

Building capacity on ecosystem-based adaptation strategy to cope with extreme events and sea-level rise on the Uruguayan coast

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Abstract

Purpose – This study aims to show a case study of ecosystem-based adaptation (EbA) measures to increase coastal system's resilience to extreme weather events and sea-level rise (SLR) implemented at Kiyú (Uruguayan coast of the Rio de la Plata river estuary).

Design/methodology/approach – A participatory process involving the community and institutional stakeholders was carried out to select and prioritise adaptation measures to reduce the erosion of sandy beaches, dunes and bluffs due to extreme wind storm surge and rainfall, SLR and mismanagement practices. The recovery of coastal ecosystems was implemented through soft measures (green infrastructure) such as revegetation with native species, dune regeneration, sustainable drainage systems and the reduction of use pressures.

Findings – Main achievements of this case study include capacity building of municipal staff and stakeholders, knowledge exchanges with national-level decision makers and scientists and the incorporation of EbA approaches by subnational-level coastal governments. To consolidate EbA, the local government introduced innovations in the coastal management institutional structure.

Originality/value – The outcomes of the article include, besides the increase in the resilience of social-ecological systems, the strengthening of socio-institutional behaviour, structure and sustainability. This experience provides insights for developing a strategy for both Integrated Coastal Management and climate adaptation at the national scale.

Keywords Stakeholders, Green infrastructure, Climate vulnerability, Integrated coastal management, Rio de la Plata estuary Coast, Socio-institutional capacity building

Paper type Case study



1. Introduction

Coastal systems such as beaches, dunes, cliffs, wetlands and estuaries are exposed to sea-level rise (SLR), flooding, erosion and habitat loss due to climate change, coastal climate extreme events and land-use change (Masselink and Gehrels, 2014; Spalding *et al.*, 2014a), and will continue to do so in the absence of adaptation measures (Wong *et al.*, 2014).

When coastal ecosystems are destroyed, degraded or are occupied, their natural and free capacity to cushion the impacts associated with wind and rain extreme events is lost, causing serious damage to infrastructure and property located in the coastal edge (Barragán and Borja, 2011). The conservation of coastal ecosystems can provide considerable protection benefits, but this role has not been sufficiently accounted for, in coastal planning (Spalding *et al.*, 2014b). Maintaining coastal environments resilience involves analysing the capacity to generate the necessary conditions for maintaining ecosystem functions that support the services provided by beaches (Flood and Schechtman, 2014) and other coastal landscapes as wetlands, lagoons and estuarine rivers.

To address the complexity faced by coastal socio-ecological systems (SES), an Integrated Coastal Management (ICM) framework is adequate. ICM promotes cross-sectoral integration of:

- governance levels;
- spatial management of environmental units;
- natural, social and traditional knowledge as a means of ensuring social and environmental well-being; and
- the correct management of SES (GESAMP, 1999; Goyos *et al.*, 2011; Sardá *et al.*, 2015).

The participation of the community in the early stages of decision-making facilitates a good short-term response from users (Ferreira *et al.*, 2015).

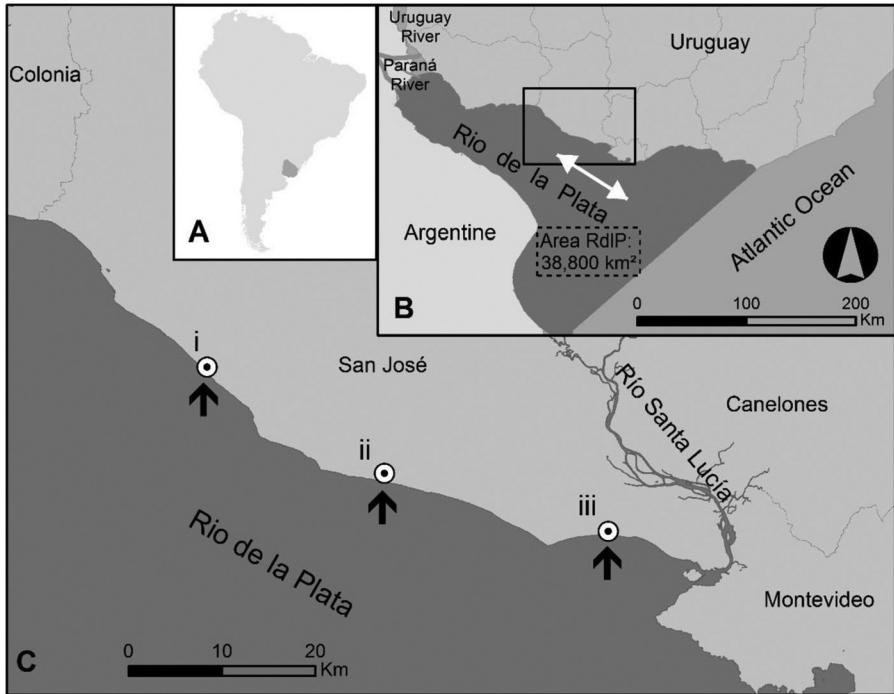
Ecosystem-based Adaptation (EbA, Vignola *et al.*, 2009) emphasises adaptive management and governance processes aimed at the optimisation and sustainability of goods and services provided by coastal ecosystems. EbA uses biodiversity and ecosystem services as part of a wider adaptation strategy to help people and communities to adapt through creating local and national capacities to the adverse effects of climate change, considering multiple scales of risks, vulnerabilities and opportunities. The purpose of EbA is to implement actions to increase the resilience and sustainable management, conservation and restoration of ecosystems, communities and infrastructure to coastal hazards and climate change within an overall adaptation strategy that considers the multiple socio-economic and cultural co-benefits for local communities (Munang *et al.*, 2013; Reid, 2016; Spalding *et al.*, 2014a).

