Reg Environ Change (2017) 17:1077–1087
DOI 10.1007/s10113-016-1044-x

ORIGINAL ARTICLE

Seawalls as a response to coastal erosion and flooding: a case study from Grande Comore, Comoros (West Indian Ocean)

Carola Betzold[1] · **Ibrahim Mohamed**[2]

Received: 29 November 2015 / Accepted: 13 August 2016 / Published online: 14 September 2016

Abstract Many coasts are eroding. In the Comoros, as in many other small island developing states (SIDS), communities frequently respond to coastal erosion by building seawalls—yet seawalls and other coastal defence structure are controversial, especially in a SIDS context, where they typically are poorly designed and constructed and thus tend to increase rather decrease erosion and are often unable to prevent flooding. Through an exploratory qualitative case study of Grande Comore, the main island of the Comoros (West Indian Ocean), we compare and contrast how local stakeholders, national elites and donors understand coastal erosion and flooding in the context of a changing climate and how they experience and perceive seawalls as a response measure. Our analysis suggests that although stakeholders are aware of different drivers of coastal erosion and flooding, including sand mining, seawalls are a frequent and customary response to coastal erosion and flooding. Little is known about their disadvantages or alternative response measures, especially among local community members. Further, a lack of capacity and resources leads not only to poorly designed and constructed seawalls but also to difficulties in enforcing rules and regulations such as bans on sand mining. From our exploratory study, three conclusions emerge: (1) local drivers of coastal erosion and flooding are more visible than global climate change while funding is more readily available for adaptation to climate change; (2) a mix of context and site-specific measures would be needed to adequately respond to coastal erosion and flooding; and (3) further information and knowledge about the extent and causes of coastal erosion and flooding as well as about the effects of different response measures would be needed to allow such context and site-specific measures.

Keywords Grande Comore · Comoros · Seawalls · Coastal erosion · Climate change adaptation

Introduction

Coastal zones have been described as being 'among the most vulnerable of all environments to global climate change', with reverberations well beyond the shoreline (Michel and Pandya 2010). They are 'vulnerability hot spots with regard to climate change' (Martinez et al. 2011) and therefore a 'crucial battleground in the current fight against climate change' (De Comarmond and Payet 2010).

How do inhabitants of this 'battleground' experience coastal and climate change, and how do they 'fight' negative impacts of these changes? These questions are of particular importance in small island developing states (SIDS), where coastlines are long compared to land area and where the majority of settlements and infrastructure is located in the coastal zone (Nurse et al. 2014). Because human activity is concentrated in the coastal zone, the coastal zone is under increasing stress. Population growth,

Electronic supplementary material The online version of this article (doi:10.1007/s10113-016-1044-x) contains supplementary material, which is available to authorized users.

✉ Carola Betzold
carola.betzold@uantwerpen.be

Ibrahim Mohamed
jesrashma@yahoo.fr

[1] Institute of Development Policy and Management, University of Antwerp, Lange Sint-Anna Straat 7, 2000 Antwerp, Belgium

[2] Département de Géographie, University of the Comoros, Moroni, Comoros

urbanisation, development activities, sand mining and other anthropogenic stressors affect shoreline processes (e.g. Defeo et al. 2009). Climate change impacts, including sea-level rise, storm surges and intense rainfall, further contribute to coastal erosion and flooding (for a full overview of climate change impacts on the coast, see Wong et al. 2014).

As the following section describes in more detail, the preferred response to coastal erosion and flooding across SIDS (and beyond) tends to focus on engineering solutions such as seawalls and other coastal defence structures (Sect. 2.2; Cooper and Pilkey 2012; Duvat 2013; Kench 2012). Nunn (2004) even speaks of a 'seawall mindset' in this context. While engineering structures may be able to protect coastal property, their long-term sustainability and effectiveness have come under growing critique. Already in the 1980s and 1990s, studies found engineering structures to have adverse effects (Gillie 1997; Kraus 1988; Kraus and McDougal 1996; Mimura and Nunn 1998). Without additional measures, seawalls tend to increase rather than decrease, or at least displace, coastal erosion (see Sect. 2.1; Duvat 2013; Jackson et al. 2012; Kench 2010). Some studies thus classify structural measures as 'resistance' and not as 'adaptation' (Cooper and Pile 2014) and argue for understanding coastal protection as protecting coastal ecosystems rather than as protecting coastal property (Cooper and McKenna 2008).

Clearly, there are no one-size-fits-all solutions; how to adequately respond to coastal erosion and flooding depends on the specific context. The purpose here is thus not to describe and assess the effectiveness of different adaptation measures including different engineering structures. Rather, we want to document and understand the experiences and perspectives of different stakeholders on climate change, coastal erosion and flooding, and response measures, especially seawalls. In particular, we seek to compare and contrast perspectives and perceptions at different levels: How do members of coastal communities on the one hand, and donors and national elites on the other hand understand erosion in the context of a changing climate? What are the causes and consequences of coastal erosion and flooding, and how do different stakeholders (want to) respond to these challenges?

We explore these questions through a case study of Grande Comore, the main island of the Comoros (see Sect. 3.1). The Comoros, a small island state in the Channel of Mozambique, faces many environmental challenges. Among other things, coastal erosion and flooding is widespread across the Comorian islands, including on Grande Comore (Abdou Rabi and Ali n.d.; ASCLME 2012; Sinane 2013; Sinane et al. 2010)—though precise data on the extent of erosion are lacking (ASCLME 2012). During fieldwork conducted in March 2015, we interviewed national-level stakeholders as well as conducted an informal survey of community members in four different villages on Grande Comore (see Fig. 1 below and Sect. 3.2) to obtain qualitative insights into local views and experiences regarding coastal erosion and flooding, climate change and response measures, specifically seawalls, at different levels.

