EXECUTIVE SUMMARY

Integrated Measurement of Naval Sonar Operations and Precise Cetacean Locations

ESTCP Project RC-201304

JANUARY 2018

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14. ABSTRACT

A GPS enabled, low impact, minimally percutaneous electronic transmitter (LIMPET) tag for the in-situ study of cetaceans was developed. The tag is dart attached to individual animals at-sea using a neumatic rifle. The tag provides GPS and dive data in real-time via the Argos satellite system. The tag was successfully developed and deployed on a number of species including Cuvier's beaked whales ("Ziphius cavirostris") on the Southern California Offshore Range (SCORE).

A generic sonar detector was also developed and tested in-situ at SCORE with mid-frequency active sonar. The detector was integrated into the Marine Mammal Monitoring on Navy Ranges (M3R signal processor) and is capable of monitoring over 200 hydrophones in real-time. It is currently being used on the three major Navy ranges including the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas, SCORE, and the Pacific Missile Range Facility (PMRF) in Hawaii.

15. SUBJECT TERMS: sonar detetcion, LIMPET tag, beaked whales, sonar, Cuvier's beaked whales, Fastloc GPS-LIMPET tag, SPLASH tag,M3R

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ACRONYMS AND ABBREVIATIONS

ASLC	Alaskan Sea Life Center
ASW	Anti-Submarine Warfare
AUTEC	Atlantic Undersea Test and Evaluation Center
Bp	Fin whale (*Balaenoptera physalus*)
CM	Centimeter
CO_2	Carbon Dioxide
CRC	Cascadia Research Collective
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
ID	Identification
LIMPET	Low Impact Minimally Percutaneous Electronic Transmitter
M	Meter
M3R	Marine Mammal Monitoring on Navy Ranges
MFA	Mid-Frequency Active
MFAS	Mid-Frequency Active Sonar
MS	Millisecond
NUWC	Naval Undersea Warfare Center
NM	Nanometer
PMFR	Pacific Missile Range Facility
ROC	Receiver Operator Curves
SCORE	Southern California Offshore Range
SD	Standard Deviation
SOAR	Southern California Antisubmarine Warfare Range
Zc	Cuvier's beaked whale (*Ziphius cavirostris*)

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1.0 OBJECTIVES AND RESULTS SUMMARY

The objectives of this project were to integrate:

1. A real-time sonar detector into existing passive acoustic Navy range monitoring systems.
2. A Fastloc™ Global Positioning System (GPS) into a remotely deployed medium-duration dart tag suitable for attachment to a beaked whale.

These technologies were validated in both the laboratory and the field. Receiver Operator Curves (ROC) against white noise were measured to validate basic system performance. The software was validated against in-situ data from the Ranges to provide a realistic measure of performance in real-world environments.

The GPS based tag was tested on land at forces that far exceed those expected in the field to verify impact survivability, ballistic performance, and down range accuracy of the delivery system. Dedicated tests to measure the positional accuracy and update rate were completed. GPS tags were placed as follows: three on Cuvier's beaked whales (*Ziphius cavirostris* [Zc]), two on fin whales (*Balaenoptera physalus* [Bp]), three on short fin pilot whales (*Globicephala macrorhynchus*), and one on a false killer whale (*Pseudorca crassidens*).

The tag deployments demonstrated that placement of tags on Cuvier's beaked whales is possible given reasonable sea-state conditions. In addition, the installation of a land-based receiver on San Clemente Island, California, proved highly successful at delivering transmitted data.

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2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

There are three major Navy undersea range facilities: the Atlantic Undersea Test and Evaluation Center (AUTEC); the Southern California Offshore Range (SCORE) off San Diego, and the Pacific Missile Range Facility (PMRF) off the island of Kauai, Hawaii. Each facility includes a broad field of bottom-mounted hydrophones spaced 1-4 nanometers (nm) apart, which monitor ocean areas of 500-1,500 nm^2. These hydrophone fields were designed to track subsurface vehicles during active sonar anti-submarine warfare (ASW) exercises, but are also being used to detect and monitor vocalizing cetaceans before, during, and after Mid-Frequency Active (MFA) sonar operations (Moretti, DiMarzio, Morrissey, Ward, & Jarvis, 2002; McCarthy, et al., 2011).

