Adaptation to Climate Change Options for Marine Turtles

Results of a survey carried out under
The Adaptation to Climate Change for Marine Turtles (ACT) project

Marianne Fish & Carlos Drews

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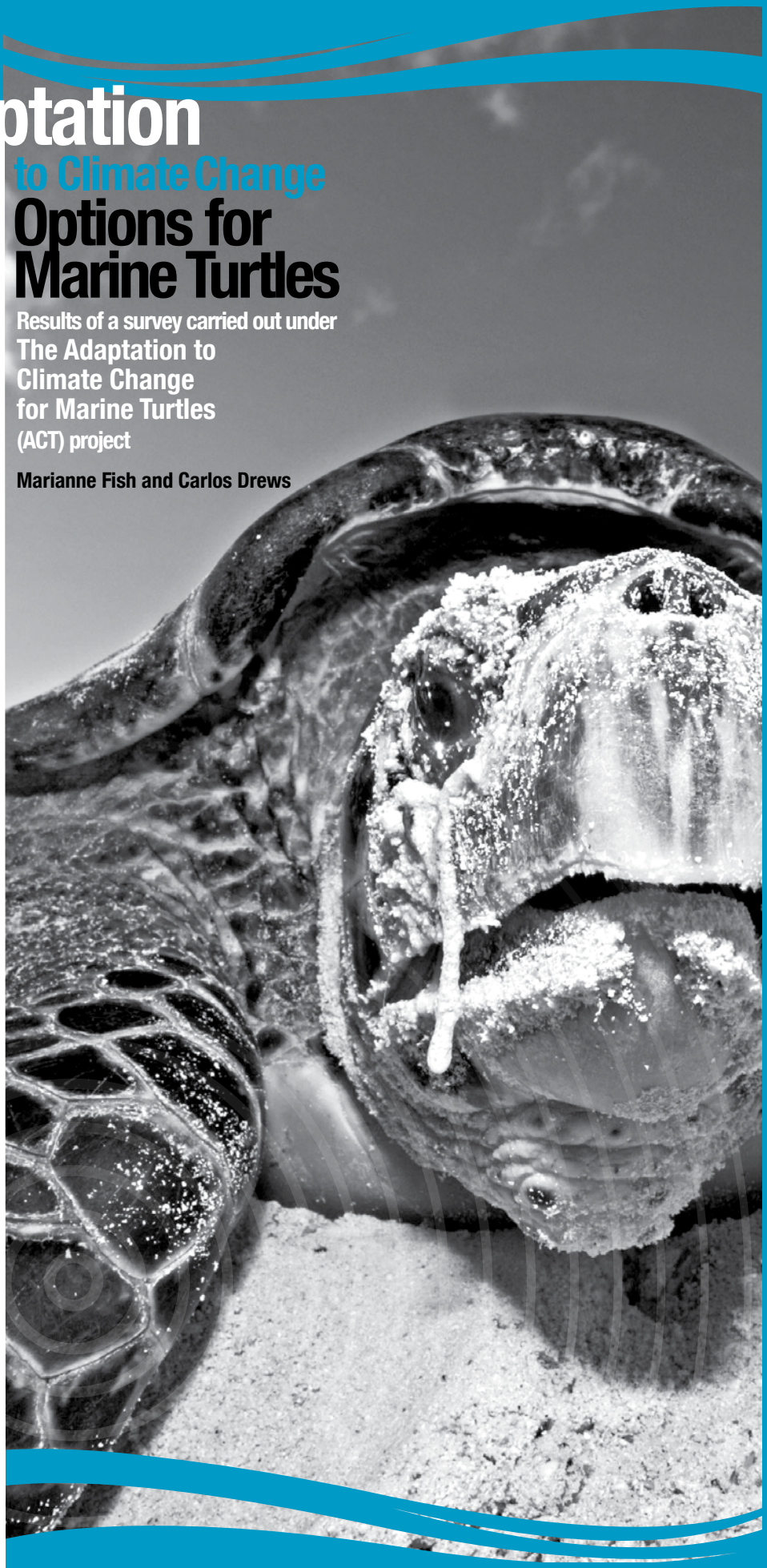

Summary

From the retreat of glaciers to shifts in species ranges and timing of breeding, the outcomes of our changing climate are clear and pervasive. As our awareness of the potential impacts of climate change grows, there is heightened interest in climate change adaptation. Here, 'adaptation' refers to management actions that are put into place to reduce vulnerability to climate change in the future. Climate change adaptation in coastal areas is vital given the importance of these areas for the people and species that depend on them. By ensuring healthy habitats for the future, adaptation measures provide protection for biodiversity and the communities that these habitats support.

Hawksbill sea turtles exemplify the interconnected nature of coastal habitats and can help to focus attention on climate-change issues in coastal areas. Reducing the vulnerability to climate change of hawksbills and their associated habitats is likely to have ecological and social benefits beyond the conservation of this critically endangered species.

The Adaptation to Climate change for marine Turtles (ACT) project, funded by the MacArthur foundation, explored coastal adaptation options for hawksbill turtles in Latin America and the Caribbean to answer three main questions:

What are the adaptation options available to us to mitigate the negative impacts of climate change on hawksbill sea turtles and the coastal and marine habitats upon which they rely?

Which of these measures can and should be implemented given current knowledge?

What are the additional benefits of managing coastal habitats for hawksbill turtles?

This report presents the findings of this study and next steps for the ACT project.

There are many avenues open to us to deal with climate change in coastal systems that are low risk and feasible for immediate implementation. Through expert discussion and surveys with conservation practitioners, academics and coastal managers, our study has identified several recommended adaptation measures that could reduce the vulnerability of sea turtles and their habitats to climate change. Many of these measures involve land protection and management, which have several benefits. In particular, most of these options are not climate-change specific and therefore acknowledge the fact that climate change is one of a host of stressors in coastal areas. In this respect, these measures are 'no regrets' options since investment will reap benefits irrespective of the extent of climate change. Finally, we discuss incorporating adaptation into current policy and the need to act promptly as we are pushed for action by ongoing climate change.

Background

What is climate change adaptation?

Recent years have seen a heightened awareness and documentation of climate-related impacts on ecosystems. From the retreat of glaciers and changes in primary productivity to shifts in species ranges and timing of breeding, the outcomes of our changing climate are clear and pervasive [1,2]. As our understanding of the potential threats associated with climate change grows, decision-makers and managers are considering how best to tackle the problem.

There are two ways for people to address climate change: mitigation and adaptation. Mitigation involves limiting greenhouse gas emissions and therefore the degree of future warming. However, even if greenhouse gas emissions were to be cut dramatically, some change in climate is unavoidable. Stabilizing present day emissions would result in a continuous increase in atmospheric CO_2 over the 21st Century [3], with consequences for society and ecosystems. Mitigation efforts alone are therefore insufficient for reducing climate change impacts on natural and societal systems and there is growing interest and research into climate change adaptation [4].

Adaptation has many definitions (see Appendix A) but essentially means an adjustment to better fit current or future conditions. For biologists the term means the process whereby organisms become better suited to their physical environment. In the climate change context, however, adaptation is generally used to mean any human initiatives and measures to reduce the vulnerability of natural systems or human infrastructure against actual or expected climate change effects [5]. Adaptation and mitigation are by no means mutually exclusive and in some cases both can be incorporated into one action, for example trees planted on a beach to provide shade for marine turtle nests or to reduce erosion also act as a carbon sink.

