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Informing Marine Protected Area Designation and Management for Nesting Olive Ridley Sea Turtles Using Satellite Tracking

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Understanding the horizontal and vertical habitat of olive ridley sea turtles (*Lepidochelys olivacea*), a threatened species, is critical for determining regions for protection and relevant gear modifications that may effectively reduce bycatch, the largest threat to this species. Satellite transmitters were used to determine the movement and dive behavior of 21 female olive ridley turtles tagged in Pongara National Park, Gabon during the 2012, 2013, and 2015 nesting seasons. A switching state-space model was used to filter the tracking data and categorize the internesting and post-nesting movements. Gridded utilization distribution (UD) home range analysis of tracking data revealed that the entire core habitat occurred in the Komo Estuary during the internesting period. Within the Komo Estuary, 58% of this core UD occurred in shipping lanes. Dive data from the 2015 tagging season revealed that during the internesting period, turtles spent the majority of their time resting on the estuary seabed. Approximately 20% of all dive time was spent on the bottom and all maximum dive depths corresponded to the depth of the seabed, indicating that bottom set gear during the internesting period may pose the greatest potential for fisheries interactions. National parks currently protect many of the nesting sites and the Gabon Bleu initiative has formally designated 10 new marine parks and a network of community and industrial fishing zones; this data was a layer used in determining the park and zone boundaries. Shared use of the estuary by fisheries, shipping, and olive ridley turtles creates a need for management measures to reduce interactions. Thus, the results from this study can further provide detailed information that can be used to support the development of evidence-based management plans.

Keywords: home range, marine protected area, shipping, bycatch, dive behavior, Central West Africa

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INTRODUCTION

Protecting long-lived, highly migratory marine species is challenging since they encounter multiple threats across broad areas and in different life stages (Witt et al., 2011; Maxwell et al., 2013; Lascelles et al., 2014), often requiring multi-faceted and multi-national conservation efforts (Blumenthal et al., 2006; Gore et al., 2008; Maxwell et al., 2011; Croxall et al., 2012; Pikesley et al., 2013b; Doherty et al., 2017). Several studies have used satellite telemetry to describe the horizontal movement data of large marine vertebrates (Godley et al., 2008; Block et al., 2011; Hawkes et al., 2011; Hazen et al., 2012; Yurkowski et al., 2016; Citta et al., 2017; Vaudo et al., 2017) and to determine overlap with anthropogenic threats such as fisheries (seabirds: Suryan et al., 2007; Bugoni et al., 2009; Žydelis et al., 2011; sea turtles: da Silva et al., 2011; Witt et al., 2011; Revuelta et al., 2015; marine mammals: Geschke and Chilvers, 2010; Rosenbaum et al., 2014; sharks: Holmes et al., 2014), shipping (marine mammals: Mate et al., 1997; Schorr et al., 2009), and in-water habitat degradation (seabirds: Montevecchi et al., 2012; marine mammals: Johnson and Tyack, 2003; Rosenbaum et al., 2014). Satellite telemetry has been critical in evaluating threat exposure for marine species (Witt et al., 2008; Maxwell et al., 2013; Lascelles et al., 2014) and assessing how efficient conservation boundaries, such as Marine Protected Areas (MPA), are at encompassing the wide ranging habitat distribution of migratory species (Hart et al., 2010; Scott et al., 2012; Young et al., 2015; Maxwell et al., 2016).

Olive ridley turtles (*Lepidochelys olivacea*), like other sea turtle species, lay multiple clutches of eggs in a nesting season (Plotkin, 2007; Maxwell et al., 2011). Therefore, they remain in the vicinity of nesting beaches for several weeks at a time (Whiting et al., 2007; Hamel et al., 2008; da Silva et al., 2011; Maxwell et al., 2011), termed the internesting period, during which they are susceptible to additional anthropogenic impacts (Pikesley et al., 2013a). This period also makes sea turtles ideal candidates for conservation measures because both sexes congregate in the same waters to breed and females typically return to the same beaches to nest multiple times in the same season (Van Buskirk and Crowder, 1994).

Olive ridley turtles are a vulnerable species as defined by the International Union for Conservation of Nature and Natural Resources (IUCN) Red List due to over-exploitation and characteristics such as slow growth rate, late reproductive maturity, and low hatchling survival rate (Abreu-Grobois and Plotkin, 2008). These factors make it difficult to maintain sufficient populations in the face of anthropogenic influences (Abreu-Grobois and Plotkin, 2008). In the East Atlantic, one of the largest threats to olive ridley turtles is fisheries bycatch, including trawls and gillnets (Frazier et al., 2007; Parnell et al., 2007). In this region, olive ridley turtles are distributed across multiple commercial and artisanal fishing hotspots as well as political boundaries, making conservation practices difficult (Godgenger et al., 2009; Wallace et al., 2013; Metcalfe et al., 2015b), however MPAs are being developed in some parts of the East Atlantic, such as in Gabon, Africa.

Horizontal movement and habitat use are important measures for conservation but dive behavior can also be critical to understanding in-water threats to marine species. Understanding water column use can influence fisheries management strategies such as gear set depth, soak time, and gear type (Lewison et al., 2013). For example, in the North Pacific, Polovina et al. (2003) used turtle dive data to determine that banning shallower set longlines would decrease the amount of bycatch for sea turtles, specifically loggerheads (*Caretta caretta*) and olive ridley turtles, because they spent most of their time in the upper water column. Presently, little is known about dive behavior of olive ridley turtles and even less is known about their dive behavior during the internesting period. The only olive ridley turtle dive studies are from the West Atlantic and focus on post-nesting dive behavior (Plot et al., 2015). Understanding how olive ridley turtles use the water column is crucial to developing evidence based management plans within the MPA fishery zones.

