Breeding Season Home Range and Migration of the Agami Heron (*Agamia agami*)

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Abstract.—Eight Agami Herons (*Agamia agami*) captured in the Marais de Kaw-Roura National Nature Reserve in French Guiana were tracked with Argos satellite transmitters in 2012 and 2013. While nesting, birds used a 100- to 200-km² area around the colony site. After breeding, four birds moved from 280 to 1,250 km in different directions along the Atlantic coasts of Venezuela, Guyana, Suriname, French Guiana, and/or Brazil. Migration paths included one stop-over of 24 to 61 days. These results show that the Agami Heron uses large areas during the breeding season and can migrate long distances. That Agami Herons congregate from large areas into a limited number of potentially large colonies provides a basis for a conservation strategy for the species. *Received 13 December 2016, accepted 11 April 2017.*

Key words.—Agami Heron, *Agamia agami*, conservation, French Guiana, home range, long-distance movement, migration, satellite telemetry.

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The Agami Heron (*Agamia agami*) is a little studied species for which there has been no information on the movements of individual birds and no indication of migration (Kushlan and Hancock 2005). Because of its shyness, only limited observations of the species have ever been published (Ramo and Busto 1982; Marin 1989; Reynaud and Kushlan 2004; Abella-Gutiérrez and López-Conlon 2008). Kushlan and Hines (2016) recently provided the first detailed published description of its nesting and feeding behavior. The Agami Heron is unique among herons owing to its elongated body structure and distinctive coloration (Kushlan and Hancock 2005; Kushlan and Hines 2016). Furthermore, it is unusual among herons for being a solitary forager yet nesting in large colonies (Kushlan and Hancock 2005). It is considered to be Vulnerable (BirdLife International 2012) and a priority species for additional study and conservation (Kushlan 2007; Stier and Kushlan 2015).

The goal of the present study was to determine the area around the colony used during nesting and to determine the extent, if any, of non-breeding movements, both of which would have significant conservation implications.

Methods

Study Area

The study was conducted in the Marais de Kaw-Roura National Nature Reserve (4° 38′ 55.300″ N, 52° 8′ 12.656′ W), a 95,000-ha national reserve in northeastern French Guiana, situated between the coast and the interior rain forest. The Agami Heron colony site, isolated in marshes, with over a thousand nests, is accessible only by helicopter (Reynaud and Kushlan 2004). Surrounding the colony are freshwater marshes, freshwater swamp forest, mangrove swamp, high forest, and coastal plain forest.

Field Methods

During the breeding season, eight adult Agami Herons were captured adjacent to the colony site using mist nets. Sexes were determined by feather analysis by the Genindexe Laboratory (France). The Agami Herons were equipped with satellite transmitters, three on 21 to 23 April 2012, and five on 24 to 27 April 2013. Transmitters were attached using a 5-g backpack harness designed by Bureau Waardenburg (Netherlands). Six individuals were equipped with a 20-g Argos battery panel Platform Transmitter Terminal (PTT) and two individuals with a 12-g solar panel PTT. Individuals weighed between 0.400 and 0.675 kg, so the extra mass was 3.5-5.1% of total body mass. Males, being larger than females, were fitted with the heavier transmitters; two out of the three equipped females were fitted with a 12-g transmitter.

The PTT duty cycles were 9 hr on/24 hr off for the solar panels, and 6 hr on/75 hr off for the battery PTTs in 2013. In 2012, PTTs were 6 hr on/90 hr off from 1 April to 15 October 2012, 4 hr on/140 hr off from 16 October 2012 to 15 January 2013 and 6 hr on/90 hr off from 16 January to 31 March 2013.

Analysis

The PTTs provided locations with an accuracy of < 250 m to > 1,500 m classified as follows: 3 (< 250 m), 2 (250-500 m), 1 (500-1,500 m), 0 (> 1,500 m), B or A (no accuracy estimate) (Argos 2016). All high quality fixes (1, 2, 3) were used for analysis. 0, A and B fixes were used if they corresponded to previous and subsequent high quality fixes, or corresponded to movement direction and flight speed based on higher quality fixes. We excluded from analyses three individuals that transmitted for 6 days or less. One individual that transmitted for only 10 days but started migration within these days was excluded from local analysis but included in migration analysis.

