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Short Note

First Satellite Tracking of the African Manatee (*Trichechus senegalensis*) and Movement Patterns in the Senegal River

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Manatees live in coastal, estuarine, and freshwater systems, and satellite telemetry is a useful tool to understand their habitat use, migratory patterns, and threats. Most habitat use studies of wild manatees have focused on movements in coastal populations (Deutsch et al., 1998, 2003; Powell et al., 2001; Castelblanco-Martinez et al., 2013a, 2013b; Slone et al., 2013; Aven et al., 2016), while few telemetry studies have focused on manatees in riparian habitat. The only telemetry study of wild Florida manatees (*Trichechus manatus latirostris*) in a freshwater system was conducted by Bengtson (1981). Fifteen manatees, radio tagged and tracked over 2 years, exclusively used the St. John's and Hontoon Dead Rivers and adjacent lakes for feeding, mating, socializing, and for warmth in winter at Blue Spring, with individuals traveling monthly means of 79.4 and 95.2 km in 1979 and 1980, respectively (Bengtson, 1981). A study of 78 manatees outfitted with satellite telemetry tags on Florida's Atlantic coast over 12 years documented manatees traveling an average one-way distance of 280 km and up to 87 km/d, mostly during seasonal migrations, and in rare cases, trips > 2,500 km (Deutsch et al., 2003). Yet others had home ranges < 50 km (Deutsch et al., 1998, 2003). Fifteen wild Antillean manatees (*Trichechus manatus manatus*) captured and tagged in Chetumal Bay, Mexico, were tracked between 4 to 301 d and exhibited two behaviors: nine manatees remained in the bay where they were tagged, while six others traveled up to 240 km over 89 d (Castelblanco-Martinez et al., 2013b). An Antillean manatee tagged in Panama was tracked for 46 d and used 15 km of a coastal river system (Gonzalez-Socoloske et al., 2015). Amazonian manatees (*Trichechus inunguis*) are found exclusively in freshwater systems and migrate seasonally in response to high- and low-water variations (Arraut et al., 2010). Only one telemetry study of wild Amazonian manatees has been published to date, which indicated that the species uses very specific home ranges, from 234 to 3,474 ha over multiple years, but travel distances were not recorded (Arraut et al., 2010).

The African manatee (*Trichechus senegalensis*) is the least studied sirenian species due to the difficulty of observing it in its mostly remote and turbid water habitats in 21 countries, its highly secretive nature, and few long-term research programs. The species inhabits the widest range of habitats of any sirenian, including rivers in equatorial rainforests, coastal lagoons and estuaries, offshore islands in the Atlantic Ocean, and rivers in the western Sahel. Very little is known about movement patterns, home ranges, or habitat use of the African manatee other than general reports that coastal populations ascend rivers in the rainy season and descend them in the dry season (Reeves et al., 1988; Powell, 1996; Silva & Araújo, 2001; Dodman et al., 2008; Keith-Diagne, 2015; Mayaka et al., 2019). Hydroelectric and agricultural dams have now isolated manatee populations in many rivers, including the Senegal River, the Volta River (which created Lake Volta) in Ghana, and the Niger River with five major hydroelectric dams and at least three more under construction. No previous study has been undertaken to understand habitat use and the movement patterns of these isolated populations.

The only prior tagging and tracking studies of African manatees were two studies conducted in Ivory Coast between 1986 and 2002 that used very high-frequency (VHF) radio telemetry equipment

(Powell, 1996; Akoi, 2004). Powell and Akoi tagged and tracked a total of 35 manatees in the N'Gni and Niouzomou Lagoons and adjacent rivers. In these studies, most manatees stayed within 10 km of their capture location, although movements of up to 42 km were documented for three female manatees that made seasonal trips from a lagoon up a river during rainy seasons.