The coastal areas of Uruguay are among the most exposed to wind-induced flooding and SLR in Latin America (Leal Filho *et al.*, 2017; Losada *et al.*, 2013; Magrin *et al.*, 2014; Nagy *et al.*, 2016a), with up to 10 per cent of its population directly exposed (Villamizar *et al.*, 2017).

The Division of Climate Change of the Directorate of the Environment (DINAMA), Ministry of Territorial Planning, Housing and Environment (MVOTMA) of Uruguay, has developed and implemented since 2008, together with the coastal sub-national governments, pilot climate adaptation experiences aimed at increasing the resilience of coastal ecosystems vulnerable to climate change and extreme weather events.

In-depth interviews with national and local-level elected officials and decision makers allowed selecting a short list of adaptation measures, e.g. soft works, climate and beach profile monitoring, training and public awareness to increase community's confidence and engagement with the adaptation process (Nagy *et al.*, 2016a, 2015).

In September and October 2012, extreme windstorm surges impacted Kiyú at the Rio de la Plata's tidal river estuary coast (Figure 1) with total direct losses of US\$1,000,000 as



Notes: (a) South America, (b) Rio de la Plata river estuary (area 38,800 km²) (the white arrow indicates the moving salt intrusion limit; SIL) (Nagy et al., [HYPERLINK "file:///chenas03\smartedit\Normalization\IN\INPROCESS\43" \o "43=Ref Nagy, G.J., Martínez, C.M., Caffera, R.M., Pedrosa, G., Forbes, E.A., Perdomo, A.C. and López Laborde, J. \(1997\), "1997\)"](#)), (c) black arrows indicate the three pilot coastal adaptation sites at San José: (i) Vulminot (up-river the SIL), (ii) Kiyú (at the upward boundary of the SIL), (iii) Ciudad Del Plata (at the mouth of Santa Lucia River estuary)

Figure 1.
The coast of San José
and Western
Montevideo

assessed by the Sub-national Government of San José. These storms highlighted the coastal exposure to extreme events, creating a window of opportunity for planning pilot adaptation measures in Kiyú, San José, from 2013 to 2014.

This article is aimed at showing the implementation of EbA measures to extreme weather events and flooding within an ICM framework in Kiyú. The EbA principles and indicators (Huq *et al.*, 2013) prioritised in this article are:

- adaptive management;
- best available science and local knowledge;
- involving local communities, enabling bottom-up adaptation policies;
- manage climate variability and long-term SLR, reducing impacts from extreme events;
- maintain ecosystem services; and
- monitor and evaluate systematically.

2. Study area

The coastline of San José is characterised by a high diversity of landscapes and ecosystems, e.g. erosive bluffs/cliffs (erosion escarpment triggered by wave erosion), the protected area at the mouth of the Santa Lucia River estuary, Ramsar (Convention on Wetlands of International Importance) wetland sites, grasslands, sandy beaches and dunes. It also has a strong cultural heritage referred to the rural tradition and archaeological sites.

These ecosystems, landscapes and cultural values are threatened by coastal erosion affecting bluffs, ecosystem services (e.g. flood control) and communities due to the impacts of extreme wind and rain events on the infrastructure and tourism services.

There are three populated areas, Vulminot, Kiyú and Ciudad del Plata (Figure 1), totalling 37,000 inhabitants, with agricultural activities and tourism, along ≈40 km of coastline characterised by erosive bluffs, gullies, sandy beaches, dunes and wetlands (EcoPlata, 1999). This micro-tidal coast (tidal amplitude < 0.5 m) is vulnerable to SLR and flooding associated with southern wind storms (Nagy *et al.*, 2014a, 2007, 2005; Saizar, 1997; Verocai *et al.*, 2015). The rate of SLR was 1-2 mm/year over the past five decades, reaching yearly maximum associated with El Niño-related river flood events (Verocai *et al.*, 2016). The storm surge in September 2012 (2.97 m, ≈ 0.01 per cent occurrence) was caused by southern winds (average: ≈ 60 km/h, and gusts > 100 km/h).

