Prospects for climate change on three Polynesian outliers in Solomon Islands: Exposure, sensitivity and adaptive capacity

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Abstract

This paper discusses future prospects for climate change, impacts and adaptation of three small islands in Solomon Islands. Based on a review of literature a climate change scenario is suggested and with point of departure in a survey of three characteristics of the islands – bio-physical conditions, economic base and social organization – the exposure, sensitivity and adaptation options of island populations are analyzed. It is argued that the three islands are likely to be very differently affected for reasons related to all three categories of characteristics. Local adaptive capacity is likely to be insufficient, especially in the case of Ontong Java (which is an atoll), and economic, social, institutional and political factors, external to the islands, will be of increasing importance.

Key words

Climate change, vulnerability, adaptive capacity, Solomon Islands, Ontong Java, Bellona, Tikopia.

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Introduction

Small islands in the Pacific are generally claimed to be particularly vulnerable to future climate change and to face great challenges of adaptation (Mimura, 1999; Nunn, 2009). However, 'small islands' constitute a very heterogeneous group when it comes to exposure and sensitivity to climate change, both because most elements of climate change are not evenly distributed spatially, and because islands have different topographies and bio-physical environments, and their populations have different livelihoods and economic bases (Mimura et al., 2007). Also, differences in social organization and degree of isolation will matter, as will the extent to which the states they belong to have the capacity and will to provide assistance when required.

Taking the study of past climate change impacts and adaptation by Rasmussen et al. (2009) as our point of departure, we will address the prospects of future climate change impacts and adaptation options on three Polynesian islands in Solomon Islands: Ontong Java, Bellona and Tikopia. A future climate change scenario will be developed, based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 4AR) from 2007 and on research published since then which provides global (Meehl et al., 2007) as well as regional projections of climate change (Christensen et al., 2007). These combine numerous climate projections originating from 21 global climate models (GCMs) that feature different scenarios depending on future emissions of greenhouse gases. In the case of sea-level changes, the projections of recent studies, which indicate stronger rises than those of the IPCC 4AR, will be used. This climate change scenario will subsequently be used to assess likely impacts, taking into account the results of a survey of the bio-physical environment, agricultural production systems, livelihoods and demography, carried out on the three islands. This assessment will then constitute the basis for an analysis of adaptation options and a discussion of the 'adaptive capacity' of the island communities.

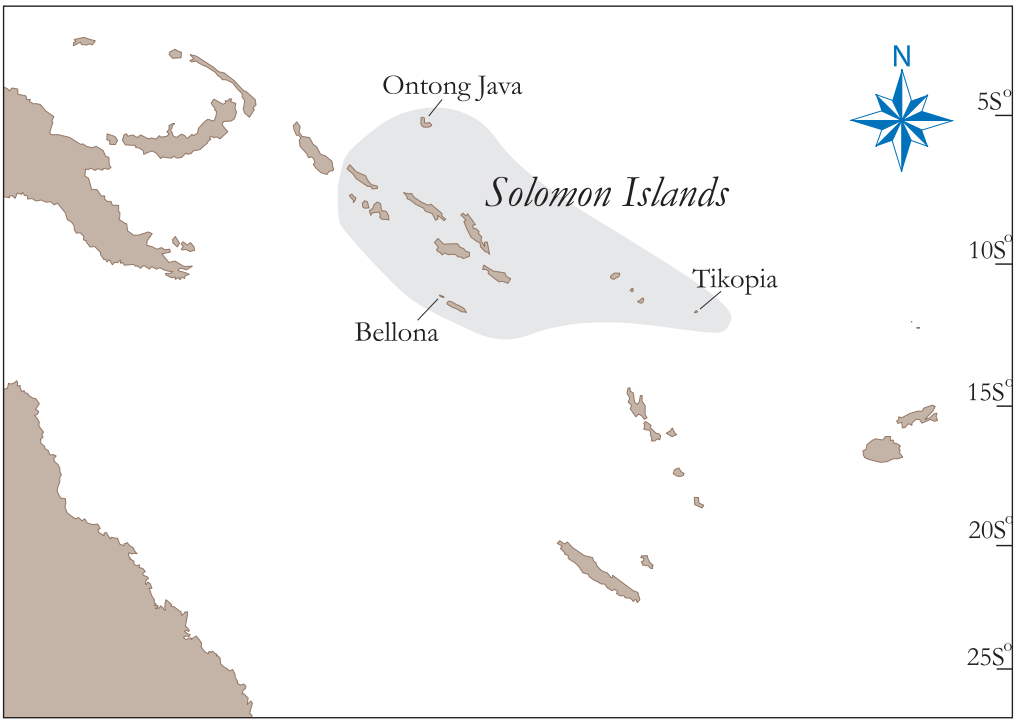

Figure 1: *Solomon Islands*

The research questions addressed are the following:

- What future climate change may be expected to affect the three islands?
- What are the likely impacts on production systems and livelihoods?
- What local adaptation actions appear possible and appropriate?
- How do concepts such as 'adaptive capacity' and 'resilience' apply in relation to long-term impacts of climate change on island communities?
- Will characteristics associated with ethnicity, cultural traits, and social organization be an asset or a drawback for the islands studied in the face of accelerated climate change?
- Will increased economic integration into a wider world have positive or negative impacts on the capacity of communities to adapt?

The conceptual framework used here builds on Rasmussen et al. (2009), which in turn is based on Mertz et al. (2009). Since the focus in this paper is on the future rather than the past, the concepts of resilience, adaptive capacity, exposure and sensitivity have particular weight. This paper defines resilience as the degree of change and disturbance a social-ecological system can endure and still retain the same function and structure while maintaining the capacity for learning and adaptation (Carpenter et al., 2001; Gunderson & Holling, 2002; Folke, 2006). In human systems, adaptive capacity refers to the social, physical and economic preconditions that are necessary in order for individuals or communities to enable adaptation (Smit & Wandel, 2006; Nelson et al., 2007). This means that the characteristics of resilience and adaptive capacity are similar in many ways (Adger, 2000; Tompkins & Adger, 2004; Smit & Wandel, 2006).

