ORPC
OCEAN RENEWABLE POWER COMPANY

U.S. DEPARTMENT OF ENERGY

ACOUSTIC MONITORING OF BELUGA WHALE INTERACTIONS WITH COOK INLET TIDAL ENERGY PROJECT

DE-EE0002657

FINAL TECHNICAL REPORT

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Project Title:	**Acoustic Monitoring of Beluga Whale Interactions with the Cook Inlet Tidal Energy Project**
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EXECUTIVE SUMMARY

Cook Inlet, Alaska is home to some of the greatest tidal energy resources in the U.S., as well as an endangered population of beluga whales (*Delphinapterus leucas*). Successfully permitting and operating a tidal power project in Cook Inlet requires a biological assessment of the potential and realized effects of the physical presence and sound footprint of tidal turbines on the distribution, relative abundance, and behavior of Cook Inlet beluga whales. ORPC Alaska, working with the Project Team—LGL Alaska Research Associates, University of Alaska Anchorage, TerraSond, and Greeneridge Science—undertook the following U.S. Department of Energy (DOE) study to characterize beluga whales in Cook Inlet – Acoustic Monitoring of Beluga Whale Interactions with the Cook Inlet Tidal Energy Project (Project).

ORPC Alaska, LLC, is a wholly-owned subsidiary of Ocean Renewable Power Company, LLC, (collectively, ORPC). ORPC is a global leader in the development of hydrokinetic power systems and eco-conscious projects that harness the power of ocean and river currents to create clean, predictable renewable energy. ORPC is developing a tidal energy demonstration project in Cook Inlet at East Foreland where ORPC has a Federal Energy Regulatory Commission (FERC) preliminary permit (P-13821).

The Project collected baseline data to characterize pre-deployment patterns of marine mammal distribution, relative abundance, and behavior in ORPC's proposed deployment area at East Foreland. ORPC also completed work near Fire Island where ORPC held a FERC preliminary permit (P-12679) until March 6, 2013. Passive hydroacoustic devices (previously utilized with bowhead whales in the Beaufort Sea) were adapted for study of beluga whales to determine the relative abundance of beluga whale vocalizations within the proposed deployment areas. Hydroacoustic data collected during the Project were used to characterize the ambient acoustic environment of the project site pre-deployment to inform the FERC pilot project process. The Project compared results obtained from this method to results obtained from other passive hydrophone technologies and to visual observation techniques performed simultaneously. This Final Report makes recommendations on the best practice for future data collection, for ORPC's work in Cook Inlet specifically, and for tidal power projects in general.

This Project developed a marine mammal study design and compared technologies for hydroacoustic and visual data collection with potential for broad application to future tidal and hydrokinetic projects in other geographic areas. The data collected for this Project will support

the environmental assessment of future Cook Inlet tidal energy projects, including ORPC's East Foreland Tidal Energy Project and any tidal energy developments at Fire Island. The Project's rigorous assessment of technology and methodologies will be invaluable to the hydrokinetic industry for developing projects in an environmentally sound and sustainable way for areas with high marine mammal activity or endangered populations. By combining several different sampling methods this Project will also contribute to the future preparation of a comprehensive biological assessment of ORPC's projects in Cook Inlet.

COMPARISON OF ACTUAL ACCOMPLISHMENTS WITH GOALS AND OBJECTIVES

Objectives:

1. *Develop and implement the technology to acoustically detect beluga whales by recording their vocalizations and echolocations.*

   The first objective involved the comparison of the 2009 visual observations and 2009 Team Cook Inlet Beluga Acoustics (Team CIBA) acoustic data collected from two Passive Acoustic Monitoring (PAM) devices: the Ecological Acoustic Recorders (EAR) and C-Pod (Task 1.1). It also utilized information from a Team CIBA study to design, build, calibrate and test two other PAM devices for Cook Inlet deployments: Directional Autonomous Seafloor Acoustic Recorders (DASARs) and an Acousonde (Task 1.2).

   <u>Accomplishments</u>
   The comparison of visual and acoustic data was completed, allowing an assessment of efficacy of visual observations to hydroacoustic detections by EAR and C-Pod devices.

   Greeneridge Sciences designed a custom DASAR, named the Cook Inlet DASAR. Four DASARs were built; but after a short test deployment in 2010 that included an Acousonde acoustic recorder, it was decided that the Acousonde would not be included in future deployments as battery and memory storage could not supply long-term data collection. Two DASARS were deployed at Fire Island for the overwinter time period from 2010-2011.

2. *Use paired acoustic and visual monitoring to study the baseline (pre-deployment) distribution, relative abundance, and behavior of beluga whales in the proposed tidal turbine deployment areas, near Fire Island and East Foreland, Cook Inlet, Alaska. Correlate visual and acoustic detections of whales*.

   Visual observation work at Fire Island was completed by November 2011 and totaled 122 days of visual observations between June 2009 – November 2009 and May 2010 – November 2010 (Task 2). LGL summarized the baseline distribution of beluga whales observed near the project site at Fire Island in reports (Attachment A and B).

   Visual observations continued at East Foreland in September and October 2012 and May 2013, but efforts were limited to vessel-based marine mammal observers (MMOs) monitoring PAM deployment and retrieval operations. Because of logistical challenges of shore-based observations at East Foreland and limited budget available to support these efforts through the end of the project performance period, no long-term visual monitoring were conducted at this location. During deployment and retrieval operations at East Foreland, an MMO observed several seals on each expedition but no belugas at the Project site. During a mooring inspection on April 26, 2013, ORPC personnel incidentally observed a beluga approximately one mile south of the Project site. This observation was shared with National Marine Fisheries Service (NMFS) for their Opportunistic Sightings Database.

Hydroacoustic data were collected at Fire Island utilizing EARs and C-Pods as part of the Team CIBA project as well as from two DASARs deployed with this Project. Visual observations overlapped with EAR deployment for 89 days, C-Pod deployment for 55 days and DASAR deployment for 9 days. The DASARs, EAR and C-Pod were co-deployed for 163 days. At East Foreland DASARs were the only devices deployed with no meaningful overlap with either visual observations or other PAM devices. 123 days of hydroacoustic data were recorded at East Foreland.

Accomplishments
Visual observations were successfully implemented at Fire Island and performed for 122 days. LGL completed annual final reports on the results of this data collection (Attachment A and B); these reports were shared with NMFS and are available publically at http://alaskafisheries.noaa.gov/protectedresources/whales/beluga.htm. The visual observation and hydroacoustic data collected at Fire Island were compared to each other, as well as to hydroacoustic data from PAM devices and from each PAM device to the other PAM devices. Hydroacoustic data were collected at East Foreland and successfully detected belugas there (Attachment C: Report on beluga detections at the East Foreland Project site).

3. *Determine the baseline acoustic environment of the study areas pre-deployment.*

The data from short duration and overwinter PAM deployments at Fire Island and East Foreland were analyzed to assess the ambient acoustic environment. A unique feature of the DASARs was the utilization of three hydrophones within each DASAR allowing removal of "pseudo-noise" contamination, potentially enabling more accurate measurements of ambient sound than recording devices equipped with only a single hydrophone (Attachments C and D).

