Coping with abrupt environmental change: the impact of the coastal El Niño 2017 on artisanal fisheries and mariculture in North Peru

Lotta Clara Kluger1*, Sophia Kochalski2, Arturo Aguirre-Velarde3, Ivonne Vivar4, and Matthias Wolff1

1Leibniz Center for Tropical Marine Research (ZMT), Fahrenheitstr. 6, 28359 Bremen, Germany
2Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Müggelseedamm 310, 12587 Berlin, Germany
3Laboratorio de Ecología Acuática, El Instituto del Mar del Perú, Esquina Gamarra y General Valle S/N Chucuito Callao, Perú
4University of Bremen, Bibliothekstraße 1, 28359 Bremen, Germany

*Corresponding author: tel: +49 421 238 00 42; e-mail: lottakluger@gmail.com, lotta.kluger@leibniz-zmt.de.


In February and March 2017, a coastal El Niño caused extraordinary heavy rains and a rise in water temperatures along the coast of northern Peru. In this work, we document the impacts of this phenomenon on the artisanal fisheries and the scallop aquaculture sector, both of which represent important socio-economic activities for the province of Sechura. Despite the perceived absence of effective disaster management and rehabilitation policies, resource users opted for a wide range of different adaptation strategies and are currently striving towards recovery. One year after the event, the artisanal fisheries fleet has returned to operating almost on a normal scale, while the aquaculture sector is still drastically impacted, with many people continuing to work in different economic sectors and even in other regions of the country. Recovery of the social-ecological system of Sechura likely depends on the occurrence of scallop seed and the financial capacity of small-scale producers to reinstate scallop cultures. Long-term consequences of this coastal El Niño are yet to be studied, though the need to develop trans-local and trans-sectoral management strategies for coping with disturbance events of this scale is emphasized.

Keywords: artisanal fisheries, El Niño, environmental disturbance, Peru, post-disaster recovery, scallop aquaculture, social-ecological system.

Introduction
Abrupt environmental changes (Alley et al., 2003), such as sudden inverse in seawater temperature rise caused by marine heat waves, reductions in salinities induced by strong rains, or oxygen depletion, can greatly affect marine and coastal resource population dynamics and survival rates in the short- to medium-term (McGowan et al., 1998; Beaugrand et al., 2008; Wernberg et al., 2016). The impacts of such changes extend to human communities that are dependent on the ecosystem and its respective natural resources (Marín et al., 2015). As a result, abrupt environmental changes carry the potential to affect entire social-ecological systems (SEs) (Walker et al., 2004). Understanding the dynamics of direct and indirect ecological and social effects of such events can guide management decisions that help to sustain human livelihoods linked to marine resources (Adger et al., 2005).

The warm phase (El Niño) of the El Niño Southern Oscillation (ENSO) is a reoccurring climate-oceanic phenomenon that causes the warming of coastal waters, disrupts the otherwise continuous upwelling of cold and nutrient-rich waters in front of the Peruvian coastline and causes extreme rainfalls along normally arid coastal stretches (NOAA, 2018). In February and March 2017, a localized coastal El Niño (CEN) off the coast of Peru
caused heavy rains in the northern part of the country (i.e. the state of Piura; Figure 1), resulting in the inundation of several towns and a large amount of damage to roads and bridges in the region. At the same time, due to altered oceanographic conditions the otherwise continuous upwelling of the Humboldt Upwelling Current came to a halt, sea temperatures rose from an average of 16–17°C to 28°C (Figure 2) and hypoxic conditions developed on the sea bottom (Aguirre et al., 2018). Salinities dropped to levels between 9 PSU (surface, at 1 m depth) and 30 PSU (near to bottom from 6 to 18 m depth; data collected by the third author, see the “Research approach” section for more details). This combination of factors caused an almost complete die-off of benthic organisms (third author, pers. obs.).

