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Off-the-shelf GPS technology to inform marine protected areas for marine turtles

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ABSTRACT

The financial expense of tracking solutions often impedes effective characterisation of habitat use in threatened marine megavertebrates. Yet some of these taxa predictably aggregate at coastal breeding sites, providing conservation opportunities. Toward a low-cost solution for tracking marine megavertebrates, we trial conventional GPS data loggers against Argos satellite transmitters for assessing inter-nesting habitat use of marine turtles. Devices were attached to green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles nesting at a study site in Cyprus, where patrol teams were in place to retrieve GPS loggers from turtles returning to lay subsequent clutches. GPS tracking revealed loggerhead turtles to predominantly use areas outside the boundaries of an MPA proposed for the region, while both species under-used much of the MPA area. Due to high location error, Argos data were considered unsuitable for such fine-scale assessments (all location classes except Z were included in our analysis). However, Argos tracking showed half the loggerhead turtles sampled also nested outside of the patrolled study area, demonstrating connectivity with other proposed MPAs. This was not accounted for by GPS tracking, because females exhibiting this behaviour rarely returned to the study beach, precluding GPS retrieval, thus, demonstrating the power of remote data access. The low-cost GPS technology could be considered in similar cases, where recapture is likely and where funding barriers preclude the use of Argos-relay fast-acquisition GPS technology. In combining the accuracy GPS and the continuity of Argos, the latter provides the best solution in most scenarios, but at far greater cost.

1. Introduction

Marine megavertebrates typically disperse over large spatial scales, across which anthropogenic threats are diverse, difficult to assess and therefore challenging to mitigate (Block et al., 2001; Croxall et al., 2005; Maxwell et al., 2013; Scales et al., 2014). As conservation becomes increasingly important to human development, animal tracking studies have become key in establishing priority areas at sea for addressing loss of biodiversity (Anadón et al., 2011; Coll et al., 2012; Ramos et al., 2017). To meet the demand of growing research and need, biologging solutions for marine megavertebrates have evolved to encompass a broad range of species, scenarios and biological questions (reviewed by Crossin et al., 2014 and Hays, 2014).

Prior to the inception of Argos-based satellite tracking in the 1980s, marine megavertebrate habitat use studies were reliant on mark-recapture methods (Godley et al., 2008). Under many circumstances recapture of study animals is highly improbable, and their movements may be broad, unpredictable and remote with great effort and extended durations needed (eg. Horrocks et al., 2016). Animal tracking in the marine realm has therefore become heavily reliant on the Argos satellite system for real time global location estimation and data retrieval (Gredzens et al., 2014; Martínez-Miranzo et al., 2016; Reynolds et al., 2017; Thums et al., 2017). The cost of taxon-bespoke Argos platform transmitter terminals (PTTs) along with the associated Argos system fees is typically $2000–6000 USD per study animal, depending on the type of unit used and the duration of tracking. This has meant that understanding the habitat requirements of many populations of conservation concern has been fiscally unachievable (Jeffers and Godley, 2016). In some cases, protected areas could have been more effective, had tracking data been incorporated in their design (Witt et al., 2008;

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Hays et al., 2014., Mazor et al., 2016).

While their broad dispersal poses a management challenge, many marine megavertebrate taxa aggregate to breed/nest/rear young at predictable locations and during set seasons, often in human-populated coastal areas, where the diversity and magnitude of anthropogenic threats can be elevated (Barlow et al., 2002; Castillo-Géniz et al., 1998; Haynes, 1987). At breeding sites, human effects (such as direct harvesting, habitat degradation) are acute because reproductive individuals and/or the process of reproduction are impacted. Conversely, breeding aggregations present a valuable opportunity for conservation. If priority coastal areas can be identified and human activities within these areas managed, then reproduction can be safeguarded and, indeed, some populations have shown significant and sustained recovery after cessation of decades or centuries of human pressures at breeding sites (Staniland et al., 2011; Weber et al., 2014).

Aggregation at breeding sites may provide an opportunity for data loggers to be deployed and subsequently retrieved, negating the requirement for remote data links. For example, onboard data loggers have been used to study incubating seabirds (Scheffer et al., 2012), whelping seals (Jeanniard-du-Dot et al., 2017) and nesting marine turtles (Houghton et al., 2002). Such taxa show fidelity to terrestrial breeding sites which they visit repeatedly within seasons, allowing adequate recapture rates for biologging studies. The reduction in size of low-cost (approximately $75 USD), off-the-shelf GPS loggers, developed for the more competitive human tracking market, has increased the financial feasibility of animal tracking (e.g. when modified to track birds: Bodey et al., 2014). Such units require extended surface time to acquire satellite ephemerides and almanac data, so for diving marine megavertebrates that surface only briefly to breathe, tags use fast-acquisition GPS logging technology such as FastLoc® (eg. Hoskins et al., 2015). But such tags are relatively expensive due to technology copyrighting and the cost of calibrating and individually testing tags for specific taxa (eg $3300 USD pers. comm Kevin Lay, Wildlife Computers). Even at discrete breeding sites where probabilities of recapture are relatively high, a proportion of tags will be lost, as not all animals will be recaptured. Given the expense of fast-acquisition GPS tag losses, an Argos-relay to upload archived GPS data is thus advisable, again at significant additional cost per study animal (eg $5000 USD pers. comm Kevin lay, Wildlife Computers), plus monthly Argos payments.

