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ORIGINAL ARTICLE

Obstacles to climate change adaptation decisions: a case study of sea-level rise and coastal protection measures in Kiribati

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Abstract International aid is increasingly focused on adaptation to climate change. At recent meetings of the parties to the United Nations Framework Convention on Climate Change, the developed world agreed to rapidly increase international assistance to help the developing world respond to the impacts of climate change. In this paper, we examine the decision-making challenges facing internationally supported climate change adaptation projects, using the example of efforts to implement coastal protection measures (e.g. sea walls, mangrove planting) in Kiribati. The central equatorial Pacific country is home to the Kiribati Adaptation Project, the first national-level climate change adaptation project supported by the World Bank. Drawing on interview and document research conducted over an 8-year period, we trace the forces influencing decisions about coastal protection measures, starting from the variability and uncertainty in climate change projections, through the trade-offs between different measures, to the social, political, and economic context in which decisions are finally made. We then discuss how sub-optimal adaptation measures may be implemented despite years of planning, consultation, and technical studies. This qualitative analysis of the real-world process of climate change adaptation reveals that embracing a culturally appropriate and short-term (~20 years) planning horizon, while not ignoring the longer-term future, may reduce the influence of scientific uncertainty on decisions and provide opportunities to learn from mistakes, reassess the science, and adjust suboptimal investments. The limiting element in this approach to adaptation is likely to be the availability of consistent, long-term financing.

Keywords Adaptation · Climate change financing · Sea-level rise · Coastal protection measures · Pacific Islands · Uncertainty · Kiribati

Introduction

The impact of human-caused climate change is expected to be greatest in developing nations, which have, in general, contributed the least to the rise in atmospheric greenhouse gas concentrations (Agarwal and Narain 1991; Adger et al. 2003). This is particularly the case with small island developing states (SIDS), where sea-level rise could threaten livelihoods and sovereignty, and the capacity to adapt is thought to be limited (Barnett and Adger 2003; Mimura et al. 2007; Hay 2013). Overcoming this inequality has been a central tenet of international climate policy since the signing of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. At the UNFCCC meetings in Copenhagen and Cancun, the developed world agreed to mobilize $100 billion per year by 2020 to assist the developing world in responding to climate change and created the Green Climate Fund to disburse some of this new climate financing (Donner et al. 2011).

Our understanding of the process and practice of climate change adaptation is, however, still in its infancy. Adaptation research and practice to date has focused more on technical or theoretical starting points, including establishing adaptation options, predicting future change and

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assessing vulnerability, than on the process of implementing adaptation measures (Smit and Wandel 2006). First, there has been extensive work defining different adaptation strategies and their potential application (Table 1). For example, some recent Pacific Islands assessments recommend “bottom-up” or community-based projects which provide communities with ownership of adaptation efforts (Barnett and Campbell 2010) and which may, at least in principle, avoid problems associated with government accountability, bureaucratic delays, and large resource-intensive projects (Burton et al. 2002; Allen 2006; Füssel 2007). Second, scientific funding and effort has been directed towards downscaling coarse climate projections to the local scale and on characterizing uncertainty. Third, researchers and aid programs are increasingly conducting technical assessments (e.g. Duvat 2013) and community consultations (e.g. Kay 2008) to identify specific areas of concern and vulnerability.

This foundational research can directly inform adaptation decisions but often it does not, nor is it intended to, capture the social, political, and economic context in which those decisions are made. Understanding the latter is particularly important for SIDS in the Pacific, which face the dual challenge of making decisions with long-term consequences while also building the institutional capacity—often using international assistance—to implement those decisions (Nunn 2009). Many researchers have proposed that successful adaptation is not precluded by the uncertainty inherent to future prediction (Hallegatte 2009; Dessai et al. 2009), in part because good governance facilitated by adaptation projects and flexible measures can overcome uncertainty (Tompkins and Adger 2005; Adger et al. 2005). This ideal could be difficult to achieve in reality if there are social, political or economic trade-offs to such flexible measures.

The objective of this paper is to provide real-world context on the decision-making challenges facing aid-funded climate change adaptation projects, using a case study of sea-level rise and coastal protection measures in Kiribati. The central equatorial Pacific country (Fig. 1) is home to the Kiribati Adaptation Project (KAP), the first climate change adaptation project administered by the World Bank. Since the World Bank is the trustee of the new Green Climate Fund, the KAP experience may provide useful lessons to other countries pursuing

Table 1 Common proposed climate change adaptation strategies

Strategy	Primary benefits	Common application	Literature examples
Anticipatory decision making	Greater capacity to be deliberate and, therefore, coordinated and equitable	Large infrastructure investments (e.g. coastal protection)	Fankhauser et al. (1999), Barnett (2001)
Mainstreaming	Enables the processes of development, adaptation, and disaster risk planning to proceed together	Development of institutions, policies, and management plans	Huq and Reid (2004), Smit and Wandel (2006)
No regrets, or “win–win”	Stresses co-benefits of adaptation measures; politically expedient	Public services (e.g. water treatment sewage) and ecosystem conservation	Barnett (2001), Heltberg et al. (2009)
Community-based	Draw upon local knowledge, experience, and resources	Small-scale projects (e.g. marine protected area creation, mangrove planting)	Burton et al. (2002), Allen (2006)
Manage for resilience	Learn from past mistake and increase ability to absorb shocks	Similar to above	Folke (2006), Eakin and Wehbe (2009)

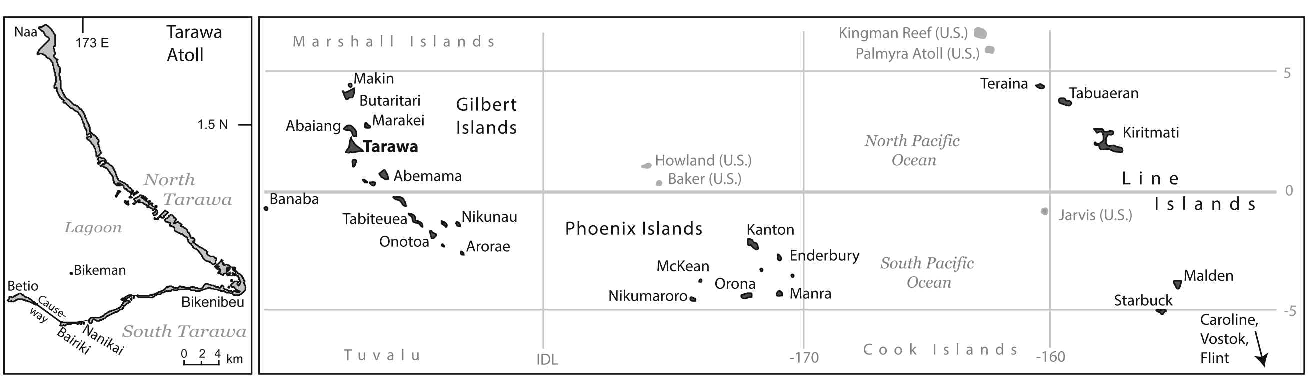

Fig. 1 Map of Kiribati and Tarawa Atoll, showing key locations and features mentioned in this article

adaptation goals via international support (Webber 2013). We draw upon qualitative field and document research to trace the forces influencing decisions about coastal protection measures (e.g. sea walls, mangrove planting), from the climate change projections (Sect. 4), to the trade-offs between different adaptation options (Sect. 5) to the governance of aid projects (Sect. 6). We then discuss how a sub-optimal adaptation measure, in this case, a series of technically flawed sea walls, can be constructed despite years of planning, consultation and technical analysis (Sect. 7). This qualitative research reveals several key themes not evident in the available technical and theoretical literature, including the value of embracing multiple, even contradictory, adaptation strategies and a rolling short-term planning horizon, to learn from mistakes, adjust suboptimal investments, and prepare for the range of possible futures.

