GEOLOCATOR DATA REVEAL THE MIGRATION ROUTE AND WINTERING LOCATION OF A CARIBBEAN MARTIN (*Progne dominicensis*)

NOAH G. PERLUT,[1,4] THOMAS C. KLAK[1] and ELDAR RAKHIMBERDIEV[2,3]

[1]Department of Environmental Studies, University of New England, 11 Hills Beach Road, Biddeford, ME 04005

[2]Department of Marine Ecology, NIOZ Royal Netherlands Institute for Sea Research, PO Box 59, 1790 AB Den Burg, Texel, The Netherlands

[3]Department of Vertebrate Zoology, Lomonosov Moscow State University, 119991, Leninskiye Gory 1, Moscow, Russia

[4]Corresponding author; email: nperlut@une.edu

Please send page proofs to the corresponding author at the above email address.

ASTRACT.--- Caribbean Martins (*Progne dominicensis*) are common breeders on most Caribbean islands, where they regularly roost and nest in urban areas from February through August. However, from September through January, the basic ecology of this species—its migration and wintering locations—are largely unknown. In 2012, we deployed seven geolocators and, in 2014, recovered one geolocator from a female Caribbean Martin on the Commonwealth of Dominica, a small eastern Caribbean island. Her wintering location was the western portion of the State of Bahia, Brazil, approximately 3550 km southeast of Dominica. Although the non-breeding grounds changed minimally, the fall departure date, migration route and length of migration to western Bahia, Brazil, was different between years. In October 2012, the female followed a coastal migration route along the Atlantic coast of South America, then flew south to the non-breeding grounds. However, in Oct 2013, she flew south from Dominica through Guyana, spent a few days in the Amazon rain forest, and then migrated southeast to the non-breeding grounds. These results provide insight into the repeatability of migration routes and wintering locations by this species, and serves as a first step in better understanding the Caribbean Martin's full life-cycle.

KEYWORDS.---Commonwealth of Dominica, *Progne dominicensis*, State of Bahia Brazil

Recent technological advances such as satellite transmitters and geolocators are rapidly expanding our understanding of the life-histories of migratory birds (McKinnon et al. 2013. For example, these tracking devices have revealed long non-stop flights (DeLuca et al. 2015), foraging patterns that allow managers to better plan fisheries activities (Phillips et al. 2006), and migratory connectivity for landbird populations (Ryder et al. 2011). Even with the availability of these technologies, the basic ecology of many common and rare species remains unknown.

Although the breeding range of Caribbean Martins (*Progne dominicensis*) is well documented (BirdLife International 2012), their migration routes and wintering areas are largely unknown (Turner 2004). Some reports of Caribbean Martins during the non-breeding season have been published from the southern Caribbean islands of Trinidad and Barbados, and from Suriname and French Guiana in South America (Voous 1983, Murphy and Hayes 2001, Wells and Wells 2005, Ottema et al. 2009, Renaudier and de Guyane 2010). The greatest number of observations come from Suriname (8), but only half of the records are from the period from November to January (Birds in Suriname 2015). However, these generally represent observations of individual birds, and provide no information about where the birds came from, the routes taken to get there, or other locations that might be used during migration.

We used a geolocator to identify the migration routes and non-breeding areas of a Caribbean Martin. In 2012, we deployed seven geolocators on the Commonwealth of Dominica.

In 2014, we retrieved one geolocator from a female and documented her movements over a two-year period.

METHODS.---We captured Caribbean Martins on the Commonwealth of Dominica, an eastern Caribbean island country with a land surface of 750 km^2 and a population of about 70,000. Here, Caribbean Martins roost and nest in both natural cliff faces and crevices in roof-tops. We focused on a colony in the village of St. Joseph (15°24’16; -61°25’34), where birds used the eaves of a small bakery located 50 m from the Caribbean Sea and 20 m from the St. Joseph River. We deployed 0.65-g solar geolocators (Intigeo-P65C2-7, Migrate Technology Ltd., Cambridge, United Kingdom) at nesting colonies using a leg-loop backpack harness made of 0.10 inch Teflon tape (Bally Ribbon Mills). To increase the probability of recovering geolocators, we aimed to deploy units on breeding birds. Prior to fieldwork, we believed that the breeding season would begin in mid- to late-March (B. Jno Baptiste, pers. comm.). From 6 to 10 April 2012, we caught birds with hand nets as they emerged from their night roost and deployed seven geolocators on birds assumed to be breeding. However, we found that these birds were not yet nesting because they never returned to the roosts to incubate eggs or feed young. We caught the birds with hand nets as they emerged from their night roost and none of the females had brood patches. All birds were banded with a numbered band on one leg, and a unique combination of two color bands on the other leg. We identified their sex by plumage. We returned to Dominica from 5 to 9 May 2013 and 3 to 8 May 2014 to collect geolocators from birds.

