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Improved Satellite-Monitored Radio Tags for Large Whales: Dependable ARGOS Location-Only Tags and a GPS-Linked Tag to Reveal 3-Dimensional Body-Orientation and Surface Movements

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LONG-TERM GOALS

Two different semi-implantable satellite-monitored radio tag technologies will be developed for whales: 1) a programmable, location-only (LO) Argos tag using contemporary technology will be available in two lengths and be adaptable to testing a variety of attachments. Ultimately, it will be suitable for many scientific users to track local and seasonal movements of medium to large whales over varying time scales (months to a year); and 2) an improved recoverable GPS/TDR tag will include 3-axis accelerometer and compass sensors to document the detailed dive behaviors and foraging ecology of large whales over scales of weeks to months and will be capable of carrying additional acoustic recording devices useful in evaluating future noise response experiments.

The goal of this project is to develop reliable sensing and monitoring technologies to identify the seasonal distributions of large whales, their underwater behavior, their ecological relationships, and ultimately their behavioral responses to man-made sounds. We have made progress this year in the development of both tag-types and were able to use funds from other projects to defray field costs for testing the ONR-funded developments.

OBJECTIVES

Location only tags
Wildlife Computers tags will be used on western gray whales (funded in 2010 and 2011 by the International Whaling Commission) to determine their migration routes and on sperm whales in 2010 and 2011 (funded by BP and NOAA-NRDA) to follow-up on the consequences of the Deepwater Horizon (DWH) oil spill. A continuing part of this project involves the photo follow-up of tags to examine wound healing, which is also the subject of a collaboration with Cascadia Research as part of a NOPP project. Results will be presented to the IWC Scientific Committee to review and recommend additional whale research as well as tag development work. Some of this research will be presented at specific science-based meetings to improve whale management and ONR's review of their investments in this field.

The GPS/TDR tag (initially funded by JIP, MMS, and ONR) will be further developed to provide an accurate depiction of underwater dive behavior to especially examine sperm whale foraging behavior. The data will be downloaded from recovered tags to evaluate complex foraging behaviors. The addition of an acoustic dosimeter remains an un-funded, but long-term goal that would help interpret TDR/3-D whale responses during future controlled-exposure experiments (CEE) or behavioral response (BRS) studies. The existing GPS/TDR tag will be field tested on whales with the 3-axis accelerometers before any attempt at integration with an acoustic dosimeter.

APPROACH

During this FY-11 and FY-12, tag western gray whales with the WC Location-only tags off Sakhalin Island, Russia to determine migration routes and tag a small number of sperm whales in the Gulf of Mexico (GoM) to compare their operation with older-style Telonics ST-15 tags (applied during 2001-2005 in the SWSS program and in 2010 during the DWH event).

Have Wildlife Computers fit 3-axis accelerometers to replacement GPS/TDR tags (from a JIP/ONR-funded 2008 field effort) to be applied to GoM sperm whales.

WORK COMPLETED

Location only tags

After design work with Wildlife Computers the semi-implantable Spot-5 tag was fielded on 18 Pacific Northwest gray whales in fall 2009, 7 western gray whales in Aug/Sept 2010 and 2011, and also on 4 GoM sperm whales in July 2011. Experienced veterinarians and the IWC Scientific Committee examined follow-up photos of tags to evaluate wound healing. They concluded only expected scarring and divot formation were seen and that these did not pose any significant hazard to whales, even for the fetus of pregnant western female gray whales if they were tagged.

Four LO tags were applied to sperm whales (out of 34 tags applied to 26 whales) during July 2011 following-up research on the DWH oil spill.

Wildlife Computers incorporated a 3-axis accelerometer into the GPS/TDR tag (also known as PATF or Mk-10). As a brief review, our previous experience developing this tag began with 2007 deployments when the corrodible wire holding the tag to the attachment sheath sheared causing a premature release of the tag. In 2008, WC modified the design to a heavier wire and we provided three large studs in the attachment sheath that penetrated into three voids in the tag float that prevented the tag from rotating and shearing the wire. However, in 2008 the manufacturer did not draw a vacuum on the casting matrix and small bubbles in the casting collapsed under the pressure of sperm whale dives to short out the electronics. Eleven tags were deployed in FY12 on sperm whales in the GoM (with ship logistics paid by the NRDA follow-up to the Deepwater Horizon/BP oil spill).