We found no consensus about the most accurate home range estimation method (Powell 2000; Downs and Horner 2009) and determined home ranges (*sensu* Kernohan *et al.* 2001) using the kernel density estimator with the fixed method (Worton 1989; Powell 2000; Kernohan *et al.* 2001). This method represented the mainstream in the literature and has performed better than minimum convex polygons and some more recent techniques (Worton 1995; Kernohan *et al.* 2001; Pellerin 2005; Lichti and Swihart 2011). Included in the analyses were the three individuals with more than 30 location points before migration, the minimum recommended for this method (Kernohan *et al.* 2001). We used R statistical software with “adehabitat”, “ade4”, “fields”, “maps” and “mapdata” packages (R Development Core Team 2016) and ArcGIS (Environmental Systems Research Institute 2013). The value of “h” was the reference value “h=href” of the “kernelUD” function in “adehabitat” package of R. We used all data available for the analyses (Swihart and Slade 1985; Powell 2000; Kernohan *et al.* 2001).

Minimum sample size was estimated by determining the sample size at which 100 home range simula-

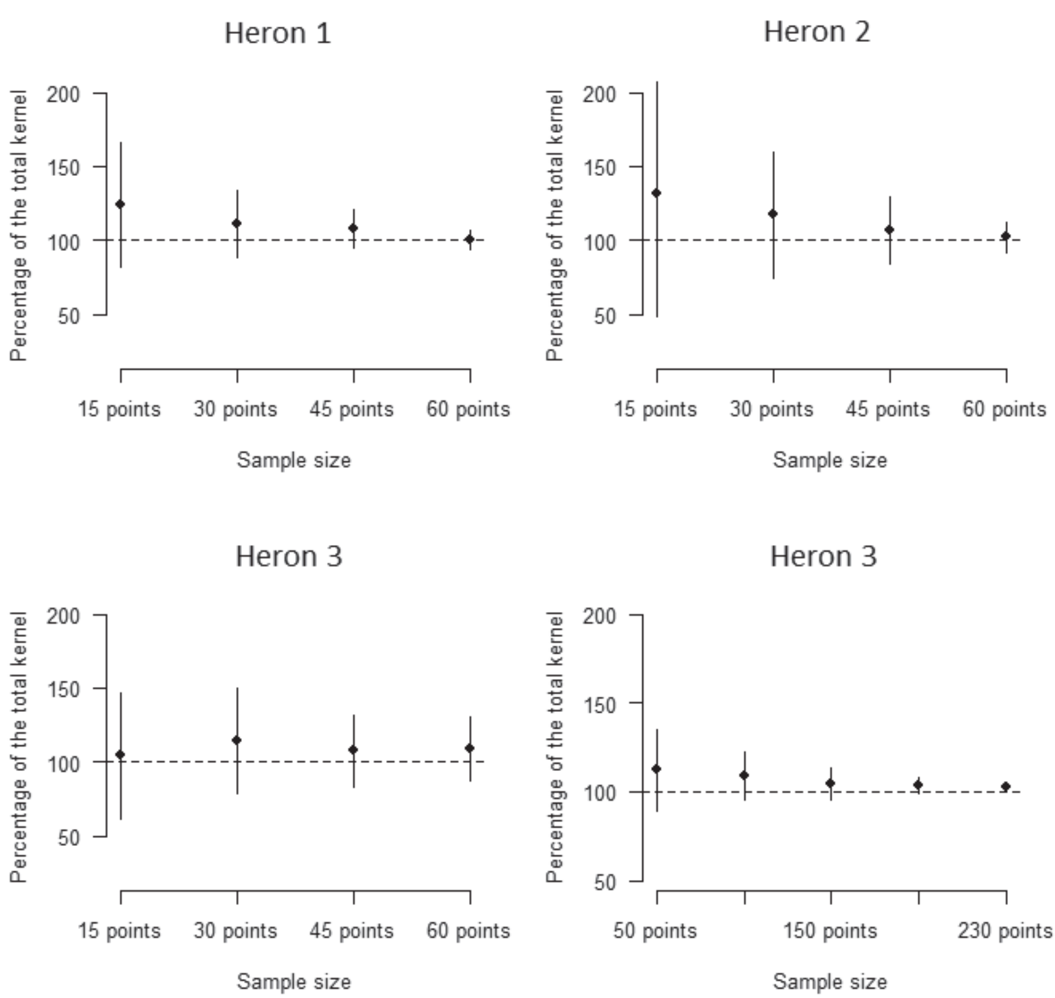

Figure 1. Home range size estimations (in percentages) vs. sample sizes for three adult Agami Herons in the Marais de Kaw-Roura National Nature Reserve marshes, French Guiana. Number of available points for each individual were: Heron 1: 67, Heron 2: 65, Heron 3: 236.

