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Innovative Measures for Mitigating Potential Impacts on Sea Turtles During Seismic Surveys

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Abstract

Sound in the ocean emanates from a variety of natural and anthropogenic sources. Low frequency sounds, such as those produced by shipping, drilling, and seismic sonar travel long distances in the ocean environment and affect marine animals both physiologically and behaviorally. The effects of anthropogenic marine sound can be short- or long-term, and can affect a single individual (e.g., disrupted feeding routines, hearing damage) or entire populations (e.g., reproductive success). While some animals can and do avoid sound, repeated exposures to sound sources can cause marine animals to habituate to or become unable to hear the sound, potentially increasing the risk of long-term physiological effects. Concern is usually directed toward marine mammals, which use sound for communication and navigation and often rely on sound perception and interpretation for survival, but less is known about the effects of anthropogenic noise on sea turtles.

Sea turtles hear well underwater, and their greatest hearing sensitivity lies within the envelope of sound produced by seismic sources. Therefore, temporal and spatial patterns of habitat use are highly relevant to consideration of mitigation schemes. To increase our understanding of habitat use, garner data useful in developing mitigation protocols and to evaluate the potential effects on sea turtles during 3D seismic survey by the Three Oil and Gas Companies Joint Venture (hereinafter, the Joint Venture) in the territorial waters of the Dutch Caribbean island of Aruba, VHF radio transmitters and GPS-equipped satellite platform transmitter terminals (PTT) were attached to four species of gravid turtles when they came ashore to nest on the island's beaches. Pathways of ingress and egress from Aruban waters and the extent to which these coincided with the seismic survey zone were documented.

The Joint Venture developed response protocols requiring all seismic operations to cease if a turtle approached the vessel to within 500 m – and to remain so until, based on VHF monitoring, the turtle cleared the area. In addition, seismic surveys were avoided within 100 m of the 50 m depth contour around the island, and around all subsurface features that rise to a depth of 50 m from the surface. The objective was to avoid exposing turtles to harmful sound levels from the acoustic source on the survey vessel, and to avoid displacing turtles from critical habitats, including nesting beaches.

This report presents the findings of the two initiatives implemented by the Joint Venture, Wider

Caribbean Sea Turtle Conservation Network (WIDECAST, a regional scientific organization), and Turtugaruba (an Aruba-based sea turtle conservation organization) with the field data obtained during the survey in the offshore of Aruba. This project implemented best practices for seismic surveys in areas where sea turtles are present, including establishment of sensitive areas based on data-supported assessments of turtle presence, home ranges and high use areas, as well as use of vessel-based VHF or acoustic monitoring for transmitter- or transponder-equipped turtles.

Introduction

Anthropogenic sound in the ocean is increasing (Andrew et al. 2002, McCarthy 2001), and high intensity sounds are known to cause physiological effects (e.g., a temporary or permanent loss of hearing) and even death (McCauley et al. 2003) in marine animals that use sound for communication and navigation, and that rely on sound perception and interpretation for survival (NRC 2003, Richardson et al. 1995).

Sea turtles exhibit the greatest sensitivity to lower frequency sound (500-700 Hz), overlapping closely with the sound generated by most seismic surveys (Dow-Piniak et al. 2012a, 2012b). However, information related to how individuals might respond behaviorally to these sounds is inconclusive (e.g., O'Hara and Wilcox 1990, Moein et al. 1994, McCauley et al. 2000) and may be species-specific. The oceanic leatherback turtle (*Dermochelys coriacea*) is of particular concern, as it may respond to sound differently than the more coastal dwelling ″hardshelled″ species (green turtle, *Chelonia mydas*; loggerhead, *Caretta caretta*; hawksbill, *Eretmochelys imbricata*).