Study design

This study draws upon field research in the Gilbert Islands of Kiribati conducted over an 8-year period in conjunction with coastal monitoring activities (Donner et al. 2010) and a review of academic literature and documentation from adaptation projects. Research visits were conducted in 2005 (4 weeks, S. Donner), 2009 (6 weeks, S. Donner) and 2010 (8 weeks, S. Donner and S. Webber), 2012 (4 weeks, S. Donner), and 2013 (4 weeks, S. Webber) to five atolls (Tarawa, Abaiang, Butaritari, Abemema, Marakei) in the Gilbert Islands. Long semi-structured interviews were conducted with staff from the Office of *Te Beretitenti* (the President), five different ministries, religious leaders, village leaders and elders, representatives of non-governmental organizations, consultants to international adaptation projects and representatives of donor agencies. Research subjects were identified via a "snowballing" strategy after initial contact with the Ministry of Fisheries and Marine Resource Development and the KAP. Interview transcripts and adaptation-related documents were analyzed for key themes influencing climate change adaptation projects and decisions. Specific interviews and documents are cited where relevant; interview subjects are listed by job description to preserve anonymity.

For Sect. 4, tide gauge data for Betio, Tarawa from 1993 to 2012 were collected from the Australian Tidal Facility (ATF), which installed a new gauge in December, 1992. Additional data from earlier gauges back to 1984, for which continuous records were available, were also collected from the University of Hawaii Sea Level Center archives (UHSLC; http://ilikai.soest.hawaii.edu/uhslc) and corrected for the change in datum.

Republic of Kiribati

The following section introduces the physical and human geography of Kiribati and the recent internationally financed adaptation projects.

Physical geography

Kiribati comprises 32 coral atolls and reef islands, as well as the raised limestone island Banaba, stretched across 3.5 million km^2 near the intersection of the Equator and the International Dateline (Fig. 1). It has a land area of 726 km^2, over half of which is found in Kiritimati Atoll in the Line Islands. There is no comprehensive topographical data for Kiribati, but available studies of atolls in the Gilbert Islands and neighboring Tuvalu suggest that two-thirds of the land is less than 2 m above mean sea level and that maximum elevations are roughly 3 m except in cases of sand dune accretion (Woodroffe 2008). The atolls like Tarawa (Fig. 1) consist of an outer rim of multiple narrow (<500 m) islets surrounding a lagoon. The typical atoll islet features a shallow lagoon-ward slope, an ocean-ward ridge that reaches 2–4 m above mean sea level, and a reef flat of varying widths. The few available topographical analyses suggest there can be substantial variability in the profile of islets within Tarawa (Duvat 2013) and other Gilbert Islands atolls (Woodroffe 2008). On islets of sufficient width (>300 m), rainfall percolating through the thin soil and limestone forms a "Ghyben-Herzberg" or freshwater lens that floats atop salt water (Fig. 2). Since the depth of the transition zone between fresh and salt water fluctuates with the tides and sea level, salinization of the freshwater lens pose an important threat to the i-Kiribati (the term for Kiribati nationals) (Kuruppu and Liverman 2011).

Human geography

Kiribati is home to 103,058 people according to the most recent census, of whom 91 % live in the Gilbert Islands chain and 48 % live in South Tarawa (Government of Kiribati (GOK) 2012). It is one of the poorest countries in the Pacific, with a gross national income of less than $2000 per capita (World Bank 2011a). Roughly half of the economy is supported by foreign sources, including foreign tuna fishing licenses, investment income from a phosphate reserve fund, international aid, and remittances (ADB 2008; GOK 2012). Since independence, population pressure and the demands of the cash economy spurred migration to more urbanized South Tarawa, where people are less likely to engage in subsistence activities, reside in homes built from traditional materials, and rely on traditional foods (Table 2). Crowded conditions, water

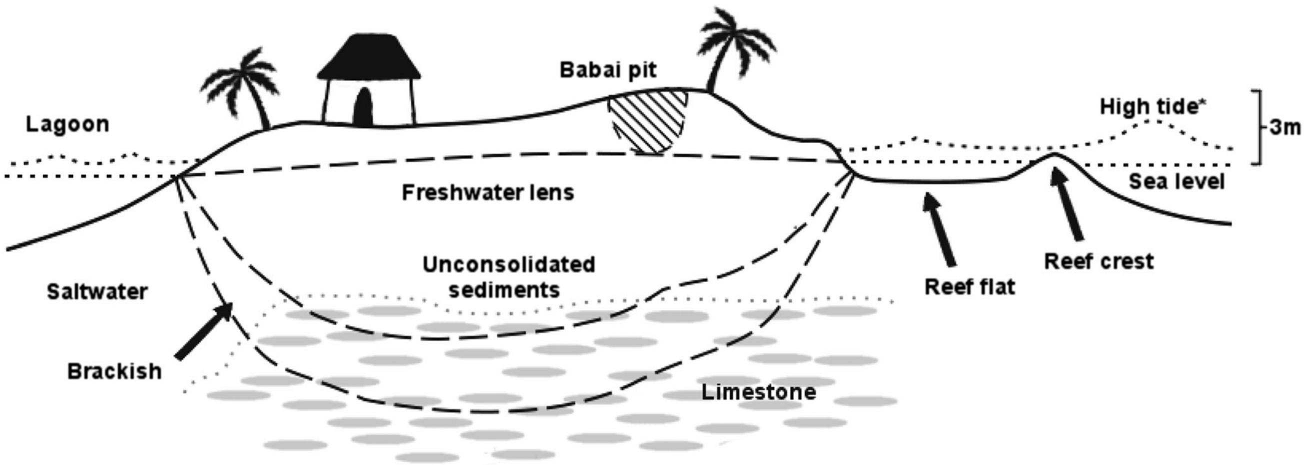

Fig. 2 Profile of a typical Kiribati atoll islet (not to scale)

Table 2 Selected household statistics from 2010 Kiribati census

	Construction materials			Source of income			Flush toilet	Access to *Babai*
	Permanent	Local	Both	Wages	Product Sale	Remittances		
Total (%)	28	48	21	50	39	31	49	50
South Tarawa (%)	51	15	32	72	26	34	65	7
Rest of country (%)	12	70	14	35	49	29	37	82

pollution, and the changing diet have contributed to declines in public health and life expectancy (GOK 2007a, b; Storey and Hunter 2010). Settlements in South Tarawa now extend beyond the traditional and relatively protected locations behind beach ridges and in the center of islets (Fig. 2) to flood-prone stretches of shoreline, former *babai* (swamp taro) swamps, and reclaimed land. Duvat et al. (2013) describe heightened population, land, and building exposure to coastal erosion and flooding in South Tarawa's Eita–Bangantebure due to reclamation of swampland and shoreline construction to accommodate a roughly sixfold increase in population since 1969.