Literature review

Coastal erosion and potential response measures

Erosion is widespread along the world's coasts. A first global assessment in the 1980s showed that 70 % of the world's beaches were eroding (Bird 1985). Many anthropogenic processes, such as land reclamation, construction of causeways and other infrastructure, or sand mining, lead to coastal erosion, which in turn makes flooding more likely. Climate change impacts, including sea-level rise and storm surges, further contribute to coastal erosion as well as flooding, although the interaction of climatic and non-climatic drivers make it difficult to attribute coastal erosion and flooding to a specific impact (Cazenave and Cozannet 2014; Defeo et al. 2009; Forbes et al. 2013; Kench 2012; Wong et al. 2014).

There are multiple measures available to respond to coastal erosion and flooding. Common response measures include seawalls, breakwaters, land reclamation, beach nourishment, reef conservation or relocation (e.g. Cooper and Pilkey 2012; French 2001; Nordstrom 2014). These measures are often classified under the three broad categories of protection, accommodation or retreat. Protection seeks to advance or hold existing defence lines through mainly structural and physical measures, hard and soft. Accommodation seeks to increase flexibility of human behaviour as well as of infrastructure, while managed retreat means leaving the shoreline to allow the coastal system to change naturally and potentially migrate landward (Wong et al. 2014).

Landward migration is a natural response to changing conditions. Coastal zones are highly dynamic, and erosion is part of this dynamic (Cooper and McKenna 2008). However, infrastructure and coastal engineering artificially fix the coastline and thus compromise the ability of beaches to adjust to changing conditions. This may lead to both passive and active erosion, beside ecological consequences (for overviews of the effects of coastal defence structures and especially seawalls, see e.g. Cooper and Pilkey 2012; Dugan et al. 2008; Kraus 1988; Kraus and McDougal 1996; Nordstrom 2014). Even 'soft' measures like beach nourishment disturb natural processes and potentially adversely affect the coastal ecosystem (Cooper and McKenna 2008;

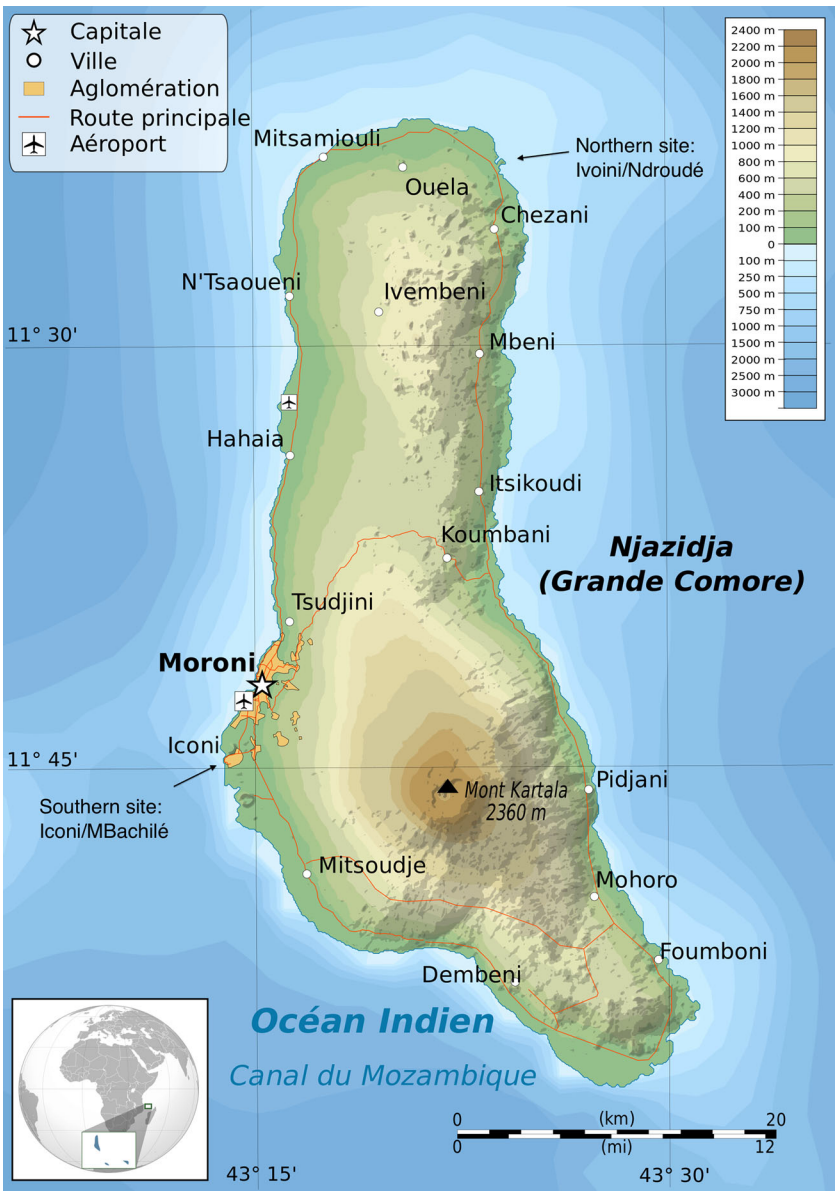

Fig. 1 Map of Grande Comoros and location of the studied villages *Source*: Wikimedia, https://commons.wikimedia.org/wiki/File:Grande_Comore_topographic_map-fr.svg

Cooper and Pilkey 2012). The exact effects of coastal management and protection, however, are highly variable and depend as much on the specific local conditions as on the specific design and form of the coastal protection measure (French 2001; Gillie 1997).

Finally, a distinction can be made between erosion of the beach, that is, movement of the sand, and erosion of the land behind the beach, where infrastructure is located. Similarly, flooding in the coastal zone may result from saltwater intrusion from the seward side, for instance during storm surges, or from freshwater overflows from rivers and streams on the landward side, for instance after heavy rains. Coastal erosion makes flooding from saltwater intrusion more likely, as the beach provides a natural buffer (Nordstrom 2014). These different processes may occur at the same time, as during a tropical cyclone. Effective coastal protection would need to take into account these different processes and their interlinkages, but this is rarely the case, especially in a developing country context (e.g. Kench 2010), as we describe in more detail below.

