Satellite Telemetry Reveals Strong Fidelity to Migration Routes and Wintering Grounds for the Gull-Billed Tern (Gelochelidon nilotica)

Authors: Goodenough, Katharine S., and Patton, Robert T.

Source: Waterbirds, 42(4) : 400-410

Published By: The Waterbird Society

URL: https://doi.org/10.1675/063.042.0405

Satellite Telemetry Reveals Strong Fidelity to Migration Routes and Wintering Grounds for the Gull-billed Tern (*Gelochelidon nilotica*)

Katharine S. Goodenough[1,2*] and Robert T. Patton[3]

[1]Biology Department, San Diego State University, North Life Sciences Room 102, 5500 Campanile Drive, San Diego, California, 92182-4614, USA

[2]Oklahoma Biological Survey, University of Oklahoma, 111 E. Chesapeake Street, Norman, Oklahoma, 73019, USA

[3]Patton Biological LLC, 4444 La Cuenta, San Diego, California, 92124, USA

[*]Corresponding author; E-mail: kgoodenough@ou.edu.

Abstract.—The Western Gull-billed Tern (*Gelochelidon nilotica*) breeds in only 16 locations in southern California, USA and the Pacific coast and Gulf of California in Mexico. Relatively little information is available on migration and wintering locations for the population. This is the first project to use satellite telemetry to document Gull-billed Tern migration routes, important stop-over locations, and non-breeding areas for the northwestern-most breeding population that nests in San Diego, California. A total of eleven deployments occurred over a period of four breeding seasons. Of the 11 deployments, five terns provided information on complete migration cycles consisting of both a fall and a successive spring migration. Four terns provided information on two fall and one spring migration, and one tern provided information on three fall and three spring migrations. Migration routes in the fall and spring are similar, with individuals crossing inland over the Peninsular Mountain Range of Baja California to stop over in the Rio Colorado Delta of Mexico, before beginning southward travel along the continental Mexico coastline and reversing the route for spring migration. The wintering distribution of individuals from the San Diego breeding colony appears to be small, consisting of a 250-km span of coastal wetlands ranging from Bahía Tóbari, southern Sonora south to Santa María-La Reforma, northern Sinaloa, Mexico. Long term monitoring of individual movements suggests strong fidelity to both breeding and wintering grounds, with individuals returning to San Diego each season to breed and then returning to previously used winter locations. *Received 2 September 2019, accepted 7 October 2019.*

Key words.—Migration, satellite telemetry, site fidelity, Sterninae, tern, winter fidelity.

Waterbirds 42(4): 400-410, 2019

The Gull-billed Tern (*Gelochelidon nilotica*) is globally distributed with an estimated population size of less than 55,000 individuals world-wide that encompasses Europe, Africa, Asia, Australia, and the Americas (Gochfeld *et. al.* 2019). In Eastern Europe, the Gull-billed Tern is listed as endangered with a suspected population decline of 30% throughout the European range while populations in Asia and Australia appear to be stable (Sánchez *et al.* 2004). The North American breeding population is estimated to be 4,160 to 5,200 breeding pairs (Molina and Erwin 2006; Molina *et al.* 2014).

In California, USA, the Western Gull-billed Tern (*G. n. vanrossemi*), herein referred to as *Vanrossemi*, breeds in two locations in the USA, the Sonny Bono-Salton Sea National Wildlife Refuge and the San Diego Bay National Wildlife Refuge, and at 14 small breeding colonies along the Pacific Coast of Mexico south to Colima. Breeding pair estimates range from 555 to 778, with the majority of the population residing in Mexico (68-82%; Palacios *et al.* 2015). *Vanrossemi* is considered a California State Species of Special Concern (Shuford and Gardali 2008) and the United States Fish and Wildlife Service classifies the tern as a Bird of Conservation Concern (USFWS 2008). In 2010, *Vanrossemi* was considered for listing under the USA Endangered Species Act based on small population size, limited distribution, and declining population trends, but status was not updated to threatened because the majority of the population lies within Mexico and the populations within Mexico appeared at the time to be stable (USFWS 2011). Breeding locations and reproductive success have been well documented in California since the early 1990s and with increasing regularity in Mexico since 1995 (Palacios and Mellink 2007; Palacios *et al.* 2015), but published wintering accounts are limited (Molina *et al.* 2009). While wintering, the Gull-billed Tern has been documented as far south as southern Ecuador (Hellmayr and Conover 1948), but subspecific taxonomy is questionable for terns documented in South America (Molina and Erwin 2006; Molina *et al.* 2009).

The 2015 population estimate of *Vanrossemi* suggests a 32% decline in the California breeding population over the past five years, attributed mainly to declining habitat quality at the Salton Sea colony (Shuford *et al.* 2002; Palacios *et al.* 2015; Bradley and Yanega 2018; Molina 2018) and a 2013 mass mortality event in San Diego that resulted in the loss of 71-92% of that colony's breeding population (Patton *et al.* 2017). While the breeding population at the San Diego colony has begun to recover from the 2013 mortality, with 38 minimum breeding pairs as of 2018 (Patton unpubl. data), zero or low breeding success has plagued the Salton Sea colony for greater than five years (Molina 2018). The potential long-term decline of the California population has created a critical need to understand factors influencing *Vanrossemi* survival throughout its entire lifecycle. Our goal for this research was to use satellite telemetry to identify migration routes, important stopover sites, and wintering locations for those individuals breeding in San Diego. We further comment on the strength of fidelity to breeding and wintering grounds for *Vanrossemi* breeding in San Diego, California.

