Chapter 7
Time-Scale in Framing Disaster Risk Reduction in Sustainability

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Abstract Disaster Risk Reduction is one of the most important topics in sustainability science, seeking to examine the vulnerability and resilience of human life and society to natural hazards through the reduction and management of risks. However, disasters are caused by many different types of natural hazard events that take place in exposed and vulnerable areas across time spans. The size of the area and times-scale of the impact can also differ greatly. Possible actions to improve preparedness, countermeasures, actors or stakeholders involved, and person(s) in charge of these measures vary depending on the type of disaster. This chapter describes two different types of coastal issues, namely tsunamis and sea level rise, and the types of countermeasures available to either Japanese coastal towns or small coral islands. How these issues are perceived and dealt with will then be discussed from the point of view of time-scales, which affect the human perception of the problem.

Keywords Sustainability science · Risk management · Natural hazards · Tsunamis · Sea level rise

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7.1 Introduction

Natural hazards pose significant threats to the long-term sustainability of human settlements, as major events can overcome measures put in place to increase resilience, and can destroy the ability of socio-cultural systems to recover (Mino et al. 2016). Thus, how to prepare and manage natural disasters are two crucial topics for sustainability scientists, given that the very essence of sustainability science is to examine the long-term links between human life, well-being, and the environmental systems on which they are based. An event such as a landslide or an earthquake that occurs in a remote area and does not impact human life is considered merely a *natural event*, not a hazard or disaster. Such natural events are not included within the subject matters of sustainability science (at least in the narrow interpretation), and thus are excluded from consideration in this chapter.

When thinking about natural hazards, it is important to keep in mind that these events tend to repeat themselves at regular intervals, based on atmospheric or geological criteria that have a range of time spans (depending on the geographical location and nature of the hazard). The scale of the area and timelines involved can vary significantly, and humans (both individually and as a society) make conscious and unconscious calculations about such issues when designing socio-economic systems. The issue of hazard preparedness is thus clearly important, and the types of countermeasures, actors or stakeholders involved, and person(s) in charge of these measures will significantly differ depending on the type of disaster, level of development, and other characteristics of a given society.

For example, considering adaptation measures to the impacts of long-term climate change and "normal natural disasters" (which occur even without human-induced climate change) requires a different type of discourse; that is, they require a different "framing", especially concerning responsibility and the causes of the event (see for example Yamamoto and Esteban 2014). Other examples include building river dikes in preparation for the scale of heavy rains that may occur once in 50 years, constructing seawalls that anticipate a major tsunami that may occur once every 1000 years, and preparing for a volcanic eruption that can take place once in every 10,000 years and cover a huge area with its lava flow. These examples are framed differently and hence require different principles and processing for developing preventive measures and emergency plans.

Essentially, in the present chapter the authors argue that, when it comes to *large-scale* natural hazards, human societies tend to think in three different time scales (see Table 7.1). The first of these involves the largest scale event that is likely to take place during the life of one individual (i.e. individuals often think that they should prepare against it, as it is something that they can expect will happen during their own lifetime). The second relates to the largest scale event that can be thought possible in the course of that individual's civilization, and typically encompasses looking at time frames of hundreds to thousands of years. In this case the time scales used by different countries may differ significantly, depending on the length of their history and the quality of historical records and geological evidence. For example,

Table 7.1 Examples of how humans view different times scales related to two difference challenges

	Time Scales		
Phenomenon	One Human Lifespan (several decades to around one hundred years)	Human Civilization (hundreds to thousands of years)	Geological Time Scales (tens of thousands of years)
Tsunami (Japan)	**Level** 1 (around 10 m or less)	**Level 2** (over 10 m, to around 20 m or so)	**Level 3** (dozens of metres)
Sea level rise	Dozens of centimetres	A few metres	Dozens of metres

for the case of tsunamis, the Chilean society is currently looking at records of tsunamis from the arrival of the Spanish in the sixteenth century (Aranguiz 2015), the Japanese are usually going back until the seventh century (San Carlos et al. 2017), and the Greeks are attempting to gain insights from as far back as the end of the Minoan Civilization (2000–1400 BCE) and the volcanic eruption of Santorini (circa 1646 BCE) (Pareschi et al. 2006). Essentially, individuals currently alive think about the consequences that these events will have on their descendants and on the long-term survival of their culture and traditions, something that tends to weigh quite heavily on the cultural conscience of many humans.

