Inter-American Convention for the Protection and Conservation of Sea Turtles

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Mitigation strategies to reduce the impact of climate change on nesting beaches

This document was prepared by the Climate Change Working Group of the IAC Scientific Committee, and it contains recommendations on: a) the minimum environmental data to collect from the index beaches identified by the IAC Parties to allow monitoring of climate change impacts on the habitat and b) mitigation strategies to reduce the impact of climate change on nesting beaches. The goal of this document is to be used by IAC Parties in the implementation of the Resolution CIT-COP4-2009-R5 on climate change adaptation of sea turtle habitats.

1. Nesting behavior in sea turtles

Sea turtles lay their eggs in clutches in sandy beaches, and egg incubation occurs within a 10^{o}C thermal tolerance range of about 25-27 ^{o}C to 33-35^{o}C, which varies with species and populations (Ackerman 1997). Embryos may be more sensitive to the time spent at a potentially stressful temperature than to the temperature alone (Howard et al. 2014). Incubation duration decreases with increasing temperature within the thermal tolerance range (Ackerman 1997). Air temperature at the sand surface affects nest temperature (Standora & Spotila 1985;Ackerman et al. 2004), with factors that influence solar radiation exposure and absorption, such as aspect and shading from vegetation (Horrocks & Scott 1991), sand colour (Hays et al. 2001), distance of the clutch from the sea (Fuentes et al 2009, Girondot & Kaska 2015), nest depth, and season (Davenport 1997; Baker-Gallegos et al. 2009) all potentially impacting the incubation temperature that eggs experience. Aside from these physical factors that affect beach temperatures, eggs generate their own metabolic heat during development and this varies with clutch size and section of the clutch (Broderick et al. 2001). High temperatures during incubation have been associated with decreased oxygen levels which have been linked to smaller sized hatchlings with reduced locomotor abilities that may affect emergence from the nest, and expose them to higher predation both during sea-finding and in the initial swim offshore (Matsuzawa et al. 2002; Segura & Cajade 2010; Howard et al. 2014).

The characteristics used by females to select nest sites on the beach are still not well understood. Most sea turtles show high fidelity, with the nesting habitat used by an adult female located within the region where she was born (Miller 1997), and nesters typically returning to nest within 5 km of their previous nests (Miller et al. 2003). Leatherbacks tend to place their nests more widely than other species (e.g. Witt et al. 2008). Nearshore bathymetry is a likely factor in determining the point of emergence on the beach (Provancha & Ehrhart 1987), but females may choose the location for egg deposition based on slope, distance inland from the high water mark, sand humidity, sand particle size, temperature and/or presence of vegetation *inter alia*. For most sea turtle species, these cues lead females to nest at higher beach elevations (Horrocks & Scott 1991; Wood and Bjorndal 2000; Santos et al. 2015) well above the high tide line, in sand that is stable for long enough to allow successful incubation. On developed beaches, built structures impeding access to suitable sites and artificial lights are likely to play a role in nest site selection (Reece et al 2013). On beaches where landward migration of beaches is prevented by human development, coastal squeeze occurs. This will have increasingly serious implications for nesting females as sea levels rise (Mazaris et al. 2009).

1.2 Temperature-dependent sex determination

Sex of sea turtles is determined by the temperature eggs experience during the middle third of development, with more females being produced at higher temperatures and more males at lower temperatures (Yntema & Mrosovsky 1982). The temperature range over which sex ratios shift from 100% male to 100% female varies between marine turtle species and between populations, but in general the range is small (1–4^{o}C), suggesting that even small increases in temperature will result in profound changes in sex ratios produced (Poloczanska et al. 2009). The pivotal temperature is defined as the temperature that produces a 1:1 sex ratio. Pivotal temperatures for sea turtle species found within the IAC region is shown in Table 1. It is notable that although there is small variation in pivotal temperatures from area to area, there is little overall latitudinal variation in pivotal temperatures.

