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Climate variability and the Peruvian scallop fishery: the role of formal institutions in resilience building

Marie-Caroline Badjeck · Jaime Mendo · Matthias Wolff · Hellmuth Lange

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Abstract Peru experiences recurrent ENSO (El Niño Southern Oscillation) events during which the Peruvian bay scallop (*Argopecten purpuratus*) undergoes substantial changes in its stock size. In the North of the country strong warm ENSO events are synonymous with floods and river discharges that negatively affect scallop biomass, while in the South increased sea surface temperatures lead to an increase in stock size. This paper explores how formal institutions respond to climate variability and resource fluctuations in the scallop fishery, and what role they play in the maintenance or erosion of resilience. The research shows that formal institutions are slow to learn, self-reorganize and respond to climate variability while fishermen's responses are spontaneous, ensuring a rapid process of individual adaptation. Institutional responses are mostly ex-post, and are not strongly shaped by past experience, thus eroding the resilience of the system. However, fishermen's responses sometimes lead to negative outcomes such as local stock overexploitation or 'invasion' of natural scallop habitats for scallop grow-out, and formal institutions play an important role in resilience building through the control of effort and entry in the fishery. In this paper causal loop diagrams are used to conceptualize the fishery system to highlight key variables and processes. The study thus provides the opportunity to

M.-C. Badjeck · M. Wolff
Center for Marine Tropical Ecology (ZMT), Fahrenheitstr. 6, 28359 Bremen, Germany

M.-C. Badjeck (✉)
The WorldFish Center, Jalan Batu Maung, Batu Maung, 11960 Bayan Lepas, Penang, Malaysia
e-mail: M.Badjeck@cgiar.org

J. Mendo
Facultad de Pesquería, Universidad Nacional Agraria La Molina,
Av. La Universidad, La Molina, Apdo. Postal 456, Lima, Peru

H. Lange
Research Center for Sustainability Studies (artec), University of Bremen,
Seminar-und-Forschungsverfügungsgebäude (SFG), Enrique-Schmidt-Strasse 7,
28359 Bremen, Germany

explore the usefulness of causal loop diagrams and conceptual models combined with participatory approaches in the exploration of the resilience of a system. The case study also illustrates that individual adaptation, a feature of resilience, is occurring and will occur spontaneously, changing property right regimes and responding not only to climate variability but also market forces. In order to maintain and build resilience and engender positive management outcomes, formal institutions not only need to shape fishermen decision-making, they must also contribute to knowledge building as well as the adoption of innovative approaches.

1 Introduction

Social–ecological systems (SESs) refer to social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units (Anderies et al. 2004). Resilience in SESs can be defined as the ability to absorb disturbance, the degree to which a system is capable of self-organization, and the capacity to learn and adapt (Berkes et al. 2003; Resilience Alliance). Theories of institutions have been widely used to gain an understanding of their role in environmental change (Young 2002; Young et al. 2006; O'Riordan and Jordan 1999) and institutions within social–ecological systems have been considered as vehicles through which resilience can be enhanced or compromised (Bingeman et al. 2004). Consequently, understanding how they respond to climate variability and how these responses enable or constrain adaptation processes within SESs is critical for the design of policies aimed at maintaining resilience.

Institutions are generally understood as any formal constraints (rule, laws, and constitutions) or informal ones (norms of behaviour, conventions) that mould interaction in a society (North 1990, 1994). Institutions can shape the decision-making process of actors, being a primary mechanism to mould and facilitate particular outcomes (Ostrom et al. 2002; Dietz et al. 2003; Noble 2000). However individuals also have the agency to change institutions to reach desired outcomes (Giddens 1984). Formal institutions can be seen as rules that are readily observable and explicit and informal institutions, in turn, as rules based on implicit understandings, being in most part socially derived and therefore not accessible through written documents or necessarily sanctioned through a formal position (Zenger et al. 2002, p. 2). In this study of formal institutional responses to climate variability, we focus on the explicit aspects of rules and norms (Hodgson 2006) related to formal organizations involved in the management of the scallop fisheries in Peru.

Adaptive capacity can be defined as the ability of institutions or actors to change inherent properties to return to a reference or alternative state of the system they belong to. Adaptive capacity thus translates into increasing the ability and speed to evolve and adapt to new situations as they arise, and the flexibility to experiment and adopt novel responses to address problems (Walker et al. 2002). In this context, response is defined as any action taken to manage environmental change, in anticipation of that change or after change has occurred (Thompson and Adger 2005). The analysis of institutional responses to climatic events allows us to gauge what role they play in the maintenance of the adaptive capacity of the system under study.

The aim of this paper is threefold: (1) to understand how formal institutions in the scallop fishery respond to climate variability in Peru with a focus on the El Niño phenomena, (2) to identify what role they play in the maintenance of system resilience and (3) to develop a conceptual model of the scallop fishery to inform future interventions and policies. After a description of the research methodology, Section 3 describes institutional arrangements underpinning the fishery and the impacts of climate variability on scallop resources (*Agropecten purpuratus)*. This is followed by a section in which responses of formal institutions to climate variability are presented. In a fifth section we apply system analysis to present a conceptual model identifying variables and drivers that shape the resilience of the system and identify the role of formal institutions. The final section presents a discussion and some concluding comments.

2 Methodology

A multiple-case study approach was warranted to understand the differential impacts of climate variability in coastal Peru. The research was thus carried out in two study sites: Pisco, in South-Central Peru and Sechura, North of Peru (Fig. 1). These sites were chosen for two reasons. The first is that both are bay ecosystems, where the extraction of scallops is of great importance for the local and regional economy. The second reason is that the sites have different histories of El Niño Southern Oscillation (ENSO)-related impacts. Evidence of the findings for the response of

