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Vulnerability assessment of the pink shrimp small-scale fishery to climate change in southwestern Atlantic brackish coastal lagoons (Uruguay)

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ABSTRACT

Assessing vulnerability using semi-quantitative approaches provide an opportunity to analyze conditions of exposure, sensitivity and adaptive capacity of socio-ecological systems concerning climate change drivers and anthropogenic factors. We assessed the vulnerability of the small-scale pink shrimp fishery of Castillos and Rocha lagoons, two coastal Uruguayan ecosystems of the southwest Atlantic, considering social factors and climate change drivers which affect atmospheric-oceanographic conditions regionally and locally. Using a risk approach, we evaluated the ecological system's exposure to environmental drivers. Then we estimated the sensitivity and adaptive capacity of fishers and the local community (social system). High vulnerability found for this fishery results from a combination of large-scale environmental drivers impacting the ecological system, and social factors causing high sensitivity and low adaptive capacity of the social system. High risk level with adverse ecosystem effects triggered by climate change drivers acting on the distribution of this migratory crustacean in the southwest Atlantic region could promote adverse consequences on harvest duration and shrimp catch levels in the Uruguayan coastal lagoons. Fishers and their communities showed high sensitivity to a set of (demographic, economic, governance, cultural and technological) factors. The social system of both lagoons showed a low adaptive capacity to prevent social impacts or to mitigate climate change hazards. A broad set of social indicators was identified in Rocha lagoon to enhance fishers and community resilience, while the indicator set was narrower in Castillos lagoon. Lastly, weak governance, dormant fisheries laws, non-compliance of fisheries regulations and lack of climate early warning monitoring hamper the adaptability of these small-scale fisher communities under global change scenarios. Comparative evaluation of spatial, environmental and social settings between lagoons can offer lessons for upscaling the assessment and adaptation measures to other small-scale fisheries regionally and globally.

1. Introduction

Climate change (CC) is a natural process that anthropogenic actions (greenhouse gas emissions, deforestation, land-use change, habitat destruction) have exacerbated during the 21st century (Cooley et al., 2022). Its global impacts on the marine environment are promoting direct effects on sea temperature (Roemmich et al., 2015; Cheng et al., 2019), sea salinity (Durack et al., 2014; Durack, 2015; Cheng et al., 2020), sea level (Kuhlbrodt and Gregory, 2012; Passeri et al., 2015; Kulp and Strauss, 2019), acidification (Kroeker et al., 2013; Calosi et al., 2017; Cattano et al., 2018), and deoxygenation (Schmidtko et al., 2017; Levin, 2018; Kwiatkowski et al., 2020), and it is causing indirect effects such as increased stratification and reduced ventilation of the upper ocean (Li et al., 2020; Sallée et al., 2021; Fox-Kemper et al., 2021), among others. These impacts produce changes in the global distribution of marine biota, and affect food security and human wellbeing (Pecl et al., 2017).

Regional CC effects have promoted a poleward displacement in wind

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patterns over the southwest Atlantic (SWA) during the past five decades, leading to a southward expansion of the subtropical gyre (Franco et al., 2020). At the same time, the southward extension of the Brazilian Current (BC) over the past decades (Yang et al., 2016, 2020) created one of the most extensive and intense warming hotspots (~25° S to 45° S) of the global ocean (Hobday and Pecl, 2014). This climatic-oceanographic trend has been accompanied by an inter-decadal increase in precipitation and freshwater discharge in the SWA region (Bertrand et al., 2018; Franco et al., 2020). El Niño/La Niña inter-annual variability influenced the precipitation in southeastern South America, particularly in spring (Grimm et al., 2000). Consequently, the freshwater discharge to the SWA from significant point sources, such as the Río de la Plata (RdlP) estuary and Patos lagoon (30–32 °S) increases during El Niño and decreases during La Niña events (Barros et al., 2002; Piola et al., 2008).

The pink shrimp *Penaeus paulensis* (Pérez Farfante, 1967) is a subtropical crustacean distributed from Ilhéus (14°47′S, Brazil) to Mar del Plata (38°00′S, Argentina) (D'Incao, 1999); Uruguay is the southern limit of commercially caught stocks (Santana et al., 2015). Their life cycle has two phases, one oceanic and the other estuarine; the adults' interaction with the industrial fishery occurs in the oceanic phase and the juveniles' interaction with the artisanal fishery in the estuarine phase. For further details about the life cycle and the species' interaction with fisheries see Figure A.1, Appendix A.

The Intergovernmental Panel on Climate Change defined Vulnerability to CC (IPCC, 2001, 2007) as a function of a system's exposure to change, a sensitivity to such change and capacity to adapt to it (Brugère and De Young, 2015). According to the same authors, socio-ecological vulnerability assessment may enhance understanding of how a given system and its dependent communities can (or cannot) cope with existing and projected changes, facilitating action to support human and ecosystem well-being. Allison et al. (2009) performed a global vulnerability assessment of fisheries by identifying exposure of socio-ecological systems and their sensitivity and adaptive capacity. Here we use a similar approach but performing a risk assessment to estimate exposure (of fishery resource species), recognizing that risk and vulnerability are intimately connected. More recently, IPCC (Oppenheimer et al., 2014) focused on risk assessment as the core action to address CC adaptation, where risk is a function of hazards, exposure and vulnerability. Most relevant fact is that either analysis allows us the opportunity to identify the main components of risk and vulnerability that we could modify to reduce both.

Marine small-scale fisheries (SSF) are particularly vulnerable to the impacts of CC (Allison et al., 2009). The SSFs of the SWA coastal areas could experience an increase in vulnerability due to CC effects, with future consequences on fishing yield and fishers' income (Bertrand et al., 2018; Franco et al., 2020). The communities linked to these SSFs are also in a vulnerable socioeconomic position, and any additional pressure could dramatically impact their way of life (Bertrand et al., 2018). This could be the pink shrimp fishery's situation in the SWA brackish lagoons. A regional assessment of the CC sensitivity (a vulnerability dimension) of key fishery resources species in the SWA (Gianelli et al., 2023), highlights that the pink shrimp showed the second-highest sensitivity across groups (crustaceans, molluscs, fishes—bony and cartilaginous). The specific sensitivity of pink shrimp was driven by ontogenetic changes (i.e., habitat requirements in early life stages) in addition to the general sensitivity attribute set of the crustacean group, such as stock status and complexity in the reproductive strategy (Gianelli et al., 2023). The generation of knowledge by this kind of approach is greatly needed for the SWA region, but additional effort is required to integrate all dimensions of vulnerability into the assessments. The vast majority of Uruguayan SSFs have not been subjected to a characterization of socio-ecological vulnerabilities, considering a better understanding of environment exposure, system sensitivity and capacity to adapt to climate or anthropogenic hazards. This is highly needed to plan adaptation strategies and resiliency mechanisms.