Marine seismic surveys create images of the geological structure beneath the ocean floor. A seismic ship tows an acoustic source which creates predominantly low-frequency pulses of acoustic energy in the form of air bubbles, sending sound waves into various buried rock layers beneath the ocean floor. Sound bursts last <0.1 sec and are typically generated every 10-15 sec as the seismic vessel moves along a straight line. Hydrophones enclosed in cables towed behind the seismic vessel listen for and record the reflected sound waves. Once collected, the data are processed to generate subsurface images.

Eckert et al. (1998) calculated an acoustic zone of influence for leatherback turtles and, in the context of the present study, re-evaluated this calculation using a sound source of 220 dB re 1μPa ref 1m (RMS) to estimate a zone of influence for all sea turtles. Levels of 160 dB re 1μPa ref 1m were assumed to cause a behavioral response and levels of 190 dB re 1μPa ref 1m to cause a physiological effect. With a spherical spreading model of projection, the zone of physiological damage was estimated to be 20.9 m and the zone of a behavioral response out to 19.9 km. These calculations, while based on our best scientific information, remain conjecture, but they are useful in considering how to reduce threats to sea turtles. While sea turtles ″look different″ than marine mammals, physical structures (e.g., lungs, inner ear) are conservative across air-breathing vertebrates (Lutcavage and Lutz 1997, Liem et al. 2001), suggesting that the types of injuries that might be sustained by sea turtles would be comparable to that of marine mammals.

Aruba supports resident and itinerant non-nesting populations of green, hawksbill and, possibly, loggerhead turtles, all of which are legally protected within its territorial waters (Barmes et al. 1993 Bräutigam and Eckert 2006). These residents forage and rest in coral reef, hard-bottom or seagrass habitats and leave these areas only when necessary to facilitate movements between foraging and resting areas or, when mature, to make long-distance migrations to their natal beaches every two or three (or more) years. Coastal foraging habitats are generally in waters less than 50 m in depth (e.g., hawksbills: van Dam and Diez 1996, Storch et al. 2005, Tröeng et al. 2005, Walcott et al. 2012; green turtles: Glen et al. 2001, Hays et al. 2000, 2007, Hochscheid et al. 2005, Southwood et al. 2003).

In addition, sea turtles migrate into Aruban waters on a seasonal basis from distant foraging grounds for the purpose of egg-laying. In general, gravid hardshelled turtles reside within the 12 nm EEZ, generally relying on reef or other benthic features to guide ingress and egress from the nesting beach (e.g., hawksbills: Walcott et al. 2012; green turtles: Carr et al. 1974, I-Jiunn 2009, Mortimer & Portier 1989;

loggerheads: Limpus and Reed 1985, Tucker et al. 1995). In contrast, gravid leatherbacks are less common in coastal waters and may range 100+ km from shore during the internesting interval (Chan et al. 1990, Eckert 2002, 2006, James et al. 2005a) before ultimately returning to high seas foraging grounds. Leatherbacks deposit an average 7.1 nests per reproductive season in Aruba and remigrate to nest on 2-3 year intervals (Turtugaruba, unpubl. data).

These temporal and spatial patterns of habitat use – as well as certain behavioral characteristics – are highly relevant to consideration of mitigation schemes related to seismic exploration. Standard mitigation techniques (ramping up, onboard observers) developed for marine mammals might be less effective for sea turtles because sea turtle surface presence per unit of time is much shorter than that of marine mammals and sea turtles have a much lower surfacing profile than do marine turtles (Brischoux et al. 2008). As a result, sea turtles are increasingly difficult to detect (both by onboard observers and from the air) in sea states greater than Beaufort 2 (Beavers and Ramsey 1998).

When using observers as a means to avoid acoustic damage to turtles, the effective spotting distance must be considered. We propose, based on the best available science, that any turtle within 20 m of the sound source will be physically injured. If avoiding injuring turtles is a primary mitigation goal of the survey, observers on the seismic vessel must focus their observation in a manner that allows 10-15 min of continuous observation 30 m forward of the array. Depending on vessel speed, it may be challenging for observers to see far enough forward for this requirement to be met.