Various types of adaptation exist, e.g. autonomous and planned, anticipatory and reactive [6]. Autonomous climate change adaptation is the unconscious process of humans altering their behaviour to cope with the prevailing circumstances [7]. Conversely, planned adaptation takes the form of deliberate, focused actions aimed at specific issues, be it a rise in sea level or an increase in temperature. Anticipatory measures are planned actions instigated now to mitigate future changes that are not yet apparent, whereas reactive adaptation is a response to detected changes. Here we discuss planned adaptation measures, which may be technical, institutional, legal, educational or behavioural [6].

Adaptation measures will often be novel and, at times, controversial. At best they should pose least risk. 'No regrets' options are actions which will have non-climate-change-related benefits beyond reducing vulnerability to climate change and whose usefulness therefore outweighs the costs involved in implementation [8]. These options are desirable irrespective of the extent of climate change. 'Low regrets' options do not necessarily have non-climate benefits but can be implemented at minimal cost and therefore hold little risk if climate impacts are not as severe as expected [8]. Climate change adaptation also involves raising awareness of climate change impacts and adaptation possibilities and building the capacity to act.

Climate change adaptation in coastal zones: sea turtles as umbrella species

Climate change adaptation in coastal areas is vital given the vulnerability of these areas to sea level rise and other climatic impacts, as well as their importance for the people and species that inhabit them. Coasts are complex and dynamic areas where habitats as diverse as coral reefs, seagrass beds, mangroves, beaches and wetlands, interact to form one of the most productive systems in the world [9]. Sixty percent of the population live within 100 km of the coast and millions derive their income directly or indirectly from coastal resources [10]. The upshot of our reliance on coasts is extensive modification and destruction of the very habitats on which we depend [11]. Climate change is acting on systems already under pressure from development, pollution, over-exploitation of fish and other extractive resources and invasive species [12,13]. The cumulative effects of these non-climate stressors have already left many areas severely compromised from their natural state and therefore particularly vulnerable to the additional pressure of climate change [14].

The projected changes in coastal zones as a result of climate change are numerous and varied. Rising sea levels, increasing wave height, extreme rainfall events, more intense storm events and storm surge are likely to result in inundation of lowlands, saline intrusion into watertables, increased coastal flooding and more severe beach erosion [15]. Coastal marine habitats will be subject to rising ocean temperatures, ocean acidification and altered location and strength of oceanic currents [3]. Coral reefs are particularly vulnerable to these physical processes and resulting coral bleaching and decreased calcification rates will leave reefs more vulnerable to physical damage [16]. On land, rising surface air temperatures and, in some localities, reduced cloud cover will cause beach temperatures to rise [17]. Given the multitude of expected impacts on heavily-used coastlines [18], the need for coastal adaptation is clear.

A renowned flagship species and commonly used emblem of coastal landscapes [19], the hawksbill turtle (*Eretmochelys imbricata*) is a useful species for highlighting the impacts of climate change and promoting adaptation to climate change in coastal areas. Moving between beach, reef and the open ocean throughout their lives, hawksbills characterize the interconnected nature of coastal habitats. Consideration of their lifecycle can, therefore, help to focus attention on the impacts of climate change. Hawksbill turtles are critically endangered [20] and maintenance or recovery of population numbers depends on the existence of suitable nesting and foraging habitats. In addition, reducing the vulnerability of these areas to climate change for hawksbills is likely to have benefits for other species and human communities. Many adaptation measures could help to protect or mitigate damage to various habitats or confer protection to other species, some of which are fundamental to coastal livelihoods. As a charismatic and well-known flagship species [21], hawksbills are also useful for raising awareness of climate change issues.

There are many possible options for helping sea turtles to cope with climate change, for example reducing non-climatic stressors (e.g. threats to reefs such as pollution, sedimentation and pesticide run-off from agricultural practices), protecting refugia (effectively managed nesting beaches and networked protected areas), direct species management (e.g. using hatcheries to maximize hatchling production when illegal take is rampant), and land management (e.g. discouraging investments in vulnerable coastal zones). In this document we refer to adaptation measures as any actions that would help mitigate the adverse impacts of climate change on sea turtles and their habitats. In the longer term, these would be activities that would help sea turtle populations to be more resistant and resilient to climate change effects, where resistance is the ability to withstand change, and resilience is the ability to recover after change. While there is still a lack of understanding regarding the exact impacts of climate change on sea turtles (but see Hawkes *et al.* 2009 [22]), the precautionary principle would suggest that action at some level is advisable. Here we explore the adaptation measures we can put into place now for marine turtles and the coastal habitats on which they rely.

Climate change adaptation measures for marine turtles: definition

"Any actions that would help mitigate the adverse impacts of climate change on sea turtles and their habitats."

Objectives

The WWF Adaptation to Climate change for marine Turtles (ACT) project, funded by the MacArthur Foundation, has focused on three main questions:

- What are the adaptation measures available to us to mitigate the negative impacts of climate change on hawksbill sea turtles and the coastal and marine habitats on which they rely?
- Which of these measures can, and should, be implemented given our current level of knowledge?
- What are the benefits of managing coastal habitats for hawksbill turtles?

An adaptation strategy for hawksbill turtles in Latin America and the Caribbean

Developing an adaptation strategy

An adaptation strategy is a broad plan of action for addressing the impacts of climate change through policies and measures to be implemented over the short, medium and long-term [8]. The objective of an adaptation strategy should be made very clear at the outset and, fundamentally, there should be synergy with other environmental strategies already in place. Usually used in the context of a country's strategy for dealing with climate change, here we take a different approach and discuss the development of an adaptation strategy for a species, with the overarching aim of addressing climate change adaptation in coastal ecosystems. Many countries are already addressing climate change and it is hoped that the measures explored here can be incorporated into national or local adaptation plans.

Step 1. Identify vulnerabilities

An important first step is to determine how the system (or species) is vulnerable, which will ultimately aid in developing the objectives of the adaptation measures. Additional information regarding adaptive capacity in the region may prove useful at this stage, including technological advances, institutional arrangements, new and existing policies, availability of financing, level of information exchange, etc.

The ACT project has examined the vulnerability of sea turtles to climate change by addressing two main questions: how are sea turtles vulnerable to climate change and which locations in the region are (more) vulnerable to climate change? Answering these key questions took the form of two separate analyses: a literature review of the current state of knowledge about sea turtles and climate change (see Hawkes *et al.* 2009[22] and summary in the Toolkit) and a spatial analysis of climate projections at sea turtle nesting sites in the Wider Caribbean (see Regional climate projections in the Toolkit).

The key vulnerabilities identified were:

- Loss of nesting habitat from sea-level rise / storm surge
- Changes in nesting conditions from rising surface air temperatures and altered precipitation patterns, which could negatively influence egg development and hatchling sex ratios
- Changes in foraging conditions from increasing ocean temperatures and/or ocean acidification, which could affect the availability of prey
- Changes in open ocean conditions that could affect distribution and range of juvenile and adult turtles
- Lack of knowledge in:
  - the magnitude of climate-related threats
  - how sea turtles might respond to changes in their environment and to what extent this could mitigate any negative impacts of changing climatic conditions
  - baseline conditions (natural sex ratios, range of natural conditions in habitats currently used)

Step 2. Identify adaptation measures

Having identified the main vulnerabilities, the next stage was to review and/or develop adaptation measures to reduce vulnerability. Whilst fully acknowledging that there is much we do not know or cannot predict about how sea turtles will respond to climate change, what can we do now to mitigate the possible negative impacts of climate change on hawksbill turtles?