Efforts to slow national population growth, internal migration to South Tarawa, and the environmental and human impacts of this demographic pressure have largely been unsuccessful (Jones and Lea 2007; ADB 2008; Storey and Hunter 2010). Past policies to ease population pressure in Tarawa include encouraging migration to the historically uninhabited atolls in the Line Islands, with an initial goal of increasing the population of Kiritimati Atoll to 25,000 people by 2025 (GOK 2005). The population of Kiritimati and the Line Islands reached 5586 and 9236 people, respectively, by 2010, but resettlement programs, including a New Zealand Aid program to build infrastructure, have either been cancelled or lost support and momentum (Storey and Hunter 2010). Since existing and proposed international resettlement programs do not keep pace with population growth, the population of Kiribati could reach 137,500–141,350 by the year 2030 (Bedford and Bedford 2011). Even in the most extreme and unlikely future emigration scenario proposed in the literature, Kiribati's population in 2030 would still be over 82,000 people, equivalent to that of the early 2000s (Bedford and Bedford 2011).

Adaptation programs

In the past 15 years, part of the focus of international aid to Kiribati has shifted towards climate change adaptation (Webber 2013). The KAP began in 2003 under the direction of the World Bank using Global Environment Facility and donor funds (World Bank 2006). The KAP is commonly described by the World Bank as a "demonstration project" (e.g. World Bank 2011b); one consultant present for the start of the KAP who was interviewed for this study described the World Bank's decision on where to situate the project as "they spun the globe" and chose the most "vulnerable" country. After an initial phase of consultations, mainstreaming and project development, the US$8.7 million Phase II of the KAP focused on the development of pilot projects in several sectors and implementation of adaptation policies (World Bank 2009b, 2011b). Phase II underwent restructuring in 2009 after which focus was narrowed to freshwater systems and coastal planning and protection. It concluded in 2011 having reportedly met pilot implementation goals (World Bank 2009b, 2011b). A US$10.8 million third phase of KAP continuing the narrower subject focus began recently (World Bank 2011c). The UN Development Program's National Adaptation Plan of Action (NAPA) for Kiribati (GOK 2007b) and other bilateral adaptation-related projects have been integrated with KAP activities (GOK 2007a; ADB 2008), and report directly to a centralized climate change planning office within the Office of *Te Berenteiti* (World Bank 2011c).

Projected sea-level rise, from global to local

This section draws upon sea-level data, scientific literature and adaptation reports to introduce the challenges involved in interpreting sea-level rise projections for local use. Focus is placed on the sources of uncertainty and variability at different scales to highlight issues for decision makers in Kiribati, which are then analyzed in subsequent sections.

Global mean sea-level projections

The evolving nature and range of future sea-level rise projections pose a dilemma for developing local sea-level rise projections (Fig. 3). The contribution from the major ice sheets to future sea-level rise is uncertain primarily because of dynamical ice sheet processes (Meehl et al. 2007). The projected mean global sea-level rise of 18–59 cm by 2100 in the 2007 IPCC Fourth Assessment ("AR4") was considered at the time to be an underestimate because of the exclusion of such ice sheet processes (Nicholls and Cazenave 2010). Post-AR4 attempts to extrapolate future sea-level rise using semi-empirical models led to estimates of up to 2 m sea-level rise by 2100. The recent Fifth IPCC Assessment ("AR5") reported a likely range of 0.52–0.98 m sea-level rise by 2100 in the RCP8.5 scenario (Church et al. 2013), the scenario which most closely matches the current greenhouse gas emissions trajectory.

These differences suggest policymakers may need to regularly reassess the scientific literature. For example, the estimated sea-level rise by 2100 in Kiribati's initial National Climate Change Adaptation Strategy was based on model results from the IPCC's Third Assessment Report. Subsequent analyses conducted for the KAP employed higher estimates of the minimum sea-level rise for 2100 to reflect more recent findings and urge precaution in long-term adaptation planning (Hay 2006; Ramsay et al. 2008). The minimum anticipated sea-level rise by 2100 in the 2008 KAP Climate Risk Report is 36 cm higher than that in the initial adaptation strategy and 23 cm higher than that employed in a related Tarawa case study (Ramsay et al. 2008). Despite the precautionary approach in the more recent reports, the upper estimate of sea level by 2100 is lower than that in the recent IPCC assessment and less than half that of the semi-empirical models (Fig. 3).

Regional variability in sea level rise

The regional influences on sea-level and rates of sea-level change add a further layer of complexity and uncertainty to

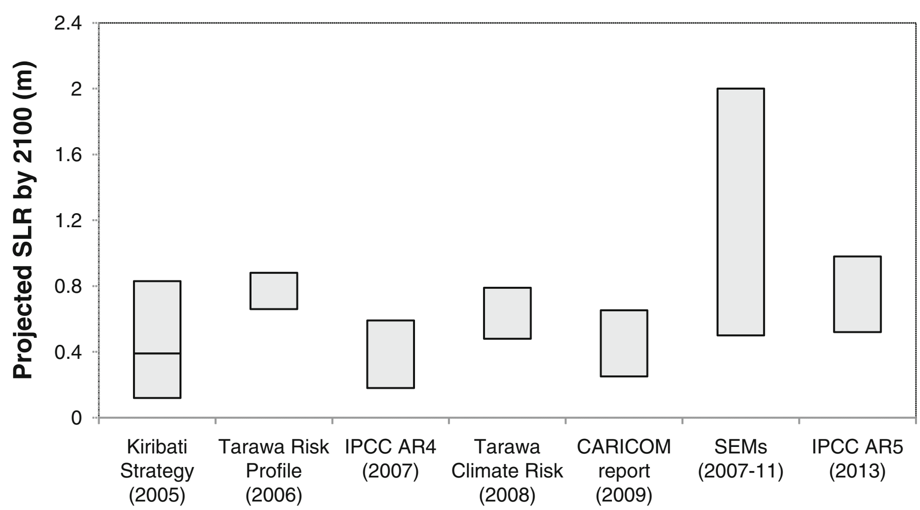

Fig. 3 Range of projected sea-level rise for 2100 from various studies. Sources from left to right: Kiribati official climate change adaptation strategy, including a minimum, median and maximum estimate (GOK 2005, 2007a, b); Hay (2006); the 2007 IPCC report (Meehl et al. 2007); Ramsay et al. (2008) completed for the KAP; Simpson et al. (2009); Semi-empirical model range from Pfeffer et al. (2008), Horton et al. (2008), Vermeer and Rahmstorf (2009), Grinsted et al. (2010), Jevrejeva et al. (2010), 2013 IPCC Report (Church et al. 2013)

