SATELLITE TRACKING OF LEATHERBACK AND LOGGERHEAD SEA TURTLES ON THE SOUTHEAST AFRICAN COASTLINE

NATHAN J. ROBINSON[1#], DARELL ANDERS[2], SANTOSH BACHOO[3], LINDA HARRIS[4], GEORGE R. HUGHES[5], DEON KOTZE[2], SESHNEE MADURAY[2], STEVEN MCCUE[2], MICHAEL MEYER[2], HERMAN OOSTHUIZEN[2], FRANK V. PALADINO[6,7] & PAOLO LUSCHI[8]

[1]Cape Eleuthera Institute, The Island School, Eleuthera, The Bahamas

[2]Department of Environmental Affairs, Branch: Oceans and Coast, Cape Town, South Africa

[3]Ezemvelo KZN Wildlife, Congella, Durban, KwaZulu-Natal, Republic of South Africa

[4]Coastal and Marine Research Institute, Department of Zoology, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa

[5] CEO, Natal Parks Board (Retd.), Howick, South Africa

[6]The Leatherback Trust, Goldring-Gund Marine Biology Station, Playa Grande, Guanacaste, Costa Rica

[7]Department of Biology, Indiana University-Purdue University Fort Wayne, Fort Wayne IN, U.S.A

[8]Department of Biology, University of Pisa, Pisa, Italy

[#]nathan@leatherback.org

INTRODUCTION

The waters of southeast Africa contain important habitats for several sea turtle species, including the leatherback *Dermochelys coriacea*, loggerhead *Caretta caretta*, hawksbill *Eretmochelys imbricata*, green *Chelonia mydas*, and olive ridley turtle *Lepidochelys olivacea*. Many of these species are of conservation concern (Rakotoniria & Cooke, 1994; Thorson *et al*., 2012; Nel *et al*., 2013) and vulnerable to regional threats such as fisheries by-catch or boat-strikes (Bourjea *et al*., 2008; Grantham *et al*., 2008; Pusineri & Quillard, 2008). To help in the development of effective conservation plans for these species, many conservation or research organisations have used satellite transmitters to help identify critical habitats for sea turtles (Harris *et al*., 2015; Robinson *et al*., 2016). Here, we review the movement patterns of sea turtles that have been tracked through satellite telemetry from their nesting beaches on the east coast of South Africa.

Sea turtles nest along most of the southeast African coast line. Leatherback and loggerhead turtles predominantly nest below 22°S from southern Mozambique to northern South Africa, while green, hawksbill, and olive ridley turtles predominantly nest above 22°S and throughout northern Mozambique (Costa *et al*., 2007). In addition, the nesting range of green and hawksbill turtles, although not olive ridley turtles, extends further north into Tanzania (Muir, 2005). The longest running monitoring program for nesting sea turtles in the region, and one of the longest running worldwide, is found in the iSimangaliso Wetland Park (hereafter referred to exclusively as iSimangaliso), South Africa. This project, which was founded in 1963, has predominantly used metal identification tags to monitor the nesting leatherback and loggerhead turtles (Hughes, 2010; Nel *et al*., 2013). In the past few decades, however, these mark-recapture methodologies have been complemented with several satellite tracking studies.

SATELLITE TAG DEPLOYMENT

Three different partnerships have deployed satellite transmitters on the leatherback and loggerhead turtles that nest in iSimangaliso. The first partnership was led by scientists from the University of Pisa, Italy, in collaboration with the Natal Parks Board. The partnership tracked 11 leatherback and four loggerhead turtles between 1996 and 2003 (Luschi *et al*., 2006). The second partnership was led by scientists working for several South African organisations, including Ezemvelo

KZN Wildlife, Department of Environmental Affairs (Oceans and Coasts), the iSimangaliso Wetland Park Authority, as well as Nelson Mandela Metropolitan University. This partnership has now tracked a total of 14 leatherback and 20 loggerhead turtles from 2006 until the present (Harris *et al*., 2015; Harris *et al*., 2017). The third partnership was led by scientists from Purdue University, USA, who tracked 20 leatherback turtles between 2011 and 2013 (Robinson *et al*., 2016, 2017).