A controversial preference for engineering solutions

In practice, studies find a preference for protection, that is, for engineering solutions: 'Historically and, for the most part, currently the response has been to defend wherever we can', as Cooper and Pilkey (2012) write. Accordingly, long stretches of the coast are at present armoured or engineered (Cooper and McKenna 2008). A similar

preference for defensive infrastructural measures can be found in SIDS. Duvat (2013) reports for Kiribati that public authorities favour engineering structures and that therefore 'new coastal structures are regularly built and planned'. For the Maldives, Kench (2012) writes that 'management responses have relied upon structural engineering solutions' (see also e.g. Sovacool 2012). David et al. (2014) compare Anjouan in the Comoros with Yaté in New Caledonia and find in both cases a demand for seawalls and other infrastructural measures to deal with erosion. Similar examples can be found for other islands in the Pacific (e.g. Monnereau and Abraham 2013; Worliczek et al. 2010), Indian Ocean (e.g. Sinane et al. 2010) and the Caribbean (e.g. Jackson et al. 2012; Mycoo and Chadwick 2012).

Engineering solutions in SIDS are often even more problematic, as they typically are characterised by poor design and construction, notably in rural areas. There is in general limited human, technical and financial capacity as well as a lack of data on site-specific conditions (Gillie 1997). As a result, the local context is not taken into consideration (Kench 2010); instead, 'the same techniques are employed whatever the situation' (Duvat 2009). Communities or resorts construct structures *ad hoc*, transposing designs from developed countries (Kench 2012) or from the core to the periphery (Duvat 2009; Nunn 2009, 2013) without adequate consideration of local conditions. As a result, coastal defence structures in many places—particularly in rural areas—fail and collapse after short time periods. They often do not stop but on the contrary even aggravate erosion (Kench 2012; Mimura and Nunn 1998; Nunn 2013).

One of the most common and popular coastal defence structures across SIDS are seawalls (e.g. De Comarmond and Payet 2010; French 2001; Nunn 2007). Seawalls are vertical hard impermeable walls erected in parallel to the coastline at the top of the high water mark to hold the coastline and to prevent erosion and flooding (French 2001; Kench 2010; Kraus 1988; Kraus and McDougal 1996; Mimura and Nunn 1998). Seawalls exemplify the problems of coastal defence structures. Although they may protect property against flooding, they often have negative effects on beach erosion, since they are typically inadequately designed and constructed in a SIDS context—a 'chronic' problem throughout the Pacific (Donner and Webber 2014; Nunn 2007, 2009) and beyond (Kench 2010). Among other things, seawalls often are too short, do not have the right slope or are not deep enough, all factors that contribute to erosion at the edges or the bottom of the seawall (see also Fig. 2). As a result, seawalls collapse shortly after construction and are often abandoned (Nunn 2009). Without additional measures to reduce wave energy, seawalls typically increase, or at least displace, beach erosion (Donner and Webber 2014; Gillie 1997; Kench 2010; Mimura and Nunn 1998).

If seawalls are so problematic, why do they nonetheless remain popular across the SIDS? Although little research has explicitly focused on explaining the popularity of seawalls, studies point to several reasons relating to custom, the (perceived) advantages and lack of understanding of disadvantages of seawalls, as well as lack of capacity and resources.

One reason for the continued popularity of seawalls relates to custom: Donner and Webber (2014) for instance highlight the 'long history of constructing seawalls to protect from the sea' in Kiribati. For Fiji, Mimura and Nunn (1998) observe that seawalls were not built before 1960, but that their numbers increased since. Similarly, 'coastal communities in Puerto Rico have historically opted for various types of shore-hardening structures', including seawalls, as Jackson et al. (2012) document. In contrast, seawalls were widespread in Mauritius and the Seychelles but in many places have recently been replaced by rip-raps (large rocks or stones) or gabions (steel wire-mesh baskets filled with stones)—although seawalls continue to be in use (Duvat 2009).

A second reason is (mis-)perceptions, that is, the perceived advantages of seawalls and lack of understanding of disadvantages. Seawalls are visible, and they give an impression of solidity and security (David et al. 2014). Hard structures are considered modern, and they represent progress because of their (perceived) capacity to provide security (Duvat 2009)—whereas soft measures seemingly are weak and temporary (Sovacool 2012). In Kiribati, an expansive modern seawall conveys status (Donner and Webber 2014). That seawalls to the contrary may have adverse effects on erosion as described earlier is not well understood (Donner and Webber 2014; Sovacool 2012).

A third reason concerns the lack of capacity and resources in SIDS. We already referred to the lack of human, technical and economic capacity resulting in the inadequate design and construction of seawalls. Lack of resources also impedes the maintenance and regular repair that seawalls require (Nunn 2009; see also Fig. 2b). Lack of capacity as well as resources further leads to a lack of information, coastal monitoring, proper diagnostics and impact assessments and hence prevents informed, context-specific decisions that would consider and respond to different drivers of erosion (Duvat 2009; Gillie 1997; Kench 2010; Nunn 2009). Even international funders and donors—which often (co-)fund seawalls and other coastal defence structures—rarely carry out assessments and project evaluations (David et al. 2014).

Fig. 2 **a** View of M'Bachilé. A seawall has been built around the entire sea-facing side of the village. **b** Detail of the seawall around M'Bachilé. At its edge (at the right end of a), the seawall partly collapsed

Materials and methods

We explore perspectives and perceptions around coastal erosion and flooding and specifically seawalls as a response measure through a case study of Grande Comore in the Comoros. Notably, we focus on understandings and views at different levels and collected data among on the one hand local community members as well as on the other, national-level stakeholders and donors. In this section, we first briefly present the Comoros and then our data collection and analysis.

Study area

The Comoros is an archipelago of four volcanic islands—Grande Comore, Anjouan, Mohéli and Mayotte. Grande Comore, Anjouan and Mohéli became independent as the Union of the Comoros in 1975, while Mayotte is a French overseas department claimed by the Comoros. The Comoros is located in the Channel of Mozambique (see Fig. 1). It is one of only two countries to belong to all three groups of countries that the political debate typically singles out as 'particularly vulnerable' to climate change: SIDS, least developed countries and African countries (UNFCCC 2009).