Data were downloaded and formatted in IntiProc v1.03 (Migrate Technology), and are available at https://github.com/eldarrak/FLightR/tree/0.3.6/examples/Caribean_Martin. All subsequent data processing and estimation were done in R v. 3.2.2 (R Core Team 2015). First we selected twilight periods without strong patterns in shading in the BAStag package (Wotherspoon et al. 2015) and then used the template-fit method (Ekstrom 2007) in the FLightR package (Rakhimberdiev 2015) to estimate positions from the light-level recordings. The BAStag output with preselected twilights and all analysis details are available at the github page referenced above. We calibrated the data during the second breeding period (15 June – 30 August 2013) when the bird was likely on the Dominica breeding grounds. We then used the particle filter in FLightR to map migration routes and identify the posterior distribution for the non-breeding locations (Rakhimberdiev et al. 2015). FLightR uses a hidden Markov chain model to obtain the most probable tracks of migrating animals from geolocator data. Because Caribbean Martins breed on islands, we used spatio-behavioral flight constraints allowing the bird to fly over (oceanic) water, but not to remain stationary there. FLightR is able to estimate positions during migration and during equinoxes (Rakhimberdiev et al 2016), but our tagged bird combined these two complications and migrated during equinox periods making estimated latitudinal positions for the migration period (shown at Fig. 1) especially imprecise (see latitudinal credible intervals at Fig. 2). FLightR estimated arrival and departure days within the function stationary.migration.summary. Function automatically finds sedentary periods and estimates when animals arrived and left the sedentary periods.

RESULTS.---Of seven birds color-banded in 2012, we resighted four birds in 2013 and 2014, but were unable to recapture them. Three of the four birds still had their geolocators attached. On May 5, 2014, we recaptured one of the four birds and recovered its geolocator; this bird was a female, initially banded on April 4, 2012. This female returned to the same non-breeding area in both years, an area located ~3550 km southeast of the Dominican breeding grounds (Fig. 1). The wintering location was in the western portion of the State of Bahia (-44.3°, -12.3°) in Brazil, located ~700 km west of the city of Salvador; the bird spent 35% of the wintering period in one grid cell with an area of ~2000 km^2.

Fall migration routes of the female Caribbean Martin differed between years. In 2012, the migration route from Dominica was along the Atlantic coast of South America. However, in 2013, the female first flew due south from Dominica, through Guyana, likely into the Amazon rainforest in the eastern portion of the State of Amazonas, Brazil, for a few days, then traveled southeast to the wintering area. Fall migration in 2012 started on 1 October, arriving on the winter location near October 31 (Table 1; Fig. 2), with a total migration duration of 30 days, and migration route length of approximately 5930 km. The spring 2013 migration—which was similar to the fall 2012 route along the Atlantic coast—began around 19 February, with the female arriving in Dominica on March 1, with a total migration duration of 11 days, and migration route length of approximately 4170 km. The fall 2013 migration started around September 11, and the female arrived at the wintering location on about October 20, with a total migration duration of 39 days, and migration route length of approximately 6370 km. Spring 2014 migration apparently occurred sometime during the period from mid-February to early March because the geolocator battery failed on February 14 while the female was still in the wintering area.