In 2014, the President of Gabon announced and initiative known as "Gabon Bleu," a marine spatial planning process that included the creation a network of MPAs in Gabonese waters. The final boundaries were released in June 2017. In order to inform this process, planners required the distribution of species as well as putative threats (Roberts and Hamann, 2016). Similar to other Central African countries, Gabon has more small-scale fishing than industrial fishing and a majority of fishermen use purse seine, drift gillnet, and bottom set gillnet techniques (Metcalfe et al., 2015b). Through field surveys, Metcalfe et al. (2015b) found that 62% of the 1,831 boats were working out of Libreville and the Komo Estuary, which is also adjacent to Pongara National Park, one of the largest olive ridley nesting beaches in Gabon (Metcalfe et al., 2015a). Artisanal fishing was also found to be heavily aggregated in estuaries, and river and lagoon mouths (Metcalfe et al., 2015b). Based on a study of sea turtle bycatch from industrial fisheries in Gabonese waters, olive ridley turtles were the most impacted sea turtle species, representing 80% of the total sea turtle bycatch (Casale et al., 2017). Furthermore, a study on beached carcasses has indicated that bycatch of sea turtles, particularly olive ridley turtles, is appreciable in Gabon (Parnell et al., 2007). The Komo Estuary is also a major shipping region, however, the impacts of shipping on sea turtles have not been well studied. Impacts may occur in the form of pollution from vessels via discharge of oil, fuel, organic pollutants, sewage, and debris, noise pollution, or through direct ship strikes (Abdulla and Linden, 2008; Maxwell et al., 2013 and references within). Even when the magnitude of impacts is unclear, understanding where and when turtles and threats overlap is necessary to inform conservation strategies.

To inform the Gabon Bleu initiative, we undertook satellite tracking of olive ridley turtles in Northern Gabon to determine distribution of sea turtles within Pongara National Park and the adjacent Komo Estuary, a heavily used waterway, and compared this distribution to threats in the region. We collected location and dive depth data from nesting female olive ridley turtles to better understand their vertical and horizontal habitat movement along the Gabonese coast. We further consider the movements of olive ridley turtles in relation to the boundaries of shipping lanes and the boundaries of newly designated MPAs. Movement and dive data provided a basis to inform the boundaries of

MPAs and other marine zones and can be used to further inform management plan for zones in the area.

METHODS

Ethics Statement

All federal, international, and institutional guidelines were followed, and this study was approved by and carried out in accordance with the recommendations of University of Exeter's College of Life and Environment Sciences Ethics Committee and the Institutional Animal Care and Use Committee at Old Dominion University (IACUC Permit 15-016). Permissions to work within park boundaries and with the study species were issued by the Gabon Agence Nationale des Parcs Nationaux (AEl5025, AR0010/12, AE140003).

Study Area

Gabon, Central West Africa, is home to the largest olive ridley rookery in the Atlantic (Metcalfe et al., 2015a), however, even with global decline and their vulnerable status this region remains data deficient. Previously, an expansive network of national parks protected 81% of sea turtle beach nesting sites (Metcalfe et al., 2015a), but in-water protection only existed in southern Gabon via Mayumba National Park. However, the government recently designated a new network of MPAs that consist of 10 marine parks covering 23% of the Gabonese Economic Exclusive Zone.

One of the newly created MPAs is contiguous to Pongara National Park. It is an important area for both people and marine life, adjacent to the Komo Estuary and proximate to Gabon's capital city, Libreville, one of the main anthropogenic use regions in Gabon and most populated city in the country with ∼800,000 inhabitants. The Komo Estuary is the location of a major port and is also an important artisanal fishing region.

Satellite Transmitter Deployment

The internesting movements of 21 olive ridley sea turtles were monitored from Pongara National Park, one of the largest nesting beaches in Gabon (Metcalfe et al., 2015a), over three nesting seasons (2012, 2013, 2015). Satellite transmitters were attached to nesting females early in the nesting season to capture internesting movements (Maxwell et al., 2011). Olive ridley turtles at Pongara National Park nest between October and January, peaking in late October to early November (Metcalfe et al., 2015a). SPOT-293A transmitters (Wildlife Computers, Redmond WA, USA) were deployed between 26th October and 5th November 2012 ($n = 6$) and 12nd October and 13th October 2013 ($n = 5$). SPLASH10-351C (Wildlife Computers, Redmond WA, USA) were deployed between 27th October and 31st October 2015 ($n = 10$). Attachment followed techniques described in Maxwell et al. (2011), and did not start until the female began oviposition and care was taken not to disturb the nest during attachment. Transmitters were attached to the flattest portion of the two front most vertebral scutes of the carapace using either T308+™ Epoxy (Powers Fastners, Brewster NY, USA) in 2012 and 2013 or Superbond 1:1 Expoxy Adhesive (FiberGlass Coatings, Inc. St. Petersburg FL, USA) in 2015. First, the carapace was cleaned of algae and smoothed using sandpaper and sea water; once cleared the area was dried with acetone. The transmitter was placed with the antennae pointing toward the head and perpendicular to the top of the carapace and the epoxy was molded to ensure attachment around the edges. To minimize stress and handling, a wooden box was placed around the female after she finished covering the nest. Once the epoxy set, the female was released and monitored to make sure she returned to the water. Before tag attachment curved carapace length (CCL) and curved carapace width (CCW) were measured, and metal flipper tags Monel 1005-62 (National Band and Tag Co., Newport, KY) were attached to the front flippers. Satellite data were collected via the Argos Satellite System.