Finally, geological time scales are typically outside the calculations of even the more advanced societies, and represent acts of society-level *force majeure* from which it is thought impossible to protect or adapt, at least under present technology levels. These are often disregarded by individuals, given the difficulty in relating to the time scales involved.

The discussion of time scales in implementing effective disaster risk reduction is particularly important, although not explicitly stated, in the most recent global disaster risk reduction framework – the Sendai Framework for Disaster Risk Reduction 2015–2030. The framework's goal is to "*prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience*" (UNISDR 2015). The framework promotes that societies should understand their risks and then plan and act accordingly, in order to absorb known and unknown shocks and disturbances. This involves understanding the retrospective and prospective intricacies of risk across time scales.

The framework has four priorities for action: (1) understanding disaster risk, (2) strengthening disaster risk governance to manage disaster risk, (3) investing in disaster risk reduction for resilience, and (4) enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation, and reconstruction (UNISDR 2015). All four priorities are to be implemented at the local, national, and global scales with emphasis on promoting long-term resilience towards disasters. The time scales in which disasters could occur enable the proper framing of preventative actions and strategies in implementing these priorities for action.

In the present chapter we discuss how these different time scales impact the framing of disaster preparedness and risk reduction using two different case studies. The first relates to tsunami disaster risk management in Japan, and the second to sea level rise using the point of view of low-lying islands and coral reefs as an indication of how time scales affect the perception of the problems involved.

7.2 Natural Hazard Return Periods: Tsunami Classification in Japan

On March 11, 2011 a large earthquake of magnitude 9.0 on the Richter scale occurred off the northeast coast of Japan, generating a devastating tsunami that inundated over 400 km^2 of land, and caused large numbers of casualties (Mori et al. 2012, Mikami et al. 2012; Ogasawara et al. 2012). Along the Sendai plain in northern Tohoku the maximum inundation height was 19.5 m, and the tsunami propagated as a bore around 4–5 km inland, with maximum run-up-heights of 40.4 m being measured (Mori et al. 2012). Widespread devastation ensued, as the waves engulfed entire settlements, with everything but the sturdiest of buildings being completely washed away (see Fig. 7.1). This event is now known as the *2011 Tohoku Earthquake Tsunami*.

This event has transformed the way that the Japanese engineering and coastal zone management community think about tsunamis. Their approach to time scales is discussed in detail in the rest of this section.

7.2.1 History of Tsunamis in Northern Japan (Tohoku region)

Historically, the *2011 Tohoku Earthquake Tsunami* was one of the worst tsunamis that has affected Japan since records began. The Sanriku coastline, which extends northwards from the city of Sendai, has been frequently affected by tsunamis. The recorded history in the region goes back over 1000 years, and five major destructive tsunamis are all well documented (Watanabe 1985):

1. Jogan (869),
2. Keicho (1611),
3. Meiji-Sanriku (1896),
4. Showa-Sanriku (1933), and
5. Chile (1960).

In fact, the *2011 Tohoku Earthquake Tsunami* has been described as a one-in-a-1000-year event, resembling the *Jogan Tsunami* in A.D. 869 (Sawai et al. 2006). The description of this *Jogan Tsunami* actually appears in a historical document known as the *Sandai-Jitsuroku*, which documents how the wave flooded a wide

Fig. 7.1 Coastal settlement of Arahama, formerly located in the vicinity of Sendai City, Japan. All residential buildings in the town were destroyed by the power of the tsunami

coastal area of Tohoku (the northern region of Japan that encompasses the Sanriku coastline and the Sendai plains, amongst other areas), killing some 1000 people (though population density at the time was significantly lower than at present). There are no records concerning the *Jogan Tsunami*, though some tsunami deposits found in sediment layers in the Sendai Plain, as well as along the Sanriku Coast, have allowed researchers to identify the area which was likely to have been inundated by this event (Minoura et al. 2001).