Table 1. Efficiency of the Platform Transmitter Terminals (PTT) placed on eight adult Agami Herons in the Marais de Kaw-Roura National Nature Reserve marshes, French Guiana. h = data used for home range analysis; m = data used for migration analysis.

Individual	Date of Equipment	Sex	PTT Type	PTT Lifetime (days)	Number of Locations
2^{hm}	25 April 2013	Male	Battery	223	175
3^{h}	25 April 2013	Male	Battery	209	236
4^{m}	26 April 2013	Female	Battery	202	201
1^{hm}	24 April 2012	Male	Battery	198	187
5^{m}	25 April 2013	Female	Solar	10[1]	42
6	22 April 2012	Female	Solar	6	28
7	24 April 2012	Male	Battery	1	4
8	26 April 2013	Male	Battery	0	0

[1]The PTT of Heron 5 sent a single last location after the 10 days of regular emissions; this location was not used for the PTT lifetime calculation.

tions using randomly-selected fixes revealed 100% of the home range as determined by all fixes (Kernohan *et al.* 2001; Pellerin 2005). Based on the results (Fig. 1), home range for each bird was recalculated using 60 randomly selected sample points. A mean "h" was calculated from the three reference h estimates, and home ranges were recalculated a last time with 60 points and the common "h" (Pellerin 2005). This data manipulation was possible because all three Agami Herons tracked for home range analysis were adult males, eliminating the possibility of gender differences (Pellerin 2005). Home range, as defined in this study (Kernohan *et al.* 2001), uses a utilization distribution, i.e., a probability density function showing the probability of finding an animal at a particular location (Anderson 1982; Worton 1989). The home range is the smallest area with a probability of use equal to 0.95 within the contour of the utilization distribution (Anderson 1982). The "core area" is defined as an area equal to 0.50 probability of occurrence.

We defined the "start of migration" for each individual as when it began long distance movements away from the colony and surrounding marshes and did not return, determined by the last position of the individual near the colony before the first distant position. We defined the "end of migration" as the individual stopping flight movements for several months. "Migration speed" (expressed as average number of km/day) is the speed from start to end of migration, excluding stop-overs. Stop-overs were locations where the individual remained for 8 or more days, the minimum that duty cycles programmed for the PTTs could detect. Total migration duration is the time individuals took from departure from the colony site to arrival at the non-breeding site.

RESULTS

Movement data on five of the eight telemetered individuals were available for analysis, three for home range analysis and four for migration analysis (Table 1). The three tracked males used an overall area of about 100 to 200 km² around the colony, whereas the core areas were of about 15 to 30 km² (Table 2). For Herons 1 and 2, home ranges were the area used during the breeding season before migration. Heron 3 did not migrate, so all points were used.

The habitats used by Herons 1, 2 and 3 within their home ranges were primarily wetland of several sorts (Fig. 2). Home ranges included the area around the colony and one or two other areas visited regularly (Fig. 3). Individuals travelled maximum distances

Table 2. Home range estimates of three adult male Agami Herons in the Marais de Kaw-Roura National Nature Reserve marshes, French Guiana. 0.95 Home Range = smallest area with a probability of use equal to 0.95; 0.50 Home Range = smallest area with a probability of use equal to 0.50.

Individual	Year	Tracking Period (days)	0.95 Home Range (km²)	0.50 Home Range (km²)
1	2012	75	131	26
2	2013	64	115	16
3	2013	209	199	31

