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Using Unmanned Aerial Vehicle (UAV) Technology for Locating, Identifying, and Monitoring Courtship and Mating Behavior in the Green Turtle (*Chelonia mydas*)

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The rapidly advancing field of unmanned aerial vehicle (UAV) technology is currently being used to address a wide variety of subjects regarding wildlife biology and conservation (Jones et al. 2006; Koh and Wich 2012; Hodgson et al. 2013). This technology is a highly applicable platform for identifying and monitoring sea turtles in their in-water habitat (Bevan et al. 2015) and is particularly useful for studying courtship and mating activities in sea turtles. These behaviors are often observed in nearshore areas adjacent to nesting beaches, near or at the water's surface, and can occur over prolonged periods of time (e.g., mating behavior in Green Turtles can last over multiple hours; Wood and Wood 1980). Additionally, surveys using UAV technology can be used for identifying critical habitat and areas used for courtship and mating activities in endangered sea turtles, while reducing the overall time, effort, and cost that has traditionally been required to conduct manned boat- and airplane-based surveys. A variety of both fixed-wing and rotorcraft UAV designs are currently available and each offers distinct capabilities that should be considered when deciding on which aircraft to use in a specific project. As an example, fixed-wing aircraft typically have longer flight durations, but do not have the ability to stop and hover above an area of interest. In contrast to traditional airplane- and boat-based surveys, as well as fixed-wing UAVs, a rotorcraft UAV provides a stable, stationary video platform that can hover directly above the behavior of interest. Therefore, upon locating sea turtles, a rotorcraft UAV can be used to hover, follow, and record video footage of their behaviors. The current study provides an evaluation of the applicability of UAVs for studying sea turtle courting and mating behavior in nearshore waters.

In the current study, we evaluated the use of the DJI Inspire 1™ (DJI, Shenzhen, China) rotorcraft quadcopter (Fig. 1) for studying sea turtle courtship and mating behavior off a major sea turtle rookery in the Gulf of Mexico near Rancho Nuevo, Tamaulipas, Mexico (Fig. 2). The DJI Inspire 1™ is a relatively small, relatively low-cost, and commercially available UAV capable of traveling at least 2 km away from the handheld controller. The aircraft is controlled through the GO app from DJI™ that runs on a tablet; we used the NVIDIA Shield ™ (NVIDIA Corporation, Santa Clara,

FIG. 1. In the current study, we used the DJI Inspire 1™ rotorcraft UAV platform for monitoring sea turtles in nearshore waters at Rancho Nuevo, Mexico. This UAV is equipped with a camera capable of up to 4K quality video. It provides a live, high-definition video feed up to 2 km from the operator. The controller interfaces with a tablet (NVIDIA Shield™ shown in the inset) running the DJI GO App™ to operate the aircraft.

California) that displays a live high-definition video feed from the aircraft as well as real-time readings for altitude, vertical and horizontal speed, and distance from the controller. Each UAV battery allows for approximately 20 minutes of total flight time (using the DJI TB48 battery which provides the longest flight time). This UAV model includes a camera capable of recording up to 4K quality video. In the current study, all surveys were recorded in 1080p video quality at 30 frames per second. The camera is attached to a three-axis gimbal system that stabilizes the video in flight and allows the operator to remotely control multiple aspects of the camera angle. The aircraft has a GPS-stabilized flight control system and is stable in relatively windy conditions (e.g., 5–7 m/sec).

The nearshore waters adjacent to the Rancho Nuevo nesting beach were surveyed over an approximate four-month period at 2–3 week intervals. A typical set of surveys was conducted over a two-day period and over the entire nesting season a total of nine sets of surveys were conducted. A set of surveys consisted of seven surveys over an approximate 30-km stretch of nearshore water at approximately 5-km intervals, ranging from Barra del Tordo to Barra el Carrizo (Fig. 2). At each survey location, transects of approximately 2 km in length, parallel to the shore, were run at 0.5 and 1.0 km offshore (Fig. 3). Thus, each survey included 4 km of transects parallel to shore, but also included an additional 4 km perpendicular to shore as the aircraft was flying to and from transect lines (see Fig. 3). An entire survey at each location typically required approximately 30–40 minutes of flight time. Therefore, each survey was conducted as two separate flights, each with a fully-charged battery, one flight surveying to the north and one to the south of the operator. The order in which the north and south segments were flown was randomized or selected based on local weather conditions (i.e., the aircraft was not flown in the direction of impending rain). All surveys were conducted between 0800 and 1800 h and we were able to identify turtles in videos throughout this range of sampling times. Collectively, the surveys over the entire study period generated approximately 40–50 h of video footage, all of which was directly viewed during analysis. The ability to identify turtles in the video feed and recording was affected by water clarity, sea conditions, wind, sun glare, and combinations of these factors. We attempted to address sun glare by using a polarizing filter and adjusting the angle of the camera between straight down (i.e., 90°) and 45° forward. Typically, we experienced less glare when the sun was near or at its zenith.

