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The risk to lose ecosystem services due to climate change: A South American case

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ABSTRACT

The effects of the global climate change on oceans and coastal areas are manifested in many ways. In coastal environments, the climate change influence on coastal ecosystems is particularly worrisome, affecting their configuration and restricting the ecosystem services they produce and their benefits to nature and society. This possible loss of ecosystem services translates well the significance of the "environmental risk" that climate change can cause. An assessment of the environmental risk generated by climate threats in coastal ecosystems was carried out through a South American case study developed on the Southern coast of Brazil – Estuary of Patos Lagoon. The study involved the implementation of a model that estimates the risk of losing ecosystem services used by different stakeholder groups as a function of (1) the climate threat, (2) the value of the service defined by the stakeholder perception, and (3) the vulnerability of each group in relation to a possible service loss. Based on information generated by scenarios predicted by the Intergovernmental Panel on Climate Change (IPCC) and from a significant database collected from interviews of several service users, the model was able to generate levels of risks for different conditions. The calculated risk values, standardized to values between zero and one, allow numerous possibilities of evaluation for ecosystems, user groups and climate variability indicators. Moreover, the model appears as a tool capable of generating comparative risk levels and can help to establish environmental management policies related to the climatic effects and the necessary adaptations.

1. Introduction

The climate change we are currently experiencing has affected ocean and coastal systems in different ways. Such effects include changes in the temperature of the oceans, the acidification of their waters and an apparent elevation of the mean sea level (IPCC, 2007; Vermeer and Rahmstorf, 2009). This set of changes in the physical aspects of oceans and coasts specifically affects the ecosystems that make them, producing important changes in their ecological functions. An important consequence of these changes is the damage to ecosystems and the consequent elimination of ecosystem services they produce (Barbier et al., 2010; Day et al., 2008).

An emblematic case of the global climate change effect on coastal systems in South America can be observed in the estuarine region of Patos Lagoon, located in the Southern coast of Brazil (Fig. 1) (Asmus et al., 2013). The estuary region of Patos Lagoon is characterized as a place that concentrates numerous economic activities with emphasis on port and industrial activity, urban development, tourism (mainly in the summer period), agriculture and aquaculture. The city of Rio Grande is the main urban concentration in the so-called Low Estuary of the Patos Lagoon (LEPL), near the connection with the Atlantic Ocean, in a coastal plain of very low relief (Asmus and Tagliani, 2009). In this region, climate change has been mainly reflected in an increase in the frequency of extreme weather events, represented by the occurrence of heavy rains, intense winds and hail precipitation. An example of the intensification of these extreme climatic events is the increasing occurrence, in the region, of explosive cyclogenesis, a meteorological event that concentrates, in a short period of time, great concentration of rain associated with intense winds (Palmeira and da Silva, 2002; Reibota et al., 2009). They are known, in popular terms, as "hydraulic bombs", generating flooding in urban, rural and natural areas along the estuary. Another significant event in Southern Brazilian region was the Catarina Hurricane in 2004, considered as the first and, so far, only recorded hurricane in the Southern Hemisphere and an indication of the surface temperature increase in the South Atlantic (McTaggart-Cowan et al., 2006).

All this extreme set of events associated, in principle, with climate change and its regional and local effects have the potential to reach and affect the ecosystems that make up the coastal zone. There is the possibility of temporarily or definitively changing the ecosystems

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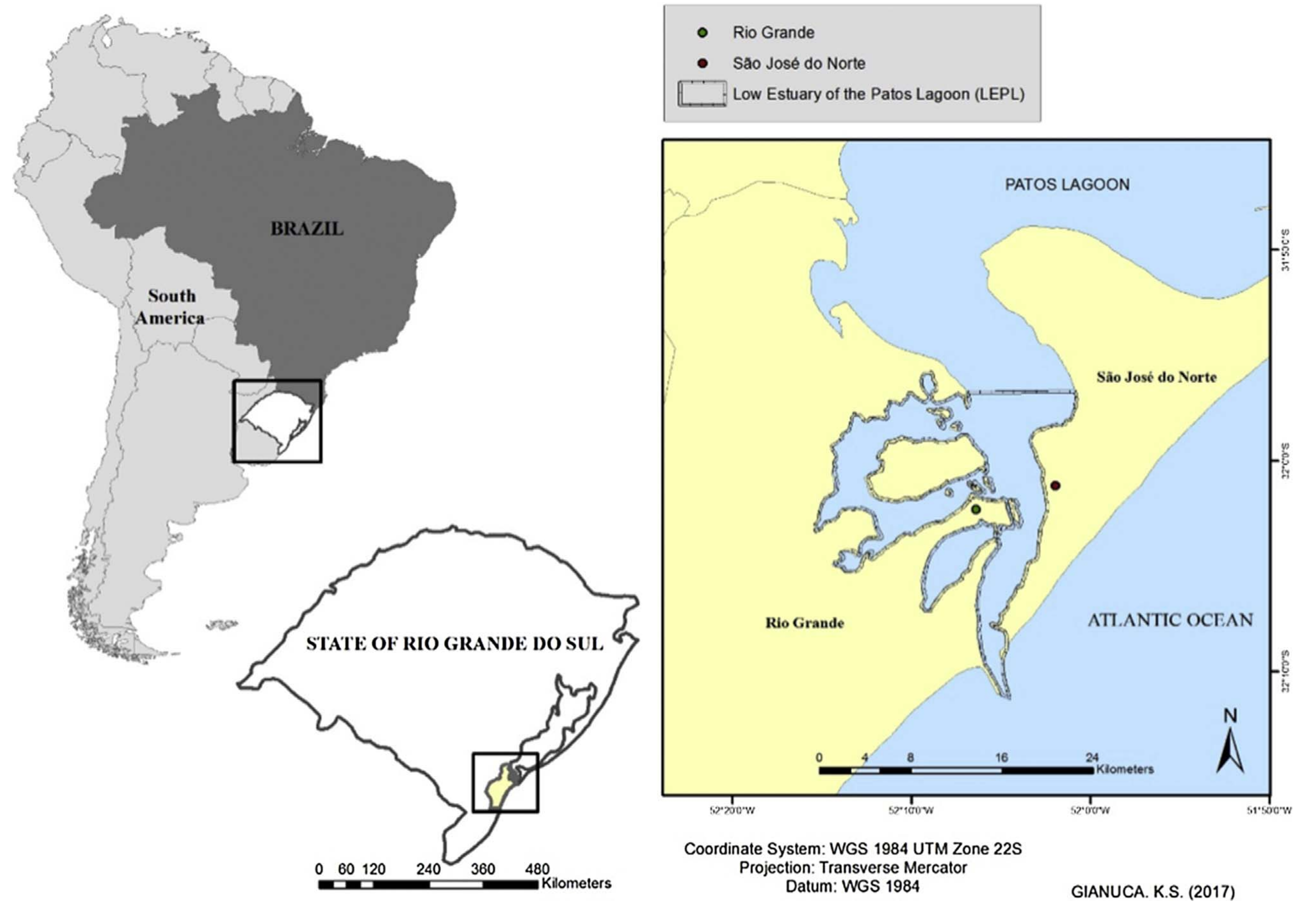

