RESEARCH SUMMARY

FROM MINI-TRANSMITTERS TO MOLECULAR MAPS: A NEW FRONTIER IN THE STUDY OF AT-SEA MOVEMENTS BY SEA TURTLES

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Every so often there comes a time when scientific knowledge in a particular field of sea turtle biology and conservation sees rapid expansion in a short period. Now, after decades of infrequent study of the lives of sea turtles on the high seas, we've seen a blossom of papers over the last few years that are enlightening our understanding of the pelagic ecology of sea turtles. Indeed, this dearth of knowledge is rooted in the logistical hurdles and inaccessibility of turtles in areas far from shore, but change is happening rapidly thanks to the development of research techniques that seemed far-fetched only a few years ago. In the passages below, I describe three areas of interest that I believe are in the fast lane of research and development. First, in one of the coolest advances in the history of satellite telemetry, we are now able to track the movements of neonate turtles thanks to the smallest-ever satellite tags and innovation in tag attachment methods. Here I describe the work of Kate Mansfield and colleagues in this endeavor. Second, in what is truly a renaissance for stable isotope research of sea turtles, I discuss how researchers are tracking the movements and prior whereabouts of turtles based on only a small piece of skin or scute. And finally, in a superb example of blending to high-technologies, I describe how researchers are linking stable isotope analysis with skeletochronology to determine the duration of an individual's oceanic juvenile stage, otherwise known as the Lost Years. Together, these avenues of research exemplify innovation and rapid technological progress, and while there is still much to be done, they are helping unravel some of the most contemplated mysteries in sea turtle science.

Solar tags and satellite tracking of neonate turtles

With the increasing application of satellite telemetry, more attention than ever is being paid to the hydrodynamics and energetic impacts of transmitter attachment to turtles (Jones *et al*., 2011). Telemetry techniques have evolved much in the last 20 years, and one of the greatest advances for tracking turtles is the development of the direct attachment technique for equipping leatherbacks with satellite transmitters (Fossette *et al*., 2007). But on an entirely new telemetric front, owing to the pioneering efforts by a team of researchers in the US, we are, for the first time able to monitor the movements of post-hatchling / neonate turtles thanks to the progressive miniaturization of satellite tags coupled with a nifty new method for attaching tags to these fast-growing critters. Of course, for years the efforts of Blair Witherington (e.g. Witherington, 2002) and others had pinpointed the whereabouts of neonate sea turtles living among the flotsam and jetsam that aggregates in frontal areas and convergence zones many km from shore. However, not much was known about how these turtles moved in the open ocean. In the mid 2000s, thanks to efforts of George Balazs, Jeffrey Polovina and colleagues, we learned about the movements of headstarted, small juvenile loggerhead turtles *(Caretta caretta)* in the North Pacific (e.g. Polovina *et al*., 2006). However, still elusive was the capability to tag even smaller neonate turtles. After years of yearning for small transmitters, there has been a new technique to come along with transmitters so small that they fit on hatchling and post-hatchling turtles. In what is to my knowledge the satellite telemetry of post-hatchling turtles, Kate Mansfield and colleagues implemented the use of small-scale solar-powered satellite tags and developed an exquisite attachment method that allows for tiny turtles' carapaces to grow while still having the tag attached (Mansfield *et al*., 2012). Owing to these efforts, we are finally able to pinpoint the movements of these small critters in their oceanic developmental grounds, and the first ever insights in this respect are coming from neonate loggerheads tracked in the western North Atlantic (Mansfield and Putman, in Press). In this study, the research team attached solar tags to 17 neonate loggerheads ranging from 11 to 18 cm and tracked their movements for up to 219 days as they moved north along the US southeast coast, and then out into the pelagic realm of the western North Atlantic. Amazingly, one of the neonates was tracked all the way to waters near the Azores, which for the size of the turtle and novelty of the attachment method is a triumph for sea turtle research.