The state of Piura is particularly important for Peru’s national coastal economy because it hosts the largest number of artisanal fishing vessels when compared to other regions of the country (Guevara-Carrasco and Bertrand, 2017) and a large part of its population depends on fisheries-related activities. The Peruvian artisanal fishery sector has historically been highly dynamic due to seasonal and long-term migrations of fishers and those involved in fishing-dependent activities following changes in local resource abundances (Badjeck, 2008; Badjeck et al., 2009). For example, during the two last strong El Niño events 1983/1984 and 1997/1998, many people migrated towards the region of Pisco as a response to increased stock sizes of a valuable benthic resource, the Peruvian bay scallop Argopecten purpuratus (Wolff, 1984, 1987; Wolff et al., 2007). However, since the El Niño 1997/1998—when water temperatures decreased along the Peruvian shores and an extended La Niña situation developed—a steadily increasing number of fishers have moved to the region of Sechura to grow scallops. The initially informal cultures were soon transformed into a legally regulated aquaculture activity through the designation of an increasing number of authorized concessions within the bay (Badjeck, 2008; Mendo et al., 2008; González-Hunt, 2010). Consequently, Sechura developed into a national hotspot for scallop culture, with up to 80% of national scallop production originating from its bay (in 2013; Mendo et al., 2016). With livelihoods and local economy being strongly dependent on the mariculture sector, a potential El Niño event was hypothesized to have strong socio-economic consequences (Kluger et al., 2018).

In this manuscript, we describe and document what has happened to the resource users of the region of Sechura as a result of the CEN 2017. The effects for the artisanal fisheries are compared to those for the mariculture sector, studying user’s autonomous adaptation (IPCC, 2007) strategies, by which is meant their own spontaneously developed adaptation measures that allow them to cope with the abrupt environmental disturbance, and users perception with respect to the recovery potential of the SES. Understanding the dynamics of
marine resource use and estimating the impact one year after the event will provide a basis for the development of management strategies that can facilitate SES recovery and enhancing SES resilience in the face of future environmental pressures. Results will also add to the general understanding of potential consequences of abrupt environmental changes in resource abundances for other coastal systems.

Methods
Study system
The bay of Sechura extends over 400 km² and is located in the province of Sechura (state of Piura) in the North of Peru (5.6° S 80.9° W; Figure 1). Situated at the northern edge of the Humboldt Current upwelling system, which almost continuously transports nutrient-rich water to surface layers (Tarazona and Arntz, 2001), and as a result of warmer equatorial water meeting the Humboldt Current just to the north, the bay is highly productive during normal upwelling conditions and sustains a diverse fishery. Since the early 2000s, the scallop bottom culture sector has grown sharply, arriving at peak production in 2013 (Mendo et al., 2016). Since natural settlement of scallop seed within the bay has remained low and hatchery production does not meet the demand to stock cultures, seed supply from natural banks of the island Lobos de Tierra still represents the main source of seed used in cultures (Mendo et al., 2008, 2016).

Research approach
Data were gathered between September 2017 and January 2018 using a mixed methods approach, i.e. combining the analysis of different written sources (newspaper articles, governmental statements) with semi-structured interviews with key informants from local industry, mariculture, and fisheries, as well as research and governmental organizations (n = 53). In addition, face-to-face questionnaires were conducted in January 2018 with artisanal fishers (n = 51) and representatives (37% president or vice president, 18% member of elected administrative panel, 55% other member) of scallop farmer associations (n = 43) from eight villages along the coastline of Sechura Bay (Figure 1). Participants were selected using a snowball sampling technique with multiple entry points into the social network and a diverse set of initial informants. For the scallop mariculture sector, the sample included around 25% of all associations, with a certain bias towards those associations whose members were still active and residing in Sechura. For the fisheries sector, a varied sample in terms of fishing gears and targets species was sought. Respondents were questioned on general aspects of their fishing or mariculture activity and their perception of what had happened during the coastal El Niño event 2017. They rated the general impact of the CEN 2017 (from 1—“zero impact” to 5—“very intensive”), the role of governmental authorities during CEN (from 1—“they helped a lot” to 4—“they helped nothing at all”), and whether the income of their organization in the year 2017 was impacted by the CEN (from 1—“we earned much more” to 5—“we earned much less”). They were asked to classify the well-being (Britton and Coulthard, 2013) of the members of their fishing group or scallop farmer association before and after the CEN on a Likert-type scale (from 1—“very good” to 5—“very bad”). To capture autonomous adaptation of individual group members, the interviewees were questioned about the current location of each member, and about the type of economic activity they were pursuing. To account for the fact that the survey would be context-specific, capturing a one-time sample during a long-lasting process of...
**Table 1.** Reply possibilities to the question in which state of the recovery trajectory (sensu Marín et al., 2015) the respondents thought their organization was (as of early 2018).