The population of 725,000 (in 2009) is rapidly growing, at an average rate of 2.1 % (between 1991 and 2003) and overwhelmingly young: in 2003, 53 % of the population was younger than 20 years (Union of the Comoros 2012). Not least because of this young and rapidly growing population, human pressure on the environment is intense, resulting in environmental degradation (ASCLME 2012; Union of the Comoros 2012). The coast is particularly affected since most settlements as well as most infrastructure are concentrated along the coastal plains (Union of the Comoros 2012).

Reliable systematic assessments of the status of the coast and the extent of erosion on Grande Comore and the Comoros overall do not exist (ASCLME 2012). There is nonetheless evidence that coastal erosion and flooding is widespread across the Comoros, including on Grande Comore (cf. Abdou Rabi and Ali; ASCLME 2012; Sinane 2013). A key driver of this erosion is sand mining: removing sand from the beach for use in construction (Sinane 2013; Sinane et al. 2010). After fishing, sand mining is the second most important source of income for coastal populations (Union of the Comoros 2006). While sand mining is formally prohibited in many locations, enforcement is difficult and sand mining continues (Abdou Rabi and Ali n.d.; Sinane 2013). Climate change and

associated sea-level rise as well as more extreme storms further contribute to coastal erosion and flooding (Montfraix 2011; Nurse et al. 2014). Estimates put average sea-level rise for the Comoros at between 13 and 56 cm by 2090, relative to 1980–1999 sea level (McSweeney and New 2008), while the National Communication (Union of the Comoros 2012) expects the sea level to rise by 20 cm by 2050, more beaches to disappear and flooding to increase (see also Montfraix 2011).

Seawalls, known locally as 'digues', are a widespread response to coastal erosion and flooding, though not all coastal villages have a seawall around their sea-facing side. Mostly, these are vertical walls built at the top of the beach around the high water mark that are made from rocks held together by mortar, a mixture of sand and cement. In the Comoros, the sand used is often marine sand from the beach. Figure 2a shows such a seawall, built around M'Bachilé, south of the capital Moroni. The seawall partly collapsed at its edge, as Fig. 2b indicates, and is fairly typical of the type of seawall found across the Comoros.

Data collection and analysis

We collected data on experiences with and perceptions of climate change in general, and coastal change and erosion in particular, as well as responses to these changes, during fieldwork on Grande Comore in March 2015. On the one hand, we conducted semi-structured expert interviews; on the other hand, we conducted an informal survey, using short structured interviews with a convenience sample of the local population in four villages at two sites on Grande Comore. Our questions did not distinguish between different types of erosion and flooding (see Sect. 2.1), since we wanted to allow a broad range of answers and understandings of these different processes.

We conducted a total of ten interviews with different national-level stakeholders. We spoke to representatives of bilateral and multilateral donors, the government, as well as researchers and a non-governmental organisation (see online appendix). Each interview lasted between 35 and 85 min, and followed a semi-structured design. We had a list of guiding questions (see online appendix) about key climate change impacts in the Comoros, and impacts on the coast in particular, as well as about responses to these changes and specifically about seawalls.

We conducted all interviews in French, which is an official language in the Comoros and the language used in education and administration. Interviews were recorded and transcribed; we then used NVivo to analyse the transcriptions, in French. We created codes as we read through the transcriptions to capture interviewees' perspectives and experiences and in a second step combined these codes into overarching themes relating to perceptions of erosion and seawalls, decision-making, (lack of) resources, description of environmental change in general and sand mining.

The informal survey focused on two different sites on Grande Comore. One site includes the villages of M'Bachilé and Iconi, just south of the capital, Moroni; the other site includes the villages of Ivoini and Ndroudé in the rural north-east of the island (see Fig. 1). Erosion occurs in all four villages (Abdou Rabi and Ali n.d.; Union of the Comoros 2012). The northern villages are more sheltered from coastal change as the coast there is more mountainous, and both villages are set back from the coast, particularly Ivoini. These villages have therefore not (yet) built a seawall. The southern villages, in contrast, are located in a low-lying coastal plain and reach all the way to the sea. Both villages have long seawalls along the entire sea-facing side of the village (see Fig. 2a for M'Bachilé).

We used short structured interviews with community members in the two sites to collect information on perceptions of and responses to coastal and climate change, with the help of students from the University of the Comoros' main campus in Moroni. The student assistants administered questionnaires to a convenience sample of 171 respondents in total, about half in the North (85 respondents) and half in the South (86 respondents; see online appendix). While the questionnaires were in French, the students conducted the short structured interviews in Comorian as respondents would feel more comfortable speaking in their mother tongue. Students then noted responses in French. The sample was a convenience sample; the students walked around the village and asked passers-by to answer a few questions. Because of this sampling procedure, the responses here are not necessarily representative of the communities at large, and we hence refer to the survey as "informal". Additionally, many of the questions were open-ended and allowed more than one response. Where we provide percentages below, numbers do not necessarily add up to 100 %, as respondents provided multiple answers or may have preferred not to answer a question.

The questionnaire (see online appendix) asked respondents first whether and if so, how the coast near their village had changed, as well as what they believed was driving these changes (if any). It then asked about response measures: How have individuals and the community as a whole responded to these changes? If they did not respond, what were reasons for this? Did they consider alternative measures? Finally, the questionnaire also contained questions about demographic information and the respondent's knowledge of climate change.

Results

We first briefly present the perceived coastal changes and their causes according to our interview partners and our survey respondents, and then review and compare their viewpoints with regard to responses to coastal changes under the three themes that the literature review highlighted as potential reasons for the preference of seawalls: custom, (mis-)perceptions around the advantages and disadvantages of seawalls, as well as lack of capacity and resources.

Note that the percentages provided here should be taken with caution, as (1) the sample is not representative and (2) respondents may have provided more than one answer.