As part of an ongoing study, we were surveying the pre-nesting and internesting locations of Kemp's Ridleys (*Lepidochelys kempii*) during their nesting season at their primary nesting beach at Rancho Nuevo, Mexico. An unanticipated addition to our regular surveys for Kemp's Ridleys was the observation of Green Turtles (*Chelonia mydas*), including turtles engaged in various reproductive behaviors. In addition to being the primary nesting beach for the Kemp's Ridley, Rancho Nuevo also provides nesting habitat for Green Turtles. The Green Turtle nesting season typically extends from June through September with several thousand nests laid annually at Rancho Nuevo. This provided the unique opportunity to evaluate UAV technology for recording and studying this critical life-history stage in Green Turtles (i.e., courtship and mating). During these encounters, the utility of

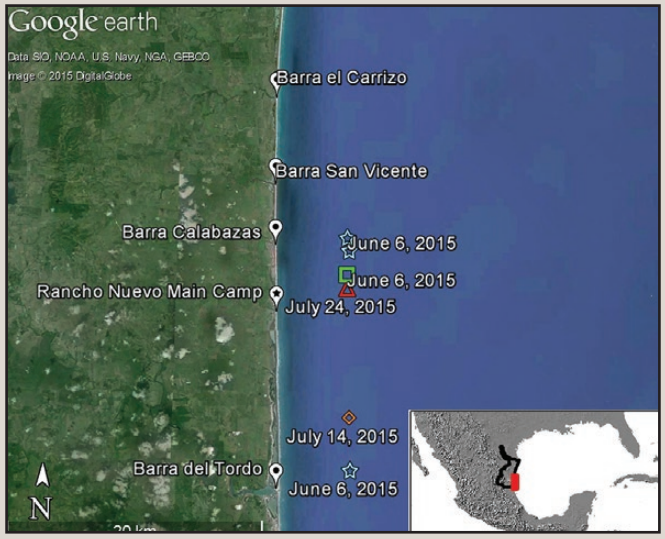

Fig. 2. UAV surveys were conducted in the western Gulf of Mexico, in the State of Tamaulipas, Mexico (study area indicated by the red rectangle on inset map). The landmarks shown in the figure represent mouths of seasonal rivers (*barras*) and are represented as white markers. Surveys were conducted at approximately 5-km intervals between Barra del Tordo and Barra el Carrizo. Reproductive behaviors between individual Green Turtles were observed on multiple occasions as shown in the figure. Shapes indicate the location and date when reproductive behaviors were observed. Blue stars represent instances when a mating pair was observed, the orange diamond represents courtship behavior, the green square represents a mated pair that was accompanied by an escort male, and the red triangle indicates an observed interaction between two male turtles.

Fig. 3. Example of a typical survey using the UAV during the current study. Each location surveyed included 2 transects that were 2 km in length and parallel to shore. These transects were conducted at 0.5 and 1.0 km from shore. The operator's location is indicated by the "H". Two flights were required to complete the transects at each location, one to the north of the operator and one to the south of the operator as indicated by the arrows in the figure. These surveys were conducted at approximately 5-km intervals over a 30-km stretch of beach at Rancho Nuevo, Mexico.

the rotorcraft UAV used in the current study (in contrast to a fixed-wing UAV) was demonstrated by its ability to hover and provide a stable video platform during our observations of a wide variety of reproductive behaviors.