Table 1. Pivotal temperatures (^{o}C) of several sea turtle species (from Ackerman 1997; *Glen & Mrosovsky 2004; #Chevalier et al. 1999; Marcovaldi et al. 2014)

Species	**Pivotal temperature ^{o}C**
Chelonia mydas	28.26
Caretta caretta	28.74
Lepidochelys olivacea	29.13
Eretmochelys imbricata	29.2*-29.32
Dermochelys coriacea	29.5

2. Climate change impacts on nesting habitat

In all except the low-emissions scenario, global temperatures at the end of the 21st century are likely to be at least 1.5°C higher, relative to 1850–1900. In the two higher emissions scenarios, global warming is likely to be 2°C and could rise by 2.6–4.8°C by 2100, if the IPCC's highest emissions scenario occurs (IPCC Fifth Assessment Report (AR5) 2014). Global sea levels have been rising 2.8–3.6 mm per year since 1993, and a rise of between 0.26 and 0.82 m is predicted by 2081-2100 for the various emissions scenarios in IPCC AR5. Rising sea levels will reduce the availability of nesting beaches on low lying coastlines or small islands, and where coastal development and beach armoring prevents landward migration of beaches (Fish et al. 2005, 2008). Continuing development of coastlines without allowing for alternative areas for sea turtle nesting threaten sea turtle populations if current areas become unsuitable or unusable. The spatio-temporal coincidence of marine turtle nesting with regions affected by hurricanes and tropical storms, suggests that cyclical loss of nesting beaches, decreased hatching success and lower hatchling emergence success could also occur with greater frequency (Fuentes et al. 2011). Air temperatures correlate with sand temperature (Laloë et al. 2014), and air temperatures have already reached or are close to reaching all-female producing temperatures at many Caribbean and Atlantic nesting beaches. A predicted reduction in tropical rainfall may exacerbate predicted rises in air temperatures further. It is important to note that any increased skew towards female hatchlings will lead to increased recruitment of females to the adult population and so a likely increase in nesting numbers for decades to come, but that reduced numbers of adult males on the breeding grounds will reduce genetic variability and may potentially impact clutch fertility in the longer term (Laloë et al. 2014).

2.1 Behavioral responses to climate change

Although sea turtles have presumably expanded into higher latitudes in the past, as temperatures rose during interglacial periods (see Bowen et al. 1993), how sea turtles will respond to loss of suitable nesting beaches on the time scale predicted is not well understood. Species with lower nest-site fidelity (e.g. leatherback turtles) may adapt more readily. For example, leatherback turtle nests are now being recorded at their most northerly extreme in a decade of monitoring (Rabon et al. 2003). Females may adapt the timing of the nesting season to suit changing thermal conditions at existing beaches, or they may expand their range into previously unsuitable areas for nesting if the latter beaches become thermally suitable (Hawkes et al. 2007, 2009; Pike et al 2006). Warmer temperatures for a greater number of months of the year may also allow an extension of the nesting season for some species or even year-round nesting (Yasuda et al. 2006). However, the behavioral responses of females depend on there being some areas on existing beaches where temperatures remain suitable or beaches available in new areas of suitable nest temperatures. Females with nesting experience have been shown to select a higher proportion of successful nest sites on a beach than inexperienced females (Pfaller et al. 2008), and therefore modification of nesting behavior potentially could occur quite rapidly.

3. Recommendations

3.1 Collection of environmental data relevant to monitoring of index beach habitats

Monitoring of beach profiles, sand temperature and potential threats to the back beach, together with regular photo-documentation of the beach, are the minimum activities recommended to monitor for climate related impacts and for baseline records.

Not all index beaches may be monitored on a regular basis, but environmental data of all index beaches should be collected at least once during the nesting season to provide a baseline for subsequent comparison.

For monitored beaches, data other than temperature should be collected every 3 months, but at least twice per year (e.g. beginning and end of the nesting season or the nest monitoring period). Temperature data should ideally be collected year round to monitor beach viability for nesting and to assess impacts of earlier or later nesting.