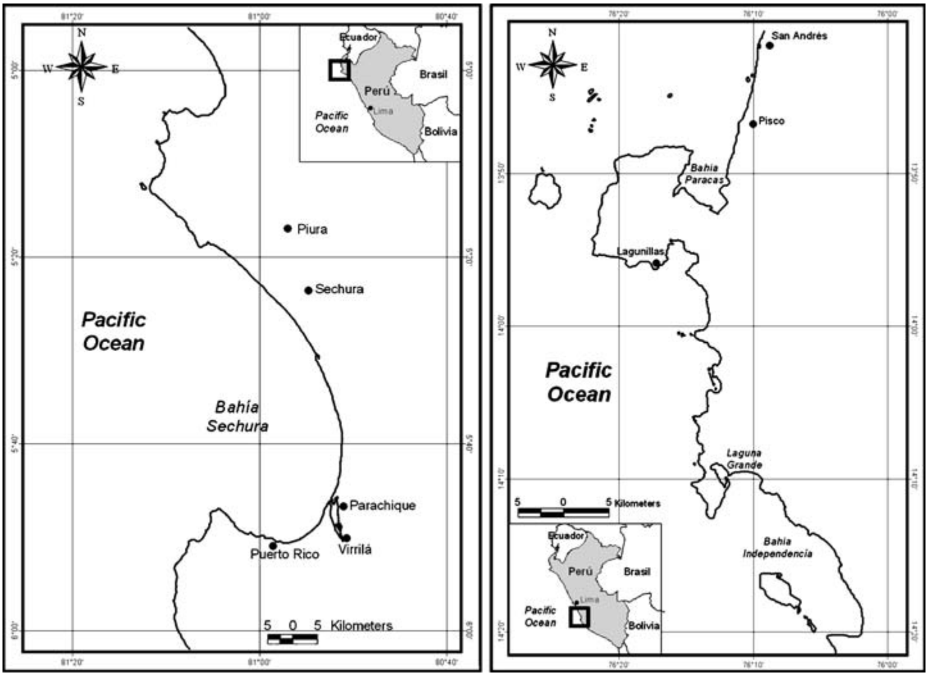
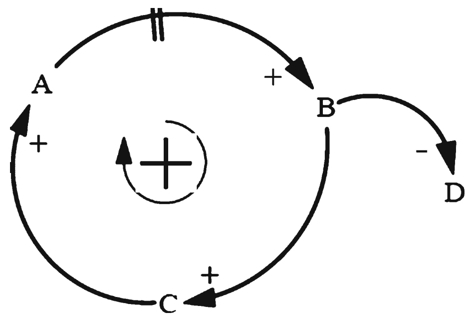


Fig. 1 Study sites

Fig. 2 Causal loop diagram



institutions to climate variability is driven by secondary data analysis, interviews and stakeholder meetings. Secondary data analysis consisted of the analysis of reports, policy statements, planning documents and archival research of fisheries legislation. Interviews were conducted between March 2005 and June 2006 with key informants from government agencies, fishermen associations, and non-governmental organizations to capture their perception of how ENSO affected the scallop fishery. Topics included the articulation between national and regional authorities, the effectiveness of fisheries policies and the impact and management of ENSO events. Interview data were analyzed using qualitative data analysis software Atlas.ti 5.0. Atlas.ti includes a set of tools that allows for the management and evaluation of text-based data through coding.

Additionally, seven stakeholders meetings were held between 2005 and 2007. Central components of these events were group discussions and expert input. The meetings provided a learning platform for the authors on local perception of management issues and the impact of climate variability on scallop resources. Finally, to understand how different driving forces affect institutions' responses, a conceptual model of the fishery was developed using causal loop diagrams (Fig. 2). Causal loop diagrams articulate our understanding of the dynamics of a system (Barlas 2002). A causal relation between variable (A) and (B) is represented by an arrow and means that the input variable (A) has some causal influence on the output variable (B). A positive (+) influence means that a change in (A), *ceteris paribus*, causes (B) to change in the same direction and a negative (−) influence, *ceteris paribus*, means a change in an opposite direction, such as an increase in (B) causes a decrease in (D). Feedback loops are a succession of cause–effect relations that start and end with the same variable, the circular causality implying dynamism over time and can either be positive (reinforcing) or negative (balancing) (Barlas 2002, p. 1147). A short line indicates that there is a delay between a change in (A) and the corresponding change in (B).

3 Scallop fishery: overview, institutional arrangements and impact of ENSO

3.1 Overview and institutional arrangements

Currently the Peruvian scallop fishery is one of the most important invertebrate fisheries, representing 41% of aquaculture products exported in 2005 (PROMPEX

2006). The fishery started in the province of Pisco in the 1950's while the first experiences with intensive culture were initiated in 1979 (Valdivia and Benites 1984; Valdivieso 1990). Diving is the main method of extraction due to the fact that scallop beds are located in relatively shallow areas (5 to 20 m). The province became the hub of the scallop diving fishery and until now the most skilled divers are still considered to come from the area. It is estimated that 39% of the 3,059 artisanal fishermen from the Pisco area are involved in the diving fishery, representing 46% of the fleet (Mendo et al. 2005). In 1975 the Paracas National Reserve, the only marine reserve in Peru, was created around Independencia Bay. This restricted the extraction of aquatic resources and only under special conditions, described in the following paragraph, can fishermen associations capture or culture scallops. In Sechura, diving is a recent activity brought by fishermen from the South in the late 1980's and early 1990's. Based on available data, it is estimated that the diving fishery represented 25% of the fleet in 2005 compared to 19% in 1995, with more than 30% of the 6,000 artisanal fishermen involved in the fishery (Fiesta, personal communication; DIREPRO 2005b; DIREPE 1995).

In terms of the legal framework, the General Fishing Law (GFL) of 1992[1] forms the basis for the exploitation of fisheries resources in Peru. The GFL states that aquatic resources are state property (*Res publica*) and certain use rights may be granted to citizens through licensing schemes. There is no territoriality related to the extraction of aquatic resources, the Peruvian fishery being considered a regulated open-access fishery (*de-facto* open access). With the liberal approach of Fujimori's government in the 1990's, the 1992 GFL aimed to attract private and foreign investments and the promotion of exports were reinforced in 2001 when the Regulation of the GFL was implemented.[2] The objective of the latter change was to simplify rules and favour investment with fiscal initiatives such as the reduction of income taxes for aquaculture companies. The Aquaculture Law and its Regulation[3] was promulgated at the same time and established two modalities to undertake aquaculture activities: through concessions (sowing in the ground or suspended culture in nets) and authorizations (stocking and re-stocking purposes). In the Paracas Reserve in Pisco special regulations[4] prevail: in "special concessions" only suspended culture is allowed and seed collection from natural banks is prohibited. Suspended culture requires significant capital investments that often fishermen associations are not able to bear. To palliate this situation associations seek financial capital from private companies, but these schemes often occur under unfavourable terms. Currently there are no management plans for the scallop fishery. Regulation is mainly through minimum capture size (>65 mm), the latter corresponding to the adult stage of the scallop and a size suitable for export markets. Nevertheless it has been argued that the minimum size should be increased in light of increased fishing effort in the last decade (Mendo and Wolff 2002, 2003). Other measures commonly applied are moratorium when low stock biomass is observed, however these are poorly enforced.

[1] General Fishing Law, Law Decree N° 25977—1992.

[2] Regulation of the General Fishing Law, Supreme Decree N° 012-2001-PE—2001.

[3] Law for the Promotion and Development of Aquaculture, Law Decree N° 27460—2001 and Regulation of Law for the Promotion and Development of Aquaculture, Supreme Decree N° 030-2001-PE.

[4] Law of Natural Protected Areas and its Regulation, Law Decree N° 26834—1997.