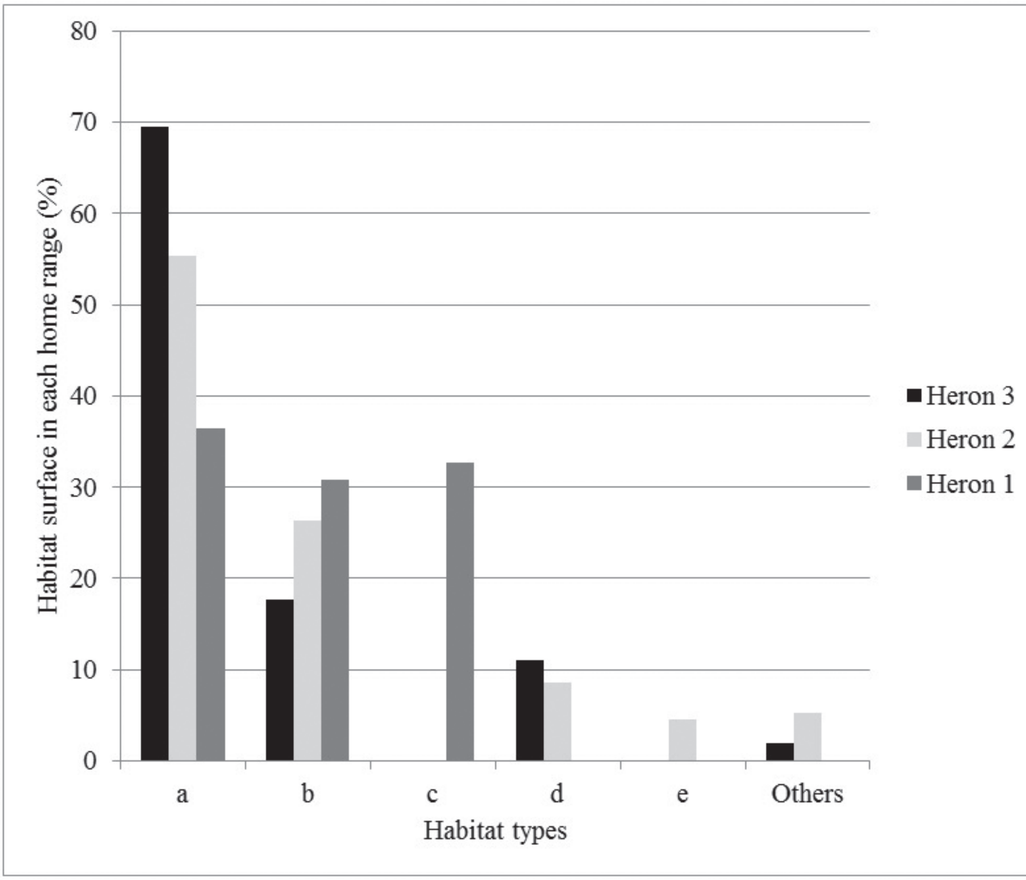

Figure 2. Habitat surfaces included in the home ranges of three adult Agami Herons in the Marais de Kaw-Roura National Nature Reserve marshes, French Guiana. a = interior marshes and wooded swamps; b = flooded/swamp forest; c = mangroves; d = high forest; e = coastal plain forest.

of 15, 19 and 21 km from the colony (calculated as the distance between the colony and the most remote home range limit).

After the breeding season, one of the individuals remained near the colony until the transmitter stopped emissions on 20 November, after 209 days. Four individuals moved away after breeding. Migration distances and dates of departure and arrival, as well as destinations, differed (Table 3). Total distance moved was 280 km to over 1,200 km. Two individuals traveled west; the other two traveled southeast (Fig. 4).

The migration path of Heron 5 could be followed only during the first 7 days of migration. The migration paths of the other three individuals were along the Atlantic coasts of Venezuela, Guyana, Suriname, French Guiana, and/or Brazil and included one substantial stop-over of 24 to 61 days (Fig. 4) at 34, 113 and 604 km from the colony, respectively, representing 12, 27 and 48% of the total migration distances. There was no apparent difference in stop-overs and migration patterns between sexes (Table 3; Fig. 4).

Total migration duration ranged from 36 to 95 days. Migration lengths, excluding the substantial stop-overs, ranged from 12 to 36 days. Migration speed, excluding stop-overs, ranged from 12 to 35 km/day.

DISCUSSION

Breeding in a colony of over 1,000 nests yet being solitary foragers, it would be ex-