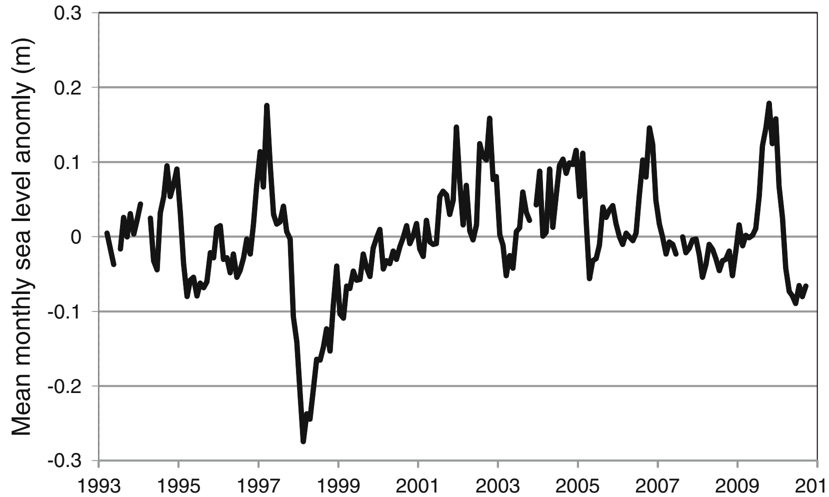

Fig. 4 Monthly mean sea level at Betio in South Tarawa, from the Australian Tidal Facility gauge installed in 1992

local sea-level rise projections and adaptation planning. The rate of future sea-level rise will vary regionally because of ocean dynamics, gravitational effects of ice sheet melt, and land subsidence (Church et al. 2013). Models employed in AR5 project that sea-level rise in the central equatorial Pacific by the end of the century will be equal to or exceed the global mean. Of particular concern to Kiribati is the annual variability in sea level and decadal variability in rates of sea-level change driven by the El Niño/Southern Oscillation (ENSO) and other large-scale climate oscillations (Becker et al. 2012). During El Niño events, reversal of the equatorial trade winds and the South Equatorial Current raises the sea level in the central and western Equatorial Pacific. The ENSO cycle drives the large inter-annual variability in sea-level data from the ATF gauge in Betio, Tarawa (Fig. 4); the standard deviation of the de-trended annual tide gauge data from 1993 through 2012 is 45 mm. Over longer time scales, the rate of sea-level rise in Kiribati is influenced by the Pacific Decadal Oscillation (PDO) or Interdecadal Pacific Oscillation, which modulates ENSO (Merrifield et al. 2012). For example, although the overall rate of sea-level rise at Tarawa since 1950 (2.2 mm/year, to 2009) has exceeded the global trend overall (1.8 mm/year), that pattern is reversed over the past 20 years (Becker et al. 2012). Stronger easterly trade winds associated with a negative phase of the PDO have led to this short-term slowing of the rate of sea-level rise in the central and eastern Pacific (Merrifield et al. 2012).

This ENSO driven-variability influences shorelines and freshwater lenses across Kiribati. El Niño events cause not only higher sea levels in Kiribati but also more westerly storms, which can drive waves into the lagoons and exacerbate erosion and flooding (Howorth 1983; Solomon and Forbes 1999). For example, the highest tide gauge recordings in Betio occurred during two storms at the peak of a Central Pacific El Niño event in February 2005. Waves scoured beaches, exposed underlying reef platforms, damaged homes and public infrastructure and drew international attention (Donner 2012). Conversely, during La Niña events, droughts can lead to failure of rainwater tanks and salinization of freshwater lens on smaller islands (White et al. 2007; White 2010). The episodic nature of El Niño and La Niña events, and the decadal-scale variability in their frequency, impedes detection of long-term trends in shorelines and water tables and attribution of those trends to climate change (Donner 2012). For example, although there is a significant increase in extreme water levels according to Betio gauge data since 1984 ($p = 0.01$, for >2.8 m above datum, respectively), the trend is driven partly by the decadal variability in the frequency of the high sea level "Central Pacific" El Niño events.

Given this natural variability, the range of possible annual and decadal sea-level in Kiribati may be substantially greater than that implied by regional or global climate projections averaged for some future decade. The variability in sea-level in the central equatorial Pacific is projected to increase by a further 20–40 mm by the end of the century due to the evolution of ENSO dynamics and other factors (Figure 13.15 in Church et al. 2013). Even without this projected increase, adaptation decision-makers may need to consider a wider distribution of sea-level futures than that implied by models mentioned in Sect. 4.1.

Local variability in sea-level and shoreline change

Spatial variability in sediment dynamics, human modification of shorelines and reef growth will influence how different islets and atolls in Kiribati respond to the sea-level rise projections described above. First, atoll islets themselves are potentially mobile as they are composed of consolidated sand and rubble and have been shaped over time by prevailing winds and waves (Solomon and Forbes 1999). On the lagoon side, sediment eroded from shorelines is generally deposited elsewhere in the lagoon (Cowell and Kench 2001). On the ocean side, the existence of a prominent ridge (Fig. 2) suggests periods of past growth and sediment accretion, rather than erosion (Woodroffe 2008). Second, shorelines in Kiribati have evolved due to direct and inadvertent human modification, including land reclamation, construction of causeways linking islets and construction of protective structures like seawalls (Donner 2012; Biribo and Woodroffe 2013; Duvat et al. 2013). As such, human modification and ENSO dynamics mentioned above may be exerting more control over Kiribati shorelines than sea-level rise in recent years (Webb and Kench 2010; Rankey 2011; Donner 2012; Biribo and Woodroffe 2013). Third, coastal erosion and wave run-up may be sensitive to the complexity and height of the reef crest, which may decline in Kiribati because of coral bleaching and a shift to more homogeneous 'weedy' coral species (Donner et al. 2010). The traditional practice of constructing sea walls and fish traps using sediment and coral rock mined from the lagoon has contributed to flooding and coastal erosion in populated parts of Kiribati (Webb 2005; Duvat 2013).