The Senegal River forms the border between Senegal and Mauritania, and it is the northern limit of the African manatees' range; there are no permanent freshwater sources to the north in the Sahara Desert. The first African manatee specimen collected for science, used by Link to describe and name the species in 1795, came from the mouth of the Senegal River at St. Louis, Senegal (Adanson, 1757). In 1984, construction of the Diama Dam, 26 km inland from St. Louis, permanently isolated the Senegal River manatee population from the coast, and the Felou Dam at Kayes, Mali, restricts manatees from moving farther east. Between the two dams, manatees have access to > 950 km of riparian habitat as well as adjacent Lake Guiers (50 km long × 7 km wide), numerous tributaries, and a vast seasonal floodplain. The eastern Senegal River region receives only 200 to 550 mm of rain annually in a brief wet season lasting 3 to 4 mo (Magistro & Lo, 2001). However, extensive seasonal rains originating in the mountains of Guinea inundate an annual Senegal River floodplain, which grows to 30 km wide in some areas and greatly increases available manatee habitat between the dams, generally during the months of August to November. Flooding persists for several months after the end of the annual rains, and water recedes slowly as the dry season progresses, with lowest water levels during the months of February to June (Magistro & Lo, 2001). Since completion of the Manantali Dam in Mali in 1988, seasonal flooding of the river has been controlled by water release schedules, and the extent of annual flooding has been highly variable (Bader et al., 2003; International Union for Conservation of Nature [IUCN], 2004; Dumas et al., 2010).

Although Nishiwaki (1984) believed summers to be too hot for the survival of manatees in the eastern Senegal River, where average summer air temperatures reach 43°C at Matam, local people have reported manatees using the river's large floodplain between Matam and Kanel since at least the 1980s (Haidar el Ali, pers. comm., 10 January 2009). During this time, the nonprofit organization Oceanium Dakar and local people in Kanel began moving seasonally trapped manatees back to the Senegal River. As floodplain waters recede in the dry season, manatees are occasionally trapped in tributaries that become cut off from the Senegal River and in seasonal lakes that completely dry before the next rainy season. In the village of Navel, near Matam, manatees did not become trapped until 2007 when an agricultural dam was constructed in a seasonal tributary. Manatees swam in through openings in the dam during the high waters of the rainy season but were unable to leave when the waters receded below the level of dam openings during the dry season. Within the first year after construction, four manatees drowned, trapped against dam grates as water receded. Oceanium Dakar staff rescued two live manatees at Navel on 26 November 2008 and observed others still trapped behind the dam. The following month, Oceanium Dakar brought the authors together to rescue and satellite tag the remaining manatees. This was a unique opportunity both to study the movements of this elusive species in the eastern Senegal River and to work to mitigate the threat created by the new dam.

The manatees in this study became trapped during autumn 2008 as seasonal floodwaters receded behind the Navel Dam in a tributary of the Senegal River near Matam (15° 37' 48.05" N, 13° 14' 33.49" W). Manatees were located within two adjoining oxbows (15° 37' 14.24" N, 13° 14' 50.48" W) of the Navel tributary, approximately 1.7 km in length with a depth of 1 to 2 m. It is unknown exactly when the manatees became trapped, but they were confined to this small portion of the tributary for a minimum of 4 mo prior to rescue. Due to a lack of aquatic and shoreline vegetation as the waters receded, a local man was hired by Oceanium Dakar to guard the manatees against poaching until they could be rescued and to provide them corn husks to eat. They were observed feeding on the husks for approximately 6 wks prior to rescue.

On 14 and 15 January 2009, five manatees were captured using hand nets that were manually dragged along the entire length of the two Navel tributary oxbows. Once the manatees were captured, they were transported 6.4 km to a release site on the Senegal River at Matam (15° 40' 6.98" N, 13° 15' 16.20" W). During transport to the release site, body condition and sex were assessed, standard lengths and peduncle girths were measured, standard photo views were taken, and genetic samples were collected (genetics results will be reported elsewhere). Three adult manatees (two males and one female—Manatees A, C, and D, respectively) were fitted with caudal peduncle belts and tethered, floating radio tags. Tags consisted of satellite-monitored Platform Transmitter Terminals (PTTs) with integrated VHF beacons for field tracking (Telonics, Inc., Mesa, AZ, USA) in cylindrical housings. Tags were attached to the peduncle belt by a flexible nylon rod (Reid et al., 1995). All telemetry gear was built and deployed per standard designs and protocols developed and used for West Indian manatees over the past 25 years (Reid et al., 1995; Deutsch et al., 1998).

All location and sensor data were uplinked to polar-orbiting satellites equipped with on-board Argos receivers (Service Argos, CLS, Saint-Agne, France). To prolong battery life, each PTT tag was preprogrammed with duty cycles, timed for predicted periods of satellite overpasses, prior to deployment. Each tag had a duty cycle of 2 h on, 3 h off, 2 h on, 4 h off, 2 h on, 3 h off, 2 h on, and 4 h off for a total of 8 h of transmission time (on time) in each 24-h period to maximize battery life while sampling around the clock. This corresponded to sampling hours between 0500-0700, 1000-1200, 1600-1800, and 2100-2300 h local time (GMT-1). The tag sensors reported summarized the floating tag tips and dive activity in 4-h time bins, which provided an indication of manatee movements, behavior, and tag detachment.