Since the Edo Era (1603~1867), the number of written records increased substantially, and thus tsunamis have been better documented. The Keicho *Tsunami* (1611), which attacked a wide coastal area from Hokkaido to Sanriku, was one of the most destructive tsunamis in this period, and in the Tohoku regions waves travelled up to 4 km inland (Sawai et al. 2006). Since the beginning of industrialization during the Meiji Era (1868–1912), the Sanriku coast has experienced three major tsunamis. The first of these three tsunamis is known as the *Meiji-Sanriku Tsunami*, which caused some 22,000 casualties. Although the magnitude of the generating earthquake was comparatively modest, the maximum tsunami height reached as high as 20 m. The second tsunami is referred to as the *Showa-Sanriku Tsunami*, which caused around 3000 casualties along the Sanriku coastline. Finally, the 1960 *Chile Tsunami*, which was triggered by an earthquake of magnitude 9.5 on the Richter scale in Chile, reached the Sanriku coastline and caused over 100 casualties.

7.2.2 New Tsunami Classification System

The *2011 Tohoku Earthquake Tsunami* led to major discussions within the Japanese coastal engineering and management community about whether hard measures (such as breakwaters or dikes) are preferable over soft measures (such as tsunami warning systems and evacuation plans) to protect the coastline and the communities situated next to it (Shibayama et al. 2013). Eventually, the concept of Level 1 and Level 2 tsunamis emerged based on ideas concerning time scales and the likelihood of an area being affected by such events. These concepts are widely used today, and formed the cornerstone of reconstruction philosophy in the aftermath of the event (as will be expounded upon later in this chapter). It is important to note that this classification is based on the frequency of these events, and that the exact period of return of each of the events has yet to be fixed, though there is a clear feeling that one of them relates to human life-spans, and the second to civilization time scales. The two levels would be:

Level 1 Tsunami Events with a return period of several decades to 100+ years (essentially, the Japanese expression which has been used in coastal engineering discussions would translate as a return period from 50–60 to 150–160 years). Although the height of the wave would depend on the event and location, Level 1 Tsunamis refer to waves which are *comparatively* low in height, typically less than 7–10 m.

Level 2 Tsunami These events have return periods of between one hundred to a few thousand years. The tsunami heights are much higher, and encompass waves over 10 m in height, and sometimes even up to 20–30 m. Clearly, both the 2004 *Indian Ocean* and 2011 *Tohoku Earthquake Tsunamis* fall under this category.

It is important to note that given the nature of the propagation process, a given event might represent a Level 2 tsunami for a certain area or country, yet only a Level 1 event for other places. For instance, the 2011 *Tohoku Earthquake Tsunami* was clearly a Level 2 event in northern Japan, though by the time it reached Chile the tsunami was only a Level 1 event.

Events such as meteorite impacts or underwater landslides, which can cause devastating waves over 50 m in height, are outside the scope of this classification. These types of hazards would have return periods of tens or hundreds of thousands of years, and would completely devastate a coastline, reaching dozens of kilometres inland and probably rendering useless any evacuation strategy in place. One could actually talk about “Level 3” events, and it is unclear whether present day technology is advanced enough to protect human society from them. To the authors’ knowledge, no strategies are currently in place anywhere in Japan (arguably the country in the world which has invested the most (Mori et al. 2012) in improving resilience against natural disasters in general, and tsunamis in particular) or any other country to protect against such events. This highlights how the time scales involved in an event dictate the type of actions (or complete lack of actions, for events with very high return periods) employed to improve resilience and mitigate the consequences of a given hazard.

7.2.3 Implications of Time Scales on Measures to Improve Resilience

The debate on whether hard or soft measures are better suited to protect against coastal hazards has used the concepts of Level 1 and Level 2 tsunamis to understand the role that each type of countermeasure has on improving resilience. At present, the idea that hard measures alone can always protect against the loss of life is no longer accepted; instead, it is thought that coastal structures should play a role in attempting to protect property against Level 1 events. Thus, the function of safeguarding human life should fall onto soft measures, which should be designed against Level 2 tsunamis. Nevertheless, hard measures might aid evacuation, and their influence can be considered when thinking about the design of evacuation systems. For example, an assessment of the effectiveness of Kamaishi Bay mouth breakwater shows that the structure could have contributed to reducing inundation heights by around 40 to 50%, and could have provided extra time for local residents to evacuate (data from the Tohoku Earthquake Tsunami Joint Survey Group and PARI 2011, also see Shibayama et al. 2013).