In the context of climate change, the adaptive capacity of an island community will depend on factors such as: the understanding of the challenges associated with changes; the social, economic and environmental resources available to it; the desired directions of development (e.g. criteria of successful adaptation); proactive planning and action; and not least the degree of disturbances they become exposed to (Mimura et al., 2007; Nunn, 2009; Barnett & Campbell, 2010). In circumstances where climate change impacts, alongside the impacts of other pressures, exceed the capability of communities to respond in ways that support their needs and wants, this may represent adaptive thresholds or limits to adaptation (Adger et al., 2009). In natural resource dependent communities, local adaptation could be viewed as unfeasible if a particular resource abruptly becomes unproductive.

In Rasmussen et al. (2009) exposure was defined as the impact of climate change on the subsistence and economic

base of the island communities in question. In this paper, we redefine this concept in order to allow for a distinction between climate *stressors* (e.g. intensity and frequency of climate events) and *impacts* (effects). For this purpose, exposure is defined as the degree of climate stress experienced at a particular system level, while the degree to which the system is affected and responds, negatively or positively, is defined as sensitivity (O'Brien et al., 2004; Adger et al., 2007).The impact depends, of course, on the changes in climate variables, topography, bio-physical conditions and the relative weights of different economic activities on the islands in question.

Methods

This study involved the use of a variety of methods and many different sources of information. In the following we will briefly present these methods and data sources.

Development of scenarios for future climate change
The standard source of information on the future climate scenario used here is IPCC AR4, in particular Chapter 10 (Meehl et al., 2007) and Chapter 11 of the WG1 report (Christensen et al., 2007). This report summarizes results of numerous climate scenarios, originating from an ensemble of 21 different GCMs. In the case of projected sea-level changes recent studies are used (e.g. Nicholls et al., 2011), which indicate stronger rises than those presented in the IPCC AR4. Also in the case of tropical cyclones, results of more recent studies (e.g. Knutson et al., 2010) are included. This combination gives the most comprehensive review of what is presently known about the future climate in the study area.

Survey of production systems, livelihoods and demography
A survey of production systems, livelihoods and demography was carried out on the three islands, in November 2006-January 2007, as described in detail in several other articles (Reenberg et al., 2008; Bayliss-Smith et al., 2010; Birch-Thomsen et al., 2010; Mertz et al.; 2010; Christensen, 2011). The survey was based on a questionnaire distributed to 40-90 households on each island and included an assessment of the land/soil resources available, the crops grown and the diet.

Methods for studying local understanding of future climate change
To allow comparison between the three islands a common approach to identification of local people's knowledge and understanding of future climate change and its potential effects on the islands was developed. On each island 7-9 semi-structured interviews were conducted with key informants, such as chiefs, teachers and elders, as well as focus groups of elders, young people, women, men and mixed groups.

Interviews covered two main themes. The first part addressed the experienced occurrence of different climate hazards (exposure), the impacts on livelihoods from each event and/or type of hazard (sensitivity) and the corresponding response to each of these events (coping and/or adaptation measures). Then, respondents were asked if they had observed gradual changes in climate and observable effects on the islands (Rasmussen et al., 2009). In the second part of the interviews, respondents were asked to reflect on previously applied coping measures and adaptation strategies, and to what extent these would be sufficient for future impacts of climate change. As an input to this discussion, simplified versions of the IPCC short- (20-50 yr.) and long-term (70-100 yr.) projections of climate change for the region were presented. To underline the uncertainties and for the sake of constructive discussions, projections were presented as scenarios rather than as predictions.

The assessment of adaptive capacity
The assessment (or 'measurement') of adaptive capacity of the local communities in the face of future climate change is a major methodological challenge (Smit & Wandel, 2006). While *ex post* analysis of adaptive capacity involves the explanation of why adaptation to some climatic change was or was not successful, which may be difficult enough, the 'predictive powers' of such analysis are even harder to assess. Climate change will involve both slow but persistent trends in certain variables, e.g. sea level, and changed statistics of extreme events, such as cyclones, and in both cases it is conceivable that adaptive strategies and actions may function well until a certain threshold of change is surpassed. An observed and documented adaptive capacity, as described for the three islands studied in Rasmussen et al. (2009), may thus disappear abruptly as the threshold is passed.

Another methodological difficulty is associated with the issue of scale (Adger et al., 2005): In the future, as climate changes reach certain levels, islands may become increasingly dependent on assistance from the outside, e.g. for building protective structures, and in this case the most critical 'adaptive capacity' may well reside outside the local community, at national or international scale. Thus

the assessment of adaptive capacity becomes a multi-scale exercise, involving also, in the present case, an assessment of capacities associated with the wider group of 'islanders' living in other parts of Solomon Islands or abroad, at provincial level, at national level, among the regional actors including Australia and New Zealand, and at the level of the global actors such as the United Nations and the World Bank. This exercise will require a range of different methodologies, including an assessment of the past behavior and analysis of policies and legal instruments.

Study area

The islands selected are similar with respect to population size, they are part of the same national state, and they are all Polynesian in cultural terms, even though strong Melanesian influences may be traced. They are, however, very different in terms of topography, location (and thus exposure to various elements of climate change) and degree of isolation. A detailed description of the islands may be found in Rasmussen et al. (2009), along with a detailed motivation for the selection of the three islands.