RESULTS

Location only tags

western gray whales

A 13-year old male western gray whale named Flex was tagged on 4 Oct 2010 off Sakhalin Island, Russia and was tracked for 128 days. After 69 days off Sakhalin Island, it migrated across the Bering Sea, the Gulf of Alaska and along the Pacific NW until it reached the central Oregon coast on 9

February 2011. In August 2011, Flex was re-sighted during additional tagging operations off of Sakhalin Island. He was in good body condition, confirming there were not unexpected adverse affects and that he had made a complete round trip to and from the eastern North Pacific. As a result of this migration, Weller et al. (2012) circulated photos to many gray whale scientists for catalog comparison. They determined that Flex and many other WGWs have previously visited the eastern North Pacific.

The 2011 tagging of 6 WG whales off Sakhalin resulted in two more significant tracks away from the island. Two females were tracked across the Bering Sea. One tag (on Agent) quit half way across the Gulf of Alaska, while the other (on Varvara) went all the way to nearly the tip of Baja and back to Sakhalin. She covered 23,000 km in 5.5 months and visited every known eastern North Pacific gray whale reproductive area. This is the world record migration for any mammal (Figure 1). The tag is still transmitting after more than 400 days at the time this report is being prepared and has provided the first complete annual track for WGWs and the smallest calculated home range and core area for any baleen whale we have ever tracked for more than 5 months.