Track Analysis and State-Space Model

All Argos location quality points except for 0 and Z were used in the movement analysis (i.e., location classes 3, 2, 1, A, B) and a hierarchal state-space model (hSSM) with a time interval of 3.5 h was used to filter the location data and determine internesting behavior (Breed et al., 2009; Jonsen et al., 2013). SSMs use parameters associated with an animal's position (Jonsen et al., 2003) and determine a behavioral state for each point in time (Breed et al., 2009; Jonsen et al., 2013). Through the use of a two part model, an equation is used to determine how behavioral states change randomly in time and previous locations are used to estimate the next location based on an independent random walk model and biological constraints of the animal, such as how far they can travel in a day (Jonsen et al., 2013). SSMs are used to draw inferences from data on behavioral changes through time and how it can be related to actual biological processes (e.g., foraging, breeding, or migrating). The model also accounts for observation error between the satellite-produced location and the unseen true location and credible limits for the predicted locations (Breed et al., 2009). A hSSM structure was used since we had multiple tagged animals and wanted to focus on population level dynamics instead of individual movement. A short track, run individually through the model, could not produce accurate behavioral states but when run with other tracks in the hSSM, behaviors can then be categorized (Breed et al., 2009). The hSSM is ideal when behaviors cannot be directly observed throughout the track, such as with the olive ridley turtles, therefore data such as speed and turn angle are used to delineate probable behavior (Jonsen et al., 2013).

We used the hSSM model to run 2 Markov Chain Monte Carlo simulations for 10,000 iterations with a burn-in of 15,000 to generate 10,000 posterior samples in the "bsam" package in R (Jonsen et al., 2005; Jonsen, 2016). We used a thinning factor of 10 to minimize the within-chain sample autocorrelation. We used a time step of 0.15, creating a 3.5-h time interval between points; time step determined by finding the average time between existing points, following Maxwell et al. (2011). Trace plots were examined for autocorrelation and to ensure that they converged on a mean density, and resulting tracks were examined to determine if tracks made biological sense, the most important validation metric (G. Breed, pers. comm.). Due to the coastal and estuarine nature of our study area, resulting hSSM locations occasionally occurred on land. These locations were shifted, such that previous and post-locations were used

to determine directionality of movement. The inland location was then manually moved to the closest in-water location. If a relatively confident location could not be estimated then the location was discarded from analysis.

The hSSM also assigned a behavioral estimate between 1 and 2 to each location point based on the mean turn angle (Θ) and the autocorrelation between speed and direction (γ). We defined the "transiting" behavior state as behavioral estimates between 1.0–1.39 and "internesting" behavioral state as 1.6–2.0, and only internesting locations were used for the remainder of the analyses. Behavioral estimates between 1.4 and 1.59 were considered behavioral transitions from internesting behavior to transiting; comprising only 2.4% (47 locations) of the data, and transition locations were not considered in the analysis.

We also identified renesting events within the tracks. Renesting events were inferred by consecutive high quality location points directed toward land and consistent with the known re-nesting interval of 17–30 days for olive ridley turtles (Miller, 1997; Maxwell et al., 2011).

Comparison of Sea Turtle Distribution, Zone Boundaries, and Commercial Shipping

Home range analysis, in the form of a gridded utilization distribution (UD) was used in the software R to determine the core use area, where 50% or more of the hSSM locations occurred during the internesting period (Maxwell et al., 2011). Using custom scripts in R 3.0.1 (R Core Team, 2003) we visually determined a base grid size of 0.015° (∼1.5 km^2) which allowed for the best spatial resolution within the restricted area of the Komo Estuary without oversmoothing as a turtle moved between cells (Maxwell et al., 2011). To aid in future zoning of the Komo Estuary, we quantified the percent of the internesting locations inside of the Komo Estuary. Additionally, we divided the estuary into 6 zones based on draft management zones in the Gabon Bleu initiative and nautical landmarks within the estuary. Zones 1, 3, 4, and 5 represent sections of current community fishing areas within the estuary, Zone 2 is the newly-designated MPA boundary adjacent to Pongara National Park, and Zone 6 is the current Pongara National Park and Buffer boundary. Zone 4 was further divided into three subsections, A-C, to examine whether turtle movement occurred equally across the zone or closer to Zone 2, the MPA boundary. The percentage of internesting locations that fell within each zone were then calculated to identify high use areas that could be used to inform development of management plans for the regions.

The UD was also compared to a UD of commercial shipping location data collected by the Automatic Identification Systems onboard vessels and downloaded from ExactEarth. Under Regulation 19 of the Safety of Life at Sea: Chapter V by the International Maritime Organization, location data, transmitted every minute at variable intervals, for shipping vessels are recorded globally for all vessels greater than 300 tons if traveling internationally and greater that 500 tons if localized (IMO, 2001). We used available vessel location data along the Gabonese coast from October and November 2012 to mirror the internesting period of the olive ridley turtles. All anchored or moored data points were removed from analysis (1.6% of all data points), such that only transiting data were used. The shipping UD was created using the same base grid as the olive ridley UD. The shipping and turtle UDs were then compared to determine the percent of overlap within the internesting habitat.