Fig. 1. Location of the studied area.

characteristics, through changes in their structures and functions, capable of compromising the ecosystem services. Such changes may adversely affect the quality or health of coastal ecosystems or impair the social and economic activities that make use of or depend on ecosystem services for their development. Eventually, the result of the eventual loss of services due to extreme events would affect, not only the coastal environmental quality, but also the level of social welfare of communities that inhabit the coast or depend on it for multiple activities. There is, therefore, an environmental and social risk present in the effect of climate change on the coastal zone (Galindo and Samaniego, 2010).

Some initiatives to develop methodologies or models for assessing environmental risk motivated by climate change in coastal zones can be observed (Soldati et al., 2011; Fitchett et al., 2016). They are methods or models that present a considerable level of complexity (Thumerer et al., 2000; Iyalomhe et al., 2015) or require a significant information base for their development or validation (Frihy and El-Sayed, 2013; Richman and Andrews, 2016).

However, in places such as the estuarine region of the Patos Lagoon there is no assessment or measurement of the environmental risk associated with extreme climatic events that have occurred in an increasing way. There is no information about the cause of the risks, the type of risk involved, where the risk manifests or even to which social group the risk is more directed. Such lack of information becomes a significant constraint to the establishment of a model of coastal management that can prevent, mitigate or compensate for any risks posed by climate change in the coastal zone. It also constrains the possibility of establishing a public policy capable of organizing and integrating actions and institutions directly or indirectly involved in the coastal management of possible risks and their effects on coastal environmental systems. Situations such as these are relatively serious in regions where state or local government initiatives have not yet reached the establishment of management support instruments and their necessary governance as envisaged in the Brazilian coastal management policy, as observed in the Patos Lagoon Estuary (Asmus and Tagliani, 2013).

Concerning with the need to generate a new information base for coastal management initiatives adaptable to the effects of climate change, the present work aims to suggest environmental risk assessment procedures in coastal systems using the Patos Lagoon Estuary as a study of case. The results presented are part of the project “Risk, perception and vulnerability to Climate Change in wetland-dependent coastal communities in the Southern Cone of Latin America” (Conde et al., 2015).

2. Materials and methods

For the carried-out analysis we assumed the concept that Environmental Risk can be understood as the “risk of losing ecosystem services”. In the same way, climate change is considered as a driver in the generation of environmental risks.

The estimation of the environmental risk in the scope of possible threats present for each ecosystem service and stakeholder was obtained through the use of the following predictive model proposed by Lozoya et al. (2014), adapted from Lozoya et al. (2011):

$$R_{ES-STK} = A_{ES} \times VAL_{ES} \times VUL_{STK}$$

In the model $R_{ES\text{-}STK}$ – environmental risk in the context of the possible threats present for each ecosystem service and stakeholder – appears as a function of how the ecosystem service provision is affected by a threat (A_{ES}), the value of the ecosystem service (VAL_{ES}) and the vulnerability of stakeholders’ users of services (VUL_{STK}). In their original version (Lozoya et al., 2014), the stakeholders (A_{ES}), (VAL_{ES}) and