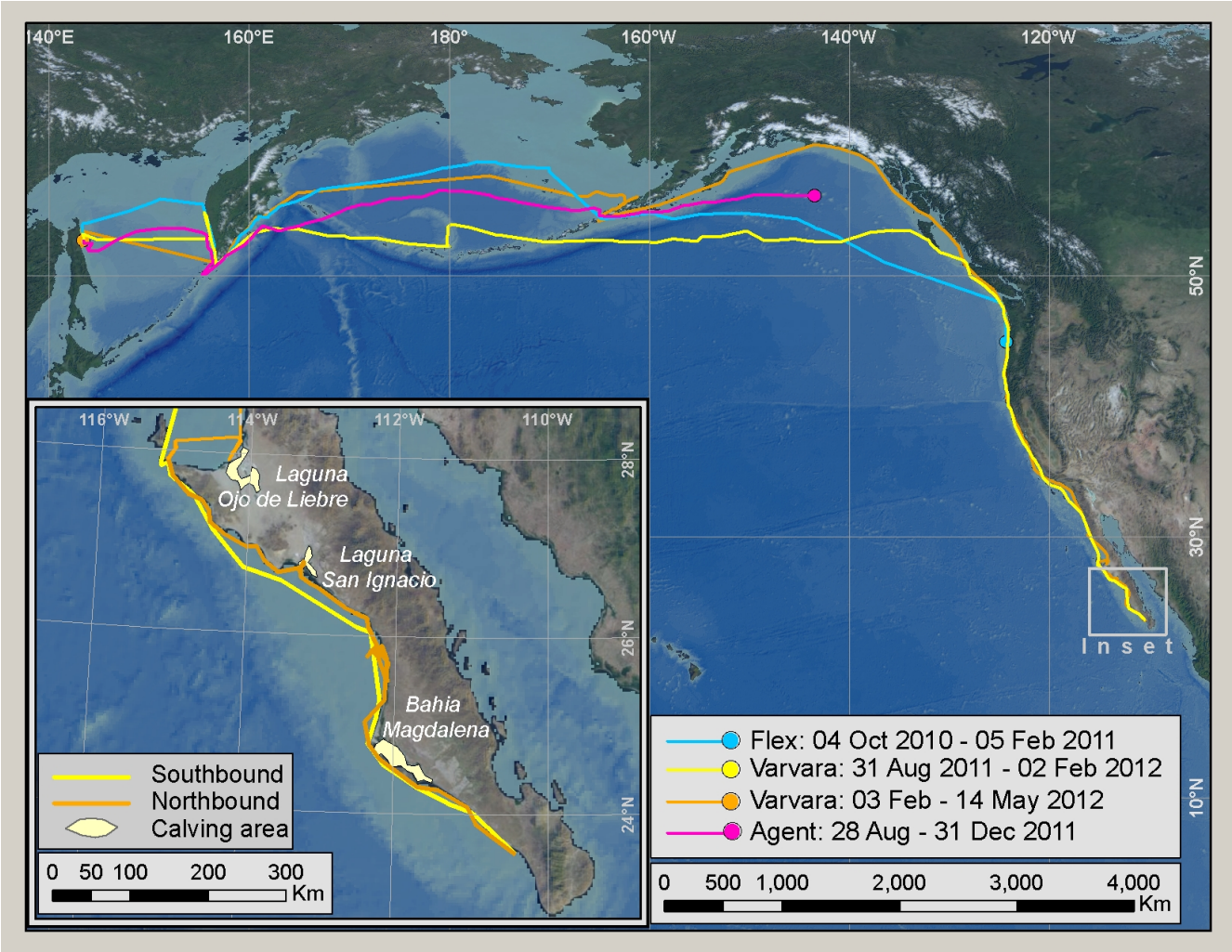

Figure 1. The tracks of three western gray whales tagged in Russia during 2010 and 2011 that migrated from Sakhalin Island to the eastern North Pacific.

ONR wanted the LO tags developed in collaboration with a manufacturer who would make them available to other researchers. Wildlife Computers made the LO tags available to other users immediately. Some users applying tags at greater distances than us have experienced tag failures upon deployment. We typically deploy tags within 2-3 meters to control the tags position on the dorsum, vertical antenna orientation, and the striking angle of the tag. We typically use deployment pressures in the ARTS applicator for baleen whales of ~5 bar (~75 psi) with somewhat higher pressures (up to 8 bar – 120 psi) for sperm whales. Groups deploying tags from greater distances have used pressures up to 10 bars and photo-documented visible tag damage upon application. To avoid this, WC now casts these tags in a thicker-walled stainless steel tube for those users to compensate for larger acceleration and deceleration pressures associated with longer deployment distances.

sperm whales

Four LO tags applied to sperm whales in July 2011 transmitted data up to 409 days (mid-September 2012). The tags were applied late in the field season with three of them in one social group (Table 1 and Figure 2). The average number of days transmitted (probably attached) was 195d for WC Spot-5 tags versus 145d for the 17 Telonics ST-15 tags. In aggregate the whales with the Spot-5 tags traveled at least 18,265 km, covering an average of 23.4 miles/day, compared to the 22.5 km/d traveled by the Telonics ST-15 tags.

Table 1. Four tagged sperm whales

PTT	Tag Type		Sex	Date Deployed	Last Location	# Msgs	# Days Tx	# Locs Rec'd	# Locs Used	Dist.(km)
05843	SPOT5		F	4-Aug-11	17-Jan-12	279	165.1	41	36	2,280
23030	SPOT5		F	2-Aug-11	22-Jan-12	1040	173.0	90	63	3,300
23034	SPOT5		F	4-Aug-11	7-Sep-11	1282	33.2	91	53	1,319
23043	SPOT5		F	4-Aug-11	17-Sep-12	7800	409.3	552	362	11,366
				SPOT5	Subtotal	10,401	195.1	774	514	18,265