However, it is important to note that the cost of using hard measures for tsunami protection is often rather high, and their effectiveness against Level 2 tsunamis is unclear, though a number of lessons have been learnt after the 2011 event (Jayaratne et al. 2016). It is also important to consider whether coastal areas are a place for recreation, or the source of potential threats. Japan is a country that regularly experiences many different types of coastal natural disasters, and countermeasures against typhoons and tsunamis require the construction of coastal defences, river embankments and other engineering structures (such as landslide countermeasures, which can take place because of high precipitation (perhaps even 150 mm of rain in 1 h) during the passage of a typhoon). Thus, important decisions must clearly be taken by society about which areas should be designated as residential areas, how those areas should be protected, and the consequences to the rest of the country if one of these areas suffers from a natural disaster (Table 7.2).

7.2.4 Case Study: Otsuchi Town

In order to illustrate reconstruction patterns and how this classification of Level 1 and Level 2 tsunamis affects the way of thinking about future hazards, it is worth looking at a case study of one city in Japan. The town of Otsuchi was particularly devastated by the 2011 event, with recorded inundation heights of 10–14 m and run-ups of around 25 m (Mori et al. 2012). The initial wave arrived just 34 min after the earthquake (Yamao et al. 2015), which explains the large numbers of casualties and the challenge that it represented from the long-term demographic sustainability of the town. Prior to the 2011 event, Otsuchi had a nominal population of around 16,000 people, and out of these 803 people died, 431 are still missing, and a further

Table 7.2 Summary of the philosophy regarding the use of hard and soft measures to protect against Level 1 and Level 2 tsunamis in Japan

Tsunami level	Hard measures	Soft Measures
1	*Primary function* Protect property *Secondary function* Help in the protection of lives	*Primary function* Protect lives Tsunami early warning and evacuation system
2	*Primary function* Possibly provide residents with some extra time to evacuate area	*Primary function* Protect lives
	Generally ineffective	Tsunami early warning and evacuation system

50 lost their lives because of the indirect consequences of the tsunami (e.g. in the aftermath of the disaster some people died because they lost access to medicines needed to treat chronic illnesses (Esteban et al. 2015). Regarding the damage, 3359 buildings were completely destroyed and another 713 suffered major or partial damage (Esteban et al. 2015).

It is worth noting that the town has a long history, and thus prior tsunamis have been well documented, as it served as a provincial capital during the Edo era. By 1948 the central downtown area was concentrated on the side of one of the hills, with the areas close to the sea left undeveloped, given that they were destroyed by previous tsunamis such as the 1896 *Meiji-Sanriku* and 1933 *Showa-Sanriku* events, and thus local inhabitants had a strong cultural memory of such types of disasters (Esteban et al. 2015; Esteban et al. 2013). Nowadays, economic activities are based around the service sector, with a significant contribution of salmon fishing, aquaculture of scallops and seaweed, and the fish processing industry to the local economy.

Local authorities are aware that the tsunami walls protecting the town were unsuccessful in stopping the tsunami wave, and that the only inhabitants that survived were those that evacuated or were in areas that were not at risk. Thus, this classification of tsunami levels and the need to further emphasize evacuation were accepted, as the ultimate objective should always be to preserve lives (Esteban et al. 2015). Nevertheless, the types of interventions that are currently being considered can be classified into three different layers of protection:

Layer 1-Prevention: consists of breakwaters or dykes aimed at preventing seawater from inundating the land;

Layer 2-Spatial Solutions: involves spatial planning and adapting buildings to mitigate losses if flooding does take place, and includes relocating important buildings to higher ground (which essentially means that areas closer to the sea should be considered as sacrificial, and only dedicated to industrial buildings or parks)

Layer 3-Emergency Management: involves the use of disaster plans, risk maps, early-warning systems, evacuation, and medical help, and mainly focuses on measures that reduce risks to human life.