Dive Depth Analysis

Dive depth was collected in 2015 only ($n = 10$), with depth recorded every 2.5 min. The transmission of dive data, however, was variable and dependent on satellite availability. Additionally, the transmitted dive data did not necessarily correspond to known locations as dive data was recorded continuously while location can only be determined by satellites when turtles are at the surface. To determine dive behavior near known locations, dive depths within a 1-h window before and after a high-quality Argos location (location quality 3, 2, and 1 only) were extracted. The maximum dive depth within this 2-h window was compared to a gridded bathymetric map of the Komo Estuary to determine if turtles likely used the estuary bottom. The gridded bathymetric map was created from *Bahia de Corsico to Estuaire du Gabon, Nautical Chart 1356*, a nautical chart of the estuary, rasterized using the Raster package in R (Hijmans, 2016) with the same resolution and extent as the grid used for the UDs.

Using all of the dive data available from the 2-h windows, regardless of location quality, we determined the portion of the water column used by the olive ridley turtles. In this analysis, we included all depth locations that were recorded along the course of the dives. We normalized the dive data from each 2-h window previously described by dividing each depth by the maximum depth of that window creating a proportion between 0 (representing surface use) and 1 (representing bottom use). This allowed us to determine where in the water column turtles spent time throughout the internesting period across all dive data. Using the proportion created for each dive depth, we compared the surface and bottom use to the time of day to look for diel dive patterns.

RESULTS

Satellite Transmitter Deployment

Twenty-one satellite transmitters were attached to nesting female olive ridley turtles in 2012 ($n = 6$), 2013 ($n = 5$), and 2015 ($n = 10$) in Pongara National Park (Table S1, **Figures 1A–D**). The overall mean track duration was 102.8 days (±58.4, min = 29, max = 203) with an average duration of 82.4 days (±53.9, min = 29, max = 151) in 2012, 169 days (±36.4, min = 112, max = 203) in 2013, and 79.9 days (±45.5, min = 34, max = 184) in 2015. The mean overall internesting period was 15.6 days (±12.2). An approximate re-nesting event was identified for turtles G, H, and, P and each event was an estimated 15, 15, and 18 days after the transmitter deployment date, respectively. Turtle M from the 2015 season stopped transmitting before switching from internesting to post-nesting movement but remained in the Komo Estuary for 43 days and was therefore retained in the analysis. Turtle B from the 2012 season was discarded from further analysis because the Argos data returned