Future climate change scenario, exposure, sensitivity and adaptation

Climate change scenario for 2050

In order to analyze the future impacts of climate change on the islands and assess the potential for adaptation, we will briefly review the potential future changes in various aspects of climate in the study area. Unless stated otherwise, we refer to the main findings of the IPCC AR4, in particular Chapter 10 (Meehl et al., 2007) and Chapter 11 (Christensen et al., 2007).

Near-surface temperatures are expected to rise between 1.8 and 3.4ºC by the end of the 21st century as compared to the end of the 20th century, depending on the underlying scenario for the greenhouse gases (IPCC, 2000). The first estimate, with an uncertainty range between 1.1 and 2.9ºC, is based on the SRES B1 scenario, and the second estimate, with an uncertainty range between 2.0 and 5.4ºC, is based on the SRES A2 scenario. The widely used SRES A1B scenario leads to a future warming of 2.8ºC with an uncertainty range between 1.7 and 4.4ºC. As for the region of Solomon Islands, these three scenarios lead to a future warming that is close to the global mean change, except for the B1 scenario with 1.5ºC.

The future global warming leads to marked changes in the geographical distribution of precipitation, with generally more precipitation in the tropical regions, accompanied by an increase in the runoff and in the soil moisture in many of the tropical land areas (Meehl et al., 2007). As for the region around Solomon Islands, an increase in the annual mean precipitation, ranging from 5% in the southern part of the region to 15% in the northern part is projected for the SRES A1B scenario, based on all the GCM simulations considered (Christensen et al., 2007). This change is fairly robust, since at least 14 of the 21 GCM simulations show a future increase in precipitation in the area around Solomon Islands. The current average annual rainfall in Solomon Islands is mostly within the range of 3000 to 5000 millimetres. However, the changes in rainfall are likely to differ within and between the islands according to their exact location, size and shape.

The El Niño/Southern Oscillation (ENSO) interannual variability is projected to continue in the future, regardless of the changes in the mean of the sea surface temperatures in the tropical Pacific basin. The simulated changes in the ENSO interannual variability differ, however, between models and no discernible changes in the amplitude or the frequency of El Niño events in the 21st century are found. Despite post-AR4 progress in the understanding of the processes that contribute to El Niño variability, it is still highly uncertain to what extent the ENSO activity will be enhanced or dampened in response to temperature changes, or if the frequency of events will change (Paeth et al., 2008; Yeh et al., 2009; Collins et al., 2010).

According to the IPCC AR4, the global mean sea-level is projected to increase by 0.18-0.59 m, depending on the greenhouse gas scenario, by the end of the 21st century as compared to the end of the 20th century. These estimates, however, do not include contributions from the Greenland Ice Cap or Antarctica. After the publication of the AR4 several studies have, therefore, included the potential contributions from these ice caps in their estimates of future changes in sea-level and have obtained markedly stronger increases (e.g. Nicholls et al., 2011). Examples of such studies are Grinsted et al. (2010) with a sea-level rise of 0.72-1.6 m, Vermeer & Rahmstorf (2009) with a rise of 0.75-1.9 m, and Jevrejeva et al. (2010) with a rise of 0.6-1.6 m by the end of the 21st century. The ranges for the sea-level rise reflect the different rates of global warming associated with different greenhouse gas scenarios. Locally, however, sea-level changes are also affected by changes in the ocean density and the ocean circulation.

Increasing atmospheric CO_2 concentrations lead di-

rectly to increasing acidification of the surface of the ocean. Multi-model projections based on the various SRES scenarios mentioned above give reductions in pH between 0.12 and 0.35 units in the 21st century, adding to the decrease of 0.1 units relative to pre-industrial times already experienced. Ocean acidification among other things affects marine calcifying organisms, and hence further threatens coral reefs, which are already affected by the warming of the surface waters (Hoegh-Guldberg et al., 2007; Veron et al., 2009).

As for the future changes in the characteristics of tropical cyclones, the IPCC AR4 reports on a likely increase of peak wind intensities and, where analyzed, increased near-storm precipitation in future tropical cyclones. In a recent review article, Knutson et al. (2010) summarize the potential future changes in the characteristics of tropical cyclones, including results from post-AR4 studies. According to this review, future projections based on theory and high-resolution dynamic models consistently indicate that global warming will cause an increase in the globally averaged intensity of tropical cyclones in the order of 2-11% by the year 2100. Existing modeling studies also consistently project decreases in the globally averaged frequency of tropical cyclones by 6-34%. Higher resolution modeling studies, however, project increases in the frequency of the most intense cyclones.

To sum up the above, the climate change scenarios for 2100 for the three islands are as follows:

For Ontong Java:

- Higher temperatures (approx. 1.8-3.4^{0}C on average)
- Modest increase in average rainfall and possible higher frequency and intensity of heavy rainfall events.
- A sea-level rise assumed to be identical to the global average, estimated to be 20-35 cm by 2050, and accelerating to anywhere between 0.6 and 1.9 m by the year 2100. This does not take into account possible local/regional tectonic effects, about which we have no information.
- A general reduction of the pH of the surface water of between 0.12 and 0.35 (in addition to the decrease of 0.1 already observed) over the period, which in association with a rise in sea surface temperature may cause serious damage to coral reefs. Again, as mentioned, this is a global phenomenon.
- No significant change in cyclone occurrence, which is generally low within latitudes 10° from the equator. Yet, local effects of wind and wave remnants from intensified cyclone activity further south are not unlikely.

For Bellona and Tikopia, the scenarios are suggested to be similar with one important difference:

- Cyclones may be expected to become more intense, but less frequent.

Exposure and sensitivity to climate change of Bellona, Ontong Java and Tikopia

Generalizations about exposure and sensitivity to climate change at the scale of Pacific islands or Melanesia are attempted by Nunn (2009) and Barnett & Campbell (2010) for the Pacific and Lal et al. (2009) for Melanesia. A wide variety of impacts are reported in these studies. We will restrict ourselves to the three islands sharing certain characteristics yet differing in other respects, thereby demonstrating that even between these islands differences are large.