The political structure of decision-making in the fisheries sector is divided into two levels: national and regional. Since 2002 Peru has been divided into 25 regions[5] with their respective elected regional government. The Production Ministry (PRODUCE) and its Vice-Ministry of Fisheries is the principal entity governing the fishing sector, with the Peruvian Marine Institute (Instituto del Mar del Perú—IMARPE) providing scientific advice. The different departments that make up the Vice-Ministry of Fisheries (aquaculture, artisanal fisheries etc.) all have their respective competencies and branches in regional offices. Despite the presence of these regional branches the management process remains highly centralized (Mendo et al. 2002). Organization among Peruvian artisanal fishermen and lobbying power are low despite the presence of a national organization (Federación de Integración y Unificación de los Pescadores Artesanales del Perú—FIUPAP). At the local level the number of fishermen organizations has been growing due to the fact that only registered associations can access grounds for scallop aquaculture.

3.2 ENSO impact on the scallop resource

The warm phase of ENSO, also known as El Niño, is characterized in Peru by positive sea surface temperatures (SSTs) and negative sea level pressure anomalies. From 1950 to 2003 there have been eight El Niño events of varying intensity affecting Peru with the 1982–1983 and 1997–1998 being the strongest ones (Wang and Fiedler 2006). The Peruvian bay scallop is highly susceptible to changes in SSTs triggered by ENSO events. During the El Niño period of 1983–1985, the scallop harvest in Independence Bay—Pisco was the highest ever recorded, yielding around 40,000 tons as opposed to about 1,000 tons in previous years (Fig. 3). The (normal) cold upwelling conditions (summer water temperature of about 16°C) were drastically altered to tropical warm water conditions (around 25°C), affecting population dynamics by increasing growth rate and recruitment, as well as the bay's scallop carrying capacity (Wolff and Mendo 2000). Scallops can reach a commercial size (65 mm) at 12 and up to 18 months in non-El Niño years between 6 to 12 months during El Niño events. Cold events have also been shown to have negative impacts on scallop populations: at low temperatures spawning and recruitment decrease (Wolff et al. 2007) leading to a decrease in landings (Fig. 3).

In Sechura during El Niño events an inverse relationship exists between scallop landings and increased SSTs and river discharge (Fig. 4). During the 1997–1998 El Niño the total accumulated rainfall in the city of Piura was 1,802 mm, 30 times its normal value (Takahashi 2004) which resulted in river discharge in the bay four times higher than normal. The low scallop catches in 1997–1998 in Sechura have been suggested by fishermen to be the result of this excessive discharge: freshwater input into the bay could be decreasing salinity beyond the scallops' tolerance limit or/and increasing mortality with higher sedimentation rates. Taylor et al. (2007) developed a model which demonstrates a significant correlation between both spawning stock size and river discharge-mediated mortality on catch levels, substantiating observational data. Few studies have directly looked at the impact of the cold phase of ENSO (La Niña) on the scallop fishery in Sechura. Nevertheless, recent modeling efforts

[5] Organic Law of Regional Government, Law Decree N° 27867—2002.

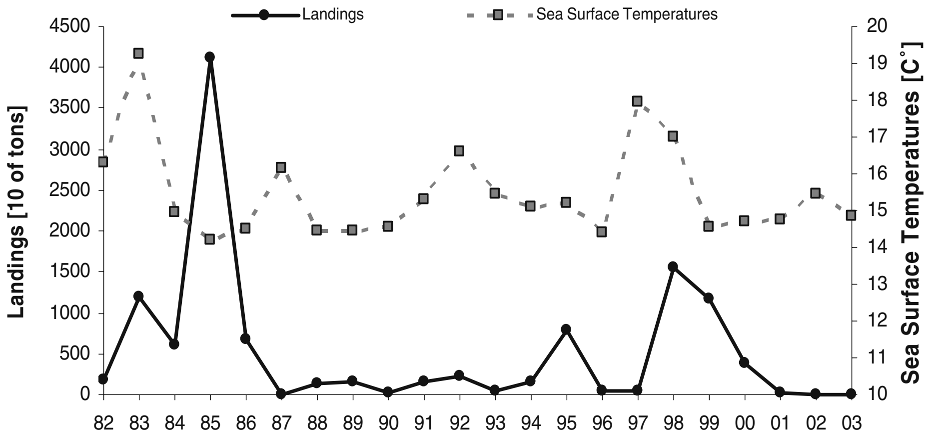


Fig. 3 Annual catch and sea surface temperature changes in Pisco 1982–2003 (Mendo and Wolff 2003; Guevara and Estrella, unpublished; Flores et al. 1994). During the El Niño 82–83 a time lag is observed between temperature peaks and increases in landings. This could be explaining by the fact that fishing effort reached its peak in 1984–1985 once the population cohort of 1982–1983 reached its marketable size and entry into the fishery by migrants was at its highest during this period. In 1997–1998, the scallop stock increased but instead of waiting for the cohort biomass to build up, small juvenile scallops of low market value were extracted leading to lower landings

(Vadas 2007) argue that the variation in stock size is not dependent on temperature but rather river discharge, lower temperature having little influence on population dynamics, the bay being located in a transition zone near warm tropical waters.

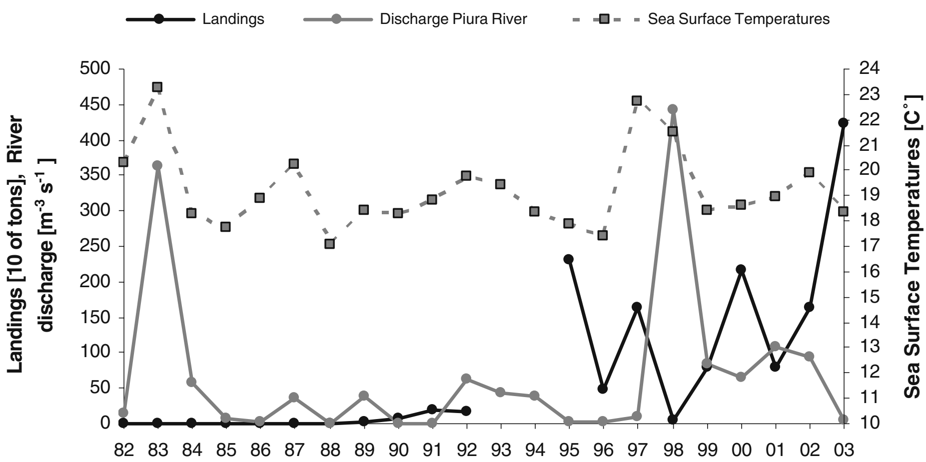


Fig. 4 Annual catch, sea surface temperature (SST) and river discharge changes in Sechura 1982–2003. Landing data was derived from IMARPE catch statistics (Flores et al. 1994) and reports (Tafur et al. 2000; Guevara and Estrella, unpublished; Flores Ysla et al. 2005). Data was unavailable for the 1992–1994 periods. SST in Paita (a research station near Sechura used as a proxy) was provided by IMARPE-Paita coastal laboratory. River discharge data was granted by the GeoforschungsZentrum (GFZ) Postam and recorded by the Sistema de Alerta Temprana—Piura (SIAT), at the Sanchez Cerro Bridge, Piura River