METHODS

Study location

The study encompasses San Diego and Imperial Counties of California, USA and south into the Gulf of California, Sonora and Sinaloa states of Mexico. *Vanrossemi* nests in only one coastal location in California at the San Diego Bay National Wildlife Refuge (SDBNWR: 32° 35' 56.81" N, 117° 6' 11.32" W) that was used to capture terns and deploy satellite telemetry devices. The South San Diego Bay Unit of SDBNWR, also referred to as the Saltworks, is a solar evaporative sea salt operation consisting of a series of linear earthen dikes surrounding 28 salt ponds of various salinities that have been used by *Vanrossemi* since 1987, when the terns were first documented to be nesting at the Saltworks (McCaskie 1987).

Telemetry deployment

For this project, we captured eleven terns on nests for platform transmitting terminal deployment (PTT; Microwave Telemetry Inc., Maryland, USA) during the 2012 to 2016 breeding seasons using remote-controlled bownets (Goodenough 2014). We attached a 5-g solar powered PTT with harness to each tern using a modified leg-loop design, based on Mallory and Gilbert (2008), and adjusted to individual tern size measurements (Fig. 1). The telemetry unit consisted of a PTT glued with cyanoacrylate to a 10 mm x 7 mm rectangle of 5-mm neoprene and attached to a harness made of a 12 cm length of 10-mm Teflon ribbon harness (Bally Mills, Inc., Baltimore, Maryland, USA). The PTT was created with metal loops in a clover-leaf pattern such that the Teflon ribbon could be threaded through the loops into a leg-loop system that is then slipped over the hips of the tern and tightened. Once the harness was fitted to the tern, the ribbon was knotted, glued with cyanoacrylate, and excess ribbon was trimmed off. The neoprene raised the transmitter above feather line to prevent the tern from preening feathers over the PTT and obstructing the photovoltaic cell from recharging the internal battery. Total weight for the leg-loop harness and transmitter was on average 5.5 g (range 5.1-6.0 grams). We targeted *Vanrossemi* greater than 187 g for capture to comply with United States Geological Survey Bird Banding Lab guidelines of 3% or less of body weight (Fair and Jones 2010) except for one tern, with approval

Figure 1. A photograph of PTT platform transmitting terminal (PTT) placement on "Tern Winehouse" after it was released from rehabilitation following the Western Gull-billed Tern (*Gelochelidon nilotica vanrossemi*) 2013 mortality event in San Diego, California, USA. Photo by KSG.

Table 1. Location accuracy for the ARGOS platform transmitting terminals (PTT) used in location data collection on Western Gull-billed Terns (*Gelochelidon nilotica vanrossemi*) in southern California, USA and western Mexico. Accuracy calculated using a Kalmann Least Squares algorithm by CLS America-ARGOS (France).

ARGOS Location	Accuracy
3	Within 250m
2	250-500m
1	500-1000m
0	>1000m
A	No accuracy, used only to ensure transmitting
B	No accuracy (not used)
Z	No accuracy (not used)

from the USGS Bird Banding Lab, that carried a satellite and harness which was 3.5% of body weight. Terns were DNA-sexed using blood samples collected during capture.

Analytical Methods

Location data (latitude/longitude) were downloaded daily from the ARGOS satellite platform system and archived at Movebank.org. Locations were developed from Doppler data using a Kalmann filter and associated with a location accuracy code (3, 2, 1, 0, A, B, Z) ranging from 3 (within 250 m) to Z (no accuracy). See Table 1 for accuracy estimates for each of the location codes. ArcMap 10.3.1 (ESRI, Redlands, California) was used to create maps of the location data and migration routes. Only data with high location accuracy (3, 2, 1) were used to plot migration route and winter location use. Other location data (0, A) were used to plot migration path only if there was not a higher accuracy point available.

We defined fall migration as the time period when terns departed San Diego in July-August and ended when the terns reached a location where they did not venture any farther south. Spring migration was identified as the time period when the terns departed their winter location and headed north to the breeding ground in San Diego. The wintering period is defined as the interval between the end of fall migration and the start of spring migration when movements did not exceed 60 km of daily travel.

RESULTS

A total of eleven deployments occurred over a period of four breeding seasons (n = 5 in 2012, n = 2 in 2013, n = 3 in 2014, n = 1 in 2016). Of the 11 deployments, five terns have provided information on complete migration cycles consisting of both a fall and a successive spring migration (Table

Table 2. Fall and spring arrival dates, length of migration, and wintering locations of Western Gull-billed Terns (*Gelochelidon nilotica vanrossemi*) tracked by satellite telemetry in southern California, USA and western Mexico.