Adaptation measures for wildlife fall into five main categories (adapted from The Heinz Center, 2009 [23]):

1) Land protection and management

2) Direct species management

3) Monitoring and planning

4) Legislation and regulations

5) Raising awareness and building capacity to act.

A review of the literature revealed several texts on adaptation measures applicable to coasts, some for particular habitats, some for species and some for communities [23-28]. From this literature and expert discussions at the WWF/MacArthur Miami workshop in December 2007, the WWF/Hewlett Packard Climate Camp workshop in February 2008 and the Reunión de Especialistas Latinoamericanos de Tortugas Marinas (RETOMALA) regional meeting at the International Sea Turtle Symposium in Brisbane 2009, among others, a comprehensive list of potential adaptation measures was created. At this stage any theoretically possible options were considered and a list of 53 possible measures was compiled (see Appendix B for the complete list).

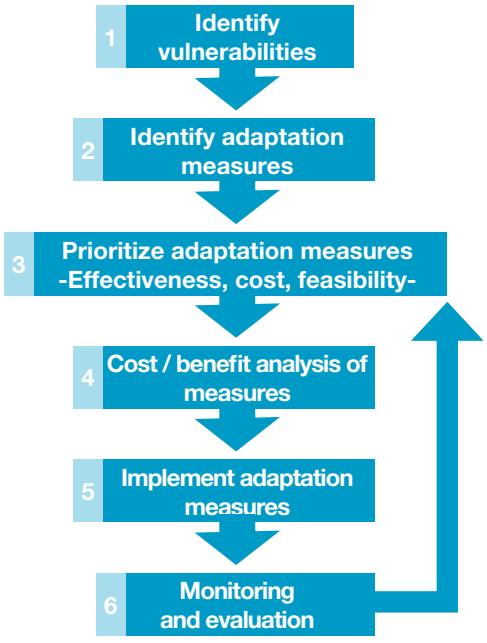

Figure 1. *The steps involved in developing an adaptation strategy (Adapted from Niang-Diop and Bosch, 2005[8]).*

Three physical changes were addressed: increasing beach temperatures, sea-level rise/storm surge and increasing ocean temperatures and acidification. These three were chosen as there is a growing body of literature on their impacts on sea turtles[22], and they are the 'easiest' to address at this stage because the possible outcomes of these changes are clearer than for other projected changes. While many of these adaptation measures are quite specific to sea turtles, and some just to hawksbills, many measures have additional benefits in that they could help to protect or mitigate damage to habitats and/or confer protection to other species, including resources for coastal communities.

Step 3. Prioritize adaptation measures

While there are many theoretically possible adaptation measures for coastal areas, logistical, technological, cultural and societal practicalities mean that some of these options are not currently feasible or desirable. There are many tools available for assessing the suitability of adaptation options, which fall into three categories: i) initial survey tools for identifying possible options or narrowing down a list of appropriate options; ii) economic analyses used to determine which option(s) is most economically efficient and the most appropriate to implement; iii) general modelling tools, used to address different adaptation strategies across a number of sectors [29]. In this stage of the project we focused on i) tools that would help us to narrow down the initial list.

Screening the theoretical range of adaptation measures

To reduce the possible options (53) to a more manageable number of feasible measures, we undertook an initial screening exercise, using expert judgement to produce a shortlist for further analysis. Screening is a matrix-based, decision-making tool that uses specific criteria to narrow down a long list of options [29]. Although subjective, it is a quick means of determining what the feasible options are at present.

The screening exercise was carried out by means of a structured online survey, consisting of background questions to initiate consideration of the topic, the screening matrix and demographic information. The self-administered survey was initially sent to a group of 105 experts, including conservation practitioners, academics, and coastal managers, from countries throughout Latin America and the Caribbean or with experience working in this region. Respondents were selected based not only on knowledge of sea turtle biology or climate change, but with local expertise to evaluate whether particular measures would be feasible in locations across the region. The survey was open and could be forwarded to any interested party.

Screening of individual adaptation measures was based on the following criteria:

1) Effectiveness - how effective would this measure be in achieving the overall aim of reducing hawksbill vulnerability to climate change?
2) Technical feasibility - does the technology and/or expertise exist to carry out this measure? Could this measure be implemented at a local or, in some cases, national scale?
3) Financial/logistic feasibility - are there sufficient resources available to carry out this measure? How much would it cost to implement this measure and who would pay?
4) Risks - are there any risks involved in carrying out this measure? Could there be any detrimental impacts on sea turtles, the ecosystem, local communities etc.? Might the results of implementing this measure be unacceptable?
5) Considering all the previous criteria, is this a practical option to put into place now and would you recommend it?

For each adaptation measure, respondents were asked to consider each of these criteria and pick the response from 'Yes', 'No', 'Maybe' or Don't know' that best reflected their opinion.

The screening matrix was broken down into three sections, each addressing a different physical change: A. increasing beach temperatures, B. sea-level rise/storm surge and C. increasing ocean temperatures/ocean acidification. Respondents were given the option to answer one, two, or all, sections and questions were not compulsory. We did not make explicit the climate scenarios used, but instead referred to the direction of change, e.g. increasing beach temperatures. Specific objectives were given for each adaptation option (see Appendix B).

The adaptation measures were divided into categories based on the majority response to the screening criteria:

1) 'Recommended' options. These were the options that the majority of respondents said they would recommend and the majority also thought there were no associated risks with the measures.
2) 'Recommended, but risky' or 'Maybe recommended'. The majority of respondents would recommend these measures, but acknowledge that there *are* risks in implementing them, there *might be* risks or the risks are unknown.
3) 'Not recommended at present'. The majority of respondents would not recommend these measures.


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Adaptation measures for hawksbill sea turtles and coastal habitats: survey results

Fifty respondents started the survey, although not all questions were answered by all respondents and so sample sizes (N) for each question are variable. The majority of respondents were from government and national non-governmental organizations (NGOs) (Fig. 2). Two respondents with affiliations outside the described categories were from an environmental consulting company and an intergovernmental organization. The sample was slightly male biased (56% male; N=34) and the modal age category was 26-35 years (38.2 % of respondents). Over half of the respondents were from the region (Latin America and the Caribbean (62.5%, N=32, Fig. 3). All respondents (N=34) had completed at minimum a university degree.

Previous work on climate change and sea turtles

The majority of respondents (92%, N=49) had worked in either Latin America or the Caribbean. Sixty three percent of respondents had worked in the Insular Caribbean, 33% in Central America and 14% in South America.

Nearly all respondents had worked on hawksbills (96%), and over 50% had worked on green (72%), loggerhead (51%) and leatherback (55%) turtles. Just over half of respondents (54%, N=50) had worked on climate-change-related issues, ranging from research on climate change impacts on sea turtles to participation in United Nations Framework Convention on Climate Change (UNFCCC) climate negotiations (Table 1).