KEY FINDINGS

Although iSimamngaliso provides comprehensive protection for the turtles that nest within its borders (Nel *et al*., 2013), until recently it was not known how effective the Park was for protecting inter-nesting turtles. Satellite tracking has now revealed that loggerhead turtles remain a mean distance of 9km from the shoreline during the inter-nesting period (Harris *et al*., 2015). In contrast, leatherback turtles tend to move far greater distances, remaining a mean of 60km from the shoreline (Harris *et al*., 2015). Leatherback turtles also show distinct variability between individuals, with some turtles remaining within 10km of the shoreline, while others making large loops extending over 100km out to sea (Harris *et al*., 2015, Robinson *et al*., 2017). Consequently, loggerhead turtles remain within the protective jurisdiction of iSimangaliso ~95% of the time whereas leatherback turtles do so for only ~25% of the time (Harris *et al*., 2015). More research is needed to determine how to effectively protect leatherback turtles during the inter-nesting period and what drives the inter-nesting movements of these animals. Nonetheless, recent studies suggest that the movements of leatherback turtles may be constrained by the Agulhas Current (Robinson *et al*., 2017).

After the completion of the nesting season, both loggerhead and leatherback turtles conduct long-distance migrations to foraging areas (Figure 1, Figure 2). Of the 20 loggerhead turtles that have been tracked since 2006, 17 have followed migratory routes in the coastal waters of Mozambique (Harris *et al*., 2017). Of the remaining three, two migrated across the Mozambique Channel and into Madagascar's coastal waters and one migrated