Our research focused on gravid female turtles of three species, established patterns of ingress and egress from the nesting beach, determined high use marine areas (to evaluate the extent to which these endangered animals might be affected by activities within the seismic survey zone), and designed an innovative ″spotting″ technique to minimize injury to sea turtles.

Rationale

Many countries and regional authorities have established guidelines and regulations specific to seismic operations. In the absence of national regulations or guidelines in a specific area, the geophysical and wider oil and gas industry implements appropriate measures to avoid harming marine life. Measures are carefully designed and implemented to address potential risks identified during project planning for the site-specific environmental conditions of each operation.

Since 2006, a group of international oil and gas companies, in collaboration with the geophysical industry, has funded a research program (the Joint Industry Project www.soundandmarinelife.org) to improve the understanding of the potential impacts of sound on marine life, under the auspices of the International Association of Oil and Gas Producers (IOGP). Tags designed to monitor the position of individual animals allow the industry to better understand the behavior, habitat use, migration patterns and reactions of marine life. To date, the JIP has mainly focused tag deployment on marine mammals.

The Joint Venture, under the Production Sharing Contract (PSC) with the Government of Aruba, undertook an offshore 2D seismic campaign in February and March 2013, followed by a 3D seismic survey in 2014. After completion of the 2D survey and before the commencement of the 3D acquisition, the Joint Venture engaged with WIDECAST and Turtugaruba to design and implement innovative mitigation measures for sea turtles in Aruban waters.

Because effective mitigation requires knowing the position of the sea turtles relative to the seismic vessel, as well as an understanding of habitats (nesting, foraging, migration) critical for survival, the Joint Venture implemented two initiatives:

1. Use VHF Receiver and Transmitters to monitor turtle presence near the seismic vessel as an active mitigation measure during the 3D seismic acquisition in 2014
2. Place GPS-equipped satellite platform transmitter terminals on nesting turtles during 2014 (and again in 2015) to provide information on critical habitats and migration routes

Global society demands energy, and there is a growing expectation that energy companies will satisfy those demands in a more sustainable manner. This means bringing environmental and social concerns to the forefront of its business activities. In this context, the partnership between the Joint Venture, WIDECAST, and Turtugaruba was crucial for developing appropriate strategies for the Joint Venture's operations in Aruban waters.

Methods

Site description

Aruba (12°30'N, 70°W) is located 32 km north of Venezuela and 67 km west of Curaçao in the southern Caribbean Sea. Sea turtles nest seasonally on the island's sandy beaches, mainly on western and northeastern facing shorelines (Figure 1).

Figure 1—Sea turtle nesting beaches in Aruba, as follows: Leatherback (*Dermochelys coriacea*: DC), Loggerhead (*Caretta caretta*: CC), Green Turtle (*Chelonia mydas*: CM), Hawksbill (*Eretmochelys imbricata*: EI).

PTT transmitters

All but one nesting turtles (n=17) encountered by beach patrol staff in 2014 and 2015 were equipped with model Splash-10, Global Positioning System (GPS)-equipped satellite platform transmitter terminals (PTT) (Wildlife Computers, Redmond, Washington). Attachment method varied by turtle species.

Immediately after egg-laying, hardshelled turtles (green, hawksbill, loggerhead) were restrained on the beach by placing a 1m x 1m plywood enclosure around the turtle. West Systems (Bay City, Michigan) 105 epoxy resin was mixed with 205 fast hardener thickened with 406 thickener and colored with dark green tinting, to create a thick green epoxy paste for securing the transmitters to a vertebral scute on the turtle. Prior to placing the transmitter, the shell was lightly sanded with 80 grit paper and wiped down with acetone to remove any residual oil, water or debris. Upon curing (ca. one hour), the turtle was released.