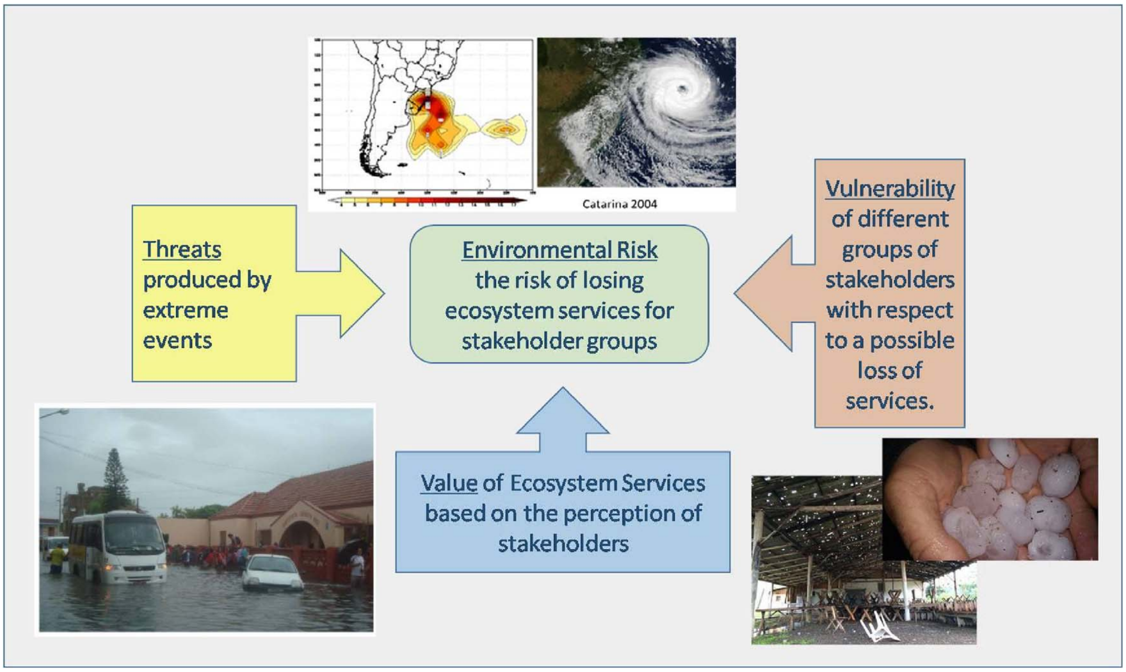

Fig. 2. Considered elements for environmental risk calculation in the studied area.

(VUL_{STK}) are composed by elements of greater detail that express several characteristics and controls intrinsic to ecosystem services and the stakeholders' vulnerability. All the stakeholders in the model are considered normalized and assume values between 0 and 1.

In applying the model in the Patos Lagoon Estuary, there was a methodological adjustment from the original one, in the sense of evaluating (A_{ES}), (VAL_{ES}) and (VUL_{STK}), in an integrated way, with specific procedures for each stakeholder. Regardless of the methodological adjustment adopted, the normalization of the model stakeholders was maintained in such a way that the calculated values for environmental risks ($R_{ES\text{-}STK}$) remained between 0 and 1. This normalization allows the results obtained in the Patos Lagoon Estuary to be comparable to others obtained with similar procedure. The main elements considered for risk calculation process are shown in Fig. 2.

The characterization of ecosystem services occurred through the elaboration of the Ecosystem Services Worksheet. It is consisted of (1) the main ecosystems, (2) the main ecosystem services generated by the considered ecosystems, (3) the types of services classified as support, regulation, provision and cultural (de Groot et al., 2002), (4) the main ecological and socioeconomic benefits generated by the services and (5) the stakeholders benefited by the services/benefits.

For the generation of "Indexes of Threats" related to climate change, sea level elevation and precipitation intensity, we used several scenarios based on reports from the IPCC. The RCP4.5 scenario was used as of moderate change in sea level and precipitation intensity and the RCP8.5 scenario was used as of severe change of these elements (IPCC, 2013).

The identification of the main threats, ecosystems, services and benefits in the study region occurred through a bibliographic review and based on "expert opinion" of scientists involved with ecosystems studied in the area. To this end, a series of workshops was conducted in 2014 at the Federal University of Rio Grande – FURG (Brezolin et al., 2014) for this specific purpose, applying principles of "expert opinion systems", defined as procedures capable of capturing the knowledge of experts in a given field, representing this knowledge on a data basis, and transmitting it to the user (Waterman, 1986; Vasconcelos and Martins-Júnior, 2004). That allowed us to obtain answers to questions related to the knowledge base of the system under consideration. Possible uncertainty around the produced data from such expert elicitation can relate to epistemic or aleatory uncertainty, as proposed by Regan et al. (2002). Following the suggestion from Martin et al. (2011), we tried to reduce uncertainty by increasing as possible the "sampling size" or the number of participants in the expert elicitation process.

Additionally, the evaluation of the main services, benefits and vulnerability of stakeholder with respect to a possible loss of services/benefits were made through interviews with representatives of several stakeholders, assumed as having a strong relationship with the ecosystem services and considered benefits. These "qualified informants" (Ghermandi et al., 2015) contributed to an adjustment in the configuration of the services/benefits considered and to a semi-quantitative evaluation, here assumed as "social value of ecosystem services".

The theoretical premise to establish the definition of social perception is based on the understanding that the man-nature relation is structured in the realization of work, here understood as the capacity to transform nature through socio-productive processes in means to ensure social and economic development of society. (Foster, 2005; Mezaros, 2009). The identification of the stakeholders considered the relation of use that they establish with the natural environment and the diverse ecosystem services. In order to do so, we sought to locate the various services and their users in the studied territory and searched for representative subjects of each category. The interviews were carried out based on a semi structured questionnaire with open questions, which characterizes the qualitative social research and the interpretation of the discursive information from the relation of the discourse of social change, as proposed by Fairclough (2001).

3. Results

The 20 ecosystems/environmental systems identified in the study were as follows: sandy beaches, coastal dunes, fresh marshes, saltmarshes, coastal fields, coastal forests, coastal lagoons, Intertidal plains, shallow waters, sea grass beds, intermediate depth zone, channels, estuarine beaches, agriculture systems, urban s areas, industrial areas, port area, forestry, jetties, and wind farms (Fig. 3).

For the presentation of the results we decided to select three representative ecosystems in different stages of development that were: saltmarshes (close to natural condition), agriculture systems (moderately developed) and urban areas (quite developed). The Ecosystem