In setting adaptation priorities within Kiribati, or within a given atoll, policymakers must consider whether these local factors exacerbate or mitigate the impact of sea-level rise on coastal erosion, wave run-up and other concerns. Given the dynamic nature of these factors and the episodic nature of ENSO, the locations of concern and the suitable adaptation options in those locations can change over time. This may be an issue, for example, in South Tarawa where Bairiki, Nanikai and other populated islets expanded in area over recent decades due to land reclamation and causeway construction redirecting sediment flow (Webb and Kench 2010; Donner 2012; Biribo and Woodroffe 2013). This areal expansion, not to be confused with vertical growth, altered the shape of islets, their interaction with alongshore currents and the balance of erosion and accretion. Though it is possible that local sediment dynamics makes some islets naturally resilient to sea-level change (Webb and Kench 2010), the human interventions that drove this observed accretion in South Tarawa tend to eventually remove sediment and inhibit such natural resilience (Biribo and Woodroffe 2013). These islet changes show that even with perfect knowledge of regional sea-level variability and global sea-level projections, local assessments of shoreline sensitivity to sea-level rise may need to be repeated periodically.

Adaptation decision-making given scientific uncertainty

In the section, we examine whether the variability and uncertainty in sea-level projections may influence adaptation decisions. We introduce the range of coastal protection options, examine observed trade-offs between those options in Kiribati, and describe areas of potentially successful compromise based on document research and interview data.

Options for coastal adaptation

Measures against coastal erosion and inundation can be divided into three categories—(i) "hard" protection measures, (ii) "soft" accommodation measures, and (iii) retreat or migration (Table 3). First, hard measures, which include land reclamation and engineered physical barriers like sea walls, can be well suited to immediately protect coastal assets from inundation and protect from land loss during high water events. The most popular hard measures in Kiribati are sea walls, normally built from coral rock, sand bags and concrete blocks; sea walls consisted of 95 % of the engineered coastal structures in four South Tarawa islets (Duvat 2013). Sea walls, however, are controversial in Kiribati and other Pacific Island countries, in part because of their adverse effects on beach erosion. Without any measures to reduce wave energy, like vegetation or engineered breakwaters, sea walls are known to exacerbate or, at minimum, displace beach erosion over time. On their own, sea walls also do not build land and thus may not explicitly protect against land loss from sea-level rise. Additionally, successful implementation of hard measures like sea walls is challenging in SIDS, where institutions may not be capable of adequate planning, hydrodynamic analysis, maintenance, monitoring or sourcing of construction materials and capital (Barnett 2001). Nevertheless, the long history of constructing sea walls to protect from the sea, the lack of local understanding of the adverse effects, and the status associated with an expensive, modern sea wall protecting a village, church or *maneaba* (community house) means that sea walls are often a default or preferred adaptation option both to i-Kiribati and to the institutions providing financing.

Inadequate sea wall construction and design is, therefore, a chronic problem throughout Kiribati and the Pacific Islands (Nunn 2009). Increasing settlement in vulnerable stretches of the lagoonal shoreline, like sand spits, has led to a cycle of local reef rock and gravel mining for sea walls, overtopping and inundation, following by further gathering of local building materials and heightened vulnerability to flooding during high water (Webb 2005; Duvat 2013). Unlike the common local sea wall built at a steep angle from locally sourced coral rock and sand, project documents (Kench 2005; Juillerat 2012) and interviews with engineers who have acted as consultants in Kiribati suggest best practice should include (i) shallow slopes (33°–40°) with sufficient beach and vegetation to

Table 3 Common measures to protect against erosion and inundation

Category	Measure	Applicability	Cost	Limitations
"Hard" (protection)	Seawalls	Erosion and inundation	High	Resource needs; slow to implement; may lead to beach loss; poor design leads to overtopping; ongoing maintenance
	Land reclamation/artificial islands	Erosion and inundation	High	Material needs; engineering demands; ongoing maintenance
	Breakwaters	Erosion	High	Resource needs; slow to implement; alters hydrodynamics
	Gabion baskets	Erosion and some inundation	Low to moderate	Prone to damage and overtopping; ongoing maintenance; not suitable in high energy environments
	Groynes	Erosion	Low to moderate	Displaces erosion; alters shoreline
"Soft" (accommodation)	Mangrove or grass planting	Erosion and some inundation	Low	Slow to implement (grow from saplings); not suitable in high-energy environments
	Beach nourishment	Erosion and inundation	Low	Limited lifetime; only suitable to beach environments; requires sediment source; ongoing maintenance
	Setbacks	Erosion and inundation	Variable	Difficult in populated or narrow, low-lying islands
	Reef conservation	Erosion; some inundation	Low	Reef sensitivity to climate change and ocean acidification
Migration	Local (island or atoll)	Avoids impacts	Moderate to high	Availability of unoccupied higher land; traditional land tenure systems
	Regional (country)	Avoids impacts	High	Availability of unoccupied higher land; distance and logistics
	International	Avoids impacts	High	Potential loss of culture, identity, land rights, power

Sources: Kench (2005), Nicholls et al. (2007), authors' observations

best dissipate wave energy, (ii) protective mesh to protect fill, (iii) adequate drainage and height above the maximum high tide to reduce overtopping and erosion behind the wall, and (iv) flank protection to capture, not lose, sediment.

Soft measures, including beach nourishment, reef restoration and mangrove planting are potential 'bottom-up' or 'no regrets' alternatives to more resource-intensive measures (Sovacool 2011). For example, mangrove restoration or planting is relatively inexpensive, can reduce erosion by stabilizing the sediment and modulating wave energy, and can also eventually also reduce flooding by building land through sediment accretion. Mangrove planting has, therefore, been encouraged in the outer atolls of Kiribati, where resources are more limited and lower population pressure means people tend to live setback from the shore (World Bank 2011b, c). There are, however, some 'hard' consequences to choosing only 'soft' measures like mangrove planting or restoration (Hallegatte 2009). Mangroves do not protect against erosion during the first years or decade or growth, are unsuitable to high energy environments like the open ocean shoreline, and could only reduce flooding in the longer term (Kench 2005; Nunn 2009). As such, in urban South Tarawa, adaptation planners sometimes recommend a combination of hard measures, to protect key assets from flooding and land loss, and soft measures, to protect against erosion including that indirectly caused by the hard measures (Juillerat 2012).

While the KAP is pursuing hard (sea walls) and soft (mangrove planting) measures to protect against sea-level rise, Kiribati government is also preparing for the possibility of large-scale international migration. The "Migration with Dignity" initiative looks to identify countries with aging populations where the relatively young i-Kiribati population can fill labor needs, provide skills and cultural training, and begin the transition through seasonal overseas work programs (Onorio 2013). Our interviews with religious and village leaders suggest there are a range of different views of migration among the i-Kiribati which would require thorough household surveys to properly assess. Community consultations conducted for the KAP indicate not only some willingness among the i-Kiribati to migrate, largely for economic reasons, but also a common sense of disappointment and sadness about eventually losing culture (Hogan 2008).

