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Building adaptive capacity to climate variability: The case of artisanal fisheries in the estuary of the Patos Lagoon, Brazil

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ABSTRACT

The vulnerabilities of fishing communities to climate and environmental change represent major issues for the governance of fisheries resources which have a direct effect on human security, livelihoods and rights. This paper explores the dynamics of social-ecological systems in the estuary of the Patos Lagoon in southern Brazil. The paper identifies key factors that increase and/or minimize the vulnerabilities of the fishing communities in this lagoon with the objective of understanding: (a) the degree to which fishing communities are able to build adaptive and learning capacities to minimize/reduce vulnerabilities and maintain their livelihoods; and (b) how and under what circumstances external and internal factors may influence and disrupt the social-ecological resilience in this lagoon system. Results show that fishing communities with a higher degree of self-organization are able to create ways to minimize their vulnerability to adverse climatic conditions. However, only a few communities have developed adaptive mechanisms to cope with the influence of climate on resource abundance and availability. Little external institutional support for small-scale fishing communities, erosion of their traditional resource use systems and decreasing fish stocks in recent decades have all led to a gradual increase in the vulnerability of fishing livelihoods in this lagoon. The uncertainties associated with climate are related to increasing vulnerability and influence the degree of resource conservation and exploitation. The lack of public policies to deal with the impact of climate variability on the livelihoods of fishing communities and the presence of weak institutions in resource governance represent major threats to the social security of fishers in this region.

1. Introduction

The vulnerability of a group of people is inversely proportional to their ability to anticipate, work, resist and recover from a natural disaster [1]. Understanding the vulnerabilities of fishing communities and their strategies to cope with and adapt from climate variability is crucial for the development of policies and operational rules that can maintain the livelihoods of these communities and their social-ecological systems. According to Berkes [2] the ability for self-organization in a system and its capacity for learning and experimentation are attributes that can be used as a rough measure of resilience. The concept of resilience is promising in the field of vulnerabilities and climate variability because it provides elements to analyse the capability of fishing systems to develop adaptive strategies to persist and transform in the face of perturbations [2].

The focus of this study is on the analysis of climatic impacts on the socioeconomic vulnerability of fishing communities, especially those engaged in pink shrimp (*Farfantepenaeus paulensis*) fisheries in the estuary of the Patos Lagoon, southern Brazil. The most important aspects of the characterization of this vulnerability consist primarily in the identification of adaptive strategies developed by fishing communities in this lagoon. The vulnerability of fishing communities to climate and environmental change is a major issue for the governance of fisheries resources and has a direct effect on human security, livelihoods and fishing rights.

This study aims to identify key factors that increase and/or minimize the vulnerabilities of the fishing communities in the lagoon with the objective of understanding: (a) the degree to which fishing communities are able to build adaptive and learning capacities to minimize/reduce vulnerabilities and maintain their livelihoods; and (b) how and under what circumstances external and internal factors may influence and disrupt the social-ecological resilience in this lagoon.

1.1. The estuary of the Patos Lagoon, southern Brazil

The estuarine region of the Patos Lagoon is located in the southern Brazilian Coastal Zone (Rio Grande do Sul State), an area of the Biosphere Reserve [3]. With an area of approximately 10,000 km^2, the Patos Lagoon is recognized as the world's largest

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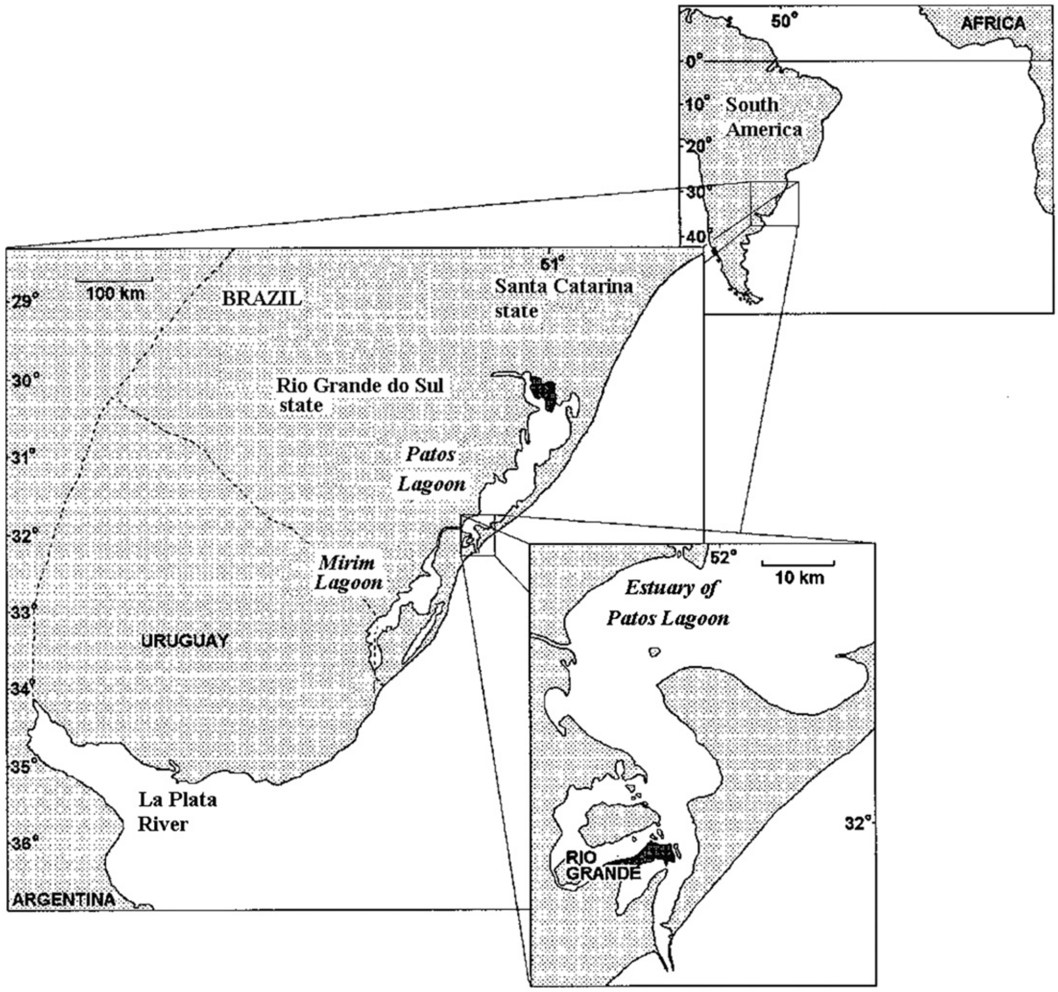

Fig. 1. Location of the Patos Lagoon estuary in southern Brazil. Source: [4].

choked lagoon, stretching from 30°30′S to 32°12′S near the city of Rio Grande where the lagoon connects to the Atlantic Ocean (Fig. 1).