Kiyé (34°42'S: 56°43'W) integrates the original rural identity, modern coastal tourism and settlement, with human interaction on ecosystems (Caporale, 2013). It is located on a coastal escarpment varying from 1.5 to 4 m. The sandy beach is narrow with a thin sand prism developed at a plain of abrasion generated by the retreat of the river scarp through the fluctuations of the coastline location during the Holocene. This plain of abrasion exerts a structural control over the underwater beach which conditions its dissipative behaviour (Gutiérrez and Panario, 2017). Bluffs maintain their vertical structure after the accumulation of material at the base due to slump during storm surges. Extreme rainfalls generate gullies' headers which, when coinciding with drainage generated by roads, become active headers, likely associated with the fragility of the Cenozoic materials composing the substrate (Pérez-Alberti *et al.*, 2005). While under normal conditions this beach tends to generate primary dune (proto-dunes), they are eroded by storm waves (Gutiérrez and Panario, 2006).

A summary of coastal impacts associated with El Niño/La Niña events at Uruguayan coastal areas, particularly at Ciudad del Plata, is shown in Box 1.

Box 1. Summary of El Niño and La Niña direct and indirect effects, and coastal responses at the Uruguayan coast of the Río de la Plata (Increase ↑ and decrease ↓).

El Niño: (i) ↑ Major tributaries River Flow (Paraná, Uruguay Rivers) and Santa Lucia River: Slight inundation (Barros *et al.*, 2005; Nagy *et al.*, 2014a); (ii) ↑ Eastern-Southeastern winds: Inundation and flooding (Gutiérrez *et al.*, 2015; Nagy *et al.*, 2007, 2005; Verocai *et al.*, 2015), beach accretion observed eastward (Gutiérrez *et al.*, 2016); (iii) ↑ Rainfall and runoff: Gully widening and beach erosion at Ciudad del Plata (this article).

La Niña: (i) ↓ Tributaries River Flow: Slight increase in salinity (>0.5 g/L) and salinisation (Nagy *et al.*, 2013, 2003); (ii) ↓ Under strong La Niña (1999-2000, 2008-2009): Salt intrusion and salt spray are possible (Nagy *et al.*, 2013, 2003); (iii) ↑ Western-Southwestern and Southwestern winds: Storm surge and beach erosion observed eastward (Gutiérrez *et al.*, 2016).

3. Approaches and methods

This article is based on three methodological approaches (Figure 2):

- (1) integrated coastal management (ICM);
- (2) vulnerability reduction assessment (VRA) and
- (3) ecosystem-based adaptation (EbA), supported by a monitoring method (1) beach profiling which was implemented before the EbA process.

3.1 Integrated coastal management framework for EbA

The full life cycle management of this research is structured into five phases (Olsen, 2003; Olsen *et al.*, 1999) as follows:

- identification and selection of key management elements;
- action planning;
- formal adoption and funding;
- implementation; and
- evaluation.

This multi-stage approach includes social learning and management based on available scientific knowledge, articulated with the local capacity to carry out EbA initiatives. This strategy in the ICM framework and EbA goals is raised as the linchpin to ensure the health and balance of coastal ecosystems (GESAMP, 1999).

3.2 Vulnerability reduction assessments

The assessment of public participation of decision makers and stakeholders' perceptions of coastal vulnerability was made through a modified United Nations Development Program (UNDP) VRA (Crane Droesch *et al.*, 2008; as modified by Nagy *et al.*, 2014b). The VRA forms a cornerstone of the UNDP Community Based Adaptation (CBA) programme's monitoring and evaluation activities designed to measure the relative change in the adaptive capacity of a community before (baseline), during and after the implementation of a CBA project activities.

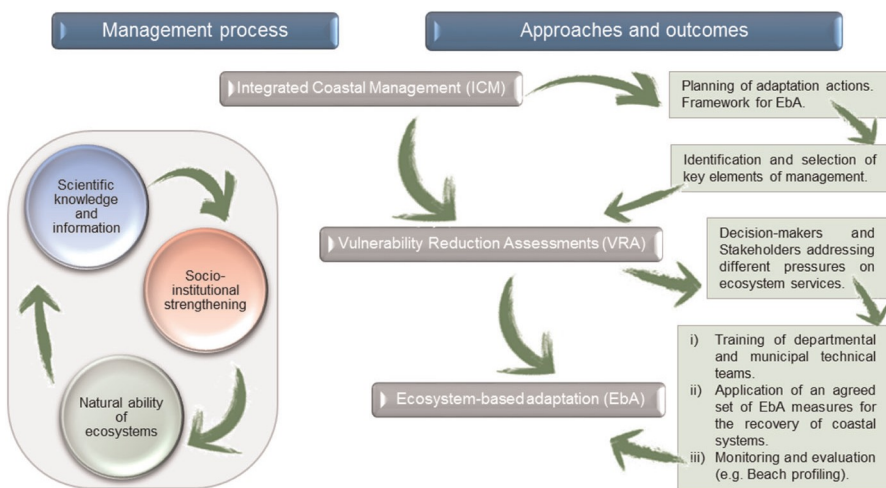


Figure 2. Schematic flow of the management process, approaches and outcomes showing adaptation actions and feedback