4 Responses to climate variability

4.1 El Niño of 82–83: the surprise

Before the 1980's the international market for scallop was limited but in July 1983 Canada entered a scallop moratorium which resulted in a high demand for the Peruvian scallop in the North American markets (Echevarria Espezua 1985). The combination of a dramatic increase of scallop population due to warm SSTs and a growing international demand resulted in the first "scallop boom". While during the first phase of El Niño commercially exploited shallow water bivalves and crabs disappeared (Arntz 1986), later on the increase in scallop populations led fishermen to rapidly focus on this species. In 1982 scallops represented 8% of the total seafood catch and the following year 88.9% (Morales 1993). The response was not only local, fishermen from all over Peru entered the fishery due to its open-access nature. In the Paracas Reserve the population went from 250 families and 80 boats to 4,500 crew, 3,000 divers and 1,500 boats (Morales 1993). Apart from the minimum size limit (65 mm) there were no measures such as effort controls and harvest levels available to the authorities to control the extraction. The government, under pressure from fishermen associations and the advice of IMARPE, responded with fishing moratoriums, but these were not enforced or respected (Table 1, B). From the interviews the absence of enforcement and control were partly attributed to the limited capacity the recently established regional office possessed and the lack of preparedness of the authorities. According to the accounts of staff working in 1983, the Fisheries Regional Direction was not well managed and the workers were characterized by a lack of training and little experience (Table 1, A).

During 1983–1984, private companies promoted the establishment of scallop sea farms in Independence and Paracas Bay. However, these were not successful due to the lack of adequate techniques and conflicts with artisanal fishermen, these sea farms being located on traditional fishing grounds (Garcia Carhuayo 1998). The state intervened in 1983 with the first of a series of new legislations for the zoning and development of the activity.[6] Subsequent to El Niño the activity decreased, with migrants leaving and some fishermen from Pisco migrating to other favourable zones like Sechura. Fishermen that persisted with aquaculture activities in Pisco had to organize themselves to obtain special concessions since by law only registered groups could have access to culture grounds. At the national level, the Ministry of Economy and Finance declared aquaculture development as a national priority in April 1989.[7] In 1994 the government (Ministry of Agriculture—INRENA) elaborated the second management plan for the Paracas Reserve[8] based around tourism and aquaculture activities, which was not the case in the first one in 1979 (Garcia Carhuayo 1998).

[6]Supreme Decree N° 021-82-PE: authorization for the installation of culture sites or "criaderos" in the Paracas National Reserve. Ministerial Resolution N° 260-83-PE: complementary norms for aquaculture of molluscs approved. Ministerial Resolution N° 357-84-PE: temporary norms and regulations for the recollection of scallop seeds. Supreme Decree N° 016-84-PE: regulation for aquaculture of molluscs approved.

[7]Supreme Decree N° 073-89-EF Declares that the development of aquaculture is of national utility and social interest for the country—1989.

[8]Management plan for the Paracas Nacional Reserve (1994) and the accompanying bianual operacional plan, R.J. N° 055/93/INRENA—1993.

Table 1 Interview excerpts from Atlas.ti.5.0

ID	Codes	Quote	Reference
A	Response to El Niño and decentralization	"[In 1982] Direccion Regional de Pesqueria moves from Pisco to Ica (30 persons) (DIREPES). Then it moves to La Puntilla [near Pisco]. They came with their lack of training, a lot of people, little experience and it was not well managed"	P51: UI-22-BB-Pisco Ex-regional fisheries office worker
B	Response to El Niño	[El Niño 82–83] "It was a total disaster, nothing was uniform [we exceeded] the limits of extraction. The state started to regulate but the contraband was born (scallop came out of gasoline drums) [...]"	P51: UI-22-BB-Pisco Ex-regional fisheries office worker
C	Migration	"I came here 15 years ago but in 1998 I went to Pisco during the boom and then I came back here after the boom."	P14: SSI-3-BB-Parachique (Sechura)—Fishermen
D		"I have been in Puerto Rico five years and I come from Pisco because here the product is better, a great variety"	P36: UI-13-BB-Puerto Rico (Sechura)—Fishermen
E	Migration and conflict	"Problem during El Niño is that people from outside are coming. It is a social problem and now the associations are fighting because they are expecting another El Niño."	P60: UI-31-BB-San Andres (Pisco)—NGO worker
F		"Right now in the sector there is a regionalization movement to fight off immigration. In Parachique people do not want people from Pisco."	P40: UI-7-BA-Lima IMARPE staff
G	Centralization	"Lima has a plan, a directive to respond to ENSO, not the DIREPRO in Pisco. We have a normative dependency with Lima. If there was the decentralization, a mini-ministry that would give a better response to Niño. Also there is no budget, we depend on the region"	P31: UI-10-BA-Pisco Regional fisheries office worker
H	Bureaucracy	For a concession they need a resolution from INRENA and the Navy and then Produce.	P60: UI-31-BB-San Andres. (Pisco)—NGO worker
I	No interaction (between actors)	[Regarding special concessions] "They [the fishermen] get together and go and see the congress but people do not receive them, there are failures and triumphs..."	P17: SSI-6-BB-San Andres Pisco—Fishermen

Reference column reads: ID (for reference in text), Atlas.ti file number, unstructured or semi-structured interview (UI-SSI), code for Word file, site and interviewee

4.2 El Niño 97–98: missed opportunity

The 1982–1983 El Niño, which influenced climate around the globe, catalyzed government and scientific interest in developing forecasting capabilities (Broad et al. 1999). As a result, by July 1997, the 97–98 event was prognosticated and government measures took place shortly afterwards in September with the creation of a multi-sectoral task force on ENSO.[9] Special concessions in the Paracas Reserve were created in September 1997 for re-stocking purposes[10] in order to control the activity and limit access. However, so many fishermen wanted to enter the fishery that the Ministry had to suspend the reception of applications and all procedures were halted[11], national level institutions responding rapidly to the "gold rush" triggered by forecasted information on the climatic event. However, regional offices were not given human (i.e. inspectors) and financial resources to ensure monitoring and enforcement. As a result between 1998 and 2000 in Independancia bay 14 organizations were formal (550 fishermen with 144 boats) while 36 were informal (1,631 fishermen and 414 boats) (Proleon and Mendo 2002). Formality refers to whether associations are registered or not, and whether they possess access rights to culture scallops in the bay. Mortality of scallops due to high-density sowing also occurred (Proleon and Mendo 2002), reflecting an inadequate adoption of knowledge, and over exploitation of the resource took place with the extraction of scallops below the minimum size (Mendo and Wolff 2002).