Table 1 Climate-change-related work undertaken by survey respondents

TYPE OF WORK
Climate change workshops
WWF
Other
Programs
Caribbean Planning for Adaptation to Climate Change (CPACC) - Mainstreaming Adaptation to Climate Change (MACC)
United Nations Framework Convention on Climate Change (UNFCCC) negotiations
Reef resilience program
Local energy/carbon reduction initiatives
Climate change and Small Island Developing States (SIDS)
Research
Predicting impacts of climate change
Temperature-dependent sex determination and sex ratios
Sea-level rise modeling
Monitoring reef bleaching and resilience
Monitoring beach temperatures/moisture/dynamics
Water temperature and sea turtles
Flood risk management
Adaptation
Exploration of mangrove restoration
Vulnerability and adaptation assessments
Education programs
Train-the-trainer
Masters degree focused on climate change

Climate-change impacts

Respondents were asked to rank from low to very high the level of threat projected climatic changes pose to hawksbill sea turtles. Sea-level rise appeared to be an issue of concern for respondents, with 64% of respondents ranking it as at least a high threat (Fig. 4). The majority of respondents ranked increasing beach temperatures, increases in hurricane intensity and ocean acidification as having a high level of threat, with 60%, 56% and 44% of respondents ranking them as high or very high respectively. Changes in ocean conditions were ranked slightly lower overall (Fig. 4). The majority of respondents ranked increasing ocean temperatures and altered oceanic currents as moderate. There was also greater uncertainty surrounding oceanic threats, with 24% of respondents answering 'Don't know' for ocean acidification and altered oceanic currents. It should be noted here that this is perceived threat and a comparison to actual threat was not done in this study. Also, these rankings are specific to hawksbills and may differ for other species and/or locations.

Respondents were asked to list any climate threats they thought were not covered by the categories above. The only other physical change mentioned was changes in weather patterns, particularly in precipitation. Other threats mentioned were outcomes of the physical changes described above and included: changes in prey availability, coral bleaching, reef destruction from hurricanes and exacerbated beach erosion. Also mentioned was the possibility of increased demand for turtle eggs and meat because of altered human use in face of other climate-related pressures on communities.

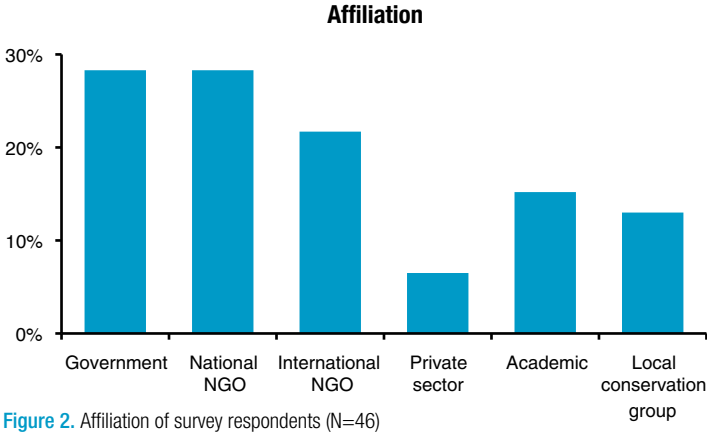


Figure 2. Affiliation of survey respondents (N=46)

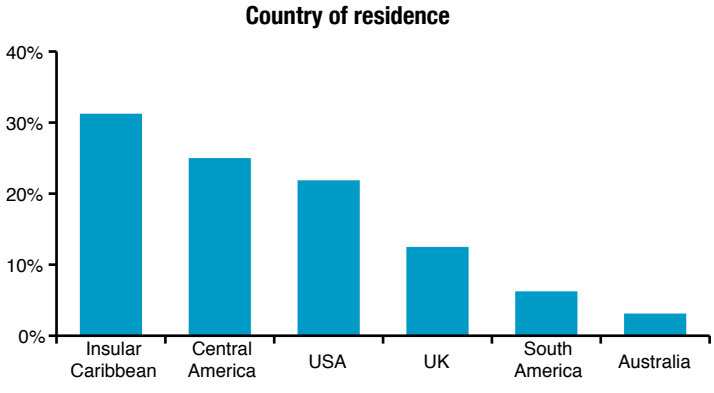
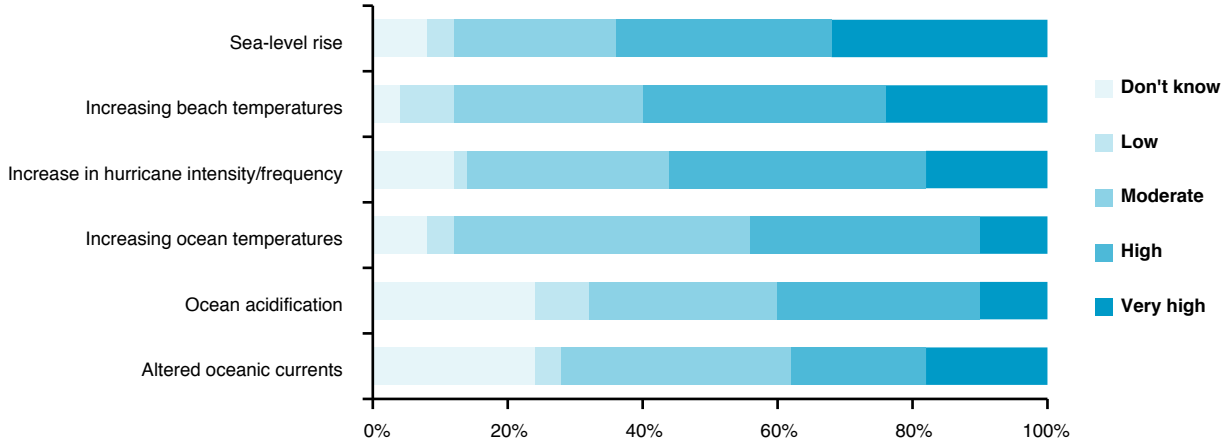


Figure 3. Country of residence of survey respondents (N=32)

Figure 4. Perceived level of threat posed to hawksbills by projected environmental changes as a result of climate change



Screening matrix

Appendix B presents the complete screening matrix results.

The adaptation measures were divided into categories, based on the majority response to the screening criteria:

1) Recommended

Twenty adaptation measures fell into this category (Table 2).

There were more recommended measures for dealing with sea-level rise than for increasing beach temperatures or increasing ocean temperatures/ocean acidification. Most measures (16/20) had high support (> 75% respondents recommended them) but only one recommendation (integrated management of coastal and marine resources) had 100% support. For all of these measures, the majority of respondents thought that they would be effective and technically and financially/logistically feasible.

Four 'recommended' measures received lower support than other measures: i) using histological examination of dead hatchlings to determine sex ratios; ii) measuring beach profiles and using them with data on wave/wind action and remote sensing records to model future beach changes under different sea-level rise scenarios; iii) identifying and protecting beaches not currently used by hawksbills but that may support nesting in the future; iv) prioritizing protection of reef with high sponge cover. One respondent commented that there is a need to determine whether there is differential mortality of male and female hatchlings to know if sex ratio estimates derived from histology of dead hatchlings are accurate. Identifying and protecting beaches not currently used produced a split between whether the majority of respondents thought that this would be effective (37.5% each for Yes and Maybe) and some uncertainty over whether it would be financially/logistically feasible (50% Maybe). There was also uncertainty of the financial/logistic feasibility of modeling future beach changes using beach profiles with remotely sensed data and wave/wind records.

Table 2 Recommended adaptation measures. Measures are ordered by physical change and the percentage of respondents that recommended them. N is variable (see Appendix B).