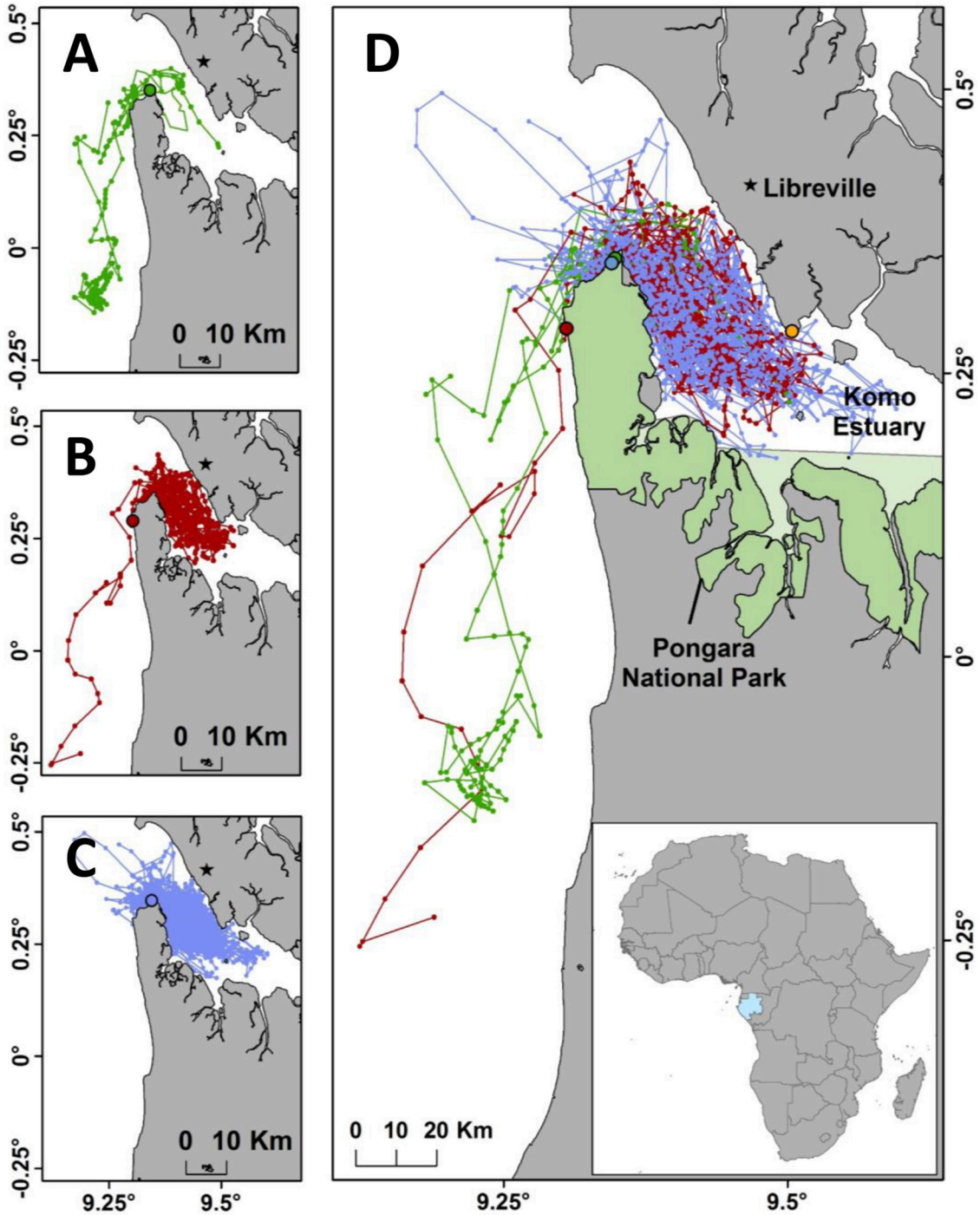

FIGURE 1 | (A) State-space modeled internesting tracks of female olive ridley sea turtles tagged from Pongara National Park, Gabon from the 2012 field season ($n = 5$). The green dot represents the tagging location for this season. **(B)** Tracks from the 2013 field season ($n = 5$). The red dot represents the tagging location for this season. **(C)** Tracks from the 2015 field season ($n = 10$). The blue dot represents the tagging location for this season. **(D)** Combined tracks from all three field seasons ($n = 20$). Green, red, and blue tracks represent 2012, 2013, and 2015 data respectively along with the coordinating colored dots representing the tagging locations. The orange dot represents the Owendo commercial shipping port in the Komo Estuary.

improbable locations and movement patterns thought to be from transmitter failure. Turtle P had location points within the internesting period that demonstrated an unexpected full behavioral switch from internesting to transiting then back to internesting. During the switch, the turtle remained in the Komo Estuary and later we saw the anticipated long-term behavioral

switch to transiting along with a southward movement toward the foraging grounds (Pikesley et al., 2013b). Therefore, we included the short behavioral change in our internesting period analysis.

Comparison of Sea Turtle Distribution, Boundaries, and Commercial Shipping Data

The full (100%) UD demonstrated that olive ridley turtles remained in the Komo Estuary and within 20 km of the coast south of the estuary during the internesting period. This includes use of the waters off the nesting beach of Pongara National Park (**Figure 2A**). The core UD highlighted that the high use areas are entirely within the Komo Estuary and at the mouth of the estuary near to where much of the nesting occurred and where most tags were deployed. Using the mouth of the estuary as an arbitrary divide, 89% of the hSSM internesting points were within the estuary and 95% of the points were in the mapped zones. Zone 2, the new MPA, and Zone 4, a new community fishing area, had the highest density of points, with 45 and 40% respectively. Zone 4A contained the highest percentage of the three subsections with 17% of the points. Zones 4B and 4C contained 11 and 12% of the internesting points, respectively. Zones 3 and 5 each had 5% of the points, Zone 1 contained 0.5%, and Zone 6, the in-water portion of the current Pongara National Park, only encompassed 0.21% of the points (**Figure 2B**).

The UD of the commercial shipping data demonstrated the highest ship traffic in the mid estuary from the Owendo port and out along the Gabonese coast line. The full shipping (100%) UD overlapped with 34.1% of the olive ridley full UD and 48.5% of the core UD (**Figure 2C**).

Dive Depth Analysis

The dive depth data from the 10 satellite tags deployed in 2015 provided a mean of 185.3 h of data across all turtles (±136.3, min = 32.0, max = 403.4) during the internesting period. The mean maximum depth recorded was 33 meters (±10, min = 19, max = 51) with mean dive depths ranging between 7 and 12 m (mean = 9 ± 2) (Table S1).

Of the transmitted dive data that correlated with high quality locations ($n = 89$), 100% of the maximum dive depths were found to coincide with depth of the seabed (**Figure 3**). Normalized depths (the proportion of time spent at depths within each dive normalized across all dives) demonstrated that 19.7% of the recorded depths occurred on the bottom and 7.8% were at the surface, with the remainder in the water column (**Figure 4**). Both surface and seabed use occurred at all hours of the day. However, 64% of surface time, represented by a proportion of 0–0.2 from the normalized depths, occurred at night between 6:00 p.m. and 6:00 a.m. The seabed use, proportions 0.8–1.0, was more evenly dispersed throughout the day with 53% of time spent during the day, 6:00 a.m.–6:00 p.m., and 47% at night, suggesting that turtles avoided coming to the surface during the day.