Due to the emergency nature of this tagging effort, funds and staff were not available to field track the tagged manatees post-release. Once the manatees were released, their locations were accessed and monitored remotely via daily data downloads from the Argos website (www.argos-system.org). Argos data were edited to remove location fixes acquired before and after each manatee's tracking period, and to eliminate low-quality location fixes (Argos location classes A, B, and 0). After the tracking periods ended, habitat use and percentiles of use area were determined for each manatee by creating Kernel densities (50 and 90%) from classes 1, 2, and 3 locations with GIS software (*ArcGIS*, Version 10.4.1; ESRI, Redlands, CA, USA).

Rescued manatees included four adults (three males, one female) and one subadult female (Table 1). A body condition scoring system developed for Florida manatees was used to assess the rescued manatees. All manatees in this study were scored as having normal body condition with one exception: one of the male manatees (Manatee C) was scored as thin due to the presence of longitudinal ventral folds.

Using six satellites, 6,518 locations were recorded for the three tagged manatees. Seventy-one percent (n = 4,614) of locations were classified as Argos classes 1, 2, or 3, indicating they were obtained by four or more satellite messages and accuracy could be determined. Location accuracies for classes 1, 2, and 3 were estimated at better than 1,500, 350, and 250 m radius, respectively (*Argos User's Manual*, 2007-2012).

The three tagged manatees used over 308 km of river distance on the Senegal River, both to the north (downstream) and south (upstream) of the release location (Figure 1). Immediately after release, both male manatees made fast, directed trips. Four days post-release, one male (Manatee A) had traveled 181 km north of the release site in the Senegal River to oxbows near the village of Dongui Donbi, averaging river distance travel of 45.3 km/d. He remained within a 20 km area in two branches of the river for the remaining 82 d (95%) of his tracking period, and within a 6-km range for 54 d (63% of tracking period).

Over the 4-d period after release, the second male manatee (Manatee C) traveled 133 km south of the release site in the Senegal River to the town of Bokeladji, averaging a river distance travel of 33.3 km/d. He remained there for 15 d. Then, over a 41-d period from 2 February to 15 March, Manatee C moved north approximately 281 km (averaging a river distance travel of 6.9 km/d), passing the release site, to an eastern branch of

Table 1. Identification numbers, sex, length and girth measurements, and body scoring of five African manatees (*Trichechus senegalensis*) rescued in the Senegal River, 14 and 15 January 2009. * indicates measurements that were not taken due to time constraints.

Manatee ID number:	A	B	C	D	E
Rescue date	14 Jan 2009	14 Jan 2009	14 Jan 2009	15 Jan 2009	15 Jan 2009
Size class	Adult	Sub-adult	Adult	Adult	Adult
Sex	Male	Female	Male	Female	Male
Length measurements (cm)					
Total length (straight)	260	185	234	260	290
Total length (curvilinear)	270	203	262	279	306
Snout to umbilicus	102	75	*	*	*
Snout to anus	204	133	*	*	*
Snout to peduncle	115	148	*	*	*
Girth at peduncle	90	74	93	102	103
Overall body condition	Normal	Normal	Thin	Normal	Normal
Satellite tagged?	Yes	No	Yes	Yes	No