The estuarine region encompasses approximately 10% of the lagoon, and is occupied by diverse and abundant flora and fauna. The abundant food resources and protection against predation provided by estuarine shoals makes this region an ideal nursery ground for several commercially important fish species.

The estuary is characterized by a relatively shallow body of water (mean depth of 7 m) with variable temperature and salinity depending on local climatic and hydrological conditions [5]. The dynamics of estuarine waters are determined by the wind and rain regimes with only a minor influence of the tide. In general in the period from September to April the dominant winds are from NE, NNE and ENE while in the winter period winds from E, S, SE and SW are most frequent. While the former favors the discharge of freshwater and creates a low salinity regime in the estuary, the latter forces the penetration of salt water through the estuarine channel and creates marine conditions in the estuary [7]. The mean annual precipitation (1200–1500 mm) varies strongly from year to year and is related to the path and passage of cold fronts [6]. Mean monthly rainfall is highest during the winter and spring (June to October), but a second peak may occur in summer. Inter-annual variations in precipitation with either a high amount of rainfall or dry periods seem to be a consequence of the El-Niño Southern Oscillation cycle on the regional climate [4]. In general, years of strong El-Niño events cause flooding in southern Brazil. This phenomenon directly influences the amount of continental freshwater runoff and the biogeochemical processes in the estuary and coastal ecosystem [8].

The Patos Lagoon system connects with the ocean via the channel between a pair of jetties, about 4 km long and 740 m apart at the mouth. All the estuarine dependent marine organisms enter and leave the estuary through this channel for nursery, reproductive and feeding purposes. Based on the seasonal abundance and movement patterns of organisms, Chao et al. [9] identified five distinct bioecological categories in the estuary: estuarine resident species, that complete their entire life cycles in the estuarine environment; estuarine dependent marine species, which utilize the estuary as nursery and feeding ground for young but spawn at sea; the anadromous species that enter the estuary to reproduce; and opportunists and occasional visitors, which include more than 50 marine and freshwater fishes. Of the more than 110 species of fish and shellfish that occur in the estuary, 4 represent important fisheries resources, and have sustained artisanal fisheries in the estuary for more than a century. Short descriptions of the life-cycles and dynamics of these species are provided in Table 1.

These characteristic life cycles create a well defined seasonal variability in the diversity and abundance of resources in the estuary and also in the availability of resources to artisanal fisheries. Fisheries landings also present a marked inter-annual variability related to the occurrence of strong ENSO events [14–16]. By affecting the amount of rainfall in the region these

Table 1
Summary of biology and life-cycle of main artisanal fisheries resources in the estuary of Patos Lagoon (sources [10–13]).

Pink shrimp, *Farfantepenaeus paulensis*	Estuarine dependent species. Adults spawn in shelf waters below 50 m deep, producing demersal eggs that hatch into planktonic larvae. When approaching estuaries the larvae develop a benthic habit settling in shallow areas where they will grow for a few months until reaching the pre-adult phase when they migrate to the ocean reinitiating the cycle. The growing phase in the estuary may last between 4 and 10 months when they reach ca. 7 cm of length. Larvae enter with varying success into the estuary all year round but mainly in the spring and summer depending on environmental forcing of wind and freshwater outflow
Marine catfish, *Netuma barba*	Slow-growing, anadromous species with a calculated life span of approximately 23 years, though adults may occasionally attain 36 years of age and a total length of 98 cm. At the end of the winter the species migrates into the Patos Lagoon estuary. Maturation takes place in early spring in the estuary followed by spawning in the coastal waters in early summer. *N. barba* has low fecundity and after reproduction the males incubate the eggs for up to 2 months. Between spawning seasons, adults disperse over the entire shelf
Croaker, *Micropogonias furnieri*	Depends on the estuary of Patos Lagoon as a nursery and feeding ground. Croakers spawn during spring and summer in coastal waters under the influence of freshwater runoff from the Patos Lagoon. Adults normally migrate into the estuary in September–October and leave the area in December–January. Young and sub-adult croakers occur throughout the year near the coast and in the estuary of Patos Lagoon. Adults are dispersed over the shelf and migrate from Uruguay to southern Brazil during the fall and winter and towards Uruguay in the summer
Mullet (mainly represented by *Mugil platanus*)	Mullets occur year round in the Patos Lagoon and adjacent coastal waters. Juveniles are more abundant in the winter and spring in nursery areas of the lagoon. In the fall, adult mullets leave the estuary and initiate their reproductive migration. Spawning occurs in warmer offshore waters at about 27°S between the end of the fall and winter. Eggs and larvae are transported from spawning grounds towards the surf zone, followed by a long-shore migration to the estuary of Patos Lagoon

events can directly influence the availability of resources to artisanal fishers in the estuary and thus impact the total landings (Fig. 2). Moller et al. [15] noted that the frequency of occurrence of strong El Niño events increased after 1970. Bakun [17] classified the period from the 70 s to the early 90 s as one of "enhanced" El Niño characteristics, which resulted in synchronous inter-decadal changes in the production of fish stocks in different parts of the world. Despite the lack of data to assess the importance of such climatic regimes to fisheries in the Patos Lagoon, it is possible that the region is also under the influence of inter-decadal climatic variability. Coupled with major changes in resource exploitation and management, such climatic regimes can amplify the magnitude of change in fisheries resources in the estuary of Patos Lagoon.

Understanding how the ecosystem is structured and how it changes in response to human impacts requires understanding the dynamics of ecosystem succession and resilience. Holling [18] and Holling et al. [19] suggested four primary phases in an ecosystem succession cycle which synthesize common features observed in both terrestrial and aquatic systems. The phases are: *exploitation*, in which rapid colonization of recently disturbed areas by opportunist species occurs and leads to growth in the size of the system; *conservation*, in which the system slowly

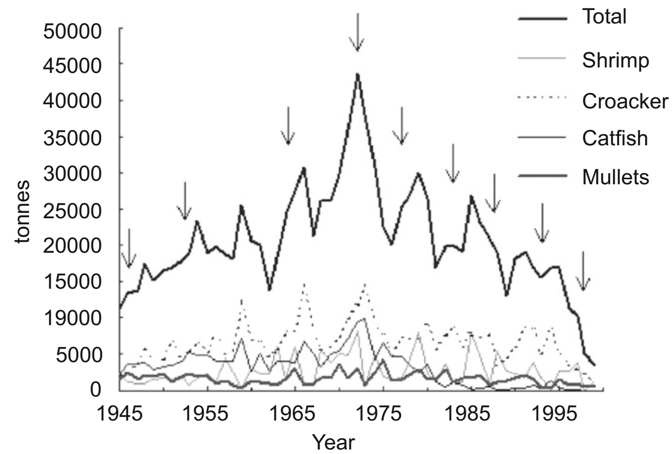

Fig. 2. Top: artisanal fisheries landings in the estuary of Patos Lagoon. The arrows indicate the years with strong El-Niño events. Bottom: result of spectral analysis of total fisheries landing variance explained by multi-annual cycles (data source: SUDEPE and IBAMA).