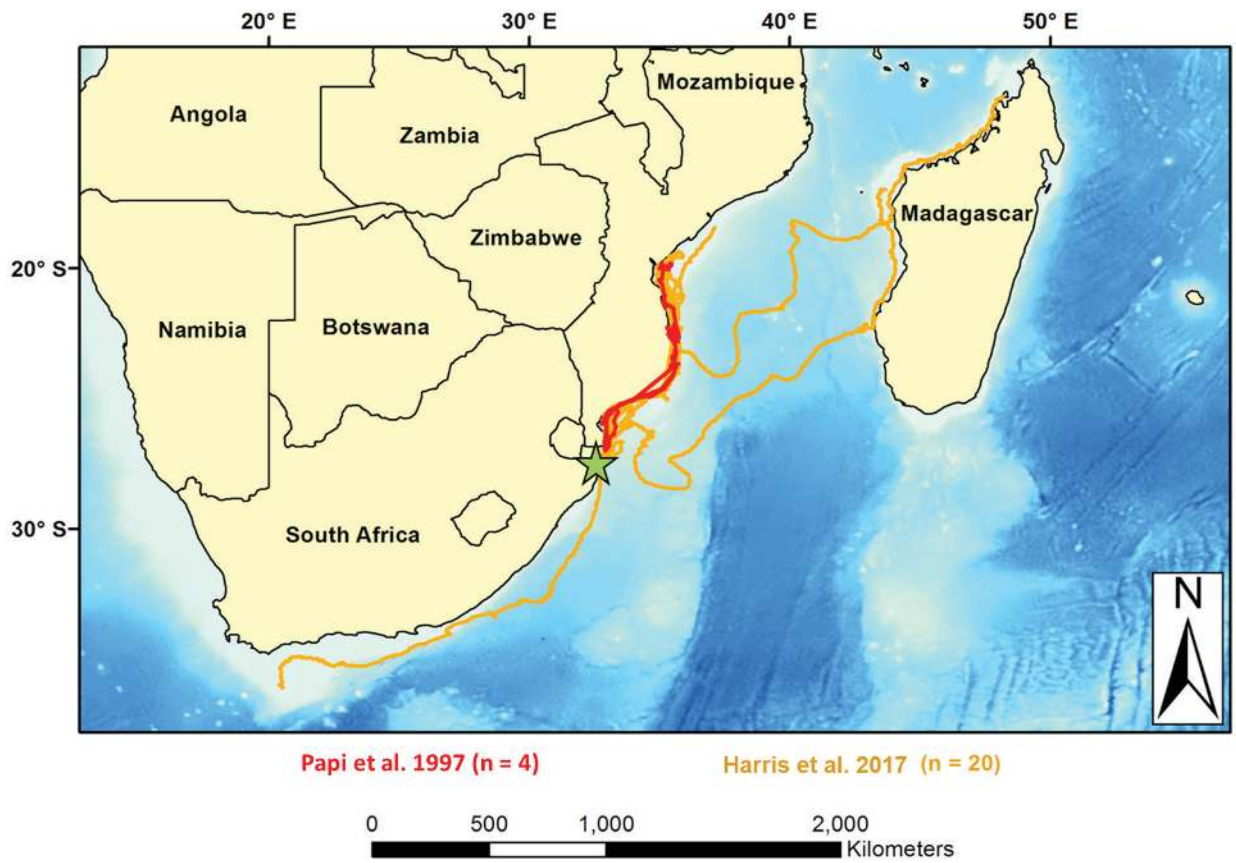

Figure 1. Movements of 24 loggerhead turtles tracked from their nesting beach in the iSimangaliso Wetland Park, South Africa (green star) between 1996 and 2013. Red lines represent the movements of four turtles that have been previously published in Papi *et al*. (1997). Orange lines represent the movements of 20 turtles that were tracked by the South African partnership and published in Harris *et al.* (2017). For reference to colours, see the pdf version available on-line.

south to the coastal waters of the Cape of Good Hope (Harris *et al.*, 2017). Evidently, this only represents a subset of all the foraging habitats utilised by this population. Of the 102 loggerhead turtles with metal tags that have been recaptured since 2012 outside of iSimangaliso, they have occurred over a far wider range of coastal habitats, stretching north from iSimangaliso into Mozambique, Tanzania, and Madagascar, and to lesser extent Kenya and Somalia (de Wet, 2012).

Other satellite tracking studies have also been conducted on the loggerhead turtles in the area to assess the navigational abilities of these animals when displaced from their capture location. In the first of these studies, loggerhead turtles were captured just before oviposition and relocated distances of up to 70km along the coast (Papi *et al.*, 1997). All but one of these animals immediately swam back to the capture site to nest, thus demonstrating an impressive capacity for homing behaviour. In the second study, five animals were captured just before beginning their post-nesting migrations and relocated distances up to 2,193km, often offshore and far away from their presumed foraging areas in the coastal waters of Mozambique (Luschi *et al.*, 2003a). Three of these turtles migrated and eventually settled in coastal foraging habitats, while two instead conducted nomadic wandering movements in the open-ocean of the western Indian Ocean (Mencacci *et al.*, 2010). Presumably, these animals were unable to compensate their migratory behaviour to account for their earlier displacement (Luschi *et al.*, 2003a).

In distinct contrast to the loggerhead turtles, the first satellite tracking studies on leatherback turtles revealed that almost all individuals migrated into pelagic habitats (Figure 2). After nesting, leatherback turtles would migrate south, following the Agulhas Current along the east coast of South Africa before heading east into the Agulhas Retroflection or west in the Benguela Upwelling System (Hughes *et al.*, 1998; Luschi *et al.*, 2003b; Lambardi *et al.*, 2008). Once in open-ocean water,