VRA workshops were conducted to assess local stakeholders' vulnerability and risk perception, as well as barriers and opportunities to implement adaptation measures in Kiyú from 2014. The participatory assessments were held with different groups of stakeholders, managers and non-governmental organisation (NGO) members (at least 15 each time) as follows:

- Meetings, semi-structured and in-depth interviews.
- Focus group discussions and brainstorming: A multiple-question matrix is filled by each participant with qualitative comments and a numerical individual assessment measured through corresponding open-ended, perception-based questions, which in turn aggregate to serve as indicators of adaptive capacity. A Likert 1-5 scale is used where 1 is low vulnerability/capacity (or high barrier to adaptation), and 5 is high vulnerability/capacity (or low barrier) perception of climate threats, impacts, uncertainties, obstacles and supportive factors to implementing adaptation.
- A dialogue between participants and experts is held to achieve a collectively agreed value for each question and oral comments to facilitate the understanding of the arguments supporting the given values, and the convergence to reduce extreme perceptions and values.

3.3 *Ecosystem-based adaptation*

The EbA approach is a public management strategy which involves different stakeholders aimed at:

- increasing the resilience of critical ecosystem services, people and economic sectors on which humans depend; and
- reducing the vulnerability of human and natural systems against climate variability and change. The set of management measures is inexpensive and readily transferable at sub-national and local-level governments (Huq *et al.*, 2013).

In the context of sustainable development, EbA can be viewed as a three-way synergy, between biodiversity and ecosystem conservation, socioeconomic development and climate change adaptation outcomes (Midgley *et al.*, 2012).

3.4 *Beach profiling*

The "simple method of measuring beach profiles" (Emery, 1961) has been used along the Uruguayan coast for ecosystem research (Lercari and Defeo, 2015, 2006) and was adopted by DINAMA to monitoring sandy beaches since 2010. Measurements of beach elevations and slopes are performed from the base of the dunes to the water level at the time of instantaneous water level (IWL), defined by as where IWL is: the position of the land–water interface at one instant in time, where the horizontal/vertical position of the shoreline could vary depending on the beach slope, tidal range and prevailing wave/weather conditions (modified from Boak and Turner, 2005).

These measurements are usually performed twice a year plus after storm surges, allowing coastal managers to monitor rough changes in the slope and width of the monitored beaches.

4. Results and discussion

4.1 *Planning of coastal management process and adaptation actions*

The extreme events of 2012 were the catalyst for an agreement aimed at managing the challenges posed by SLR, extreme events and consequent erosion. This agreement sought to articulate the institutional coordination of the sub-national, local and national-level

governments through networking and cooperation, linking the different government levels with the neighbours and DINAMA scientists. To overcome the problems inherent in the fragmentation of coastal management tasks, the sub-national government created in 2013 the Departmental Office of Climate Change (DOCC) (Figure 3).

The first decisions undertaken by the DOCC in 2013-2014 were as follows:

- to plan the implementation of a life cycle five-step ICM and EbA actions at Kiyú;
- to assess the previous VRA and organise new ones to identify and select the EbA actions (Figure 2);
- to test low-cost soft technologies for the conservation of degraded coastal systems in the San José;
- to build staff management capacity; and
- a municipal foreman was charged to coordinate the execution of EbA actions and monitoring.

This science-based and informed management process and socio-institutional strengthening were made possible, besides the natural resilience of ecosystems (Figure 2), by:

- an institutional framework and capacity building laid by ICM EcoPlata Programme (Martínez and Fournier, 1999; Pérez-Cayeiro and Chica-Ruiz, 2015);
- previous management interventions at sandy beaches (Gutiérrez and Panario, 2006, 2005; Panario *et al.*, 2008; Panario and Gutiérrez, 2003); and
- climate adaptation and governance experiences (Gutiérrez *et al.*, 2015; Nagy *et al.*, 2015, 2014b).