Leatherbacks do not require restraint because the application process does not require curing. During egg-laying, PTTs were secured by drilling two 0.48 cm holes through the dorsal ridge about 60% of the distance back from the anterior edge of the carapace. Two tubular nylon inserts were placed though the holes. Prior to drilling the holes, the area was treated with a surgical scrub (alternating alcohol, iodine solution), a silicon putty pad (Equinox 35, Smooth-On Inc., Macungie, Pennsylvania) was formed over the ridge, and the transmitter was pressed into the putty. To secure the transmitter, two 200 lb test, nylon coated stainless steel leaders were laced through holes in the PTT and through the tubular nylon inserts and secured with copper line crimps.

All sea turtles equipped with transmitters were tagged with monel 1005-49 style metal flipper tags(National Band and Tag, Newport, Kentucky) according to best practices (Eckert and Beggs 2006), and each tag was embossed with a unique alphanumerical imprint. Finally, flipper tag numbers, PTT tag number, time and date of nesting, Latitude and Longitude of nesting event, curved carapace length (CCL), and curved carapace width (CCW) were recorded for each turtle.

Turtle locations and transmitter sensor data were reported by ARGOS CLS-America, which provided an estimate of location accuracy using location classes 0-3, with ″0″ the least and ″3″ the most accurate. ARGOS also reported GPS data from the transmitter, which is generally considered as accurate as (or better than) class ″3″. Location data where accuracy was largely unknown were reported by ARGOS as class ″A″ or ″B″.

To assess turtle home range during interesting intervals, data were filtered to include one best location per day. Kernel Home Range estimators assume some level of independence in each location; therefore, by using a single location per day, the potential for autocorrelation is reduced (Eckert 2006, but see De Solla 1999). The data were then filtered to include internesting periods only, exported to Biotas 2.0 (Ecological Software Solutions LLC), converted to Universal Transverse Mercator projection (UTM zone 19) locations, and a fixed Kernel Home Range 95% Utilization Distribution (UD) polygon created for each turtle. The smoothing function (h) was set to least squares coefficient, and the resulting polygons imported to MapInfo v. 11.0 GIS software to visualize the distribution of location points.

VHF transmitters

All nesting turtles (n=8) encountered by beach patrol staff in 2014 were equipped with model mm150, Very High Frequency (VHF) radio transmitters (Advanced Telemetry Systems, Isanti, Minnesota). VHF transmitters were attached to hardshelled turtles in the same manner as the PTT transmitters (see above). In the case of leatherbacks, the VHF transmitters were secured using #6 x 2.5 cm stainless steel screws placed directly into the dorsal ridge, immediately posterior to the PTT (see above). The survey vessel was equipped with a VHF receiver (ATS model 4500) which logged the time, date, duration, and strength of VHF signals emitted from the turtles. Empirical tests were conducted to evaluate the range of detection and transmitter signal strength.

Results

Eighteen turtles (10 leatherbacks, 5 green, 2 loggerheads, 1 hawksbill) were equipped with satellite and/or VHF transmitters during the 2014 and 2015 nesting seasons (Table 1). Deployments in 2014 occurred too late in the season to provide sufficient data to determine home range patterns. Similarly, data points were too few for hardshelled turtles in 2015 to determine home range. However, we were able to determine 95% Utilization Distributions (UD) for leatherbacks tagged in 2015 (Figures 2, 3).

Table 1—Species, size, transmitter type and number, and date of deployment for sea turtles nesting on Aruba whose movements were monitored during and after nesting in 2014 and 2015.

SPECIES	SIZE (CCL)	PTT ID	DATE DEPLOYED
Leatherback	163.0	——	7/2/14
Leatherback	153.0	140956	7/4/14
Leatherback	148.0	140955	7/5/14
Leatherback	165.0	140957	7/10/14
Leatherback	157.5	140958	4/30/15
Leatherback	140.0	140959	5/3/15
Leatherback	141.0	140972	5/11/15
Leatherback	154.0	140973	5/21/15
Leatherback	163.0	140974	6/18/15
Leatherback	140.0	140975	6/19/15
Green Turtle	114.0	140960	7/15/14
Green Turtle	114.0	140962	9/26/14
Green Turtle	109.0	140963	9/4/14
Green Turtle	109.5	140966	8/21/15
Green Turtle	112.0	140967	8/28/15
Loggerhead	99.0	140961	7/28/14
Loggerhead	107.5	140964	6/22/15
Hawksbill	92.0	140965	7/14/15