DISCUSSION.---Over two years, we found that a single female Caribbean Martin captured on Dominica used the same wintering area in the southern portion of the State of Bahiain Brazil. This area is ~2100 km further south than areas where Caribbean Martins have previously been reported during the winter in scientific literature (Voous 1983, Murphy and Hayes 2001, Wells and Wells 2005, Ottema et al. 2009, Renaudier and de Guyane 2010) and through citizen science observations (eBird.org; accessed 1/20/2017) . Fall migration routes likely differed between years, with the female taking a coastal route one year and an inland route the next. The inland route is similar to the route taken by a Purple Martin (*Progne s. subis*), that, migrating south from North America, took a southeasterly land-route from Central America to Brazil (Stutchbury et al. 2009). Likewise, some Barn Swallows (*Hirundo rustica*) migrating from northeastern North America followed both routes identified in our study (Hobson et al. 2015), although annual variation within individuals was not assessed. In fact, few geolocator studies have assessed the repeatability of fall migration—and thus we know little about what factors drive variation in routes within individuals. A study of Wood Thrush, *Hylocichla mustelina*, found repeatable timing but non-repeatable migration routes (Stanley et al. 2012). Stanley et al. (2012) measured route repeatability by comparing an individuals' longitude while crossing 23.4°N during spring and fall migration; they suggested that this lack of repeatability was likely caused by individual energetic condition and variable weather patterns. For the Caribbean Martin we tracked, fall migration started 20 days earlier in 2013 than 2012; this difference could indicate improved autumn body condition between years, or variation in favorable weather conditions.

The western portion of Bahia is a remote, semi-arid and economically-marginal interior region. It consists primarily of sparsely forested uplands (approximately 60% of land cover), cattle and other livestock rearing, forestry, and small-scale agriculture along a network of roads (30%), and scattered towns and villages (10%). The region is transitional between scrub lands called the *Sertão* to the east and moister, heavily irrigated, and densely cropped agricultural region called the *Cerrado* to the west (Fig. 3; IBGE 2016; Klak pers.obs.).

We acknowledge that these results represent the migration routes and wintering locations of a single individual over two years and may or may not be representative of the species as a whole. Nonetheless, these results provide insight into the repeatability of migration routes and wintering locations by this species, and serves as a first step in better understanding the Caribbean Martin's full life-cycle.

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LITERATURE CITED.---

Birds in Suriname. 2015. <http://www.surinamebirds.nl/php/bird.php?prdo> (accessed 23 February 2016).

BirdLife International. 2012. *Progne dominicensis*. The IUCN Red List of Threatened Species 2012. <http://dx.doi.org/10.2305/IUCN.UK.2012-1.RLTS.T22712104A38539526.en> (accessed 23 February 2016).

DeLuca, W. V., B. K. Woodworth, C. C. Rimmer, P. P. Marra, P. D. Taylor, K. P. McFarland, S. A. Mackenzie, and D. R. Norris. 2015. Transoceanic migration by a 12 g songbird. Biology Letters 11: 2014105.

Ekstrom, P. 2007. Error measures for template-fit geolocation based on light. Deep Sea Research Part II Topical Studies in Oceanography. 54: 392–403.

Fraser, K. C., B. J. M. Stutchbury, C. Silverio, P. M. Kramer, J. Barrow, D. Newstead, N. Mickle, B. F. Cousens, J. C. Lee, D. M. Morrison, T. Shaheen, P. Mammenga, K. Applegate, and J. Tautin. 2012. Continent-wide tracking to determine migratory connectivity and tropical habitat associations of a declining aerial insectivore. Proceedings of the Royal Society B 279: 4901-4906.

Hobson, K. A., K. J. Kardynal, S. L. Van Wilgenburg, G. Albrecht, A. Salvadori, M. D. Cadman, F. Liechti, and J. W. Fox. 2015. A continent-wide migratory divide in North American breeding Barn Swallows (*Hirundo rustica*). PLoS ONE 10: e0129340.

IBGE (Instituto Brasileiro de Geografia e Estatística). 2016. Cidades. <http://ibge.gov.br/cidadesat/xtras/home.php> (Accessed 27 April 2016).

Lisovski, S. and S. Hahn. 2012. GeoLight—processing and analyzing light-based geolocator data in R. Methods in Ecology and Evolution 3: 1055–1059.

McKinnon, E. A., K. C. Fraser, and B. J. M. Stutchbury. 2013. New discoveries in landbird migration using geolocators, and a flight plan for the future. The Auk 130: 211-222.

Murphy, W. and F. Hayes. 2001. First records of Caribbean martin (*Progne dominicensis*) for Trinidad, with comments on its supposed migration to South America. Pitirre 14: 61-62.

Ottema, O. H., J. H. Ridot, and A. L. Spaans. 2009. Annotated checklist of the birds of Suriname. WWF Guianas-World Wildlife Fund, Paramaribo, Suriname.