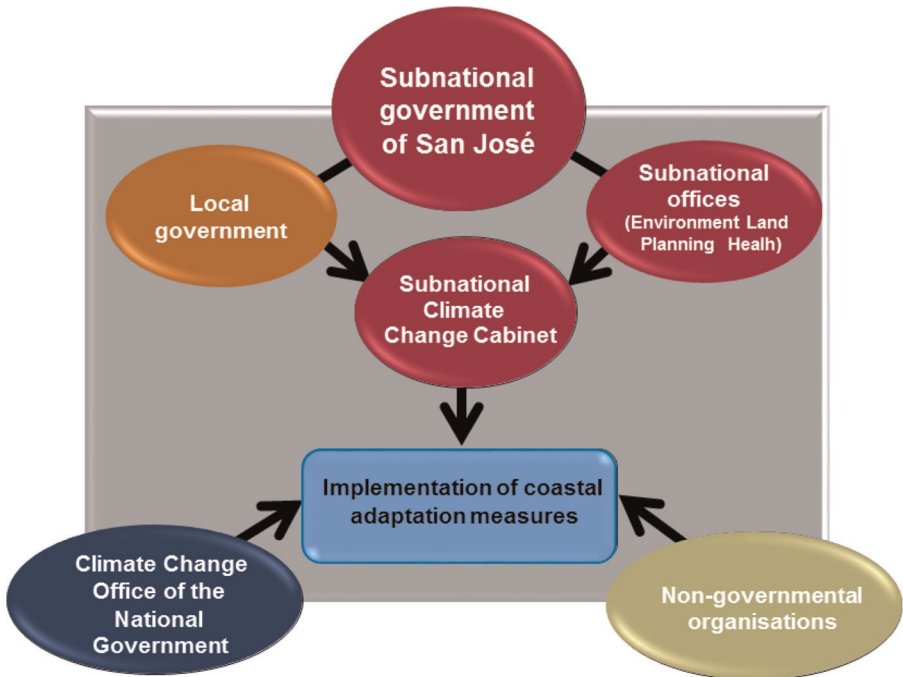


Figure 3. Organisational management flowchart showing the involvement of all government levels and NGOs in the coastal management process at Ciudad del Plata and particularly Kiyú

4.2 Stakeholders' participation and perception (VRA): identification and selection of options

In the late 70s, residents of Kiyú created a Neighbourhood Commission ("The neighbours") aimed at promoting the summer tourism, which developed, together with local government, actions for the enhancement and protection of natural and cultural values of the area. These joint efforts of stakeholders and authorities from 2011-2015 allowed certifying Kiyú as a "natural beach".

The baseline VRA workshop was held in 2011 (Nagy *et al.*, 2014b), and the two others were held before (2013) and after (2014) the implementation of EbA measures (Carro *et al.*, 2017). More than 100 decision makers, local and institutional stakeholders participated in them, which perceived EbA measures positively due to their low cost against hard measures, but also with distrust of their effectiveness to improve the coastal system (Table I).

Groups of stakeholders	Organisation	Interests	Identified threats and vulnerabilities	VRA Pre-intervention willingness to incorporate EbA measures
1. Kiyú neighbours	Neighbours' Association	Local development; Tourism; Beach; Environment	Erosion	Positive; because of low cost; curiosity about the effectiveness
2. Non-clustered neighbours	Without organisation	Beach quality and conservation	Erosion	Negative; distrust about the effectiveness of measures
3. Non-clustered traders	Without organisation	Beach quality and conservation	Erosion	Negative; disbelief and preference for hard engineering defences
4. Municipality	Local government	Socio-economic development; impacts on infrastructure; natural beach re-certification	Infrastructure	Very positive; because of the low cost and applicability to other sites in the coastal zone
5. Climate change cabinet (DOCC)	Sub-national government	Climate agenda in land-use and ICM	Infrastructure	Very positive; because of the adaptive management approach and low cost
VRA Date	Main threats and impacts	Quantitative 1: low; 5: very high Vulnerability/capacity	Main perceived barriers and supportive factors to adaptation	
1. Baseline (2011)	Extreme events; erosion	4.2/1.5	Lack of local adaptive capacity	
2. Before EbA implementation (2013)	Wind storms; floodings; beach and bluff erosion	2.5/2.1	Lack of adaptive capacity and information regarding impacts and feasible adaptation measures / confidence in local commitment and local authorities	
3. After EbA implementation (2014)	Wind storms; Rain storms; SLR, increased extremes	1.8/3.3	Increased perception of threats after the damaging rainstorm in early 2014. Increased confidence in adaptive capacity	

Table I. Kiyú stakeholders' description. Interests, vulnerability perception, willingness to implement EbA measures and VRA results

The baseline workshop showed a perception of high vulnerability (4.5) due to erosion and extreme events, barriers and lack of capacity (1.5); the before-implementation VRA showed a moderate perception of vulnerability (2.5) and low adaptive capacity (2.1) despite that the presence and involvement of local authorities was recognised as a facilitator.

A set of appropriate and feasible actions were prioritised from a series of pre-selected adaptation measures in addition to the pre-existing beach profiling. Agreed implementation measures included:

- training of municipal teams;
- application of a set of EbA measures for the recovery of coastal systems; and
- monitoring (beach profiling) and evaluation.