Essentially, the idea is to move towards a more resilient and flexible system that relies on multi-layer (Tsimopoulou et al. 2012, 2013).

Given financial consideration and guidance from the national government, following the concepts of Level 1 and Level 2 tsunamis described earlier requires that Layer 1 coastal defences should be rebuilt against a Level 1 tsunami, but not necessarily against a Level 2 tsunami. Prior to the 2011 event, the highest tsunami walls in the town were built up to a height of +6.4 m T.P.[1]

Simulations carried out by the national and prefectural governments indicate that the *meiji-sanriku* tsunami should become the benchmark for a level 1 event (which flooded otsuchi to a level of around +11.5 m t.p.). Nevertheless, because the town is located close to Kamaishi city it was decided that most of the tsunami walls would be built to the same inundation height as that expected in Kamaishi, i.e. to a level of +14.5 m t.p. Simulations of the 2011 event indicate that even for such a wall partial overtopping is possible, allowing some water to flood the land behind it. Thus, Layer 2 countermeasures, in the form of "land adjustment," are also necessary. Under the new land use maps. The areas immediately adjacent to these walls can only be utilized for fishing industries and parks.

However, in some neighbourhoods in Otsuchi, local residents decided that the wall should be rebuilt to the same height as that which existed prior to the tsunami (+6.4 m T.P.), much lower than the walls protecting the main downtown area, in some cases for aesthetic reasons (Esteban et al. 2015). It is important to note that such considerations can be quite important for the mental well-being of the population, as the connection to nature and the sea is usually very important for communities living close to the coastline. Also, the economy of the area has a significant component of tourism, and thus in many cases thinking about how to preserve the natural beauty of the land is also necessary. Nevertheless, in order to compensate for this, Layer 2 countermeasures have been significantly improved by raising the entire residential areas by over 8 m, to bring them to a height of almost 15 m above sea level, which is higher than the inundation height during the 2011 tsunami. Aside from these special areas, the entire central part of Otsuchi has been elevated by at least 3 m (see Fig. 7.2). This would mean that, in combination with the Layer 1 measures described earlier, the town would not be flooded if an event like the 2011 event were to recur. Paradoxically, this seems to imply that the defences have been planned against a Level 2 tsunami, which poses significant questions regarding the long-term sustainability of the Japanese country as a whole (Can the government of the country afford to financially protect all communities in Japan to the same degree?). However, considering such question is outside the scope of the present chapter.

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[1] These heights are presented relative to Tokyo Peil (T.P. corresponds to mean sea level of Tokyo Bay).

Fig. 7.2 The entire downtown area of Otsuchi is being elevated, as part of the strengthening of Layer 2 countermeasures

7.3 Sea Level Rise and Low-lying Lands

Climate change and sea level rise are expected to pose considerable challenges to human civilization in the coming centuries, and their consequences in the course of the twenty-first century alone are widely discussed in media and academia. However, the problem posed by sea level rise depends on the time scales on which it is considered. Though present-day society concerns relate to the likely sea levels within the lifespan of those alive today, it is important to remember that such changes will not stop by the year 2100. Hence, when considering the sustainability implications of sea level rise, it is important to keep this factor clearly in mind, as it will influence how to deal with the issues involved. To illustrate how time scales influence the choice of adaptation strategies, the authors will describe the problems being faced by low-lying coral islands, which traditionally depend on coral reefs to supply the materials necessary to compensate for sea level rise (Yamamoto and Esteban 2014).

7.3.1 Past Sea Level Rise and Twenty-First Century Projections

The International Panel on Climate Change fifth Assessment Report (IPCC 5AR) mentions how surface temperatures have oscillated for millions of years following glacial cycles. This in turn has influenced sea levels, which have risen and fallen according to such variations in temperature (because of thermal expansion of the oceans and the melting or accumulation of water in polar caps). During most of the twentieth century the global mean sea level rose by around 1.7 mm per year on average, though this intensified to 3 mm per year towards the end of the century (IPCC 5AR). The IPCC 5AR estimates that sea levels could rise by between 26 and 82 cm by 2100, substantially higher than the 18–59 cm projections that had been given by IPCC 4AR. So-called "semi-empirical methods" (see IPCC 5AR) such as those by Vermeer and Rahmstorf (2009) provide more onerous predictions, indicating sea level rise for 1990–2100 could be in the 0.75–1.9 m range.