Tern	Year	Fall Depart	Fall Arrival	# Days	Winter Location	Spring Depart	Spring Arrival	# Days	Length Tracked (months)
Louisa	2012	06 Jul	31 July	25	Bahía Santa María-La Reforma, Sinaloa	23 Apr	06 May	12	13
Winehouse	2013	23 Jun	26 Oct	123	Lechuguilla, Sinaloa	04 Apr	10 Apr	7	18
Winehouse	2014	22 Jun	06 Jul	14	Lechuguilla, Sinaloa	n/a	03 Apr[d]	n/a	
Lolo	2014	02 Jul	09 Aug	38	Agiabampo, Sinaloa	16 Mar	26 Mar	10	13
Lolo	2015	03 Jul	01 Aug	28	Agiabampo, Sinaloa	n/a	n/a	n/a	
Hendrix	2014	20 Jun	09 Jul	19	Yavaros, Sonora	02 Apr	12 Apr	10	18
Hendrix	2015	28 Jun	18 Jul	20	Yavaros, Sonora	n/a	n/a	n/a	
Joplin[a]	2014	29 Jun	n/a	n/a	n/a	n/a	n/a	n/a	3
Sid	2016	26 Jun	16 Jul	20	Bahía Tóbari, Sonora	09 Apr	14 Apr	5	36
Sid	2017	28 Jul	04 Aug	7	Bahía Tóbari, Sonora	08 Apr	10 Apr	2	
Sid	2018	03 Jul	16 Jul	13	Bahía Tóbari, Sonora	02 Apr	07 Apr	7	

[a]The transmitter on Joplin stopped at 90 days.
[b]Arrival date determined by observation as the PTT was not operational for second spring migration.
[c]n/a indicates data not available.

2). Four terns have provided information on two fall and one spring migration, and one tern has provided information on three fall and three spring migrations. As several PTTs were refurbished and reused, we refer to tracked terns by names instead of tracker number to minimize confusion.

The first four deployments in 2012 had mixed success with harnesses on four individuals failing within three weeks of deployment due to harness attachment issues. One PTT from 2012 was recovered before the terns departed on migration and was re-deployed on Tern Louisa on June 16, 2012. Louisa successfully collected 368 high accuracy locations over a period of 13 months. In 2013, one individual was captured for PTT attachment (Tern Aqua), but the tern died within two weeks of capture due to acute peritonitis caused by acanthocephalan parasites (Patton *et al.* 2017). A second tern, that survived acanthocephaliasis, was released from rehabilitation with a PTT to monitor survival on June 8, 2013 (Tern Winehouse). The PTT on Winehouse lasted 18 months and provided 1,091 high accuracy locations. Three terns were captured for deployment in 2014: Tern Lolo, Tern Hendrix, and Tern Joplin. The PTT on Joplin ended before the tern had completed a full migration providing 78 data points over a period of 90 days. The PTTs on Hendrix and Lolo lasted 18 and 13 months, respectively, and collected 748 (Lolo) and 949 (Hendrix) data points. A final deployment in 2016 (Sid) expanded the research to provide 36 months of individual tracking data collecting 5,069 high accuracy location points. A switch to a newer battery system in the PTT improved collection of data by 120%.

Fall migration

Tracked terns began to depart San Diego in late June through July as chicks fledged and became capable of longer distance flight. Individuals departed during the early morning hours between 01:00-03:00 coinciding with moonrise. The first leg of the journey south consisted of travel inland through the Tijuana River watershed southwest over the Peninsular Mountain Range of Baja California to the Rio Colorado Delta (RCD; Figs. 2, 3), with the exception of Lolo and Hendrix who stopped at the Salton Sea for two to five days before heading to the RCD. Mean time to complete the 250 km from San Diego to the RCD was 15.7 hours (range 14-17 hours). Terns that detoured to the Salton Sea completed the San Diego to Salton Sea segment in 8-10 hours. All terns spent five to 21 days within the RCD before traveling south along the western continental Mexico coastline to southern Sonora and northern Sinaloa (Fig. 2). The route taken southward from the RCD to wintering locations by each tern was similar. Mean length of the fall migration period was 20 days (range 13-38 days) except for Winehouse, who took 123 days to finish fall migration in 2013 compared to fall 2014 which took 14 days to complete. Please refer to Table 2 for annual differences in the timing and length of fall migration.

Spring migration

The spring migration route was similar to the fall migration route by following the Pacific Coast of Mexico northward and then crossing the Peninsular Mountain Range of Baja California (Fig. 2). The start of spring migration began in mid-March to early May and took two to 12 days. The timing of departure among individuals ranged about six weeks; although all terns arrived by 12 May of each year. See Table 2 for timing of spring migration for individual terns. Movement data from Hendrix documented the northward movement from the wintering ground in Sonora, but the last segment of migration was missed due to the operating schedule of the PTT with the last transmission placing the tern crossing the Peninsular Mountain Range about 28 km south of the US-Mexico border. Subsequently, when the transmitter turned on, location data placed Hendrix in Orange County, California, at the Bolsa Chica Ecological Reserve for a day before the tern flew farther north to Port Hueneme, Ventura County, California and then returned to San Diego on 12 April. The three spring arrival dates for Sid indicate the tern took 5-7 days to complete spring migration (Table 2).