ADAPTATION MEASURES	% RESPONDENTS
Increasing temperatures	
Replant native coastal vegetation in areas where it has been removed	92.1
Prevent removal of beach vegetation	89.7
Monitor sand temperatures in different areas of the beach and monitor use of each area by nesting females	83.3
Monitor sand and/or nest temperatures using temperature data loggers and record nest success	80
Monitor sand and/or nest temperatures using temperature data loggers and measure hatchling sex ratio through histological examination of dead hatchlings	66.7
Sea-level rise/storm surge	
Establish, or enforce existing, setback regulations that prohibit construction within a set distance from the high water mark	96.7
Promote incorporation of climate change into land-use planning	96.7
Regulate new coastal development to ensure that it is 'turtle-friendly'	89.7
Monitor beach profiles at set points along a beach over time to get an estimate of the rate of erosion/accretion	87.5
Encourage nesting in all areas by making developed areas more 'turtle-friendly' (e.g. reduced lighting, removal of beach furniture etc.)	86.2
Ensure that new buildings adhere to existing legal set back regulations (distance that buildings must be built back from the beach)	86.2
Measure beach profiles and use them with data on wave/wind action and remote sensing records to model future beach changes under different sea-level rise scenarios	71.9
Identify and protect beaches that are not currently used by hawksbills but may support nesting in the future	45.2
Increasing ocean temperatures/ocean acidification	
Integrate management of coastal and marine resources	100
Control land-based activities to reduce pollution and sedimentation	94.4
Identify key foraging areas and ensure adequate coverage of these areas in marine protected areas	88.9
Prioritize protection of reefs with high coral cover	77.8
Identify and protect critical "refugia" that are resistant/resilient to bleaching	77.8
Establish a network of protected areas to enhance transport and replenishment of coral polyps	77.8
Prioritize protection of reefs with high sponge cover	61.1

2) Recommended, but risky

This category contained 18 measures: 14 options that are recommended but have associated risks (Table 3) and four that might be recommended (numbers 5, 7, 40 and 51; see Appendix B).

Unsurprisingly given that there are greater risks associated with these measures than for those in the first 'recommended' category, support was not as clear-cut (the average percentage of respondents recommending these measures was 58% as compared to 82% for the 'recommended' measures).

There was greater uncertainty surrounding these 'recommended, but risky' measures, particularly in terms of their feasibility. Respondents thought that only half of these measures were feasible and the other half may be feasible. There was a great deal of uncertainty in most criteria when considering measures designed to maintain foraging areas. For example there were reservations about the effectiveness or feasibility of using coral nurseries. Some respondents commented that they would have to know more to give an opinion, most importantly about what coral species would be propagated, whether they were native species to the area in question, and what role they played in the ecosystem currently in place.

Respondents comments provide some insight into other adaptation measures. One respondent noted that managed retreat may take some time as it is costly to relocate heavy infrastructure. Re-vegetating beaches in the context of ensuring suitable nesting conditions was recommended but support for this may depend on the species used. The lower support for re-vegetating here than for a similar measure for addressing increasing beach temperatures may be due to the fact that it was not made explicit whether native vegetation would be used and support may well vary depending on the plants used. As one respondent pointed out, use of some plant species for vegetation would not be appropriate. For example, the manchineel tree (*Hippomane mancinella*) has caustic sap that could harm tourists and as a result is being removed from some beaches and coconut palms, although popular on tourist beaches, do not hold sand well.

3) Not recommended at present

The remainder of the adaptation options was not recommended at present. All 15 options were considered risky and although most (14) were thought to be technically feasible (the exception being sprinkling/shading reefs), seven were not deemed to be economically feasible. The majority of respondents thought only three of these options would be effective, nine might be effective and were unsure about the other two measures.

Table 3 Adaptation measures that were recommended by the majority of survey respondents but have associated risks. Measures are ordered by physical change and the percentage of respondents that recommended them.

ADAPTATION MEASURES	% RESPONDENTS
Increasing temperatures	
Monitor sand and/or nest temperatures using temperature data loggers and infer sex ratios from known pivotal temperatures	50.0
Identify and legally protect cooler beaches	47.2
Using artificial shade over the hatchery	37.5
Sea-level rise/storm surge	
Establish rolling easements (voluntary agreement between landowner and landtrust/government that limits amount/type of development on property)	96.7
Plan urban growth, redirecting development away from nesting areas	90.0
Re-vegetate areas where native coastal vegetation has been removed	86.2
Move nests from areas of high erosion/inundation risk further back on beach	67.9
Ban permanent shoreline-hardening structures in areas of development	58.6
Remove permanent shoreline-hardening structures, such as sea walls, to allow natural beach movement landwards	48.1
Managed retreat - move existing structures landward to ensure that beaches have space to shift landward as sea levels rise	41.9
Increasing ocean temperatures/ocean acidification	
Reduce harvesting of herbivorous fish species on coral reefs by enforcing catch and/or effort restrictions	50.0
Use coral nurseries of known resilient species to restore reef areas impacted by localized warming events	47.1
Explore/identify potential dietary shifts as a response to decline in sponge abundance and quality and provide protection to possible "new" dietary items	44.4
Create artificial substrate for sponges in areas where coral reefs are too degraded to support sponges	38.9

Most of those that were not recommended involved direct manipulation of nests or habitats, e.g. manipulating conditions in hatcheries, building artificial structures such as groynes or breakwaters to manage beach erosion, providing artificial shading on the beach or head-starting nesting populations. Respondents comments revealed many of the concerns behind specific measures (Table 4).

In general the comments relate to a lack of sufficient knowledge to guide the intervention. For example, manipulation of nesting conditions to produce a particular sex ratio is tricky when the desired outcome (assuming this outcome is restoring natural sex ratios) is unknown. There are also technical and financial restrictions, in that for most of the above measures, intervention would need to be ongoing and may not be affordable year after year.

The shortlist

The 'recommended' measures can be grouped based on commonalities to give an overall list of ten recommended adaptation measures:

1) Integrate management of coastal and marine resources
2) Establish and enforce setback regulations
3) Incorporate climate change into land-use planning
4) Prevent removal of native vegetation and replant where it has already been removed
5) Ensure that new and current coastal development is 'turtle-friendly'
6) Monitor sand/nest temperatures and record nesting areas, nest success, hatchling sex ratios (through histological examination of dead hatchlings)
7) Measure beach profiles and beach dynamics for modelling future impacts of sea-level rise/storm surge
8) Identify nesting areas that may be used in the future
9) Control land-based activity to reduce pollution and sedimentation
10) Identify and prioritize protection of key foraging sites/refugia/areas of high coral/ sponge cover by ensuring their coverage in a network of protected areas

Additional measures for consideration are:

1) Land protection and management
   - Establish rolling easements
   - Managed retreat
   - Plan urban growth
   - Re-vegetate where native coastal vegetation has been removed

2) Direct species management
   - Move nests from areas of high erosion, inundation risk further back on the beach
   - Use artificial shade over the hatchery
   - Use coral nurseries of resilient species to restore reef areas
   - Create artificial substrate for sponges in areas where reefs are too degraded to support sponges

3) Monitoring and planning
   - Monitor sand temperatures and infer sex ratios from known pivotal temperatures
   - Identify and protect cooler beaches
   - Explore potential dietary shifts