There is little doubt that climate change – and consequently sea level rise, as it is greatly affected by global temperatures – is mostly being driven by the release of greenshouse gases into the atmosphere. Current world efforts to reduce greenhouse gas emissions, centred around the United Nations Framework Convention for Climate Change (UNFCCC), have not yet convincingly managed to halt their increase, despite the signing of the Paris Agreement in 2015. However, even if emissions were to reduce, the IPCC 4AR points how "if actions are taken to reduce the emissions, the fate of the trace gas concentrations will depend on the relative changes not only of emissions but also of its removal processes" (Bindoff et al. 2007). This means that it could potentially take a very long time for the Earth to revert to its current condition. As CO_2 emissions continue unabated, global temperatures will inevitably continue to rise unless drastic action is taken to curtail them. Such effects can very well lead to the flooding of low-lying deltaic areas such as the Mekong delta (see Nguyen et al. 2013; Takagi et al. 2014; Nobuoka and Murakami 2011) or atoll islands (Yamamoto and Esteban 2014), unless significant adaptation measures are implemented.

The IPCC 5AR discusses the long-term climate change and commitment up to the year 2500. Essentially, if greenhouse gas concentrations rise to between 500 and 700 ppm CO_2, sea level rise could exceed 1.5 m by the year 2300; or if concentrations were to exceed 700 ppm CO_2 sea level rise could surpass 3 m by 2300, reaching almost 7 m by 2500. Essentially, the most optimistic scenarios related to sea level rise require a positive outcome of UNFCCC efforts and negotiations. The entire Earth climate system, however, exhibits a certain lag, due to the thermal inertia of the oceans. The oceans will gradually absorb heat from the atmosphere, and this will lead to the heating of the top layers, gradually extending deeper into the ocean. Even when air temperatures stop increasing, the heat absorbed by the oceans will be slowly released, meaning that the oceans would become a "very weak heat source" and dampen the decline of surface atmospheric temperatures (Schewe et al. 2011). Hence, the effects of current increases in CO_2 concentrations will manifest themselves in the future, much in the same way that present climate change is being caused by past CO_2 emissions. Also, the process of CO_2 removal from the atmosphere is quite complex, and although more than half of the CO_2 emitted is removed within a century, a fraction remains in the atmosphere for millennia. Another mechanism that slows down global cooling is the change in oceanic convection, which enhances ocean heat loss in high latitudes and reduces the surface cooling rate by almost 50% (Schewe et al. 2011). In this sense, greenhouse gases released at present "commit" us to certain future effects, as yet unfelt.

Simulations by Schewe et al. (2011) suggest that if a maximum warming of 1.5 °C is reached by middle of the twenty-first century (for CO_2 concentrations of just over 550 ppm), then temperatures will likely decline slowly afterwards and reach present-day levels by 2500. This would be achieved by GHG concentrations peaking in 2040 and declining subsequently to become negative after 2070. If this is achieved, the rate of sea level rise caused by thermal expansion (where the volume of the seawater would increase due to the change in temperature) would continue for over 200 years after the peak in air temperatures and stabilize around 2250. The rate of temperature decrease is significantly slower than the current rates of temperature rise, and are on average around −0.16 °C per century. This slow rate of cooling is quite significant, and highlights the need to rapidly reduce emissions of greenhouse gases and the importance of current climate negotiations between different countries. Not achieving these objectives could result in global warming continuing for much more prolonged periods of time. Another scenario by Schewe et al. (2011) shows how CO_2 concentrations of almost 1500 ppm by 2100 can see warming of up to 8.5 °C and result in 1.3 m of sea level rise due to thermal expansion alone by 2250 and a 2 m rise by 2500 (though some of the ranges given in the IPCC 5AR are much higher, as noted earlier).