<table>
<thead>
<tr>
<th>Recovery Trajectory</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;After the coastal El Niño 2017,...&quot;</td>
<td>Innovation</td>
</tr>
<tr>
<td>...we have taken the opportunity to do new or different things.&quot;</td>
<td>Normalization</td>
</tr>
<tr>
<td>...we have managed to recover a condition similar to what we had before.&quot;</td>
<td>Recuperation</td>
</tr>
<tr>
<td>...we still strive to move towards standardization.&quot;</td>
<td>Stagnation</td>
</tr>
<tr>
<td>...we try hard but we are still stagnant.&quot;</td>
<td>Recession</td>
</tr>
<tr>
<td>...there is no way we could recover.&quot;</td>
<td></td>
</tr>
</tbody>
</table>

Groups in the state of “recession”, “stagnation”, and “recuperation” may be considered as still impacted by the CEN 2017 (since normal, i.e. pre-CEN, conditions are not reached as yet), while “normalization” or “innovation” indicates the achievement to have obtain (at least) pre-CEN conditions. For the results to this question see Figure 6.

**Figure 3.** Perceived strength of the coastal El Niño (CEN) 2017 by scallop farmers (mariculture, n = 43) and artisanal fishers (fisheries, n = 46) associations.

recovery, respondents were also asked in which state of the recovery trajectory they considered their organization to currently be in (“innovation”, “normalization”, “recuperation”, “stagnation”, “recession”; sensu Marín et al., 2015; Table 1). Finally, respondents were encouraged in open-ended questions to state what they felt was necessary for their own activities and Sechura Bay to recover and to be successful in the future.

The third author measured several environmental parameters including salinity during a visit to Sechura Bay in March 2017, i.e. during the months of the Coastal El Niño event. This data was used to describe the environmental conditions as presented in the introduction of this manuscript.

**Results**

**Impacts on artisanal fisheries in Sechura**

Due to heavy rains during the months of the CEN event (February and March 2017), an area of 27 km² was flooded in the province of Sechura alone (Figure 1), with more than 5000 homes being lost in the entire state of Piura and public infrastructure and roads being damaged (key informant KI#52, Sechura, 18.01.2018). The majority of fishers rated the coastal El Niño event 2017 as being “intense” (22%) or “very intense” (54%; Figure 3). In most villages, fishing could not be conducted during February and March 2017, the months of CEN exhibiting heavy rains. Where fishing could take place, income was reduced because fisheries products could not reach national markets outside the region due to the flooding and impassable roads between Sechura and the city of Piura (fisher #78, Sechura, 24.01.2018). The inability to access markets was highly relevant for the towns that were furthest away from the local administrative centre of the town of Sechura. These towns were cut off from the road system during the CEN 2017, i.e. La Tortuga in the north (72 km distance), as well as Playa Blanca and Bayóvar in the south of the bay (60 km distance). Towns that were heavily inundated included Constante, Parachique and Bayóvar, all of which lacked adequate drainage systems. In Bayóvar in the south of the bay, the inundations were further aggravated by landslides that respondents attributed to mining activities along the mountain slopes behind the town (key informant KI#53, Puerto Rico, 19.01.2018).