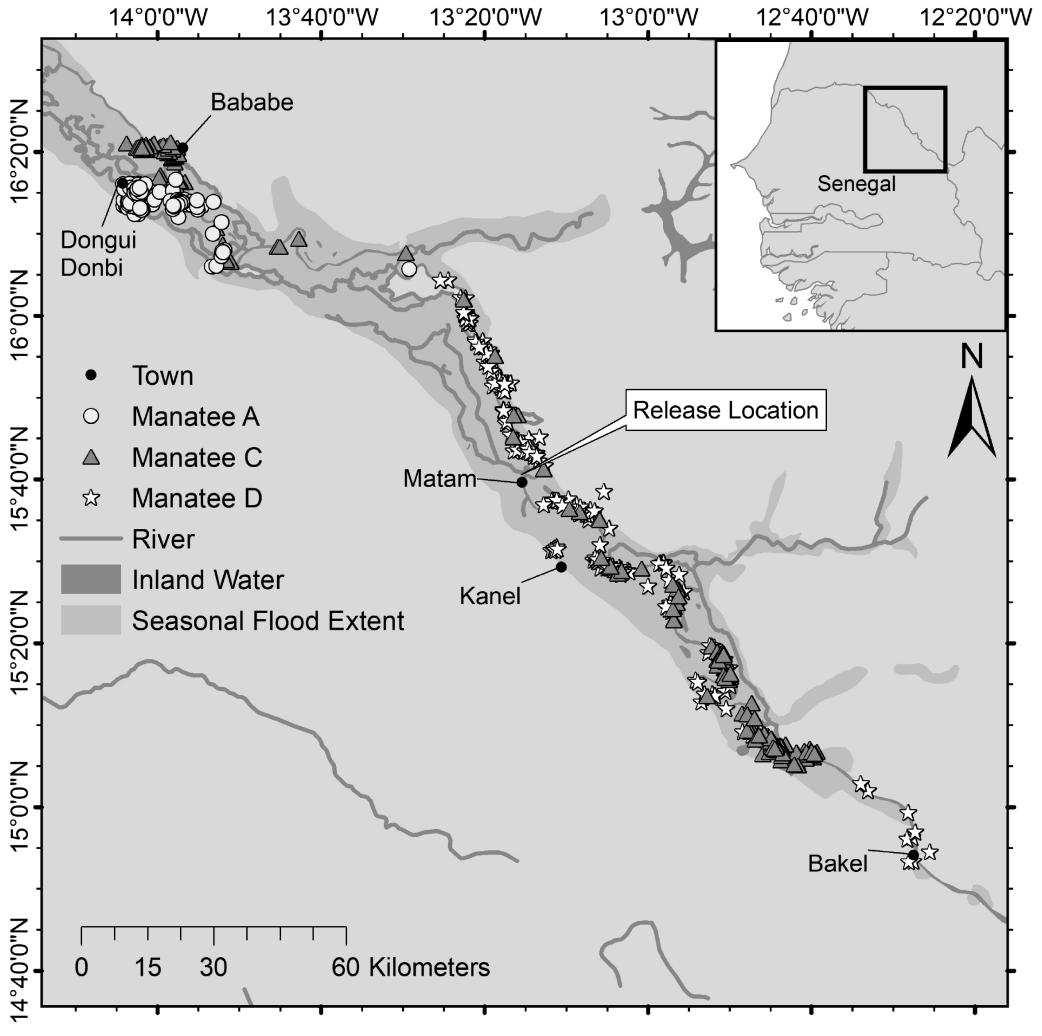

Figure 1. All Argos location classes 1, 2, and 3 for three tagged African manatees (*Trichechus senegalensis*) in the Senegal River between 14 January and 5 December 2009

the Senegal River at Bababe. At this location, Manatee C was within 6 km of Manatee A but in a different branch of the river (Figure 2). Manatee C stayed in this location for 26 d, the remaining 30% of his tracking period. Both male manatees were tagged for 86 d and lost all their gear on 9 April 2009. Initially, it was thought the tags may have been cut off due to the coincidence of both manatees losing their tags the same day; however, when the tagging gear was later recovered, both belts were found to be broken internally at weak links specifically designed to break and free the manatees if they became entangled. Both tags were also heavily wrapped with monofilament net. Interviews with the local people who found the gear and a review of tag tips recorded by Argos also confirmed that both manatees became entangled in fishing gear, with the belts breaking at the weak links as they were designed to, allowing the manatees to escape.

The female's (Manatee D) tag functioned for 325 d. The tag updated daily through 25 August 2009 (223 d); and then from September to December, it only updated locations on the fifth day of each month, and these data were not included in analyses. After release, Manatee D moved north of the release site and remained 12 to 20 km north of it for the first 20 d. Then, between