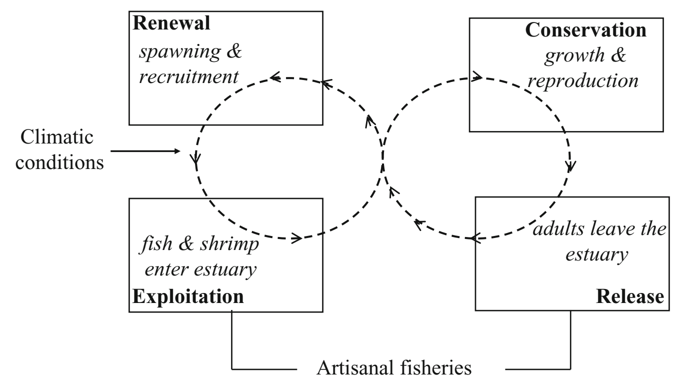

Fig. 3. Four phases model of fisheries resource dynamics in the estuary of the Patos Lagoon and coastal areas (adapted from [18]). During the cycle of exploitation, conservation, release and reorganization, biological time flows unevenly. It is slow from the exploitation to the conservation phase, then very rapid to the release, rapidly to reorganization and back to the exploitation phase.

accumulates and stores energy and material, and develops a more complex structure until a climax is attained; *release*, in which the tightly bound accumulation of biomass and nutrients becomes increasingly fragile until they are suddenly released by physical or biological disturbances and unexpected events; and *reorganization*, in which physical–biological processes minimize losses and renew the system to become available for the next phase of exploitation.

This model considers that these phases cycles are driven by a few dominant variables organized across scales in time and space [18,19]. Examples of regional resource management [20] also suggest that institutions and societies achieve periodic advances in understanding and learning through similar cycles of growth, production (greatest efficiency), release (crisis) and renewal that shape the spatial and temporal dynamics of ecosystems. Holling's four phases model thus provides a framework that is useful for understanding the relationships between, and resilience of, both the dynamics of ecosystems (its structure and change) and the functioning of institutions.

Fig. 3 represents the dynamics of artisanal fisheries in the estuary of Patos Lagoon and illustrates the four major phases in life cycles of the living resources in the estuary and coastal areas. In the *exploitation* phase, fisheries resources enter the estuarine environment for growth or reproduction, leading to the *conservation* phase in which these resources increase in size and mature. Adults leave the estuary in the *release* phase to spawn and recruit in the marine environment, and close the cycle with the *renewal* phase. The influences of climatic conditions (and harvest) are conspicuous in the transition from *renewal* to *exploitation* phases because of their effect on recruitment success and on the migration/dispersal of resources towards the estuarine environment.

2. Methodology

Primary data were obtained through interviews with artisanal fishers. Information was collected according to criteria adapted from Marschke and Berkes [21] for the assessment of vulnerabilities and resilience of social-ecological systems:

(1) Diversification and specialization: fishers who diversify, whether with other species or other activities, are likely to be less vulnerable.
(2) Trading and subsistence: the food security of artisanal fishers' families depends on animal protein obtained from the fisheries products.
(3) Innovation and conservation: tactics used for resource maintenance and as adaptation to adverse events.
(4) Fisheries policies and integration: the role/lack of public policies to assist fishers to maintain their livelihoods and avoid segregation in the case of adverse climatic conditions.
(5) Location and externalization: the relationship between local and national markets; the more dependent on one particular market, the more vulnerable.
(6) Changes in fishing practices: changes in fishing calendars, fishing techniques and species caught may be related to an increase or decrease in vulnerability.
(7) Uncertainties: greater uncertainties generate greater vulnerability if mechanisms to cope with it are non-existent (e.g. variation of the price of fish/shrimp in a year/season in relation to fish abundance and market strategies).
(8) Scale and social cohesion: the level of cohesion among fishers and its relation to livelihood strategies to deal with vulnerability issues.
(9) Community self-organization: the more organized the community, the greater the probability of successfully dealing with vulnerabilities.
(10) Adaptation and learning mechanisms: the more flexible the fishery rules and practices are, and the more that learning and adaptation strategies are present, the lower will be the vulnerabilities.

Interviews were done face-to-face through the use of a semi-structured questionnaire which worked as a guide for the interviewer, allowing for both focus and flexibility in data collection [22,23]. The questions were adjusted to the fishers' language, with both interview structure and language being previously tested in fishing communities. In order to identify prospective respondents, a snowball technique was used [22,23]. Fishers recognized by the local fishing community as highly knowledgeable on the study area were sought. Interviews were recorded with the interviewees' consent, and anonymity was granted in order to create the least constraints possible for the elucidation of the raised themes, which were often related to delicate issues such as illegal fishing practices. One member of the fishing community was included in the research team to help with field trips, to provide access into the communities, to find fishers to be interviewed, and also to make the presence of the interviewers the least awkward for the interviewees, thus improving data quality. Digital voice files were transcribed into text files and analyzed based on: (1) identifying the vulnerabilities of fishing systems, (2) identifying and analyzing the most vulnerable systems and why they are so, and (3) understanding the means by which the fishing communities become less vulnerable to climatic events which damage the main harvests

Table 2
Interviews held according to fishing system and communities.