The logistical difficulties in observing sea turtle courtship and mating behaviors have limited the information generated on this subject. Initial observations of courtship and mating behavior were reported for wild Green Turtles by Booth and Peters (1972) and Bustard (1972) and for captive Green Turtles at the Cayman Turtle Farm (Comuzzie and Owens 1990). The last study led to the development of an ethogram that identified 11 specific behaviors associated with courtship and mating (Table 1) in captive Green Turtles (Comuzzie and Owens 1990). The high-resolution video from the UAV surveys in the current study allowed us to identify many of these behaviors in the wild (Table 1) as well as previously undescribed behaviors associated with courtship and mating. Further, the mobility and relatively wide observation window provided by UAVs significantly increases the probability of chance encounters with sea turtles in contrast to traditional boat-based observations. Although it was not possible to identify the sex of all individual turtles observed during surveys, males were frequently identified based on tail length (Fig. 4) and were observed on at least seven occasions. The ability to identify the sex of turtles using UAVs could provide insight on when male turtles potentially move into mating areas. Our observation of courting and mating behaviors and the presence of male sea turtles in the current study also indicate that this region in the western Gulf of Mexico is not only an important nesting ground, but a critical mating habitat as well. Collectively, these attributes demonstrate the potential of UAV technology to advance and enhance field-based studies of courtship and mating behavior of sea turtles, as well as the identification of critical habitat.

Table 1. Courtship and mating behaviors that were observed in the current study that had been previously reported for captive and wild Green Turtles.

Behavior	Observed	Possibly observed
Nuzzling[1]	X	
Biting neck and rear flippers[2,3]		X
Male chasing fleeing female[1,2,3]	X	
Female circling and biting male[2]		
Male circling and biting female[2,3]	X	
Female refusal position[2]		
Gular rub[3]	X	
Cloacal check[1,3]	X	
Attempted mount[1,2,3]	X	
Successful mount[1,2,3]		
Copulation interference/escorting[1,2,3]	X	

[1]Bustard 1972
[2]Booth and Peters 1972
[3]Comuzzie and Owens 1990

Fig. 4. Example of a male green sea turtle observed during the nesting season in nearshore waters off the nesting beach at Rancho Nuevo, Mexico. Arrow shows the distinct tail extending beyond the carapace.

Among the various behaviors that were documented in the current study, courtship behaviors between a male and female Green Turtle were observed, as shown in Fig. 5 (A–F). These behaviors included A) circling of the female by the male, B) cloacal checks, C) gular (throat region) rubbing, D) possible biting, D) fleeing of the female from the male, and F) attempted mounting. During circling behavior, a male approached the female from behind and the female then turned to face the male, thereby forcing the male to circle in an apparent effort to mount the female from behind (Fig. 5A). Circling behavior has been previously described for Green Turtles in the wild (Booth and Peters 1972) and in captivity (Comuzzie and Owens 1990). In all of the courtship interactions observed in the current study, the male approached the female from behind and placed his head in the vicinity of the female's tail and cloaca (Fig. 5B). Cloacal checks and subsequent "gular rubbing" by both male and female captive Green Turtles have been described by Comuzzie and Owens (1990). That study also suggested that cloacal checks could represent a method of chemosensory investigation of the approximate readiness of a female for mating (Comuzzie and Owens 1990) and the release of a pheromone from the cloaca of the freshwater turtle, *Trachemys scripta*, has previously been hypothesized (Jackson and Davis 1972). Male turtles were also observed biting the neck and both front and rear flipper areas of females and males (Fig. 5D). Bustard (1972) reported males biting the rear flippers of females in wild Green Turtles, while Comuzzie and Owens (1990) reported biting of the front and rear flippers by both male and female captive Green Turtles. Males were also observed positioning their gular regions on top of the females' heads (Fig. 5C). Periodically during the courting process, the female would quickly swim a relatively long distance away from the male, then slow her pace and partially turn towards the male, causing the male to pursue her (Fig. 5E). Fleeing behavior by females, followed by pursuit behavior by males, has been reported for Green Turtles in the wild (Booth and Peters 1972; Bustard 1972) and in captivity (Comuzzie and Owens 1990). On several occasions, the male approached the female from behind and attempted to position himself for mounting, but was unsuccessful and slid off the side of her carapace (Fig. 5F). Unsuccessful mounting has previously been observed for both wild (Booth and Peters 1972; Bustard 1972) and captive Green Turtles (Comuzzie and Owens 1990).