In Sechura, between 1994 and 1997, the scallop fishery experienced a rapid development which resulted in an increase in the fishing effort (Tafur et al. 2000). However, this development was cut short by the 1998 El Niño, interviews revealing that divers either switched prey (for instance to warm water species like shrimps) or migrated to other fishing zones liked Pisco (Table 1, C). Data from surveys undertaken in Pisco and Sechura revealed that the decision to migrate is usually made by fishermen themselves, only 19% of interviewees reporting that they simply follow the decision of boat owners (Badjeck et al. 2008). During El Niño, crew as well as owners thus make the decision to change fishing grounds, with information about changes in scallop abundance mainly coming from friends and family members (Badjeck et al. 2008). This highlights the important role of social networks in enabling fast responses to changes in resource abundance through knowledge sharing. This migration flux increased the pressure on scallop resources in Pisco and workshop results highlighted the fact that controlling access into the fishery was a major concern of local fishermen (Mendo et al. 2006a, b).

A disaster management plan at the national level was written for the first time by the Fishery Ministry during this El Niño event (CAF 2000). The major focus of the plan for the fisheries sector was on small pelagics like anchovies (mainly exploited by industrial fishermen and negatively affected by El Niño) and infrastructure damages. There was no specific mention of resource management plans and regulations for coastal benthic resources such as scallops. The regional fisheries office in Pisco did

[9] Supreme Resolution N° 053-97-PE—1997.

[10] Ministerial Resolution N° 406-97-PE Creation of special concessions for collection of larvae and re-stocking for social purposes—1997.

[11] Ministerial Resolution N° 418-98-PE Suspension of all application procedures for concession and the attribution of concessions in the Province of Pisco—1998.

not receive any specific instructions to deal with a new scallop boom (Table 1, G). Broad et al. (1999) in a study on the impact of El Niño on Peruvian industrial fishery observed similar behaviour in terms of institutional response: limited proactive measures were put into place to minimize the negative effects or enhance positive ones. This was a missed opportunity to learn from past events and mainstream climate variability into fisheries management, switching from short-term responses to long term management policies.

4.3 The 2000–2006 period: steps toward adaptation?

After the 1998 El Niño, fishermen in Pisco formed associations in order to qualify for special concessions in the Reserve. Special concessions are renewable every three years but between 2001 and 2006 no concession renewals were approved. Among the factors that slowed the process of renewal was the discord between the Ministry of Fisheries and the Ministry of Agriculture (MINAG) branch that manages the Paracas Reserve over the management plans proposed by associations. Interviews with fishermen associations' presidents and government officials revealed that conservation objectives versus exploitation of the resource were at the center of the debate between the two agencies. The bureaucratic red tape, the lack of communication between the different agencies from the local to the national level as well as the absence of political will to reach an agreement impeded the renewal process to go forward (Table 1, H–I). Additionally, in 2000 the Peruvian government suspended the export of bivalve molluscs as a response to the discovery of the presence of Hepatitis A virus in a shipment from Peru in Spain.[12] Many organizations who at first were interested in acquiring a special concession gave up, seeing no short term benefits. Only a few organizations remained in the "sea ranching" adventure, surviving by supplying the national market (Mendo et al. 2006a). The bivalve moratorium also coincided with a cold ENSO event which resulted in low catches in the Paracas and Independancia bays.

In mid-2006 when positive SST anomalies appeared in the equatorial Pacific, workshop data (Mendo et al. 2006b) and interviews (Table 1, E–F) revealed that fishermen, while hopeful of a new boom, were fearful of the migration and chaos that would ensue. With a possible El Niño in sight and pressure from associations, the newly elected government urged the MINAG and the Navy to authorize aquaculture activities in the Reserve so that the Fisheries Ministry could issue a Ministerial Resolution granting special concessions (24 Horas Libres 2006). As a result in April 2007, after 5 years of stalemate, special concessions were granted.[13] The 2006–2007 diving season in the end did not result in the expected scallop bonanza, SSTs only being slightly above normal temperatures, but the combination of a new political environment (presidential elections in 2006), the forecast of El Niño (albeit incorrect) and pressure from associations were drivers for institutions to enforce their policies. Nevertheless a proactive stand is still not taken by the government: no scallop management plans that include climate variability currently exist, and

[12] Directorial Resolution N° 0327/2000/DIGESA/SA—2000.

[13] For instance Directorial Resolution N° 027-2007-PRODUCE/DGA granting a special concessions to the fishermen association 'Asociacion Comunidad Artesanal de Extractores y Maricultores'.

migration is still not being considered when designing fishery policies. Finally, the lack of cooperation between INRENA and PRODUCE hinders the management of the Marine Reserve in Pisco.

In Sechura, since 1999–2000, the bay is experiencing a rapid development of the scallop fishery (Fig. 4) due to optimal growth conditions during non-El Niño years. Additionally, favourable international and national markets, the issuance of the sanitary certificate for export to the European Union, and lower landings in the south of the country favoured this expansion of the fishery (Flores et al. 2005). A slight decline in landings was observed in 2001, attributed to the export moratorium. Interviews revealed that migration from the center and the south of the country increased during those years, causing conflict between the new migrants and local fishermen not involved in the diving fishery (Table 1, D–F). In 2003–2004, the regional government granted 12 authorizations to fishermen associations to conduct aquaculture activities in the bay.[14] Since then the number of associations undertaking sea-ranching activities without authorizations dramatically increased (DIREPRO 2005a). This activity is particularly sensitive to changes in river discharge and being a more capital intensive activity, losses might lead to more hardship for fishermen. In May 2006 a red tide event resulted in the mortality of 70.5% of scallop stocks in stock-enhancement areas (DePeru.Info 2008). In response the government granted a credit consisting of scallop seeds for re-sowing with a two year period of grace for repayment. If aquaculture activities continue to increase in the bay the question remains on whether the government will be able to provide to operators during El Niño events emergency aid that covers losses. Additionally, in 2006, amid fears of a strong El Niño event, fishermen involved in aquaculture expressed fear of losing their investment and their inability to maintain their household due to lack of savings. While the El Niño event was not perceived, the red tide revealed the vulnerability of these operators. The development of aquaculture-type operations thus poses new challenges: access restriction which limits adaptation options such as migration, and increased vulnerability in the North in the absence of adaptive management plans that do take into account migration patterns and the impact of environmental variability on aquaculture operations.

4.4 Responding to disturbance: a synthesis

Disturbances can be defined as changes, surprises and crisis. Surprises are a qualitative disagreement between ecosystem behaviour and a priori expectations and become a crisis when they reveal an unambiguous failure of management actions and policy (Gunderson 2003). From a management perspective Folke and colleagues (2003) identify three generic responses when a crisis occurs in socio-ecological systems: (1) no effective response, (2) response without experience and (3) response with experience. Figure 5 summarizes institutional responses to disturbances in Pisco and Sechura in the last 25 years. No effective response refers to institutions that try to preserve the status quo, weakening the resilience of ecosystems. We observe that in

[14]For instance Directorial Resolution N° 103-2003 GOB.REG-PIURA-DIREPE-DR granting authorizations to two associations in Sechura.