Characteristics of fishing systems of the estuary of Patos Lagoon	*n*	Fishing community	Municipality
1: Exclusively professional fishers, who live far from urban centers, and who specialize in fishing in the inner waters of the estuary and the Lagoon itself. They mainly use stownets in the pink shrimp fishery	8	Marinheiros Island (Marambaia), Torotama Island, Varzea and São José do Norte,	Rio Grande São José do Norte
2: Exclusively professional fishers, who live in communities near the channel of the port of Rio Grande, and specialize in both inner-water fishing and costal marine fishing. They mainly use trawl nets to catch pink shrimp within the estuary and also to catch sea shrimp (*Artemesia longinaris*) outside the mouth of Patos Lagoon	7	4a Secção da Barra, Povoação da Barra and 2a Seção da Barra	Rio Grande
3: Occasional fishers who do not rely entirely on fishing as source of income. The fishers in this system do other work in the city, usually low-grade, part-time construction work. They live in communities within the urban area. These fishers specialize in fishing in the inner waters of the estuary, mainly working in the stownet pink shrimp fishery	7	Vila São Miguel, Henrique Pancada, Don Bosquinho and Embratel	Rio Grande
4: Exclusively professional fishers, who live near or in relatively well-developed communities (such as Arroio Sujo). The access to quality housing and services differs among communities representing this system. They show a highly diversified fishery; it is common to find within the same community fishers with distinct fishing technologies (e.g., trawls and stownets) and fishing areas (both outside the mouth and within the Lagoon). Some also have additional activities other than fishing	8	São José do Norte urban área, Bosque, Praia do Norte, Arroio Sujo	Rio Grande, São José do Norte and Pelotas
5: This fishing system is the one located furthest north in the estuary, and presents a singular fishing calendar, benefiting from both estuarine-dependent oceanic and fresh water fishing resources. For example, the preferential closed season for these communities is during the spring (while for the others it is during the winter), as these fishers conduct an important catfish fishery during the winter months. Fishery technologies are similar to the other communities in the estuary. A sizable proportion of these fishers also use the marine coastal zone as fishing grounds (mainly for the white croaker), though they have not developed a fishery for sea shrimp	8	São Lourenço do Sul	São Lourenço do Sul
6: The fisher-farmer, found in rural areas surrounding the estuary of Patos Lagoon. This system focuses mainly on the pink shrimp fishery with stownets during the harvest, and is also dedicated to year-round rural activities	8	Marinheiros Island, Leonídio Island and Torotama Island	Rio Grande

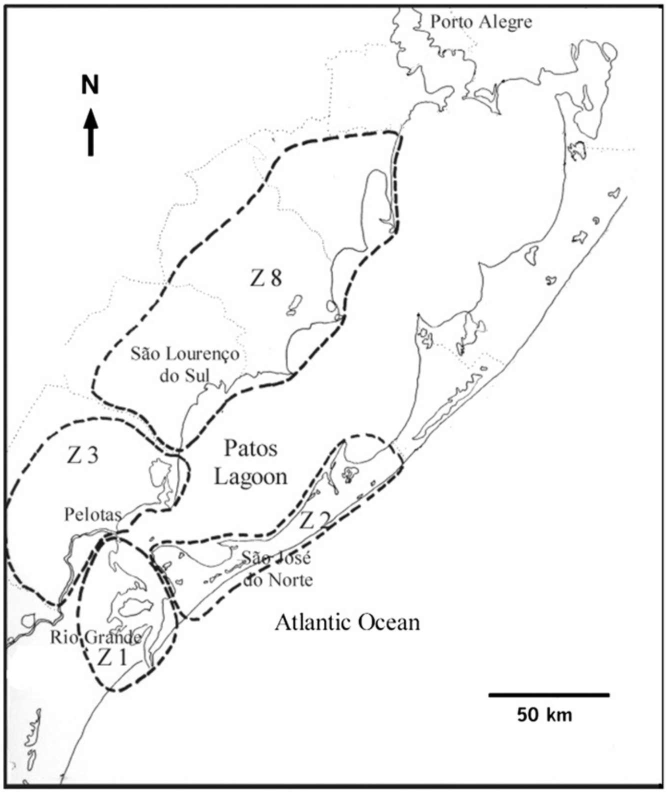

Fig. 4. Fishing colonies in the estuary of Patos Lagoon. Fishing systems 1 and 2 are constituted by members of fishing colonies from São José do Norte (Z2) and Rio Grande (Z1), while fishing systems 3 and 6 are solely formed by fishers from Rio Grande. Fishers from Pelotas, belonging to Colony Z3, and fishers from the urban area of São José do Norte integrate the fishing system 4, while fishers from São Lourenço, represented by Colony Z8, constitute fishing system 5.

that support the small-scale fishery sector in the region. Comparison across the fishing systems of the estuary of the Patos Lagoon (Table 2) was done to focus on the features that make one system environmentally, economically, and socially more resilient or more vulnerable than another. The survey was applied to 46 fishers in January and February, 2006 according to the fishing systems typology of the estuary of Patos Lagoon (Table 2 and Fig. 4).

3. Results and discussion

3.1. Adaptive capacity in fishing systems: strategies through fishers' ways of living

Several tactics are used to maintain fishers' livelihoods, typically related to unfavorable climatic conditions in which fishers find themselves threatened by events that result in poor harvests. Among them is the search for activities in which they usually do not work, whether related to artisanal fishing itself, industrial fishing, or activities unrelated to fishing. One adaptive mechanism is the exploration of species as yet unexploited, such as fresh water fish, or blue crabs (*Callinectes sapidus*). In recent years, for example, this crustacean has been an important source of alternative income for fishers with the development of a new consumer market such that crab may become one of the main sources of income in some communities.

Outside the fishery sector, fishers find temporary work in the urban area (e.g., construction work) or in the rural area (e.g., pine reforestation). Large numbers of fishers, particularly those who live in areas distant from the cities, often turn to small-scale farming activities or find jobs in the farms which usually include rice and onion culture. Artisanal fishers often find temporary work in the industrial fishery sector, both fishing aboard vessels or accomplishing dockside activities such as unloading fish or fixing nets.

Fishers recognize species that are abundant and still to be explored, indicating some potential for commercialization. Among them is the menhaden (*Brevoortia* spp.), which have been marketed by fishing companies in the past. Fresh-water (e.g. curimatid—*Cyphocharax* sp), and salt-water species (e.g., swordfish—*Trichiurus lepturus* and red shrimp—*Aristeus antennatus*) are also recognized as having considerable potential yields, but currently low market value.

Due to the overexploitation of some harvests (e.g., catfish and black drum) and an increase in the occurrence of unsuccessful seasons for the most important harvests—particularly pink shrimp—an increase in fishing effort has taken place. Increase in the fishing effort includes the use of high-technology gear such as fish-school detection echo-sounders; the use of more and larger nets; longer time spent fishing (in boats with greater autonomy); a broader search for fish schools and the expansion of each fisher's fishing territory. Fishers have also applied a variety of fishing gears to increase capture (e.g., the use of trawl nets particularly otter trawling in shallow areas as a way to make up for bad harvests), resulting in predatory resource exploitation. One exception is the development of new stownet placement methods with different positions through the night.