The environmental changes during CEN also contributed to the altered composition of the fish community. Species that were reported to be reduced in stock sizes were the Peruvian anchovy Engraulis ringens, Eastern Pacific bonito (Sarda chilensis), Common Peruvian weakfish (Cynoscion alalutis), Coco croaker (Paralichthys peruvianus), and a number of coastal demersal species such as rays, e.g. the Flathead guitarfish (Rhinobatus planiceps). In contrast, warm water species such as shrimps (Panusus californiensis and Panusus vannamei), Skipjack tuna (Katsuwonus pelamis), and Yellowfin tuna (Thunnus albacares) seemed to occur in greater abundance during and shortly after CEN months. Lisa (Mugil cephalus) was reported to be caught during CEN months in a shallow lagoon that formed as a result of increased river discharge. Soon after the CEN—in April or May 2017—fishing was taken up again in all sampled villages, though the fish catch composition was not perceived to have normalized (i.e. to non-El Niño conditions) until the second half of 2017. Despite better market prices for the scarce fisheries products during CEN, most fishers still rated their income as “less” (57%) or “much less” (18%) when compared to a normal year (i.e. to 2015; Figure 4). Given that entire families rely on income generated by...
fishing, even a short interruption of the fishing season can have economically strong impacts in Sechura. Many fishers delayed their return to fishing due to losses of personal material goods such as houses and fishing vessels. Assistance from government authorities in terms of dealing with the impacts from the CEN event 2017 was described as nonexistent by most respondents (“helping nothing”; fishers 63%; Figure 5). The only exception was the provision of food rations to the villages that were cut-off during the months of CEN. Given the absence of governmental support, fishers relied on their own capacities to deal with the CEN event. Switching to a different economic sector was perceived as unfeasible, and most of the fisher groups opted for continuing fishing as soon as they could. The autonomous adaptations included not only fishing for different species, but also travelling further and, in some cases, cooperation with other fishing vessels to increase the detection rate of worthwhile fishing opportunities (key informant KI#51, Parachique, 20.01.2018). Fishing crews stayed the same if they were based on family ties, but hired crew members were sometimes dismissed during and after the CEN. Some fishers migrated with their vessels to other areas along the coast of Peru to seek better fishing opportunities during and after CEN, although this adaptation strategy was not possible with every gear and vessel type. In January 2018, 19% of fishing group members resided outside of Sechura (8%) or were of unknown location (11%). The various adaptation strategies of the fishers enabled them to sustain a basic livelihood in 2017, but the direct and indirect impacts of CEN still meant higher costs and precarious living conditions in terms of the provision of food and healthcare in a year of lower income.

Though most fishers were unable to fish during the CEN 2017, i.e. the months February to April 2017, almost all respondents had taken up fishing again one year later (96%). Most interviewed fishers considered themselves on a good path of recovery to pre-CEN conditions (indicated by 71% stating their group was on the pathways of “recovering”, “normalization”, or “innovation”; Figure 6), with perceived production levels comparable to pre-CEN conditions. Reasons for this may be found in the dynamic nature of artisanal fisheries even under non-CEN conditions. Fishers naturally adapt to fluctuating stocks, either using different gear types or targeting other species. While the artisanal fisheries sector of Sechura province was, without any doubt, hit hard by the CEN 2017, the scallop sector appeared to be suffering stronger long-term effects (as of January 2018).

**Impacts on scallop mariculture**

Insufficient seed supply from natural banks of the island Lobos de Tierra was considered the main reason for a slow decline of aquaculture output ever since the peak year in 2013 (Cabrera Campos, 2016; key informant KI#47, Sechura, 25.01.2018). From 2014 to 2016, the sector was additionally impacted by reoccuring localized spontaneous environmental disturbances (i.e. red tides, anoxic sulphidic waters entering the bay) and high temperatures during summer, resulting in reoccuring (though smaller-scaled) scallop mortality events (key informant KI#13, Sechura, 11.09.2017). The majority of scallop farmer associations that were able to maintain aquaculture operations in the pre-CEN period seem to have worked with hatchery-produced scallop seed (key informant KI#2, Sechura, 11.09.2017). Due to these preceding challenges, several associations opted to wait for the critical summer period (January–March) to pass before starting the scallop grow-out period of 2017. These associations were therefore not as strongly affected as associations culturing scallops when the CEN happened.