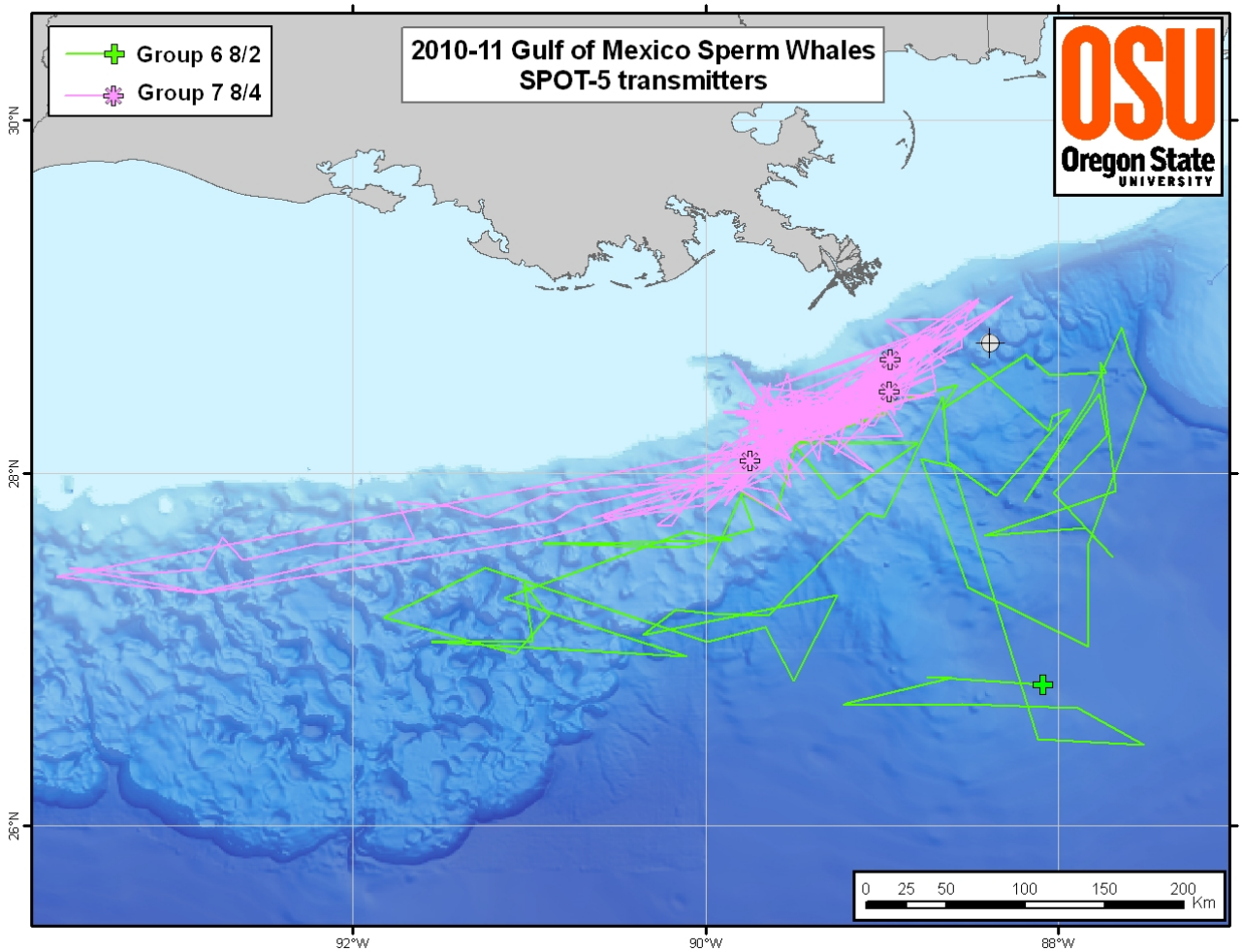

Figure 2. The tracks for four WC Spot-5 LO Argos tag locations applied to sperm whales in the Gulf of Mexico in August 2011 and lasted up to 409 days.

Mk-10 PATF 3-axis accelerometers incorporated into GPS/TDR tag

Eleven Mk-10 tags were deployed on sperm whales during July 2011 (Table 2 and Figure 3). These tags lasted an average of 26.1 days, but a software error failed to release the tags at their pre-programmed release times. One tag was recovered.