Thus, our study aimed to assess the socio-ecological vulnerability of the pink shrimp SSF in two lagoons on the Uruguayan Atlantic coast. We addressed interdisciplinary and multidimensional issues through a holistic approach, considering expected environmental hazards for the shrimp fishery resources, socioeconomic characteristics, governance/government policies and cultural factors affecting the fishers and local communities. The comparative analysis between lagoons provides the opportunity to evaluate different spatial, environmental and social settings, which can offer lessons for upscaling the assessment and adaptation measures to other SSF systems along the Uruguayan coast, regionally and even globally.

2. Methods

2.1. Study area

The pink shrimp fishery in Uruguay occurs in four brackish coastal lagoons on the SWA coast: Castillos, Rocha, Garzón, and José Ignacio (Santana and Fabiano, 1992). This SSF is currently developed mainly at Castillos and Rocha, which are the two lagoons with the largest surface and are the sites selected for this study (Fig. 1). They are shallow (average depth <1 m) temperate ecosystems, with variable temperatures (4–28 °C), low salinity and high turbidity (Fabiano and Santana, 2006). The percentage of time that the sand bar is open connecting each lagoon with the SWA ocean varies, being higher in Castillos lagoon (open >80% of the time) than in Rocha lagoon (open approximately 48% of the time) (Fabiano and Santana, 2006). Castillos lagoon is connected with the sea by the Valizas stream. Both ecosystems are included within the National System of Protected Areas under the figure of Protected Landscape (Laguna de Rocha: decree 457/016, promulgation date: 12/30/2016; Laguna de Castillos: decree 59/020, promulgation date: 02/14/2020).

Inter-annual shrimp landings are highly variable in and between lagoons, with higher yearly landings and a more extensive variability range in Castillos lagoon (0.5–131 tons) than in Rocha lagoon (0.0–87 tons) along a 30-years time series (1989–2018, 83% of cases). For details see Figure A.2 (Appendix A).

2.2. Data sources and collection

Quantitative, semi-quantitative and qualitative information was collated from three sources: (i) literature review, (ii) key informant interviews, (iii) surveys. For details about methods and approaches to collect information see Appendix B. Survey responses applied to fishers and local community of Castillos lagoon can be found in Appendix C.

2.3. Vulnerability assessment: model framework

We adapted the IPCC Vulnerability model (Allison et al., 2009; Brugère and De Young, 2015) to carry out a CC socio-ecological vulnerability assessment of the shrimp SSF that involves the assessment of the ecological system (relevant to the fishery resource species) exposure along with the sensitivity and adaptive capacity of the social system.

The ecological system included both the SWA region and coastal brackish lagoons. Regional climatic and oceanographic processes or features that adversely affect the pink shrimp life cycle (distribution of larvae, juveniles and adults) were considered. Our vulnerability assessment included direct and indirect drivers linked to CC as well interactions and feedback between climate drivers. The rationale of drivers included, supporting evidence on driver impacts, supporting bibliography and expected effects on pink shrimp, are given in Table A.1 (Appendix A). Appendix A also covers interactions and feedback between environmental drivers, other CC drivers not included in the current assessment and some considerations about future vulnerability assessments.

The social system included the shrimp SSF, fishers and the local

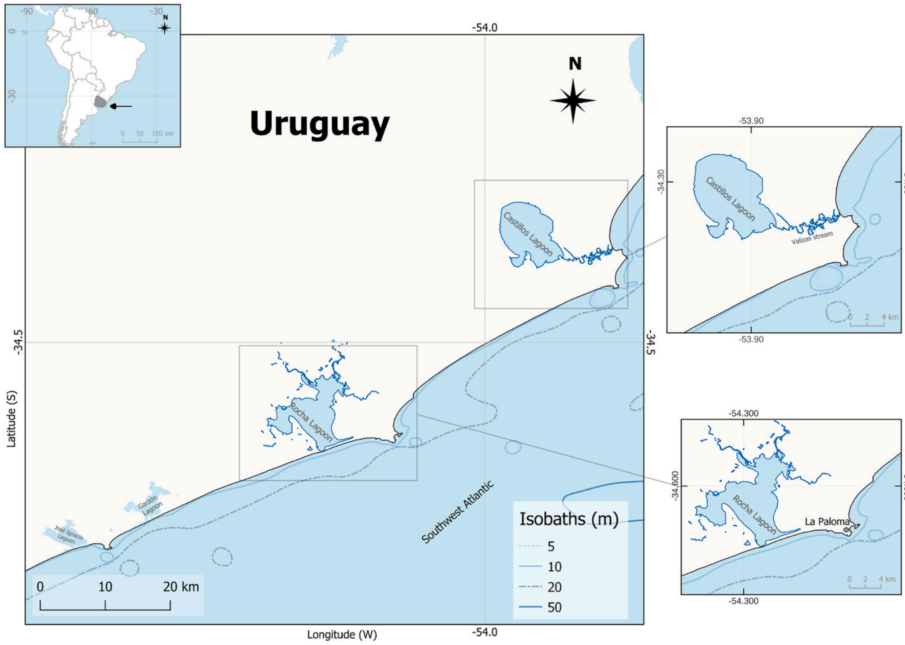

Fig. 1. The brackish coastal lagoons at the Uruguayan Atlantic (from north to south): Castillos, Rocha, Garzón, and José Ignacio. The right panels highlight the geographic position of Castillos and Rocha lagoons and coastal geomorphology details.

community linked to this extractive activity in the lagoons. A set of social, economic, technological, governance and cultural indicators with negative effects on the sensitivity of the social system or with positive effects on their adaptive capacity were evaluated. Details of the rationale of the indicators and the procedure to estimate each are given in Tables A.2 and A.3 (Appendix A). The model inputs (indicators and scoring) were selected and agreed by a group of 8 academic experts: biologists (4), anthropologist (1), social worker (1), lawyer (1) and natural resource economist (1). The scoring relies on their expert judgment using different information sources (e.g. literature review, interviews, surveys) following the methodology proposed by Morrison et al. (2015) to provide a score for each exposure factor, and each sensitivity or adaptability indicator. This methodology uses individual and group expert elicitation practices to minimize bias and increase precision of the results (Burgman et al., 2011). The quality of information source by factor was scored as: 1.00-literature, 0.66-collected data, 0.33-expert judgment (due to unavailability of information).