Accomplishment
Ambient sound was characterized at East Foreland and Fire Island, with and without pseudo-noise removed, to compare the efficacy of this method and enhance the rigor of ambient sound data collected with a stationary hydrophone system.

4. *Provide recommendations on best practice for collecting data on beluga marine mammal occurrence in Cook Inlet for future data collection and project monitoring efforts.*

Through this Project, ORPC gained experience working at two distinct sites utilizing two entirely different modalities (visual and hydroacoustic data collection) and several different PAM technologies (EAR, C-Pod and DASAR). This experience allowed ORPC to compare and contrast different data collection techniques, technologies, and data analysis methods.

Accomplishment
Comparison of data collected concurrently between visual and hydroacoustic data (EAR and C-Pod) highlighted that each technique was effective in detecting belugas at different times and at different ranges from the project site, showing the relevance of each technique. Analysis of data from the different hydrophone types showed a striking difference between the detections from a device that targets echolocations (C-Pod) from devices that target the frequency of social vocalizations (EAR and DASAR) and showed that collecting data on these two different hydroacoustic signals from beluga whales added value to understanding belugas' use of a given habitat. Comparison of devices targeting social vocalizations showed a tendency for continuous recording over a limited frequency range (DASAR) to be more effective in detecting belugas than a duty-cycled device with a wider frequency range (EAR). Ambient sound characterization was successfully performed utilizing a stationary PAM device - the DASAR - and included filtering some pseudo-noise out of the data to provide a more robust representation of actual ambient sound conditions.

SUMMARY OF PROJECT ACTIVITIES

Original Hypotheses
The Project proposed adapting the use of passive hydroacoustic devices and visual observations to determine both relative abundance and location of beluga whale vocalizations at proposed deployment areas of tidal energy devices and comparing the efficacy of each method for rigorous data collection to allow comparison of beluga use of an area before and after the deployment of tidal energy devices.

Approaches Used
Several data collection approaches were used including visual observations as well as hydroacoustic measurements utilizing three different types of PAM devices: EARs, C-Pods, and DASARs.

Visual observations
Visual observations were the most established and utilized method for collecting data on beluga occurrence in Cook Inlet when this Project began. Typically, visual observations were made from relatively long detection ranges and from a good vantage point. By using this approach, data collected for this Project could be compared with data collected at other project sites. There were, however, several disadvantages of visual observations: (1) observations were limited to daylight hours, (2) there were seasonal limitations due to inclement weather in fall, winter and

spring, (3) ice floes impeded effective visual observations, and (4) there were limits in duration of effective continual observations due to observer fatigue.

Visual observations of the presence, abundance, and surface-behavior of beluga whales and other marine mammals were conducted by trained observers stationed on a tower atop a cliff 64.5 m (212 ft) above the Mean Low Water line overlooking the proposed Deployment Area. Observers surveyed for belugas from land (at the observation site), as well as from the air during flights to and from Fire Island. Observations were also conducted from a research vessel used to transport observers to and from Fire Island on a few occasions and from the deployment and retrieval vessel used for PAM device operations at Fire Island and East Foreland.

Land-based observers used hand-held binoculars, spotting scope, a survey grade theodolite, and the naked eye to search for belugas in the proposed Deployment Area and surrounding areas as far as the Susitna River and Point MacKenzie. Beluga locations were recorded in two ways: (1) by using a 500 m x 500 m (1,640 ft x 1,640 ft) grid-cell map of the field of view and, (2) using a theodolite and software combination. See Figure 1 for the field of view of visual observers at the Fire Island observation site.

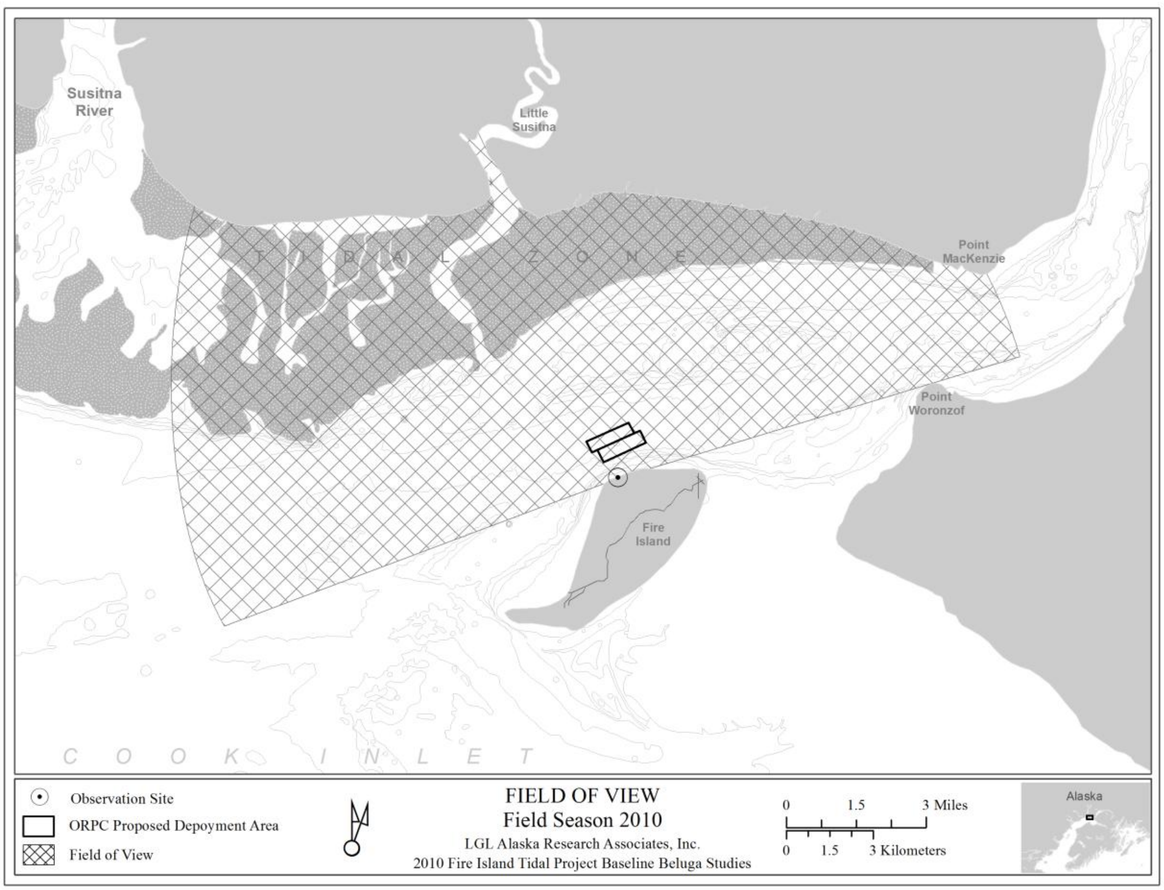


Figure 1. The maximum field of view as seen from the observation tower and measured with the theodolite. The Deployment Area may be subject to change upon further development of the Project.