Trade-offs and “no regrets” decisions

Many authors recommend that decision-makers focus on flexible policies and “no-regret” measures which would improve living standards and reduce disaster risk regardless of the magnitude of climate change (Hallegatte 2009; Adger et al. 2005; Dessai et al. 2009). Good decision-making frameworks and flexible practices are sensible in Kiribati given the variability and possible irreducible uncertainty described in Sect. 4. The episodic nature of El Niño erosion and inundation events combined with the lack of expertise, data, and advance planning have already led to poorly designed coastal protection measures and uncoordinated activities (e.g. beach mining) which decrease resilience to sea-level rise (ADB 2008).

Phase II of the KAP emphasized what were considered “no regrets” measures in its choice of pilot projects. These include (i) development of a coastal zone management system, to aid in decisions; (ii) mangrove restoration on outer islands and parts of South Tarawa, generally viewed as a success in project documents and interviews with KAP management and government officials; and (iii) improvements to the water reticulation system in South Tarawa (not specifically addressed in this study), needed to address public health and sanitation issues (World Bank 2011b, c). Another concurrent “no regrets” measure, external to the KAP, is an ongoing €2.2 million European Union funded effort to reduce destructive beach mining by dredging construction material from the outer lagoon of Tarawa. Although many coastal geologists may not view a system that could lead to sea wall construction a “no regret” strategy, the adoption of the coastal zone management system and an associated “coastal calculator” were among the stated principle achievements of Phase II in official reports (World Bank 2011c). The management system provides a framework for selecting measures to “climate-proof” key public assets and villages based on a balance of economic, environmental, and cultural concerns (Kay 2008). The coastal calculator is a simple, spreadsheet-based model that allows trained users at the Ministry of Public Works and Utilities (MPWU) to predict future wave heights, volume of overtopping, and beach run-up under user-selected future climate scenarios (Ramsay et al. 2008; Ramsay 2010). Together, the tools provide precise information for setting development standards, evaluating construction proposals, and designing coastal protection measures. They also empower the government officials, rather than foreign consultants, to make decisions based on their choice of scenario and wave event.

Precision in climate prediction, however, is different from accuracy (Dessai and Hulme 2004). Model projections depend upon the choice of climate scenario, the suite of scenarios from which to choose, and the state of knowledge at the time the model was developed. In making infrastructure “climate-proof”, the precision of numerical models can provide false confidence. For example, the coastal calculator employs scenarios from the 2008 Climate Risk Report (Ramsay et al. 2008), where the most extreme scenario in the coastal calculator leads to a sea-level rise of 85 cm by 2100, less than half the maximum value published in post-AR4 studies (Fig. 3). The chosen reference height for coastal measures to be climate-proof given a maximum sea-level rise of 85 cm by 2100 and a 50-year event may be insufficient with the higher rates of sea-level rise in the AR5 and the semi-empirical models (Fig. 3) or with a change in El Niño frequency. Moreover, even if future sea-level was perfectly knowable, decision-makers must still make normative judgments about the reference height and/or the acceptable level of risk from flooding (e.g. protect for a 20-, 50- or 100-year event).

These judgments involve present-day tradeoffs which may have consequences a decade or more in the future. Although the selected reference height or future scenario can be regularly revisited, the initial selection may (i) affect near-term decisions between adaptation measures, which may have different up-front costs, maintenance costs, and expected lifetimes (Table 3), or (ii) lead to capital lock-in to substandard infrastructure. First, sound fiscal caution can lead to rejecting resource-intensive hard measures—and thus avoid making difficult choices about variables like the reference height—in favor of inexpensive and more generic community-based soft measures (Barnett and Campbell 2010). For example, according to a policy officer interviewed in 2013, the medium climate scenario was chosen in planning a sea wall constructed under KAPII because “by the time you go to the worst scenario, the more money you require”. Second, implementation of a hard measure, like a sea wall built to a prescribed height or with a particular design, can lead to capital lock-in to suboptimal infrastructure which will fail or require maintenance not financed in the original plan. As we will see in Sect. 7, the sea wall decisions made under KAPII may be considered by some a case of such maladaptation.

With a planning horizon on the decade-to-century scale, there may not always be clear “no regrets” choices. Decision-makers must weigh trade-offs between the short- and long-term costs, as well as the social and political value of different adaptation measures. Even if uncertainty about long-term sea-level rise was epistemic, delaying implementation of expensive adaptation measures (e.g. land reclamation) until further data are available risks near-term harm given the year-to-year ENSO variability in sea-level.

Time horizon of adaptation decisions

A culturally appropriate solution to the trade-offs created by variability and uncertainty may be found in the coastal calculator. The calculator allows users to choose the timeframe of expected protective measures: for the grandchildren *te tibu* (2012–2036), the great-grand-children *tibu-toru* (2036–2050) or the great-great-grand-children *tibu-mwamwanu* (2060–2084) (Ramsay 2010). A precautionary approach of adapting to the highest projected sea-level rise may not be prohibitively expensive if the measures are only designed for *te tibu*. The anticipated sea-level rise in Tarawa for the year 2025 in GOK planning assumptions is 3–10 cm. The AR5 projections and semi-empirical models suggest that the upper limit may need to be roughly twice the planning assumption (Sect. 3.1). With this short time horizon, increasing the sea-level planning assumption might not substantially affect the choice between adaptation measures. On a household level, many structures are renewed on a *te tibu* time scale since they are constructed by choice or out of necessity from local natural building materials (Table 2). If only a small fraction of the shoreline containing recognized key public assets like *maneabas*, churches, and other public facilities are protected for beyond *te tibu,* the scientific uncertainty about sea-level rise need not be a major limiting factor in many shoreline protection decisions. Thus, as in KAP II, resources could be directed towards mangrove planting and restoration on lagoon shorelines, improving the freshwater distribution system, and the investing in hard measures built following best practices (Sect. 5.1) to protect key public assets.

A multi-decadal planning horizon required for other assets and community planning may lead to the aforementioned trade-offs, given existing scientific uncertainty. The GOK assumption for 2050—the end of the *tibu-toru* period—is 6–26 cm sea-level rise, with a mean of 14 cm. In that case, there may be a difference between the measures chosen for adapting to the mean (14 cm), original maximum (26 cm), and a precautionary maximum sea-level rise reflecting more recent projections (e.g. 32 cm globally in AR5; Church et al. 2013) and/or ENSO variability. Planning for a precautionary maximum rise could, for example, involve land reclamation measures; redeveloping flood-prone South Tarawa villages to incorporate setbacks; migration to wider islets (with more freshwater) or those with greater protection and water infrastructure; and further investment in a migration strategy (Table 3). The longer the planning horizon, the more the uncertainty and variability in sea-level rise projections may influence adaptation decisions.