3.1.1 Beach profiles

Beach profiles can be used to measure *slope* and *beach width*. Beach width is a simple measure of sand accretion and erosion.

Permanent reference markers (i.e. trees, or structures located high enough above the beach to be unaffected by the highest storm tides) should be established to ensure that profiles are measured at exactly the same point along a pre-set compass heading perpendicular to the sea to allow comparison over time. Profile data should be recorded at low tide.

Either the Emery method or the Abney method (see Table 2 for manuals that describe both methods) for beach slope can be used, as they are comparable with each other. Ideally, Parties should choose one method and use it consistently at a particular location.

The number of transects should be influenced by how dynamic the beach is and its length. If it is a stable beach, one transect per kilometer would be sufficient, if it is an unstable beach, more frequent transects would be needed.

The number of transects chosen and the frequency should be based on the resources available.

Parties with index beaches on the Atlantic and Pacific coasts should establish environmental monitoring at beaches on both coasts.

3.1.2 Temperature

Temperature readings can be taken along the same permanent transect(s) established above or at several points along the length and width of the beach which differ in levels of shade or sand characteristics.

Sand temperatures should be taken at the sand surface and at average nest depth. Air temperature should be taken 1–1.5 m above the sand surface. If dataloggers are utilized, the distance of the datalogger from nearest vegetation and the high tide line should be recorded. The Temperature Monitoring Manual (Table 2) provides details on how to set up a temperature monitoring programme.

Table 2. Recommended manuals for collection of environmental data relevant to monitoring of index beach habitats

Reference	Contents	URL link
Guidelines for Monitoring Beach Profiles (Fish, M.R. 2011. Guidelines for monitoring beach profiles. WWF, San Jose, 16 pp	The Abney and Emery methods for beach profiling are explained with useful diagrams.	http://awsassets.panda.org/downloads/beach_profile_monitoring__web_.pdf
Sandwatch Manual UNESCO. 2010. Sandwatch: adapting to climate change and educating for sustainable development. Paris: UNESCO (Available in Spanish, English, Portuguese and French).	The Abney method for measuring beach profiles is explained and a simple programme to plot beach profile data is provided. This manual was primarily designed to quantify how environmental change on beaches will affect coastal communities. Less emphasis was put into the development of tools and methods that might enable a better understanding of how coastline change would affect biodiversity.	http://www.sandwatch.ca/images/stories/food/SW%20Docs/Sandwatch%20-%20Spanish%20-%202012.pdf

Sea Turtle Nesting Beach Characterization Manual Varela-Acevedo, Elda, Karen L. Eckert, Scott A. Eckert, Gillian Cambers and Julia A. Horrocks. 2009. Sea Turtle Nesting Beach Characterization Manual, p.46-97. In:Examining the Effects of Changing Coastline Processes on Hawksbill Sea Turtle (*Eretmochelys imbricata*) Nesting Habitat, Master's Project, Nicholas School of the Environment and Earth Sciences, Duke University. Beaufort, N. Carolina USA. 97 pp.	This manual describes methods to characterize nesting beaches (including beach profiling using the Abney method) and how to evaluate the vulnerability of sea turtle nesting beaches to climate change. The manual includes definitions and lists of equipment needed to take measurements. It has now been incorporated into Sandwatch and is available on their website.	www.widecast.org/Resources/Docs/Varela Acevedo_et_al_2009_Nesting_Beach_Characterization_Manual.pdf
Temperature Monitoring Manual Baker-Gallegos J., M.R. Fish & C. Drews. 2009. Temperature monitoring manual. Guidelines for Monitoring Sand and Incubation Temperatures on Sea Turtle Nesting Beaches. WWF report, San José, pp. 16	This manual provides specific details on how to set up a temperature monitoring programme on a nesting beach. Its objectives are to describe the thermal conditions of the beach and how they are affected by shading, moisture, sand grain size, and albedo *inter alia*, and how to standardize the methodology for the collection of temperature data. It also provides guidelines on how to establish temperature monitoring in hatcheries.	http://awsassets.panda.org/downloads/temperature_monitoring__manual.pdf

3.1.3 Back beach habitat characteristics

What is behind the beach and what % of the back beach is affected should be estimated. Habitat characteristics could include native beach vegetation, mangrove, forest, buildings, sea defenses, road etc.