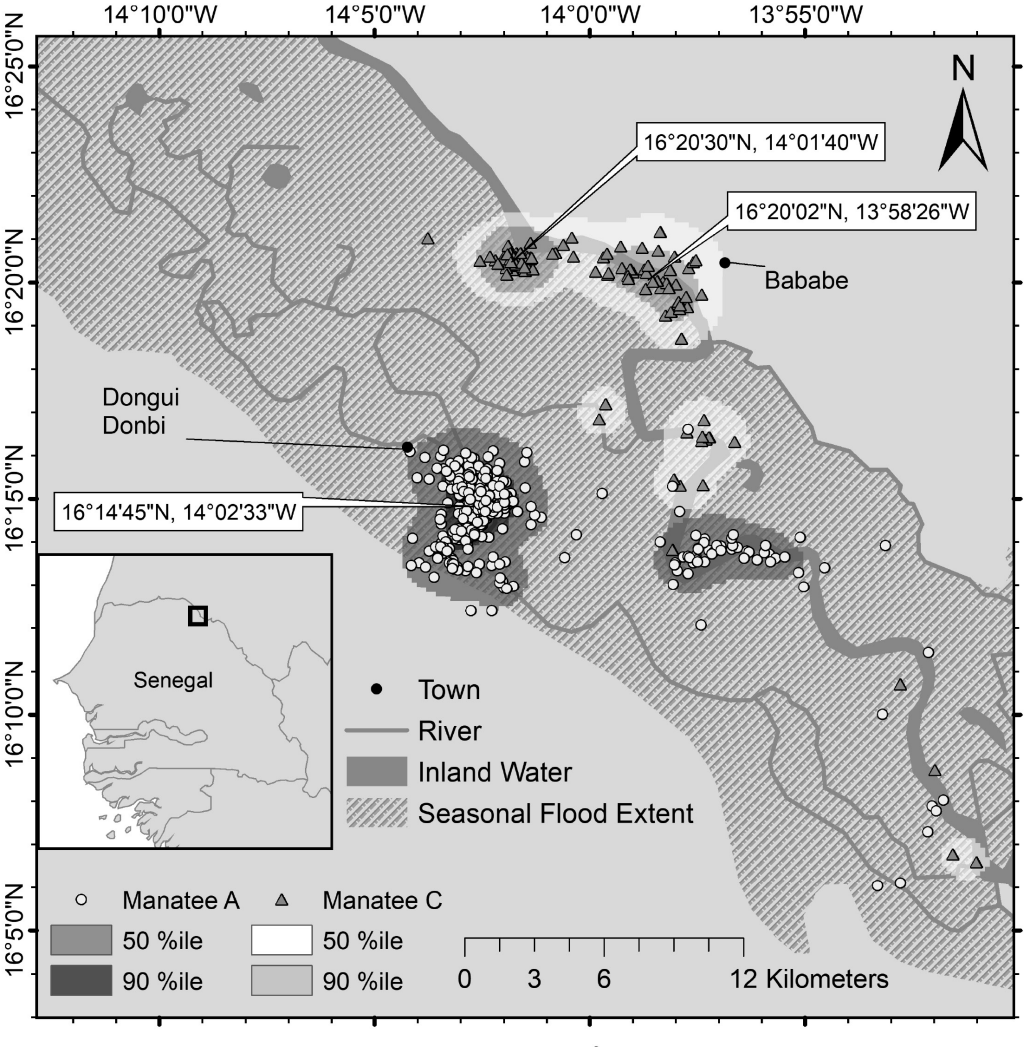

Figure 2. Argos location classes 1, 2, and 3 utilizing 50 and 90th percentiles to show dry season use areas for two tagged male manatees in two branches of the Senegal River. Latitude and longitude coordinates are shown at the center of the 90th percentile primary use lobes for each manatee. During the rainy season, flooding engulfs the area between the two branches. Use area for Manatee A is shown for 62 of the 86 total days tracked (72% of the tracking period), and use area for Manatee C is shown for 19 of the 86 total days tracked (22% of the tracking period).

2 February and 16 August, Manatee D made three round trips south from the area of Matam/Kanel to the same location in the Bakel vicinity, 30 km from the border of the Senegal River with Mali (Figure 3). On the first trip, Manatee D passed Manatee C in the river as he swam northward. On all trips, Manatee D stayed in the Bakel vicinity for less than 1 d and then began returning north to Kanel. The first trip south (2 February to 6 March) took 32 d; the return trip north (6 March to 13 April) took 38 d; the second trip south (19 May to 4 June) took 16 d; the return trip north (4 to 15 June) was 11 d; the third trip south (15 June to 23 July) took 39 d; and the final return trip north (23 July to 16 August) took 24 d. Average trip duration was 26.7 d, with travel rates for one-way trips varying from 3.8 to 13.4 km/d (total trips average 7.1 km/d). The six trips accounted for 165 d (74%) of the tracking period from 15 January to 25 August when the tag was providing daily updates. Each trip was more than 135 km, the longest one-way trip was 211.7 km, and this

