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Climate change impacts on leatherback turtle pelagic habitat in the Southeast Pacific

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ABSTRACT

Eastern Pacific populations of the leatherback turtle (*Dermochelys coriacea*) have declined by over 90% during the past three decades. The decline is primarily attributed to human pressures, including unsustainable egg harvest, development on nesting beaches, and by-catch mortality. In particular, the effects of climate change may impose additional stresses upon already threatened leatherback populations. This study analyzes how the pelagic habitat of Eastern Pacific leatherbacks may be affected by climate change over the next century. This population adheres to a persistent migration pattern; following nesting at Playa Grande, Costa Rica, individuals move rapidly through equatorial currents and into foraging habitat within the oligotrophic South Pacific Gyre. Forty-six nesting females were fitted with satellite tags. Based on the turtle positions, ten environmental variables were sampled along the tracks. Presence/absence habitat models were created to determine the oceanographic characteristics of the preferred turtle habitat. Core pelagic habitat was characterized by relatively low sea surface temperatures and chlorophyll-a. Based on these habitat models, we predicted habitat change using output from the Geophysical Fluid Dynamics Laboratory prototype Earth System Model under the Special Report on Emissions Scenario A2 (business-as-usual). Although the model predicted both habitat losses and gains throughout the region, we estimated that overall the core pelagic habitat of the Eastern Pacific leatherback population will decline by approximately 15% within the next century. This habitat modification might increase pressure on a critically endangered population, possibly forcing distributional shifts, behavioral changes, or even extinction.

1. Introduction

The impact of climate change on migratory species is difficult to predict. Unlike resident species, they travel long distances, increasing their exposure to regions that will likely be affected by climate change (Robinson et al., 2009). On the other hand, migratory species have acclimated to various habitats to complete their seasonal or inter-annual journeys; thus, they may be able to adapt to climate fluctuations (Robinson et al., 2009). Climate change adaptations, such as range shifts and altered phenology, have already been documented in migratory species (Walther et al., 2002). However, migratory species with low genetic variability and long generation times are unable to rapidly adapt to a changing climate (Robinson et al., 2009). Particularly for threatened and endangered species, this potential inability to adapt to habitat losses could further increase population declines (Burrows et al., 2011; Hazen et al., 2013).

The Intergovernmental Panel on Climate Change (IPCC) generated six climate change scenario families based on several hypothetical futures characterized by varying levels of greenhouse gas emissions (IPCC, 2000). The six potential scenario families projected an average sea surface temperature rise of 1–6 °C by 2100 using an

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Abbreviations: SRDL, Satellite Relay Data Logger; SPOT, Smart Position Only Tag; GFDL, Geophysical Fluid Dynamics Laboratory; CRW, Correlated Random Walk; GAMM, Generalized Additive Mixed Model; GAM, Generalized Additive Model; SSHRMS, Sea Surface Height root mean square; bathy, bathymetry; bathyrms, bathymetry root mean square

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[1] The authors dedicate this paper in memoriam of our colleague and coauthor, David Foley.

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ensemble of 23 models (IPCC, 2007). As temperatures rise, ocean currents, nutrient availability, water-column stratification, the spatial distribution of primary production, and relative abundance and species composition will be altered (Hoegh-Guldberg and Bruno, 2002; Fogg, 1991; Hinder et al., 2012). Temperature changes will most likely affect marine ectotherms more directly than other species because they already occupy the entirety of their thermal tolerance range, i.e. the extent of their latitudinal habitat based on their temperature tolerance (Sunday et al., 2012).

Leatherback sea turtles (*Dermochelys coriacea*) are the largest living turtle and among the largest living reptiles (Paladino et al., 1990). They are a late-maturing, long-lived species (Hawkes et al., 2009; Avise et al., 1992). Leatherbacks utilize their large body size, blood flow regulation, and changes in swimming speed and activity to regulate internal temperatures (Paladino et al., 1990; Bostrom and Jones, 2007; Bostrom et al., 2010). Leatherbacks are distributed globally and every population undergoes long-distance migrations, traveling from breeding habitats to foraging grounds (Benson et al., 2007, 2011; Shillinger et al., 2008, 2011; Fossette et al., 2010).

The Eastern Pacific leatherback population is distinctive because the population has a persistent migration pattern; female turtles follow a specific migratory corridor and seem to use similar foraging areas (Shillinger et al., 2008). The main nesting population in the Eastern Pacific is located in Playa Grande, Costa Rica (Spotila et al., 1996). At the end of the nesting season, females move rapidly south through strong equatorial currents and disperse into the vast South Pacific Gyre, characterized by low ocean energy and low productivity (Shillinger et al., 2008). In their foraging grounds, the population may feed on gelatinous zooplankton (i.e. jellyfish); although much of their ecology still remains a mystery (Fossette et al., 2011; Heaslip et al., 2012).