Another adjustment fisher use against the decrease in harvests is to reduce costs, with adjustments including performing boat maintenance with cheaper materials, buying used nets instead of new gear, and attempts to use other light sources instead of gas lanterns in the stownet pink shrimp fishery. A considerable number of fishers compensate for low captures by adding value to the products they sell. Instead of trying to catch more fish, fishers concentrate on activities such as removing the carapace of shrimp and making fillets of finfish to get higher prices.

3.2. Influence of fishing changes and uncertainties

The low prices paid for the main species caught by small-scale fishers, the reduction in catch, and the increasing costs of fishing have made the pink shrimp harvest, economically the most important one in the estuary of Patos Lagoon, fundamental to the well-being of the fishing communities in this region. Paradoxically, pink shrimp harvests, which could guarantee a reasonable income for most fishers, are highly unpredictable as this species is affected the most from climatic variability [14,15]. This creates an uncertain situation in regard to the catch of shrimp which varies as a function of the rain regime. Abundant rain in the upper watersheds makes it difficult for pink shrimp larvae to enter the estuary due to intense runoff, jeopardizing fisheries activities in the lagoon. In addition to the rain regime, economic variables add uncertainty. For instance, the export rates of fish products influence the price paid for pink shrimp. Due to such uncertainties, fishers often consider the fishing profession to be psychologically less comfortable than any other economic activity, as most other activities generate a more predictable income.

In spite of federal and state-level public policies to help finance artisanal fishers to obtain better equipment, the number of fishers that received loans has decreased, most probably because fishers are becoming less sure they will be able to honor their debt. In fact, those who have had access to financing programs such as the National Program to Strengthen Small-scale Agriculture (*Programa Nacional de Fortalecimento da Agricultura Familiar—PRONAF*) and the State of Rio Grande do Sul Fisheries Program (*RS-Pesca*) have complained of increasing debts because of market interest, as the failure of previous harvests have prevented them from being able to repay their debts as planned.

Most fishers—with the exception of those who regularly practice agriculture as an important source of income or at least for subsistence—do not have a livelihood strategy in case the pink shrimp harvest fails. Since it is not always possible to obtain a temporary or casual job to maintain basic house expenses, their families often endure periods of shortages, at times depending on government help or other assistance to survive.

3.3. *Social cohesion and institutional relationships*

Kinship and friendship ties among fishing communities are important mechanisms which allow fishers and their families to minimize uncertainties. Mutual protection of fishing gear, fishing grounds and knowledge sharing about the best fishing spot in a given fishing season increase the chances of each fisher obtaining his/her catch and illustrate a level of community self-organization which decreases vulnerability. Although the shrimp fishing nets are fixed nets, fishers do move their fishing spots according to changes in shrimp abundance in the lagoon. Therefore, during the season, fishing locations may change from day to day if there is space available. This mobility is part of the territorial accords made informally among fishers and is well respected. During the day when fishers are selling the shrimp, they leave the nets hung in the fishing spot. There is an exchange of favors between fishers, and generally when one fisher sells his shrimp the others help to take care of the fishing equipment and locations to make sure that no invasion and/or robbery occurs. In all fishing systems, although there is intrinsic secrecy concerning the best fishing spots, the sharing of information about the catch through kinship and friendship ties reduces uncertainty and increases the chances of each fisher obtaining his/her own catch. Mechanisms to monitor such equipment as boats, engines, and fishing gear similar to those in the pink shrimp fishery, were also created as a consequence of increased theft. Day and night shifts to monitor fishing equipment have been agreed upon among fishers who work near each other. Such ties are described by Begossi [24] and identified in the Patos Lagoon by Almudi et al. [25] as being important for the development of territoriality. That implies respect for traditionally established rules such as stownet placement stations for the pink shrimp harvest and the enforcement of fishing locations by family members and by those with shared affinities.

The existence of a fishery co-management arrangement, i.e. the Forum of the Patos Lagoon, creates an opportunity for decreasing vulnerabilities through the involvement of fishers in decision-making [26–29]. Nevertheless, issues of sub-optimal participation jeopardize that potential. There are several levels of participation in the Forum of the Patos Lagoon [27,29]. Some fishers do not know about the Forum, but there are others who take part in most of its meetings. According to Kalikoski [27], 31% of the artisanal fishers in the estuary of Patos Lagoon have attended at least one Forum meeting. Of those, 76% feel that the Forum works in some way on behalf of fishers' interests [27]. Although some fishers consider the meetings important, they complain that such meetings are too time-consuming and disorganized. The lack of participation is mainly due to the locations where the meetings take place. Other factors pointed out by the fishers include scheduling problems with the date or time, as most of them are working when meetings are held, problems with invitations, and transportation costs to the meeting place [27].

Considering the uncertain number (approximately 5000 families) of fishers in the estuary of Patos Lagoon, the proportion present at meetings is very low. Usually, the presidents of the fishing colonies[1] attend most meetings, and the most involved fishers end up becoming leaders in their communities, communicating information about the subjects discussed in the meetings. This is because the Forum of the Patos Lagoon represents a co-management arrangement that is not purely community-based, which hampers the full involvement of fishers in the process [29].

3.4. *Self-organization of fishing systems and public policy*

Public policy may act upon the artisanal fishing systems of the estuary of Patos Lagoon at different levels or scales. The public policies that directly help the small-scale fishery sector in the region include the unemployment benefit program during fishing closures and loans from the National Program for Empowering Small-scale Agriculture (*Programa Nacional de Fortalecimento da Agricultura Familiar—Pronaf*) and from the state program *RS Pesca* which aims to improve fishing livelihoods and the productive capacity of fishers. These are federal and state programs that give fishers access to credit at the local level [30]. In addition, during fishing closures, fishers are entitled to receive unemployment benefits as an incentive to comply with regulations and as a mechanism to maintain their livelihoods during this period. The granting of unemployment benefits was a victory obtained through the Forum of the Patos Lagoon co-management arrangement, and the demands from the fishers themselves within the Forum.

In spite of the higher degree of cohesion and organization found among fishers in some of the fishing systems, such as fishing system 4, public policies towards minimizing community vulnerabilities associated with climate change have not yet been implemented for the fishery sector. For instance, at the time of writing this article, the National Plan for Climate Change[2] did not include fisheries among the sectors potentially vulnerable to climate change, even though there are successful examples of public policies applied to other sectors, such as agriculture.

3.5. *Adaptive mechanisms used by fishers*

One of the single most important characteristics of estuarine artisanal fisheries is the fishing calendar. Prior to the time when practically no formal fisheries management rules existed (before the 1960s), artisanal fisheries followed a calendar of activities (rules in use) determined by the abundances of different fisheries resources during the year and by the fishing technologies in use. The calendar was established by and reflected the experience of local fishers. As such, it represented a form of traditional ecological knowledge with important consequences for the resilience of artisanal fisheries because it posed limits on the exploitation of resources.