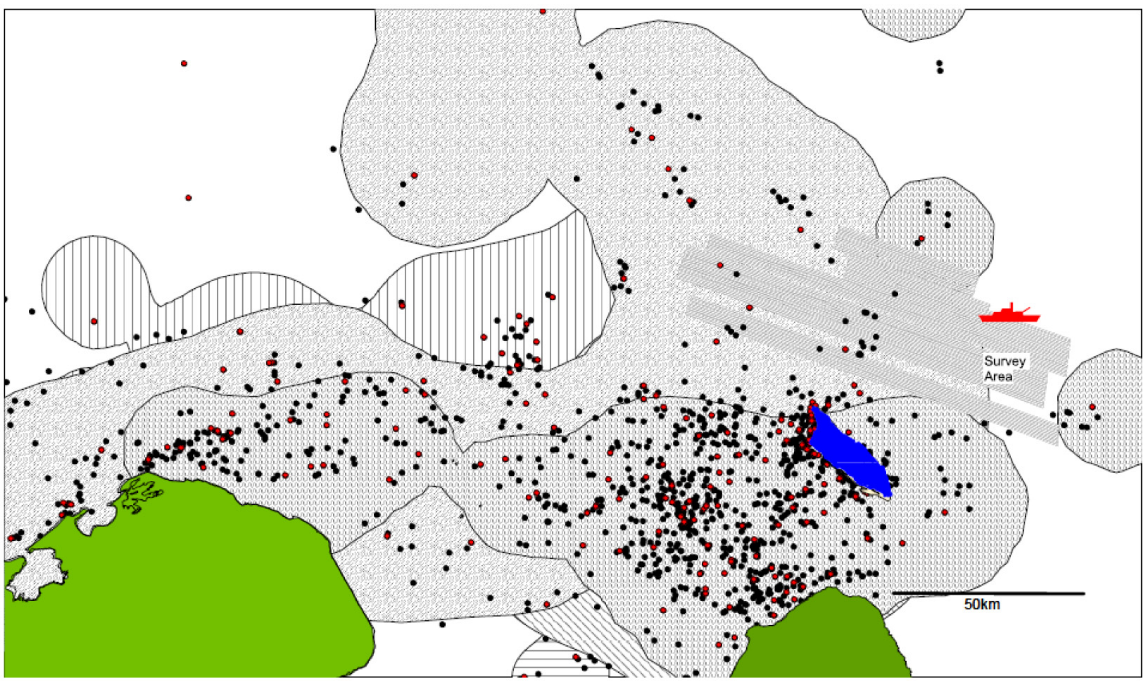

Figure 2—95% Utilization Distributions of Home Range as calculated using fixed kernel home range estimation (KHRE) methods for the internesting intervals of 6 leatherback sea turtles (*Dermochelys coriacea*) in the waters of Aruba, during the 2015 nesting season. Smoothing variable (*h*) was set using Least Squares Cross Validation. Black and Red dots on the figure represent all Argos locations with a location quality better than location class 0. The red dots are the single best location per day and were used in the kernel density analysis.