While agriculture remains a most important economic 'sector' in *Bellona*, local produce presently hardly covers more than 50% of the dietary requirements of the population, and the export is insignificant (Reenberg et al., 2008; Birch-Thomsen et al., 2010). Future increased intensity of cyclones will thus mainly cause loss of crops for local consumption. The severity of this loss depends very much on the extent to which an additional supply is provided by family members outside the island, provincial or national institutions, from other countries or from international organizations, and on the extent to which local social institutions are able to cope with the challenge of re-distributing food to avoid hunger. We will return to the efficiency of these institutions below.

While rainfall is likely to increase, it is possible that Bellona may experience increased intensity and duration of drought periods, e.g. associated with El Niño episodes. If so, these will have similar, though probably less catastrophic, effects on crops, and the same considerations as above will apply. In addition, fresh water supplies will be depleted more frequently, causing considerable welfare loss, forced migration (internal as well as external) and health problems, if not dealt with by adaptive action.

Infrastructural damage caused by increased intensity of cyclones is likely to constitute a major impact, measured in economic terms. Also, the overturning of large trees may cause a loss of valuable timber for construction.

Towards 2100, sea-level rise in the order of 0.6-1.9 m will obviously create huge problems on *Ontong Java*. In addition, the possible decay of reefs due to ocean acidification will make it impossible for reef building to keep up with sea-level rise.

Sea-level rise in the range of 20-35 cm over the next

40-year period is likely to cause net coastal erosion and expose some parts of Ontong Java to more frequent flooding. Based on topographical surveys, this will primarily impact on unvegetated sand cays and smaller uninhabited islets, while the larger *motu* islands, including the two permanently inhabited islands Luaniua and Pelau, appear less exposed. Leveling transects reveal that the interior of both islands exceeds 2 m above sea level, while the main settlement areas lie between 0.5 and 1.5 m above sea level. However, the ecological exposure and sensitivity of atoll land forms to the effects of climate change and sea-level rise depend not only on topography but also on other variables, including: the level of the emerged reef flats underpinning the islands; the consolidation of surface sediments by trees etc; and the alterations in external factors such as sediment supply, wave direction, wave height, frequency of high-magnitude events (e.g. tropical storms) and vegetation growth (Bayliss-Smith, 1988; Woodroffe, 2008; Dickinson, 2009). In the case of Ontong Java, Bayliss-Smith (1988) documented the short- and long-term effects of cyclone Annie in 1967, and found that immediate deterioration was followed in some places by accretive or 'constructive' effects on island morphology. Although this study confirmed the devastating effects cyclones have on social-ecological systems, it also indicated that atoll islands have differing sensitivities and rates of recovery. This insight was reemphasized by Woodroffe, who proposed that *"island resilience may be expressed by the degree of lithification of sediments and extent of vegetation cover"* (Woodroffe, 2008: 94). As Dickinson (2009) points out, the height of the limestone plateau on which atoll islands rest may represent a crucial 'tipping point' for the capability of the islands to sustain habitation. Thus, atoll islets may become subject to enhanced erosion when the sea-level rise exceeds this threshold. Based on a sample survey in Ontong Java, a calcareous brittle crust or pavement was found at depths above the ground water table, but we have insufficient data to derive the exact level of this plateau.

Even before sea levels reach the levels of 20-35 cm projected for 2050, there are other impacts which need to be considered. Along with the gradual increase of sea levels and erosion rates, the risk of salt water intrusion to the limited groundwater lens will also increase. This may have detrimental effects on local crop production; especially the taro (*Cyrtosperma*), which is grown in artificially excavated freshwater swamps. In Ontong Java, the importance of taro production, as well as coconut production, decreased rapidly between 1970s and 2005 (Bayliss-Smith et al., 2010; Christensen, 2011). The main explanation was a rise of bêche-de-mer harvesting as an economic activity, which gives much larger incomes and thereby makes it possible to replace local agricultural products with imported food, such as rice. However, a government ban on the export of bêche-de-mer due to problems of overexploitation has been in operation since 2005, with few exceptions, including a temporary export allowance in 2007 and 2009, which was initiated as a form of disaster relief. Consequently, taro and coconut have regained some of their importance as food staples in Ontong Java.

Fish is another major component of the diet in Ontong Java, and the most important fishing area and fish habitats are the coral reefs and the coral flats. Impacts of increased sea surface temperature and ocean acidity on the health and even survival of coral reefs would affect the livelihoods of the islanders considerably. The coral reefs surrounding the Ontong Java atoll acts as shelter and resource base to important fish species, which are significant energy and protein sources for the island community. The threat to the health and survival of the reefs is therefore of great significance in the medium to long term. The coral reefs also act as a combined coastal protection and a source of island sediments, and are therefore a necessary condition for atoll ecological resilience in the longer term (see above), and it is difficult to see how people would sustain their lives on an atoll without the important ecosystem services provided by the coral reef.

Based on the current situation on Ontong Java, marine and land based resources may provide sufficient food production and potential income for many years to come. In the absence of bêche-de-mer export, there are other marine species not yet commodified to be harvested for economic purposes. Moreover, the significance of social networks and institutions linking Ontong Java with the outside world has to be considered, including the importance of migrant remittances from the capital Honiara. Previously, this has been studied by Bayliss-Smith (1986, 2010), Christensen (2011), and Christensen & Mertz (2010), although not in a climate change context. Thus, within the next decades, the sensitivity of local livelihoods to climate changes and sea-level rise may be limited, but has to be viewed in a context of the wider political economy. In the mid- to longer term, increased ocean acidity and a sea-level rise in excess of 1 m are likely to cause substantial degradation of local resources, which may exceed the capability of the atoll to sustain human habitation in its current form. Consequently, the prospect of full or partial abandonment of the islands needs to be considered among the range of adaptation options and potential impacts.