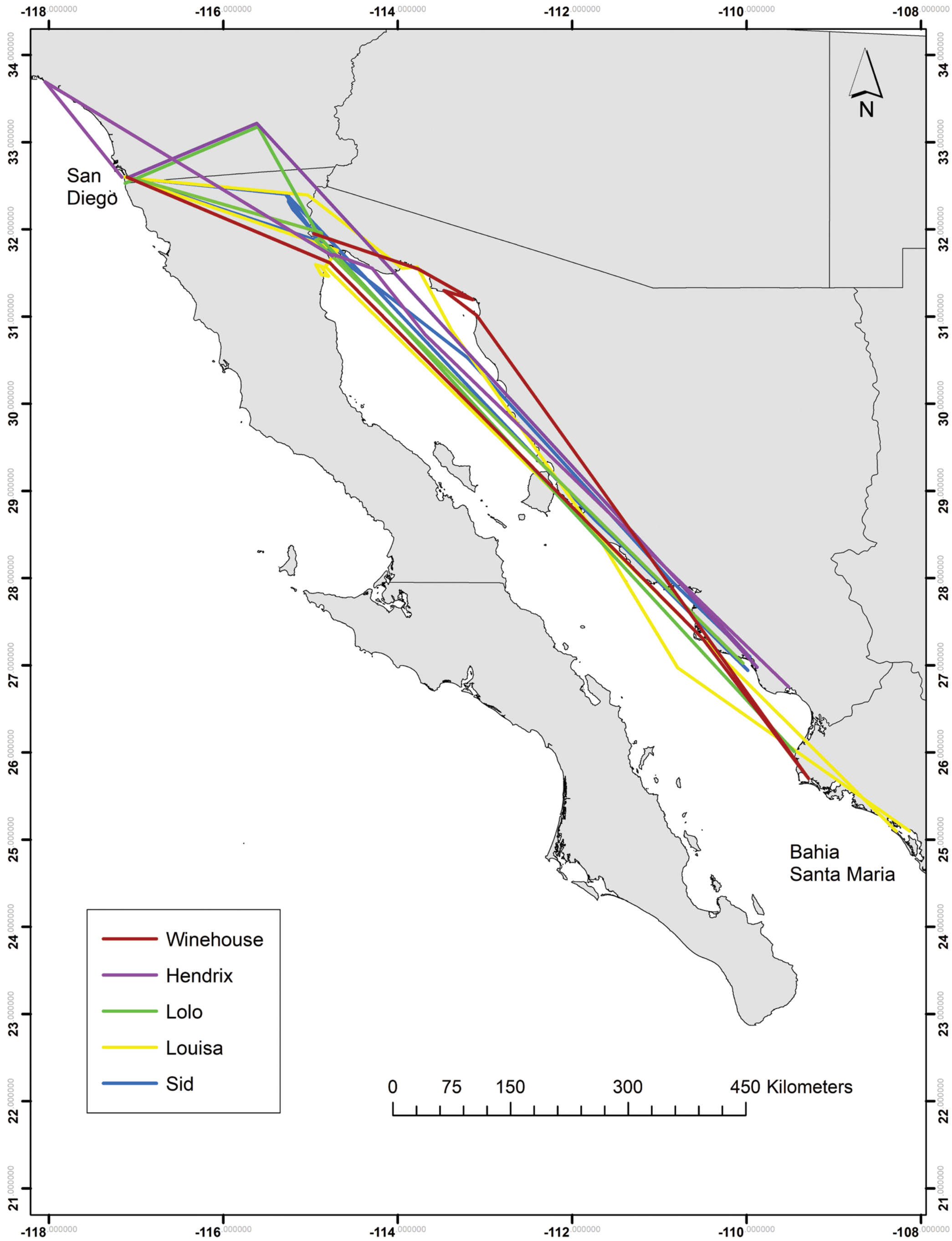

Figure 2. Spring and fall migration routes for tracked Western Gull-billed Terns (*Gelochelidon nilotica vanrossemi*) breeding in San Diego, California, USA and wintering in western Mexico. Routes between individuals were comparable using a similar route to navigate between breeding and winter location.

Important Stop-Over Locations

The Rio Colorado Delta (RCD: 31° 47′ 53.8″ N 114° 54′ 16.7″ W, Fig. 3) was an important stop-over location for both spring and fall migrations indicating a high degree of dependence on this location for refueling and rest before continuing migration. Stays at the RCD