4) Legislation and regulations
   - Ban permanent shoreline hardening structures
   - Catch/effort restrictions to reduce harvesting of herbivorous fish species on coral reefs

Table 4 Comments related to adaptation measures that are not recommended at present

ADAPTATION MEASURE	RELATED COMMENT
Provide areas of artificial shading on the beach	Artificial shading could bias sex ratios the other way, risky when do not know what aiming for, unnecessarily complicated when trees do it for free
Move nests to hatcheries and manipulate incubation temperature by: i) using sand with different grain size and colour in the hatchery	Need sufficient background studies prior to moving nests Altering sand colour would not alter temperature
Locate nests and water them Watering nests in the hatchery	Watering could result in excessive cooling and limit gas exchange; increase fungal infection; could have significant deleterious effects and strongly recommend against it; danger of over-watering and no studies to show how much to water
Move all nests from hottest parts of beach to hatcheries in cooler parts of the beach Artificially incubate eggs in controlled temperature rooms Move nests from hottest parts of the beach to incubators	Lack of evidence that sand is going to warm beyond tolerance Relocating nests - may not be moving them to favourable conditions. Ex situ increases risk of disease/fungus/other adverse biotic factors Working out natural sex ratios must precede artificial manipulation of primary sex ratios Need more lab studies to determine variation within and among populations in pivotal temperature
Measure hatchling sex ratio through histological examination of sacrificed hatchlings	Sacrificing a few hatchlings would be worth it for incredibly important information
Head start (raise eggs and hatchlings in captivity and release when approx. one year old) selected rookeries that are known to produce a higher proportion of male offspring	Head-starting has a very low rate of return relative to investment and is not financially feasible
Enhance eroded/eroding beaches using sand replenishment/beach nourishment Re-create beaches using sand nourishment	Maintaining beach area is probably a losing battle, regardless of SLR. Need to build resilience into coastal systems
Prevent further erosion of beaches by lessening wave energy, using offshore breakwaters	Beach nourishment has its own problems
Encourage beach expansion using groynes (structures built perpendicular to shore that stop the flow of sand alongshore)	Groynes can lead to sand depletion further down beach/coast
Screen/sprinkle/shade reef areas to mitigate effects of increased surface temperatures and UV light penetrance (i.e. to reduce temperatures and UV radiation from ozone depletion that have been implication in coral bleaching)	Insufficient knowledge to know whether to recommend or not

Discussion

There are many avenues open to us to deal with climate change in coastal systems that are low risk and feasible for immediate implementation. Our study has revealed a list of recommended adaptation measures that could reduce the vulnerability of sea turtles and their habitats to climate change.

Overall, there was greater support for measures that involve land protection/management, monitoring and legislation than direct species manipulation. In many respects these results are unsurprising. People tend to err on the side of caution, particularly where endangered species are concerned, and measures that have no obvious associated risks are clearly 'easier' to recommend than a more experimental approach that includes direct intervention and for which there is greater uncertainty over the outcome. From respondents comments, it appears that the general feeling against direct management of species or habitats is a reaction to lack of knowledge about natural responses of sea turtles. Obviously, the overarching aim is to build up population numbers and ensure survival of the species but often we are not certain of the ideal conditions to reach these goals. Reluctance to adopt more experimental approaches is likely a fear of inadvertently reducing the population viability of already critically endangered species. This would also explain the support for monitoring measures to gain more background information on which to base our decisions.

Many of the recommended measures involve land protection and management, which have clear additional benefits. Firstly, the majority of these options is not climate-change specific and therefore acknowledges the fact that climate change is one of a host of stressors in coastal areas. In this respect, these measures are definitely 'no regrets' options in that investment will reap benefits irrespective of the extent of climate change. Setback regulations are a prime example of an adaptation measure with benefits far beyond reducing sea turtle vulnerability to climate-change impacts. Many Caribbean countries are dependent on beach-based tourism but are also experiencing severe beach erosion as a result of declining reef health and beach-side hotels and restaurants restricting natural beach movement. Coastal development is therefore a key stressor, particularly on small islands. While the attraction of a beach-front hotel is obvious, there are long-term ben-

efits to be gained from setting buildings back from the beach. Beaches are much more likely to persist and therefore continue to provide a key tourism resource and buffer against damage from heightened storm surge and flooding.

There has long been an understanding that management of coastal areas, including climate-change adaptation measures, should take into account the dynamic interactions and relationships among different coastal habitats. Many of the adaptation measures recommended here explicitly address this issue, for example the recommended integration of coastal and marine management. While the inter-connected nature of coastal habitats is widely recognized, the diverse range of habitats and processes that constitute the coastal zone often fall under the jurisdiction of separate government agencies that may have conflicting interests. Integrated coastal zone management, which moves beyond traditional approaches of addressing each sector individually towards managing the coastal zone and its resources as a whole, has been established in some countries. The benefits of this integrated management are clear as conservation and planning efforts are more likely to succeed if they incorporate all potential influences on the system. In many cases, changes in legal and institutional frameworks may be required to ensure that coastal zones are managed as a whole and that climate change is incorporated into those plans.

While options such as integrated coastal management are widely recommended, their actual implementation is not so clear-cut. Constraints may be logistical, financial, technological, institutional, or social. This should not be a deterrent, but rather a recognition of the obstacles to be overcome and the criteria to be addressed when proceeding with implementation. One survey respondent commented that one of the main issues in implementing adaptation measures may be a lack of buy-in from stakeholders. This pertinent point highlights the importance of early stakeholder engagement, building capacity and raising awareness as an integral part of the implementation process. Some measures will have considerable associated costs, but these costs may escalate if action is held-off until serious consequences of climate change are already occurring [30].

Box 1

Adaptation in Action: Junquillal Beach

At Junquillal Beach, a leatherback nesting beach on the Pacific coast of Costa Rica, the community is strongly involved in climate change adaptation activities. Lead by WWF turtle specialist, Gabriel Francia, the sea turtle conservation project is run by a group of young men from the community, the 'Baula boys'. In June 2009, a tree planting day was held on World Tree Day, to re-vegetate the back beach area where the natural vegetation had been removed. The list of native species was selected by community members through participatory workshops and 50 people from the community joined in to plant more than 1,300 trees. The shade of trees along the beach has been shown to reduce the incubation temperature in exposed beach areas by 2-3 degrees centigrade.

The time-scale involved in the above measures is another consideration in implementation. While establishing setbacks or promoting integrated coastal zone management are important and useful, they cannot be implemented overnight and will necessarily take some time to generate results. There are, however, options with clear, immediate benefits. Re-vegetating beaches is relatively cheap and has benefits ranging from cooling beaches through shading, to reducing beach erosion by stabilizing sediment to mitigation of greenhouse gases by acting as a carbon sink. In addition, tree planting is an ideal activity to raise awareness of climate impacts and adaptation in coastal areas as it can easily be made into a community activity, involving all ages, the results of which are obvious and tangible (see Box 1).

Many of the measures mentioned here are not unique to climate change management and may already be in place, or planned, in some areas. The fact that we are not starting from scratch when considering climate change adaptation measures, will ultimately aid implementation. Support for these coastal management measures in the context of climate change provides added incentive to put these measures into place in a timely fashion.