In *Tikopia* it is evident that the major climate related threat is the risk of cyclones becoming more powerful. Even though emergency assistance has been provided after cyclones in recent decades, the total destruction of houses and gardens is a major stress factor for the population, as is the associated loss of tools, utilities and equipment, the south-eastern side being the most threatened. The observed effects of Cyclone Zoe in 2002 (Anderson-Berry et al., 2003) as well as earlier cyclones indicate that there are few major negative medium-to-long term effects of cyclones on agriculture. As in the case of Ontong Java, damage to the reef, caused by climate change and ocean acidification, will have immediate effects on the very important reef fishery and cause even greater exposure of the current housing areas, gardens, schools, churches and sacred areas to flooding associated with cyclones.

Local expectations of future climate change

On the three islands the majority of people have heard about climate change, either from relatives, the media and/or as part of their education. Based on interviews with key stakeholders and mixed groups of people, the awareness of causes and consequences varies greatly within communities. On a general level, climate change was commonly seen by the islanders as a problem that has and/or will have negative impacts on their livelihoods. Admittedly, this view may have been promoted by our enquiries, although the format of the interviews allowed for discussions about other drivers of environmental change and the uncertainties associated with climate predictions were made clear to the interviewees.

In *Ontong Java*, islanders mainly express concern about the experienced impacts of flooding and erosion, which many of the respondents explicitly associated with climate change and sea-level rise. When confronted with the conservative scenario of sea-level rise referred to above, responses were similar from the majority of people in the group interviews: e.g. *"Within the next 50 years it* [sea-level rise] *will be a disaster to this island because we live in a lowland compared to others. We need places and countries to help us with assistance now – assistance in ways of protecting against these things*." (young man, Pelau, Ontong Java).

Respondents were not systematically confronted with scenarios of possible degradation or death of coral reefs, yet when the issue was discussed the reactions ranged from despair to dismissal. People were well aware that undesirable scenarios, involving degradation of coral reefs, implied that their current ways of living on the islands would be hard to sustain. Moreover, the prospect of continued sea-level rise, if not abatable by changed coastal management practices, was highlighted as the main concern. According to members of the house of chiefs, the option of relocation had already been discussed, but with no clear outcome.

In *Tikopia* where Cyclone Zoe is still fresh in peoples' memories, it is hard for islanders to imagine the possible devastating effects of a cyclone with 10% higher wind speeds. When confronted with this possibility during individual and group interviews, the interviewees reacted by suggesting greater out-migration as a likely consequence.

Adaptation strategies and adaptive capacity

As mentioned above, adaptation to climate change may take place on a range of levels/scales, from the global to the individual. In the following we will discuss possible adaptive strategies, taking past adaptive behavior as the point of departure, as well as adaptive capacity in the longer term.

Household and island level adaptation and adaptive capacity

As described in Rasmussen et al. (2009), the populations of the three islands studied have a long tradition of coping with and adapting to climate change and variability, embedded in their socio-cultural traditions and fine-tuned to the islands they live on through generations. Extreme weather, such as prolonged droughts and intense tropical cyclones, are known to have affected the islands as far back as records are available (Nunn et al., 2007). As we consider longer time perspectives, it becomes increasingly difficult to predict whether the observed adaptive capacity of the island communities will suffice.

With the challenges of sea-level rise as currently projected (e.g. Rahmstorf, 2010), it is difficult to envisage long-term adaptation strategies for *Ontong Java* without considering migration or partial relocation of the island populations. Based on interviews and observations, there is no reason to believe that communities have a desire to migrate from their ancestors' land; rather they consider it as an option of last resort. However, at some point it may be seen as necessary by the islanders themselves or by outsiders, and it has already been proposed in government strategies (MECM, 2008). Whether this will be termed 'adaptation' is a matter of definition; it also relies on the criteria of successful implementation. As mentioned, mobility has always been part of the Polynesian tradition and reality, and presently a substantial percentage of islanders live outside Ontong Java, mainly in the 'Lord Howe settlement' in the outskirts of Honiara. Traditional social

structure and cultural traits persist here, yet in a diluted form. Whether an extension of this trend may meaningfully be termed a case of 'successful adaptation' is doubtful. Rather one might consider Ontong Java as a case illustrating the possible limits to local adaptation. It should be noted that while relocation potentially moves people away from certain types of risks, the socio-cultural consequences or 'secondary' effects of this adaptation may be considerable and need to be taken into account (Kates, 2000; Orlove, 2005; Adger et al., 2007; Barnett & Webber, 2009). Thus, any future relocation of communities must be considered carefully. Thorough preparation and planning is required in order to select appropriate destinations for community resettlement and secure land ownership rights and livelihood opportunities.

In the shorter term, strengthening disaster preparedness and food security on Ontong Java may be the most important response. This could be accomplished in a number of ways, including awareness campaigns, improved communication and transport, diversification of incomes, introduction of new crop varieties and promotion and enforcement of more sustainable natural resource management practices (Bayliss-Smith et al., 2010). Another pressing issue is the replanting of vegetation and trees along eroded coastlines, as well as better management of human waste disposal. Engineering solutions, including investments in artificial coastal protection are often associated with high costs and low efficiency, but insofar as 'sea walls' are requested they need to be carefully tested and focused only in strategic places (e.g. exposed buildings or village areas, taro gardens).