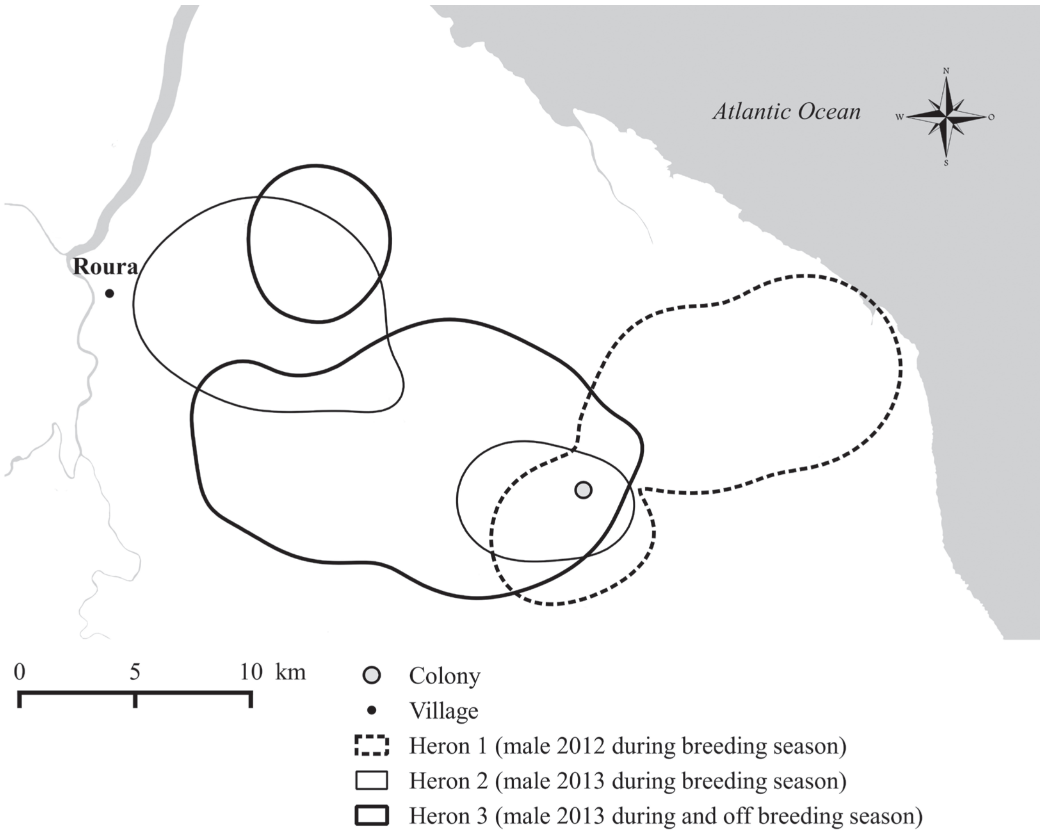

Figure 3. Home ranges estimated at 95% for three adult Agami Herons in the Marais de Kaw-Roura National Nature Reserve marshes, French Guiana.

pected that nesting Agami Herons must distribute themselves widely across the landscape within flight distance of the colony. This supposition is supported by the findings that nesting individuals had home ranges of up to 200 km^2 and that adults feeding young did not return daily (Kushlan and Hines 2016). Thus, a colony of this size must be supported by thousands or perhaps tens of thousands of hectares of natural habitat, suggesting the importance of protecting not only the colony site but a substantial amount of habitat nearby. That this colony accumulates individuals from long distances suggests that over its entire range the species may be composed of distinct populations that accumulate into large regional colonies for nesting and then redistribute themselves more widely. The genetic consequences of such population partitioning would be of considerable interest.

Of course, any individual would not be using all of the habitats within its overall home range. The habitat utilization distribution results indicate that wetlands of several sorts are used by individuals. The resulting calculated use areas are so large they suggest that large areas of wetland are needed for each bird and certainly for the colony as whole.

Although the possibility of local movements had been suggested (Alvarado 1995), this species has never been considered to be migratory (Hancock and Kushlan 1984). That this study shows it to be capable of migrations exceeding 1,000 km requires a substantial revision in understanding its biology as a variably migratory species, and these migrations can be international in scope.

The demonstration that individuals use stop-over sites is of consequence bio-

Table 3. Post-breeding migration characteristics of five adult Agami Herons equipped with satellite transmitters in the Marais de Kaw-Roura National Nature Reserve marshes, French Guiana. Migration length and average migration speed were calculated excluding stop-overs.

Individual	Date Transmitter Installed	Sex	Migrating Individual	Migration Distance (km)	Departure	Arrival	Migration Length (days)	Number of Stop-overs	Stop-over Length (days)	Migration Length (days)	Average Migration Speed (km/day)
4	26 April 2013	Female	yes	280	29 April 2013	04 April 2013	36	1	24	12	23
3	25 April 2013	Male	no	—	—	—	—	—	—	—	—
2	25 April 2013	Male	yes	411	28 April 2013	01 April 2013	95	1	61	34	12
5[1]	25 April 2013	Female	yes	n/a	28 April 2013	n/a	n/a	n/a	n/a	n/a	n/a
1	24 April 2012	Male	yes	1,250	08 April 2012	06 April 2012	60	1	24	36	35

[1]The migration of Heron 5 could not be followed until the end.

logically and for conservation. These stops may be required by energy demands of migration or to take advantage of special foraging opportunities encountered along the migration path. Given that the stop-over locations and times differed between the individuals, it is possible they needed to stop to replenish energy. This could explain earlier observations that Agami Herons are present in some areas only for parts of the year (Hancock and Kushlan 1984).