Leatherbacks are of conservation concern due to development on nesting beaches, illegal egg harvesting, and fisheries bycatch, that latest being considered the main driver behind leatherback population declines (Hammann et al., 2010). Approximately 1500 Pacific female leatherbacks were killed every year in longline and driftnet fisheries during the 1990s (the total population was 34,500 in 1996; Spotila et al., 1996), which drove Eastern Pacific leatherbacks to the verge of extinction (Spotila et al., 2000). In the past three decades, the Eastern Pacific population has declined by over 90% (Spotila et al., 2000; Santidrián-Tomillo et al., 2007) and climate change may exacerbate these population declines (Saba et al., 2012). For instance, population dynamic models project that temperature increases may reduce Costa Rican leatherbacks′ hatching success and hatchling emergence rate by more than 50% over the next 100 years due to warming of the nesting beach and changes in rainfall (Saba et al., 2012). However, recent studies only consider climate change impacts on the Eastern Pacific population′s nesting grounds. To fully understand how climate change will impact Eastern Pacific leatherbacks, habitat changes need to also be quantified in their migratory and foraging habitat.

This study evaluates projected impacts of climate change on Eastern Pacific leatherbacks′ primary pelagic habitat to forecast vulnerable leatherback habitat and to potentially inform adaptive management strategies and conservation efforts. We also assess the hypothesis that climate change may transform previously undesirable environments into beneficial leatherback habitats (Robinson et al., 2009).

2. Methods

2.1. Tagging and data processing

Female leatherback sea turtles were instrumented with either a Sea Mammal Research Unit (SMRU) Satellite Relay Data Logger (SRDL) tag ($n=36$) or a Wildlife Computer Smart Position Only (SPOT) tag ($n=10$) from 2004 to 2007 (Shillinger et al., 2008). The SRDL tags were programmed to transmit position, temperature, dive data, and tag diagnostic information. The SPOT tags were programmed to collect position data. The satellite transmitters were mounted on the turtles during oviposition using a harness technique (Eckert, 2002). Data from the tags were transmitted via radio signals sent to the Argos satellite system (Argos, 2007). Final position estimates were generated at six hour intervals based on the mean number of raw locations per day using a switching state-space model (SSSM), which was applied to the raw Argos position data. The SSSM incorporated the measurement error in Argos telemetry data to improve position estimates (Jonsen et al., 2007; Shillinger et al., 2011; Bailey et al., 2012).

For each of the 46 leatherback tracks, 150 correlated random walks (CRWs) were created. CRWs are paths that consist of a succession of random steps. Each CRW step is randomly sampled from the distributions of distance and turning angle simultaneously, which are derived from the original leatherback track. Consistent with the 46 tracks, the CRW′s starting point was at Playa Grande, Costa Rica. Each CRW′s initial direction matched its corresponding tag while the speed and turning angle were chosen together randomly from the tag′s entire movement distribution (Fig. 1S). The CRWs serve as pseudo-absences and describe a null model where turtles could travel independent of oceanographic parameters and ecological forcing. Comparing environmental parameters along the CRWs to those along the actual leatherback tracks can test whether leatherbacks are selecting for specific oceanographic features. Pseudo-absences are however not true absences because the migration pathway of untagged leatherbacks is unknown and untagged turtles may have potentially followed a CRW track. However, Wisz and Guisan (2009) determined that randomly selected pseudo-absences can successfully identify the importance of predictor variables for highly mobile species if true absence data is unavailable. The suite of CRWs were flagged and ranked based on the similarity to the actual track in angle and distance traveled (from the starting point to the end point); the lower the flag value, the more similar the CRW was to the leatherback track′s total distance and angle. Twenty-five percent of the highest CRW flag values per leatherback track were removed from the analysis to exclude the most dissimilar tracks, accounting for leatherback turtles known migration patterns (Fig. 2S).

2.2. Satellite-derived environmental data

Remotely sensed environmental data were obtained for both the leatherback and CRW tracks using Xtractomatic (http://coastwatch.pfel.noaa.gov/xtracto/). The data sets included time-series of sea surface temperature (SST), surface chlorophyll-a (chl a) concentration, sea surface height (SSH), SSH variability (root mean square, SSHRMS), vertical current due to Ekman pumping (wekm), SST frontal probability index (FPI), bathymetry (bathy), and rugosity (bathyRMS). These variables have been previously explored as important for leatherbacks in the Southeast Pacific as they are important proxies for ocean features (SSH, SSHRMS, wekm, FPI, bathy, bathyRMS), physiological constraints (SST), and forage base (chl a; Shillinger et al., 2011, Bailey et al., 2012). Estimates of zooplankton distribution globally show similar patterns to chlorophyll (Strömberg et al., 2009), but there are no data currently available on the prey field. For each oceanographic parameter, a mean value was calculated within a box based on the mean latitude and longitude error ($.2^\circ$ longitude $\times$ $.2^\circ$ latitude $\times$ (5–10 day intervals)) and centered at the position of each six hour SSSM-interpolated turtle position (Shillinger et al., 2011). Transformations of the parameters were explored to ensure data were normally distributed. A logarithmic transformation was