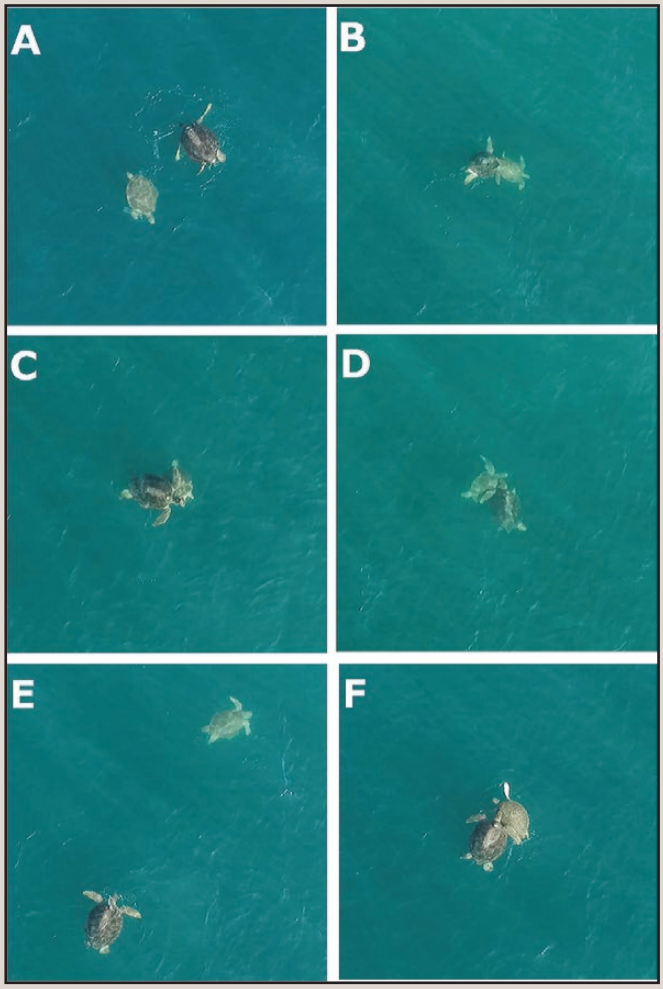

Fig. 5. Courtship behavior between a male and female Green Turtle was recorded for approximately 10 minutes by an UAV off Rancho Nuevo, Mexico from an altitude of approximately 20 m. The courtship behavior involved A) circling of the female by the male, B) cloacal checks, C) gular rubbing, D) possible biting, D) fleeing of the female from the male, and F) attempted mounting.

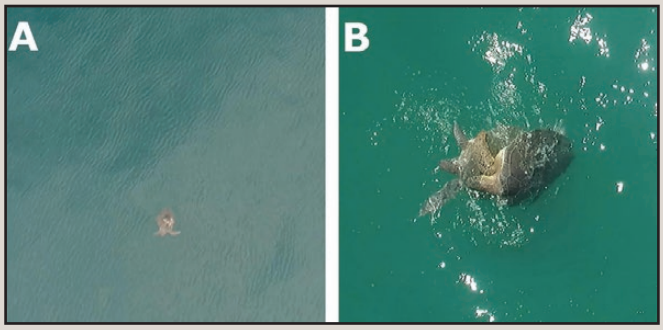

Fig. 6. Examples of screen shots from an approximate 10-minute video of mounted green sea turtles (*Chelonia mydas*) off the nesting beach at Rancho Nuevo, Mexico, observed at altitudes of A) 30 m and B) 6.2 m.

In addition to courtship behavior, mounted pairs of copulating Green Turtles were observed on seven occasions. A mounted pair of Green Turtles that was recorded for an approximate 10-minute period (due to limited battery life), initially at an altitude of 30 m (Fig. 6A) and later at an altitude as low as 6.2 m (Fig. 6B). This observation was typical of many of our encounters: once a mating pair was spotted from the standard 30-m survey altitude, the remaining flight time based on battery life was used to hover and observe the behavior. We often reduced the altitude of the aircraft to approximately 20 m to enhance observations and on the occasion noted above, the aircraft was lowered to an altitude of 6.2 m above the mating pair. We did not detect changes in turtle behavior that appeared to result from the presence of the UAV during any of our observations. Although seven mounted pairs were encountered, the initial mounting of the male onto the female was not observed. In the case of mounted pairs, the males were observed to use front and rear flippers as well as the tail to stay securely attached to the female throughout the period observed. Due to limited flight time per battery (20 min or less), we were unable to determine the full duration of mating, but in all of our encounters of mating pairs, mating continued for the entire length of the observation (i.e., approximately 5–10 min). Observations in captivity and in the wild indicate that mating can occur over prolonged periods of time, up to 119 h (Wood and Wood 1980).