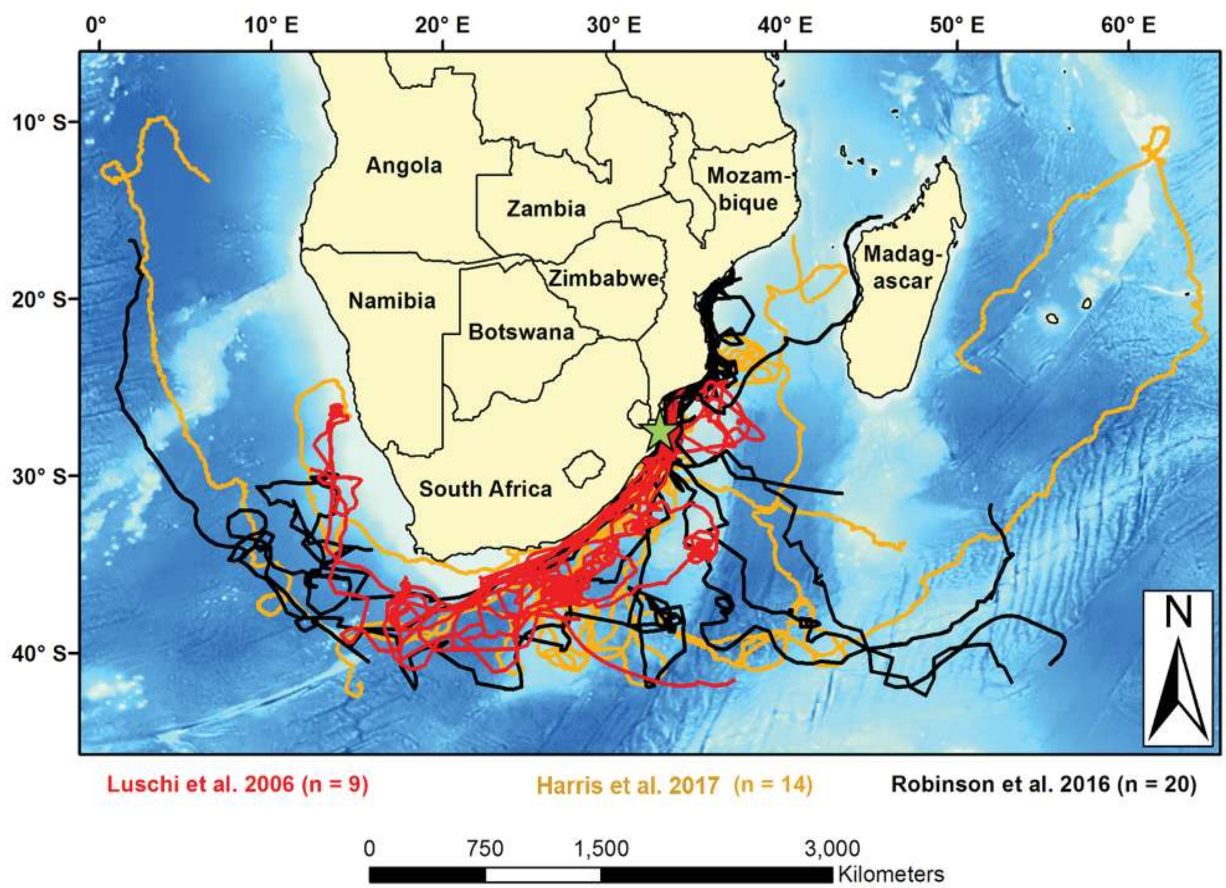

Figure 2. Movements of 42 leatherback turtles tracked by satellite telemetry from their nesting beach in the iSimangaliso Wetland Park, South Africa (green star) between 1996 and 2013. Red lines represent the movements of nine turtles published in Luschi *et al*. (2006). The orange lines represent the movements of 14 turtles published in Harris *et al.* (2017). The black lines represent the movements of 20 leatherback turtles published in Robinson *et al*. (2016). For reference to colours, see the pdf version available on-line.

the leatherback turtles followed meandering movement patterns that were considered more "as a prolonged sojourn in vast feeding areas than as a true migration" in Luschi *et al*. (2006). Oceanographic analyses revealed that these movements largely followed the prevailing surface flow of the Agulhas Current (Luschi *et al*., 2003b; Lambardi *et al*., 2008), which flows south along the east coast of South Africa. However, these turtles did not drift passively within the currents, but were found to swim actively during most of their journey, albeit without being able to detect the direction of the flow that they were being entrained by (Galli *et al*., 2012). Satellite telemetry data also revealed that turtles dove almost continuously throughout their journey, mainly at depths shallower than 200m, but with occasional deep dives that could exceed 1,000m (Sale *et al*., 2006; Robinson, unpubl. data).

