (Uruguay) como hábitat para *Cygnus melancoryphus* y *Coscoroba coscoroba*: análisis espacio-temporal de la abundancia y estudio de comportamiento. Tesis de Maestría, PEDECIBA-Biología, UDELAR., Montevideo.

Schallenberg, M., Larned, S.T., Hayward, S., Arbuckle, C., 2010. Contrasting effects of managed opening regimes on water quality in two intermittently closed and open coastal lakes. Estuarine, Coastal Shelf Sci. 86, 587–597.

Sei, S., Rossetti, G., Villa, F., Ferrari, I., 1996. Zooplankton variability related to environmental changes in a eutrophic coastal lagoon in the Po Delta. Hydrobiologia 329 (1–3), 45–55.

Shackeroff, J., Campbell, M.L.M., Crowder, L.B., 2011. Social-ecological guilds: putting people into marine historical ecology. Ecol. Soc. 16 (1), 52. www.ecologyandsociety.org/vol16/iss1/art52.

Smakhtin, V., 2004. Simulating the hydrology and mouth conditions of small temporarily closed/open estuaries. Wetlands 24, 123–132.

Sommaruga, R., Conde, D., 1990. Distribución de materia orgánica en los sedimentos recientes de la Laguna de Rocha (Rocha Uruguay). Atlántica 12, 35–44.

Soutullo, A., Bartesaghi, L., Berazategui, P., Clavijo, C., Díaz, I., Faccio, C., García, M., González, E.M., 2010. Diseño espacial del Sistema Nacional de Áreas Protegidas de Uruguay: sitios a integrar al sistema, prioridades de conservación en esos sitios y aportes a la protección de la biodiversidad fuera de áreas protegidas. In: Proyecto Fortalecimiento del Proceso de Implementación del Sistema Nacional de ÁreasProtegidas, Serie de Informes N° 24, 50 pp.

Suzuki, M.S., Figueiredo, R.O., Castro, S.C., Silva, C.F., Pereira, E.A., Silva, J.A., Aragon, G.T., 2002. Sandbar opening in a coastal lagoon (Iquipari) in the northern region of Rio de Janeiro state: hydrological and hydrochemical changes. Braz. J. Biol. 62 (1), 51–62.

Suzuki, M.S., Ovalle, A.R.C., Pereira, E.A., 1998. Effects of sandbar openings on some limnological variables in a hypertrophic tropical coastal lagoon of Brazil. Hydrobiologia 368, 111–122.

Thomas, C.M., Perissinoto, R., Kibirige, I., 2005. Phytoplankton biomass and size structure in two South African eutrophic, temporarily open/closed estuaries. Estuarine, Coastal Shelf Sci. 65 (1–2), 223–238.

Thompson, D., 2008. Economía e identidad de los pescadores de la Barra de la Laguna de Rocha. In: Anuario de Antropología Social y Cultural. Nordan Comunidad, Facultad de Humanidades y Ciencias de la Educación, Montevideo.

Thorton, E.B., Guza, R.T., 1983. Transformation of wave height distribution. J. Geophys. Res. 88 (C10), 5925–5938.

U.S. Army Corps of Engineers, 2002. Coastal engineering manual. Engineer Manual 1110-2-1100. U.S. Army Corps of Engineers, Washington, DC.

UNESCO, 2006. Evaluación de los recursoshídricos. Elaboración del balance hídrico integrado por cuencas hidrográficas. Documentos técnicos del PHI-LAC N° 4. UNESCO.

Vizziano, D., Forni, F., Saona, G., Norbis, W., 2002. Reproduction of *Micropogonias furnieri* in a shallow temperate coastal lagoon in the southern Atlantic. J. Fish Biol. 61, 196–206.

Whitfield, K., Adams, J.B., Bate, G.C., Bezuidenhout, K., Bornman, T.G., Cowley, P.D., Froneman, P.W., Gama, P.T., James, N.C., Mackenzie, B., Riddin, T., Snow, G.C., Strydom, N.A., Taljaard, S., Terörde, A., Theron, A.K., Turpie, J.K., van Niekerk, L., Vorwerk, P.D., Wooldridge, T.H., 2008. A multidisciplinary study of a small, temporarily open/closed South African estuary, with particular emphasis on the influence of mouth state on the ecology of the system. Afr. J. Mar. Sci. 30, 453–473.

Yáñez-Arancibia, A., Day, J.W., Sánchez-Gil, P., Day, J.N., Lane, R.R., Zárate-Lomelíc, D., Alafita Vásquez, H., Rojas-Galavizc, J.L., Ramírez-Gordillo, J., 2014. Ecosystem functioning: the basis for restoration and management of a tropical coastal lagoon, Pacific coast of Mexico. Ecol. Eng. 65, 88–100.

Young, G.C., Potter, I.C., 2002. Influence of exceptionally high salinities, marked variations in freshwater discharge and opening of estuary mouth on the characteristics of ichthyofauna of a normally-closed estuary. Estuarine, Coastal Shelf Sci. 55, 223–246.

Zagonari, F., 2008. Integrated coastal management: top-down vs. community-based approaches. J. Environ. Manage. 88, 796–804.