From January to May fishers captured primarily shrimp and mullet, although some also fished for black drum, catfish and menhaden. Mullet were fished mainly in two periods: in January when the adults were returning from their spawning grounds in the sea, and during the spawning runs, which normally occurred between April and June. Elder fishers recall that until 1950 the main triggers for mullet to start schooling and to migrate to the

[1] The Fisher Colony is a professional organization of fishers of a given municipality, which is legitimized by the Federal Constitution of Brazil as one form of working union.

[2] Available at www.mma.gov.br

sea were the last quarter moon of May and the cold temperatures accompanying the fronts from the Southwest.

Beginning in the month of June, fishers prepared to catch menhaden, young croakers and silverside fish. Menhaden were caught during the spawning migration towards the lagoon. Menhaden were among the most important artisanal fisheries resources between the late 1940s and early 1960s when the average catch was on the order of 2,000 tonnes per year [31]. Although fishers claim that menhaden are still abundant in the estuary and coastal areas, the species is no longer the target of a commercial fishery.

The catfish season normally began in August and lasted until early November. This fishery targeted the catfish spawning grounds in the upper estuary and the large adult catfish that were entering the Lagoon. A less intensive fishery also occurred during the summer months, especially in February, when catfish migrated back to the sea, and the males were incubating the young in their mouth. Only a few fishers were involved in this fishery because the catfish was normally "thin" and did not have a high value.

The croaker and black drum season started in October or right after the catfish season. Initially croakers were caught mainly on the beaches at the mouth of the estuary. Schools of black drum were located by the noise produced by the fish which vibrated in the wood walls of the fishing boat. The black drum fishery has never reached the economic importance of croaker, even when the species was still abundant in the estuary. The peak production of black drum during the 1960s was on average 690 tonnes, while during the same period the average croaker production was on order of 7,000 tonnes (SUDEPE).

The fishing calendar in the estuary of Patos Lagoon is, according to fishers, strongly influenced by the strength of the intrusion of salt water and the rainfall regime. Saltwater is considered by many fishers the single most important factor controlling artisanal fisheries activities in the estuary of Patos Lagoon. This influence is particularly conspicuous in the shrimp fishery. Shrimp is considered to be controlled more by the climate than the other fish resources. A good fishing season usually occurs if the salinity of the estuary is ideal in the period from October to December; the earlier the estuary is replenished with saltwater the earlier will be the shrimp season. "*It does not matter if the winter was rainy or not*, *the important period for shrimp is the end of the spring*", a fisher stated. Such relationship between rainfall regime and shrimp production was demonstrated by Castello and Moller [14] and Moller et al. [15]. A warm winter is also viewed by fishers as beneficial for the shrimp season.

Croaker, black drum and catfish migrate into the estuary during the flood regime when marine waters enter the estuary, which is determined largely by the strength of southern winds. According to fishers, croakers are dispersed and at the bottom when in the marine environment, and before entering the lagoon they aggregate in large "pelagic" schools. It is in this period and areas that croakers are most vulnerable to the fishery, both to artisanal gillnets and industrial purse seiners. Once in the estuary the fish remain in areas with saltwater or brackish water—a fisher suggested that "*of a school of 100 tonnes of croaker only 5 will go to areas with freshwater*". Fishers know by the color of croakers if they came from the sea or if they have been in the estuary for a period of time. The presence of saltwater in the estuary in the Fall is also viewed as beneficial for the mullet season since it controls the formation of schools and the timing of the spawning run. This is corroborated by Vieira and Scalabrin [13] who demonstrated that the reproductive migration of adult mullet intensifies with the decrease in temperature and increase in salinity of the estuarine waters observed during the Fall.

Resource use by small-scale fishers in the estuary of Patos Lagoon was and still is to a large extent conditioned by the availability of the resources in the estuarine environment. This, in turn, is controlled seasonally by the influence of the weather and is also affected by the influence of the moon on the behavior of the fish. As explained by a fisher:

> …nature makes its own fishing closure with the moon, the bad weather, and also the fish, because if it is too windy the fish do not move and you cannot catch them. For instance, if the mullet sees the net it does not enmesh. If it is not the right time, and the fish do not want to be captured, you cannot catch them.

However, resource use practices changed markedly with time when new fishing technologies were introduced and the industrialization of fisheries brought exploitation beyond the limits of the carrying capacity of resources. Changes in fishing practice and resource conditions are described in detail in Kalikoski [27].

What is learned from the above forms of resource use? When resources were abundant, the fishing calendar worked in a way that allowed fishers to benefit from the most abundant resources in a season, while limiting the amount of fishing pressure (time) over a particular species and/or a critical period. For instance, fishing for catfish during the summer months, when the males are incubating the young, was normally discouraged and unnecessary given the availability of other resources such as croaker and shrimp. Similarly, the capture of large amounts of shrimp below the optimal size (between late spring and early summer) was in part prevented by the type of fishing technology in use, and also by the existence of alternative fishing resources. A failure of a fishing season, which was normally verified with shrimp, resulted in a re-distribution of fishing effort to the other resources available in the period, but not to the point of over-exploitation because the fishing practices were more compatible with the carrying capacity of the system and a smaller number of people were involved in the activity.

Until the recent creation of formal rules defining the calendar for each estuarine fishery (Decrees MMA/SEAP 03/2004), an informal calendar was still in place but was much less significant than in the past. Fig. 5 shows the changes in the fishing calendar of the main artisanal fisheries between the 1960s and the early 1990s. Species such as mullet, that were fished mostly in late fall (April to June) during the spawning run, were in the early 1990s fished almost equally throughout the year. For other resources, such as catfish, the collapse of the stock brought a change in the fishing calendar from spring to winter when the few remaining catfish sustained a smaller fishery in the upper estuary.