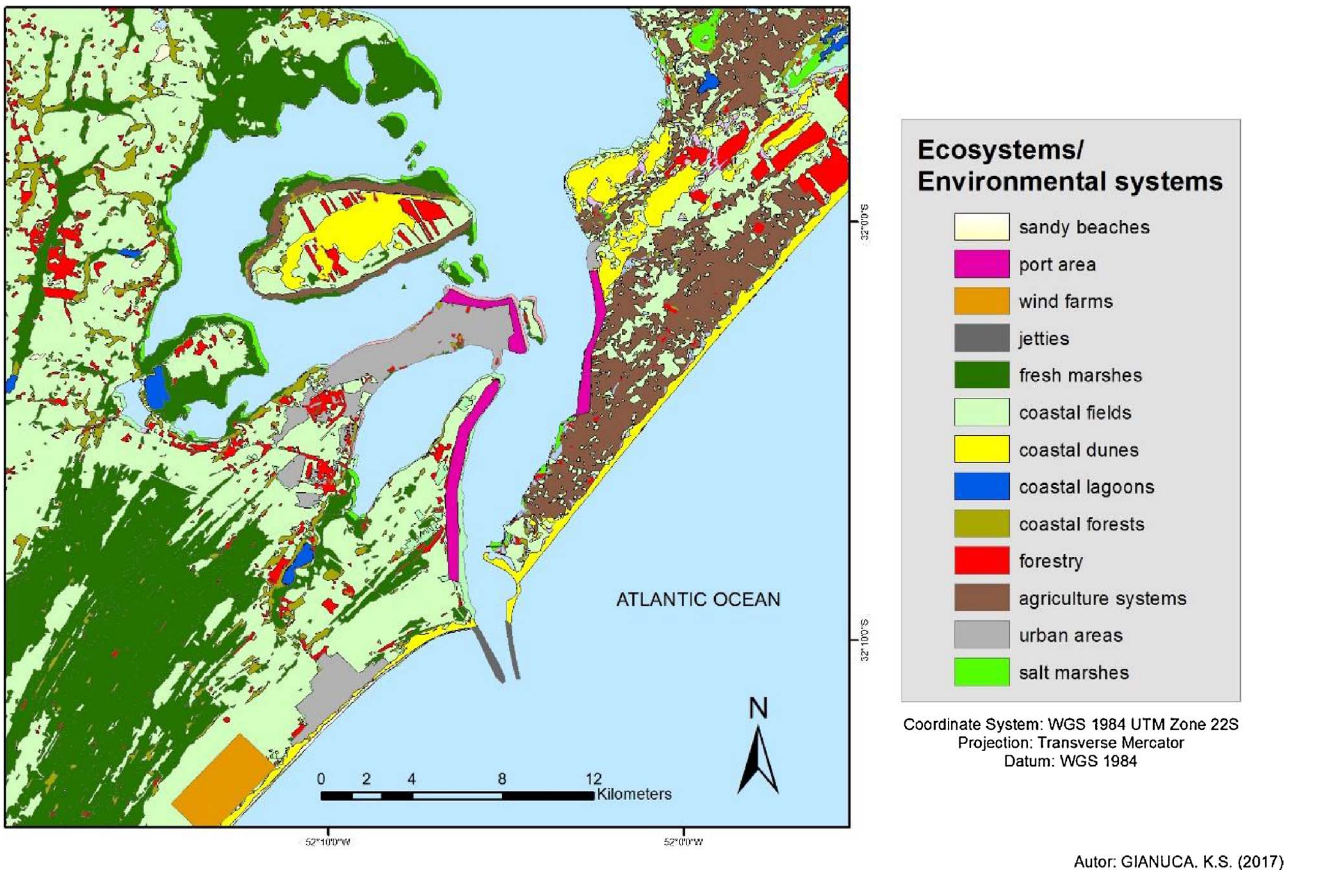

Fig. 3. Distribution of the main ecosystems in the low estuary of Patos Lagoon.

Table 1
Ecosystems, services, benefits and actors benefited in the estuary of Patos Lagoon.

Ecosystems	Classification	Services	Benefits	Actors
Saltmarshes	Support	Refuge area		
	Provision	Biomass production	Artisanal fishing	Artisanal fishermen
	Regulation	Flood control/filtration	Security for occupation/Water quality	Local community
	Cultural	Scenario	Contemplative value/environmental education	Local community, tourist/visitors, educational institutions, NGOs
Agriculture systems	Support			
	Provision	Biomass production	Food production	Family farmer
	Regulation	Economic regulation	Social relationships	Rural community
	Cultural	Cultural reproduction	Social relationships	Rural community
Urban areas	Support	Urban services	Accessibility to services/Social well-being	Local community/visitors/tourists/Government sector
	Provision	Waste/noises	Recycling	Local cooperatives/Local community
	Regulation	Economic regulation	Social and institutional relationships	Local community
	Cultural	Cultural reproduction	Social and institutional relationships	Local community

Services Worksheet for the selected ecosystems is presented below (Table 1):

3.1. Threat assessment on the considered ecosystem services

The Intergovernmental Panel on Climate Change (IPCC) believes that global warming is unequivocal and, since the 1950s, many changes have been observed, some of which have been unprecedented for decades to millennia. The atmosphere and ocean have warmed up, amounts of snow and ice have declined, sea level has risen, and concentrations of greenhouse gases have increased.

As a way of understanding and predicting the consequences of this phenomenon on the planet, the IPCC has been proposing, since 1990, scenarios of different degrees of pessimism regarding the effects of climate change on the globe since its first report. The scenarios were updated in the publication of the fifth (and most recent) report in 2013 (IPCC, 2013). This update consists of a combination of adaptation and mitigation and aims to produce a range of responses to continuous warming. The most optimistic scenario is one where there is a strict mitigation of the causes of global warming (scenario RCP2.6) and the most pessimistic scenario considers that nothing or very little will be done in terms of mitigation and adaptation (scenario RCP8.5).

The scenarios RCP4.5 (moderate) and RCP8.5 (extremely pessimistic), with predictions up to the year 2065, were used to define the threat levels of this work, taking into account the following threats: (1) precipitation;(2) extreme events and; (3) elevation of mean sea level. Each scenario was treated separately in worksheets for the classification of the level of threat against an ecosystem service. The projections for the scenarios in question can be visualized in Table 2.

From the projections mentioned in Table 2, it was sought to

Table 2
Projections for the IPCC RCP4.5 and RCP8.5 scenarios up to the year 2065 in relation to the following threats: Surface temperature increase, Average sea level increase, Average precipitation changes.