Supporting the early characterisation of leatherback turtles as pelagic specialists, by 2010 only five leatherback turtles with metal tags had ever been captured outside of iSimangaliso (de Wet, 2012). However, a recent study has shown that the migratory behaviour of these animals might be far more diverse. In a recent satellite tracking study, eight of the 16 leatherback turtles tracked swam to coastal foraging areas. Specifically, these animals swam north of the nesting area before reaching resident foraging areas in the shallow waters (less than 50m depth) of the Sofala Banks in the Mozambique Channel (Robinson *et al*., 2016). These turtles, which were tracked up to 209 days, remained in this coastal habitat for the entire tracking duration. The importance of these habitats for leatherback turtles was further confirmed by stable isotope analysis which estimated that 41% of the leatherback turtles nesting in iSimangaliso forage in the Sofala Banks (Robinson *et al*., 2016). Although leatherback turtles have been recorded foraging in relatively small, shallow coastal habitats in other locations around the world (James *et al*., 2005; Dodge *et al*., 2014), such behaviour is usually tied to seasonal abundance of food in these habitats during summer months (Wallace *et al*., 2015). The presence of leatherback turtles year-round in the Sofala Banks suggests that this habitat must also host an exceptionally high abundance of gelatinous zooplankton – the obligate prey of leatherback turtles.

CONCLUSION

The leatherback and loggerhead turtles of South Africa have been satellite tracked intensively for many years now and much is now known about their in-water behaviour. Interestingly, some of the earliest paradigms concerning the habitat preferences of these species, e.g. leatherback turtles as open-ocean wanderers and loggerhead turtles as coastal specialists, were largely established following studies conducted on these populations (Luschi *et al*., 2006). Through continued tracking however, it is now clear that the migratory patterns of both species are far more diverse than originally considered. This highlights how far we have come in understanding the spatial ecology of these animals and how much there is still to learn. For example, satellite tracking studies in iSimangaliso are yet to investigate the movements of male or non-adult leatherback or loggerhead turtles in the region. Green and hawksbill turtles are also commonly encountered in the waters of iSimangaliso, yet no published studies have reported on the movement patterns of these animals.

ACKNOWLEDGEMENTS

The satellite tracking studies presented in this study were conducted by scientists from several organizations including University of Pisa (Italy), Natal Parks Board (South Africa) and its successor Ezemvelo KZN Wildlife, Department of Environmental Affairs: Oceans and Coasts (South Africa), the iSimangaliso Wetland Park Authority (South Africa), Nelson Mandela Metropolitan University (South Africa), Purdue University (USA), and The Leatherback Trust (USA).

Literature cited:

Bourjea, J., R. Nel, N.S. Jiddawi, M.S. Koonjul & G. Bianchi. 2008. Sea turtle bycatch in the West Indian Ocean: Review, recommendations and research priorities. *Western Indian Ocean Journal of Marine Science* 7: 137-150.

Costa, A., H. Motta, M.A.M. Pereira, E.D.J. Videira, C.M.M. Louro & J. João. 2007. Marine turtle in Mozambique: Towards an effective conservation and management programs. *Marine Turtle Newsletter* 117:1-3.

de Wet, A. 2012. Factors affecting survivorship of loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtles of South Africa. Masters' Thesis. Nelson Mandel Metropolitan University. South Africa.

Dodge, K.L., B. Galuardi, T.J. Miller & M.E. Lutcavage. 2014. Leatherback turtle movements, dive behavior, and habitat characteristics in ecoregions of the Northwest Atlantic Ocean. *PLoS ONE* 9: e91726.

Galli. S., P. Gaspar, S. Fossette, B. Calmettes, G.C. Hays, J.R.E. Lutjeharms & P. Luschi. 2012. Orientation of migrating leatherback turtles in relation to ocean currents. *Animal Behaviour* 84: 1491-1500.

Grantham, H.S., S.L. Petersen & H.P Possingham. 2008. Reducing bycatch in the South African pelagic longline fishery: The utility of different approaches to fisheries closures. *Endangered Species Research* 5: 291-299.

Harris, L.R., R. Nel, H. Oosthuizen, M. Meÿer, D. Kotze, D. Anders, S. McCue & S. Bachoo. 2015. Paper-efficient multi-species conservation and management are not always field-effective: The status and future of Western Indian Ocean leatherbacks. *Biological Conservation* 191: 383-390.

Harris, L.R., R. Nel, H. Oosthuizen, M. Meÿer, D. Kotze, D. Anders, S. McCue & S. Bachoo. 2017. Managing conflicts between economic activities and threatened migratory marine species toward creating a multiobjective blue economy. *Conservation Biology* 32: 411-423.