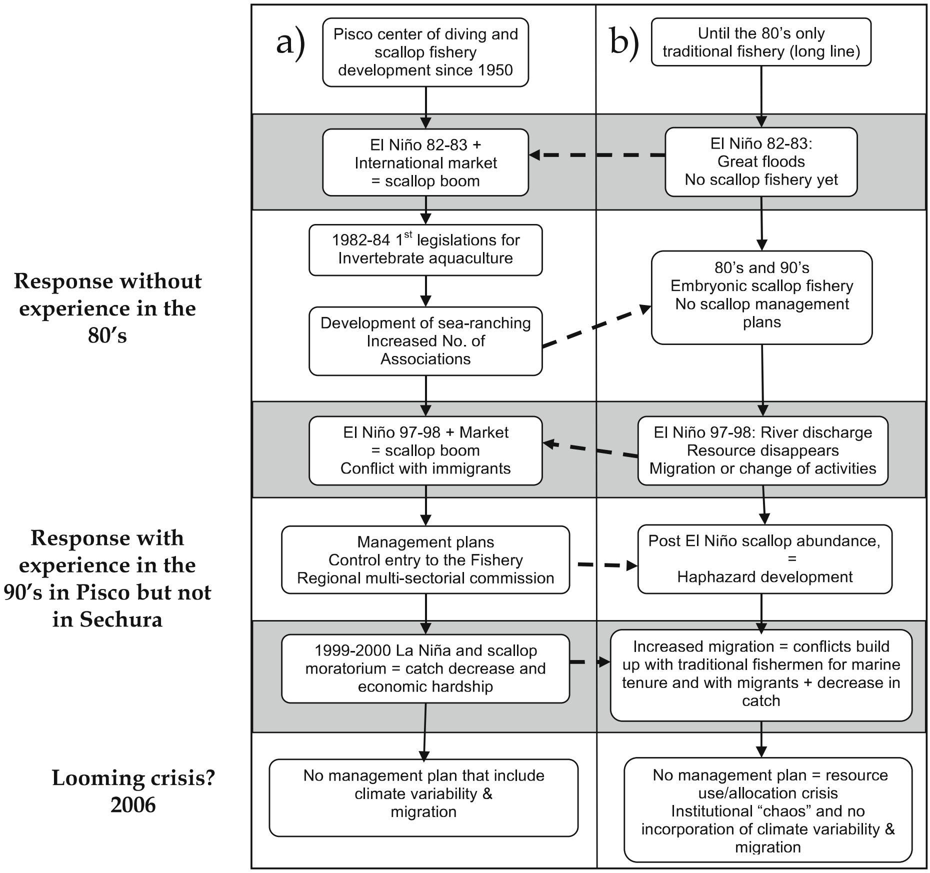


Fig. 5 Institutional responses to disturbance over time in Pisco (**a**) and Sechura (**b**). *Shaded areas* are disturbances (environmental, socio-economic etc.) while *non-shaded areas* are responses. *Dashed lines* represent migration fluxes of fishermen

Pisco formal institutions did not preserve the status quo, mainly due to pressure from fishermen's adaptive capacity, individual fishermen in both sites being not only able to self-organize to fluctuating resources through the application of existing available responses (migration, prey switching) but also to adopt new techniques such a scallop culture.

The second type of response occurs when previously tested policies are not available (Folke et al. 2003, p. 360). This was observed during the 82–83 El Niño, when one of the strongest El Niño events of the century took the government by surprise and led to a spontaneous adaptation by fishermen (migration, adoption of new technology). Formal institutions had no existing responses available apart from moratoriums and minimum size, and local authorities' capabilities were limited in terms of man power and knowledge. Nevertheless, the disturbance was an opportunity to re-organize the fishery with the development of aquaculture legislations. In Fig. 6 we refer to this period as "learning by doing", where institutions tried to formulate a new regulatory framework for scallop extraction (Fig. 6, phase A).

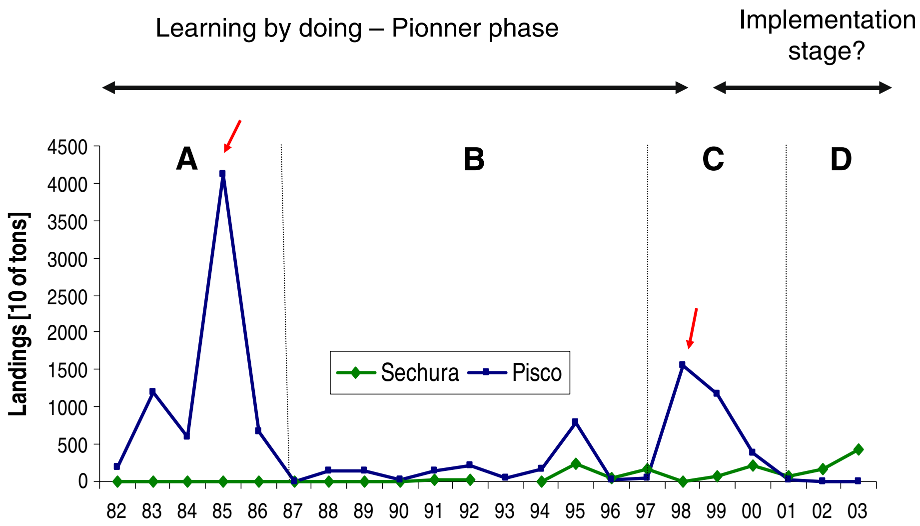


Fig. 6 Phases of policy development for the scallop fishery for the period 1982–2003 related to landings in Sechura and Pisco. Identified are: *a* from underdeveloped fishery to new regulations, *b* exporting and regulating, *c* "boom" and "bust" *d* fast north, slow south

Additionally, the scallop boom created a platform for collective action with the increased number of fishermen associations since these were necessary to obtain concessions, as well as increased scientific knowledge and technological change (development of sea ranching) which migrants would bring back to their regions. Following El Niño, and driven by increased exports and neo-liberal policies, the policy landscape continued to flourish (Fig. 6, phase B).

The third type of response is when learning occurs based on previous crises and socio-ecological memory (Folke et al. 2003, p. 360). Albeit some institutional learning occurred in Pisco in 1998 with measures to stop entry to the fishery being promulgated, re-organization was not sufficient, instruments and allocation of resources to enforce management intervention were non-existent, and coordination and collaboration with local actors limited, leading to an enforcement crisis. The 97–98 "boom" in Pisco and "bust" in Sechura revealed not only the government inability to control access into the fishery but also its lack of acknowledgement of migration patterns as an important driver of the fishery at the local scale (Fig. 6—phase C).