In *Bellona* the main challenge will be to adapt to an increased intensity of cyclones. The destruction caused by cyclones can be dealt with by efficient disaster relief, by improved cyclone early warning systems, and by constructing suitable cyclone shelters. Except for the latter, these activities are not local, and we will return to them in a later section. While rainfall may generally be expected to increase, the frequency and length of droughts may increase as well, and the water tank capacity of the rain water based fresh water supply may have to be increased, something which is already taking place. It may be argued that Bellona is already well integrated into the national economy; remittances and food imports into Bellona have reached a considerable scale, rendering the island community unsustainable as an isolated entity. Still, in terms of social structure, Bellona is characterized by a high social coherence. As mentioned, it is not as exposed and vulnerable to climate change as Ontong Java and Tikopia, and factors other than climate change are likely to play a decisive role for the development of the Bellonese society. A key issue is the development of its economic base. In the absence of such development, young people will increasingly migrate to Honiara and beyond, possibly leaving Bellona as a 'holiday island' for Bellonese (and others) living outside, and as a place to which elderly Bellonese retire. Thus, the adaptive capacity to climate change may not be the most critical issue.

In *Tikopia*, the great threat will be the expected increase in intensity of cyclones, in combination with the degradation of the coral reef. As described for Bellona, relatively little, apart from a possible improvement of emergency shelters, can be done locally. The southeast facing side of Tikopia, and in particular the Ravenga area, is most exposed, and it was certainly most affected by Zoe in 2002. From a purely rational point of view it may be suggested that relocation of people from Ravenga to a safer area could be a possibility. There are, however, many cultural obstacles to such relocation. It may be argued that the isolation of Tikopia makes it more vulnerable, and improving access by establishing regular ship service would thus serve as an adaptive measure. Tikopia's prospects of successfully adapting to climate change in the longer term may be seen as mainly a function of its future degree of isolation. Should its traditional isolation be maintained, and should livelihoods be worsened by increasing severity of cyclones and (possibly) degradation of the reef, it is likely that partial depopulation will take place, strengthening the already observable trend. If regular transport to/from Tikopia (e.g. with weekly or monthly connections) was to be established (as planned), this would greatly contribute to improving livelihoods (including improved access to health and educational services), developing the economy, including the potential for tourism, and increasing short-term migration. All this may be expected to increase adaptive capacity by allowing Tikopians to withstand the negative consequences of climate change. On the other hand, the high social coherence of present Tikopian society may well be challenged by greater exchange with the wider world and the diversification of the economic base. The fact that most Tikopians actually live in settlements in other parts of Solomon Islands, where they have reproduced the Tikopian social structure, offers special adaptive strategies, since it allows Tikopians to migrate to other islands without losing their Tikopian identity. The infrastructural requirements of adapting successfully to climate change in Tikopia itself (e.g. construction of improved emergency shelters) may well be overcome, provided that external resources are

available. Greater integration into the national state, associated with easier access, will also imply that emergency assistance will be more readily available, provided that the capacity, at national level, to respond to natural disasters is increased. Thus, it may be argued that in the case of Tikopia, the adaptive capacity is not so much a characteristic of Tikopian society, but rather mostly determined from outside the island.

Income, social organization and institutions have great significance for the capacity of local communities and households to adapt to climate change (Smit & Wandel, 2006; Vincent, 2007). For all three islands income generating activities are relatively few and insignificant, though Ontong Java experienced a boom in income from bêche-de-mer exploitation in the years 1985-2005 (Christensen, 2011). However, over-utilization of the resource caused a collapse and subsequently an export ban in 2005, reducing the income to zero. This left Ontong Java in the same situation as Tikopia and Bellona, both of which have very limited local income sources. In Bellona, interaction and exchange with Bellonese living in Honiara and elsewhere provides some income in the form of remittances, but otherwise options for developing new income generating activities are relatively few. Tourism is seen by some islanders as a way forward, yet it is hard to see the comparative advantage of Bellona as a tourist destination, and while Ontong Java may have more potential attractions, it is more difficult and expensive to get to. Tikopia also has potential, but its current isolation is an obstacle, apart from visits by cruise ships from Fiji which are already taking place. On all islands, the reef is a major asset, and the threats to the health of coral reefs, mentioned above, are therefore a possible threat to incomes and adaptive capacity as well.

Most climate change related impacts are likely to affect the poor more than the wealthy and redistribution of food and other assets will be required in order to avoid short- and long-term destabilization of local communities. Systems of redistribution of food and other goods, as well as community-level organization of reconstruction of houses and other infrastructure, following extreme weather events and/or droughts, are known to exist in many societies. On the islands studied, such mechanisms are reported both for Bellona in the 1960s (Christiansen, 1975), for Ontong Java in the 1970s and 1980s (Bayliss-Smith, 1988), and for Tikopia in the 1930-1960s (Firth, 1939, 1959, 1961). These mechanisms are observed still to be in function on all three islands, and they are frequently mentioned by the islanders themselves as a means of coping with the consequences of cyclones. They are part of the local self-image and discourse, and the solidarity and will to share are seen by the islanders as a part of the 'Polynesian heritage'. The efficiency has not been 'measured', however, in cases of long-term stresses, such as those associated with climate change. The exchange may take place among neighbors, among family members, clan members and church communities, or at island level. While the discourse is often associated with the island level, both the historical accounts and our own observations and interviews point to the importance of neighborhood, family, clans and churches.

The three islands differ considerably in terms of social organization: While traditional institutions, based on clans/chiefdoms, have great impact on daily life in Tikopia, they tend to be less important in Ontong Java (Bayliss-Smith et al., 2010), and particularly in Bellona. This may well be a matter of traditional institutions losing importance as economic exchange with the wider world increases, and as new institutions for natural resource management are imposed by the government, as they have been since colonial times. Little concrete evidence is available, yet it may be hypothesized that with weaker central institutions, within-island and within-clan exchange relations become weaker as well, and this may have a negative impact on the ability to cope with extreme events and adapt to climate change. However, in the case of Ontong Java, Bayliss-Smith et al. (2010) describe that traditional institutions may regain power when the national government fails, implying that the erosion of traditional institutions may not be irreversible.