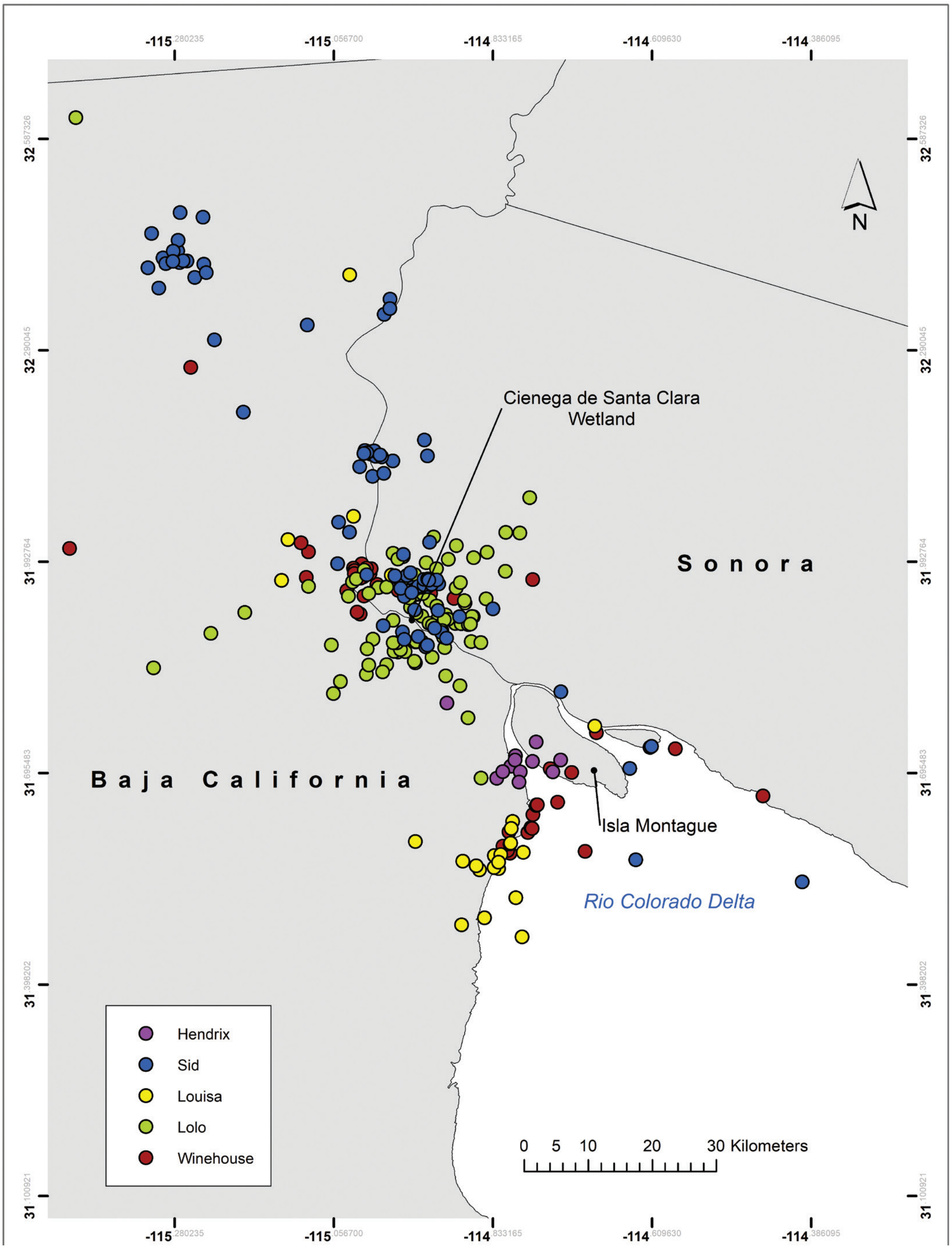

Figure 3. Stop-over locations used by each Western Gull-billed Tern (*Gelochelidon nilotica vanrossemi*) within the Rio Colorado Delta, Mexico (RCD). Length of stays were variable among individuals and across years with spring stop overs being shorter in duration (1-5 days) compared to fall stop overs (5-42 days). The Cienega de Santa Clara wetland was used by all terns during their annual fall migration in addition to the shallow waters of the Gulf of Santa Clara, Sonora, Mexico.

during fall migration ranged from five to 21 days, while stays during spring migration were much shorter at one to four days (Table 3). Winehouse spent a considerable time in the

Table 3. Length of stay in the Rio Colorado Delta (RCD) for spring and fall migration of each tracked Western Gull-billed Tern (*Gelochelidon nilotica vanrossemi*) in western Mexico.

Individual	RCD (Fall)	RCD (Spring)
Louisa	21	2
Winehouse 2013	11	n/a
Winehouse 2014	8	4
Lolo 2014	10	n/a
Lolo 2015	5	4
Hendrix 2014	10	n/a
Hendrix 2015	5	2
Sid 2016	12	3
Sid 2017	6	1
Sid 2018	10	1

RCD and the Puerto Peñasco region (42 days) before heading south to its non-breeding location during the 2013 fall migration, which we believe was due to poor health after the acanthocephalan outbreak, as the second fall migration (2014) only took a total of 14 days. The primaries were well worn after being in a flight cage at the rehabilitation center. We suspect Winehouse may have used the RCD region to molt primary flight feathers before heading farther south to the wintering location. Tern locations within the RCD were focused mainly near shallow water mudflats of the delta, Isla Montague, and Cienega de Santa Clara wetland to the northwest of the delta proper.

Wintering Locations

There was little overlap of wintering birds in Mexico. Five locations were identified as winter locations for the five individuals (see Table 4) that ranged 250 km along the Mexico Pacific coastline (Fig. 4). Bahía Tóbari, Sonora (27° 5′ 55.8″ N, 110° 0′ 46.4″ W) was the most northern location where a tracked tern wintered, whereas the Santa María-La Reforma wetland complex to the west of Culiacan, Sinaloa (24° 58′ 55.8″ N, 108° 6′ 25.9″ W) was the farthest south that a tracked *Vanrossemi* was documented to winter (Fig. 4). Other winter locations included Lechuguilla, Yavaros, and Agiabampo (Fig. 4). When splitting winter locations by sex, the only female tracked (Louisa) wintered the farthest distance from the breeding location (Table 4).

Table 4. Winter location in western Mexico and distance traveled from the San Diego, California, USA breeding location for each tracked Western Gull-billed Tern (*Gelochelidon nilotica vanrossemi*; sex determined by molecular methods).