For this Project visual observations were performed for a total of 122 days at Fire Island. This included concurrent observations with 89 days of EAR deployment, 55 days of C-Pod deployment and 9 days of DASAR deployment. Because the overlap with DASAR data collection was not significant, the focus of comparison with PAM data collection was on the concurrent observations with EAR and C-Pod deployments. Overall visual observations detected beluga whales on 48 of the 122 days or 39% of the time. During the times of concurrent deployment, visual observations proved effective detecting whales on 33 days when they were not acoustically detected by the EAR and 13 days they were not detected by the C-Pod. By comparison there were 4 days when the C-Pod detected whales that were not visually observed and 4 days in which the EAR detected whales that were not visually observed, while there were 11 days of concurrent detections between visual observations and PAM detections. The larger amount of visual observations as compared to PAM detections may largely be due to the greater range of detection, up to 7 km, as compared to an assumed (but not measured) range of approximately 1.5-3 km for the EAR and 1 km for the C-Pod. However, there were 7 occasions when visual observations were made within 4 km of the PAM devices that were not acoustically detected; two of which were a single beluga whale less than 1 km away from the PAM devices. It is possible that this indicated a lack of frequent vocalizations for solitary beluga whales or small groups.

Visual observations were demonstrated to be an effective means to augment hydroacoustic data as they clearly enhanced the understanding of beluga use of an area, particularly by extending the observation field to a larger area but also by detecting whales that may not be engaged in vocalizing. Data on whales over a wide spatial range from the Project could help estimate at what range behavioral responses (if any) to a project might be noticed.

<u>Hydroacoustic data collection</u>

Three different PAM technologies were utilized at Fire Island and one at East Foreland.

Two DASARs manufactured by Greeneridge Sciences, one Ecological Acoustic Recorder (EAR) from Oceanwide Science Institute, and one C-Pod manufactured by Chelonia Ltd. were deployed at Fire Island (Figure 2), whereas two DASARs were utilized at East Foreland. Each of these devices has specific capabilities and limitations based on the nature of the deployment configurations required for long-term autonomous deployment in Cook Inlet. Table 1 outlines the specifications of each device as they were configured for deployment in Cook Inlet. Of key importance in distinguishing the capabilities of each device was the frequency range over which they each sample sound. The DASAR had the lowest frequency range sampling from 100 – 2250 Hz, which only covers the lower portion of the beluga whale vocalization spectrum. However, due to the lower sample rate, it is able to record continuously during long-term deployment. The EAR samples sound from 1000 - 12,000 Hz, covering nearly the entire range of beluga vocalizations. But due to the higher sample rate, it must be duty-cycled to only record 10% of the time to conserve limited hard drive and battery storage during long-term deployments. The C-Pod sampled the highest frequency range of the devices from 20,000 – 160,000 Hz and covered the range of echolocation clicks used by beluga whales. While the C-Pod is able to monitor continuously over this range during long-term deployments, it is designed to process the sound data onboard and only logs detections rather than recording the acoustic signals themselves, thus allowing it to conserve hard drive space over long term deployments. This analysis compared the efficacy of these different PAM devices as they were configured for long-term deployment in Cook Inlet and for efficacy in detecting beluga whale vocalizations at potential tidal energy sites in Cook Inlet.

Figure 2. Cook Inlet DASAR and mooring frame, left. Ready for deployment onboard vessel, right.

Table 1. *Fire Island data collection and analysis*

Device	**Sampling**	**Range of Sound**	**Mode**	**Target**
DASAR 101 and 103	Continuous	100 - 2,250 Hz	Recording	Beluga vocalizations; ambient sound levels
EAR	Duty cycled to record 10% of the time, 30 seconds every 5 minutes.	1,000 and 12,000 Hz	Recording	Beluga vocalizations
C-Pod	Continuous	Up to 160,000 Hz	Detection logging	Beluga echolocations

For purposes of comparison the Fire Island deployment was the main focus, as co-deployment of the devices allowed comparison of their efficacy in detecting beluga whales. Between November 13, 2010 and April 24, 2011 two DASARs were deployed north of Fire Island in northern Cook Inlet, Alaska, near ORPC's proposed deployment area for a tidal energy project. Deployment required a Land Use Permit from the Alaska Department of Natural Resources (LAS 27690). The DASARs (SN 101 and 103) continually sampled for sounds over the 163 days of deployment to collect data on beluga vocalizations near the project area and ambient sound levels in Cook Inlet. At the same time a mooring containing an EAR (vocalizations) and C-Pod (echolocations) were operating in the same vicinity with the C-Pod. The EAR was configured for duty-cycling recording 10% of the time, 30 seconds every 5 minutes. The C-Pod continuously sampled for echolocations and data logged detections after on-board processing, but did not store sound files. These PAM devices were all located within 700 m of one another, with DASAR SN103 and the EAR/C-Pod mooring within 300 m of one another (Figure 3). The data were processed from DASAR SN103, the EAR and C-Pod for the 163-day period of co-deployment in order to compare the efficacy of each device for detecting belugas in the project area and to gather baseline information on frequency and seasonality of beluga occurrence at the project site.