2.4. Model description

The model involved three components: i) *Exposure* (*E*), understood as the risk of losing pink shrimp for the fishery due to regional drivers linked to CC in their oceanic and estuarine phases; ii) *Sensitivity* (*S*), represented by social indicators negatively affecting the security, welfare and life quality, self-economy and the development of fishers and the local community, and iii) *Adaptive Capacity* (*AC*), represented by social indicators able to promote community or fishers' resilience in their capacity for overcome welfare losses after a perturbation that was originated by CC stressors or non-climate factors. We assigned a weight of 1/3 to each model component. The model formulation was as follows:

$$VA = (1/3 * E) + (1/3 * S) + (1/3 * (1\text{-AC})) \quad (1)$$

The output for *Vulnerability* (*VA*) ranges from 0 (non-vulnerable) to 1 (very high vulnerability). One model was built per lagoon (i.e. Castillos and Rocha).

Exposure (*E*) was estimated through a semi-quantitative risk assessment (*R*) resulting from a combination of the likelihood that an adverse event will happen and the consequences or magnitude of the event if were to occur (Oppenheimer et al., 2014). The latter is a function of the potential shrimp catch to lose and of the condition of the fishery, *i.e.* if it is overexploited the consequences would be greater, while a healthy fishery could stand better the impacts.

$$R = P \text{ x } M \quad (2)$$

Where P = probability of occurrence, M = magnitude of the impact.

To estimate *E* (equivalent to *R* in eq. (2)), a risk matrix was developed considering four regional CC drivers having potential to harm the shrimp and using information on recent past events and expected future ones at a temporal scale of decades. The four selected CC drivers were supported with scientific information. These included intensification of ENSO events, inter-decades increase in regional rainfall, intensitfication of southeasterly winds, and increase in frequency of harmful algal blooms (Table 1).

We estimated a *P* value by driver as the average of the indicators in past events (*Pa*) and expected future events (*Fu*); such that $P = (Pa + Fu)/2$. To estimate *M* we used indicators for the catch that could be lost (*Sca*) based on current catches and the over-exploitation condition of the fishery (*Sfe*); $M = (Sca + Sfe)/2$. For each driver *R* values were divided by 25 (as the maximum value resulting from 5x5 scores) to obtain normalized risk-values. The score categories for *P* components were: 1- not likely, 2- low likelihood, 3- likely, 4- highly likely, 5- almost certain. The score categories for *M* components (*Sca* and *Sfe*) were: 1- very low, 2- low, 3- medium, 4- high, 5- very high; the maximum score represents the worst situation.

To estimate *S* (Table 2) we used indicators for 5 relevant components of sensitivity; namely demographic, technological, economic, cultural and management. The score values ranged between 0 (absence) and 1 (maximum).

To estimate *AC* (Table 3) was used demographic, housing, economic, markets, technological, cultural, government policies, governance, research and early warning system indicators (17 indicators that were classified in 5 categories). The scores for each ranged between 0 (absence of the measure or condition) and 1 (maximal or optimal condition).

To estimate *S* and *AC*, we used indicators that could be calculated directly as a score (e.g. a proportion or an index); otherwise the score

Table 1
Exposure/Risk matrix for the ecological system of Castillos and Rocha lagoons. Rows indicate the regional drivers linked to climate change. Columns show scores for estimators used to calculate risk (R) by driver, where the information about past events (Pa) and expected future events (Fu) allow estimating Probability of occurrence (P), while the catch that could be lost (Sca) and the fishery exploitation status (Sfe) indicate on the Magnitude (M) of the resource loss due to the driver effects. Information source (IS: collected data-a; published data-b; expert judgment-c). Last row shows the overall E value (median). For methods details see section (2.4).

Castillos lagoon: Exposure/Risk								
Drivers	Pa	Fu	P	Sca	Sfe	M	R	IS
Intensification of ENSO events	4.0	5.0	4.5	5.0	4.0	4.5	0.81	b
Rainfall increase at regional/inter-decadal scale	4.0	5.0	4.5	5.0	4.0	4.5	0.81	b
High intensity of southeasterly winds	3.0	5.0	4.0	4.0	4.0	4.0	0.64	c
Harmful algal bloom frequency increase	3.0	5.0	4.0	5.0	4.5	4.75	0.76	b
E (median)							**0.79**	
Rocha lagoon: Exposure/Risk								
Drivers	Pa	Fu	P	Sca	Sfe	M	R	IS
Intensification of ENSO events	4.0	5.0	4.5	5.0	4.0	4.5	0.81	b
Rainfall increase at regional/inter-decadal scale	4.0	5.0	4.5	5.0	4.0	4.5	0.81	b
High intensity of southeasterly winds	3.0	5.0	4.0	4.0	4.0	4.0	0.64	c
Harmful algal bloom frequency increase	3.0	5.0	4.0	5.0	4.0	4.5	0.72	c
E (median)							**0.77**	

Table 2
Sensitivity (*S*) estimated for the social system at Castillos and Rocha lagoons. Rows describe indicators of factors that make fishers and local community more susceptible to be affected by negative impacts on the shrimp fishery. Columns specify *S* scores ranging from 0 to 1 (the highest condition of sensitivity). See Table A.2 (Appendix A) for calculation details. Information source (IS: collected data-a; published data-b; expert judgment-c). Last row shows the overall *S* value (median).

Castillos lagoon: Sensitivity		
Indicators	*S*	IS
High settlement of fishers and local community around the lagoon/next to the stream	1.00	a, b
High –direct or indirect- economic dependency on pink shrimp fishery by fishers and local community	0.80	a
High illegal fishing	0.70	b
High linkage between inter-family ties and leadership within the pink shrimp fishery	0.60	a
Low technology applied to post-harvest processing and lack of product diversification	0.60	a
***S* (median)**	**0.70**	
Rocha lagoon: Sensitivity		
S drivers	S	IS
High settlement of fishers and local community around the lagoon/next to the stream	1.00	b
High illegal fishing	0.70	b
High linkage between inter-family ties and leadership within the shrimp fishery	0.60	b
High –direct or indirect- economic dependency on pink shrimp fishery by fishers and local community	0.45	c
Low technology applied to post-harvest processing and lack of product diversification	0.40	b
***S* (median)**	**0.53**	

Table 3
Adaptive Capacity (*AC*) indicators that promote fisher community resiliency for the social system connected with the pink shrimp fishery in Castillos and Rocha lagoons. Columns specify scores from 0 to 1 (the highest system adaptive capacity). See Table A.3 (Appendix A) for calculation details. Information source (IS: collected data-a; published data-b; expert judgment-c). Last row shows the overall *AC* value (median) .