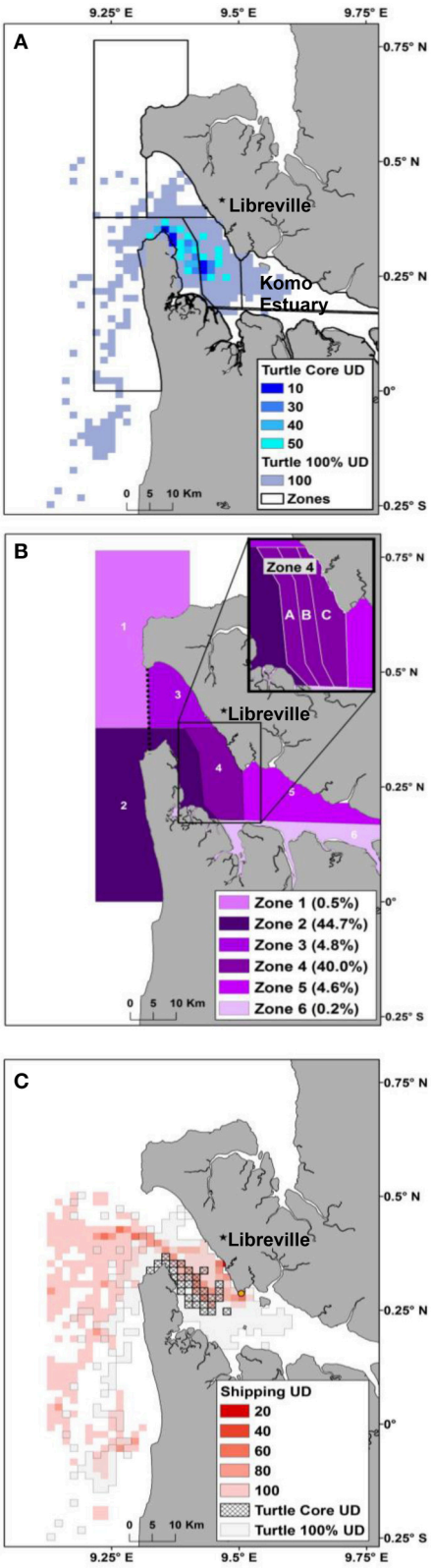

FIGURE 2 | (A) Utilization distribution (UD) of all female olive ridley sea turtles during the internesting period tagged in Pongara National Park, overlaid by

(Continued)

FIGURE 2 | Continued
zones. Zonation of the Komo Estuary is based on newly designated MPA boundaries and community fishing areas as well as nautical landmarks. The turtle core (50%) UD represents the most used areas, dark blue representing the most intensely used, by the olive ridley turtles. **(B)** Zones are colored based on utilization by the tagged olive ridley turtles during the internesting period with darker areas more heavily used and Zones 2 (the new MPA) and 4 (community fishing area) being the most utilized areas, implying areas of conservation potential. The dotted line represents the boundary used to calculate density in and out of the estuary. **(C)** UD of October 1—November 30, 2012 transiting shipping location data (red) compared to the olive ridley full UD (dotted) and the core UD (hashed) within the Komo Estuary. The orange circle represents the Owendo Port, the majoring shipping port in the Komo Estuary.

DISCUSSION

In 2014, the President of Gabon announced plans to create a network of marine protected areas (MPAs) in Gabonese waters and the final boundaries were released in June 2017. The planning process explicitly incorporated the habitat utilization data of sea turtles, including the olive ridley turtles tagged in this study, and as a result an MPA has been designated is located off of Pongara National Park matching Zone 2 (**Figure 2B**). To examine estuary use and inform the process, we created zones similar to those being considered within the planning process and our results indicate that the area around the mouth of the estuary, Zone 2, is a critical area in need of conservation strategies and will be protected as a marine protected area under the newly established Nature Preservation Agency, and likely designated as an expansion of Pongara National Park. The beaches within Pongara National Park are the most heavily used nesting beach for olive ridley turtles in northern Gabon, hence where most tagging occurred. As a result, close to 45% of the tracking locations occurred within Zone 2 and with its protection, particularly during the nesting season, it is more beneficial than the existing park boundaries (Zone 6), which encompass 0.2% of the locations. This reaffirms the benefit of the new network of marine parks that have recently been implemented.

Internesting Estuarine Movements

The female olive ridley turtles that nest in Pongara National Park are an example of marine vertebrates whose habitat use is understudied and are at risk from fishing pressures in the adjacent estuary. The telemetry tracks illustrate that females remain in the vicinity of the nesting beach (<20 km), and spend a majority of their time within the Komo Estuary (89% of locations, **Figures 1A–D**). There can be considerable variability in internesting movements among species at different nesting beaches and within the same nesting population (Godley et al., 2008). In most leatherback populations, females cover extensive areas between nesting events, though normally stay within the continental shelf (Eckert et al., 2006; Georges et al., 2007; Hitipeuw et al., 2007). Despite some loggerhead, olive ridley, and green sea turtle (*Chelonia mydas*) populations undertaking oceanic loops during internesting periods (Blumenthal et al., 2006; McMahon et al., 2007) and flatback sea turtles (*Natator depressus*) demonstrating variable behaviors in Western Australia (Waayers et al., 2011; Whittock et al., 2014), most hard shelled turtles tend to stay close to their nesting beaches (loggerheads: Godley et al., 2003; greens: Hays et al., 1999; Craig et al., 2004; Troëng et al., 2005; Fuller et al., 2008; hawksbills (*Eretmochelys imbricate):* Troëng et al., 2005; Whiting et al., 2006; Hoenner et al., 2016; Kemp's ridley (*Lepidochelys kempii*): Seney and Landry, 2008; Shaver and Rubio, 2008). This intense habitat use allows for more targeted conservation measures (Godley et al., 2008).

Some of the tracked females remained in the area for over a month before switching to the transiting phase and moving south, likely to known foraging grounds off the coast of Angola (Pikesley et al., 2013b). This is the first noted occurrence where olive ridley turtles almost exclusively used estuarine habitat during their internesting period. Green sea turtles nesting in French Guiana similarly used the Maroni River Estuary during their internesting period (Chambault et al., 2016) but additional occurrences are not known. In the Indian Ocean, female olive ridley turtles tagged on nesting beaches in Oman display consistent coastal use (Rees et al., 2012) but other populations of olive ridley turtles have been seen to move to offshore waters adjacent to the nesting beaches or immediately end the internesting period after their last nesting event and migrate toward foraging grounds (Whiting et al., 2007; Maxwell et al., 2011; Plot et al., 2015).