If these hypotheses hold, it should be noted that we have two trends with opposite implications for long-term adaptation: Greater integration into a wider economy may have positive effects on adaptive capacity, yet the weakening of local social institutions, which can be associated with this integration, may have negative impacts. How these two trends balance is difficult to foresee, yet one certain consequence is that greater social inequality will result, leaving parts of the population with less adaptive capacity and higher vulnerability to climate change and (increased) variability.

Migration, seen as a possible adaptation strategy, deserves special mentioning. Individuals on the three islands are characterized by high mobility at a range of spatial and temporal scales, and households are often divided. While climate change, and in particular the perceived increase in cyclone frequency and strength, is sometimes referred to as a possible reason for migrating from Tikopia, other factors, not least access to public services (health care and secondary schools) and economic opportunities, have played a

greater role in the past. It is quite possible, however, that relocation can become a necessity for atoll societies in the longer term, as also stated in the citation above.

Impacts of regional and national level adaptation on the islands

Climate change adaptation in Bellona, Ontong Java and Tikopia has to be seen against the background of a region that is already experiencing climate variability and extreme weather events such as extreme rainfall tropical cyclones. The pressures from other non-climatic events and stresses such as tsunamis, an unstable political climate, and open and receding economies call for holistic adaptation strategies seeking to achieve sustainable development. This requires mainstreaming of climate change adaptation in development planning. Mainstreaming of climate change adaptation into governance and decision-making is one of the underlying principles of the newly endorsed Pacific Islands Framework for Action on Climate Change (PIFCC) 2006-2015 (Pacific Regional Environment Programme, 2005). The PIFCC is also part of the wider Pacific Plan which is the overarching regional plan signed by Pacific Island leaders to enhance and stimulate economic growth, sustainable development, good governance and security for Pacific countries through regionalism. However, the mainstreaming of climate change adaptation at the national development planning level may cause a loss of focus on the specific nature and significance of climate change impacts, not least with respect to its longer time horizon than most other development issues.

The articulation and implementation of these regional plans within national development plans remains a challenge for various reasons directly linked to the pervasive weak adaptive capacity throughout the Pacific region. Preplanned and proactive adaptation to climate change still appears to be a 'side-line' issue for most Pacific Island Countries (Nunn, 2009; Barnett & Campbell, 2010). This is reflected in the limited direct national budgetary allocations for climate change activities apart from project funds from development donors and the Global Environment Facility (GEF). Even national fund allocations under GEF are under-utilized by Pacific Island countries including Solomon Islands. However, the under-utilization of GEF funds is also linked to the limited capacity of local governmental and academic institutions for large project development, adaptation planning and implementation. Further it is reflected in the problems of meeting national obligations under the United Nations Framework Convention on Climate Change (UNFCCC), such as the production of a National Adaptation Programmes of Action (NAPA) and National Communications.

A recently initiated pilot-study program including 13 Pacific countries has some potential in setting up guidelines for national policies on climate change adaptation. The programme 'Pacific Adaptation to Climate Change' (PACC) is scheduled to run for five years, and received a good portion of the budget from the Global Environment Facility's Special Climate Change Fund (SCCF). In each country pilot studies combining top-down and bottom-up assessments, will test the ability of government appointed country teams to integrate specific local needs in the development of national policy frameworks. In Solomon Islands, the low-lying islands, and particularly Ontong Java, have been chosen as anchor destinations for a study of how to increase food security in remote islands and communities (SPREP, 2007). PACC will in most country cases be the first step towards meeting adaptation needs as identified by each of the countries in their NAPAs. In mid-2010, the PACC programme was still in its initial phase and adaptation measures had not yet been identified.

Apart from food security, Solomon Islands NAPA identifies relocation as a potential adaptation measure for low-lying islands such as Ontong Java and suggests this to be: *"... one of the few practical options (if not the only one) for adaptation to climate change ..."* in these places (MECM, 2008: 86). However, it remains unclear whether this observation has been shared with or is shared by communities in Ontong Java, as they were not consulted as part of the NAPA preparation process. Apart from relocation, the NAPA lists a broad range of policy sectors where adaptation is urgently needed (see Table 1). Several project proposals are currently under review by the GEF implementing agency (UNDP) in close collaboration with the national Climate Change Division (CCD) and relevant ministries.

The great inter-island differences observed in this study imply that the first step towards building adaptive capacity at all levels from the national to the household is to build national capacity for analysis and diagnosis. This is a prerequisite for both proper political action and planning and initiating local level adaptation activities. The national capacity should be anchored in research into problems as they appear from an island perspective.

At the national level, it is evident that climate change needs to be mainstreamed in a range of national policies as recommended for many other countries (Halsnæs & Trærup, 2009). All economic and physical planning should take probable climate change scenarios into account. Many

Table 1: *Summary of national adaptation priorities and estimated budget. The table is adopted from the Solomon Islands National Adaptation Programmes of Action (MECM, 2008).*

Priority	Priority Adaptation Activity	Budget (USD)
1	Agriculture and Food Security, Water and Sanitation, Human Settlements and Human Health, Education Awareness and Information	6,500,000.00
2	Low-lying and artificially built-up Islands	3,500,000.00
3	Waste Management	1,500,000.00
4	Coastal Protection	1,750,000.00
5	Fisheries and Marine Resources	1,500,000.00
6	Infrastructure Development	2,000,000.00
7	Tourism	500,000.00
Total		17,250,000.00

of the adaptation strategies at national level are likely to overlap or coincide with strategies to obtain other desirable objectives. The main divergence is likely to be a matter of time horizons and uncertainty: Many climate change effects, such as the threats to coral reef health, are still scientifically uncertain, and they may only be relevant at time scales of several decades or even centuries. Persuading a government to take changes with such time scales into account is not necessarily easy, given the many other challenges facing Solomon Islands government. International support, both in terms of expertise and funding, is required to achieve this. This points in the direction of long-term investments in capacity development with impact on the awareness of the importance of climate change.