While evidence suggests that beaked whales are unusually sensitive to sonar (McCarthy, et al., 2011; Tyack, et al., 2010; Moretti, et al., 2014), several species have been documented in significant numbers at all three Navy ranges (Falcone, et al., 2009; Marques, Thomas, Ward, DiMarzio, & Tyack, 2009). Range populations are being studied in-situ using a combination of passive acoustics, photo-identification (ID), and tag data. Interactions between tagged whales and Navy sonar are being analyzed where the datasets overlap. Beaked whales produce loud directional echolocation clicks only during foraging dives, detections of which can be used to estimate their spatial and temporal distribution on the range and as a proxy for their foraging behavior (Johnson, Madsen, & Zimmer, Foraging Blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation, 2006; Johnson M. , Madsen, Zimmer, Aguilar de Soto, & Tyack, 2004). Passive acoustic detectors/classifiers for both Cuvier's and Blainville's beaked whales have been developed, and when possible, simultaneous detection data from multiple hydrophones are combined to determine animal locations. Location data are combined with detection reports in a comprehensive, time-synchronous archive.

Precise ship-track data can also be obtained from the ranges during MFA sonar exercises. However, the timing of sonar transmissions during these exercises must be laboriously extracted from multiple hydrophones through a manual inspection of associated detection archives, when available. Integration of a sonar detector in the existing hydrophone monitoring system allows each sonar ping to be detected and the received level, directly at the face of the hydrophone, is measured in real-time. These data are then stored along with the time-synchronous animal detections that are already being captured. The sonar algorithm has been implemented and system integration completed. A Linux cluster-based architecture has been developed that allows the monitoring of all range hydrophones in real-time. For example, 198 hydrophones are currently monitored at PMRF. Hydrophone data are digitized, packetized, time-tagged, and cast on a dedicated 1G-byte network. This allows the addition of independent processing nodes on the network as algorithms become available. The sonar detector has been incorporated into the Marine Mammal Monitoring on Navy Ranges (M3R) software built and installed on the M3R signal processor on the three major Navy undersea ranges. The software has been tested in-situ and is being used to collect data on a continual basis.

While Low Impact Minimally Percutaneous Electronic Transmitter (LIMPET) tags are currently being applied to beaked whales on the Navy ranges to monitor their behavior during MFA events, limitations inherent in spatial data derived from the Argos system presented challenges to the data analysis. The Argos-only LIMPET satellite tags can only provide a location estimate during the infrequent times when the whale surfaces and an overpass of an Argos-system satellite occur simultaneously.

In contrast, there is always a sufficient number of GPS satellites overhead to allow a location to be calculated after every dive. Traditional GPS receivers require tens of seconds to acquire both range and ephemeral data, but most whales surface for too short of a time. The Fastloc™ system, however, captures only the satellite ID and range information within ~ 300 milliseconds (ms) and then those data are used for post-processed location calculations by the user, allowing GPS receivers to be incorporated into marine mammal tags.

A Fastloc™ GPS receiver was successfully integrated into a LIMPET-style package appropriate for deployment onto beaked whales. The GPS LIMPET tag was tested on land to ensure accurate flight trajectory for remote deployment from 3 to 20 meters (m) and sufficient robustness to high-force impacts using simulated dorsal fin targets prior to field use. The GPS enabled tag can be projected from a Dan-Inject carbon dioxide (CO_2)-powered rifle at a sufficient velocity to achieve a reasonably flat trajectory over the range at which beaked whales are usually approached for tagging (3 to 20 m). When sighted in to hit a bulls-eye target at 10 m (zeroed at 10 m), the tag will hit the target no more than 20 centimeter (cm) lower than the aim point if the target is moved out to 15 m. This allows the tagger to hit a small target, such as a beaked whale dorsal fin, without needing to accurately estimate distance to the whale and make a large compensation in aim point. The required performance is achieved with the combined mass and aerodynamic packaging of the new GPS LIMPET tag. Land-based simulated tagging experimental data verified that the tag can accurately (within 10 cm) hit the aim point on a target in the shape and size of a beaked whale dorsal fin.