Castillos lagoon: Adaptive Capacity		
Indicators	*AC*	IS
Socio-cultural structure and organizational capacity of fishers		
High sense of place-belonging	0.92	c
Adequate ecological knowledge by fishers (about climate change, ecosystem, and pink shrimp behavior)	0.83	a
High fisher capacity to move to other fisheries or other economic sectors	0.45	a
High leadership of women or with decision-making positions within the pink shrimp fishery	0.40	c
Majority of fishers with formal employment (taxes, social security, occupational security)	0.20	c
High organizational or associative capacity of fishers	0.10	c
Government policies and governance		
Existence of a fisheries management plan	0.30	c
High level of reported catches	0.30	a
Endorsement of law and implementation of Fisheries Councils (fishers, local and national government)	0.20	c
High monitoring, control and surveillance of the fishery	0.10	c
High compliance with the rules of the fisheries management plan	0.00	c
Trade and market		
High added value for the pink shrimp products	0.29	a
High influence of fishers on the pink shrimp market and trading (storage capacity, middleman)	0.29	a
Annual income of fishers' equivalent to 12 minimum wages or more**	0.20	a
Research		
High number of academic initiatives and research linked to the fishing sector	0.10	c
Early warning and mitigation system		
Existence of a social emergency plan aimed at hazards linked to CC	0.00	c
Existence of an environmental protocol to attend damage by hazards linked to CC	0.00	c
Castillos *AC* (median)	**0.20**	
Rocha lagoon: Adaptive Capacity		
Indicators	*AC*	IS
Socio-cultural structure and organizational capacity of fishers		
High leadership of women or with decision-making positions within the pink shrimp fishery	1.00	b
High sense of place-belonging	0.90	c
Adequate ecological knowledge by fishers (about climate change, ecosystem and pink shrimp behavior)	0.80	c
High fisher capacity to move to other fisheries or other economic sectors	0.70	c
High organizational or associative capacity of fishers	0.60	c
Majority of fishers with formal employment (taxes, social security, occupational security)	0.10	c
Government policies and governance		
Existence of a fisheries management plan	0.50	c
High level of reported catches	0.30	c
Endorsement of law and implementation of Fisheries Councils (fishers, local and national government)	0.20	c
High monitoring, control and surveillance of the fishery	0.10	c
High compliance with the rules of the fisheries management plan	0.00	c
Trade and market		
High added value for the pink shrimp products	0.90	b
High influence of fishers on the pink shrimp market and trading (storage capacity, middleman)	0.45	c
Annual income of fishers' equivalent to 12 minimum wages or more**	0.30	c
Research		
High number of academic initiatives and research linked to the fishing sector	0.90	c
Early warning and mitigation system		
Existence of a social emergency plan aimed at hazards linked to CC	0.00	c
Existence of an environmental protocol to attend damage by hazards linked to CC	0.00	c
Rocha *AC* (median)	**0.38**	

Note. ** Minimum income to cover basic needs of a household.

was assigned by expert judgment. For calculation details, see Tables A.2 and A.3 (Appendix A).

The overall values of *E*, *S* and *AC* were estimated as the median of the resulting value for each indicator, thus the median values of *E*, *S* and *AC* are the input for the vulnerability model.

3. Results

3.1. Data sources and collection

The bibliographic review included 127 sources spanning from published to grey literature. The information reviewed was classified in three large groups: regional CC drivers (63), shrimp fishery dimensions (36), and small-scale fisheries vulnerability (28). The scientific evidence regarding global CC drivers and stressors with regional impacts on the SWA continues to increase, however the mechanisms linking the CC drivers with other processes or events at different temporal scales (e.g. inter-decadal, inter-annual) still need to be addressed and better understood. The vulnerability of SSF to CC impacts is an emerging research topic in the SWA region. Some knowledge has been accumulated about the socio-ecological effects of CC on Uruguayan SSF for yellow clam *Mesodesma mactroides* (Meerhoff et al., 2022; Defeo et al., 2018 and references therein), an intertidal sandy beach mollusc of the SWA.

The surveys were conducted in the settlement of Castillos' lagoon at the Valizas stream bridge zone. No surveys were conducted in Rocha lagoon; information already available was used. While having different sizes, the local communities of Castillos lagoon (~64 persons, this study) and Rocha lagoon (~295 persons; Lagos et al., 2019) share social context and governance features. The shared indicators are the irregular dwellings located on state land and distributed in mostly flood-prone areas, the subsistence economy as a lifestyle, the usage of kinship relations as an intra-group domain strategy, the illegal fishing, the middleman as a decisive stakeholder in the economic chain initiated with the capture, and the low technology applied to post-harvest processes. However, a clear difference between the communities is the women's role, which is stronger and more visible in Rocha lagoon, since they are currently enrolled in marketing fishery products through a gastronomic venture.

Qualitative information based on local knowledge of fishers, local community and park rangers as well as the perceptions and cumulative evidence from field experience of government agents and academics were used as complementary to information obtained from the literature. More details on results obtained from each information source in Appendix B.

3.2. Vulnerability assessment model

A final set of 26 indicators, representing 63% of the ecological and social factors that were initially collected, were included in the vulnerability assessment model of the Uruguayan pink shrimp fishery.

3.2.1. Exposure

The model revealed a relatively high risk-level and exposure of the Uruguayan brackish ecosystems to CC drivers (Fig. 2), similar between Castillos lagoon ($E = 0.79$) and Rocha lagoon ($E = 0.77$). The selected CC drivers were scored with medium to high probability of occurrence and high to very high magnitude of impact, resulting in high individual risk-levels ranging from 0.64 to 0.81 (Table 1). Considering different scenarios (past and future) resulting in high risk for distribution changes of the pink shrimp in the SWA region, the regional CC drivers could promote adverse consequences on harvest duration and fishing yields at the Uruguayan coastal lagoons, leading to shrimp catch losses and possible deterioration in the exploitation state of the fishery (more effort, less yield).