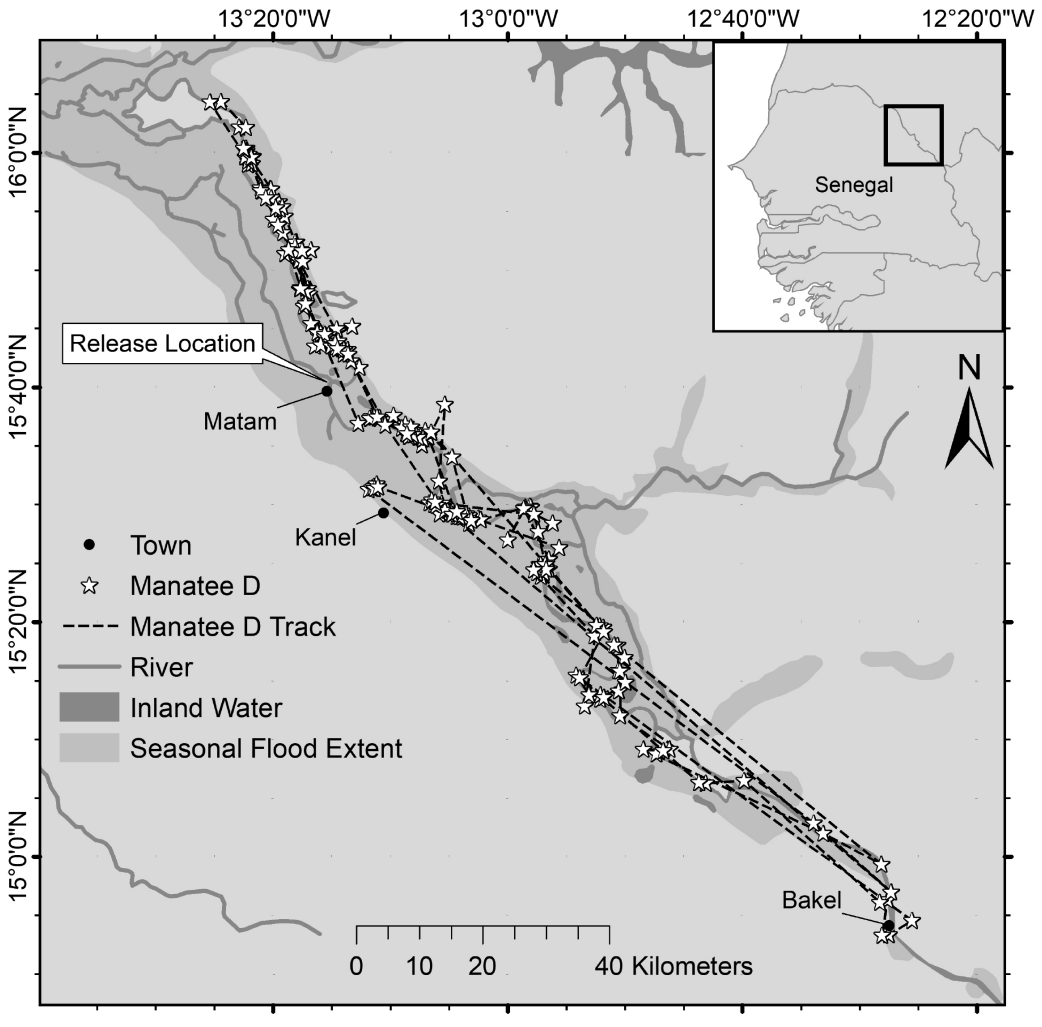

Figure 3. Argos location classes 1, 2, and 3 showing six one-way trips made by the female tagged manatee (Manatee D) to specific locations near Matam, Kanel, and Bakel over 6 mo between 2 February and 16 August 2009

manatee swam a total of 962.3 km in 160 d. These were also the farthest southward movements of the three tagged manatees. In August 2009, as tributaries flooded in the subsequent rainy season, Manatee D moved to a seasonally flooded plain at Wendou Kanel, 12.4 km south of, and connected to, her rescue location the previous January. The tag stopped providing regular updates on 25 August, but a visual sighting of the manatee with the tag attached confirmed the female's presence on the floodplain at Kanel on 6 September. The last Argos location, on 5 December, placed Manatee D in the Senegal River south of Kanel.