A compromise solution may be a rolling *te-tebu* planning horizon, allowing for gradual revision of policies and measures in response to observed sea-level rise and new scientific findings. While further investment in research may not reduce uncertainty in global climate predictions (Dessai et al. 2009), there are disciplines and regions for which additional research and model development could help constrain decision-making. For example, restricting analysis to climate models with highest ENSO skill could constrain predictions of the frequency of wave overtopping events in Tarawa. In addition, further effort to characterize local hydrodynamics, topography, susceptibility to flooding, and the effects of human shoreline manipulation could help guide near-term decision-making (Rankey 2011; Duvat 2013; Duvat et al. 2013). Although the output of models like the coastal calculator ultimately depend on assumptions about global mean sea-level rise, better characterization of local hydrodynamics could identify islets that will be *relatively* more prone to erosion and inundation.

One risk of a short-term planning horizon is a bias towards inexpensive measures which may be inadequate to combat the more existential decade-century scale threats from sea-level rise. Without concurrent long-term or *tibu-mwamwanu* planning, the more resource-intensive adaptation measures, like land reclamation and international migration, will be more challenging to implement. Thus while the KAP has targeted "no regrets" measures and "climate-proofing" key infrastructure, Kiribati President Anote Tong has spoken broadly about the "Migration with Dignity" initiative and a land purchase in Fiji. Though there is skepticism about these initiatives—officials from government ministries and adaptation programs interviewed about the KAP since 2009 expressed concerns that the high-profile public statements about migration would undermine efforts to raise international funds for the KAP—the uncertainty about the magnitude of sea-level rise past mid-century warrants investment in both in-country adaptation and international migration strategies.

Adaptation planning in an aid environment

Small developing nations, which generally lack resources or technical expertise, are heavily reliant on international aid for development and adaptation (Barnett and Adger 2003). Kiribati has increasingly attracted climate change aid due to the country's developing status, perceived vulnerability to the effects of climate change, and minimal contribution to the causes of climate change. The governance of aid projects and the general aid environment further influences climate change adaptation decisions in Kiribati. The KAP experience illustrates three problems commonly associated with international aid—(i) aid competition, (ii) pressure on local human resources, and (iii) changing money flows and priorities—which together can slow project implementation and compromise the goal of making optimal adaptation decisions.

First, aid competition or "competitive humanitarianism" (Stirrat 2006) can result in ineffective solutions and poor governance in small but high 'demand' countries. The challenge of coordinating multiple donor-driven projects and meeting foreign reporting requirements results in bureaucratic logjams, redundancy, and the appearance of corruption. For example, there have been nine different internationally funded reports on Tarawa's water supply problems since 1992, all of which assert the same basic points (White 2010). Different management structures for initial adaptation projects in Kiribati initially led to competition for resources and slow progress on project implementation (ADB 2008). Although these problems were assuaged by the creation of a cross-ministry climate change team under the direction of the Office of *Te Berenteiti*, the slow progress led to internal cynicism about the use of international funds and ability of local institutions to deliver results. Consultants and government policy officers (interviewed in 2007, 2009, 2010 and 2013) commonly responded to questions about the challenges of the KAP with concerns the locally unsuitable and "cumbersome" World Bank procedures, referred to as a "bureaucratic nightmare" by one consultant. Such concerns about the "absorptive capacity" of developing nations are also at the forefront of international discussions about climate change financing (Müller 2008).

Second, genuine efforts to build local capacity to meet international standards for project management and to "mainstream" climate change adaptation into government business can be undermined by the pressure on local human resources. Countries that receive development aid contribute hidden overheads to the development projects in the form of the use of limited personnel and facilities (Barnett and Campbell 2010), a problem that is exaggerated in small developing countries with limited access to higher education (Kandlikar et al. 2011). A small number of well-trained i-Kiribati often get recruited to work on new government projects or out the country entirely to regional organizations, thus limiting institutional memory. Others must direct a large fraction of their time to the challenge of meeting the unfamiliar reporting requirements mentioned above and to attending overseas meetings, rather than to meeting in-country needs like training people in their unit and implementing projects. Phase II of the KAP faced "severe human resources and logistical" problems, due to lack of specialist skills and difficulty retaining personnel (World Bank 2009b). KAP documents (e.g. Kay 2008) and expert interviews from 2010 to 2013 revealed that technical capacity-building efforts were hurt by the aforementioned bureaucratic obstacles shortening planned staff training opportunities and by reassignment of the government staff that were trained under KAP consultancies. The frequent absence of staff due to international commitments, noted by Nunn (2009) as a problem throughout the Pacific, was also reported to us by government staff and consultants during each of the field visits.

Finally, the inconsistent and short-term nature of aid flows limits implementation and long-term maintenance of knowledge, equipment, and infrastructure. Expensive, hard measures require regular maintenance; there are so many broken aid-funded sea walls, roads, and water systems in South Tarawa that the KAPII final report labelled the atoll a "graveyard of short-lived infrastructure investments" (Hughes 2011). Similarly, measures aiming at behavioral or system changes, like new coastal planning or decision-making systems, require a long-term commitment to training and monitoring. With different donors, ministries, and consultants involved at different stages (see above), there can be a lack of ownership of these efforts; reports produced by past projects, like the water system reports mentioned above (White 2010), are thus not considered by subsequent projects. The international consultancies, typically measured in weeks, producing this work are too short to provide outsiders with sufficient understanding of local culture to install a new management system. For example, the i-Kiribati custom of respecting and not confronting elders and guests can lead government officials to defer some decisions to foreign experts and consultants, who are often only in Kiribati for short visits (Watters 2009; Donner, pers. obs.). Government policy officers, aid representatives and KAP documents (Kay 2008) frequently stated that capacity-building programs tended to be too short to gain the staff trust, develop staff commitment to the program, or to adequately prepare staff to do the work for which they were trained or to train others to do that work. Lack of staff confidence to train others is especially critical given the uncertainty of long-term funding and the aforementioned personnel turnover. One solution to these challenges, proposed by two engineering consultants interviewed in 2013, is increasing the contribution of the well-equipped regional agencies like the South Pacific Applied Geosciences Commission (SOPAC) and the Secretariat of the Pacific Community (SPC) to adaptation research, monitoring, and training.

Taken together, these challenges posed by the aid environment can directly slow project approval and implementation. More than 2 years into the 3-year Phase II of the KAP, 73 % of the project management budget had been used, but 96 % of the "land use, physical structures, and ecosystem" funds, which includes coastal protection measures, remained (World Bank, 2009b). Among the stated challenges in spending implementation funds was the broad scope, the large number of independent consultants, local struggles with the World Bank procurement systems, and the limited capacity at the MPWU to process applications for coastal measures through the new coastal zone management framework. In the latter case, a long lag in approvals could have led to a "vicious circle" in which pressure for reactive management reduces the time and energy available for proactive or longer-term management which fully considers climate change (Kay 2008). As a result, KAPII was extended for a year and restructured with the narrower focus and key consulting contracts offered to fewer, larger firms.