Table 2. A comparison of the GPS and Argos locations for the 11 Mk-10 tags applied to sperm whales in the Gulf of Mexico as a follow-up to the DWH oil spill.

ptt	Tag Type	Double Tag #	Sex	Date Deployed	Most Recent	# Msgs	# Days Tx	# Locs Rec'd	# Locs Used	Dist.(km)
00833	MK-10	00845	U	20-Jul-11	15-Aug-11	825	25.3	214	109	1,486
00838	MK-10		F	17-Jul-11	7-Aug-11	449	20.5	173	83	1,089
00840	MK-10	05826	F	10-Jul-11	23-Jul-11	110	12.8	68	37	520
04173	MK-10	00823	F	17-Jul-11	5-Sep-11	1762	49.6	708	175	2,728
04177	MK-10	00832	U	11-Jul-11	15-Aug-11	788	34.8	285	142	1,220
05640	MK-10		U	11-Jul-11	29-Jul-11	260	17.9	123	56	623
05644	MK-10	05910	F	23-Jul-11	22-Aug-11	995	29.9	269	114	1,679
05654	MK-10		F	17-Jul-11	21-Aug-11	1027	34.2	253	107	1,894
05685	MK-10	05921	F	20-Jul-11	18-Aug-11	804	28.4	227	110	1,700
05701	MK-10	05655	F	23-Jul-11	17-Aug-11	800	24.4	219	94	1,343
05838	MK-10	05803	F	23-Jul-11	2-Aug-11	491	9.6	109	58	564
					MK-10 Subtotal	8,311	26.1	2,648	1,085	14,846

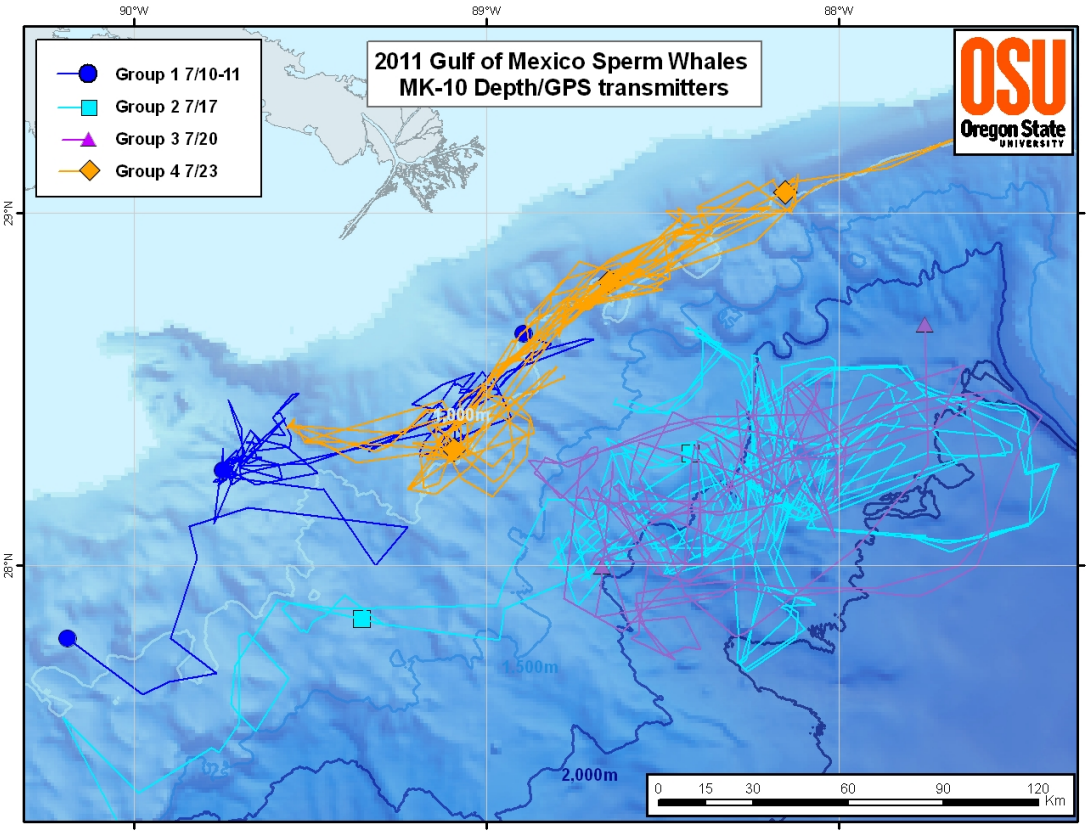

Figure 3. The tracks for 11 WC Mk-10 PATF (GPS/TDR Argos) tags with 3-axis accelerometers applied to sperm whales in the Gulf of Mexico in August 2011.