Coastal change and its causes on Grande Comore

The coasts of Grande Comore are changing, as both survey respondents and interview partners observe. A large majority of survey respondents (152 respondents, 89 %) find the coast to have changed. There is less agreement as to how the coast had changed. About half of the respondents indicate that the coast is eroding (95 respondents, 56 %) and that flooding is more frequent (70 respondents, 41 %). Interview partners also describe problems of erosion and flooding. A large part of sandy beaches have already disappeared (interview 2) and flooding of coastal villages is recurrent across the Comoros, with the 2012 flooding having caused particular damage (e.g. interviews 4, 6, 9). For Grande Comore in particular, one interviewee observes that 'in the past we didn't have flooding on Grande Comore but now they are everywhere'[1] (interview 3; see also e.g. interview 5).

When asked about the causes of this change, both survey respondents and interview partners highlight sand mining as a central driver of erosion. In the informal survey, respondents relate erosion and flooding mainly to extracting sand or rock from the beach (65 respondents, 38 %). Other causes were cited less frequently, including waste and pollution (24 respondents, 14 %); weather events such as rainfall, wind and seasonal change (25 respondents, 15 %); and coastal squeeze, that is, houses being built too close to the sea (10 respondents, 6 %). Two respondents specifically mention climate change, while four respondents refer to sea-level rise and thus indirectly to climate change.

Our interview partners also emphasise the role of sand mining (e.g. interviews 1, 2, 6, 7); all government buildings for instance are built with mortar made from mined marine sand (interview 9). Yet several interviewees further point to climate change and sea-level rise as a key contributor to erosion, more so than survey respondents: 'It is true that in certain areas, this [erosion] is due to sand mining, but in other areas where there is no sand mining, it is quite simply the effect of climate change' says one interviewee (interview 2; see also e.g. interview 6; 9).

Seawalls as the customary response to coastal erosion and flooding

How to respond to coastal erosion and flooding? In the survey, respondents agree on the need to stop extracting sand and rocks, with 80 respondents (47 %) pointing to this solution. It should be noted that several villages on Grande Comore, including Ndroudé, have prohibited sand mining though enforcement of such rules is difficult (see below). Many respondents (69 respondents, 40 %) further call for the construction of seawalls, often alongside a ban on sand mining, particularly in the southern villages of Iconi and M'Bachilé where houses reach all the way to the coast and where seawalls are already in place (see Fig. 2). For some respondents, these seawalls were insufficient; they asked for the seawalls to be improved and their height and/or length increased. Overall, our observations as well as the informal survey showed that seawalls are a common measure against coastal flooding and erosion. Although there is a demand for seawalls, survey respondents largely are aware about local drivers of erosion—notably sand mining—that need to be addressed, too.

The interview partners on the other hand portray seawalls as the first reaction to coastal erosion and flooding among the local communities: 'There are no alternatives [to seawalls] that have been proposed', says one interviewee (interview 9). Another even characterises seawalls as a 'reflex': 'It is the communities' reflex; as soon as they see erosion coming towards the village, they immediately think of a seawall' (interview 2; see also e.g. interviews 4, 7, 9). Building a seawall is what has been done in the past and therefore should be done in the future: 'it is a habit' (interview 2). One interviewee speaks of a 'copy/paste system', where no one even looks for alternative approaches: 'it is as if there were no other solutions' (interview 6).

(Mis-)perceptions

How do our interview partners explain this 'reflex'? According to the interviews, the local population favours seawalls as solid and robust, as safe and modern, even beautiful. As one interviewee explains, 'in the minds of the people, cement means durability, and durability means defying all risks, including climate change', adding that 'people want pretty things, something out of cement' (interview 10). Another interviewee similarly comments,

[1] All interviews were conducted in French. The translations here are by the authors.

'there is nothing more solid than a wall' (interview 1). Seawalls are thus seen as more effective and safer than 'softer' approaches like re-vegetation (interviews 2, 10).

Nonetheless, seawalls are known to have failed and/or collapsed (e.g. interviews 1, 9). Where a seawall has failed or collapsed, this is not taken as a sign that seawalls may not be the best response, but rather as a sign of the insufficient height or bad quality of that particular seawall: 'the problem is the height of the seawall, and not the seawall *per se*. […]. That is their [the communities'] logic: if it does not hold, it has been badly built. They will not understand that the particular site is not suitable for a seawall' (interview 2; see also interviews 8, 9, 10).

To some extent, the survey reflected this call for new and/or improved seawalls, as described earlier. One respondent for instance says that 'only the construction of a seawall or another [defence structure] can avoid these changes' (survey respondent, male, 25 years, Ndroudé). Yet, not all respondents are convinced about the usefulness of seawalls in general. One respondent comments that 'the problem has not been solved because you can see that seawalls have been destroyed and the water comes up into our house' (survey respondent, female, 54 years, Iconi), while another respondent explains: 'I don't think that seawalls can protect us, but for the moment, they will do' (survey respondent, male, 36 years, M'Bachilé).

A problem here is little awareness about other response measures including alternative designs and forms of shoreline stabilisation. A few survey respondents mention reforestation or relocation as alternative responses to coastal erosion and flooding, but none seems aware of different types of shoreline stabilisation, an observation also made during informal conversations during the fieldwork. The interviews reflect this lack of awareness. 'We do not know the alternatives […]. We do not know which technologies are most adequate', says a government official, wondering what other countries like the Pacific islands do to counter erosion (interview 9). Another interview partner mentions two different coastal defence structures on Mohéli, one using re-vegetation and wooden palisades, and another using a rip-rap from rocks. Despite the potential of such alternative measures, the local population is not convinced: 'There are ideas and examples [of alternative response measures] but they are not appreciated by the villagers […]. It is easier [to build a seawall] than to innovate' (interview 10).