Scenario	Average surface temperature (C°)	Average sea level (m)	Average precipitation
RCP4.5	average: 1.4; max: 2.0	average: 0.26; max: 0.33	between 15 and 30%
RCP8.5	average: 2.0; max: 2.6	average: 0.30; max: 0.38	between 15 and 30%

Table 3
Threat level classification according to the possible consequences on ecosystem services.

Threat level	Definition and possible consequences for services
0	No threat.
0.25	Real threat- can cause small short-term losses in relation to the service.
0.5	Real threat- may have relevant short to medium-term consequences in relation to the service.
0.75	Serious threat- may cause serious losses in the medium-long term of the service.
1	Very serious threat- may result in a complete and/or long-term loss of service.

qualitatively define the level of threat in relation to the service provided by each ecosystem according to the classification proposed in Table 3. This definition occurred in two workshops that were attended by specialists from the Federal University of Rio Grande, where each ecosystem and services were described, and mentioned their classification and the benefits and stakeholders involved. In this way, it becomes possible to analyze the effect on the services, due to the affectation of the set of ecosystems that provides them by the threats.

The results obtained in this step, in relation to “extreme events” (the main threat in Patos Lagoon Estuary) for the selected ecosystems (saltmarshes, agriculture systems, and urban areas) can be visualized in the table that follows (Table 4). After defining the degree of threat according to the pre-established scenarios (Table 3), the next step was to define the contribution percentage that each ecosystem in the estuary provides for the maintenance of a certain service (Table 5). This procedure considered, as premise, the results related to the level of threats classification, and from the holding of a new expert meeting (further presented in the integration and discussion).

3.2. Assessing the value of ecosystem services and stakeholders’ vulnerability

Data gathered from field campaigns used, as a reference, the ecosystems composing the Ecosystem Services Worksheet. It helped to identify stakeholders intrinsically linked to these ecosystems through a relationship of dependence on the services offered by such ecosystems for their socioeconomic reproduction. This choice was due to the fact that those stakeholders – would be the first to suffer the consequences of an eventual loss of such services due to climatic changes.

Stakeholders’ groups with broader geographically distribution along the estuary and, at the same time, presenting the largest possible kinds of dependence relationships with ecosystems were prioritized for data gathering. Thus, 14 locations were selected in the city of Rio Grande (west side) and another 5 in the city of São José do Norte (east side) (Fig. 4), where interviews were conducted with 27 stakeholders.

The semi-structured interviews helped to understand the importance that stakeholders at the estuarine area attribute to ecosystem services they benefit from, as well as the perception of their environmental vulnerability to which these services are prone to extreme atmospheric events. During the interviews, photos of the ecosystems occurring in the estuary were shown to the stakeholders, so that they could identify those that are peculiar to them or ecosystems they are in daily contact.

Complementary to the interviews, experts were asked to analyze the stakeholders' perception of the services they are dependent on, as well as their perception of the vulnerability related to extreme atmospheric events. It showed to be important because, despite the perceptions that individuals have about the benefits of ecosystem services, there are benefits that sometimes are not perceived or that for your understanding a more advanced technical knowledge is needed, such as nutrient cycling and sediment storage services. In other words, the results were based on a combination of the perception that the stakeholders have about the services more related to their place of residence and work with those services that were not easily perceived by stakeholders, but based on expert opinion.

To fit in the general model, values between 0 and 1 were attributed to reflect the importance of ecosystem services to stakeholders, as well as to the vulnerability of such services to extreme atmospheric events. Regarding the importance of services, the scale used was as follows (Table 6)

To quantify the vulnerability of ecosystem services related to extreme weather events and, consequently, the vulnerability of the communities that depend on these services, the following scale was used (Table 7):

The potential lack of awareness by stakeholders who are prone to

Table 4
Calculation of Threat values to Environmental Services (A_{ES}) in relation to the “extreme events” (rain, hail and high winds) for selected ecosystems.

Ecosystems	Classification	Services	Benefits	Actors	IPCC scenarios	
					RCP4.5	RCP8.5
Saltmarshes	Support	Refuge area			**0.25**	**0.5**
	Provision	Biomass production	Artisanal fishing	Artisanal fishermen	**0.25**	**0.5**
	Regulation	Flood control	Security for occupation	Local community	**0.25**	**0.25**
		Filtration	Water quality	Local community	**0.25**	**0.25**
	Cultural	Scenario	Contemplative value/environmental education	Local community, tourist/visitors, educational institutions, NGOs	**0.25**	**0.25**
Agriculture systems	Support					
	Provision	Biomass production	Food production	Family farmer	**0.75**	**1**
	Regulation	Economic regulation	Social relations	Rural community	**0.75**	**1**
	Cultural	Cultural reproduction	Social relations	Rural community	**0.75**	**1**
Urban areas	Support	Urban services	Accessibility to services /Social well-being	Local community/visitors/tourists/Government sector	**0.75**	**1**
	Provision	Waste/noises	Recycling	Local cooperatives/local community	**0.25**	**0.25**
	Regulation	Economic regulation	Social and institutional relations	Local community	**0.5**	**0.5**
	Cultural	Cultural reproduction	Social and institutional relations	Local community	**0.25**	**0.25**

Table 5
Calculation of Threat values to Environmental Services (A_{ES}) in relation to the "extreme events" grouped by type of Ecosystem Service, and the Percentage Contribution by Service of each Ecosystem, for selected ecosystems.