Yet, environmental changes which took place during February and March 2017 caused a complete scallop die-off in the bay of Sechura. High water temperatures exceeded the optimum temperature range of 16–20°C of *A. purpuratus* (Navarro et al., 2000; González et al., 2002). Furthermore, the strong rains, which led to respective drops in salinities, meant that environmental conditions reached the lower levels of physiological salinity tolerances (of 27 PSU; Navarro and González, 1998). Other factors, such as increasing particulate matter loads from increased riverine input and local anoxia created by altered oceanographic conditions, might have also contributed to the complete die-off (third author, pers. obs.). As a consequence, the entire industry came to a halt and most of the 160 scallop associations and the unofficial...
groups lost the seed that they had invested. Losing their investment and, in some cases, their personal financial freedom was perceived as very challenging by the scallop farmers: “During the coastal El Niño 2017, we lost everything—product [i.e. scallops], boats, motors, houses” (scallop farmer #97, Parachique, 27.01.2018). Consequently, 93% of the interviewed scallop associations rated the impact of the CEN as “intense” (26%) or “very intense” (67%; Figure 3), and 100% stated to have earned “less” (25%) or “much less” (75%) during 2017 (Figure 4). Of the respondents interviewed, 90% stated that the government had helped “nothing at all” (Figure 5). Autonomous adaptation strategies of scallop farmers to obtain some income during 2017 were manifold. Many scallop farmers had been fishermen in the past, and some had continued fishing alongside their engagement in the mariculture. Thus, they could switch back to fishing in 2017, either using their own boats to fish within the bay, or working as a crew member on larger (sometimes industrial) fishing vessels (targeting e.g. Peruvian anchovy E. ringens, Humboldt squid Dosidicus gigas). Others collected scallop seed from natural banks at the island Lobos de Tierra (see Figure 1) to sell to the operating associations or to the larger scallop producing plants who grow scallops in suspended culture in the north or just to the south of the bay. Some respondents worked for these companies in different production steps (key informant KI#34, Bayovar, 25.09.2017). Others were reported to be paid to grow small scallop seed from hatcheries in their local areas until these were large enough for transfer to bottom cultures of operating associations. Though this is not a legal procedure—in fact, pearl nets used for the grow-out of these small scallops are hidden beneath the water surface—it appears to be a lucrative method of gradually recovering financial losses to eventually be able to restart own cultures. Other respondents found work in terrestrial industries, such as agriculture, or in the building or (to a very small extent) the mining sector. Many others, however, left the region of Sechura and moved towards other locations along the entire coastline (such as Ancash, Lima, or Pisca) or to the interior of the country (e.g. to the state of San Martín; scallop farmer #88, Parachique, 25.01.2018) to work there in the fisheries sector or in a different economic activity altogether. The association representatives were asked about the current (January 2018) location of all members of their association. They stated that 28% were either not residing in Sechura (22%) or of unknown location (6%) at the time of questioning. Members who had left seem to be predominantly persons originally from outside the Sechura region, relying on their still existing social networks to enter labour markets in other locations.

In 2018, the mariculture sector continued to be impacted by the CEN 2017 due to a lack of seed supply and difficulties in recovering the financial means to start a new-grow out cycle. Scallop seed, representing the most important cost item to initiate a new grow-out cycle, was valued at 0.93–1.55 USD/manojo (1 manojo = 96 scallop individuals; key informant KI#47, Sechura, 25.01.2018) at the start of 2018. With an average of 30,000 manojos being used as a start-up, this translates into 27,827–46,379 USD. These funds were already difficult to raise in a normal year, meaning that the challenge of acquiring start-up capital for manojos is even greater if most associations had lost their pre-CEN investment (in scallop seed) when CEN hit and caused a scallop die off. At the time of writing, those affected were still struggling with the financial consequences, e.g. paying the debts (credits for buying scallop seed) caused by these losses. If the associations had lost their own investment, a new grow-out cycle could be initiated if they had savings, or if they still had access to financial credits. For those associations who lost loans from banks or private investors, this often brought even further, —personal, material—losses, e.g. when sponsors reclaimed their securities (cars, houses, etc.). As of January 2018, 57% of interviewed scallop farmer associations had initiated a new grow-out cycle, but not a single group had already harvested. Not all scallop farmers were planning a full production cycle but rather stated they had “some” product to maintain their areas. Only 45% were working in their own culture areas, with the remaining groups working in culture areas rented from others (7%) or in informal areas (5%). 5% reported fishing together as a group. The losses experienced during CEN 2017 has led the remaining 38% of interviewed scallop farmer groups to stop working together as a group, and to begin engaging in alternative livelihoods. This is also reflected in the perceived recovery, with only 58% (compared to 71% for fisher groups) of interviewed scallop farmer associations considering themselves on a good path to recovering pre-CEN conditions (i.e. on the pathways of “recovering”, “normalization”, or “innovation”; Figure 6).