Phillips, R. A., J. R. D. Silk, J. P. Croxall, and V. Afanasyev. 2006. Year-round distribution of white-chinned petrels from South Georgia: Relationships with oceanography and fisheries. Biological Conservation 129: 336-347.

Rakhimberdiev, E., D. W. Winkler, E. Bridge, N. E. Seavy, D. Sheldon, T. Piersma, and A. Saveliev. 2015. A hidden Markov model for reconstructing animal paths from solar geolocation loggers using templates for light intensity. Movement Ecology 3: 25.

Rakhimberdiev, E., N. R. Senner, M. A. Verhoeven, D. W. Winkler, W. Bouten, and T. Piersma. 2016. Comparing inferences of solar geolocation data against high-precision GPS data: annual movements of a double-tagged Black-tailed Godwit. Journal of Avian Biology 47: 589-596.

Renaudier, A. and C. d’H. de Guyane. 2010. Rare birds in French Guiana in 2005-07. Gotinga 32: 95-104.

Ryder, T. B., J. W. Fox, and P. P. Marra. 2011. Estimating migratory connectivity of Gray Catbirds (*Dumetella carolinensis*) using geolocator and mark-recapture data. Auk 128: 448-453.

R Core Team. 2015. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, Vienna, Austria. <http://www. R-project.org>.

Schmaljohann, J., J. W. Fox, and F. Bairlein. 2012. Phenotypical response to environmental cues, orientation and migration costs in songbirds flying halfway around the world. Animal Behaviour 84: 623-641.

Stanley, C. Q., M. MacPherson, K. C. Fraser, E. A. McKinnon, and B. J. M. Stutchbury. 2012. Repeat tracking of individual songbirds reveals consistent migration timing but flexibility in route. PLoS ONE 7: e40688.

Stutchbury, B. J. M., S. A. Tarof, T. Done, E. Gow, P. M. Kramer, J. Tautin, J. W. Fox, and V. Afanasyev. 2009. Tracking long-distance songbird migration by using geolocators. Science 323: 896.

Voous, K. H. 1983. Birds of the Netherlands Antilles, second edition. De Walburg Pers,, Zutphen, The Netherlands.

Wells, J. V. and A. M. C. Wells. 2005. First record of Caribbean Martin (Progne dominicensis) for Aruba. North American Birds 59: 670-671.