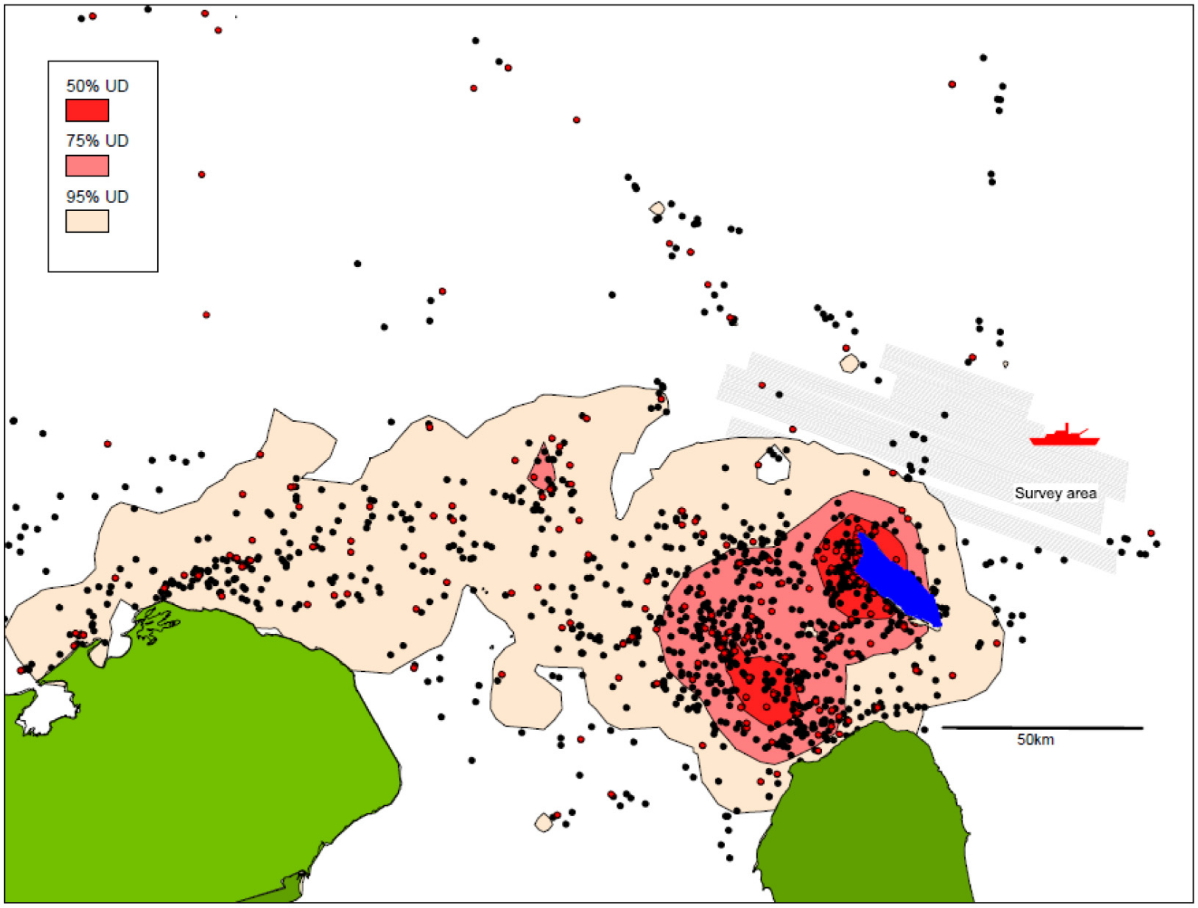

Figure 3—Hotspot analysis of high use areas for leatherback sea turtles in the waters of Aruba, during the 2015 nesting season. Colored polygons represent the 95%, 75% and 50% Utilization Distributions as calculated using fixed kernel home range estimation (KHRE) methods. Black and Red dots on the figure represent all Argos locations with a location quality better than location class 0. The red dots are the single best location per day and were used in the kernel density analysis.

Empirical tests of our shipboard receiver demonstrated that a transmitter-equipped turtle could be detected out to 1.5 km from the receiver (surface to surface distance – slightly higher at the elevation of the ship's wheelhouse). We were also able to develop a signal strength estimation table to allow shipboard observers to approximate the transmitter's distance from the ship when detected (Table 2). Using these values, we were able to advise shipboard observers that, at signal strength of 50 or more, the turtle was within 500 of the vessel and airgun operations should be suspended due to high risk of injury or death to the animal. Over the course of our study, the VHF receiver onboard the survey vessel did not receive any signals from VHF-equipped turtles.