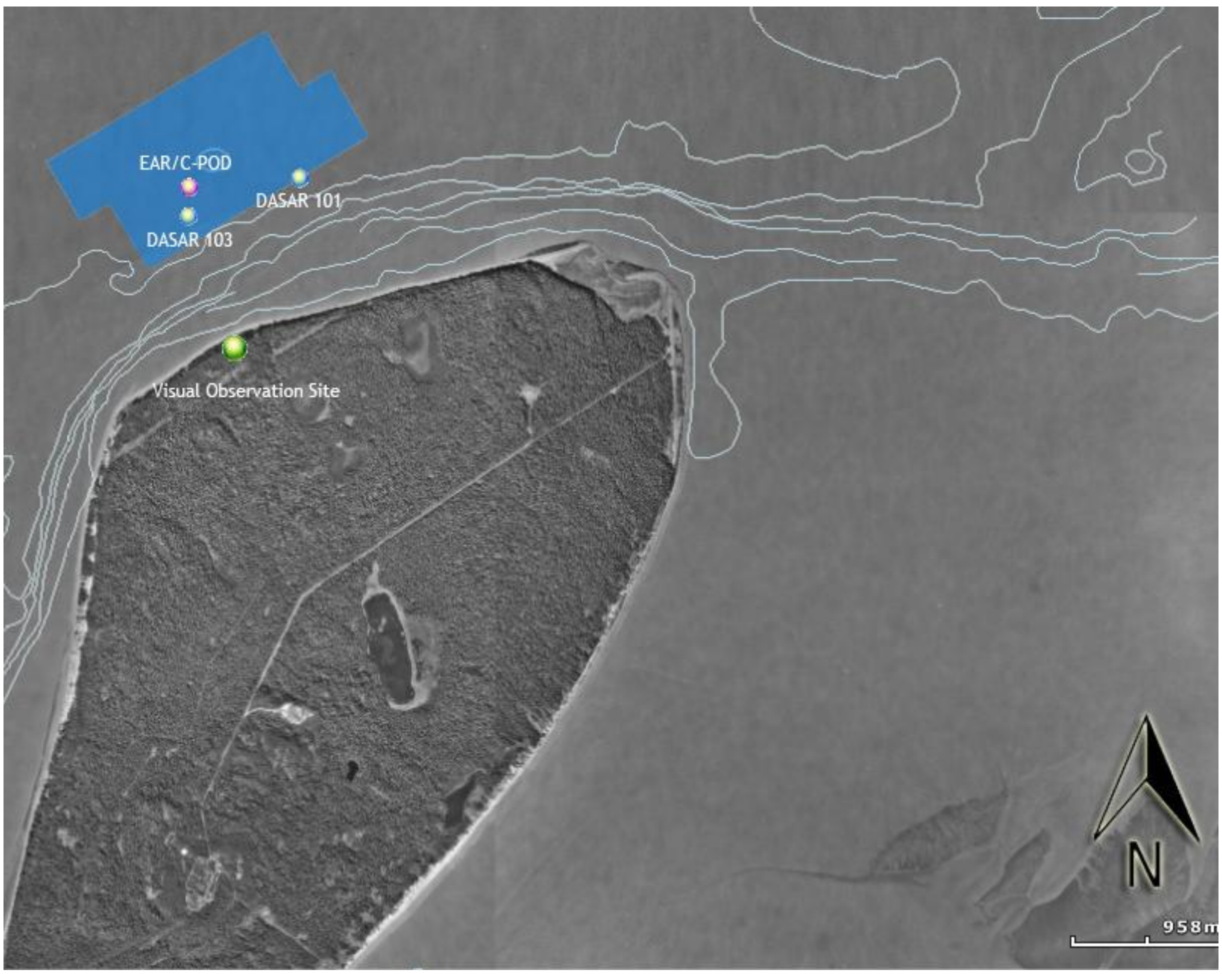


Figure 3. Relative location of the EAR/C-Pod and DASAR moorings, as well as the visual observation tower.

Belugas were detected hydroacoustically in all months near the Fire Island Project site. The EAR detected beluga vocalizations in November, March and April, while the DASAR and the C-Pod detected vocalizations and echolocations, respectively, in all months of deployment. Figure 4 displays the total days per month containing detections of beluga whale vocalizations or echolocations per month for each device. Figure 5 shows the total number of detections per month, while the total duration of detections per month is displayed in Figure 6. It should be noted that the classification of detections and detection time was based on how the data from the EAR were analyzed and presented to ORPC. The EAR data analysis classified detection as a single continuous detection if a subsequent beluga call was heard within one hour of the previous beluga call. If more than one hour elapsed it was classified as a new detection, to which the same rule applied: if yet another call was heard within one hour it was classified as continuous. The duration of the detection also had to be classified; thus two beluga calls less than 60 minutes apart constituted a continuous detection. The data from the other devices were normalized to this classification in order to allow comparison, although the data from the C-Pod and DASAR allowed for more finer-scale analysis.

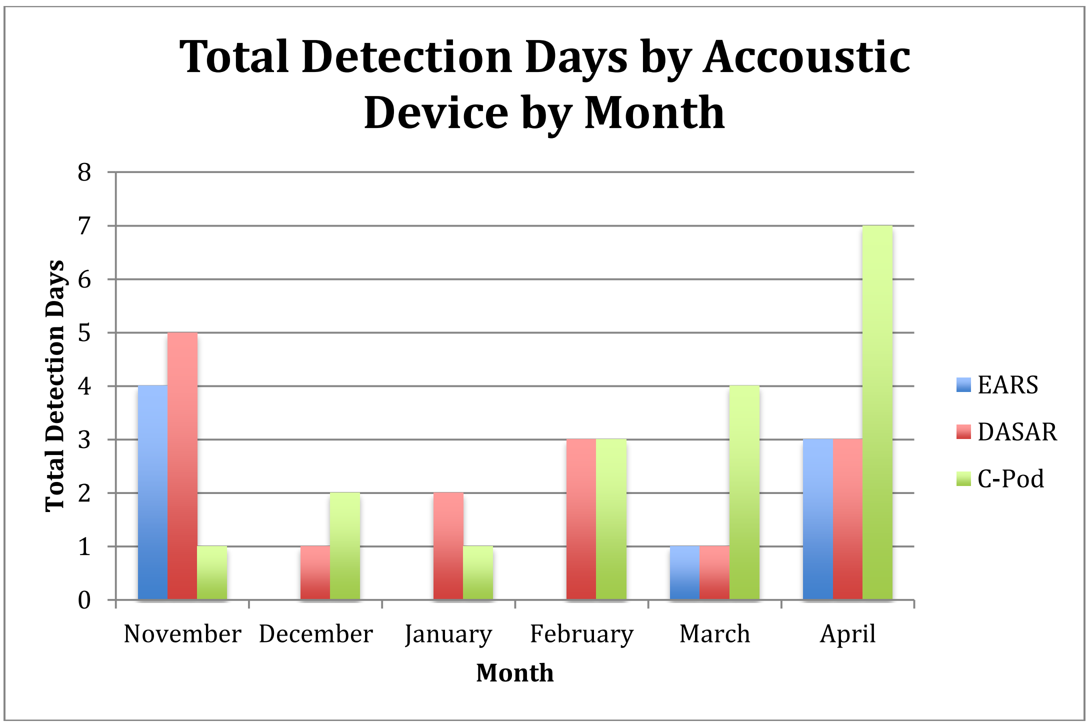


Figure 4. The number of days with detections by month for each PAM device recording at Fire Island between November 13, 2010 and April 24 2011.

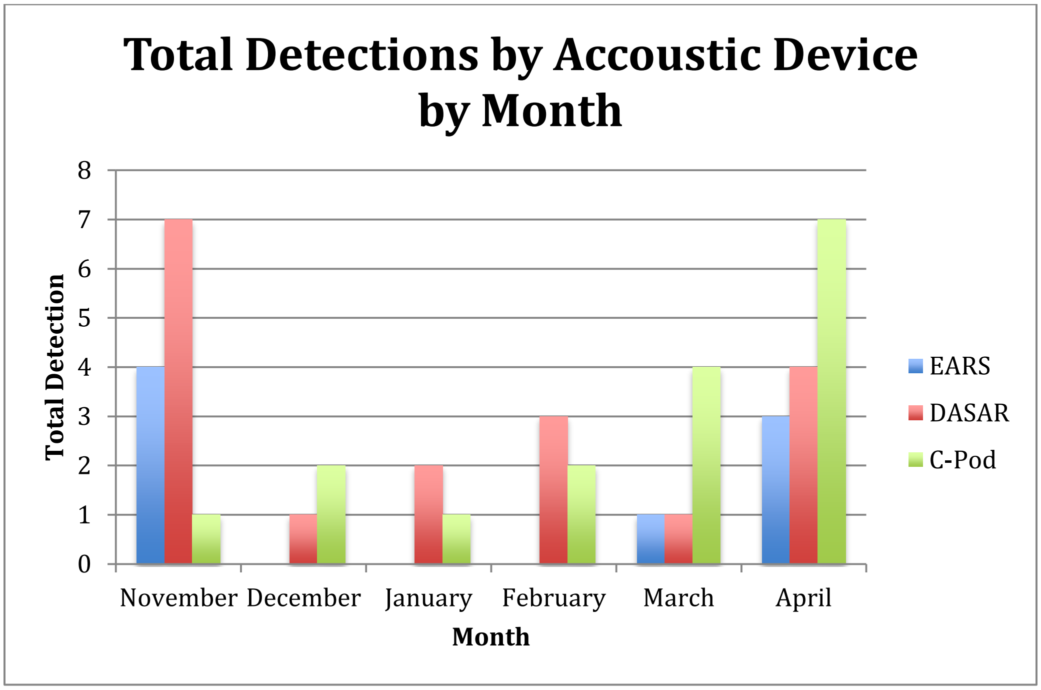


Figure 5. Total number of detections per month by device for each PAM device recording at Fire Island between November 13, 2010 and April 24 2011. A single detection was defined as one beluga detection with no further detections within one hour. If another detection was encountered within one hour, it was included as the same detection until at least one hour elapsed with no detection.