Individual	Sex	Winter Location	Latitude, Longitude	Distance from San Diego (km)
Louisa	F	Bahía Santa María-La Reforma, Sinaloa	24° 58' 55.8" N, 108° 6' 25.9" W	1,077
Winehouse 2013	M	Lechuguilla, Sinaloa	25° 42' 26.1" N, 109° 20' 33.9" W	1,050
Winehouse 2014		Lechuguilla, Sinaloa	25° 42' 26.1" N, 109° 20' 33.9" W	1,053
Lolo 2014	M	Agiabampo, Sinaloa	26° 7' 56.9" N, 109° 18' 6.0" W	1,009
Lolo 2015		Agiabampo, Sinaloa	26° 7' 56.9" N, 109° 18' 6.4" W	1,017
Hendrix 2014	M	Yavaros, Sonora	26° 42' 25.3" N, 109° 30' 56" W	979
Hendrix 2015		Yavaros, Sonora	26° 42' 25.3" N, 109° 30' 56" W	982
Sid 2016	M	Bahía Tóbari, Sonora	27° 5' 55.8" N, 110° 0' 46.4" W	980
Sid 2017		Bahía Tóbari, Sonora	27° 5' 55.8" N, 110° 0' 46.4" W	977
Sid 2018		Bahía Tóbari, Sonora	27° 5' 55.8" N, 110° 0' 46.4" W	980

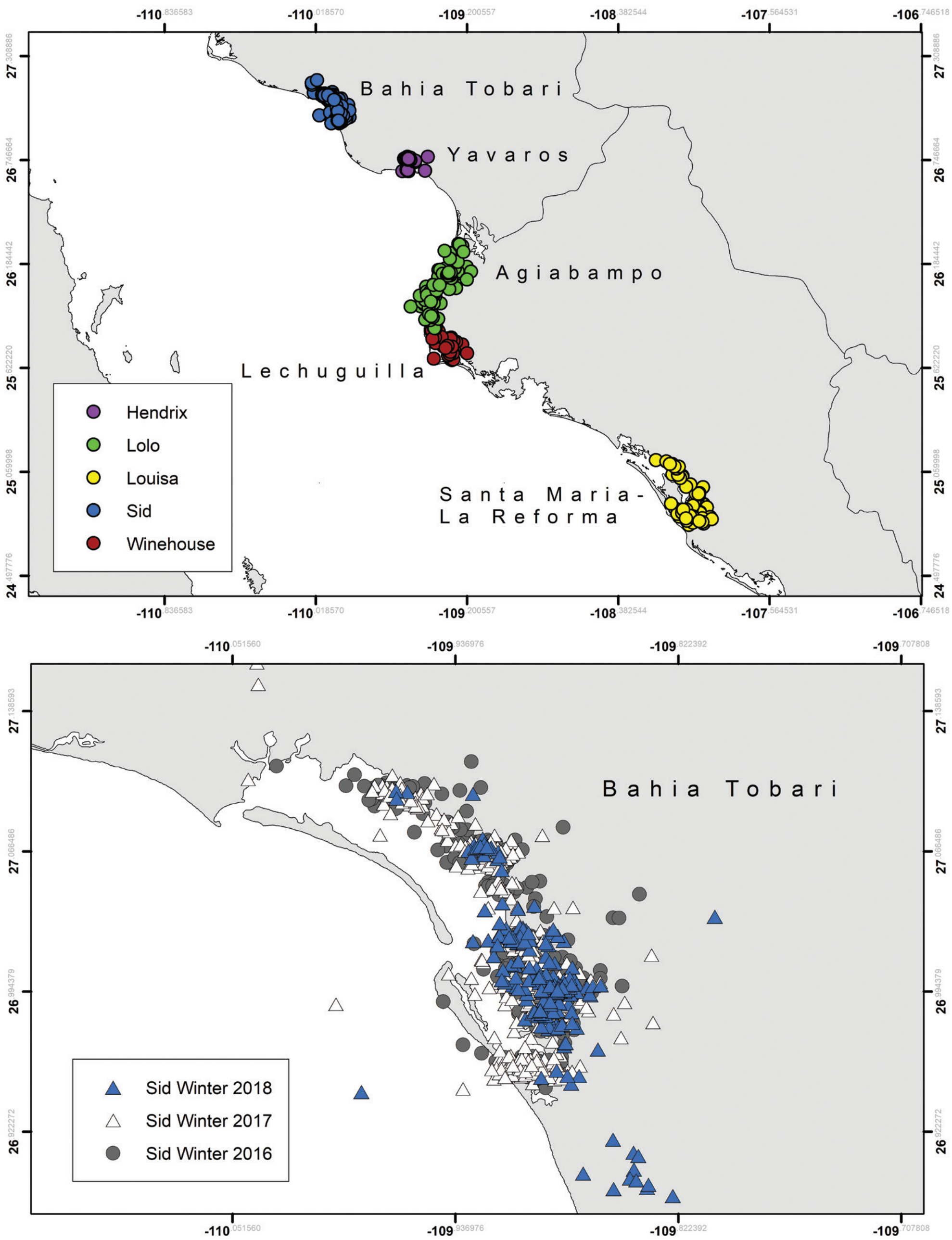

Figure 4. Winter locations of five tracked Gull-billed Terns (*Gelochelidon nilotica vanrossemi*) in southern Sonora and northern Sinaloa, Mexico [top]. Once they reached these locations, tracked individuals did not venture farther than 60 km from the area until the advent of spring migration the following April. Winter location movements of Sid [bottom], tracked continuously for 36 months. Across years, Sid's movements within Bahía Tóbari did not vary significantly.

While at their wintering locations, daily movement distances averaged about 30 to 45 km. There were no movements greater than 60 km outside of the winter location. Once the terns arrived at their winter location (late August through October), they did not leave until it was time to depart to San Diego the following April. Louisa spent the entire

2012 winter within the Bahía Santa María-La Reforma wetland system. Winehouse wintered in the same location for both 2013 and 2014, west of Los Mochis near Isla Lechuguilla, Sinaloa, just 127 km northwest of Santa María-La Reforma. Tern Lolo wintered about 48 km northwest of Winehouse in Agiabampo, Sinaloa. Tern Hendrix wintered at Yavaros, Sonora, while Tern Sid wintered at Bahía Tóbari, Sonora (Fig. 4). Sid has spent all three winters in Bahía Tóbari (Fig. 4).