Summaries of dives and 1.5 to 5 GPS-quality locations/day were received from all MK-10 tags via Argos. MK-10 behavior messages received through Argos summarized 74% of all dives by reporting the dive duration, maximum dive depth, shape of dive, and subsequent surface duration of dives > 10 min duration and > 10 m depth. Histograms summarizing time spent in various depth ranges, maximum dive depths and dive durations were also received via Argos and included data from ~ 60% of the tag durations.

Despite the failure of the release software, one MK-10 tag was recovered and contained a continuous 42 day record of: 1) 1 s temporal resolution depth data, which recorded 744 dives > 350 m depth, 2) a 1 s resolution 3-axis accelerometer data record from which body orientation of the whale could be derived, and 3) 855 GPS-quality locations. Median dive duration was 40.6 minutes and the average depth of the bottom phase of dives was 588 m. Rate of change in body orientation was calculated and used to identify instances of high rates of change (acceleration), which were assumed to be foraging attempts. A median of 14 lunge events occurred during dives >10 min and > 350 m deep. Lunges occurred almost exclusively during the bottom phase of dives (not descents or ascents) and occurred most frequently between 12:00 – 24:00 CST. The number of lunge events per dive dramatically increased during the last two weeks of the data record, but was still highly variable, suggesting the whale encountered an area of higher average prey density. Dives with many lunge events (likely high prey density) were close to regions where dives showed few lunge events per dive despite similar dive depths and durations (Figure 4). The spatial variability in lunge events across the whale's track suggests that sperm whale prey have a patchy distribution. On a dedicated future cruise with GPS/TDR tags, EK-60 echo-sounder data co-located with dive behavior from the MK-10 tags could provide important information on prey detection, foraging, and thus habitat selection.

The GPS/TDR tags produced high quality, detailed data on sperm whale diving behavior that were summarized and transmitted as Argos messages. The level of detail recorded and ability to transmit summary information makes this technology ideal for conducting behavioral response studies for sperm whales (or controlled exposure experiments), especially with simultaneous monitoring of acoustic exposures (seismic or sonar) to be tested for disturbance, possible habituation, and subsequent recovery from disturbance. The long-lasting attachments of GPS/TDR tags and their ability to report values via satellite during such experiments makes them ideally suited to developing both good baseline control values and repeated exposures to better document thresholds, responses, and recovery patterns.