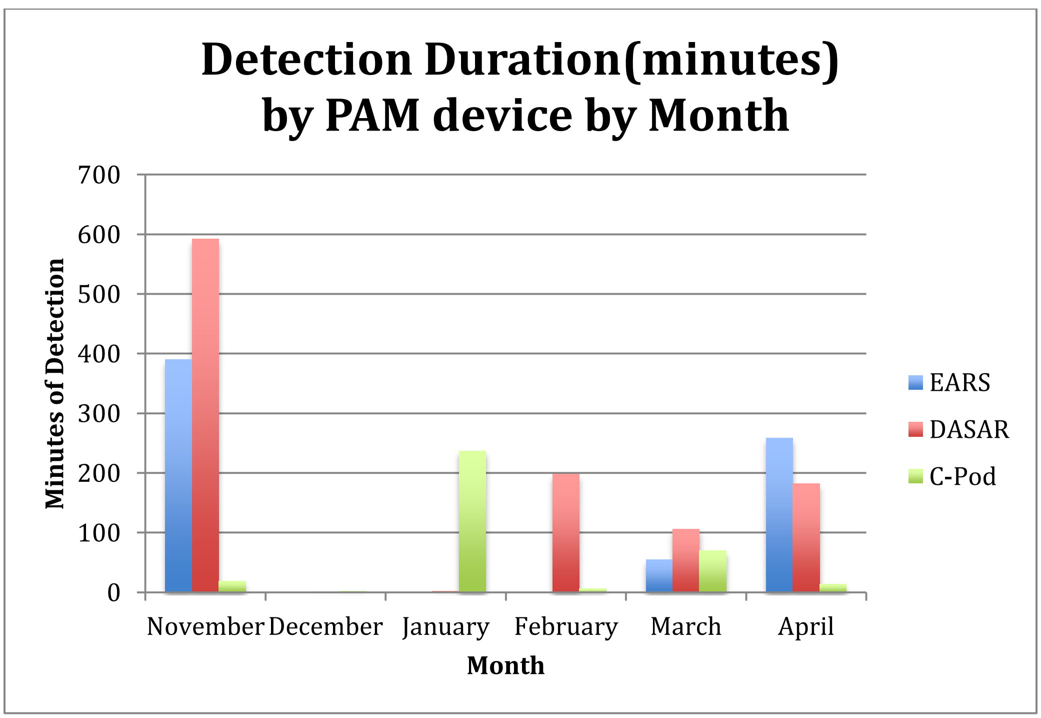


Figure 6. Total detection time by device for each PAM device recording at Fire Island between November 13, 2010 and April 24 2011. Detection time was classified similar to the total number of detections where subsequent detections within one hour of one another were classified as continuous detections. * Note: It is difficult to see due to scale, but DASAR had 1 minute of detections in December and 2 minutes in January, C-Pod had 2 minutes of detections in December and 6 minutes in March.

The C-Pod detected belugas on 17 (10.5%) of 163 days of co-deployment with the DASAR (Table 2). The DASAR had positive beluga detections on 15 (9%) of the days, and the EAR made detections on 8 (5%) of the days. There was one day the EAR detected a beluga, and the DASAR did not. However, the DASAR made detections on 8 days when the EAR did not. The C-Pod had lower levels of correspondence with the other two devices than they had with each other, detecting beluga whales on only 4 days concurrently with the EAR and 3 with the DASAR (Table 2). This may be because the C-Pod sampled for echolocation sounds while the EAR and DASAR sampled for vocalization sounds.

Table 2. *Number of days with concurrent detection by each PAM device at the Fire Island site*

Same Day Device Detection (11/13/2010 - 4/24/2011)			
	EARS	**C-Pod**	**DASAR**
EARS	8 days	4 days	7 days
C-Pod		17 days	3 days
DASAR			15 days

Concurrent detections

On limited occasions there were true concurrent detections by the different devices. The EAR and DASAR, for example, detected belugas concurrently four times. However, due to the fact that EAR data as delivered to ORPC was only presented on an hourly basis, rather than indicating exact times of beluga call detections, it is impossible to tell if there were detections at the exact same moment, indicative of the same call being recorded by both devices. The DASAR and C-Pod detected belugas simultaneously on two occasions – November 28, 2011 from 8:44 - 9:03 and March 26, 2011 from 22:09 - 22:10. On no occasions during the 163 day deployment period did the EAR and C-Pod detect belugas simultaneously.

East Foreland data collection and analysis

A single DASAR was deployed for a one-month test deployment at East Foreland on September 26, 2012, and successfully recovered on October 21, 2012. Following the recovery on October 21, 2012, two DASARs were deployed the same day for the overwinter time period. Due to challenging environmental conditions at the site, only one DASAR was recovered in June 2013.

The recovered DASAR showed significant damage, and had stopped recording acoustic data on January 27, 2013. Between both deployments, a total of 123 days of data were successfully collected and analyzed for beluga detections.

Figures 7, 8, and 9 show the analysis of beluga vocalizations recorded near the East Foreland site. Successful data collection included 5 days in September, all of October, November, and December, and the first 27 days of January. While this limited data set does not provide a complete picture of beluga use of the area, detections in November, December, and January confirmed beluga presence at those times. Long detection durations in December may be indicative of more intensive use of the area during that month. As no data existed on beluga use of this area in the overwinter time period, this data was invaluable in confirming the presence of beluga whales near the Project site during mid-winter months.