Within the estuary both the shallower coastal and deeper mid-estuary areas were used, highlighting the importance of this enclosed area to the internesting females. There are several hypotheses for estuarine use. Shallower depths in the estuary may result in reduced energy expenditure by turtles coming to the surface to breathe as they wait for egg development between clutches. During their time in the estuary, the olive ridley turtles appear to be utilizing the bottom habitat with U-shaped dives, which are likely related to resting or foraging (**Figures 3**, **5**, Plot et al., 2015). In addition, turtles may find increased foraging opportunities in the estuary; whether olive ridley turtles forage during the internesting period is unclear, but some turtles remained in the estuary long after nesting was completed, suggesting that they were likely taking advantage of available resources, as has been hypothesized in other regions (Rees et al., 2012).

Turtle-Threat Overlap and Conservation Measures

Using a multi-use human area, we showcase an example where data collected on a marine vertebrate species overlaps with putative threats in the habitat. We further augment with diving data, a behavioral component, to evidence where bycatch and boat interaction risk might be high and where management interventions may lead to improved conservation outcomes. The newly designated MPA boundary, Zone 2, is an example of management intervention for the marine species utilizing the Komo Estuary. The Gabon Bleu initiative also took socioeconomic impacts into consideration in designating

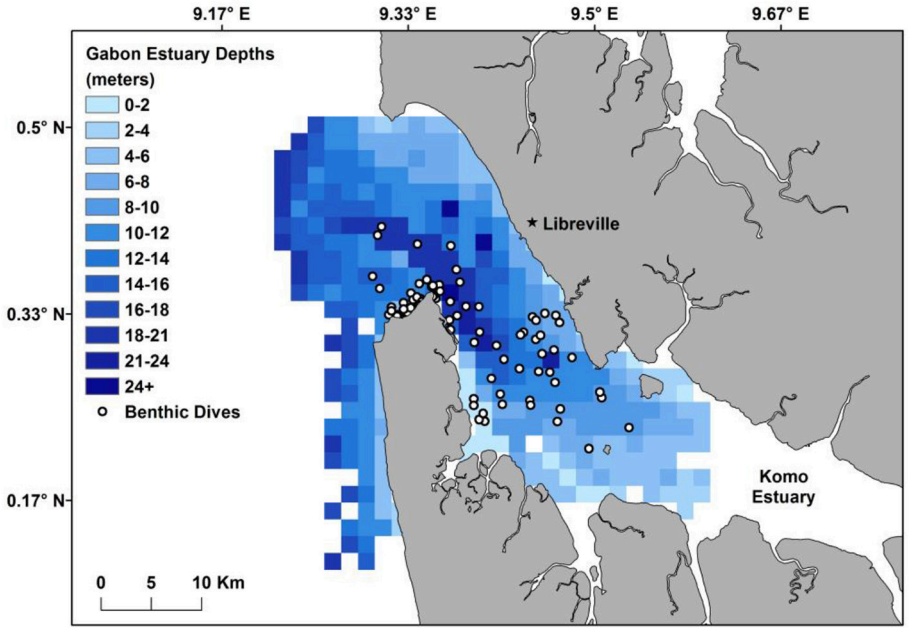

FIGURE 3 | Benthic grid of the Komo Estuary highlighting locations where olive ridley turtles location data correlated with dive depth data (white points) providing a comparison between max dive depth and the estuary bottom.

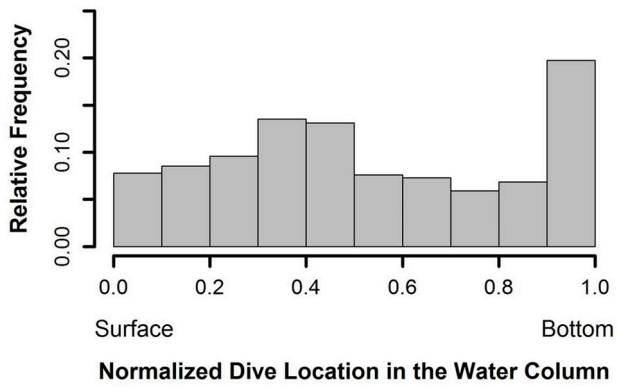

FIGURE 4 | Proportion of time spent at dive depths, normalized across all dives. Dive data was extracted from the 2-h window surrounding each location where dive data was transmitted and normalized based on the maximum depth of the respective window.

the zones and MPA, resulting in the community fishing areas where industrial fishing will be prohibited but artisanal fishing is allowed. While artisanal fishing can result in bycatch, commercial fishing gears such as trawls are also responsible for considerable bycatch (Metcalfe et al., 2015b) so the restriction of commercial vessels in this region will be beneficial to turtles.

Dive data indicated that olive ridley turtles spent a large portion of their time on the estuary bottom during all hours (**Figures 3**, **4**). Bottom set gillnets, which are widely used by artisanal fisheries in Central Africa (Metcalfe et al., 2015b, 2016), pose a direct threat to sea turtles resting on the bottom and studies have highlighted the depth at which fishing occurs can influence the bycatch rates of sea turtles (Polovina et al., 2003; Gilman et al., 2006). Outside of the MPA, the estuary has been designated for community fishing activities; management plans may consider seasonal fishing restrictions during the internesting period, particularly for bottom-set fishing gear, which restricts turtles' ability to breathe at the surface. Midwater or surface gear also has the potential to result in interactions with turtles, particularly as our data demonstrates that the olive ridley turtles spend more time at the surface between the hours of 6:00 p.m. and 6:00 a.m. Gear set at the surface and frequently monitored for capture of turtles could be an alternative to bottom-set gear to at least increase the potential for turtles to be released alive if captured.