It is noteworthy that many interview partners themselves are rather sceptical of seawalls, or of seawalls as the only response: 'Seawalls are good but they do not solve the problem. I am not against seawalls but they are not the only solution' says one interviewee (interview 4); another interviewee similarly notes that seawalls are not *per se* bad or good, but that the seawall 'becomes bad when it is badly built, with no prior study, with inadequate material, without respect [for the local conditions]' (interview 6; see also e.g. interviews 2, 7, 10). Real adaptation would require behaviour change, not infrastructural change; seawalls address only part of the problem—and not the most important part (interview 1). Donors thus push for softer approaches like re-vegetation and capacity building (see below), but recognise the local demand for seawalls: 'we suggested a softer approach, they [the community] did not want it, they say that a seawall is needed' (interview 2; see also e.g. interview 4). In the end, decisions about building a seawall are taken at the local level, where misperceptions are most widespread, with the community then seeking funding from different sources, including donors. Even where these donors are sceptical of the selected measures, they (co-)fund seawalls as there is no general policy against seawalls, as one interviewee explained, for 'seawalls *may*, in specific cases, be a solution' (interview 2).

Lack of capacity and resources

The informal survey asked respondents about factors that impeded the individual or community to respond to coastal erosion and flooding. Here, many respondents indicate a lack of resources (26 respondents, 15 %) or a lack of knowledge and capacity (25 respondents, 15 %). Some respondents also do not feel affected (21 respondents, 12 %) or responsible (17 respondents, 10 %), arguing instead that village elders or the government needs to intervene: 'It is the state that needs to intervene' (survey respondent, female, 48 years, Ndroudé).

Yet the Comorian state is considered a weak state, in that it lacks capacity and resources to effectively enforce rules and regulations (e.g. interviews 1, 2). All interview partners recognise the limited local resources and hence the important role of donors (e.g. interviews 7, 8, 9). International aid is a major source of funding for seawalls; sometimes, remittances or local contributions (co-)fund the construction, too (interviews 1, 6). External funding, however, is not always well spent: 'The money that enters the country is neither well used nor well focused' (interview 3). External funding also takes away political pressure. It is easier to blame coastal erosion and flooding on climate change and sea-level rise and request external funding for building a seawall than to demand behaviour change, that is, to stop sand mining (interview 1). The choice of whether and where to build a seawall is political and not guided by impact studies or technical expertise. There should be studies, an interviewee admits, but 'this is not done, we do not consult experts to find a long-term solution' (interview 6). Similarly, there is little follow-up and project evaluation (interview 1). Even where projects are evaluated, experts are recruited abroad, their reports

ending up unread: 'the experts coming here on mission, we do not have or we do not read their reports' (interview 10). There seems thus to be little learning from past projects, and mistakes are repeated (e.g. interviews 1, 10).

Lack of capacity and resources also translates into a lack of implementation of rules and regulations, a problem that occurs in other SIDS, too (Nunn 2010). In the survey, several respondents refer to problems around prohibiting sand mining, since sand mining is an important source of income for many villagers: 'we are not in a position to ban people from taking sand or corals', says one respondent (male, 39 years, Iconi), while another similarly finds 'we are not able to impose such a decision' (survey respondent, male, 27 years, Iconi). Interview partners echoed this. Specifically with regard to the environment, there may be plans and strategies, but little action, little enforcement of national rules and policies, little political will (interviews 5, 8, 10), not least with regard to sand mining: 'It is difficult to make people respect a ban on sand mining' (interview 1).

Clearly, environmental and developmental challenges are linked, and addressing one without the other prone to failure: 'We need to link environmental protection with income-generating activities' (interview 2). For a ban on sand mining to be respected, alternative source of income is required (e.g. interviews 3, 7)—'it is a question of survival for the people […] so how to stop them?' asks one interviewee (interview 4). On Grande Comore in particular, crushed volcanic lava rock would provide an alternative to mined marine sand but is more expensive (interview 9). It is easier to take sand from the beach for free when building a house rather than buy crushed volcanic lava rock (interview 1).

Both survey respondents and interview partners thus recognise the need for building capacity and raising awareness. Several survey respondents mentioned awareness as part of the solution—or the lack thereof as a current barrier to adequately dealing with environmental challenges. To some extent, survey respondents also mentioned that they could raise awareness, though this was mainly with regard to (visible) waste deposits and pollution, and did not reflect knowledge of (invisible) climate change and the role of different drivers of coastal erosion and flooding. Interview partners also recognise the need for raising awareness among the government, the communities and the population at large (e.g. interviews 2, 4, 6, 7). Although interview partners admit that there is still a lot of work to be done (e.g. interview 10), several interview partners also see reason for optimism. They find a nascent awareness, notably among the youth: 'where youth associations exist that are aware about [the need to] protect the coastal zone, we manage better to stop or at least limit sand mining' (interview 7; see also interviews 6, 9). Raising awareness, finally, should also highlight the limitations of seawalls and the need for other solutions: 'Maybe in 2 or 3 years, maybe a seawall is unavoidable in one place or another, but seawalls should not be [used] systematically. That is what we are trying to do: to show the people that there are not only seawalls[…], that there are other solutions' (interview 2).

Discussion and conclusion

The coast of Grande Comore is changing as global climate change and sea-level rise interact with local factors, notably sand mining. In many places, communities respond to coastal erosion and flooding by building coastal defence structures, although the effectiveness and sustainability of such structures, particularly seawalls as used on Grande Comore and other SIDS, have been questioned (e.g. Cooper and Pilkey 2012; Nunn 2009, 2013). We explored the continued popularity of seawalls despite such criticism through an informal survey of villagers as well as semi-structured interviews of government officials and other experts, and found similar factors to be at play on Grande Comore as have been observed in other SIDS: seawalls are the customary, default response measure, perceived as solid, safe and modern. Further, a lack of capacity and resources impedes alternative measures, including adequately designed and constructed defence structures that are adapted to local conditions, or enforcement of rules and regulations such as a ban on sand mining.

From our exploratory case study, three conclusions emerge, regarding the distinction between local and global drivers of coastal change; the need for a mix of context and site-specific response measures; and the need for information and knowledge to allow such specific response measures.