Table 2—A table of reported signal strength and transmission distance for Advanced Telemetry Systems model mm150 VHF radio transmitters as determined with an ATS 4500S VHF radio receiver and single dipole antenna.

Distance (m)	Signal Strength	Distance (m)	Signal Strength
0	90.2	450	60.4
5	89.8	500	57.1
10	89.5	550	53.8
15	89.2	600	50.4
20	88.8	650	47.1
25	88.5	700	43.8
30	88.2	750	40.5
35	87.9	800	37.2
40	87.5	850	33.9
45	87.2	900	30.6
50	86.9	950	27.3
60	86.2	1000	24.0
70	85.5	1050	20.7
80	84.9	1100	17.3
90	84.2	1150	14.0
100	83.5	1200	10.7
150	80.2	1250	7.4
200	76.9	1300	4.1
250	73.6	1350	0.8
300	70.3	1400	0.0
350	67.0	1450	0.0
400	63.7	1500	0.0

Discussion

In our study, four species of threatened sea turtle (IUCN 2015) were present in the waters off the Caribbean island of Aruba during seismic exploration, and their movements were monitored using a combination of remote sensing technologies.

Kernel Home Range estimations (95% Utilization Distributions - UD) determined that leatherback turtles, an oceanic (high seas) species present seasonally in Aruba's waters for the purpose of nesting, showed a strong preference for waters west of Aruba. Internesting movements extended as far as 200 km west and 40 km east of the island, and each turtle showed a distinct preference for specific areas (Figure 2). Leatherbacks have been reported to travel 45-65 km per day (Eckert 2002) during internesting intervals, and movements can be extensive (Chan et al. 2006, Eckert 2006, Eckert et al. 2006), but the range reported by our study exceeds other published estimates.

When all location data are integrated into a single probability map, a fixed Kernel analysis (Figure 3) reiterates the gravid leatherbacks' preference for the western region of the island, with distinctive hotspots (as denoted by the 50% UD) out to 10 km from preferred nesting beaches. Similar results are observed from satellite telemetered leatherbacks at much larger nesting colonies (e.g., northeastern Trinidad: Eckert 2006). What is quite extraordinary, however, is the size of the 75% UD extending slightly more than 50 km to the west of Aruba and the second 50% UD location to the southwest. Despite the wide distribution of location points to the far west, it is clear that this species spends the majority of time within these utilization distribution polygons (perhaps a reflection of calmer seas associated with the leeward sea).

Seismic survey operations (2014) overlapped the 95% UD's for leatherbacks (2015) to the northwest of the island, though turtle presence in this area was limited. We cannot know the full extent of internesting habitat use in 2014 when seismic exploration operations were underway (because the turtles were tagged very late in the season), but satellite telemetry data confirms that Turtle #140955 left Aruba on 16 July 2014, moved through the area of operations on 17 July 2014, and crossed the trackline of the seismic vessel at 12:04 GMT when the vessel was 40 km to the southeast and outside the range of the VHF receiver (Figure 4). A second leatherback (#140956) also crossed through the area of operations on 5 August 2014 at 02:36 GMT; however, the seismic vessel was not operating at this time and the turtle was not detected. Additional field trials are needed in order to more fully evaluate the effectiveness of the VHF tags and the shipboard receiver as a mitigation tool.