Classification	Services	Ecosystems	Contribution to the service (%)	Benefits	Actors	IPCCs Scenario	
						RCP4.5	RCP8.5
Support	Nutrient cycling	Salt marshes	30	Water quality	Local community/Artisanal	**0.5**	**0.75**
	Refuge area	Salt marshes	60			**0.25**	**0.5**
	Urban services	Urban areas	100	Access to services/Social well-being	Local community/visitors/tourists/Government sector	**0.75**	**1**
Provision	Biomass production	Salt marshes	25	Artisanal fishing	Artisanal fishermen	**0.25**	**0.5**
	Biomass production	Agriculture system	25	Food production	Family farmer	**0.75**	**1**
	Waste/noises	Urban areas	100	Recycling	Local cooperatives/local community	**0.25**	**0.25**
Regulation	Erosion control	Salt marshes	25			**0.25**	**0.5**
	Flood control	Salt marshes	60	Security for occupation	Local community	**0.25**	**0.25**
	Filtration	Salt marshes	60	Water quality	Local community	**0.25**	**0.25**
	Economic regulation	Agriculture system	15	Rural social relations	Local community	**0.75**	**1**
	Economic regulation	Urban areas	20	Social and institutional relations	Local community	**0.5**	**0.5**
Cultural	Scenario	Salt marshes	3	Contemplative value/environmental education	Local community, tourist/visitors, educational institutions, NGOs	**0.25**	**0.25**
	Cultural reproduction	Agriculture system	20	Rural social relations	Rural community	**0.75**	**1**
	Cultural reproduction	Urban areas	35	Social and institutional relations	Local community	**0.25**	**0.25**

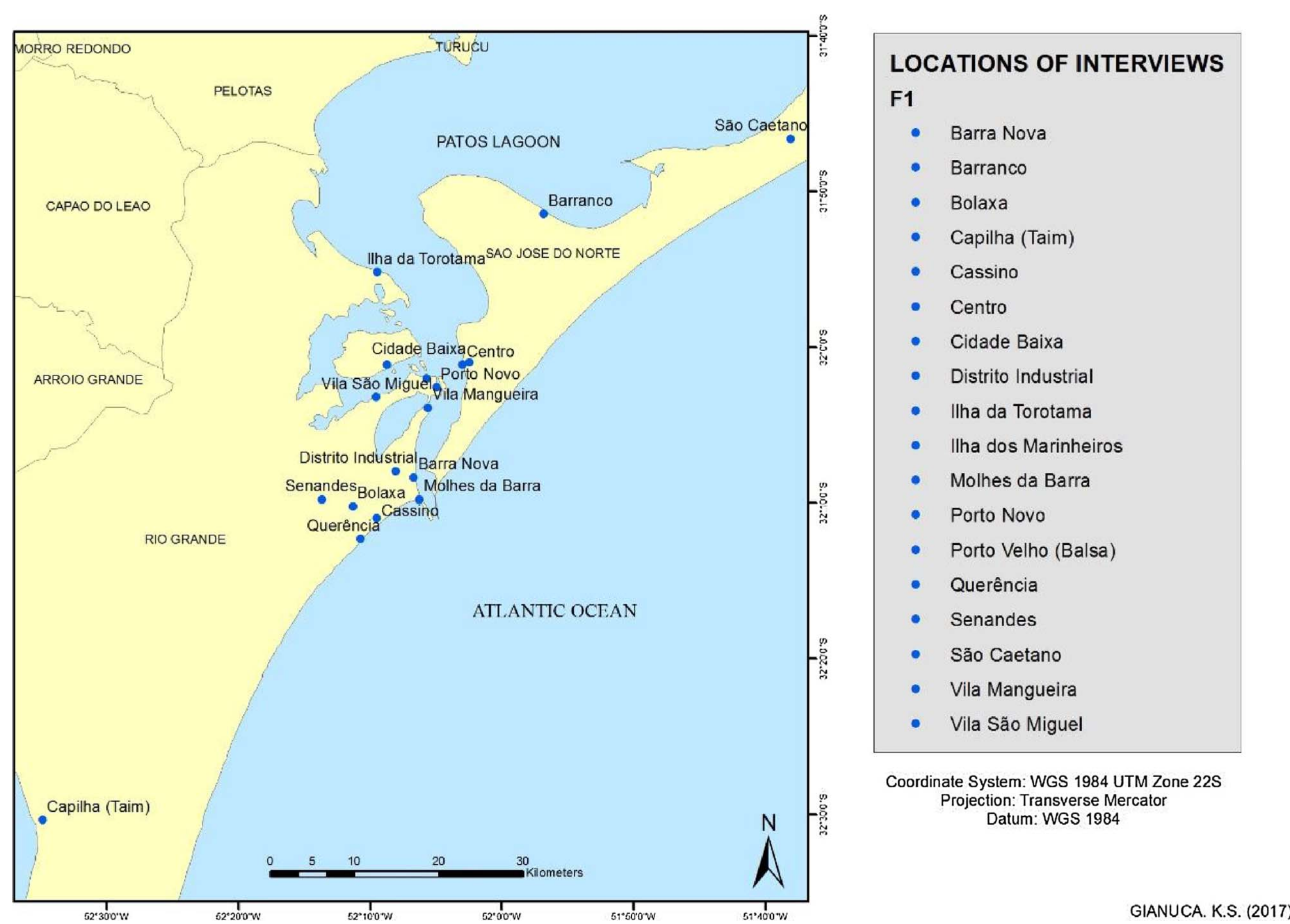

Fig. 4. Selected locations for interviews.

the loss of ecosystem services due to extreme atmospheric events increases their vulnerability to such threats. On the other hand, the understanding that such threats can lead to the loss of services in which these stakeholders benefit, reduces vulnerability in the sense that it allows better coping in preparing them for such events. Therefore, the final objective of such quantification is the support for decision making by managers, since priority actions can be defined for those ecosystems and communities facing higher vulnerability.

Results were compiled by localities, including: Balsa RG-SJN, Barra Nova, Bolaxa, Cassino Industrial District, Torotama Island Marinheiros,

Table 6
Scale Value Assigned to Ecosystem Services.

0	He/she does not mention anything about such a service.
0.5	He/she recognizes the importance, but such service is not indispensable to his/her work/home.
0.75	Important for his/her activity, but not indispensable.
1	Recognizes the importance of the service and it is fundamental for their work/home; It is important for their social, cultural and economic reproduction.