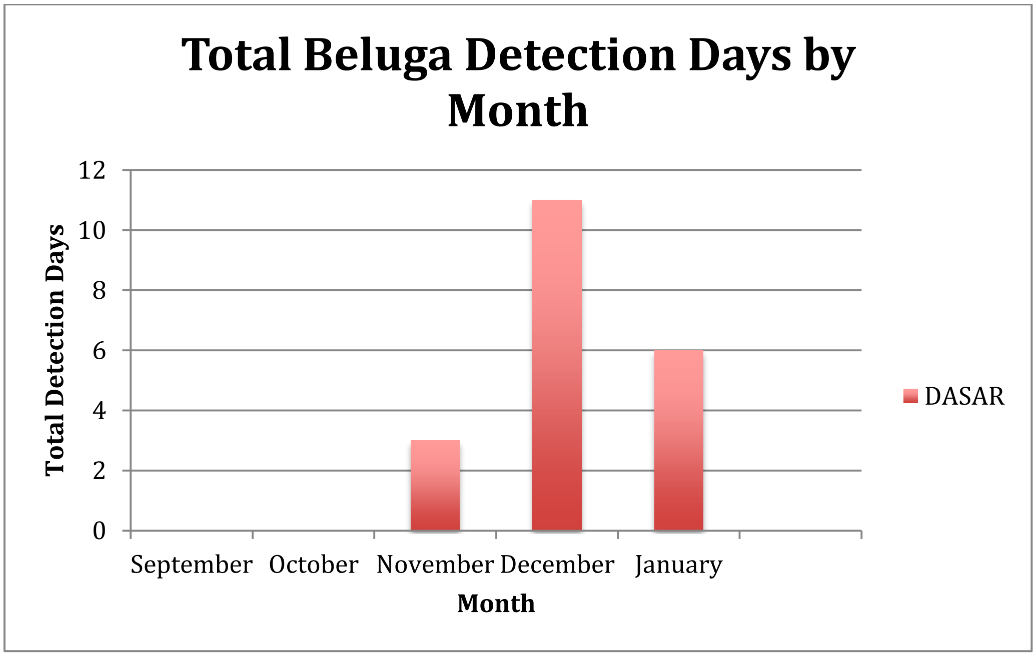


Figure 7. The number of days with detections by DASAR at East Foreland from Sept 21 2012-January 27 2013. Note - September only included 5 days of monitoring and January included 27 days of monitoring,

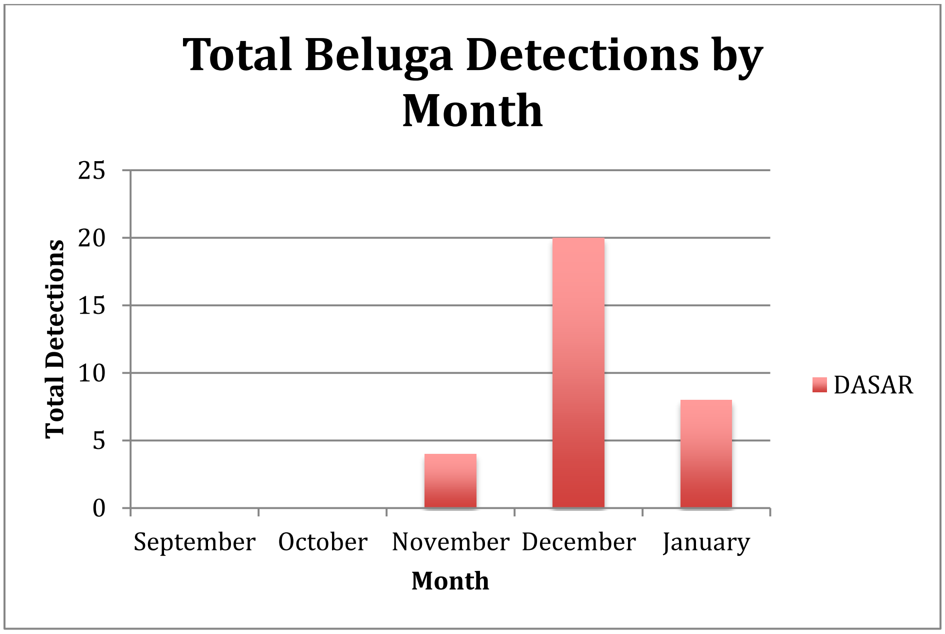


Figure 8. Total number of detections per month by DASAR deployment at East Foreland from Sept 21 2012-January 27 2013. A single detection was defined as a beluga detection with no further detections within one hour. If another detection was encountered within one hour it was included as the same detection until at least one hour elapsed with no detection. Note: September only included 5 days of monitoring and January included 27 days of monitoring.

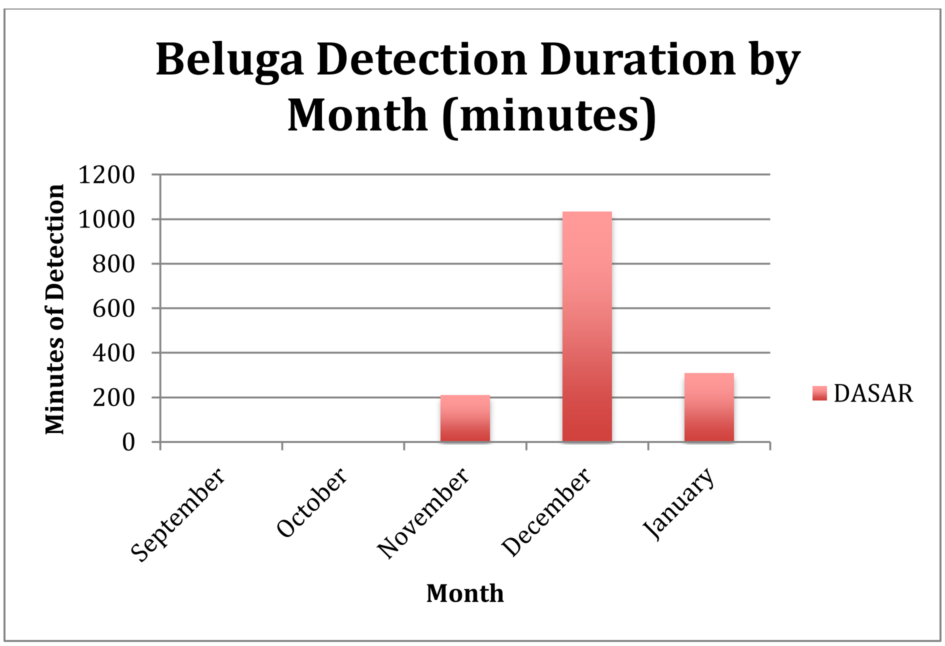


Figure 9. Total detection time by DASAR deployment at East Foreland from Sept 21 2012-January 27 2013. Detection time was classified similar to the total number of detections where subsequent detections within one hour of one another were classified as continuous detections. Note: September only included 5 days of monitoring and January included 27 days of monitoring.

Ambient Sound data collection and analysis
Characterizing the ambient acoustic environment of a potential tidal energy site, both before and after project deployment, is an important component of successful permitting of a tidal energy project. Conducting this characterization is challenging because the natural acoustic environment of high-energy tidal sites can at times exceed harassment thresholds for marine mammals established by NMFS as 120 dB @ 1 μPa for continuous noise, complicating the ability to measure and understand if a tidal energy device itself is contributing to this harassment level of sound. Furthermore, anthropogenic underwater noise can further exacerbate this problem and make it difficult to differentiate noise produced from a tidal energy device from an already noisy ambient environment. For instance, at the East Foreland site during a one-month test deployment, vessels were detected in the recordings on every day but one day, and airguns used for seismic exploration were detected on four days, approximately 3% of the time. The problem is further complicated by the logistical difficulties of accurately measuring sound in areas of strong tidal currents due to self-noise (e.g., cable strum or resonance of device cavities) or pseudo noise (e.g., noise generated by turbulent water flowing by the hydrophone). Several methods have been investigated to mitigate this latter noise contamination effect. One method utilized by ORPC in Maine involved using a Drifting Noise Measurement System (DNMS) that allowed the hydrophone to float by the site with the tidal currents, eliminating current-induced noises. The method investigated here involved utilizing the inherent design advantage of the DASARs for Cook Inlet to mitigate noise contamination.