Climate change permeates all aspects of resource management and adaptation should ideally be incorporated into, or complement, current policies. There is no one ideal solution in adapting to climate change, and we will need to act at many levels starting from top down and bottom up to tackle the environmental challenges of the coming decades. In many cases, we will need to view coastal management in a new, more dynamic and flexible way. Some solutions will take a matter of months to implement, some may take years, but the need to act is urgent and holding off making decisions is not an option. The whole process should be dynamic and adaptive in that we learn as we go, taking on board new information as it becomes available and adjusting conservation and land management plans accordingly.

Finally, while some of the more controversial options lack support at the moment, climate change adaptation is a flexible process and these options should not be ruled out indefinitely. Some options that are not practical now, may become more viable in the future through changes in support through outreach and awareness, changing laws, or advances in knowledge and/or technology. If the pace of climate change occurs as in high emissions scenarios, we might not have time to collect the evidence that would normally make us comfortable in proceeding with recommendations. We are charting new territory and are being hurried for a decision by ongoing climate change.

Conclusions and next steps

In this first phase of the ACT project we have narrowed down the possible range of adaptation options to a feasible list for implementation. The next phase of the project will address Steps 4 to 6 – reviewing which measures are most appropriate in specific locations and their implementation. The implementation of climate adaptation measures is already being tested in some nesting sites, however (e.g. see Box 1).

Step 4. Cost/Benefit analysis: prioritizing adaptation measures for a specific location

The measures put into place in any particular country or community will depend largely on factors unique to each location. There will be costs and benefits to each and in order to determine which measures are most suitable for implementation, a more detailed cost/benefit analysis of these options will be carried out. There are four main methods for prioritising and selecting adaptation measures at this stage [5, 8]:

1) Cost Benefit Analysis (CBA) - is based on balancing the gains and losses of alternative measures and is useful when only considering one criterion, usually economic efficiency, but has substantial data requirements.

2) Multi-Criteria Analysis (MCA) - considers more than one criterion and is useful when quantitative

analysis of costs or benefits is not possible, for example where there are non-monetary benefits, such as preserving biodiversity. This option is normally used for ranking options but if a 'no action' option is included can also help to clarify whether intervention is better than the 'status quo'.

3) Cost Effectiveness Analysis (CEA) - is useful for identifying the most economic way of achieving a particular goal if more than one measure is available. Benefits are not measured in monetary terms, but costs are. This method produces a ranking similar to MCA.

4) Expert judgement. Expert opinion can be sought in a more thorough analysis through workshops or using questionnaires, as here.

The next phase of the ACT project will involve selection of case study sites where adaptation measures are to be implemented. An MCA will be carried out for each of these sites to determine the best options. Multiple stakeholders will be involved in the process at all levels.

Steps 5 and 6. Implement adaptation measures and monitor their progress

Once the appropriate adaptation measures for a particular site have been decided upon, the next step is the actual implementation of the activity. Planning prior to implementation is essential and should consider the time frame for implementation and details of the implementation process, including necessary resources, implementing agency and how measures are to be incorporated into existing strategies or management plans. Development of an adaptation strategy is a cyclic process and lessons learned from implementation of measures at pilot sites will feed back into local adaptive management and future recommendations. A vital part of the entire process is to evaluate the success or failure of projects, and to reach out with lessons learnt to a wider community of stakeholders, conservationists and community leaders.

Capacity building

Alongside the development of adaptation options, WWF-ACT will seek ways to build capacity for coastal managers, sea turtle groups and other interested stakeholders in the region wishing to carry out vulnerability assessments and/or implement adaptation options. The ability to act on recommendations is not assumed and therefore support will be provided wherever requested and possible to facilitate implementation of adaptation measures.

Raising awareness

The success of adaptation activities is dependent on support from individuals, groups and governments in the locations where they are to be carried out. As such it is essential that awareness of climate change issues and the reasoning behind adaptation activities are communicated to the appropriate individuals and groups. Raising awareness will be an ongoing process throughout the project through local and regional meetings, website updates, press releases and talks at all levels from local communities to international audiences.

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For more information on ACT, coastal adaptation and updates to the Toolkit, please visit:

www.panda.org/lac/marineturtles/act

If you are interested in trialling adaptation measures or wish to join the ACT network, please contact:

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Appendix A: What is adaptation?

The term 'adaptation' is widely-used in climate change literature. However, the meaning of this term is subject to some confusion and may apply to a variety of processes and scales. To many biologists, adaptation is synonymous with beneficial responses of species of animals and plants to their environment; to wildlife managers it can be aligned with conservation techniques (such as adaptive management); to donors / funding agencies it can be sequestering carbon dioxide. To try to alleviate some of this confusion, here we outline the meaning of adaptation in various different settings and organizations and what we mean by adaptation in the ACT project.

Definitions of adaptation and related terms

Adaptation

General

'The process of modifying a thing so as to suit new conditions' (*Oxford English Dictionary*)

'To change to much better match present or future circumstances' (*Websters Dictionary*)

In the context of climate change:

(An) adjustment in ecological, social or economic systems in response to actual or expected climatic stimuli and their effects or impacts. This term refers to changes in processes, practices or structures to moderate or offset potential damages or to take advantage of opportunities associated with changes in climate. It involves adjustments to reduce the vulnerability of communities, regions or activities to climatic change and variability (*IPCC 2001*)

Adaptation is: (a) adjustments to the pace of use or access to the natural resource base in order to maintain a reliable services from the affected ecosystem; or (b) reorganization to reduce exposure to loss or to exploit new opportunities from the affected resource (*Arnell et al. 2004, World Bank*)

A complementary strategy to mitigation for effectively managing climate change risks and must be placed within the context of a country's sustainable development (*UNDP & GEF* http://www.undp.org/gef/adaptation/climate_change/02.htm)

Adjustment in practices, processes or structures in response to actual or expected climatic stimuli or their effects, with an effort to reduce a system's vulnerability and to ease its adverse impacts (*CBD*)

Adaptation in the ACT project:

'any actions that would help mitigate the adverse impacts of climate change on sea turtles and their habitats.'

Anything else I can read to find out more?

WWF has made significant inroads into incorporating adaptation into conservation work. There are several excellent sources of information available, which give more information about the nature of adaptation. "Buying time" (http://assets.panda.org/downloads/buyingtime_unfe.pdf) is a manual for protected area managers to cope with climate change effects and has some core information about adaptation. WWF has also produced a library of different information about climate change and WWF's climate change work (http://www.panda.org/about_our_earth/aboutcc/). For even more information, see the Adaptation resources document included in the WWF Adaptation Toolkit.

Appendix B: Screening matrix results

Table 5 Screening matrix of adaptation measures to mitigate the potential negative impacts of climate change on hawksbill turtles and the habitats they rely on.