Since 2001 policies related to scallop extraction and aquaculture have overall remained unchanged, poorly implemented and enforced (Fig. 6—phase D). Government agencies and users need to reflect on the future direction of fisheries policies (extraction versus aquaculture) and how ENSO might impact them. The organizational failure to learn from past events and integrate them into on-going management and policy interventions highlights a lack of long term planning and mainstreaming of climate variability into fisheries management, despite the recurrent nature of ENSO events on the Peruvian shores.

5 Exploring the role of formal institutions in resilience building with causal loop diagrams

The purpose of this section is to identify the mechanisms that maintain the system or offer potential for other alternative states under El Niño conditions, and what role formal institutions play in these processes based on the information compiled in the previous sections. Causal loop diagrams are used to build a conceptual model of the fishery. One of the principles of the system perspective is that external forces do not explain everything and the causes of dynamic problems can be endogenous (Barlas 2002). The system approach, in which the resilience perspective is embedded, reminds us that a key factor for response [to change] is the presence of effective and tight feedback mechanisms or coupling of stimulus and response in space and time (Berkes et al. 2003, p. 269).

5.1 Conceptual model description

The causal loop diagram in Fig. 7 represents the scallop fishery in Pisco and Sechura, taking into account current management practices and policies, and was constructed

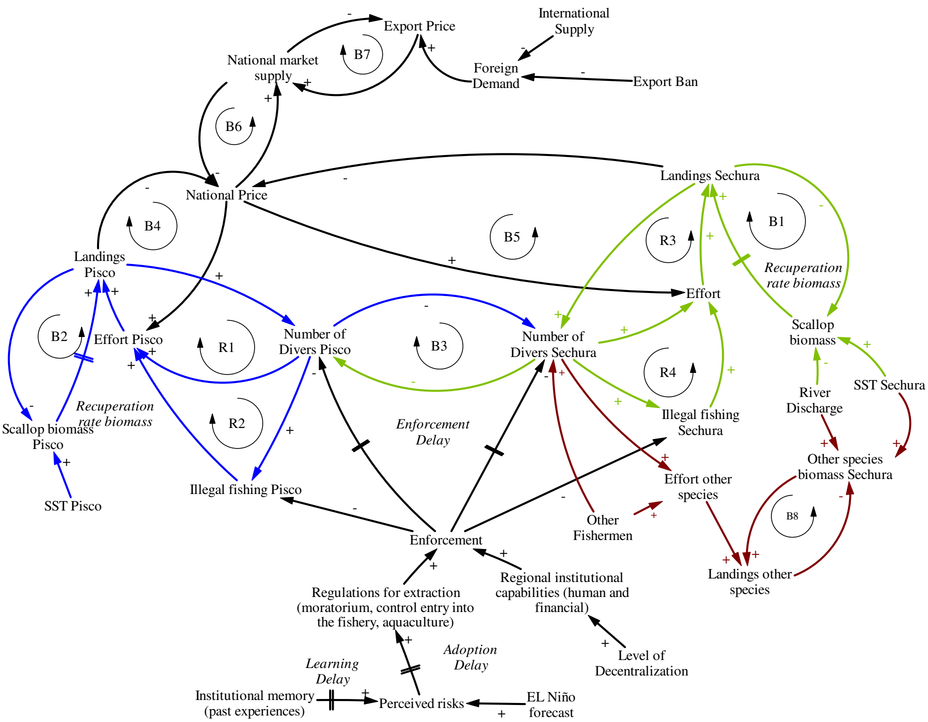


Fig. 7 Conceptual model of institutional response to ENSO events using causal loop diagrams. Delays are represented in *italics*. In *blue*, dynamics in Pisco, in *green* and *red* in Sechura and *black arrows* represent institutional dynamics (markets and formal institutions)

based on the analysis presented above. In our effort to identify the underlying mechanisms that shape resilience and what role formal institutions play we made the following assumptions to simplify system representation:

- Environmental external drivers only include SST and river discharge despite the fact that factors such as pollution and algae blooms significantly affect scallop biomass.
- Fishermen are separated only into two groups: scallop divers and other fishermen. The scallop fishery is an open system and prey-switching is an adaptation strategy of other fishermen (gill nets, long line etc.) which has an impact on levels of effort and design of management interventions. The conceptual model however does not take into account the heterogeneity of the other fishermen.
- Similarly biomass changes in other species (predators, competitors and other commercial species) and impact of ENSO in other sectors (agriculture) can have impacts on the scallop fishery (prey switching and entry in the fishery sector, reduced biomass) but system boundaries had to be defined for the purpose of this study and some of these factors were excluded for the time being.

The conceptual model presented is divided into three components which reflect analytical and geographical scales: sub-system in Pisco and Sechura and formal institutions (market and government).

5.2 Identifying causality and feedback loops

In the conceptual model we have identified eight balancing feedback loops and four reinforcing ones. Reinforcing (positive) feedback loops create growth or crash and tend to be destabilizing, while balancing (negative) feedback loops tend to have a stabilizing effect on the system. The eight balancing loops in the model can be described as follow:

- B1: Scallop biomass mediates amount of catches that can be achieved overtime in Sechura
- B2: This refers to the same pattern as B1 but in Pisco
- B3: The number of fishermen in Pisco (fleet size) is related to the number of fishermen in Sechura (fleet size). Indeed the previous sections showed that strong migration patterns exist between these two locations based on boom and bust periods of the scallop fishery.
- B4 and B5: The amount of landings is linked to market prices in Pisco and Sechura, abundance and price following the economic law of supply and demand. This reflects government neo-liberal policies and free market economy described in other sections.
- B6 and B7: Similarly, at the national and international level, prices and amounts supplied are locked in the economic law of supply and demand with no government control possible.
- B8: For other species experiencing positive impacts of El Niño, biomass mediates the amount of catches that can be obtained over time. These species include shrimp and octopus favoured by warmer temperature and less affected by river discharge, and mullet favoured by brackish water.