In the Cook Inlet DASARS, the acoustically-transparent ABS plastic shroud provided physical protection against debris and reduced flow noise at the hydrophone heads. In addition, multiple hydrophones within the DASAR enabled further reduction in pseudo-noise contamination in post-processing by exploiting the spectral coherence between two hydrophones to identify pseudo-noise contamination (Deane 2000)[i] and then applying a correction to sound pressure spectral density levels using the coherence estimate (Buck and Greene 1980).[ii] These methods allowed a more rigorous assessment of ambient acoustic levels from a stationary device while providing long-term data collection of ambient sound levels.

For analysis purposes, the acoustic data set was "sampled" at the first 60 s of every 128 MB file, or about once an hour. The sampled data was then analyzed using spectral estimation, and then pseudo noise was removed utilizing the aforementioned spectral coherence method. After analyzing the data from Fire Island and East Foreland utilizing this method, there was an average decrease in ambient sound levels of 3.3–3.9 dB at Fire Island and 2.3 dB at East Foreland compared to the same sound levels before the pseudo noise was diminished utilizing spectral coherence methods.

Figure 10 shows the percentile sound spectral density without pseudo noise removed from overwinter data collected at East Foreland, and Figure 11 shows the same data with pseudo noise removed utilizing this method. In both spectrograms, peak sound levels around 260 Hz and 620 Hz were likely induced by resonance associated with the cavity of the DASAR itself, a sound contamination that could not be removed by the spectral coherence method since the sound was correlated on all hydrophones. Figure 12 and Figure 13 show the same data analyzed in one-third octave band levels again with and without pseudo-sound removed, respectively. It is clear, particularly around the 50% percentile (i.e., 50% of the time), that this method noticeably reduced reported ambient sound levels. Utilizing this technique to remove some of the pseudo-sound contamination not only provided a more rigorous assessment of ambient sound levels, but also enhanced the possibility of detecting low signal-to-noise level marine mammal calls within the frequency of interest for marine mammal detection. For a more detailed description of the analysis of ambient sound levels at Fire Island and East Foreland, see Attachments C and D.

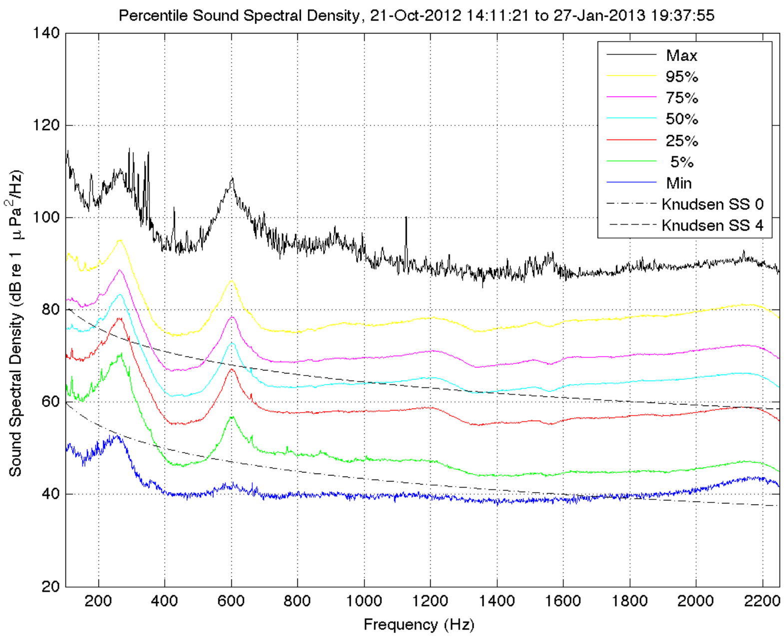


Figure 10. Percentile sound pressure spectral density levels measured by DASAR SN101 over the overwinter deployment period October 21, 2012 – January 27, 2013 at the East Foreland site.

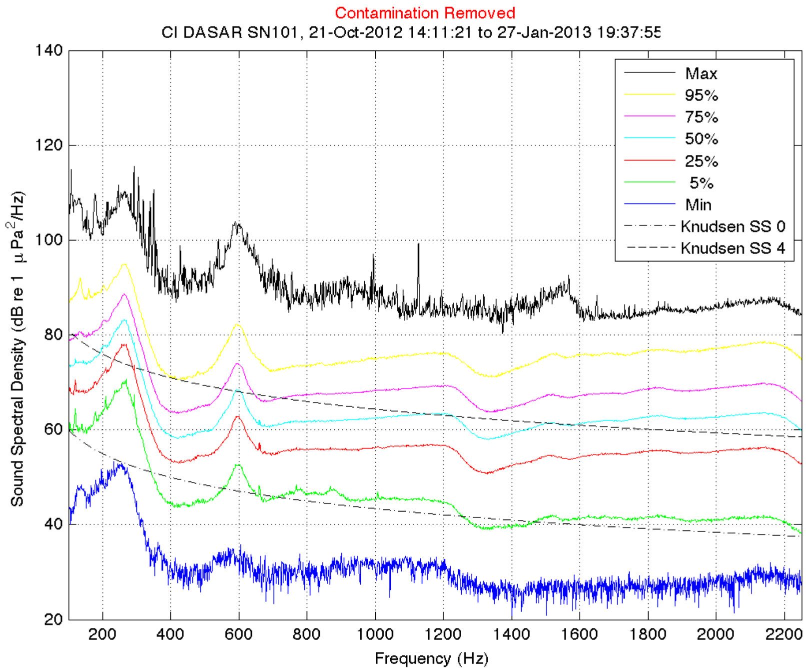


Figure 11. Percentile sound pressure spectral density levels measured by DASAR SN101 over the overwinter deployment period October 21, 2012 – January 27, 2013 at the East Foreland site with pseudo-sound noise contamination removed.

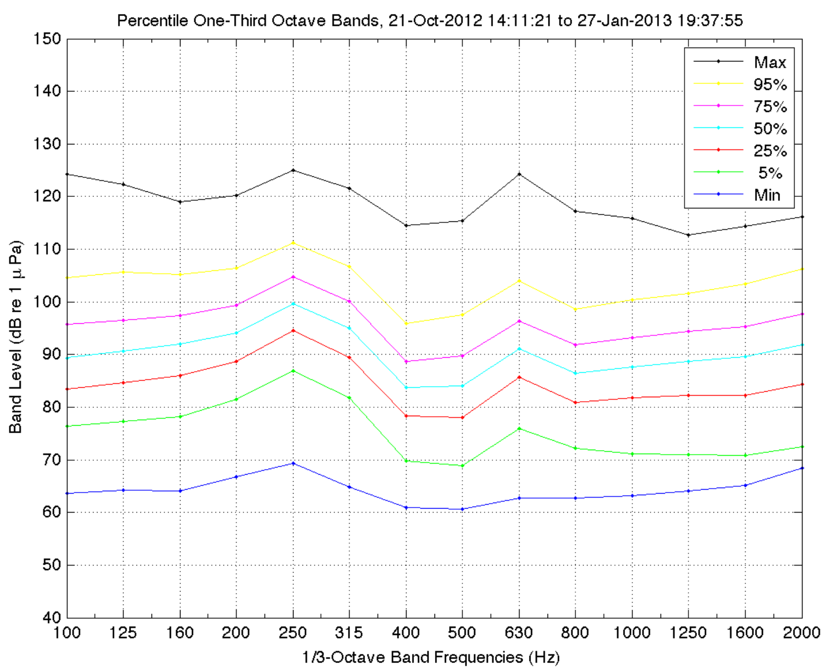


Figure 12. Percentile one-third octave band levels measured by DASAR SN101 over the overwinter deployment period October 21, 2012 – January 27, 2013 at East Foreland.