As listed in Section 1.0, the tag was field tested on four different species of cetaceans. Deployments were executed on Cuvier's beaked and fin whales at SCORE, short fin pilot whales off the coast of North Carolina, and a false killer whale in Hawaii. Coincident data from the GPS tag with data and sonar were collected at SCORE. Currently, these combined data are being analyzed to better understand the animals' reaction to mid-frequency active sonar (MFAS).

As stated in Section 1.0, the land-based receiver on San Clemente Island provided a significant increase in received data. With inclusion of GPS into the tag, these data provided both dive and position data. To test the accuracy of the tags positional data, on-shore simulations were run that mimicked the expected dive behavior of whales. With reception of data from five satellites a mean accuracy of 52 m (standard deviation [SD]=31 m) was measured. With four satellites, a mean accuracy of 163 m (SD=233.9) was obtained.

Elements of the M3R program have been transitioning to the Fleet for cetacean monitoring during operations. The technologies developed as part of the Environmental Security Technology Certification Program (ESTCP) program were incorporated into the M3R system and transitioned for Fleet use. The inclusion of automated sonar detections along with precise tag locations will provide a significant advantage over current technologies and methodologies.

3.0 PERFORMANCE OBJECTIVES

Table 1 shows performance objectives which represent quantitative measures of performance for both the sonar detector and GPS-based tag.

Table 1. Performance Objectives

Performance Objective	Metric	Data Requirements	Success Criteria	Final Result
Provide integrated sonar detector to M3R range monitoring signal processor	Probability of Detection	SCORE Range Recorded Data	70% correct detection/ classification rate when interfering species present	100% (For sonar sources within the Southern California Antisubmarine Warfare Range [SOAR])
	False Alarm Rate	SCORE Range Recorded Data	1 per 1000 seconds	~1 per 3,600 seconds
	Measure Signal Level	Controlled signal in Gaussian white noise	+/- 10% of measured value (dBV)	< +/- 10%
Provide satellite tag with embedded GPS	Impact survival	Data collected with land-based targets	<10% failure in extreme tests that exceed expected force in field	0% Failure Rate
	Successful attachment and function	Data from tags attached to whales	Six tags must be attached to and function (for at least 2 days) on beaked whales or surrogate species*	**9 tags attached** 19.49 days mean attachment duration
	Update Rate	Data from tags attached to whales	18 per day	16.2/day overall Min 3.2/day Bp Max 30/day Zc **Zc mean = 18.6/day**
	Positional Accuracy	Data from tags tested at sea fielded on rigid-hulled inflatable boat and whales compared to vessel-based tracks	90% < 200 m error	**Overall 163 m (SD = 233.9) >=4 satellites** 52 m (SD = 31 m) w/ >= 5 satellites

*Surrogate species for beaked whales could include Risso's dolphins or fin whales.

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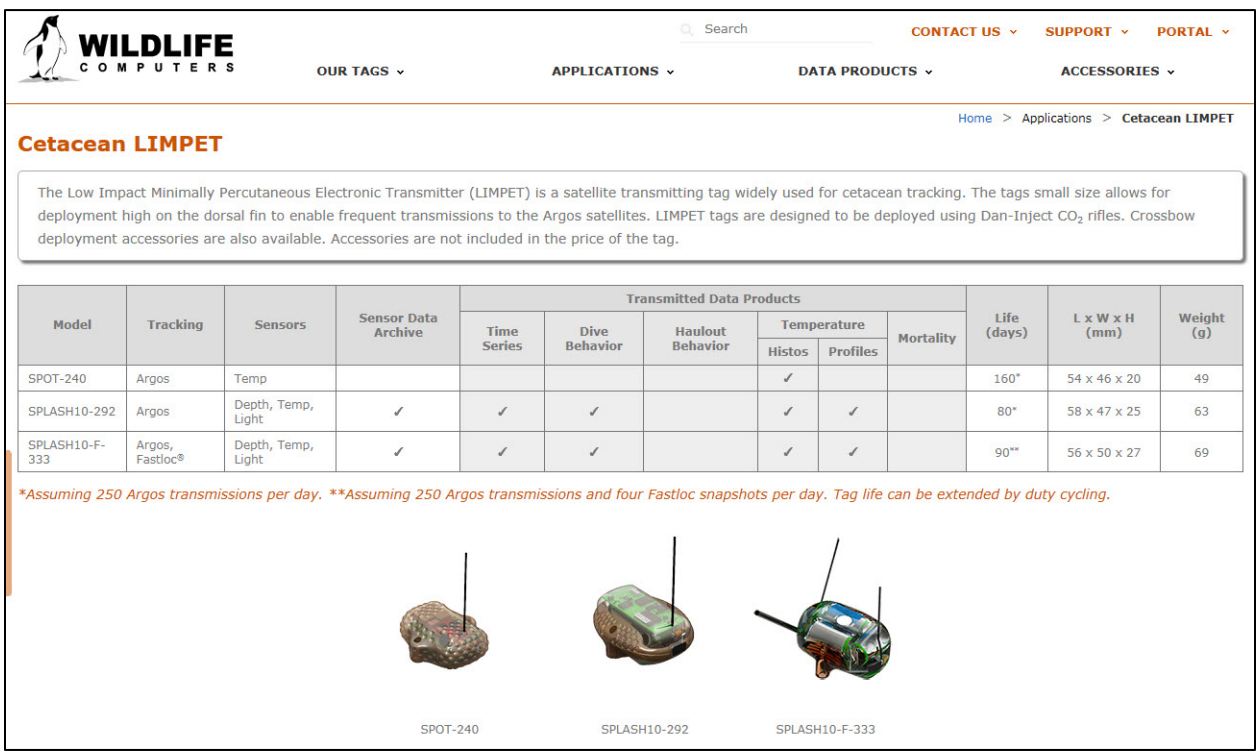
4.0 COST SUMMARY