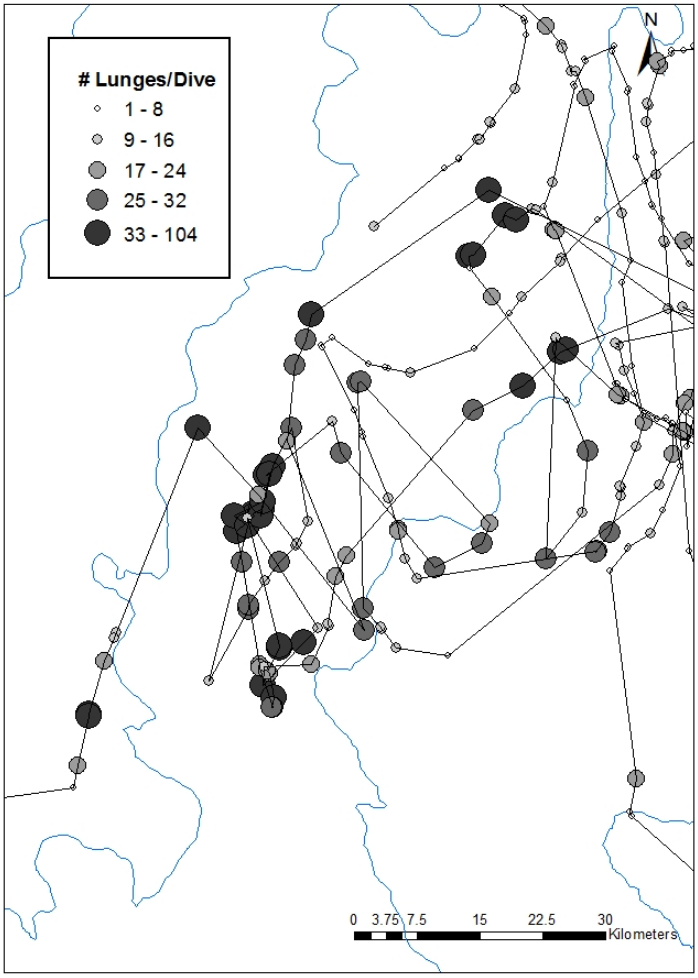

Figure 4. The lunge rates of a GPS/TDR-tagged sperm whale shown during its track over a 42-day period in the Gulf of Mexico. This image is just a portion of the full track. The size and shading of the circles relates to the number of lunge events that occurred during the bottom phase of a dive > 350 m at that position. Darker colors and larger circles equate to more lunge events per dive. The highly variable lunge rate, despite dives of similar duration and depth, suggests very patchy prey distribution is the main reason for whales to travel over such large areas.

WORK PLAN

We will test LO tag software modifications changing the saltwater switch's sensitivity and examine the summary wet/dry data to determine if it accurately summarizes the laboratory testing. We will apply the subsequently tested tags on PCFG gray whales to determine if the tags can maintain their long-term transmission schedule.

We will be laboratory testing the new 3-axis magnetometer sensors, Fasloc-3 GPS receiver system, and modifications to the tag release process to accurately portray the whale's activities and reduce the

chances of failure during future deployments. The resulting 3-axis accelerometer and magnetometer data will help determine how sperm whales coordinate their foraging movements and animate their underwater tracks.

IMPACT/APPLICATIONS

The LO tags from WC cost ~$2000, about half of the older (obsolete) Telonics LO (ST-15) tags, and require little time for assembly of the attachments and penetrating tip (an additional ~$150). The new tags are user-programmable for duty cycles and functions, which include "haul-out" histograms (dry time) useful in determining surface-oriented diurnal behaviorals throughout the day. The resulting data are helpful in developing correction factors (probability of sighting) to estimate populations from aerial and ship-board surveys. However, problems have been detected in maintaining the user-programmed transmission schedule. The on-board data suggest this is a "haul-out" issue, where the tag's saltwater switch does not detect submergence and continues to transmit (at a 10 second interval) until the user-programmed limit of transmissions (250/day in our case) was reached. This happened in the first 42 minutes of the first one-hour transmit period, so the transmitters did not transmit at other times of the day. A recent meeting with the WC manufacturing staff has resulted in a strategy to determine the issue(s) that may contribute to the surfacing sensitivity of the saltwater switch contact. Tags are being re-programmed to address this issue and will be tested in FY-13.

An adaptation to prevent the tags from penetrating too far (sub-surface) has been developed for the FY-12 field work and will be further tested in FY-2013. This modification should be especially useful for smaller tags deployed on smaller species (minke whales and some larger beaker whales) than the larger whales that have been tagged to date.

TRANSITIONS

The proof of concept was demonstrated for the lower cost LO casting technique and the utility of the easily changed attachments and penetration tips. Reviews by IWC and IUCN science panels approved the use of the 3-cell (longer version) tags on female Western gray whales for FY-12 and resulted in a record-long track for gray whales. A WGW female's tag exceeded 400 days (at this report writing and is still sending data), which included a 23,000 km migration. While Wildlife Computers is already offering these LO tags as a mainstream product (fulfilling one ONR goals of this project), we are continuing to work with them to resolve problematic issues for ourselves and other users.

The proof of concept demonstation for GPS/TDR tags during the DWH sperm whale project was impressive, despite release problems. We are continuing to work with WC to evolve the tag further, which will include the incorporation of Fasloc-3 technology (a 90% savings in energy consumption) and magnetometers to provide compass bearings so an accurate depiction of the underwater movements of the whales can be obtained. This is important, so that individual whale underwater foraging "maps" (worms) can be accurately be depicted to determine where whales are navigating during their dives (between surfacings). These data can then be co-registered in 3-D space and time (merged) to evaluate social foraging strategies, such as the "foraging volume" of sperm whales working on a bait ball of squid. This anaylsis would be useful to better understand how possible impacts to individuals may in fact be impacts to a larger group. There will likely be interest in understanding this for the impacts of sounds (sonar, seismic, ship noise, explosions, etc.).