We observed a copulating pair of Green Turtles with an "escort" male (Fig. 7A). The occurrence of escort males with a mated pair has previously been reported for Green Turtles in several studies (Booth and Peters 1972; Hendrickson 1958; Hirth 1971). In the current study, the escort male appeared to exhibit interference behavior that included attempting to disrupt the forward swimming of the female and positioning his head along the sides of the mated pair to potentially dislodge the copulating male. This group of turtles was recorded for approximately 10 min from an initial altitude of 30 m and then at 20 m as shown in the panel of photos in Fig. 7. During the time period observed, the escort male was unsuccessful at separating the mated pair. In Fig. 7 (B–D), the escort male can be seen B) circling, C) attempting to interfere with the copulating pair, and D) potentially engaging in cloacal checks and/or biting. In addition to the behaviors described in the current study, Comuzzie and Owens (1990) also described an additional interference behavior during which the escort male bit the tail and rear flippers of the copulating male.

In addition to courtship and mating interactions between male and female turtles, an interaction between two males was observed on 24 July 2015, with no female turtle visible in the camera's field of view. When initially encountered during the survey, the two males were engaged in circling behavior and their interaction was observed for approximately 8 min prior to the males departing from each other (Fig. 8). During this interaction, the males engaged in what appeared to be A) circling, B) cloacal checks, C) possible biting, and D) attempted mounting, before E) the two turtles departed from one another and left the vicinity. Based on these observations, this could represent mate-recognition behavior. Alternatively, it is possible that this interaction could represent a display of dominance between two males, as has been commonly documented in many other reptilian taxa (Brattstrom 1974). Although the specific behaviors of circling, biting, cloacal checks, and attempted mounting have been described for Green Turtles, the interaction of two males followed by departure represents a new observation.

The results of the current study document a variety of courtship and mating behaviors in Green Turtles in the wild and indicate that the nearshore waters off the nesting beach near Rancho Nuevo in the western Gulf of Mexico potentially represents critical habitat for mating in Green Turtles. In addition,

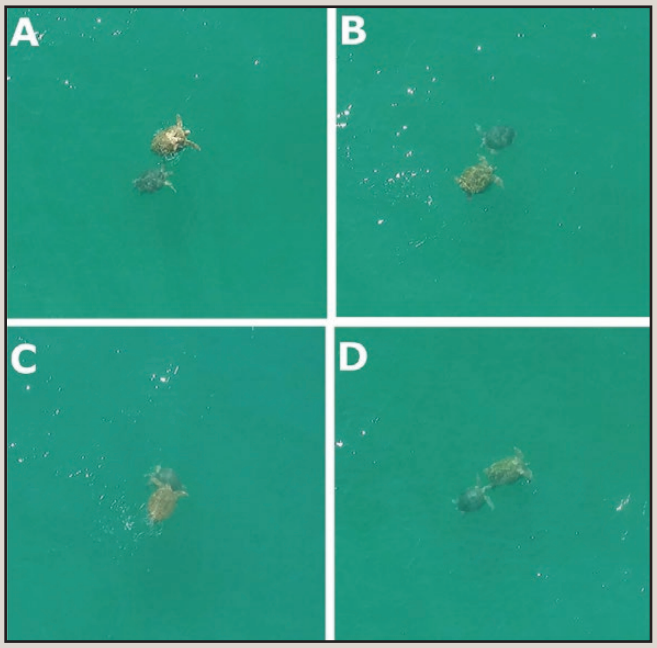

Fig. 7. A copulating pair of Green Turtles accompanied by an escort male was recorded by UAV off Rancho Nuevo, Mexico from an altitude of 20 m for approximately 10 min. In this panel, the escort male can be seen A) accompanying the mated pair, B) circling the pair, C) attempting to interfere with the pair, and D) potentially engaging in cloacal checks and/or biting.