Past geological records of sea level rise indicate that sea levels could very well have been much higher than current levels. For example, during a period known as the marine isotope stage 11 (MIS 11, 401 to 411 ka), global temperatures may have been 1.5–2.0 °C higher than those on the planet today, with sea levels possibly also being 6–15 m higher (IPCC 5AR). Also, during the last interglacial period, temperatures might have been 1–2 °C higher than pre-industrial levels, with sea levels several metres (around 4–8 m, see IPCC 5AR) higher than at present. Since then, in the late Holocene (some 12,000 years ago) it is likely that global sea levels rose 2 to 3 m to near present-day levels. All this indicates the necessity to factor time scales into the framing of the problems that coastal areas face because of sea level rise.

Finally, it is worth pointing out that these projections have only been made at the global level and on general, average terms. Although islands are expected to be most vulnerable to sea level rise, precise information about how much sea level rise a particular island or island state will experience are yet unavailable. Due to this, it is important to further discuss the particular impacts of sea-level rise on coral islands and the communities that inhabit them.

7.3.2 Island Communities

While environmental factors such as the natural survival of islands are important in predicting the sustainability of the communities living in them, recent studies about the impacts of sea-level rise have highlighting social factors, such as human adaptation, as a greater determinant (Perch-Nielsen et al. 2008; Gibbons and Nicholls 2005). However, given the lack of climate projections at the local level, time-scales are also important in understanding the impacts of climate change and the ways that communities can adapt to them. In particular, when considering the survival of island communities, differentiating between short-term (decades) and long-term (centuries) impacts, as well as potential short-term and long-term adaptation strategies is critical (Fig. 7.3).

In the long-term, mass migration theory suggests that, because of land loss, entire populations could be driven out of their homes (Yamamoto and Esteban 2014). However, in the short-term, the theory also argues that, due to disruption in food and water supply through saltwater intrusion, mass migration could also happen well before total land loss (Keener et al. 2012). Although this theory is dominant in the discussion surrounding sea-level rise adaptation, historical and empirical evidence so far indicates otherwise.

Fig. 7.3 Low-lying coral islands are particularly vulnerable to the consequences of sea level rise, unless coral species can successfully adapt to changing ocean conditions

Fig. 7.4 Adaptation strategies to rapid relative sea level rise in small islands in the Philippines, caused by earthquake induced land subsidence (see Jamero et al. 2016)

Historically, the world's biggest coastal cities have been able to prevent tidal flooding through engineering methods and land use planning (Nicholls and Cazenave 2010). A case study from the central Philippines also provides evidence that it is indeed possible for island communities to adapt to changes in sea levels of less than 1 metre, even if they happen quickly as a consequence of earthquake induced land subsidence (Jamero et al. 2016). Essentially, the 2013 Bohol Earthquake in the Philippines caused a number of small islands to immediately subside by up to 1 metre, which means that they are now flooded during high tides. The strategies implemented by these communities, mainly on a self-funded basis, are designed to accommodate the effects of tidal flooding, including building stilted houses (see Fig. 7.4) and raising the roads and floors of important community buildings (such as schools and chapels). The communities have also changed their evacuation behaviour to protect lives from the potential risks of passing typhoons (including high waves and storm surges; see also Jamero et al. 2017).

However, pressure from coastal settlements and bleaching events due to high ocean water temperatures are causing large-scale damage to many coral systems around the planet. Essentially, from the point of view of a human's lifespan, large-scale mortality and devastation will take place in these fragile ecosystems in the coming decades. Biologists fear that thermal stresses caused by sea water warming and ocean acidification – brought about by the absorption of CO_2, which reduces the ability of corals to produce their skeletons – will result in more prolonged episodes of bleaching and increased mortality. Veron et al. (2009) estimate that by the 2030s coral reefs could very well be in severe danger throughout the world, which could create many problems for small island nations, given the reduction in sediment supply that this would represent. Given that these islands are geomorphologically very dynamic, it is unlikely that they would disappear (Kench et al. 2009, Webb and Kench 2010), though this could lead to greater damage due to high waves and the need for substantial adaptation strategies. Nevertheless, evidence proves that it is indeed possible for coastal communities to adapt to changes in sea levels of less than 1 m, even if those changes happen quickly (Jamero et al. 2016).