Prior to industrial fisheries a large proportion of the habitat in the Patos Lagoon and in the southern Brazilian shelf acted as a *de facto* spatial refuge since artisanal fisheries were limited to specific areas of the estuary of Patos Lagoon and adjacent coastal shallow waters. Therefore the increasing competition for resources between artisanal and industrial fisheries and the technological improvements (e.g. more powerful engines and the use of sonars) undermined important factors that made artisanal fisheries resilient in the past, i.e. the limited time and areas of resource exploitation. The fishing technologies and resource use practices in the past depended upon nature cycles, through the influence of the moon, the behavior of the fish, and weather conditions. This concept is represented in Fig. 6 using Holling's four phases model. Artisanal fisheries were limited to two phases in the life stages of the resources: the exploitation phase, when species such as croaker, catfish, black drum and mullet were entering the estuary, and the release phase, when these species and pink shrimp were leaving the estuary to the

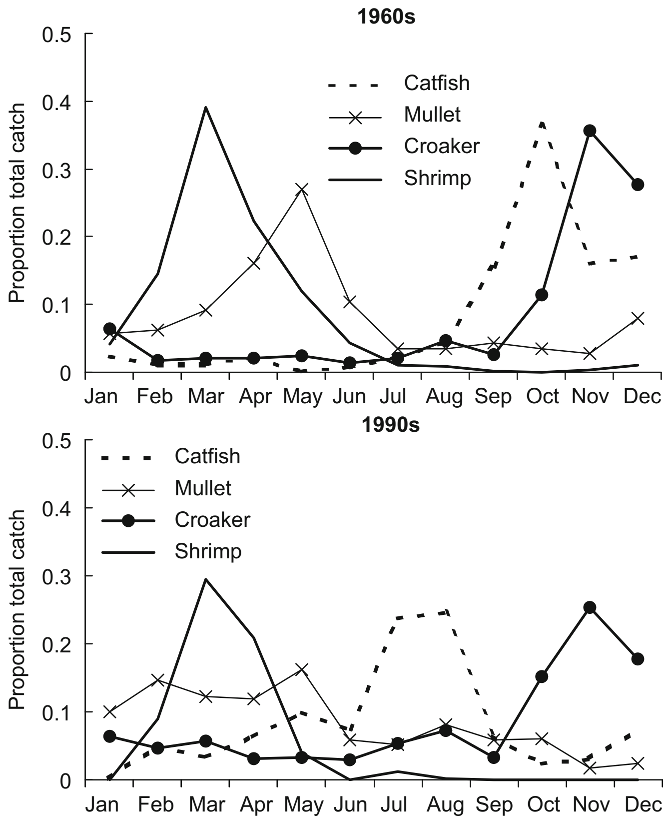

Fig. 5. Fishing calendar of artisanal fisheries in the estuary of Patos Lagoon and coastal waters during the 1960s and 1990s. The lines represent the proportion of the total annual catch of each species obtained in each month.

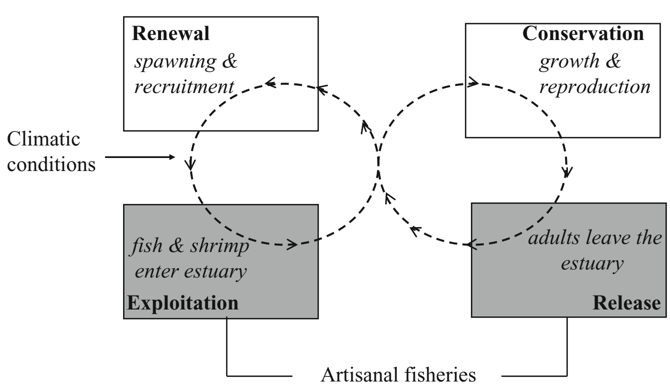

Fig. 6. Four phases model of the dynamics of fisheries in the estuary of Patos Lagoon prior to industrial fishing, adapted to represent the phases where artisanal fisheries activities were concentrated (adapted from [16]).

shelf waters. The other two phases (renewal and conservation) were not targeted by fishers until technological improvements and the industrialization of the fisheries which made the resources available to be exploited at any time and area.

Until recently, the pattern of resource use by artisanal fisheries in the estuary of Patos Lagoon served conservation purposes and made resources less vulnerable to over-exploitation while helping to maintain the cycle of resource renewal. The fishing practices of artisanal fishers sustained a very productive fishery from the early 1900s until the late 1980s [28]. For instance, in 1960 artisanal fisheries were responsible for over 80% of the total fisheries landings in southern Brazil (ca. 27,000 tonnes/year; IBAMA). The above analysis also shows that these fishing practices depended on an informal knowledge system to deal with the dynamics of the resources. Internal and external factors triggered changes in the local resources management, which disrupted a pattern of resource use that was a key for the sustainability of the artisanal fisheries.

Today, the resources are under intensive pressure, from both the industrial and artisanal fisheries, increasing the risk of overfishing and collapse of important stocks such as white croaker and mullet ([32], Vasconcellos, pers. Comm., Federal University of Rio Grande, Rio Grande). A vicious cycle has been created, so that the more effort is increased, the less the catch. In order to make up for dwindling profits, fishing effort is further enhanced, thus increasing the pressure on the stocks. The fishers now talk of periods of ever-increasing difficulties for those who depend on fishing for their livelihood.

3.6. Vulnerabilities of fishing systems

In the context of variability in fishing practices, social-economic conditions, and the tactics used to face unfavorable conditions in the small-scale fishing systems in the estuary of Patos Lagoon, several factors indicate greater vulnerability to internal (e.g. resource exploitation) and external (e.g. market) disturbances. By focusing on these factors, it is possible to identify which systems are more or less vulnerable, and to compare their characteristics. Table 3 present strategies used by each fishing system to face difficult situations. Table 4 present the primary factors that mediate the vulnerability of these fishing systems. It is noticeable that most factors are common to every system, indicating the need for solutions to be sought for each system individually, but also for those that cover all systems together.

Drivers leading to vulnerability of the Patos Lagoon fishing systems include:

(1) Diversification and specialization: while systems 1, 3, and 6 showed little diversification, being restricted to the crab fishery, the other systems presented more robust forms of diversification and specialization, at times including the crab fishery, at others using various fishing methods or the exploration of other environments, such as the coastal sea or adjacent fresh waters.
(2) Trading and subsistence: systems 3 and 6 showed lower vulnerability, as they do not depend exclusively on fishing as a source of income.
(3) Innovation and conservation: multiple strategies are used in all systems, including activities not related to fishing and alternatives within artisanal and industrial fisheries, both in rural and urban areas. Such activities tend to be related to the geographic location of fishing communities.
(4) Fisheries policies and integration: the lack of specific public policies at local, regional and national levels was identified. This constrains local community-based initiatives as there are no mechanisms to create fishing governance systems that address the vulnerabilities of communities in the face of climate variability.
(5) Location and externalization: systems 4 and 6 have lower vulnerability because these fishers depend less on middlemen. System 4 stands out for having developed innovative approaches demanding organization and persistence, which bring greater benefits to the communities. These approaches include selling directly to consumers and forming a cooperative with hundreds of members.
(6) Changes in fishing methods: similar changes in fishing procedures took place in every fishing system, usually increasing fishing capacity, but often with the introduction

Table 3
Variables describing strategies used by each fishing system in the Patos Lagoon to cope with unfavorable situations.