Table 7
Scale Value Assigned to Vulnerability.

0	No vulnerability.
0.5	Medium Vulnerability- Certain service may, in some way, be in a condition of vulnerability to extreme atmospheric events;
0.75	High vulnerability- The services are vulnerable to extreme atmospheric events due to the occurrence of such events at any given time.
1	Absolute vulnerability- The services have high vulnerability to extreme atmospheric events due to the high frequency of such events in the region.

Vila Mangueira, Molhes da Barra, Porto, Querência, Senandes, Taim and Vila São Miguel, in the city of Rio Grande, and Centro, Cidade Baixa, Barranco, Gravatá and São Caetano, in the city of São José do Norte. For each locality, we produced the indexes for Value of Ecosystem Services and Stakeholders' Vulnerability capable to fit the Environment Risk Model. Those results are presented in detail in the complementary information at http://ppgc.furg.br/images/general/Asmus-et-al-ANNEX.xlsx. The combined distribution of indexes can give some clue and indications about the spatial distribution of the ecosystems and communities considering the frequency and types of extreme atmospheric events. A set of information that can suggest some adaptation systems used by the stakeholders in relation to each kind of event.

The interviews showed that, from the perception of the stakeholders surveyed, the estuary is more vulnerable to climatic events such as rains, hail, floods and strong winds that directly affect their houses sites as well as their livelihood. It is also clear, in these communities, a working relationship established straight with nature, especially in the cases of artisanal fishing and family farming.

Among the investigated localities, it was verified that the communities most vulnerable to climatic events were the Torotama Island and Taim in the city of Rio Grande, and Gravatá and São Caetano in the city of São José do Norte. We also observed that some more exposed communities to extreme events adopted different kinds of spontaneous adaptations, as in Marinheiros Island where the local community developed bamboo fences to protect them against strong winds.

It was clear that the perception about ecosystem services and vulnerability is something subjective and, therefore the analysis of interviews was mediated through the analysis of the researchers involved. Failure to perceive a specific vulnerability means that he or she is even more vulnerable to some threats.

4. Integration and discussion

The final and integrated evaluation of the results suggests that the objectives have been acceptably achieved. Despite being based on an innovative and non-trivial methodology for environmental risk assessment, the values of threats for ecosystem services, values of services (from the perception of stakeholder) and vulnerability of stakeholders to threats were adequately produced for the Low Estuary of Patos Lagoon (LEPL). In the same way, the relative importance of each ecosystem for generating the services in the studied area was estimated. All this information together can feed the proposed model and allow the calculation of environmental risks under several circumstances.

The importance of different ecosystems for the generation of some selected important services for the community are presented as follow in Fig. 5. They are: Biodiversity Production, Biomass Production, Navigability, Landscape (or landscape attractiveness) and Flood Control.

The results demonstrate the relative importance of different ecosystems to generate essential services for the estuary, which can be taken as an important information base for estuary planning and management policies. The prominent role of saltmarshes, for example, to guarantee the Flood Control Service (Fig. 5) supports an initial premise of the study, in the sense of wetlands importance in the control of floods, possibly caused by extreme climatic events, driven by global climate change.

A practical aspect of the results is the fact that the entire evaluation of threats (A_{ES}), Values of Services (VAL_{ES}), and Vulnerability (VUL_{STK}) have followed the standardization proposed in the study and produces, through the model, values between zero (no risk) and one (maximum risk or risk of loss of the totality of the service). In this sense, the information provided by the model allows risk forecasts to be generated for any service, ecosystem or group of stakeholders in an isolated or combined manner, always generating a risk scenario within the established normalization.

The following is a demonstrative example: When we compare the risk to lose flood control service offered by the saltmarshes between the municipalities of Rio Grande and São José do Norte (municipalities that delimit the low estuary), we find different results. In Rio Grande (west side of the estuary), where a large part of the saltmarshes has been greatly altered or lost, the perception of the stakeholders about their role in the preservation of floods is non-existent. On the other hand, in São José do Norte (east side of the estuary), where marshes have a good degree of conservation, stakeholder attribute a greater value to the flood control service (Table 8).

The values obtained in this case are as follows:

(1) Flood threat (A_{ES}) to the "Flood Control" Service produced by the marshes when considering the IPCC scenario RCP4.5: 0.50
(2) Flood threat to the "Flood Control" Service produced by the marshes when considering the IPCC scenario RCP8.5: 0.75
(3) Integrated value of this service (VAL_{ES}) for the set of stakeholders interviewed in Rio Grande: Not recognized (zero)
(4) Integrated value of this service for the set of stakeholders in São José do Norte: 1.0
(5) Integrated Vulnerability (VUL_{STK}) of the set of Rio Grande stakeholders in relation to losing this service: Not recognized (zero)
(6) Integrated vulnerability (VUL_{STK}) of the set of stakeholders in São José do Norte in relation to losing this service: 1.0

When using the model, we obtain the following risks for the Flood Control Service:

Using the IPCC RCP4, for Rio Grande the calculated risk would be: (Risk = 0.5 × 0.0 × 0.0 = 0.0) and for São José do Norte the calculated risk would be: (Risk = 0.5 × 1.0 × 1.0 = 0.50). With the IPCC RCP8 index, for Rio Grande the calculated risk would be: (Risk = 0.75 × 0.0 × 0.0 = 0.0) and for São José do Norte the calculated risk would be: (Risk = 0.75 × 1.0 × 1.0 = 0.75).

That is, due to the altered condition of the marshes in Rio Grande and by the non-significant perception of the stakeholders regarding this service, the risk in losing it is represented as zero in the model. On the other hand, in São José do Norte, the risk of losing the same service by the role of the marshes (or, at least, perceived as) in that municipality is calculated as 0.50 and 0.75 depending on the used scenario of floods. In other words, the model suggests for São José do Norte a risk of service loss setting from about 50% in the most conservative scenario to about 75% in the most severe one.