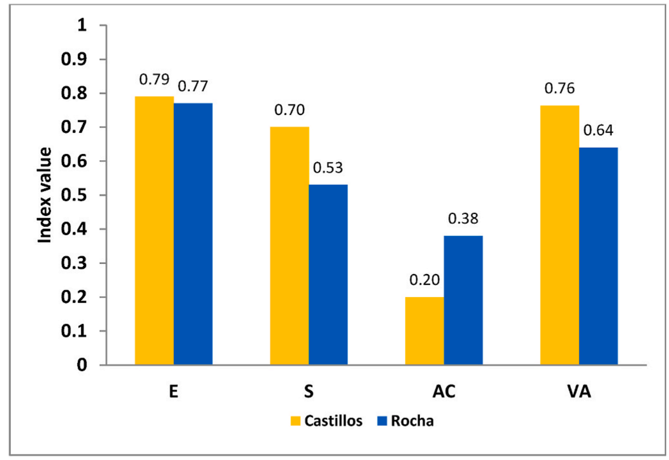

Fig. 2. Semi-quantitative vulnerability model output for the pink shrimp small-scale fishery of Castillos (yellow) and Rocha (blue) lagoons. Index values for Exposure/Risk (*E*), Sensitivity (*S*), Adaptation Capacity (*AC*), and Vulnerability (*VA*) are shown.

3.2.2. Sensitivity

High sensitivity due to the same demographic, economic, governance/government policies, cultural and technological factors were detected in both social systems (Castillos, $S = 0.70$; Rocha, $S = 0.53$) (Fig. 2). These sensitivity factors were scored differently according to a context-specific given by each local community (Table 2).

3.2.3. Adaptive capacity

A low adaptive capacity of the social system was identified to mitigate CC hazards or to prevent social impacts at both Castillos lagoon ($AC = 0.20$) and Rocha lagoon ($AC = 0.38$) (Fig. 2). A broad set of social indicators was identified in Rocha lagoon to enhance fishers and community resilience. In contrast, the indicator set resulted narrower in Castillos lagoon (Table 3). Three indicators with higher *AC* scores in a single category (named 'socio-cultural structure and organizational capacity of fishers') led the system adaptability in Castillos lagoon. These indicators were: a high sense of place-belonging; adequate ecological knowledge by fishers; and high fishers' capacity to move to other fisheries or other economic sectors. In contrast, the system adaptability in Rocha lagoon was explained by nine indicators that were included in four categories (socio-cultural structure and organizational capacity of fishers (5); government policies and governance (1); trade and market (2); research (1)). Weak governance, unfulfilled management measures or unregulated fisheries policies, and lack of climate early warning monitoring appeared as factors that hamper the adaptive capacity of the local communities at Castillos and Rocha lagoons.

3.2.4. Socio-ecological vulnerability

High socio-ecological vulnerability at Castillos lagoon ($VA = 0.76$) and Rocha lagoon ($VA = 0.64$) was diagnosed (Fig. 2). The vulnerability was higher in the ecosystem which historically has record higher shrimp catch levels (see Fig. A.2).

4. Discussion

4.1. Socio-ecological vulnerability

This study developed the first CC vulnerability assessment of one of the few remaining SSF of wild (juvenile) shrimp in the SWA region and globally. Complex relationships and dynamics of the environment, fishing resources and human influences under different spatial-temporal scales were evident at the two sites. Vulnerability is described as a cross-scale issue (Islam and Chuenpagdee, 2022), which implies that individuals and communities experience various multi-scale social, political, economic, and environmental events to which they are vulnerable and must adapt (Bennett et al., 2016). In our case, the environmental stressors linked to CC act at a large-scale (spatial: regional, inter-regional; temporal: inter-annual, inter-decadal), connecting the ecological and social system through regional biophysical dynamics. While social factors act in a small range (local, seasonal), they can exacerbate context-specific vulnerabilities of fishers and local communities in Uruguayan brackish lagoons when combined with large-scale environmental impacts.

The high socio-ecological vulnerability of the shrimp fishery in our study results from a high exposure, as described by the risk-level, of this migratory crustacean to multiple CC drivers (Table 1, Table A.1). High exposure promotes adverse socioeconomic effects linked to alteration of harvest duration and fishing yields along the latitudinal range where this species is captured by SSF fisheries (juveniles in southwest-south Brazilian and Uruguayan coastal lagoons) and industrial fisheries (adults in southwest Brazilian ocean waters).

A comparative study with SSF in coastal lagoons of the southwest-south Brazilian zone would be necessary in the future to understand the broad framework of this issue, considering the combination of large-scale environmental drivers with context-specific social factors, and fishery variables (fleet size, fishing power) in each case. The vulnerability comparison between different pink shrimp SSF in the SWA region could be a valuable tool for fishery management by country (Uruguay and Brazil) and eventually in the adaptation of measures for collaborative management between these countries, which share two main characteristics: i) a coastal lagoon system which covers an extensive area of the South American Atlantic coast, from Santa Catarina (Brasil) to Canelones (Uruguay) (Panario and Gutiérrez, 2011) and, ii) a fishery species with migratory habits which uses the coastal lagoons.

Risk level also depends on the management status and trend of the fishery. The assessment of this indicator in Uruguayan coastal lagoons (*Sfe* in Table 1) shows it to be poor. That means the shrimp fishery shows poor management and/or displays a marked downward trend because of overexploitation. Our assessment suggests that better fisheries management is vital to reduce risk in this SSF, and this depends on a multiplicity of socio-ecological factors to reverse the fishery status and to reduce potential overfishing. Previously, D'Incao et al. (2002) indicated that the fishery status of the pink shrimp was critical, with yields decreasing by 35.6% between 1973 and 1995 in the south-southeast of Brazil. A current stock assessment of the pink shrimp in the SWA region is urgently needed.

Even though exposure (estimated as risk level) in both lagoons studied here was very similar (Table 1), the vulnerability was higher in Castillos, being further exacerbated by high sensitivity and low adaptation capacity (Fig. 2). This is an excellent case to underscore the potential of reducing vulnerability by modifying the social system and its governance. This could improve the sensitivity indicators (Table 2) and those of adaptive capacity (Table 3) in Castillos lagoon, reducing its vulnerability. In fact, after the end of our study, a cold-room for fishery products from SSF was installed in Castillos lagoon (in 2023). Therefore marketing capacity could improve (Table 3), improving community resilience and reducing their socioeconomic vulnerability. In parallel, the recent arrival of electricity for the fisher community of Rocha lagoon (in 2022) could increase the marketing capacity and efficiency indicators reported in Table 3.