The after-implementation VRA showed an increase in the perception of threats due to the occurrence of erosive extreme rainstorms in early 2014, despite what vulnerability perception lowered (1.8) due to the perceived reduction of barriers and the high increase in adaptive capacity (3.3) attributed to the observed recovery of sandy dunes and participatory monitoring activities.

This kind of participation in local governance and monitoring legitimate management actions and facilitates the reduction of the perception of vulnerability, while also serving as an input for Scenario Planning of futures and new adaptation plans (Nagy *et al.*, 2017, 2014b).

4.3 Implementation of EbA measures for ecosystem recovery and strengthening of the natural capacities of adaptation and coastal defence

Training of municipal teams was carried out in 2013 to address the issues related to climate change, extreme events, impacts due to pressure use and the types and design of ICM and EbA measures.

A set of six low-cost and easy to implement measures for the recovery and conservation of coastal ecosystems was implemented – in addition to the pre-existent monitoring (beach profiling) – at Kiyú pilot site along almost 2,000 linear meters (Figure 4) where the pressure use was the greatest (Table II).

The set of EbA of measures was implemented as follows:

Forest vegetation.

Large-size Eucalyptus trees (≈ 30 m high) were cut to reduce the effect of shade on the dune grasses and prevent the breakdown of the bluffs by trees fall due to windstorms. Native coastal shrubby specimens were planted over the bluff and behind the fence captor, at the foot of the regenerated proto-dune. The selected species were fast growing, small sized and better to face extreme winds than the extracted trees.

International and local experiences show that the logging of tall trees and the plantation of small shrubby foredune prevent the destructive fall of trees due to windstorms because they reduce wind speed and the supply and deposition of sand and modify natural vegetation (Kim *et al.*, 2014; Panario and Gutiérrez, 2005; Picketts *et al.*, 2014). Consequently, the growth of dune plant species due to increased insolation and less soil detachment is expected.

Sand captor fences and dune recovery monitoring.

About 1,200 linear meters of captor fences made with biodegradable cut Eucalyptus branches were installed to capture the sand moved by the wind. A proto-dune of 1 m high and 6 m wide at its base was created after three months, increasing the slope of the beach through accumulating 6 m^3 per meter per captor fence during 2013. This value is in close agreement with the one calculated with a sand transport model adjusted for the Uruguayan coast by Panario and Piñeiro (1997) which estimates that for SW winds the transported volume would be 7 m^3 of sand. The estimated total volume of rebuilt dunes was up to $10,000 \text{ m}^3$.

A monitoring program was developed from June to August 2014 (austral winter) to assess the ability of the captor fences for dune recovery which, once decomposed, served as both substrate and nutrient to facilitate attachment of dune grasses.

The sand captor fences have demonstrated to be efficient to accumulate sand, rebuild dunes and increase resilience to extreme events. Extreme events such as the erosive rainfalls in early 2014, the greatest ever recorded over a 15-day period (Nagy *et al.*, 2016b), the windstorm (average: $\approx 61 \text{ km/h}$ and gusts $> 100 \text{ km/h}$) and storm surge (2.43 m, ≈ 0.1 per cent occurrence) in September 2016 did not erode the sandy beach, dunes, bluffs and shrubby forest.

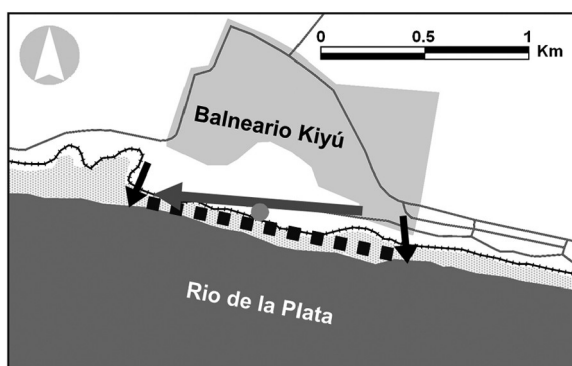
Sustainable drainage systems.

Over 600 m of storm drains (“gutters”) were built near the “Parador Chico” to reduce the erosive impact of rainstorms (Figure 4).

Reprofiling of the coastal roads.

Roads were re-profiled along $\approx 1,000$ linear meters to allow the rainwater be captured by the gutters and prevent runoff of erosive flows through the gullies.

The installation of gutters and the change of slope of the road system reduce the erosive impact of rainwater runoff on the bluffs and dune field along 1,500 m on both sides of “Parador Chico” (Figure 4).