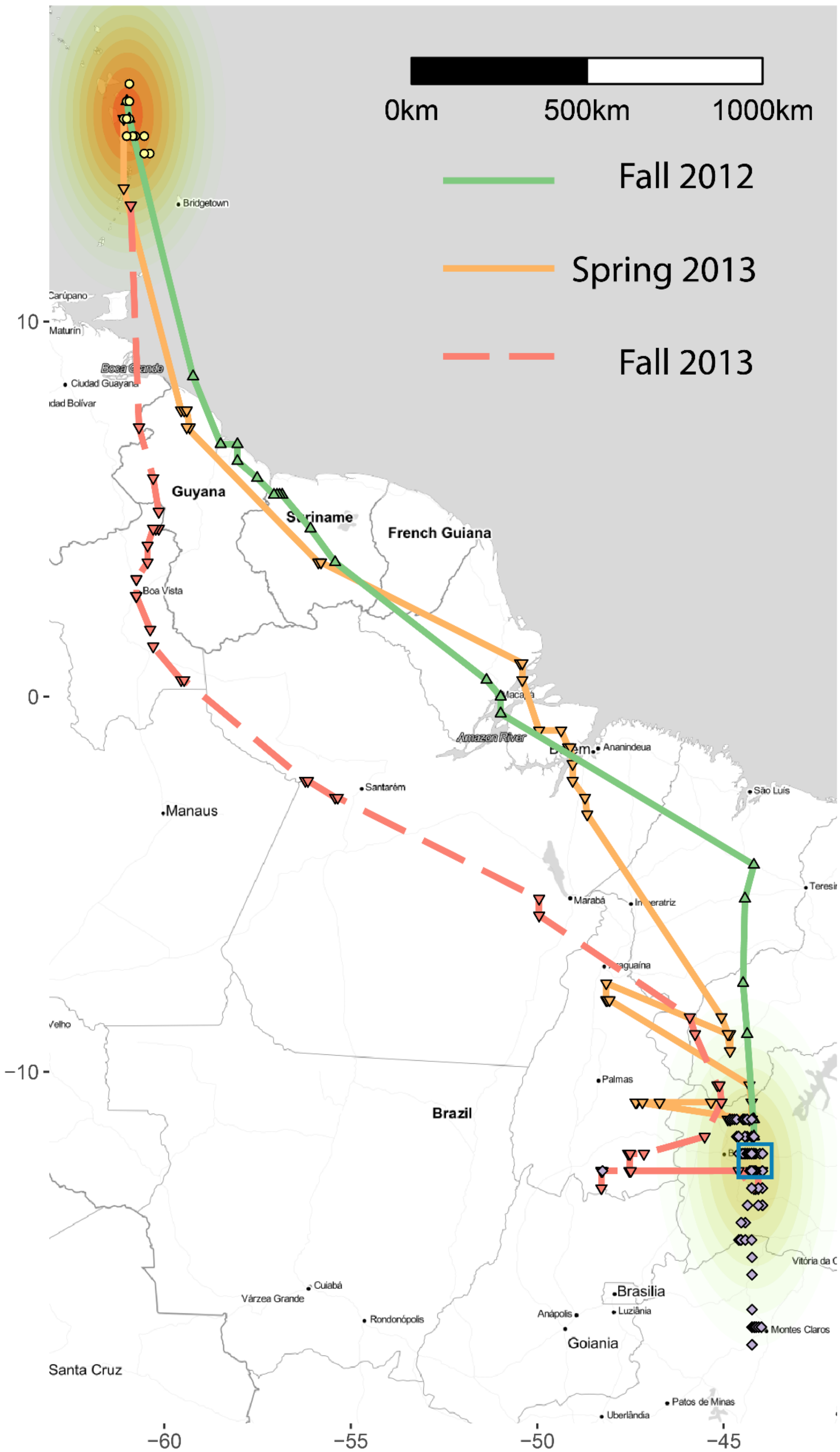
Wotherspoon, S., M. Sumner, and S. Lisovski. 2013. BAStag: Basic data processing for light based geolocation archival tags. R package version 0.1-3. < https://github.com/SWotherspoon/BAStag >

Table 1: Summary departure and arrival dates, including migration lengths for a female Caribbean Martin who bred on Dominica and wore a geolocator for two years.

	2012	2013
Fall migration departure date	1-Oct	11-Sep
Arrival to winter location	31-Oct	20-Oct
Fall migration length	5930 km	6370 km
Spring migration departure date	19-Feb	> 14-Feb
Arrival to breeding grounds	1-Mar	
Spring migration length	4170 km	

Figure 1: Migration route of a female Caribbean Martin over two years estimated from solar geolocator data; she bred on the Commonwealth of Dominica, a 750-km^2 island in the eastern Caribbean, and wintered in the western portion of Bahia, Brazil. Daily median positions are shown with the lines (green = fall 2012; orange = spring 2013; pink = fall 2013) and overall probability of occurrence regions with color (darker sections indicate higher probability). Fall migration in 2012 started on 1 Oct, arriving in the wintering area on about 31 October. Spring 2013 migration began about 19 February, and fall 2013 migration started about 11 September,

with the female arriving in the wintering area on 20 October. Blue square shows extent of the main wintering area zoomed at Figure 3. Circles represent stationary periods in the breeding period, diamonds during the non-breeding period, and triangles represent movement periods.



0km
500km
1000km
Fall 2012
Spring 2013
Fall 2013
Bridgetown
Carúpano
Maturín
Boca Grande
Ciudad Guayana
Guyana
Suriname
French Guiana
Boa Vista
Amazon River
Ananindeua
Santarém
Manaus
São Luís
Marabá
Palmas
Brazil
Cuiabá
Várzea Grande
Rondonópolis
Brasília
Anápolis
Luziânia
Goiania
Montes Claros
Santa Cruz
Patos de Minas
Uberlândia
10
0
−10
−60
−55
−50
−45

Figure 2: Longitudes (upper panel) and latitudes (lower panel) of a track of a Caribbean Martin as estimated by FLightR. The medians of twilight positions estimated by FLightR include quartile ranges and 95% credible intervals.