Habitat use for all individuals was a combination of natural estuarine shallow water with adjacent extensive mudflats, agricultural fields, aquaculture ponds, dry scrub, and sandy beach areas. Habitat use for each of the terns varied in terms of the number of locations documented within each habitat, but the majority of location points for the terns were within natural estuarine habitats that consisted of mangroves, exposed mudflats, and shallow water areas within embayments (67-98%). Use of agriculture fields (3-11%) and aquaculture ponds (5-10%) occurred, but to a limited extent.

DISCUSSION

Our research is the first to document Gull-billed Tern migration and site fidelity to both breeding and wintering grounds using satellite telemetry focused on the northern-most breeding population in southern California. Terns deployed with a PTT lasting longer than 12 months exhibited a return to San Diego in the spring the following breeding season, and all terns that were tracked longer than 18 months returned to the same winter locations that were used the previous year, suggesting that there is a strong degree of fidelity to both breeding and winter locations within the San Diego breeding population. Breeding location fidelity has been reported to be low to moderate in Gull-billed Terns along the Atlantic coast (Erwin *et al.* 1998; Miller *et al.* 2013; Gochfeld *et al.* 2019), but it is noted as varying widely between nesting locations in Europe (Møller 1982; Sánchez *et al.* 2004). We are unaware of any other research focused upon Gull-billed Tern wintering site fidelity.

One of our concerns with this research was the small sample size of terns we tracked because a small sample size may suggest false positive site fidelity (i.e. the site fidelity may actually be individual response rather than being representative of the entire San Diego breeding population), but band recovery data of *Vanrossemi* during the 2013 mortality event in San Diego suggest otherwise. Gull-billed Terns have been banded as chicks at the San Diego colony since 2001, and adults have been banded for three separate research projects investigating foraging ecology and movements in San Diego, California (Goodenough 2014). We found that 78% of the recovered terns were banded. Of those, 89% had been banded as non-volant chicks at the San Diego Bay NWR. A further 8% were banded as breeding adults at the Refuge between 2001-2012. The recovery data supports the results we obtained from the telemetry project, confirming that there appears to be a high degree of natal philopatry and breeding location fidelity in the San Diego breeding population.

The high degree of fidelity documented in this tracking projects suggests that *Vanrossemi* in San Diego are likely to be limited in their response to large-scale environmental change such as habitat loss and continuing land use in the form of urbanization. While *Vanrossemi* is capable of habitat and prey resource switching (Møller 1982; Bogliani *et al.* 1990), there may be a limit to its ability to mitigate continued landscape change. Therefore, the potential for continued *Vanrossemi* population expansion in California may be hindered by the tern's ability to mitigate annual variability in food resources. Continued habitat loss and fragmentation due to expansion of industrial and agricultural activities has already begun to affect *Vanrossemi* breeding colonies in Mexico (Hernández-Vázquez *et al.* 2014; Palacios *et al.* 2015; Mellink and Riojas-Lopez 2017).

While we have been successful in describing aspects of migration and site fidelity for the northern-most breeding population of *Vanrossemi*, this research represents only a small percentage of the overall population. Multi-population tracking studies will be crucial in order to understand population dynamics of the species and to comment upon life history variation and migratory connectivity for the entire population, rather than just a small breeding colony. We recommend additional movement research focused upon populations in the Pacific Coast of eastern Mexico, Gulf Coast USA, and the USA Atlantic Coast to fully integrate movement research to better understand factors influencing survival and fitness for Gull-billed Tern in North America.

ACKNOWLEDGMENTS

Vanrossemi capture occurred under USGS Bird Banding Permit 27783A, U.S. Fish and Wildlife Service San Diego Bay National Wildlife Refuge Special Use Permit 81680-10002, and California Department of Fish and Wildlife Scientific Collection Permit SC-6884 with a Memorandum of Understanding for work with Gull-billed Terns. All applicable ethical guidelines for the use of birds in research have been followed, including those presented in the Ornithological Council's "Guidelines to the Use of Wild Birds in Research" (Fair *et al.* 2010). We would like to thank the San Diego National Wildlife Refuge Complex, Brian Collins, and Andy Yuen for access to the Gull-Billed Tern breeding colony and for funding support. This work was supported through a Costshare grant with the USFWS San Diego National Wildlife Refuge Complex, San Diego Unified Port District, and San Diego County Regional Airport Authority. Thanks to John Turman and Darryl York of US Department of Agriculture, Wildlife Services, for construction of and use of the bownet trap used to catch terns for the project. The following individuals are appreciated for their assistance with tern capture and PTT deployment: Matt Sadowski, Lea Squires, Dalia Ruiz, Lesley Handa, and Brian Foster. We would also like to thank Dr. Michael Erwin and one anonymous reviewer for their comments on this manuscript.

LITERATURE CITED

Bogliani, G., M. Fasola, L. Canova and N. Saino. 1990. Food and foraging rhythm of a specialized Gull-billed Tern population *Gelochelidon nilotica*. Ethology, Ecology & Evolution 2: 175-181.

Bradley, T. J. and G. M. Yanega. 2018. Salton Sea: Ecosystem in transition. Science 359: 754.

Fair, J., E. Paul and J. Jones (Eds.). 2010. Guidelines to the use of wild birds in research. Ornithological Council, Washington, D.C.