Vulnerability of SSF is mainly related to low governing capacity or weak governance (Islam and Chuenpagdee, 2022). As in other SSFs around the planet, the capacity of the Uruguayan shrimp fishery to adapt to environmental hazards, social pressure and socioeconomic conditions needs to be improved, strengthening key factors. First, there is low government capacity to implement fisheries regulations and to control them appropriately (i.e. compliance with closed-season, access to fishing areas, number of shrimp traps per fisherman, requesting access to fishing permits by local and foreign people, illegal fishers), due to a lack of logistics and staff. The latter generates cascading socioeconomic effects, promoting a short and rapidly evolving shrimp harvest with high landings at the beginning which saturate the market and, consequently, decreases prices and income for the community. Thus, some sensitivity factors conflict, like the subsistence economy as a lifestyle for fishers and the presence of middlemen as decisive stakeholders regulating the market price. In response, kinship relations as an intra-group domain strategy strengthen. This situation is worsened by the low technology applied to post-harvest processes and the need of product diversification. Second, weak governance due to inactive public policies, despite the existing fishery legal framework (Local Fisheries Councils) focused on a participatory process involving fishers, fishery authorities and the different government levels. Also, the role of the Advisory Local Committee of the Protected Area is crucial to develop participatory climate early warning monitoring to prevent CC damages, apply territorial mitigation strategies to CC hazards, and offer social assistance in case of damage from climate threats.

An enabling scenario that could help local fishery management organizations to broaden their role should include concern for fishing community wellbeing by addressing both their broader vulnerabilities and aspirations, which may help to address some of the current disincentives of fishers to participate in long-term stewardship by better compliance and enhancing support for fisheries management (Njock et al., 2008; Barratt and Allison, 2014). Uruguay implemented the ecosystem approach to fisheries (Ostrom, 2009) between 2009 and 2014 (Defeo, 2015). This approach enhanced SSFs and set high-level policy fisheries goals, ecosystem principles and co-management (Pomeroy and Berkes, 1997) in four pilot sites -management units- (Gianelli et al., 2018). In 2013, a new fisheries law was approved where consultative (not binding) Local Fisheries Councils were established. However, lacking budget and human resources, and little institutional involvement generated a bad transition towards national and long-term sustainability to achieve governance changes (Gianelli et al., 2018; Trimble and Plummer 2018). The Uruguayan government should not use the CC as an alibi, while governance factors must be addressed to diminish the risk level of the pink shrimp SSF to regional drivers linked to CC. Active fisher participation in governance, women's self-organize ability and their work to add value to shrimp products could be critical stepping stones to increasing the adaptive capacity of these SSF communities. Like other SSFs, communities can often find successful solutions when they are actively involved and empowered to collaborate on identifying social and environmental issues (Bower et al., 2019) without top-down solutions imposed by government authorities or through research projects.

Our study represents an effort to understand direct and indirect CC drivers acting at different spatial scales with possible consequences on the shrimp harvest yield and socioeconomic implications in Uruguayan coastal lagoons. Although the approach includes many uncertainties because we do not understand precisely the interactions and feedback among some of the environmental drivers and we cannot foresee unexpected events (e.g. heat waves), it allows us to explore ways to reduce vulnerability by reducing some aspects of the sensitivity and increasing adaptive capacity in each lagoon.

4.2. Perspectives

Systematic monitoring is recommended to compare future vulnerability scenarios of the pink shrimp fishery within a period of >2 years but ≤ 5 years. The base-line built here could be compared with future vulnerability studies, adding other environmental drivers and social factors influencing vulnerability dimensions (exposure, sensitivity and adaptive capacity) at various spatial and temporal scales. Ecological drivers could be considering, including water mass circulation changes, coastal water acidification, lagoon salinity increase, wetlands area coverage increase, and biodiversity modification, all with effects on the exposure dimension. New social factors can be incorporated into the sensitivity dimension, like the high climatic uncertainty in the harvest phase, the high economic uncertainty in the post-harvest phase, and the ice capacity unevenly distributed among fishers. Other indicators having the potential to impact the adaptive capacity of each local community could be included, such as strengthening the role of women in decision-making that influences the shrimp market; increase in compliance of fishery management measurements by fishers; increase of fisher empowerment by co-participative decision-making; increase of surveillance and control of illegal fishing by the government; increase in public policies to support the development of alternative and diversified livelihoods for small-scale fishers, and increase of species' habitat protection through adaptive spatial management within the protected areas (Castillos and Rocha lagoons). Most of the above factors should be considered in future vulnerability assessments of the pink shrimp SSF and in strategies to increase CC resiliency.

4.3. Conclusions

This first approach to explore the socio-ecological vulnerability of the pink shrimp Uruguayan fishery reveals a high risk-level to biophysical threats linked to CC along the oceanic and estuarine phases of this migratory crustacean, which could lead to catch losses in Uruguayan coastal lagoons and a decrease in this SSF income. High sensitivity of local fisher communities was identified in Uruguayan coastal lagoons. Although sensitivity factors were scored differently by each local community, the irregular dwellings located on state land and distributed in flood prone areas was a demographic indicator that scored high in both lagoon fisher communities. Low adaptive capacity to prevent social impacts or to mitigate CC hazards was detected in both social systems. Weak governance, unfulfilled management measures or unregulated fisheries policies, and lack of climate early warning monitoring hamper the system's adaptability in both sites. Comparative evaluation of spatial, environmental and social settings among Uruguayan coastal lagoons provides the opportunity for upscaling the vulnerability assessment and adaptation measures to other shrimp SSF in the SWA region.

CRediT authorship contribution statement

Rodolfo Vögler: Conceptualization, Methodology, Results, Discussion, Writing – first draft & revised version, Writing – supplementary material. Edition – figures, tables. Doris Soto: Conceptualization, Methodology, Results, Discussion, Writing – first draft & revised version. Renato Quiñones: Conceptualization, Results, Discussion, Writing – second draft & revised version. Gastón Martínez: Methodology, Results, Discussion, Writing – second draft & revised version, supplementary material. Edition – figures. Leticia D'Ambrosio, Soledad Alaggia, Ana Surroca: Methodology, Results. Manuscript revision. Federico Pérez: Methodology, Results, Writing – supplementary material. Manuscript revision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: R. A. oQuiñones reports financial support was provided by Interdisciplinary Center for Aquaculture Research (INCAR). D. Soto reports financial support was provided by Interdisciplinary Center for Aquaculture Research (INCAR).

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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References

Allison, E.H., Perry, A.L., Badjeck, M.C., Neil Adger, W., Brown, K., Conway, D., et al., 2009. Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish. 10 (2), 173–196. https://doi.org/10.1111/j.1467-2979.2008.00310.x.