In conjunction with the Mk-10 tag, we anticipate the develop of an acoustic dosimeter, which would be extremely useful in conjunction with the underwater behavioral (dive) data to determine what levels of sounds may affect "normal" behavior and what exposure whales may have to ambient sounds in the course of their "normal" movements, some of which may include exposure to significant levels of sound, such as sperm whales in the GoM or at Gibralter and near shipping routes. There will likely be other agencies and industry interest in developing this type of information (BOEM, oil & gas, shipping interests, and NOAA).

Additional interest in the products of this ONR project have been expressed by the JIP (co-funders of the early tag development), trustees of the Deep Water Horizon oil spill, and possibly colleagues planning BRS projects in Australia with humpback whales using industry seismic sources

RELATED PROJECTS

Additional taggings of Pacific Coast Feeding Group gray whales will take place this year between this ONR project to test the sensitivity of the saltwater switch details and a Navy regional project (through HDR) to learn more about Pacific NW whale habitats. This will include an analysis of some previously collected regional EGW data. We hope to re-tag some of the EGWs tagged in 2009, so we can simultaneously follow-up on both old and new tag-wound healing and also see if the whales have the same migratory departure times, speeds, and destinations year after year.

We are approaching the NRDA trustees to continue work on sperm whales in the GoM using the next iteration Mk-10 tags in 2013, which will allow the calculation of the volume of the area worked by a group of socially affiliated whales. This will also allow us to evaluate how consistent roles are in groups of foraging sperm whales, the way humpbacks seem to be during coordinated bubble-net feeding. We will also be able to determine if all whales in an affiliate group have the same relative response to variable prey densities (i.e.: they all have proportional increases or decreases in their foraging lunge rates as they move through the region).

PUBLICATIONS

Block, BA, Jonsen ID, Jorgensen SJ, Winship AJ, Shaffer SA, Bograd SJ, Hazen EL, Foley DG, Breed GA, Harrison A-L, Ganong JE, Swithenbank A, Castleton M, Dewar H, **Mate B,** Shillinger GL, Schaefer KM, Benson SR, Weise MJ, Henry RW, Costa DP. 2011. Tracking apex marine predator movements in a dynamic ocean. Nature. 479:86-90.

Cotté, C, d'Ovidio F, Chaigneau A, Levy M, Taupier-Letage I, **Mate B**, Guinet C. 2011. Scale-dependent interactions of Mediterranean whales with marine dynamics. Limnology and Oceanography 56:219-232.

Mate, B, Best P, **Lagerquist BA, Winsor M.** 2011. Coastal, offshore, and migratory movements of South African right whales revealed by satellite telemetry. Marine Mammal Science. 27:455-476.

Ortega-Ortiz, JG, Engelhaupt D, **Winsor M, Mate B,** Hoelzel AR. 2011. Kinship of long-term associates in the highly social sperm whale. Molecular Ecology.

Bentaleb, I, Martin C, Vrac M, **Mate B,** Mayzaud P, Siret D, de Stephanis R, Guinet C. 2011. Foraging ecology of Mediterranean fin whales in a changing environment elucidated by satellite-tracking and baleen plate stable isotopes. Marine Ecology Progress Series. 438:285-302.

Peterson, CH, Anderson SS, Cherr GN, Ambrose RF, Anghera S, Bay S, Blum M, Condon R, Dean TA, Graham M, Guzy M, Hampton S, Joye S, Lambrinos J, **Mate B,** Meffert D, Powers SP, Somasundaran P, Spies RB, Taylor CM, Tjeerdema R, Adams EE. 2012. A Tale of Two Spills: Novel Science and Policy Implications of an Emerging New Oil Spill Model. BioScience. 62(5):461-469.