Erwin, R. M., J. D. Nichols, T. B. Eyler, D. B. Stotts and B. R. Truitt. 1998. Modeling colony-site dynamics: a case study of gull-billed terns (*Sterna nilotica*) in coastal Virginia. Auk 115: 970-978.

Gochfeld, M., J. Burger, G. M. Kirwan and E. F. J. Garcia. 2019. Common Gull-billed Tern (*Gelochelidon nilotica*). *In* Handbook of the Birds of the World Alive (del Hoyo, J., A. Elliott, J. Sargatal, D. A. Christie and E. de Juana, Eds.). Lynx Edicions, Barcelona,Spain.

Goodenough, K. S. 2014. Gull-billed Tern, *Gelochelidon nilotica*, inter-and intra-annual variation in movements and diet in San Diego, California (Master's dissertation, Sciences). San Diego State University. San Diego, California, USA.

Hellmayr, C. E. and B. Conover. 1948. Catalogue of birds of the Americas, part 1, no. 2. Field Museum of Natural History, Zoological Series.

Hernández-Vázquez S., J. Bojorques-Castro, H. Almanza-Rodríguez, D. Rodríguez-Torres and D. Díaz-Pereyra. 2014. New records of Van Rossem's Gull-billed Tern (*Gelochelidon nilotica vanrossemi*) nests in the Coast of Jalisco, Mexico. Huitzil, Revista Mexicana de Ornitología 16: 16-20.

Mallory, M. L. and C. D. Gilbert. 2008. Leg-loop harness design for attaching external transmitters to seabirds. Marine Ornithology 36: 183-188.

McCaskie, G. 1987. The nesting season June 1-July 31, 1987: Southern Pacific Coast region. American Birds 41: 1486-1489.

Mellink E. and M. E. Riojas-López. 2017. The Demise of a Tropical Coastal Lagoon as Breeding Habitat for Ground-Nesting Waterbirds: Unintended, but Anticipated Consequences of Development. Coastal Management 45: 253-269.

Molina, K. C. and Erwin, M. 2006. the distribution and conservation status of the Gull-billed tern (*Gelochelidon nilotica*) in North America. Waterbirds 29: 271-295.

Molina K. C., K. Garrett, K. W. Larson and D. P. Craig. 2009. The winter distribution of the western Gull-billed Tern (*Gelochelidon nilotica vanrosemmi*). Western Birds 40: 2-20.

Molina, K. C., J. F. Parnell and R. M. Erwin. 2014. Gull-billed Tern (*Gelochelidon nilotica*), version 2.0. *In* The Birds of North America (A. F. Poole, Ed.). Cornell Lab of Ornithology, Ithaca, New York, USA.

Molina, K. C. 2018. The breeding of gulls, terns, and skimmers at the Salton Sea, 2018. Unpublished report, US Department of the Interior Fish and Wildlife Service, Sonny Bono-Salton Sea National Wildlife Refuge, Calipatria, California.

Møller, A. P. 1982. Coloniality and colony structure in Gull-billed Terns *Gelochelidon nilotica*. Journal of Ornithology 123: 41-53.

Palacios E., K. S. Goodenough, J. A. Castillo-Guerrero, S. Hernández-Vázquez, M. A.González-Bernal, E. Soto-Montoya, E. S. Amador-Silva, E. Mellink, M. Riojas-López and S. Gómez del Angel. 2015. Population Assessment for the Western Gull-billed Tern *Gelochelidon nilotica vanrossemi*: 2014 and 2015 breeding seasons. Final Report to U.S. Fish and Wildlife Service, 2800 Cottage Way, Sacramento, California, USA. USFWS Agreement No.: F13AC00670.

Palacios E and E. Mellink. 2007. The colonies of van Rossem's Gull-billed Tern (*Gelochelidon nilotica vanrossemi*) in México. Waterbirds 30: 214-222.

Patton R. T., K. S. Goodenough, S. E. De La Cruz, H. Nevins, R. Cole, B. Bodenstein, V. Shearn-Bochsler, B. Collins, J. Beck, M. Sadowski and J. Y. Takekawa. 2017. Mass Mortality Attributed to Acanthocephaliasis at a Gull-billed Tern (*Gelochelidon nilotica*) Colony in Coastal California, USA. Journal of Wildlife Diseases 53: 885-90.

Sánchez, J. M., A. Muňoz del Viejo, C. Corbacho, E. Costillo and C. Fuentes. 2004. Status and trends of Gull-billed Tern *Gelochelidon nilotica* in Europe and Africa. Bird Conservation International 14: 335-351.

Shuford, W. D., N. Warnock, K. C. Molina and K. K. Sturm. 2002. The Salton Sea as critical habitat to migratory and resident waterbirds. Hydrobiologia 437: 255-274.

Shuford, W. D. and T. Gardali (Eds.). 2008. California bird Species of Special Concern: a ranked assessment of species, subspecies, and distinct populations of birds of immediate conservation concern in California. Studies of Western Birds 1. Western Field Ornithologists, Camarillo, California, and California Department of Fish and Game, Sacramento, California.

U.S. Fish and Wildlife Service (USFWS). 2008. Birds of Conservation Concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia.

U.S. Fish and Wildlife Service (USFWS). 2011. Endangered and threatened wildlife and plants: 12-month finding on a petition to list Van Rossem's Gull-billed Tern as endangered or threatened; proposed rule. Federal Register 76(183): 58650-5868