Barratt, C., Allison, E.H., 2014. Vulnerable people, vulnerable resources? Exploring the relationship between people's vulnerability and the sustainability of community managed natural resources. Development Studies Research 1 (1), 16–27.

Barros, V.R., Grimm, A.M., Doyle, M.E., 2002. Relationship between temperature and circulation in southwestern south America and its influence from el Niño and La Niña events. J. Meteorol. Soc. Jpn. 80, 21–32. https://doi.org/10.2151/jmsj.80.21.

Bennett, N.J., Blythe, J., Tyler, S., Ban, N.C., 2016. Communities and change in the anthropocene: understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. Reg. Environ. Change 16, 907–926.

Bertrand, A., Vögler, R., Defeo, O., 2018. Chapter 15. Climate change impacts, vulnerabilities and adaptations: southwest Atlantic and Southeast Pacific marine fisheries. In: Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., Poulain, F. (Eds.), Impacts of Climate Change on Fisheries and Aquaculture: Synthesis of Current Knowledge, Adaptation and Mitigation Options, vol. 627. FAO, Roma, Italy, pp. 325–346. Fisheries and Aquaculture Technical Paper.

Bower, S.D., Song, A.M., Onyango, P., Cooke, S.J., Kolding, J., 2019. Using transdisciplinary research solutions to support governance in inland fisheries. Transdisciplinarity for small-scale fisheries governance: Analysis and Practice 341–355. https://doi.org/10.1007/978-3-319-94938-3_18.

Brugère, C., De Young, C., 2015. Assessing Climate Change Vulnerabilityin Fisheries and Aquaculture. Available Methodologies and Their Relevance for the Sector. FAO, Rome. FAO Fisheries and AquacultureTechnical Paper. No. 597.

Burgman, M.A., McBride, M., Ashton, R., Speirs-Bridge, A., Flander, L., Wintle, B., et al., 2011. Expert status and performance. PLoS One 6 (7), e22998.

Calosi, P., Melatunan, S., Turner, L.M., Artioli, Y., Davidson, R.L., Byrne, J.J., et al., 2017. Regional adaptation defines sensitivity to future ocean acidification. Nat. Commun. 8 (1), 13994.

Cattano, C., Claudet, J., Domenici, P., Milazzo, M., 2018. Living in a high CO2 world: a global meta-analysis shows multiple trait-mediated fish responses to ocean acidification. Ecol. Monogr. 88 (3), 320–335.

Cheng, L., Trenberth, K.E., Gruber, N., Abraham, J.P., Fasullo, J.T., Li, G., et al., 2020. Improved estimates of changes in upper ocean salinity and the hydrological cycle. J. Clim. 33 (23), 10357–10381.

Cheng, L., Abraham, J., Hausfather, Z., Trenberth, K.E., 2019. How fast are the oceans warming? doi.org/10.1126/science.aav7619 Science 363, 128–129.

Cooley, S., Schoeman, D., Bopp, L., Boyd, P., Donner, S., Ghebrehiwet, D.Y., Ito, S.-I., Kiessling, W., Martinetto, P., Ojea, E., Racault, M.-F., Rost, B., Skern-Mauritzen, M., 2022. Oceans and coastal ecosystems and their services. In: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B. (Eds.), Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 379–550. https://doi.org/10.1017/9781009325844.005.

Defeo, O., Gianelli, I., Martínez, G., Ortega, L., Celentano, E., Lercari, D., de la Rosa, A., 2018. Natural, social and governance responses of a small-scale fishery to mass mortalities: the yellow clam Mesodesma mactroides in Uruguay. In: Guillotreau, P., Bundy, A., Perry, R.I. (Eds.), Global Change in Marine Systems. Studies in Environment, Culture, and Society Serie. Routledge, pp. 237–252.

Defeo, O., 2015. Enfoque ecosistémico pesquero: conceptos fundamentales y su aplicación en pesquerías de pequeña escala de América Latina. FAO Fisheries and Aquaculture Technical Paper. Roma, Italia. 592, 49–54.

D'Incao, F., 1999. Subordem Dendrobranchiata (camarões marinhos). In: Buckup, L., BondBuckup, G. (Eds.), Os Camarões Do Rio Grande Do Sul. Porto Alegre. Editora da Universidade UFRGS, pp. 271–299.