Notes: The reprofiled roads (dark grey arrow) and the sites of storm drains entrances to the beach area (black arrows) are shown

Figure 4. Sketch of the placement of sand captor fences and planting of coastal forest species (black dotted line: $\approx 1,200$ linear m), which in turn is the zone used for beach profiling, where the starting point reference is the base of “Parador Chico” hostel (grey point)

Table II.
Set of EbA and monitoring measures implemented in Kiyú during 2013: Outcomes, and summary of pros and cons of each management options

Implemented measures	Pros/cons	Outcomes	Links to environmental and human community issues
Sand captor fence for dune recovery Revegetation of coastal forest and redesign of the park	Easy to implement; low cost; rapid results / maintenance Reforestation with native species/ investments	Regeneration of the dune system, protection of the bluff The introduction of native species in bluffs and natural storm drainage to prevent erosion and strengthen the storm water runoff	Increased resilience and preservation of sandy ecosystems; stakeholders' engagement Shadow effects; altered landscape; replicability
Vehicular traffic and parking planning	Easy to implement; low cost; improves; access/ resistance of users	Decreased use pressure and vehicular traffic on the edge of the bluff	Protection of bluffs; traffic security; alteration of uses in the community
Sustainable drainage system	Efficient; cost-effective/ investments; medium maintenance	Improved rainwater evacuation to protect the bluffs from erosion	Protection of bluffs; improvements in beach quality and accessibility
Road restructuring	Easy to implement; cost-effective; improves access/investments; medium maintenance	Reprofiling of the slope to cushion the rain flows over the bluffs and dunes	Protection of bluffs; facilitation of circulation
Signposting	Easy to implement; low cost / medium maintenance	Identification of adaptation measures undertaken by the visiting public and responsible tourist use	Environmental education and community ownership
Monitoring	Easy to implement; low cost; cross-comparison / low accuracy; medium maintenance	Monitoring of beach profile; early warning (EW) for sand loss	Short-term management; EW of sand loss; community involvement

Vehicle traffic and parking planning.

About 300 m of wooden fences were placed at the “Parador Chico” camping area to prevent Sport Utility Vehicle parking and circulation.

Billboards and signage.

Billboards were installed aimed at educating tourists and visitors including contact numbers in the case of occurrence of emergencies or complaints.

The traffic planning, the installation of wooden fences and the signage stimulate the growth of replanted species, increase the resilience to face extreme events and promote effective environmental citizenship, respectively.

The pros and cons of implemented management options are summarised stating their links to the environmental and human community issues (Table II).

4.4 Beach profiling

Beach profiling was done from the front of the “Parador Chico” as part of the national beach monitoring network and to survey sand accumulation by captor fences. Since the installation of captor fences, a 30 per cent increase in beach profile and a thickening of the

berm area were observed. The evolution of beach profile before and after the soft intervention and the desired state for the near future are shown in Figure 5.

4.5 Summary of outcomes of the management process undertaken

The main outcomes of the implemented management process developed in San José are as follows:

- The achievement of ICM and EbA actions needed capacity building, socio-institutional innovation and stakeholders' participation through the VRA approach was developed.

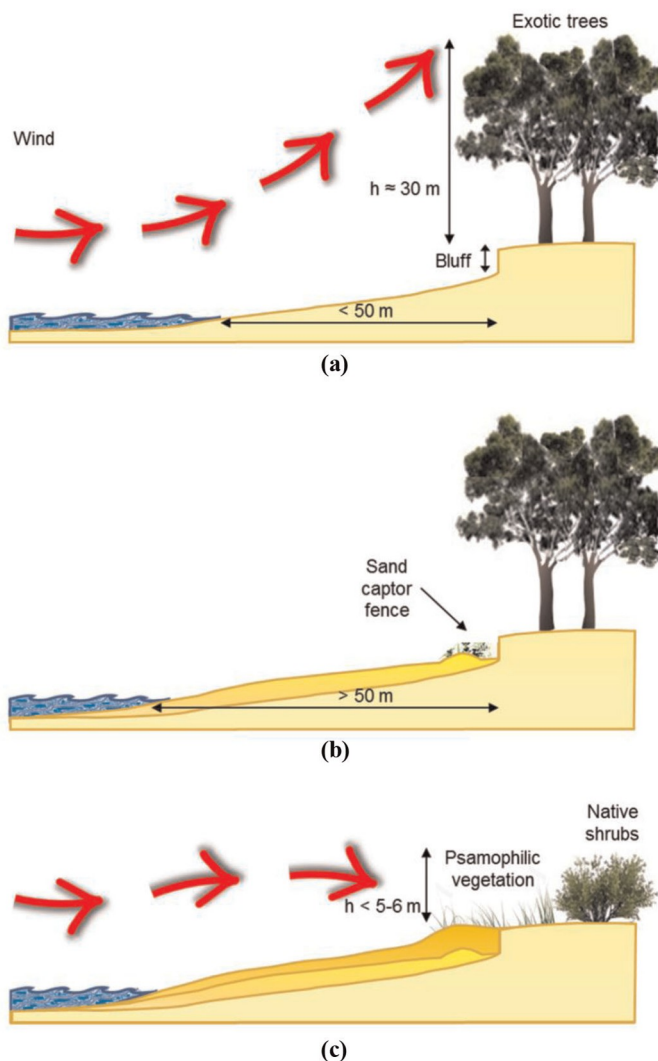


Figure 5. Schematic representation of the beach profile before (a) and after (b) the soft intervention in 2013 (inspired by Kim *et al.*, 2014); the desired near-future state (c) shows an ideal rebuilding of both beach profile and ridge of dunes