Strategies	Fishing system 1	Fishing system 2	Fishing system 3	Fishing system 4	Fishing system 5	Fishing system 6
Diversification and specialization	Little diversification	Ocean fishery	Little diversification/ crab fishery	Use of several fishing methods	Fresh water fishery	Little diversification
Dependence	Great dependence on fishery resources	Great dependence on fishery resources	Lower dependence on fishery resources	Great dependence on fishery resources	Great dependence on fishery resources	Lower dependence on fishery resources
Innovation and conservation	Other fishery species and casual jobs	Work in industrial fleet	Casual jobs in the city	Other fishery species and casual jobs	Casual jobs and work for industrial fleet	Agriculture
Public policies and integration	Unemployment benefit	Unemployment benefit	Unemployment benefit	Unemployment benefit	Unemployment benefit	Unemployment benefit
Location and externalization	High dependence on middlemen	High dependence on middlemen	High dependence on middlemen	Relatively low dependence on middlemen	Dependence. On industrial fishery and local colony	Relatively low dependence on middlemen

Fishing systems are described in Table 2.

Table 4
Factors influencing the vulnerability of fishing systems in the Patos Lagoon.

Resilience and vulnerabilities	Fishing system 1	Fishing system 2	Fishing system 3	Fishing system 4	Fishing system 5	Fishing system 6
Changes in fishing practices	Vulnerability increases as a function of increased fishing effort and weakening of informal agreements among fishers					
Uncertainties	Vulnerability increases due to growing uncertainties in regard to harvest success, particularly for pink shrimp					
Scale and social cohesion	Little cohesion	Little cohesion	Little cohesion	Medium cohesion	Little cohesion	Little cohesion
Community self-organization	Medium to decreasing organization	Medium to decreasing organization	Medium to increasing organization	Low organization	Low organization	Low organization
Adaptation and learning mechanisms	Low level of adaptation and learning in every system, with loss of fishing control mechanisms through agreements among fishers; low participation in Patos Lagoon Forum, with the exception of system 4					

Fishing systems are described in Table 2.

of highly effective gear and excessive nets leading to a level of exploitation greater than the stocks' capacities for renewal.

(7) Uncertainties: mainly related to the climate and to the lack of appropriate public policies and governmental mechanisms. The uncertainties related to a good pink shrimp fishing season influenced all fishing systems, as shrimp is the most important source of income in years of favorable weather. Although less susceptible to climatic changes, the main finfish harvests (i.e. croaker and mullet) are also poorly predictable.

(8) Scale and social cohesion: with the exception of fishing system 4 we identified little social cohesion among artisanal fishers, with weak or non-existent self-organization, little or no local leadership, and weak community-based institutions. As a result, these fishers have little capacity to represent their interests when faced with opposition from other stakeholders and are more likely to be affected by undesirable changes. The erosion of traditional fishing practices and fishers' compliance with informal rules and agreements established by them in the Patos Lagoon has decreased the degree of control over resource use, facilitating overexploitation.

(9) Community self-organization: fishing system 4 is the best organized, which is acknowledged by its members but also by those from other systems. Such organization is reflected in demand-oriented street protests, better articulation within the Forum of the Patos Lagoon, the presence of local leaders, and the creation of more profitable trading procedures. In fishing system 3, a stronger organization is developing among fishers with the support of the Catholic Church (*Pastoral da Pesca*), already reflected in the establishment of a cooperative including 21 fishers. In the other fishing systems, traditional fishing practices identified in the past such as a rotation system for trawlers, monitoring of fishing spots, and maintaining distance among pink shrimp nets, have been eroded.

(10) Adaptation and learning mechanisms: a small degree of adaptive learning in unfavorable situations was found for all fishing systems. Control mechanisms for fishing activities through agreements among fishers have been weakened, making them more vulnerable to unfavorable events.

4. Conclusions

Artisanal fishing communities from the Patos Lagoon system in southern Brazil are highly affected by climatic events as they depend directly on natural resources for maintaining their livelihoods. The rain regime is an essential factor determining the success of the pink shrimp fishery which represents the most important source of income for the fishers in the Lagoon. Fishers' vulnerabilities are increased by the fact that they lack financial resources to sustain their families in the event of unfavorable climatic conditions for fish populations.

Decreasing catches of the main fished species has been a major concern of the fishers from all of the fishing systems. It causes them to become more dependent on fewer species and decreases their options to diversify. Moreover, fishers perceive that the costs of maintaining and renewing fishing gears have increased more than the income provided by the fisheries products. Results show that fishing communities that diversify and have a higher degree of self-organization are able to create ways to minimize their vulnerabilities during adverse climatic conditions. Some fishing communities are characterized by having several sources of income while others are impelled to switch strategies when their most important resources are not available. Diversification can take place by varying the species caught, working on industrial fishing vessels, exploring fresh water resources, and having alternative sources of income from agriculture and other temporary jobs. Fishing communities which are relatively better organized usually have more opportunities for commercialization and, as a consequence, have a higher probability of coping with periods of unfavorable conditions. A lack of opportunities and processes for commercializing the captured species has also increased the vulnerability of fishing systems. Most fishers rely on middlemen for selling their fish products. Although the middlemen provide some assistance to fishers in different ways (e.g. transport to hospitals in case of emergency, lending money, etc), fishers feel obligated to sell their catches to specific middlemen who can therefore control the prices of the fish. Fishing systems 4 and 6 are less vulnerable in this sense as fishers have devised strategies to depend less on middlemen. They sell fish and shrimp directly to consumers in street markets or keep them in store houses for commercial sale when conditions are more favorable.

Throughout the Lagoon system, however, only a few communities have developed adaptive mechanisms to cope with the influence of climate on fish resource abundance and availability. Little external institutional support for small-scale fishing communities, erosion of their traditional resource use systems (e.g. informal rules and agreements among fishers), and decreases in fish stocks in recent decades are factors leading to a gradual increase in the vulnerability of fishers' livelihoods. Although governmental programs exist to assist artisanal fishers with fixing fishing gear, in addition to the employment benefits which represent important sources of income during fishing closures, the lack of public policies to deal with the impact of climate variability and change on the livelihoods of fishing communities is a major threat to the social security of these communities. Marginalization and little institutional support for the artisanal fishing sector was another issue detected by this study. Although participatory multi-stakeholder/institutional bodies exist for managing the fisheries, the level of participation of fishers in such bodies has been weak and the role of these institutions in empowering local communities has been limited.

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