3.1.4 Photographs of the beach

Beaches should be photo-documented every year.

3.2 Recommended mitigation strategies to protect sea turtle nesting beaches

The following strategies include many of those proposed by Fuentes et al. (2012), but in some cases they are modified. Fuentes et al. (2012) separated strategies into Recommended and Potential, and emphasized that some of the potential strategies could have costs to sea turtle reproductive output. They provide a list of the critical gaps in information that need to be filled in order to understand the risks posed by some of the potential management strategies. Many of these strategies require the collection of baseline data prior to implementation and the socio-cultural context of each region should be considered in deciding the most appropriate mitigation strategies. Priority should be given to strategies that maintain suitable natural nesting conditions and areas.

3.2.1 Protect index beaches from development to reduce likelihood of coastal squeeze.

Incorporate climate change scenarios into land use planning.

Establish or enforce existing set back regulations.

Ban permanent shoreline hardening structures and replace with soft options like vegetation.

Utilise managed retreat and rolling easements to allow space for index nesting beaches to migrate landwards. This may require incentives for landowners.

Prohibit sand removal from beaches.

3.2.2 Ensure that there are beaches or areas of beach where females can choose microclimates conducive to nesting and production of males

Identify and legally protect male-producing beaches.

If index beaches are found to be female-producing, cooler beaches within the region where females of the same population unit nest, should be protected.

Conserve, revegetate or plant beach vegetation.

3.2.3 Reduce nest temperatures *in situ*

Reduce incubation temperature through planting vegetation, artificial shading (Patino-Martinez et al. 2012) or addition of lighter coloured beach sediment on the surface of nests.

Watering nests may help to reduce temperatures (Naro-Maciel et al. 1999) and increase hatch success and hatchling size in areas experiencing lower rainfall than normal (Hill et al. 2015). However, watering could also cause excessive cooling, impede gas exchange or increase fungal infections.

These approaches require a good understanding of beach conditions, such as the thermal profile of the beach, the pivotal temperature and the sex ratio of the population. Consideration needs to be given to timing and materials used. For instance, as rainfall is important in cooling beach temperatures, it is important to consider the permeability of the material/fabric when considering shade structures (Fuentes & Jourdan 2015). All interventions require careful monitoring to determine their impact on hatching success and sex ratio.

3.2.4 Relocate eggs

Egg relocation can be used as a tool to increase hatching success and control sex ratios, but egg relocation may increase movement-induced mortality and, if nest site selection is heritable, may increase survival of eggs from nesters that consistently choose poor nest sites and whose eggs would ordinarily not survive (Pfaller et al. 2009).

Move eggs to areas of the same beach (e.g. under vegetation) or neighboring beaches with suitable incubating temperatures.

Move eggs to hatcheries. Concentrating release of hatchlings into smaller areas can increase mortality of hatchlings in the initial swim offshore (Stewart & Wyneken 2004), and the impacts of transplanting eggs on nest site selection by hatchlings once they reach adulthood are not well understood.

3.2.5 Restore eroding beaches and create new beaches

It may become necessary to install offshore breakwaters and groynes to counteract sand loss due to rising sea levels or storm erosion. Note though that breakwaters must be designed so that they do not impede access of females to the beach, and that groynes may have the unwanted impact of starving sand from adjacent nesting beaches.

Potentially, beaches with suitable temperatures could be artificially created by selecting orientation, aspect, slope and sediment colour. Sand nourishment must use sand from an appropriate source, and be of the correct grain size. Note though that sand nourishment can create escarpments that make beaches inaccessible to sea turtles, can cause sand compaction and can alter the gaseous and hydric environment that eggs are incubating in (Grain et al. 1995).

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