- The life cycle five-step management process (Olsen, 2003) followed for the selection and implementation of a set of agreed measures (soft works, capacity building and monitoring) – allow building local capacity and ensure its sustainability through the incorporation of scientists, decision makers, stakeholders and local knowledge and culture. In doing so, the buy-in from interested parties, scientific rigour and local legitimisation are facilitated (Gray *et al.*, 2014; Huq *et al.*, 2013).
- The dune reconstruction and the replacement of the forested park by the resilient deciduous native forest species close the recovery cycle. The former allows accumulating sand due to the presence of vegetation which captures sand and recycles its structure after each windstorm event. The latter reduces the impacts of extreme weather events on coastal bluffs while allowing sunlight to reach the dune grasses to develop and consolidate the dunes.
- A by-product of EbA measures is the building of a nursery at Kiyú to generate endogenous capacities for the production of both native psammophyte forest and herbaceous species, and specimens since late 2014.

These experiences were incorporated into the planning of the second cycle of coastal management in 2014 (e.g. installation of 1,000 linear meters of sand captor fences per year and displacement of touristic infrastructure far away from the bluffs). Both the DOCC and EbA activities were budgeted in the fiscal year 2015 to expand the actions along the coast of San José, whereas from 2015, all the sub-national coastal governments had incorporated EbA approaches in their coastal management.

The implications of EbA measures implemented at Kiyú are reported in the literature, e.g. they generate stakeholders' capacities, enable socio-institutional innovation (Naumann *et al.*, 2013; Rabbani, 2010; Rubin and Rossing, 2012) and reduce local perceptions of vulnerability to climate variability and extremes (Stein *et al.*, 2013; Vignola *et al.*, 2009).

This new socio-institutional structure implies the interchange, mobilisation and use of knowledge between research users and scientific producers, a process defined as "knowledge exchange" (Mitton *et al.*, 2007), which is likely to increase the use of knowledge and evidence in policy and practice decisions (Cvitanovic *et al.*, 2015).

This institutional learning process is a success of the Kiyú management experience, as previously suggested by Nagy *et al.* (2014b) for another successful experience (Laguna de Rocha sand bar management, Conde *et al.*, 2015) because it assures the sustainability of science-based participatory management initiatives.

The mix of ICM steps and EbA approaches are possible, thanks to new socio-institutional structure and adaptive governance, that is to say: Understanding environmental change and using information in decision-making to sustain the resilience of desirable ecosystem states while reviewing decisions as new information becomes available (modified from Evans *et al.*, 2011), which is followed since 2015 as part of the evaluation process.

5. Conclusions, lessons learned and recommendations

5.1 Conclusions

The Kiyú management process allows the articulation of local stakeholders with local, sub-national and national-level decision makers. This socio-institutional ICM framework facilitates the implementation of effective coastal EbA measures for the preservation of coastal systems and to cope with extreme events. Stakeholders' participation in the management process provides social legitimacy and consolidates trust and knowledge exchange between stakeholders, government managers and scientists.

This experience is a valuable input for DINAMA's national adaptation plan (NAPA) for coastal areas and Coastal Management Division. The set of tested EbA measures could be replicated at the country's coastline, which is currently facilitated by the progressive incorporation by local governments of EbA approaches.

Some successes of the Kiyú experience are the:

- rapid recovery of sandy beach and dunes after the implementation of measures;
- socio-institutional learning process and strengthening;
- capacity building in soft ecological actions (green infrastructure) to sustain the process;
- subnational and local governments budget for ICM and EbA activities; and
- mainstreaming of EbA approach at the scale of the sub-national and local governments.

5.2 Lessons learned

The implementation of EbA measures catalysed the development of useful by-products for the ICM of San José:

- the VRA provides inputs for participatory Scenario Planning of futures and adaptation plans;
- the nursery to sustain a progressive reforestation to stabilise the dune system;
- the DOCC allows reaching cross-sector efficient coastal management partnership with the national government and stakeholders, beyond the specific climate adaptation goals; and
- the creation of the DOCC by the sub-national government is an example of knowledge exchange.

5.3 Recommendations

Further actions need to be implemented to achieve the desired state of Kiyú landscape and ecosystem, e.g. to prevent storm drains continue wetting the recovered sand, the displacement of the touristic infrastructure far away from the bluffs and to organise a fourth VRA to evaluate outcomes.

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