Hughes, G.R., P. Luschi, R. Mencacci & F. Papi. 1998. The 7000-km oceanic journey of a leatherback turtle tracked by satellite. *Journal of Experimental Marine Biology and Ecology* 229: 209-217.

Hughes, G.R. 2010. Loggerheads and leatherbacks in the Western Indian Ocean. *Indian Ocean Turtle Newsletter* 11: 24-31.

James, M.C., C.A. Ottensmeyer & R.A. Myers. 2005. Identification of high-use habitat and threats to leatherback sea turtles in northern waters: new directions for conservation. *Ecology Letters* 8: 195-201.

Lambardi, P., J.R.E. Lutjeharms, R. Mencacci, G.C. Hays & P. Luschi. 2008. Influence of ocean currents on long-distance movement of leatherback sea turtles in the Southwest Indian Ocean. *Marine Ecology Progress Series* 353: 289-301.

Luschi, P., G.R. Hughes, R. Mencacci, E. De Bernardi, A. Sale, R. Broker, M. Bouwer & F. Papi. 2003a. Satellite tracking of migrating loggerhead sea turtles (*Caretta caretta*) displaced in the open sea. *Marine Biology* 143: 793-801.

Luschi, P., A. Sale, R. Mencacci, G.R. Hughes, J.R.E. Lutjeharms & F. Papi. 2003b. Current transport of leatherback sea turtles (*Dermochelys coriacea*) in the ocean. *Proceedings of the Royal Society of London B: Biological Sciences* 270: S129-S132.

Luschi, P., J.R. Lutjeharms, P. Lambardi, R. Mencacci, G.R. Hughes & G.C. Hays. 2006. A review of migratory behaviour of sea turtles off southeastern Africa. *South African Journal of Science* 102: 51-58.

Mencacci, R., E. De Bernardi, A. Sale, J.R. Lutjeharms & P. Luschi. 2010. Influence of oceanic factors on long-distance movements of loggerhead sea turtles displaced in the southwest Indian Ocean. *Marine Biology* 157: 339-349.

Muir, C. 2005. The Status of Marine Turtles in the United Republic of Tanzania, East Africa. In: *Sea Sense*. Report commissioned by the National Tanzania Turtle Committee. 40pp.

Nel, R., A.E. Punt & G.R. Hughes. 2013. Are coastal protected areas always effective in achieving population recovery for nesting sea turtles? *PLoS ONE* 8: e63525.

Papi, F., P. Luschi, E. Crosio & G.R. Hughes. 1997. Satellite tracking experiments on the navigational ability and migratory behaviour of the loggerhead turtle *Caretta caretta*. *Marine Biology* 129: 215-220.

Pusineri, C. & M. Quillard. 2008. Bycatch of protected megafauna in the artisanal coastal fishery of Mayotte Island, Mozambique Channel. *Western Indian Ocean Journal of Marine Science* 7: 195-206.

Rakotonirina, B. & A. Cooke. 1994. Sea turtles of Madagascar - their status, exploitation and conservation. *Oryx* 28: 51-61.

Robinson, N.J., S.J. Morreale, R. Nel & F.V. Paladino. 2016. Coastal leatherback turtles reveal conservation hotspot. *Scientific Reports* 6: 37851.

Robinson. N.J., S.J. Morreale, R. Nel & F.V. Paladino. 2017. Movements and diving behaviour of inter-nesting leatherback turtles in an oceanographically dynamic habitat in South Africa. *Marine Ecology Progress Series* 571: 221-232.

Sale, A., P. Luschi, R. Mencacci, P. Lambardi, G.R. Hughes, G.C. Hays, S. Benvenuti & F. Papi. 2006. Long-term monitoring of leatherback turtle diving behaviour during oceanic movements. *Journal of Experimental Marine Biology and Ecology* 328: 197-210.

Thorson, J.T., A.E. Punt & R. Nel. 2012. Evaluating population recovery for sea turtles under nesting beach protection while accounting for nesting behaviours and changes in availability. *Journal of Applied Ecology* 49: 601-610.

Wallace, B.P., M. Zolkewitz & M.C. James. 2015. Fine-scale foraging ecology of leatherback turtles. *Frontiers in Ecology and Evolution* 3: 15.