Among diving marine megavertebrate taxa, marine turtles are an appropriate group for tracking studies using archival data loggers, because they migrate from dispersed foraging grounds to aggregate off discrete beaches, onto which females emerge predictably to lay multiple nests. During mating and inter-nesting periods (the period between subsequent nesting events), marine turtles usually spend many weeks or months within habitats proximal to their nest sites, where Marine Protected Areas (MPAs) can be established to mitigate threats such as fisheries bycatch (Casale et al., 2017; Casale and Heppell, 2016), industrial activities such as seismic surveys (Nelms et al., 2016) or dredging (Whittock et al., 2017), limited or prolonged pollution events (Lauritsen et al., 2017; Wallace et al., 2017), boat strikes (Denkinger et al., 2013), human exploitation (Stringell et al., 2015) and human disturbance (Schofield et al., 2010; Zbinden et al., 2007). Many of these are prevalent in the Mediterranean (Casale et al., 2018).

To delimit priority marine turtle habitat-use zones, telemetry is often the most efficacious method. Where habitat use is being studied at such fine scales as during inter-nesting movements, GPS-quality location estimates have been advised (Thomson et al., 2017; Witt et al., 2010), but, due to the short surfacing periods of marine turtles, these have to date required Argos-relay fast-acquisition GPS devices (Schofield et al., 2007, 2009a; Shimada et al., 2017., Thomson et al., 2017). Considerable funding barriers (tens to hundreds of thousands of dollars per site) therefore exist to establishing well managed MPAs off the thousands of protected nesting beaches identified and monitored around the world (Hamann et al., 2010).

At a monitored nesting site in northern Cyprus, where nearly all nesting turtles are encountered by an established field team (Stokes et al., 2014), we set out to trial and compare the utility of conventional GPS loggers and Argos-only satellite telemetry (PTTs), in assessing the inter-nesting habitat use of sympatric green (*Chelonia mydas*) and loggerhead turtles (*Caretta caretta*). Using marine turtles as a case example for diving marine megavertebrates, our goals were to determine whether Argos-linked fast-acquisition GPS technology was necessary, or whether either Argos PTTs or conventional GPS loggers could be used at lower cost.

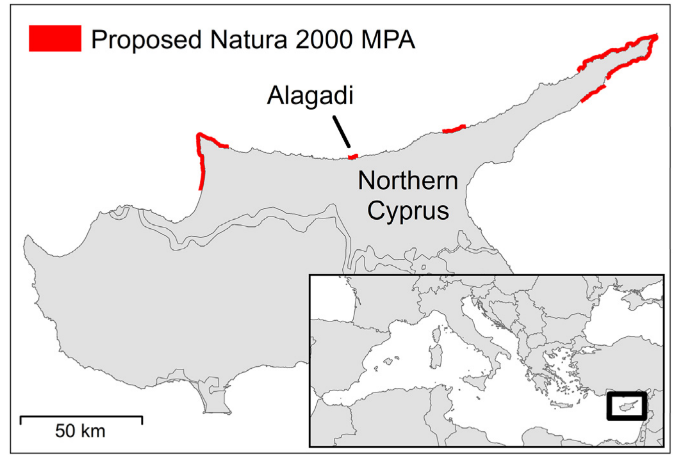

Fig. 1. Location of study site in the Eastern Mediterranean and proposed Natura 2000 MPAs.

2. Methods

2.1. Study area

In northern Cyprus, nesting of green turtles and loggerhead turtles is sympatric; some nesting beaches are used more intensively by one species than the other, but both species use all monitored beaches at least occasionally. Intensive night-time monitoring and tagging has been undertaken at Alagadi Beach (Fig. 1) since 1993. These two bays of 1.2 and 0.8 km in length, form part of a locally designated Specially Protected Area and boundaries have been delineated for a proposed Natura 2000 site (European Union network of protected areas; Fuller et al., 2009a). The Natura 2000 site management plan includes an MPA, within which fisheries and other human pressures are to be regulated to protect marine turtles while they are aggregating off the nesting beaches (Fig. 1). To prevent disturbance of nesting females the Department for Environmental Protection enforce closure of the Alagadi beaches between 20:00 and 08:00 and the Society for the Protection of Turtles (SPOT) in partnership with the Marine Turtle Research Group at University of Exeter, are permitted to undertake studies. An international team of volunteers are hosted by SPOT near Alagadi beaches and beach patrols are made at 10 min intervals throughout each night to ensure that all nesting females of both species are identified, monitored and tagged (Broderick et al., 2002; Stokes et al., 2014). The mean annual number of green and loggerhead turtles nesting at the study site are 74 and 35 females respectively (2013 to 2017).

2.2. Deployment method and location data handling – Argos PTT

Twenty-six female green turtles and 18 female loggerhead turtles were tracked after nesting at Alagadi between 1998 and 2015 (for post-nesting analysis see Stokes et al., 2015; Snape et al., 2016, Bradshaw et al., 2017). Argos PTTs ((Platform Terminal Transmitters) for details see online Appendix Table A1) were attached using epoxy resin according to the method described by Godley et al. (2002). Of the tracked females 17 green turtles and 11 loggerhead turtles laid subsequent