D'Incao, F., Valentini, H., Rodrigues, L.F., 2002. Avaliação da pesca de camarões nas regiões Sudeste e Sul do Brasil. 1965-1999. Atlantica 24 (2), 49–62.
Durack, P.J., 2015. Ocean salinity and the global water cycle. Oceanography 28 (1), 20–31.
Durack, P.J., Wijffels, S.E., Gleckler, P.J., 2014. Long-term sea-level change revisited: the role of salinity. Environ. Res. Lett. 9 (11), 114017.
Fabiano, G., Santana, O., 2006. Las pesquerías en las lagunas costeras salobres de Uruguay. In: Menafra, R., Rodríguez- Gallego, L., Scarabino, F., Conde, D. (Eds.), Bases para la conservación y manejo de la costa uruguaya. Vida Silvestre, Montevideo, pp. 557–565 (in Spanish).
Franco, B.C., Defeo, O., Piola, A.R., Barreiro, M., Yang, H., Ortega, L., Möller, O.O., 2020. Climate change impacts on the atmospheric circulation, ocean, and fisheries in the southwest South Atlantic Ocean: a review. Climatic Change 1–19. https://doi.org/10.1007/s10584-020-02783-6.
Fox-Kemper, B., et al., 2021. Ocean, cryosphere and sea level change. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (Eds.), Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
Gianelli, I., Orlando, L., Cardoso, L.G., Carranza, A., Celentano, E., Correa, P., et al., 2023. Sensitivity of fishery resources to climate change in the warm-temperate Southwest Atlantic Ocean. Reg. Environ. Change 23 (2), 49.
Gianelli, I., Horta, S., Martínez, G., de la Rosa, A., Defeo, O., 2018. Operationalizing an ecosystem approach to small-scale fisheries in developing countries: the case of Uruguay. Mar. Pol. 95, 180–188.
Grimm, A., Barros, V., Doyle, M., 2000. Climate variability in southern south America associated with el Niño and La Niña events. J. Clim. 13, 31–58.
Hobday, A.J., Pecl, G.T., 2014. Identification of global marine hotspots: sentinels for change and vanguards for adaptation action. Rev. Fish Biol. Fish. 24 (2), 415–425.
IPCC, 2001. Climate Change 2001: impacts, adaptation and vulnerability. In: McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., White, K.S. (Eds.), Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UKCambridge, UK, and New York, USA, 1032 pp. ISBN 0-521-80768-9.
IPCC, 2007. Climate Change 2007: Impacts, adaptation and vulnerability. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 976 pp.
Islam, M.M., Chuenpagdee, R., 2022. Towards a classification of vulnerability of small-scale fisheries. Environ. Sci. Pol. 134, 1–12. https://doi.org/10.1016/j.envsci.2022.03.023.
Kroeker, K.J., Kordas, R.L., Crim, R., Hendriks, I.E., Ramajo, L., Singh, G.S., et al., 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biol. 19 (6), 1884–1896.
Kuhlbrodt, T., Gregory, J.M., 2012. Ocean heat uptake and its consequences for the magnitude of sea level rise and climate change. Geophys. Res. Lett. 39 (18), L18608 https://doi.org/10.1029/2012GL052952.
Kulp, S.A., Strauss, B.H., 2019. New elevation data triple estimates of global vulnerability to sea-level rise and coastal flooding. Nat. Commun. 10 (1), 4844. https://doi.org/10.1038/s41467-019-12808-z.
Kwiatkowski, L., Torres, O., Bopp, L., Aumont, O., Chamberlain, M., Christian, J.R., et al., 2020. Twenty-first century ocean warming, acidification, deoxygenation, and upper-ocean nutrient and primary production decline from CMIP6 model projections. Biogeosciences 17 (13), 3439–3470.
Lagos, X., Laporta, C., Burgos, C., Baptista, M., Fernández, I., 2019. Asociatividad y fortalecimiento comunitario desde el Manejo Costero Integrado. La experiencia de Mujeres Pescadoras en el área protegida de Laguna de Rocha (Rocha, Uruguay). Revista Costas 1 (2), 11–134 (in Spanish).
Levin, L.A., 2018. Manifestation, drivers, and emergence of open ocean deoxygenation. Ann. Rev. Mar. Sci 10 (1), 229–260. https://doi.org/10.1146/annurevmarine-121916-063359.
Li, G., Cheng, L., Zhu, J., Trenberth, K.E., Mann, M.E., Abraham, J.P., 2020. Increasing ocean stratification over the past half-century. Nat. Clim. Change 10 (12), 1116–1123.
Meerhoff, E., Combes, V., Matano, R., Barrier, N., Franco, B., Piola, A., Hernández-Vaca, F., Defeo, O., 2022. Large-scale connectivity of the sandy beach clam Mesodes mamactroides along the Atlantic coast of South America, and climate change implications. Mar. Environ. Res. 176, 105591.
Morrison, W.E., Nelson, M.W., Howard, J.F., Teeters, E.J., Hare, J.A., Griffis, R.B., Scott, J.D., Alexander, M.A., 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commer., NOAA. https://www.st.nmfs.noaa.gov/Assets/ecosystems/climate/documents/TM%20OSF3.pdf. (Accessed 27 April 2021).
Njock, J., Allison, E.H., Konan, A., 2008. Institutional innovations in fisheries Comanagement. In: Westlund, L., Holvoet, K., Kébé, M. (Eds.), In Achieving Poverty Reduction through Responsible Fisheries: Lessons from West and Central Africa. FAO, Rome, Italy, pp. 67–81.
Oppenheimer, M., Campos, M., Warren, R., Birkmann, J., Luber, G., O'Neill, B., Takahashi, K., 2014. Emergent risks and key vulnerabilities. In: Field, C.B., Barros, V. R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1039–1099.
Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325 (5939), 419–422.
Panario, D., Gutiérrez, O., 2011. Introducción a la geomorfología de lagunas costeras, lagos someros y charcas de Uruguay. In: García-Rodríguez, F. (Ed.), El holoceno en la zona costera de Uruguay. Universidad de la República, Montevideo, pp. 49–64 (in Spanish).
Passeri, D.L., Hagen, S.C., Medeiros, S.C., Bilskie, M.V., Alizad, K., Wang, D., 2015. The dynamic effects of sea level rise on low-gradient coastal landscapes: a review. Earth's Future 3 (6), 159–181.
Pecl, G.T., Araújo, M.B., Bell, J.D., et al., 2017. Biodiversity redistribution under climate change: impacts on ecosystems and human well-being. Science 355, eaai9214.
Piola, A.R., Romero, S.I., Zajaczkovski, U., 2008. Space-time variability of the Plata plume inferred from ocean color. Continent. Shelf Res. 28, 1556–1567.
Pomeroy, R.S., Berkes, F., 1997. Two to tango: the role of government in fisheries co-management. Mar. Pol. 21 (5), 465–480.
Roemmich, D., Church, J., Gilson, J., Monselesan, D., Sutton, P., Wijffels, S., 2015. Unabated planetary warming and its ocean structure since 2006. Nat. Clim. Change 5 (3), 240–245.
Sallée, J.B., Pellichero, V., Akhoudas, C., Pauthenet, E., Vignes, L., Schmidtko, S., et al., 2021. Summertime increases in upper-ocean stratification and mixed-layer depth. Nature 591 (7851), 592–598.
Santana, O., Silveira, S., Fabiano, G., 2015. Catch variability and growth of pink shrimp (Farfantepenaeus paulensis) in two coastal lagoons of Uruguay and their relationship with ENSO events. Braz. J. Oceanogr. 63 (3), 355–362.
Santana, O., Fabiano, G., 1992. Aspectos relevantes del camarón rosado (Penaeus paulensis) en las lagunas costeras uruguayas. Frente Marítimo 12, 89–94 (in Spanish).
Schmidtko, S., Stramma, L., Visbeck, M., 2017. Decline in global oceanic oxygen content during the past five decades. Nature 542, 335–339. https://doi.org/10.1038/nature21399.
Trimble, M., Plummer, R., 2018. Participatory evaluation in times of governance transition: the case of small-scale fisheries in Uruguay. Ocean Coast Manag. 161, 74–83.
Yang, H., Lohmann, G., Krebs-Kanzow, U., Ionita, M., Shi, X., Sidorenko, D., et al., 2020. Poleward shift of the major ocean gyres detected in a warming climate. Geophys. Res. Lett. 47, e2019GL085868 https://doi.org/10.1029/2019GL085868.
Yang, H., Lohmann, G., Wei, W., et al., 2016. Intensification and poleward shift of subtropical western boundarycurrents in a warming climate. J. Geophys. Res.: Oceans 121, 4928–4945.