The GPS tag was successfully designed, built, and field tested. The tag is now commercially available at a cost of approximately $7,000, through Wildlife Computers (Figure 1), and is marketed as the Splash10-F-33 (www.wildlifecomputers.com/applications/cetacean-limpet/).

A final invoice and cost summary from Cascadia Research Collective (CRC) (Figure 2), a Contract Officer's report documenting the Alaskan Sea Life Center (ASLC) final invoice and contract cost summary (Figure 3), along with a final drawing package from ASLC were received. CRC successfully completed the Naval Undersea Warfare Center (NUWC) contract N66604-14-C-2438, Option 2, for a total of $72,372. ASLC successfully completed the NUWC contact N66604-14-C-0144 for a total of $110,493.

NUWC will have expend funds ($45,953) provided on funding document W74RDV70544626 as of 17 February 2018.

The MFAS sonar detector has been integrated into the M3R system and is running in real-time on the three major Navy ranges: SCORE, AUTEC, and PMRF. Sonar detection reports are being produced and incorporated into the monitoring archives on a continual basis.



Model	Tracking	Sensors	Sensor Data Archive	Transmitted Data Products						Life (days)	L x W x H (mm)	Weight (g)
				Time Series	Dive Behavior	Haulout Behavior	Temperature		Mortality			
							Histos	Profiles				
SPOT-240	Argos	Temp					✓			160*	54 x 46 x 20	49
SPLASH10-292	Argos	Depth, Temp, Light	✓	✓	✓		✓	✓		80*	58 x 47 x 25	63
SPLASH10-F-333	Argos, Fastloc®	Depth, Temp, Light	✓	✓	✓		✓	✓		90**	56 x 50 x 27	69

*Assuming 250 Argos transmissions per day. **Assuming 250 Argos transmissions and four Fastloc snapshots per day. Tag life can be extended by duty cycling.

Figure 1. Wildlife Computers Website Listing the GPS Enabled LIMPET Tag

Cascadia Research Collective
non-profit research and education since 1979

Phone: 360. 943.7325
Fax: 360.943.7026
Homepage: www.cascadiaresearch.org

INVOICE NO. 480_17_05

Date: 29 December 2017

Contract #: **N66604-14-C-2438, Option 2, CLIN 0005, SUBCLIN 000501, CIN: 130058987200001**

To: Receiving Officer, Naval Station Newport
Attn: Thomas N. Fetherston
47 Chandler Street
Newport, RI 02841-1716

Mark for: NUWC Division, Newport – P.O.#: N66604-14-C-2438
Purchase request number: 1300589872

Remit to: Cascadia Research (at address below). Project code: 480-ESTCP

Invoice Amount: $19,660.08
Invoice History:

Current invoice	$19,660.08
Previous invoice amounts for option 2	$52,711.92
Total option 2 contract amount	$72,372.00
Remaining on CLIN 0005, SUBCLIN 000501	$0

Comments: This is the sixth and final invoice for option two (CLIN005, SUBCLIN 000501) of the contract. This represents a combined 100% of the option year 2, Task C of N66604-14-C-2438 under this firm-fixed price contract for conducting testing of a new GPS LIMPET tag. The final report for our part of the demonstration plan under Task C is attached.