However, when looking at a time scale of several centuries, the situation changes. Sea level rise will not stop by the year 2100, and it would be increasingly difficult for the inhabitants of small islands to adapt to changing water levels if all the coral dies. This could eventually lead to societal collapse in the islands, forcing their inhabitants to migrate (Yamamoto and Esteban 2014, 2016).

When looking at a longer time frame, it is clearly possible that coral communities will somehow adapt to these new changes (through the recruitment of new, better-adapted species, Kench et al. 2009), and there is evidence that coral reefs have adapted in the past to changing conditions (Kench et al. 2009). The Census of Marine Life (2010) found relics of cold water corals off Africa's Mauritanian coast extending over 400 km in waters 500 m deep in one of the world's longest reefs. This highlights how corals have continuously evolved to adapt to changing ocean conditions, and this will likely continue to happen in the future, though the time frames involved are unclear. From an evolutionary point of view, coral diversification has occurred in pulses, and mass extinctions have caused bottlenecks in the evolution of corals (Simpson et al. 2011). It is thus possible that major increases in coral mortality also retard the time it takes the species to re-adapt to the new environmental conditions, as a less diverse coral population has less of a genetic base from which to re-adapt. However, such evolution may already be taking place, and some evidence indicates that certain species around the Persian/Arab Gulf may have adapted or evolved to withstand higher sea temperatures, perhaps as much as 35 °C, that would normally prove fatal to corals elsewhere (Hume et al. 2016).

Researchers in Japan have also stated that there is large scale evidence that several major coral species have begun spreading polewards at speeds of up to 14 km/yr. (Yamano et al. 2011), showing how species can also adapt by moving to other areas of the planet where they find more favourable conditions. Thus, these areas may serve as a refuge for tropical corals in an era of global warming and could later move towards the equator again if and when temperatures return to their present values. One absolute limiting condition to this shifting of species towards the poles may be acidity, as corals stop growing in pH concentrations of 7.7 or lower (Fabricious et al. 2011), although it appears that some coral species can survive in conditions of higher acidity. It thus appears that corals could somehow adapt to a changing environment (by evolutionary or migration modes), assuming that this lower level of ocean acidification is not reached. This adaptation happens even with gradually rising water levels, and there is some evidence that the Maldives may have originated during a period of sea level rise, as noted by Kench et al. (2005).

Thus, it is clear that a variety of time scales and mechanisms must be taken into account when considering the long-term sustainability of small low-lying island nations. Currently, scientific knowledge regarding what is mostly likely to happen is incomplete, and much depends on what happens to coral reefs along different time scales, which in turn will determine the types of adaptation strategies that are required. If corals adapt within decades, the morphological resilience of the islands may prove sufficient to avert disaster, as their inhabitants can resort to rising the islands using dredged materials or coral stones (providing that the biological limits of sediment supply are not breached). When considering longer time scales, it is more difficult to see how a good solution can be reached unless corals adapt, though a number of options could be available.

7.4 Conclusions

In the present chapter the authors have attempted to show how the time scale through which a sustainability scientist looks at a problem will clearly influence disaster preparedness and management. Looking at these issues is indispensable for examining the sustainability of human life and well-being in the face of natural hazards, and for attempting to develop measures to improve the resilience of human societies. Such kind of measures should always carefully consider the different stakeholders and actors involved in order to attempt to arrive at a holistic assessment of the problem, taking into account present conditions and how things are likely to change in the middle to long term (hence once again the importance of looking at different time scales).

To illustrate the issues involved, the chapter presented two different types of hazards, namely that of tsunamis and the problems that will be brought about by sea level rise and ocean acidification (and the consequences it will have on coral reefs). Then, the case study of the reconstruction of Otsuchi town in northeastern Japan after the 2011 Tohoku Earthquake Tsunami and small islands of the coast of Bohol following the 2013 Bohol Earthquake in the Philippines, were presented. The discussion of both cases proved that the solutions to any given problem depend on the time scale considered, though much uncertainty exists about the likely future consequences and return periods of any given hazard. This highlights the need for more research on the topic of natural hazards taking into account long-term sustainability, in order to attempt to improve resilience and minimize the consequences of such events.

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