The eight feedback loops highlight the fact that one way to stabilize the system and maintain its resilience is to maintain biomass and keep to a certain extent the open access nature of the fishery that permits migrations, allowing one bay ecosystem to recover while the other experiences a boom. The causal loop diagram places emphasis on the central role played by market forces and how inappropriate macroeconomic policies could destabilize the system. But what processes erode resilience of the scallop fishery at the two sites? This is highlighted by the four reinforcing feedback loops in the conceptual model, which present the following characteristics:

- R1: A higher number of fishermen in Pisco leads to an increase in effort, resulting in increased landings. Based on the data presented above we know that an increase in landings in the area leads to an increase in the total number of fishermen due to migration, this being enabled by the *defacto* open access and the social networks and information sharing existing among fishermen.
- R2: As presented in other sections a larger number of fishermen increases illegal practices. By illegal practices we refer not only to the non-compliance with, for instance, the moratoriums set by state agencies but also non-compliance with local rules designed by local fishermen (fishing zones, daily limits). Illegal practices lead to increase effort and landings in Pisco.
- R3: This refers to the same patterns as R1 but in Sechura.
- R4. This refers to the same patterns as R2 but in Sechura

These reinforcing loops can spiral the system into decline, driving the scallop stock to collapse. Complexity of the system is also heightened by the development of aquaculture operations in both bays and its accompanying changes in property rights that would limit the existence of changing fishing grounds. Indeed, the conceptual model highlights the importance of migration and access within the dynamics of the system: migration patterns and the *de facto* open access regime are endogenous and thus controllable variables, as opposed to exogenous variables such as SST, river discharge and international markets that play an important role in the system, but are beyond the jurisdiction of (Peruvian) formal institutions. Additionally, the causal loop diagram illustrates the role knowledge (ENSO forecast, institutional memory) plays in changing the fishermen variable through regulations. The conceptual model also reveals the central role played by market forces, also highlighting that a better control of landings could ensure better prices for fishermen.

Another key feature of the conceptual model is the presence of delays intervening between causes and their effects. Delays are divided into two types: delays resulting from the time involved in processing physical material (material delays) and delays resulting from the time involved in perceiving and acting upon information (information delays) (Roberts et al. 1983). Four types of delays were identified: recovery rate of scallop biomass, rate of learning from past experiences ("social memory"), rate of adoption of new regulations and enforcement effectiveness. Of the four types, only scallop biomass is not considered an information delay. In terms of information delays, individuals and organizations often make decisions based on averaged or imperfect information (Roberts et al. 1983). For instance a small increase in scallop landings will not lead to migration but an above-average increase will cause fishermen to change fishing zones while institutions will only respond to significant changes in landings, resulting from higher number of fishermen. Our research shows that formal institutions do not respond instantaneously to changes while individuals respond immediately to information and small variations (hence the lack of delay in loops involving fishermen).

The causal loop diagram presented here is a first attempt to build a system dynamic model in the study areas integrating ecological and social dimensions. Based on the data from interviews, workshops and archival research a representation of the fishery system could be undertaken taking into account stakeholder perceptions. This type of approach offers the possibility to explore scenarios to solve complex management problems and can be used as a basis for formal quantitative models.

6 Discussion and conclusion: pathways to resilience?

The Peruvian scallop fishery operates in a highly fluctuating environment where climate inter-annual variability is a key driver of change. Formal institutions responses to climate variability have been shown to vary according to the level of maturity (rate of exploitation) of the fishery. In Pisco, where the fishery dates back to the early 1950s, formal institutions were mainly reactive to El Niño events and while past experiences have been integrated in the last strong event of 98 into the response mechanism, institutional and organisational adoption of past and new knowledge is still inadequate to maintain resilience. For instance the incorporation of migration patterns in fisheries policy is currently absent despite the crucial role spatial mobility of fishermen plays in the system. While literature on how characteristics of property rights affect fisheries management is extensive (see for instance Crean 2000; Toufique 1997; Gordon 1991; Béné et al. 2003; Newkirk 2006; Shotton 2000), fishermen migration is less explored and warrants further studies (Curran 2002; Kramer et al. 2002), especially in the context of aquaculture development. Indeed aquaculture results in the privatization of waterways and conflicts over farm sitting (Primavera 2006; Hernández-Cornejo and Ruiz-Luna 2000). Changing property rights regimes can have a detrimental effect such as those portrayed by Marshall (2001). Marshall describes how the privatization of marine commons on the Canadian east coast for the development of aquaculture has undermined small fishing communities' ability to get access to wildlife resources. In the Peruvian case, spontaneous individual responses to El Niño, ensuring a rapid process of adaptation, might be jeopardized by the changing property right regime, mainly motivated by market demand for aquaculture products.

Additionally, while controlling the level of fishing effort, entry into the fishery and the establishment of property right regimes is crucial to maintain the resilience of the system, the role of formal institutions in fisheries management goes beyond these traditional functions. The conceptual model shows that formal institutions through 'institutional memory' need to contribute to knowledge building regarding ENSO impacts and interventions, to reflect on past interventions and to adopt new approaches, all of which are absent from the current management framework. In Sechura, no response by formal institutions was identified in light of increasing aquaculture development in an area prone to floods. Innovative approaches such as risk transfer instruments should be put into place (Badjeck 2008). In the agricultural sector small microfinance activities have grown over the years in rural areas. Currently in this sector weather insurance products (index-based risk transfer products) are being developed to help small farm holders face climate-related risks in Peru (Skees et al. 2007). In the fisheries sector there is a need to increase access to financial services and explore the feasibility of insurance products. Aquaculture activities have significantly increased in the bay since 1999 and the development of financial instruments to reduce risks in this activity needs to be investigated. FAO has already undertaken several studies on risk management in aquaculture (Van Anrooy et al. 2006; Secretan et al. 2007) and a study at the local level based on this information and the experience gained in the agricultural sector should be undertaken.

The analysis also highlights the failure of decentralization in Peru. Decentralization refers to the systematic and rational dispersal of power, authority and responsibility from the central government to lower or local level institutions (Pomeroy and Berkes 1997, p. 469), however responsibility are often the only aspect governments are willing to devolve. It is now widely acknowledged that if decentralizing means only the devolution of responsibilities without increasing capabilities (whether financial or normative) at the local level, management outcomes would be as detrimental as top-down approaches (Satria and Matsuda 2004; Ribot et al. 2006). Instead of focusing on redesigning institutions at one scale only (in the case of Peru at the regional or local level) attention should be directed towards the cross-scale linkages between the different levels. In their review of co-management in Asian fisheries, Wilson and colleagues (2006) posited that cross-scale institutional linkages were essential for successful co-management, the state having an important role in using its authority to structure and balance interactions between various groups in order to allow them to be responsive to the changing demands of aquatic resource management. In Peru, changes in property rights are a self-organization process, what Menger (1981) (cited in Hodgson 2006 p. 13) called “organic” institutions, where as a consequence of changes users change the rules of access. Formal institutions at the national and regional level, while promoting flexibility and adaptation, should ensure that maintaining the resilience of the fishery in one region by securing access rights does not decrease the resilience in another region by limiting adaptation strategies such as migration. The focus of policy reforms should thus be not only on issues of functional scale, which is the interaction between levels of social organization and political linkages (local versus regional and national institutions), but also spatial dimensions of scale with issues such as migration.

To conclude, system analysis concepts and causal loop diagrams allowed us to conceptualize this system behaviour and identify processes that play an important role in resilience building. The resilience of the system depends on the ability of formal institutions to shape fishermen’s decision making by creating and enforcing a regulatory framework as well as the ability to build and adopt knowledge in order to self-organize and transform. Conceptual models are useful tools in that direction, allowing the exploration of various past, current and future scenarios to inform policy making.

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