Besides the scallop farmer associations, unofficial groups, independent divers, and the scallop processing sector were indirectly affected by the scallop die-off. Scallop farmer associations without a designated culture area (i.e. those cultivating scallops illegally) depend on formalized groups to whom they sell their product, a process through which this catch is included in the declared amounts produced by legally recognized associations. Illegal groups will not be able to recommence mariculture as long as the recognized groups also remain unable to do so. This concerns a large number of scallop farmers, though official and exact figures are difficult to obtain. Prior to the CEN event 2017, eleven companies processed scallops, being specialized either in primary processing (including the shucking, washing, weighting, and freezing of scallops) or preparing the final product to be exported to international markets. Each of these companies provided employment for 250–500 workers (key informant KI#46, Sechura, 23.01.2018). The CEN 2017 hit the scallop industry in Sechura to such an extent, that only two plants remain active as of January 2018. These two companies were processing a variety of marine species (i.e. not only scallops) before the CEN 2017, which enabled them to maintain their operations in 2017. The remaining processing plants had to dismiss their workers, leaving these to search for alternative sources of income, such as in the agriculture or construction sector.

Discussion

Strategies for facilitating SES recovery

The artisanal fisheries and scallop mariculture sectors in the region of Sechura were greatly affected by the CEN 2017 (see “Results” section). The medium-term effects were not as strong for fisheries as for the scallop sector because the fish community composition quickly normalized to that of pre-CEN conditions and fishers had the experience to adapt to fluctuating stocks by using different gear types or targeting other species (see “Impacts on artisanal fisheries in Sechura” section). The long-lasting effects of the CEN on the mariculture sector indirectly also affects the fisheries sector, however, because a great number of scallop farmers resumed fishing during and after the CEN event. Fishers, accordingly, complained about the increased fishing pressure and
irresponsible behaviour of former scallop farmers fishing with nets with small mesh sizes, which removes entire fish communities. This situation requires monitoring and of meaningful management measures, which have yet to be developed to avoid overexploitation of fisheries resources and to maintain the vulnerable pre-CEN livelihoods of fishers.

Whether the scallop mariculture sector may return to pre-CEN production levels or not will likely depend on (i) environmental and ecological conditions facilitating scallop growth and survival, (ii) scallop seed being available either from the natural environment or hatcheries, (iii) financial means being made available on the producer level to re-start grow-out cycles (i.e. to make use of the scallop spat), and (iv) scallop farmers being willing to resume the activity that previously carried a high risk potential.

Environmental conditions had almost normalized one year after the CEN 2017. By early 2018, temperatures were in the expected range for non-El Niño summer seasons (Figure 2), though scallop farmers were wary. Even those who were financially able to start a new scallop grow-out cycle were unwilling to do so. They preferred to wait for the end of the summer. As for the state of the ecosystem, interviewed fishers, scallop farmers, and scientists shared the view that a pre-CEN state has still not been achieved. They reported dark layers of organic matter—likely leftovers of benthic organisms that died during CEN—forming large, sometimes anoxic patches on the seafloor. Some scallop farmer associations had conducted self-organized “cleaning” operations, retrieving dead organic matter from their designated culture areas to facilitate the environmental normalization process. The uncertainty of statements with respect to environmental conditions is based on the very recent establishment of monitoring stations within the bay, which provide environmental data that may help to record and predict dynamics and allow some form of preparation for the potential consequences of a developing El Niño event in the future. Such strategies are urgently needed to accompany the recovery process of the ecosystem after the CEN and to prepare for future disturbance events of this dimension.

Scallop seed represents the main bottleneck for re-starting cultures (see “Results” section), since scallop farmers depend entirely on the occurrence of cheap scallop seed on natural banks. Seed from hatcheries, a potential alternative, is highly expensive and currently not produced in sufficient quantities as to stock all culture areas within the bay. Thus, scallop farmers must wait for seed to occur in the wild, which only appears to have happened recently (in early 2018; key informant KI#47, Sechura, 25.01.2018). Due to the difficult financial situation of many scallop farmer associations (see “Results” section), it remains to be seen whether this is a viable option for the future.

Even if associations were able to initiate a new grow-out cycle, no immediate income is generated until scallops are harvested. The lack of income from their primary activity has further complicated re-starting cultures (i.e. buying available scallop seed), and several farmers complained about the absence of investors. Many of those that currently (as of January 2018) conduct culture seem to have been supported by larger (scallop processing) companies in regaining footing. These companies issued loans and special conditions to associations of trust to help them restart their businesses (scallop farmer #102, Sechura, 27.01.2018).