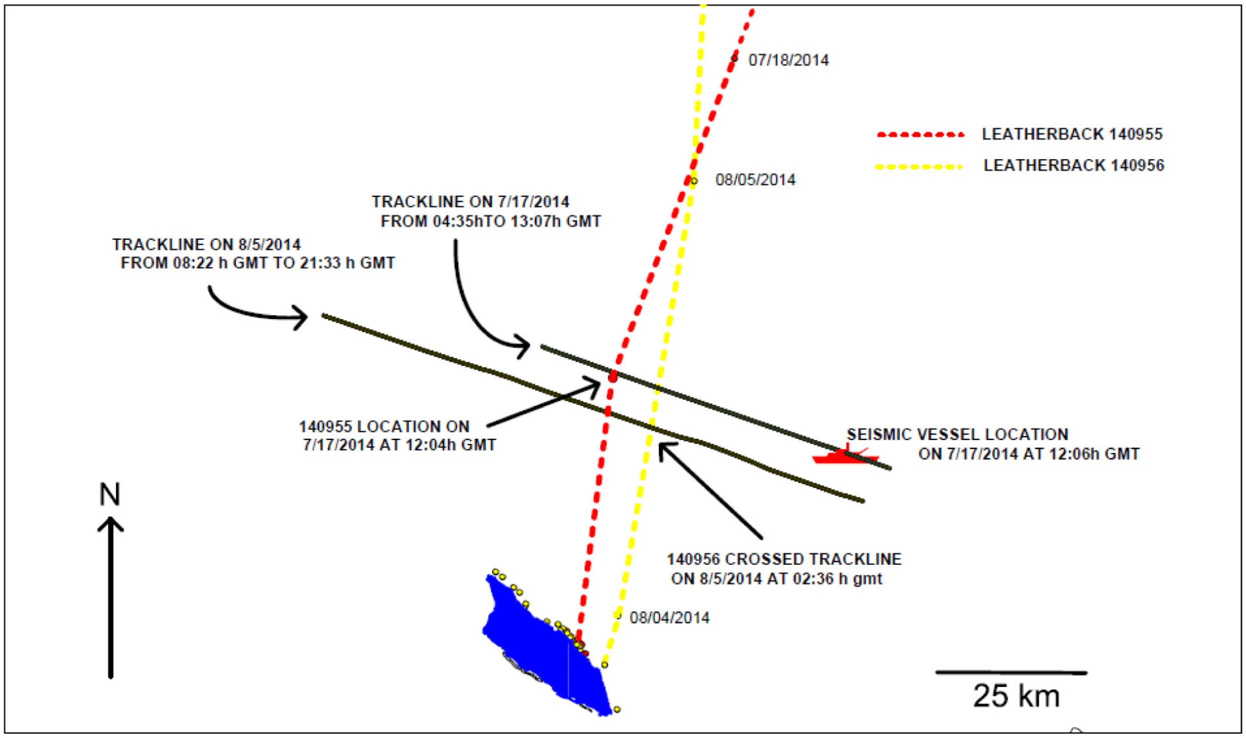

Figure 4—Egress pathways of two leatherback sea turtles, as they finished nesting on Aruba, and began their northward migrations. The figure also illustrates the location of the seismic survey vessel tracks on the day that the turtles passed through the survey area. Turtle #140955 (red) crossed the survey trackline when the vessel was 40 km to the SE and Turtle #140956 (yellow) cross the trackline at a time when the vessel was not yet operating for the day.

While this study provides proof of concept, a single year's data is inadequate to define internesting home ranges, as these would be expected to vary seasonally and yearly. Our partnership will continue with additional deployments in 2016, and the resulting data will provide a better understanding of sea turtle habitat use in Aruba – and support the development of more specific mitigation recommendations going forward.

Conclusions

Effective mitigation requires that we know where sea turtles are in relation to a seismic vessel, as well as understand the geography of high-use and other sensitive habitats critical to their survival. Our study addressed this need by equipping locally-occurring sea turtles with VHF radio transmitters and simultaneously placing a receiver on the survey vessel, as well as by utilizing satellite technologies to develop the first hot-spot analysis for sea turtles in Aruba. The results were promising and provide a potentially cost-effective and operationally efficient mitigation strategy for small populations of sea turtles. The Joint Venture has shown commitment for responsible management as it has designed and implemented, through the partnership with a regional scientific body and a local sea turtle conservation organization, data-driven measures for mitigating the impact of seismic surveys on locally-occurring sea turtles that are protected by law in Aruban waters.

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