It deserves special mention that the three islands studied here are atypical for Solomon Islands because they are culturally Polynesian, whereas Solomon Islands are predominantly Melanesian. Whether this has or will have any impact on the role the national government will play in taking the needs and interests of the island populations into account in national climate change adaptation strategies and actions is hard to judge at this stage, but it may contribute to marginalizing the islands even more than their isolated locations imply.

One important field where national and regional initiatives have been taken, and where success has been achieved is within early warning of cyclones (as well as tsunamis). Solomon Islands are served by the early warning centres in Fiji and in Australia, and warnings from these centres are widely used at both national level, where they form the basis of the activities of the Meteorological Service of Solomon Islands, and at island level. Even the most remote islands, such as Tikopia, receive and react to these warnings. Strengthening the predictive capacity, the dissemination of warnings, as well as local preparedness is likely to have positive impacts, since it increases the time available to take protective measures and thus has the potential to reduce loss of life and material damage. Also, further advances in observation and regional modeling of climate change are required. This will reduce the uncertainties in climate prediction, and thus make it easier to obtain consensus to act.

Conclusions

The results presented and discussed above indicate that assessing 'adaptive capacity' of island communities in a consistent manner is a difficult task: Past experiences in coping with extreme events, current perceptions of future climate change and associated adaptation strategies, along with analysis of the exposure and sensitivity of the production systems (or 'economic base') may give some indications, yet the climate change scenarios describe challenges which may threaten island communities far more than previously experienced.

Often, Polynesian island communities are seen as characterized by a social organization assuring a high adaptive capacity, not least due to its emphasis on solidarity, sharing and redistribution. While this has also been observed, with Tikopia as the clearest example, it is not evident that this will suffice in the future. The traditional social

structure may not be able to cope with the consequences of future climate change, and not the least the more extreme events which are likely to occur. Also many tendencies point towards an erosion of traditional social structures. It is unclear to what extent the increase in importance of social structures, including the 'modern' political system and possibly the churches, will contribute to 'adaptive capacity'. Likewise, it is uncertain whether the increasing monetarization of the island economies, presently particularly visible in Ontong Java, will lead to the erosion of redistributive mechanisms, and thus undermine adaptive capacity, or whether the positive effects of a more diversified economic base will actually increase adaptive capacity.

On all three of the islands studied, the role of the wider world in providing security and 'adaptive capacity' in relation to climate change and increased severity of extreme weather events is observed to be great. While in Ontong Java the economic dependence on the production and export of marine resources is extreme, its use is controlled by the government. In Tikopia, the government also partly controls transport, which is the bottleneck for economic development and food security. In Bellona income earned outside the island is of key importance, both for the economy and the food security. Thus, in the short-to-medium term livelihoods are to a great extent influenced by national authorities on all three islands. If concrete adaptive measures are to be taken, funds are likely to come from international sources through national institutions. As noted by Barnett (2008), the effects of aid on Pacific countries' adaptive capacity can be mixed, since it assists with finances but often has negative impacts on governance. In the case of Solomon Islands, different types of 'top-down' rural development funding have generally been associated with high transaction costs and lack of transparency. In the longer term, reliance on outside assistance, be it at national or international level, is likely to increase further, not least in the case of Ontong Java.

While the climate change scenario presented above focuses on the expected gradual changes in variables such as temperature, rainfall, wind speeds, sea level and ocean acidity, most of the perceived impacts of climate change will be associated with extreme weather, be it tropical cyclones (or storms in the case of Ontong Java) or prolonged drought periods. The effects of 'slow processes' of sea-level rise and possible reef degradation may be partly gradual, e.g. seen as increasing erosion, but it will also worsen the effects of cyclones and storms, as well as non-climatic events, such as tsunamis.

It is therefore worthwhile considering adaptive capacity in the context of 'disaster preparedness', which is already a major issue in the Pacific region (Gero et al., 2011). Also in concrete terms, many actions which may be taken to improve disaster preparedness may be considered equally relevant and beneficial in a climate change adaptation context. For example, early warning systems, for cyclones as well as tsunamis, may serve both purposes, as may infrastructure for faster provision of food relief.

The main findings may be summarized as follows:

- Due to differences in bio-physical, economic and social characteristics of the islands studied, both short-, medium- and long-term prospects for climate change, impacts and adaptation vary widely. While for Ontong Java there is a risk that the islands will become uninhabitable in the medium to long term, Bellona will be much less affected, and prospects for Tikopia depend to a great extent on non-climatic factors.
- Different elements of climate change will determine the prospects for each of the islands. Ontong Java will mostly be affected by sea-level rise and coral reef degradation, while Bellona and Tikopia will be more sensitive to changes in severity of tropical cyclones.
- On the one hand, traditional social structures greatly reduce vulnerability of island populations, yet these structures may be challenged and eroded by greater monetarization of island economies and greater exchange with the outside world.
- On the other hand, integration of the islands into a larger, national economy and diversification of the economic base of the islands may increase adaptive capacity.
- The limit of local adaptive capacity may be expected to be exceeded due to climate change, at least in the case of Ontong Java, and adaptation will to an increasing extent require the active participation of national and international institutions. This undermines the usefulness and predictive powers of the concepts of 'adaptive capacity' as a characteristic of island communities.
- Adaptation to climate change should be seen in association with the promotion of 'disaster preparedness', both because climate change may well manifest itself as more frequent or worse 'disasters', and because the measures to be taken towards climate change and disasters may often overlap. An example may be improvement of cyclone early warning systems.

- Likewise, in order to increase the chances of successful implementation, local adaptation activities need to be mainstreamed with other development efforts.

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