Stable isotope tracking of sea turtles

In addition to the value of stable isotope analysis (SIA) for determining the trophic status and diet of sea turtles, this technique can decipher the key foraging habitats used by sea turtles. While not as precise as satellite telemetry, SIA is much lower in cost, and a viable tool for tracking animal movements because the isotopic composition of consumer tissues integrates isoscape information from foraging environments, such that when a sea turtle moves among spatially discrete food webs that are isotopically distinct (i.e. isoscapes), stable isotope values of its tissues can provide information about its previous location. There have been several studies that have shed light on marine isoscapes, and this is an area of rapid advancement that for now still depends on blending the isotope technique with satellite telemetry, so that turtles' isotopic signatures can be ocean-truthed for their whereabouts. A study by McClellan *et al.* (2010) of loggerhead turtles in the eastern United States was the first study, to my knowledge, that used satellite telemetry to establish the spatial patterns of marine isoscapes; in their case, showing an isotopic dichotomy between juvenile loggerhead sea turtles that foraged coastally versus those that foraged in offshore waters. Zbinden *et al.* (2011) similarly showed a migratory dichotomy and associated phenotypic variation in Mediterranean loggerhead turtles. However, it wasn't until even more recently that researchers have started to decipher the isotope spatial patterns in the oceans in hopes of tracking animal movements based exclusively on the isotope technique (i.e no telemetry). And in some of the first steps to establish an 'isotope map' of the ocean, two studies of loggerheads in the western North Atlantic (Ceriani *et al*., 2012; Pajuelo *et al.,* 2012) linked satellite telemetry with isotope analysis to help elaborate the isotopic spatial patterns in the western Atlantic Ocean, finding that variation in δ13C and δ15N in post-nesting Florida loggerheads can be explained by differences in food-web baseline isotopic signatures that vary spatially. An effort by Seminoff *et al.* (2012) in the Pacific has provided similar insights for Indonesian leatherbacks that used eastern and western Pacific foraging areas. Indeed, there is much more we need to learn to fill out the isoscape map based on sea turtle migrations, but the foundation is being laid for stable isotopes to more richly augment spatial movement information derived from the much-more costly telemetry technique.

Using stable isotopes and skeletochronology to determine the Lost Years duration

Elucidating the duration of time turtles spend in distinct habitats – particularly in the remote pelagic stretches of our World's oceans – is critical to successful conservation, as threats and protection strategies vary greatly between coastal and open ocean habitats. While Archie Carr was the first to speculate on the multi-year duration of small sea turtles' oceanic phase (a.k.a. the Lost Years), there has been a growing suspicion that this phase may be better termed the 'Lost Decade'. But to get at this question required some means to age turtles, and this did not come along until George Zug perfected the skeletochronolgical aging technique (e.g. Zug *et al.*, 2001). With this technique firmly established in the repertoire of next-generation skeletochonologists, such as Melissa Snover and Larisa Avens, the possibilities seem endless. As mentioned in the previous passage, stable isotope values vary spatial in many ocean regions, and that fact that sea turtle humerus bones deposit annual growth rings with nutrients derived from their foraging areas means that each growth ring should have the isotopic profile of the foraging area(s) that was occupied during that year deposited within it. Thus, by studying the isotopes in these growth rings, and knowing what year of life each ring corresponds to, researchers have a chronological annual record of where that turtle resided prior to its death. This is possible because nearshore and offshore regions often have isotope 'signatures' that are distinct from one another. The first efforts linking skeletochronology and SIA were conducted by Melissa Snover, and she was able to discern habitat shifts in loggerhead turtles that had stranded along the U.S. east coast (Snover *et al*., 2010). Since then, a series of new studies have been conducted – or are being conducted – by the likes of Larisa Avens, Bradley MacDonald, and Cali Turner-Tomaszewicz. These studies have expanded from the western North Atlantic to include areas in the Pacific, and I expect that soon we'll have insights on oceanic juvenile stage durations for multiple loggerhead and green turtle *(Chelonia mydas)* populations from around the world. Archie Carr would have been proud.

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