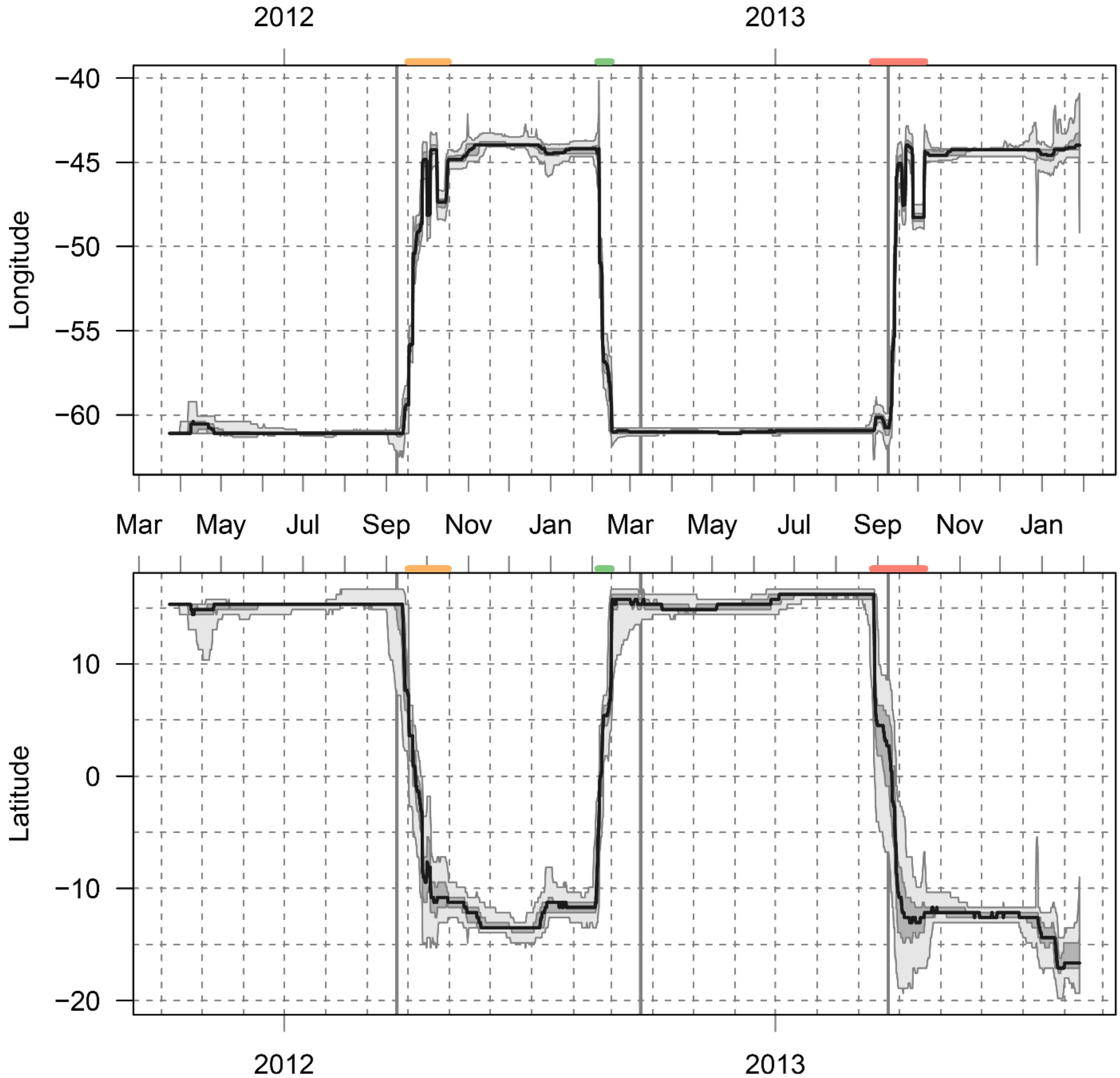


Figure 3: The wintering region of the Caribbean Martin was ~700 km west of the city of Salvador (see box in Fig. 1); colored contours correspond to the smallest regions that contain

25% (purple), 50% (blue) and 75% (grey) of modeled probability of occurrence. This region consists primarily of sparsely forested uplands, cattle and other livestock rearing, forestry, small-scale agriculture along a network of roads, and scattered towns and villages.