Manatee movements directly after release were likely to feeding locations. No aquatic plants were found during low water in the Navel tributary for 3 mo prior to the manatees' rescue, and there was very limited shoreline vegetation accessible to the manatees. Although corn husks were placed in the water several times per week for 6 wks prior to the manatees' rescue, and they were observed eating them, all individuals likely had limited food while entrapped prior to their rescue.

The fast, directed trip 181 km north made by Manatee A after release and a later trip to the same region by Manatee C, as well as the length of their stays in this region before tag loss (82 and 26 d, respectively), suggest that it may be a preferred low-water feeding area and that both manatees knew the locale prior to their entrapment by the

Navel Dam. During low-water levels in June 2012 and February 2019, authors LKD and TD traveled to the two branches of the river where these manatees had been located (Dongui Donbi and Bababe), documenting abundant aquatic plants, primarily *Potamogeton coloratus* and *Crinum natans*, as well as abundant shoreline grasses, primarily *Cyperus dives*. These species are all documented food sources for the African manatee (Powell, 1996; Keith-Diagne, 2014). The abundance of aquatic plants in this region differs from Matam and Kanel where very sparse *C. natans* was the only aquatic plant found during a survey by LKD in 2012. Interviews with local people living near Dongui Donbi indicated that manatees were frequently sighted in the Senegal River there, particularly after annual flooding begins in August, but sightings were reported year-round.

In contrast, the female manatee (Manatee D) made six directed trips over 6 mo without staying at the southern destination longer than a day, which may indicate searching behavior. Stops lasting several days at specific points in the Senegal River that are adjacent to large lakes during multiple trips north and south may have indicated feeding. Previous studies have documented African manatees moving in search of food resources during the dry season (Bessac & Villiers, 1948; Powell, 1996; Akoi, 2004). Manatee D was confirmed returning to a flooded region at Kanel at the beginning of the rainy season that connects to the same area where she was rescued, suggesting that this is a preferred area for this individual during the wet season. By December 2009, when the last tag locations were recorded, water levels on the floodplain had receded, which is likely why the manatee was in the main river.

In comparison to previous radio-tracking studies in Panama and Ivory Coast, all three tagged manatees in this study traveled greater distances. The distances traveled by Manatees A and C are comparable to travel distances of manatees in previous studies in Florida, Mexico, and Belize (Bengtson, 1981; Castelblanco et al., 2013b), while the total travel distance of Manatee D exceeds all but the longest trips documented for Florida manatees that traveled up the eastern seaboard to Chesapeake Bay and Rhode Island (Deutsch et al., 2003) and is the longest record for an African manatee. Long distance movements may be a necessity in the eastern Senegal River, which has very limited aquatic and shoreline vegetation compared to the tropical lagoons of Ivory Coast, the Amazon River, and coastal rivers in Panama. Additionally, the manatees in this study may have left the release location area because it was not a preferred dry season habitat. Movement of the female manatee back to previously used rainy season habitat is similar to the behavior of three VHF radio-tagged females studied in Ivory Coast (Powell, 1996; Akoi, 2004). Our study suggests manatee movements in the eastern Senegal River are likely strongly tied to areas of the main river where food resources can be found in the dry season, and alternate areas where subsequent plant growth and forage availability is associated with seasonal flooding in the rainy season.

The rescued manatees in this study and the actions of the organizations involved raised awareness of the problem of manatee entrapment behind the new Navel Dam. Managers at the Senegal River Basin Authority (SAED) office in Matam announced that the dam grates had been removed in early October 2009, but this was shown to be false on 18 October 2009 when three additional manatees were found dead against the grates that were still in place. Shortly after, the grates were finally removed by SAED. Future dams built on the Senegal River, its tributaries, and on all other African rivers where manatees occur should take the species into consideration to avoid additional entrapment and mortality.

This was the first time satellite telemetry was used to study African manatee movements and habitat use. The results of this research demonstrate that it is an indispensable tool for studying the movements and habitat use of this elusive species. The manatees in this study were tracked for less than a year in a riparian system, primarily during the dry season, so there is still a need for rainy season and year-round movement pattern studies in both coastal and riverine ecosystems. Additional studies of the impacts of dams on African manatees are needed, and future tracking studies should include field observation to better elucidate African manatee behavior and ecology.

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