The overlap between the core turtle UD and the shipping lane poses a potential threat, however the new MPA also overlaps with the deepest part of the estuary and necessary depths for a shipping channel. While management plans for the new MPA have not been completed, the new MPA is likely to restrict fishing but regulations on shipping are unclear. With a major port located in the Komo Estuary, heavy ship traffic occurs throughout the year in addition to coinciding with the internesting period (**Figure 2C**, **Figure S1**). Management, however, could include speed restrictions or designated shipping lanes during the internesting months.

CONCLUSIONS

There are examples of marine vertebrates from all ocean basins that are under threat throughout their range as seen by large-scale declines in recent decades (Baum et al., 2003; Myers and

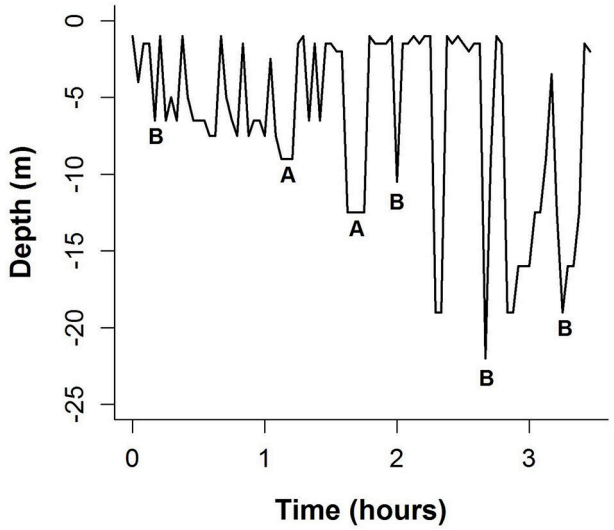

FIGURE 5 | Dive profile of Turtle U during the internesting period. "A" represents a U-shaped dive indicative of resting or foraging and "B" represents a V-shaped dive indicative of exploratory dives.

Worm, 2003; Heithaus et al., 2008). Red List Status might be improving for some species (Balazs and Chaloupka, 2004; Dutton et al., 2005; Simpfendorfer and Dulvy, 2017), highlighting that improved knowledge can lead to better management and conservation outcomes. Nonetheless, threats are highest where species aggregate such as to breed or forage (Edgar et al., 2008; Hays et al., 2010) and where species and humans frequently overlap; for marine species this is often in coastal zones (Maxwell et al., 2013). Quantifying specific threats can be difficult due to limited data, largely because of the feasibility of collection, but quantitative data is necessary to undertake comprehensive assessments and quantify impacts on marine vertebrates. With robust data on human impact and species distribution it becomes possible to accurately gauge threats in space and time, and then appropriately manage human activities for the preservation of species of conservation concern. Here, as the first study to look at internesting movements at this site, we were able to quantitatively determine fine-scale movements of olive ridley sea turtles and compare them with anthropogenic activities, and—critically—this data was used to development of an MPA designated off of Pongara National Park.

While the insights gained from this study greatly improve knowledge on the movement of female olive ridley turtles during the internesting period, there are still critical data gaps for this population. We know very little about male olive ridley turtle movement in general (Godley et al., 2008) and also in this area and they could also be at risk from fishing and boat strikes if they aggregate in the area to breed. Coastal waters could be even more of a conservation concern if the males are shown to utilize coastal waters such as zone 2, as has been demonstrated in other regions (James et al., 2005; Shaver et al., 2005; Hays et al., 2010), but this is entirely unknown in Gabon. Additionally, we are lacking data on the seasonality of males in the region. As they are likely to arrive at breeding grounds prior to females (Plotkin, 2007), they are potentially exposed to threats before the internesting period highlighted in this paper. Understanding this seasonality is critical to ensuring that management measures align with when turtle abundance occurs across sexes. Furthermore, while our data spans three nesting seasons, looking at long-term interannual data could reveal different patterns and habitat use of this area. There may be interannual variability in habitat utilization as well as variability in the distribution of threats such as fishing and shipping. More information on threats would also better aid in designing effective conservation measures. While there is the potential for sea turtle-ship interactions, little is known about how likely these interactions are to occur, or what the impact is on either individuals or populations. More detailed fishing data on the bycatch rate of sea turtles, specifically within the artisanal fisheries, in the estuary or off the coast could guide conservation strategies for restrictions or gear modifications in the area that best suit both the species and fishermen. Though more knowledge is needed, the current data we provide can lead to beneficial conservation strategies for the nesting females from Pongara National Park, Gabon, and provide a framework for studies in other regions.

AUTHOR CONTRIBUTIONS

TD, PDD, AF, BG, KM, DT, MW, and SM conceived the study and conducted data analyses. All authors contributed to the data collection and logistics and writing the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://journal.frontiersin.org/article/10.3389/fmars.2017.00312/full#supplementary-material

Figure S1 | AIS location points of the transiting ships from October 1 to November 30, 2012 illustrating the shipping channel within the Komo Estuary. The orange circle represents the Owendo Port, the majoring shipping port in the Komo Estuary.

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