the observations from the current study reveal the utility and applicability of UAV technology for documenting and studying courtship and mating behaviors in sea turtles. The advantages of this technology include a stable, high-resolution video platform located at an optimal angle of observation, as well as the ability to maintain this viewpoint as turtles move in their environment. However, the effectiveness of using UAVs for in-water sea turtle studies will depend upon multiple factors, including water clarity and the depth of the turtles in the water. Thus the applicability of this technology may vary by location, species of interest, and specific sea turtle population. Currently, the primary weakness inherent to this type of UAV platform is limited flying time due to battery life. This is of particular importance to studies of courtship and mating behavior in sea turtles since chance encounters of mating in the wild may require a significant amount of time searching for turtles. Additionally, these behaviors can occur over many hours (Comuzzie and Owens 1990), which limits the use of UAVs for determining total mating duration. However, although each flight in the current study was limited to approximately 20 min, the GO app from DJI™ made it possible to return to specific locations where turtles were initially recorded after returning to the operator for battery replacement. The results from the current study indicate that the rapidly evolving UAV technology can significantly advance our ability to study sea turtle behavior in the natural environment. We detected very few weaknesses using the rotorcraft UAV platform for this application. The primary limitations were the flight time per battery (approximately 20 min or less) and the maximum distance from the controller. However, even with these limitations, UAV technology is useful for not only enhancing our understanding of sea turtle behaviors in the natural environment, but also in identifying the location of critical habitat for important life-history events, such as courtship and mating.

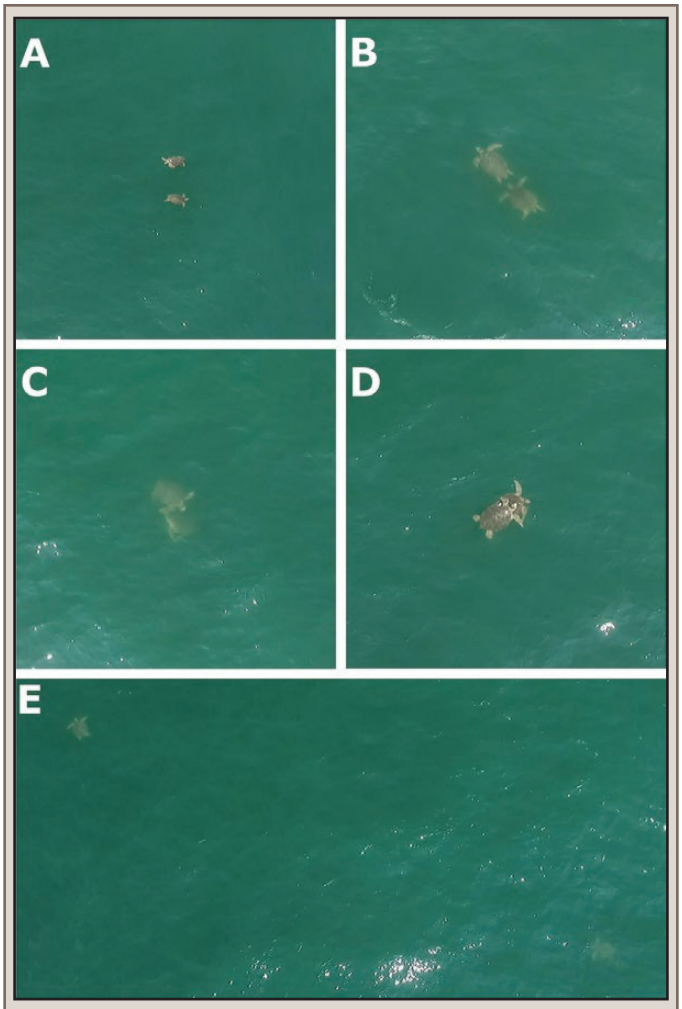

Fig. 8. Interaction observed between two male Green Turtles observed on 24 July 2015. This interaction involved A) circling, B) cloacal checks, C) possible biting, D) attempted mounting, and E) final departure from one another.

Acknowledgments.—This research was conducted as part of the Binational Kemp's Ridley Recovery Program which is coordinated in Mexico by the General Directorate for Wildlife of the Secretariat of the Environment and Natural Resources (SEMARNAT), the National Commission of Natural Protected Areas (CONANP), and the Tamaulipas State Wildlife Agency (SEDUMA). The Binational Recovery Program includes the U.S. agencies U.S. Fish and Wildlife Service, NOAA Fisheries, National Park Service, and Texas Parks and Wildlife. Funding was provided, in part, by the UAB Department of Biology and the NOAA Fisheries and the U.S. Fish and Wildlife Service through the Marine Turtle Conservation Fund. We thank Diana Crowell Comuzzie for her help and insight.

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