Questionable decisions: the KAPII sea walls

In general, delays in implementation may create frustration within government, among the local people, who hear of multi-million dollar international aid projects but do not see results, and among the financers, who wish to see the impact of their aid investments. As in other former colonies, the legacy of colonialism and the history of international development interventions have undermined actual and perceived adaptive capacity in Kiribati (Watters 2009). Some of the Kiribati public expects that their government is responsible for development, while some in the government expect that the international community is responsible for development (Watters 2009; Donner, pers. obs.). Confirming our anecdotal observations, Kuruppu and Liverman (2011) found evidence that residents of South Tarawa expressed lower confidence in their ability to cope with climate change than residents of outer islands, who receive limited aid or government support. The slow implementation of adaptation measures dims public views of government-run adaptation projects and dims government views of the international financers of the project. A common local complaint is that the government—or the international financer—holds plenty of community consultations but fails to implement actions.

Under the KAP, these dynamics contributed to compromises that may have undermined the initial goal of "no regrets" adaptation planning. After the restructuring of Phase II, a new foreign firm was contracted to manage all coastal projects. A top priority was constructing locally replicable sea walls protecting the airport runway and three other pilot implementation sites. The walls were constructed using a new variation of the vertical sandbag design commonly used in the past in Kiribati. This new design included an apron to help maintain the wall structure over time, but no specific measures to protect against erosion at the base or edges of the walls. Thus, after years of investing in capacity-building for coastal zone management, establishing approval systems for coastal projects, and developing predictive models, a major output of the KAPII was a set of sea walls that did meet best practice standards.

Within months of their construction, the Office of *Te Berenteiti* complained that "the KAPII seawalls have serious erosion problems" (World Bank 2011b). Erosion occurred at the ends of some of the walls shortly after construction. Interview subjects with coastal expertise and experience in Kiribati all agreed this was to be expected from a design that poorly dissipates wave energy. Of the 26 experts questioned in 2013 about any general failures and challenges of the KAP, twelve were able to answer, seven of whom volunteered the sea walls and erosion as an example; the other five focused on broader issues like World Bank procedures. The walls themselves were broadly seen as sub-standard and described using terms including "embarrassing", "built wrong", "poorly done", "not best practice", and "not right" in interviews.

Interviews and project documents (Hughes 2011; Juillerat 2012) revealed that a genuine effort to implement a locally appropriate solution combined with the pressure to take visible action, aid dynamics and momentum led to the construction of the sea walls. After numerous delays and problems, the project was under pressure to do something figuratively and literally concrete; one interview subject referred to "scrambling around to slap up sea walls". Though questioned by many as adaptation measures, the adverse effects of sea walls are not well understood in Kiribati, so sea walls continue to carry status and be a clear way to demonstrate public spending on adaptation. The new firm was tasked with building walls that could realistically be replicated in Kiribati by the MPWU; the design may not reflect best practices developed for the KAP, but still represents a technical improvement on the traditional i-Kiribati design. Momentum and World Bank procedures may have also influenced the final construction decision. Despite the Kiribati government ostensibly being in charge of KAP decisions, the World Bank process of hiring foreign consultants to provide recommendations leads the Kiribati government to conclude, in the words of a senior government policy officer, "either we do that [their recommendations], or we just do away with the money".

Most interview subjects viewed the sea walls as a failure from an engineering perspective. However, positive comments about the process demonstrated that there are various ways of defining "success". Three of the 2013 interview subjects—a project manager, an engineer and a policy officer—who were critical of the sea wall design nonetheless emphasized that the goal was to find a compromise that the existing MPWU sea wall team could easily replicate. Each subject recognized the design flaws but also the challenge of implementing any large coastal protection project in Kiribati; regardless of the design issues, the sea walls have in the end provided at least near-term protection to key infrastructure. Currently, under Phase III of KAP, there are plans to add flank protection, wave dissipating structures and new geotextiles, and to develop new provisions about this revised design and incorporation of soft measures into the Planning Act. These actions, however, will depend on the availability of resources.

From a policy perspective, the sea walls could then be viewed as part of the learning process. Given the scientific uncertainty, the resource limitations, the training challenges, the many actors involved, and the expenditure, the implementation of any adaptation measure, suboptimal or not, will be considered by many a preliminary success.

Conclusions

The physical impacts of climate change can be difficult to detect, even in the low-lying atolls of Kiribati (Donner 2012). The physical impacts of the climate change adaptation projects, however, are becoming easily visible. Visitors to Tarawa can see the office of the KAP, public notices and signs, new seawalls, equipment for the mid-lagoon dredging project, mangrove saplings planted alongside several causeways, new water tanks in certain villages, and construction of new water pipes for the reticulation system. Like all first steps, these initial actions towards adapting to an uncertain future are cautious, unsure, and sometimes backwards.

Our qualitative analysis of climate change adaptation efforts in Kiribati reveals several key themes, which may not be apparent from more a technical assessment of climate change adaptation. First, a culturally appropriate short-term (~20 years) planning horizon may help reduce uncertainty and the trade-offs between adaptation options. In the short-term or *te-tibu*, the range of sea-level predictions may be small enough to not seriously confound adaptation decisions. Second, these decisions must be regularly revisited, based on data collected on their effectiveness and reviews of the latest global sea-level data and predictions. Third, a broad adaptation program needs a concurrent mid- to late-century planning horizon, which considers expensive adaptation measures (e.g. land reclamation) and international migration, as a precautionary measure and to avoid biasing all adaptation decisions towards easier short-term actions. Finally, revisiting decisions and maintaining multiple planning horizons require consistent long-term financial support and personnel. Otherwise, new projects and new personnel will expend time and resources maintaining, repairing or replacing old systems and infrastructure.

The financial cost of such adaptation may match or exceed that of mitigation (Donner et al. 2011). The financing required to further notoriously sluggish capacity building efforts, to maintain rolling short-term implementation efforts, and to correct mistakes is enormous. For example, Phase III of the KAP budgeted US$2.8 million for coastal protection, which includes protecting an ambitious 1.6 km of shoreline for a 25-year period using various measures, maintenance funds for three of the 25 years, as well as advisory support and other inexpensive supporting projects. At that rate, protecting the shoreline of South Tarawa, one of dozens of atolls in the Pacific and Indian Ocean, would cost well in excess of US$100 million, without accounting for maintenance costs, rehabilitation or reconstruction after storm events, or the sourcing of material. While it is neither realistic nor advisable to construct such protective measures along the entire shoreline of South Tarawa, the estimate is demonstrative of the scale of financing that may be required for climate change adaptation in one small nation.

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