First, the local population attributes change largely to (visible) local drivers, namely sand mining and waste deposits and pollution. While sand mining undoubtedly contributes to coastal erosion on Grande Comore, this is not the case for waste deposits and pollution. Although waste deposits and pollution degrade coastal ecosystems, there is no immediate link to coastal erosion and flooding. For national elites and donors, local drivers play a role, but they also point to global climate change, more so than survey respondents. This focus may partially reflect global funding logics: funding for adaptation to climate change is more readily available than other types of support, in particular for vulnerable countries like the SIDS—which may thus (over-)emphasise their vulnerability to climate change to obtain funds, as Webber (2013) argues for Kiribati, where 'climate change adaptation is becoming the main game in town', and where 'climate change aid has eclipsed traditional 'development' aid'.

Second, climate change and sea-level rise interact with local anthropogenic pressures on the coastal zone on Grande Comore and the other Comorian islands (Sinane 2013). Accordingly, response measures should be context and site-specific and take into account local circumstances and conditions as well as future climate change. Interview partners recognise the need for customised, tailor-made solutions, a mix of measures that may include coastal defence structures, including seawalls, but also for instance construction setbacks and sand mining regulations. In contrast, the informal survey indicates little awareness in village communities about different types of response measures, including different forms and designs of coastal defence structures. There is thus a need to inform stakeholders about diverse response measures, their potential as well as their limitations. In the Maldives, government officials note the positive effects of capacity building and awareness raising: 'communities may think they all want seawalls until they learn about the range of different options available to them', says one official, while another recognises the need to look for 'our own, softer and natural ways of adapting to climate change' (cited in Sovacool 2012).

Finally, for communities to identify their own—hard and soft—ways of adapting, their own context and site-specific response measures, there is a need for more information and knowledge: about the extent of coastal change and erosion, about the causes and consequences of this change and about different response measures and their effects. We should experiment with different response measures, document them and assess their impacts over time (Duvat 2013) as well as monitor and document coastal change and erosion in places where no response measures have (yet) been taken. In more touristically developed countries, hotel resorts—which crucially depend on sandy beaches—serve as 'field laboratories' (Duvat 2009), they continually try out new approaches (Kench 2010, 2012). In less touristically developed countries like the Comoros, communities could take over this role, given adequate financial and technical support from donors, who should also help with disseminating and communicating lessons learnt. We need to find out what works where and why—and what does *not*. Importantly, these experiences need to be disseminated and shared (see e.g. Weir et al. 2016)—across communities, across islands and across countries so that others can learn from them and avoid making the same mistakes.

Acknowledgments We would like to thank the many people that have contributed to this project, in particular Dr. Kamardine Sinane, Hamid Soulé, the staff and interns at the Herbier des Comores, the student research assistants, and of course all our interview partners and survey respondents for sharing their views with us. We would also like to thank the editors of the special issue as well as two anonymous reviewers for comments on previous versions of this paper. We also gratefully acknowledge financial support from the Gothenburg Centre for Globalisation and Development. We thank the special issue editors for this point. We thank the special issue editors for pointing out these common design shortcomings.

References

Abdou Rabi F, Ali B (n.d.) Bilan sur l'extraction du sable en Grande Comore. Programme régional environment COI/UE Coordination des Comores. http://www.commissionoceanindien.org/archives/environment.ioconline.org/Bilan_extraction_sable_-_Grande_Comore_140124_011400ff7c.zip?eID=tx_mm_bccmsbase_zip&id=101886189852e02c0ce8182. Accessed 10 April 2016

ASCLME (2012) National Marine Ecosystem Diagnostic Analysis. Contribution to the Agulhas and Somali Current Large Marine Ecosystems Project (supported by UNDP with GEF grant financing), Comoros

Bird ECF (1985) Coastline changes: a global review. Wiley, New York

Cazenave A, Cozannet GL (2014) Sea level rise and its coastal impacts. Earth's Future 2:15–34. doi:10.1002/2013EF000188

Cooper JAG, McKenna J (2008) Working with natural processes: the challenge for coastal protection strategies. Geogr J 174:315–331. doi:10.1111/j.1475-4959.2008.00302.x

Cooper JAG, Pile J (2014) The adaptation-resistance spectrum: a classification of contemporary adaptation approaches to climate-related coastal change. Ocean Coast Manage 94:90–98. doi:10.1016/j.ocecoaman.2013.09.006

Cooper JAG, Pilkey OH (eds) (2012) Pitfalls of shoreline stabilization: selected case studies, vol 3. Coastal Research Library. Springer, Dordrecht

David G, Dumas P, Lancelot L, Sabinot C, Sinane K (2014) Quand la mer fait le mur. In: Paper presented at coastal risks: hazards, issues, representations, management, 3–4 July, Brest

De Comarmond A, Payet R (2010) Small island developing states: incubators of innovative adaptation and sustainable technologies? In: Michel D, Pandya A (eds) Coastal zones and climate change. The Henry L. Stimson Center, Washington, pp 51–68

Defeo O, McLachlan A, Schoeman DS, Schlacher TA, Dugan J, Jones A, Lastra M, Scapini F (2009) Threats to sandy beach ecosystems: a review. Estuar Coast Shelf Sci 81:1–12. doi:10.1016/j.ecss.2008.09.022

Donner SD, Webber S (2014) Obstacles to climate change adaptation decisions: a case study of sea-level rise and coastal protection measures in Kiribati. Sustain Sci 9:331–345. doi:10.1007/s11625-014-0242-z

Dugan JE, Hubbard DM, Rodil IF, Revell DL, Schroeter S (2008) Ecological effects of coastal armoring on sandy beaches. Mar Ecol 29:160–170. doi:10.1111/j.1439-0485.2008.00231.x

Duvat V (2009) Beach erosion management in small island developing states: Indian Ocean Case Studies. In: Brebbia CA, Benassai G, Rodriguez GR (eds) Proceedings of the 1st international conference on physical coastal processes, management and engineering, Malta, 2009. WIT Transactions on Ecology and the Environment. WIT Press, Southhampton, pp 149–160. doi:10.2495/CP090141

Duvat V (2013) Coastal protection structures in Tarawa Atoll, Republic of Kiribati. Sustain Sci 8:363–379. doi:10.1007/s11625-013-0205-9