The colony in the Marais de Kaw-Roura National Nature Reserve (Reserve) marshes in French Guiana could be used as a model to consider conservation approaches. That it receives individuals from a wide region indicates that this and similar large colony sites deserve particular protection. That individuals nesting in the Reserve marshes cross national borders on migration with substantial stop-overs and spend long periods in distant non-breeding areas shows that multi-site and multi-national conservation and management are clearly critical aspects of the conservation strategy for this species (Stier and Kushlan 2015).

This study has revealed new, unexpected and critical aspects of the biology of the Agami Heron as a migratory species, but it also suggests the need for additional study. It remains unclear, for example, how a species that is exceptionally solitary for most of its annual cycle becomes highly social when nesting. There are similarly unresolved questions about the species' migration biology, such as the factors determining whether an individual migrates or remains near the colony site and if individuals from different colonies overlap outside the nesting season. Similarly, nothing is known of colony site philopatry and genetic structuring of the populations.

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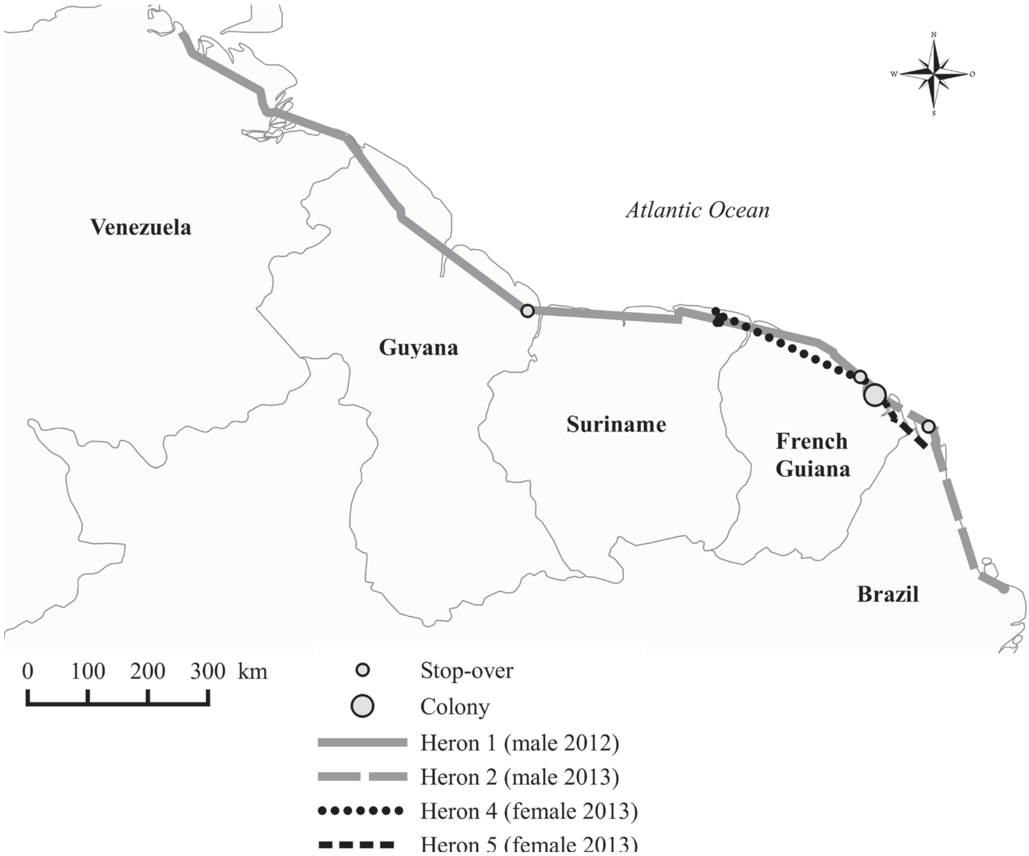

Figure 4. Post-breeding migration paths of four adult Agami Herons. The migratory path of Heron 5 could not be followed until the end.

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