Results are the majority responses and colour relates to the strength of the response: >75% of respondents; >50% of respondents; >25% of respondents

			Would this be effective?	Is this technically feasible?	Is this financially logistically feasible?	Are there any risks associated with this option?	Would you recommend this adaptation measure?	N
SECTION A		***Aim: ensure that cooler areas are available for nesting now and in the future.***						
	1	Prevent removal of beach vegetation	Yes	Yes	Yes	No	Yes	39
	2	Replant native coastal vegetation in areas where it has been removed	Yes	Yes	Yes	No	Yes	38
	3	Provide areas of artificial shading on the beach	Yes/Maybe	Yes	Maybe	Yes	No	37
	3	Identify and legally protect cooler beaches	Yes	Yes	Maybe	Yes	Yes	36
		Aim: control the temperature of nests in situ						
	5	Locate and artificially shade nests on the beach	Yes/Maybe	Yes	Yes	Yes	Maybe	35
	6	Locate nests and water them	Maybe	Yes	Maybe	Yes	No	35
	7	Move nests to cooler areas of the beach	Yes/Maybe	Yes	Yes	Yes	Maybe	34
		Aim: control the temperature of nests ex situ						
		Move nests to hatcheries and manipulate incubation temperature by:						
	8	i) using sand with different grain size and colour in the hatchery	Maybe	Yes	Maybe	Yes	No	32
	9	ii) watering nests in the hatchery	Maybe	Yes	Yes	Yes	No	31
	10	iii) using artificial shade over the hatchery	Yes	Yes	Yes	Yes	Yes	32
	11	iv) reducing clutch size by dividing clutches when transferring them to the hatchery	Don't know	Yes	Yes	Yes	No	31
	12	Move all nests from hottest parts of beach to hatcheries in cooler parts of the beach	Maybe	Yes	Yes	Yes	No	32
	13	Head start (raise eggs and hatchlings in captivity and release when approx. one year old) selected rookeries that are known to produce a higher proportion of male offspring	Maybe	Yes	No	Yes	No	32
	14	Artificially incubate eggs in controlled temperature rooms	Yes	Yes	No	Yes	No	32
	15	Move nests from hottest parts of the beach to incubators	Yes	Yes	No	Yes	No	32

SECTION A		***Aim: increase knowledge of natural sex ratios and how temperature changes may affect hawksbill sea turtles in the future***						
	16	Monitor sand temperatures in different areas of the beach and monitor use of each area by nesting females	Yes	Yes	Yes	No	Yes	30
		Monitor sand and/or nest temperatures using temperature data loggers and:						
	17	i) record nest success	Yes	Yes	Yes	No	Yes	30
	18	ii) measure hatchling sex ratio through histological examination of dead hatchlings	Yes	Yes	Yes	No	Yes	30
	19	iii) measure hatchling sex ratio through histological examination of sacrificed hatchlings	Yes	Yes	Yes	Yes	No	30
	20	iv) infer sex ratios from known pivotal temperatures	Yes	Yes	Yes	Yes	Yes	30
SECTION B		***Aim: determine how much beach will be available in the future to inform coastal planning***						
	21	Monitor beach profiles at set points along a beach over time to get an estimate of the rate of erosion/accretion	Yes	Yes	Yes	No	Yes	32
	22	Measure beach profiles and use them with data on wave/wind action and remote sensing records to model future beach changes under different sea-level rise scenarios	Yes	Yes	Yes/Maybe	No	Yes	32
		Aim: maintain current beach area						
	23	Enhance eroded/eroding beaches using sand replenishment/beach nourishment	Maybe	Yes	No	Yes	No	31
	24	Prevent further erosion of beaches by lessening wave energy, using offshore breakwaters	Maybe	Yes	Maybe	Yes	No	31
	25	Encourage beach expansion using groynes (structures built perpendicular to shore that stop the flow of sand alongshore)	Maybe	Yes	Maybe	Yes	No	31
	26	Managed retreat - move existing structures landward to ensure that beaches have space to shift landward as sea levels rise	Yes	Yes	Maybe	Yes	Yes	31
		Aim: ensure sufficient beach area is available in the future						
	27	Establish, or enforce existing, setback regulations that prohibit construction within a set distance from the high water mark	Yes	Yes	Yes	No	Yes	30
	28	Establish rolling easements (voluntary agreement between landowner and landtrust/government that limits amount/type of development on property)	Yes	Yes	Yes	Yes	Yes	30
	29	Identify and protect beaches that are not currently used by hawksbills but may support nesting in the future	Yes/Maybe	Yes	Maybe	No	Yes	31
	30	Re-create beaches using sand nourishment	Maybe	Yes/Maybe	No	Yes	No	29
	31	Remove permanent shoreline-hardening structures, such as sea walls, to allow natural beach movement landwards	Yes	Yes	Maybe	Yes	Yes	27
	32	Ban permanent shoreline-hardening structures in areas of development	Yes	Yes	Maybe	Yes	Yes	29
	33	Plan urban growth, redirecting development away from nesting areas	Yes	Yes	Yes	Yes	Yes	30
	34	Promote incorporation of climate change into land-use planning	Yes	Yes	Yes	No	Yes	30
		Aim: ensure that existing beaches have suitable nesting conditions						
	35	Encourage nesting in all areas by making developed areas more 'turtle-friendly' (e.g. reduced lighting, removal of beach furniture etc.)	Yes	Yes	Yes	No	Yes	29
	36	Regulate new coastal development to ensure that it is 'turtle-friendly'	Yes	Yes	Yes	No	Yes	29
	37	Re-vegetate areas where native coastal vegetation has been removed	Yes	Yes	Yes	Yes	Yes	29
	38	Ensure that new buildings adhere to existing legal set back regulations (distance that buildings must be built back from the beach)	Yes	Yes	Yes	No	Yes	29
		Aim: reduce nest loss to flooding/erosion						
	39	Move nests from areas of high erosion/inundation risk further back on beach	Yes	Yes	Yes	Yes	Yes	28
	40	Move nests from areas of high erosion/inundation risk to hatcheries	Yes	Yes	No	Yes	Maybe	28
SECTION C		***Aim: reduce the likelihood of loss of coral reef habitat through coral bleaching***						
	41	Screen/sprinkle/shade reef areas to mitigate effects of increased surface temperatures and UV light penetrance	Don't know	No	No	Yes	No	18
	42	Use coral nurseries of known resilient species to restore reef areas impacted by localized warming events	Maybe	Maybe	Maybe	Yes	Yes	17
		Aim: protect key current and future foraging sites						
	43	Prioritize protection of reefs with high coral cover	Yes	Yes	Yes	No	Yes	18
	44	Prioritize protection of reefs with high sponge cover	Yes	Yes	Yes	No	Yes	18
	45	Identify and protect critical "refugia" that are resistant/resilient to bleaching	Yes	Yes	Yes	No	Yes	18
	46	Identify key foraging areas and ensure adequate coverage of these areas in marine protected areas	Yes	Yes	Yes	No	Yes	18
		Aim: maintain reef health through reduction of non-climate stressors						
	47	Control land-based activities to reduce pollution and sedimentation	Yes	Yes	Yes	No	Yes	18
	48	Integrate management of coastal and marine resources	Yes	Yes	Yes	No	Yes	17
	49	Reduce harvesting of herbivorous fish species on coral reefs by enforcing catch and/or effort restrictions	Yes	Yes	Yes	Yes	Yes	18
	50	Establish a network of protected areas to enhance transport and replenishment of coral polyps	Yes	Yes	Yes	No	Yes	18
		Aim: maintain suitable foraging areas						
	51	Develop and implement sponge aquaculture of key sponge species in the lab and create artificial feeding stations for turtles on real or fabricated reefs	Maybe	Maybe	Maybe	Yes	Maybe	18
	52	Create artificial substrate for sponges in areas where coral reefs are too degraded to support sponges	Yes/Don't know	Yes	Maybe	Don't know	Yes	18
	53	Explore/identify potential dietary shifts as a response to decline in sponge abundance and quality and provide protection to possible "new" dietary items	Yes/Maybe/ Don't know	Yes	Maybe	Don't know	Yes	18

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