Forbes DL, James TS, Sutherland M, Nichols SE (2013) Physical basis of coastal adaptation on tropical small islands. Sustain Sci 8:327–344. doi:10.1007/s11625-013-0218-4

French PW (2001) Coastal defences: processes, problems and solutions. Routledge, London
Gillie RD (1997) Causes of Coastal Erosion in Pacific Island Nations. J Coast Res 24:173–204
Jackson CW Jr, Bush DM, Neal WJ (2012) Documenting beach loss in front of seawalls in Puerto Rico: Pitfalls of Engineering a Small Island Nation Shore. In: Cooper JAG, Pilkey OH (eds) Pitfalls of shoreline stabilization: selected case studies. Springer, Dordrecht, pp 53–71
Kench P (2010) Coastal monitoring, Reef Island Shoreline Dynamics and Management Implications. Final Report. Prepared for Environment Protection Agency Ministry of Housing, Transport and Environment, Government of the Maldives. http://www.environment.gov.mv/v1/download/288. Accessed 18 May 2015
Kench P (2012) Compromising Reef Island shoreline dynamics: legacies of the engineering paradigm in the Maldives. In: Cooper JAG, Pilkey OH (eds) Pitfalls of shoreline stabilization: selected case studies. Springer, Dordrecht, pp 165–186
Kraus NC (1988) The effects of seawalls on the beach: an extended literature review. J Coast Res 4:1–29
Kraus NC, McDougal WG (1996) The effects of seawalls on the beach: part I, an updated literature review. J Coast Res 12:691–701
Martinez G, Bizikova L, Blobel D, Swart R (2011) Emerging climate change coastal adaptation strategies and case studies around the world. In: Schernewski G, Hofstede J, Neumann T (eds) Global change and baltic coastal zones. Springer, Dordrecht, pp 249–273
McSweeney C, New MGL (2008) UNDP climate change country profiles. Comoros. http://country-profiles.geog.ox.ac.uk/. Accessed 17 Nov 2015
Michel D, Pandya A (eds) (2010) Coastal zones and climate change. The Henry L. Stimson Center, Washington
Mimura N, Nunn P (1998) Trends of beach erosion and shoreline protection in rural Fiji. J Coast Res 14:37–46
Monnereau I, Abraham S (2013) Limits to autonomous adaptation in response to coastal erosion in Kosrae, Micronesia. Int J Global Warning 5:416–432. doi:10.1504/IJGW.2013.057283
Montfraix B (2011) Etude de vulnerabilité aux changements climatiques: Evaluation qualitative. Indian Ocean Commission, Quatre Bornes, Mauritius
Mycoo MA, Chadwick A (2012) Adaptation to climate change: the coastal zone of Barbados. Marit Eng 165:159–168. doi:10.1680/maen.2011.19
Nordstrom KF (2014) Living with shore protection structures: a review. Estuar Coast Shelf Sci 150:11–23. doi:10.1016/j.ecss.2013.11.003
Nunn PD (2004) Understanding and adapting to sea-level change. In: Harris F (ed) Global environmental issues. Wiley, Chichester, pp 45–64
Nunn PD (2007) Adapting to climate change in the Pacific Islands. Kagoshima University Research Center for the Pacific Islands. Occas Paper 47:29–40
Nunn PD (2009) Responding to the challenges of climate change in the Pacific Islands: management and technological imperatives. Clim Res 40:211–231. doi:10.3354/cr00806
Nunn PD (2010) Bridging the gulf between science and society: imperatives for minimizing societal disruption from climate change in the Pacific. In: Sumi A, Fukushi K, Hiramatsu A (eds) Adaptation and mitigation strategies for climate change. Springer Japan, Tokyo, pp 233–248
Nunn PD (2013) The end of the Pacific? Effects of sea level rise on Pacific Island Livelihoods. Singapore J Trop Geo 34:143–171. doi:10.1111/sjtg.12021
Nurse LA, McLean RF, Agard J, Briguglio LP, Duvat-Magnan V, Pelesikoti N,Tompkins E, Webb A (2014) Small Islands. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 1613–1654
Sinane K (2013) Les littoraux des Comores, dynamique d'un système anthropisé: le cas de l'île d'Anjouan. Dissertation, Université de La Réunion
Sinane K, David G, Pennober G, Troadec R (2010) Fragilisation et modification des formation littorales sur l'île d'Anjouan (Comores): Quand l'érosion d'origine anthropique se conjugue au changement climatique. VertigO—rev électron en sci de l'environ. doi:10.4000/vertigo.10528
Sovacool BK (2012) Perceptions of climate change risks and resilient island planning in the Maldives. Mitig Adapt Strateg Glob Change 17:731–752. doi:10.1007/s11027-011-9341-7
UNFCCC (2009) Copenhagen Accord. Document number FCCC/CP/2009/11/Add.1
Union of the Comoros (2006) National action programme of adaptation to climate change (NAPA). Ministry of Rural Development, Fisheries, Handicraft and Environment, Moroni
Union of the Comoros (2012) Seconde Communication Nationale sur les Changements Climatiques. Vice-Presidency in charge of the Ministry of Production, Environment, Energy, Industry and Handicraft, Moroni
Webber S (2013) Performative vulnerability: climate change adaptation policies and financing in Kiribati. Environ Plan A 45:2717–2733. doi:10.1068/a45311
Weir T, Dovey L, Orcherton D (2016) Social and cultural issues raised by climate change in Pacific Island Countries: an overview. Reg Environ Change. doi:10.1007/s10113-016-1012-5
Wong PP, Losada IJ, Gattuso J-P, Hinkel J, Khattabi A, McInnes K, Saito Y, Sallenger A (2014) Coastal systems and low-lying areas. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmnetal panel on climate change. Cambridge University Press, Cambridge
Worliczek E, Allenbach M, Mückler H (2010) Climate change and the acceptance of coastal sand mining on Wallis Island. Unpublished manuscript. http://www.academia.edu/249171/Climate_Change_and_the_acceptance_of_coastal_sand_mining_on_Wallis_Island. Accessed 16 June 2016