Enhancing SES resistance in the face of future environmental pressures

Besides the fact that El Niño is a reoccurring phenomenon and has brought large-scale damages to the region during past events, this study is, to our knowledge, the first one to study the recovery process of the SES, i.e. the fisheries and mariculture sector, after such an event. In the past, the scallop A. purpuratus was fished through an open-access regime, and fishers migrated towards regions with high abundances during El Niño phases [i.e. to Pisco in the south, where scallop populations were positively impacted—increasing 60-fold and causing respective landings to rise dramatically (Wolff, 1987) during the strong El Niño events of 1983/1984 and 1997/1998; Badjeck, 2008]. For the scallop sector, Sechura gained importance with the establishment of cultures in the early 2000s, with an increasing number of previously mobile fishers remaining permanently in the region. The damage inflicted by the CEN 2017 demonstrates the absence of planned adaptation (IPCC, 2007) strategies at the policy level, i.e. the need for deliberate management measures designed to facilitate short-term adaptation of individual actors of the SES and to produce long-term strategies so as to cope with such a disturbance to the SES. In conclusion, it is recommended (i) to establish a reliable early warning system for potential environmental disturbances and to develop emergency plans in the case of such an event, especially in terms of protecting human livelihoods that depend on marine resources, (ii) to support local small-scale producers in establishing long-term financial plans that enable them to better cope with the consequences of losses caused by mortalities of their target resource (i.e. making savings during non-El Niño years), and to develop strategies that provide structured support to resource users for the post-disturbance phase, e.g. through financial support and/or affordable credits, or rapid and effective assistance with reconstruction of damaged infrastructure, and (iii) to spread the risk of a localized environmental disturbance.

With rising temperatures during a developing El Niño event, scallop farmers may harvest their product before environmental conditions reach lethal thresholds for scallops. Although this might result in lower return rates due to the early (and potentially undersized) harvest, this would allow recovery of parts of the initial investment. However, during the months of CEN 2017, the region of Piura was declared as being in a state of emergency and the bay was closed. Local authorities did not authorize the landing (and thus marketing) of scallops (key informant KI#47, Sechura, 25.01.2018). Consequently, some scallop farmers lost their product because of the ban even though they might have been fast enough in their harvest response (key informant KI#46, Sechura, 23.01.2018). Affected scallop farmers perceived this decision as an additional challenge, and expressed willingness to ignore official rules in the case of a new El Niño (key informant KI#46, Sechura, 23.01.2018). This highlights the necessity of developing an emergency adaptation plan by local decision makers that should include strategies for effective rapid harvest of product that would otherwise be lost.

In the last decade, Sechura has become a hotspot for scallop aquaculture (Mendo et al., 2016). Although the scallop business is much more profitable for (small-scale) producers than artisanal fishing during non-El Niño conditions, the former activity bears a much higher risk due to its dependency on a single-species that is sensitive to environmental disturbance. This potentially threatens the livelihood of 25 000 people in the region. Fishers, in comparison, draw from a multitude of target species, adapting their gears to make use of those resources occurring during El Niño and thus coping with the disturbance event by maintaining fishing. This leads us to conclude that livelihood diversification of scallop farmers might represent an adaptive strategy that may
increase their resilience in the face of future environmental changes and/or market pressures. One example would be through the (managed) harvest of other benthic resources or the culture of other species as is current practice in the system of Territorial Use Rights for Fishing (TURF, Spanish AMERB; Christy, 1992) in Chile (Gelich et al., 2005, 2006, 2010; Aburto et al., 2013; Aburto and Stotz, 2013). In addition, spreading the risk of a single, localized disturbance event by establishing cultures in other parts of the country might allow farmer associations to mitigate financial losses (Kluger et al., 2018). This, however, requires a trans-local management initiative which focuses on designing long-term adaptation measures which have yet to be implemented by local and national governance authorities.