Greg Schorr
Project Manager

Waterstreet Building 218½ West Fourth Ave. Olympia, Washington 98501

Figure 2. Cascadia Research Collective Final Invoice and Cost Summary

COR MONTHLY REPORT (NUWCDIVNPT TEMPLATE) v.2.1 - June 2015

September 2017

From: Contracting Officer's Representative
To: Contracting Officer

Subj: COR MONTHLY REPORT FOR CONTRACT/ORDER N66604-14-C-0144

Ref: (a) NUWCDIVNPTINST 4330.1E

Encl: (N/A)

1. In accordance with reference (a), this monthly report is hereby submitted on the subject contract/order.

2. Overall the contractor's performance was:
   [ ] EXCEPTIONAL
   [ ] VERY GOOD
   [X] SATISFACTORY
   [ ] MARGINAL
   [ ] UNSATISFACTORY

3. Approved a voucher in iRAPT from Alaska Sea Life Center for $4,667.64. This is the final invoice submitted under Option 2, the original total of which was $110,493. A balance of $3.67 remains to be returned to the sponsor.

SIGNATURE OF COR Thomas N Fetherston DATE 19 OCT 17.
Thomas N. Fetherston

Copy To:
COR's Supervisor
COR's Department Head
Subject Contract COR File

Figure 3. Contract Officer's Report Documenting the Alaskan Sea Life Final Invoice and Contract Cost Summary

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5.0 REFERENCES

Falcone, E., Shorr, G., Douglas, A., Calambokidis, J., Henderson, E., McKenna, M., et al. (2009). Sighting characteristics and photo-identification of Cuvier's beaked whales (Ziphius cavirostris) near San Clemente Island, California: a key area for beaked whales and the military? *Marine Biology, 156*, 2631-2640.

Johnson, M., Madsen, P. T., & Zimmer, W. X. (2006). Foraging Blainville's beaked whales (Mesoplodon densirostris) produce distinct click types matched to different phases of echolocation. *Journal of Experimental Biology, 209(24)*, 5038-5050.

Johnson, M., Madsen, P., Zimmer, W., Aguilar de Soto, N., & Tyack, P. (2004). Beaked whales echolocate on prey. *Proceedings of the Royal Society of London Series B Biological Sciences, 271(Suppl.6)*, S383-S386.

Marques, T., Thomas, L., Ward, J., DiMarzio, N., & Tyack, P. (2009, April). Estimating cetacean population density using fixed passive acoustic sensors: an example with Blainville's beaked whales. *Journal of the Acoustical Society of America, 125(4)*, 1982-94.

McCarthy, E., Moretti, D., Thomas, L., DiMarzio, N., Dilley, A., Morissey, R., et al. (2011, July 2). Changes in Spatial and Temporal Distribution and Vocal Behavior of Blainville's Beaked Whales (Mesoplodon densirostris) during Multi-Ship Exercises with Mid-Frequency Sonar. *Marine Mammal Science, 27(3)*, E206-E226.

Moretti, D., DiMarzio, N., Morrissey, R., Ward, J., & Jarvis, S. (2002). Open ocean marine mammal monitoring using widely spaced bottom mounted hydrophones. *Journal of Underwater Acoustics, 52*, 651-668. U.S. Navy.

Moretti, D., Thomas, L., Marques, T., Harwood, J., Dilley, A., Neales, B., et al. (2014). A risk funciton of Blainville's beaked whales ("Mesoplodon densirostris") derived from Mid-Frequency Active (MFA) sonar operations. *PLoS ONE, 9*(1).

Tyack, P., Zimmer, W., Moretti, D., Southall, B., Claridge, D., Durban, J., et al. (2010). Beaked Whales Respond to Simulated and Actual Navy Sonar. *Public Library of Science*.