The example taken is very simple and basically illustrative, but it clearly expresses the model's enormous flexibility in designing risk scenarios in endless combinations of ecosystems, stakeholders, services and/or activity or residential locations. In the same way, it is clear the

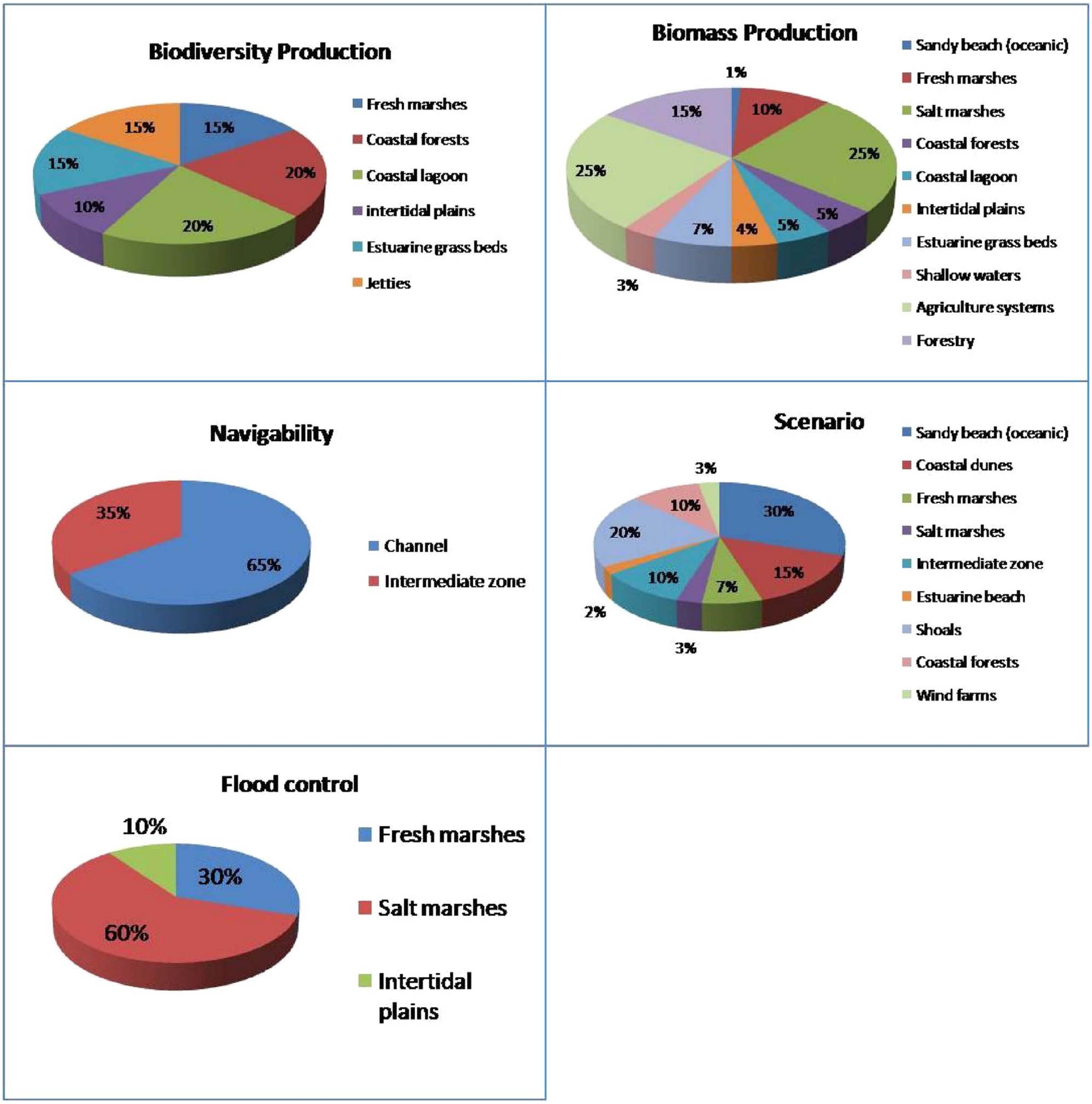

Fig. 5. Selected ecosystems for the generation of some important services for the community.

Table 8
Risk to lose ecosystem service (Flood Attenuation) perceived by local fishermen, for different saltmarsh conditions.

Service: Flood Attenuation – perceived by local fishermen		
Enviromental condition	IPCC Scenario*	Index of risk
Saltmarshes are badly conserved	**RCP4.5** Risk = 0.50 × 0.0 × 0.0 **RCP8.5** Risk = 0.75 × 0.0 × 0.0	0.0 “negligible” 0.0 “negligible”
Saltmarshes are well conserved	**RCP4.5** Risk = 0.50 × 1.0 × 1.0 **RCP8.5** Risk = 0.75 × 1.0 × 1.0	0,50 “considerable” 0.75 “more serious”

RCP4.5 (moderate change in sea level rise and precipitation).
RCP8.5 (severe change in sea level rise and precipitation).
Model Lozoya et al. (2014) $R_{ES\text{-}STK} = A_{ES} \times VAL_{ES} \times VUL_{STK}$.

possibility of the model being fed from a relatively simple database, possible of being easily and quickly generated. This feature can be considered as an innovative element in the proposed methodologies and models for the assessment of environmental risks caused by climate change in coastal zones. In this sense, its potential use for assessing environmental impacts caused by climate change in the region and as a key instrument for planning and management actions of the estuary seems to be undeniable. In this way, understanding the effects of extreme atmospheric events and climate change allows us to develop strategies that can mitigate their consequences. In addition, the results included in this data collection demonstrate, not only the events to which ecosystems are more exposed, but also point out the communities most affected, which helps to prioritize decision-making on where policies and environmental management actions should be concentrated.

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