Before the CEN, scallop mariculture in Sechura was run by small-scale producers, and the granting of quasi-property rights over designated culture areas was argued to transfer direct monetary benefits and risks of the operation to those scalp farmer associations (Kluger et al., 2018). In theory, this direct connection to individuals’ livelihoods is assumed to create an incentive for the sustainable use of the resource (Aburto et al., 2013), while costs of enforcement are passed to those who benefit from the appropriate management of the resource (Stotz, 2000). This would imply long-term planning by resource users, e.g. including (financial) adaptation scenarios in the face of environmental disturbances. Several interviewees mentioned the need to create an alternative investment plan for scallop farmers, especially under difficult circumstances such as the ones described above. One possibility could be to establish a politically supported system of micro-credits that allows scallop farmers to quickly obtain affordable credits for resuming their mariculture activities. At the very last this should be considered for post-El Niño situations if not for other disturbances to scallop production. At the same time, joint savings of the scallop farmer associations would allow the members of the association to sustain their livelihoods during periods of low income (e.g. when high scallop mortalities diminish harvest returns), rather than forcing them to work in a non-fisheries-related sector or to migrate to a different location. As yet, these aspects do not appear to be common practice, as can be seen by how the majority of scallop associations struggle to overcome the consequences of CEN. If anything, the few remaining processing plants appear to have played a role in offering financial aid for scallop farmers in the post-CEN phase. These contracts between companies and associations had already been established before the CEN, but became more frequent afterwards. Accordingly, it is strongly recommended to include strategies that can assist with financially overcoming such events into associations’ individual management plant, thereby allowing them to maintain their independence.

One additional aspect that will influence mariculture recovery is the recent change in legislation which requires scallop farmer associations to transform into small-scale companies (DS 003–016-PRODUCE; PRODUCE, 2016). Previously, these groups were exclusively allowed to conduct sea ranching (bottom culture) in designated culture areas. As the law does not explicitly state who may obtain concessions for bottom culture (and who may not), this potentially offers an opportunity for external investors to join the business. Especially in the current situation, in which small-scale producers have no financial means to start their business, this legislative move carries the potential to alter the nature of scallop culture in Sechura entirely. One key informant even speculated that in the future, larger-scale companies will dominate the scallop business in Sechura (key informant KI#48, Sechura, 29.01.2018). The lack of financial power and the gradual changes in legislation potentially open up a window of opportunity for external investors, who could enter the business by offering financial support for re-initiating cultures, whilst gaining decision-making power (through pre-arranged selling conditions). Whether or not these potential changes should be considered positive or negative remains open to discussion, and local stakeholders, together with governance institutions, should decide whether small-scale producers should be supported, or whether the top-down control/management through larger companies should be encouraged. Clearly, there are advantages and disadvantages which need to be clarified. The societal discussion should consider all options in the light of the required long-term planned adaptation strategies that will allow stakeholders to cope with future disturbance events of this magnitude throughout the region.

Conclusion

In conclusion, the coastal El Niño 2017 has hit the region of Piura, particularly Sechura Bay, hard. While the artisanal fisheries sector is on its way to pre-CEN production levels, the scallop mariculture sector remains heavily impacted and long-term consequences and potential recovery pathways will needed to be monitored. Institutional support for small-scale producers from both sectors is urgently required to facilitate re-establishment. The results of the present study demonstrate the possible magnitude of an abrupt environmental disturbance on a SES depending on marine resources. The tragedy of this example should be used for the development of adaptive management and planning strategies—not just for Sechura but also other coastal systems around the world—in order to prevent future crises of this intensity.

Acknowledgements

The authors would like to thank Leslie Odar, Lesly Eche, Génesis Ordoñez, Gustavo Castellanos, and Mario Mechán, who have provided much appreciated help in conducting the interviews during the field phase in Sechura and Daniella Schaumlöffel for English proof reading. The third author expresses his gratitude towards the Laboratório Mixto Internacional (LMI) DISCOH which enabled him to record the environmental data presented in this paper. He wants to especially thank Jonathan Flye Sainte Marie for his participation in field work during March 2017 and for his constant support to the maintenance of the environmental observation network in Peruvian coastal bays. Most importantly, our gratitude goes to the many interviewees who decided to share their stories with us.

Funding

This paper was prepared as part of the bilateral MOSETIP project (“Modelling Socio-Ecological Tipping points for the Latin American center of scallop cultivation”) which is a cooperation between the Leibniz-Center for Tropical Marine Research (ZMT) in Bremen, Germany, and the Peruvian Marine Science Institute (IMARPE) in Lima, Peru. This project is financed by the German Federal Ministry of Education and Research (BMBF, MOSETIP 01LC1725A).