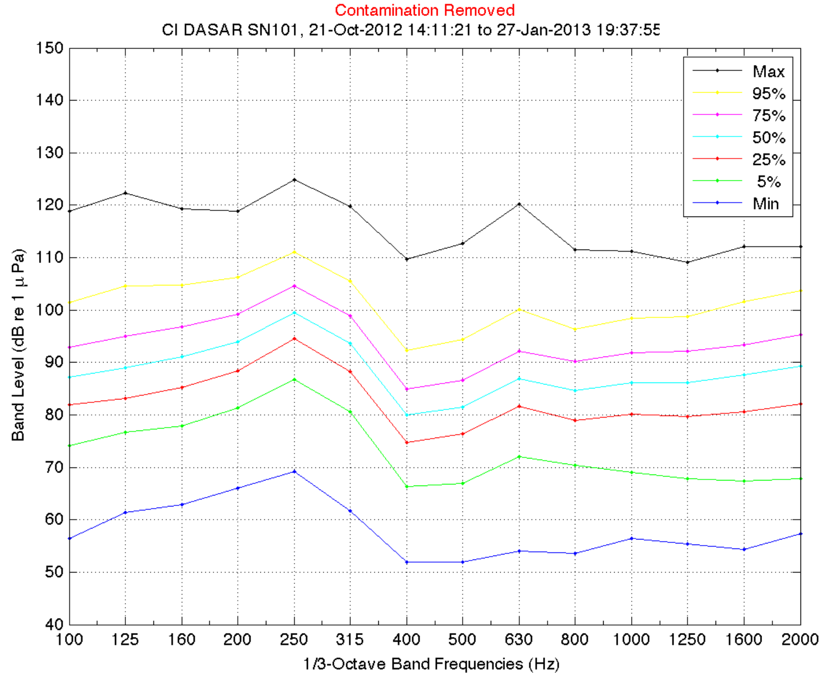


Figure 13. Percentile one-third octave band levels measured by DASAR SN101 over the overwinter deployment period, with pseudo-sound noise contamination removed October 21, 2012 – January 27, 2013 at the East Foreland site.

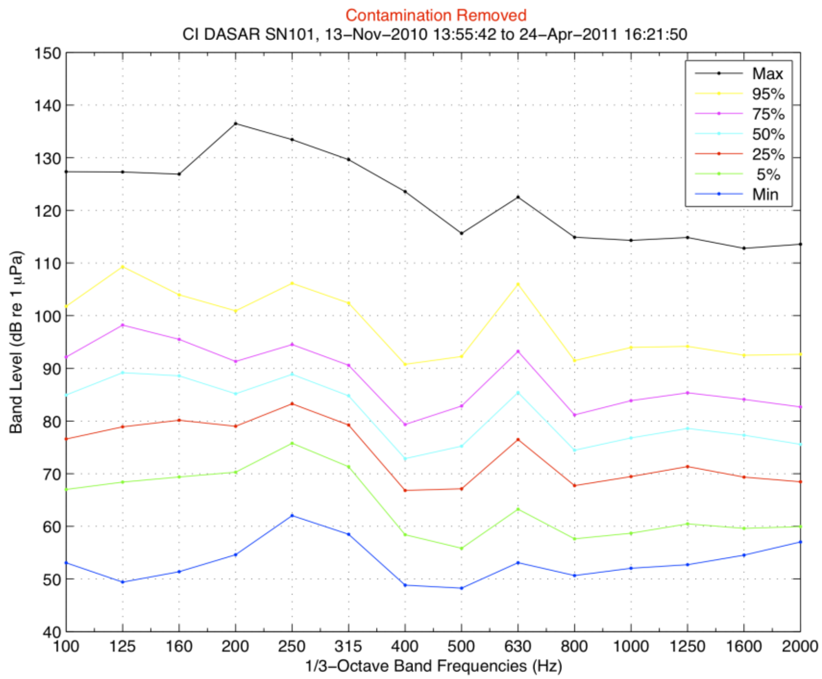


Figure 14. Percentile one-third octave band levels measured by DASAR SN101 over the overwinter deployment period, with pseudo-sound noise contamination removed November 13, 2010 – April 24, 2011 at the Fire Island site.

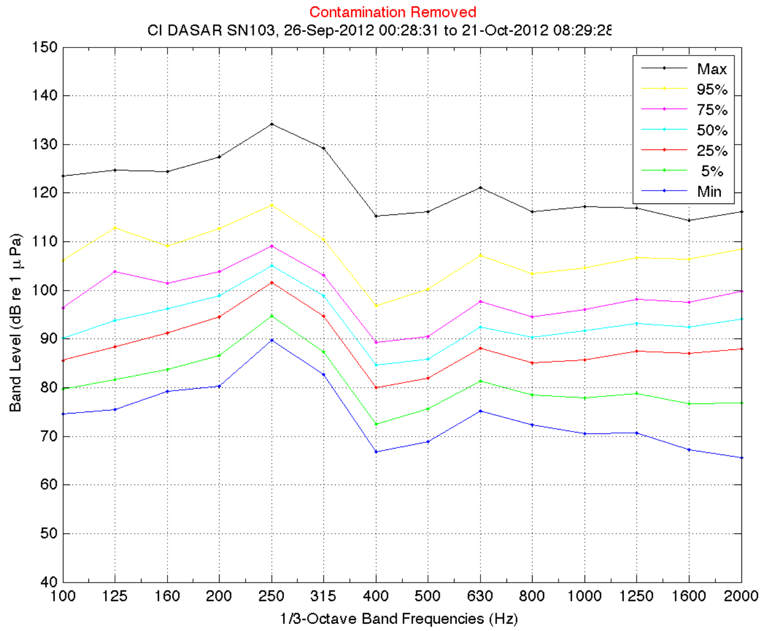


Figure 15. Percentile one-third octave band levels measured by DASAR SN103 at the East Foreland site from September 26, 2012 – October 21, 2012 with pseudo-sound noise contamination removed.

The relatively long data sets from each over winter deployment allow some measure of confidence that ambient sound levels were well characterized for ice-free and winter ice conditions. Short-term deployments in the fall at each site also provided further information at times when anthropogenic sounds were more prevalent.

Comparison of the longer term overwinter data from East Foreland to Fire Island (Figure 13 and Figure 14) showed that maximum sound levels were higher at Fire Island, while average sound levels were 10 dB to 20 dB higher at East Foreland than at Fire Island.

Maximum (100%) sound levels hovered around the 120 dB threshold at the East Foreland site for frequencies between 100 Hz and 300 Hz, with a 120 dB peak occurring near 630 Hz (likely due to the aforementioned DASAR cavity resonance), while median (50%) levels varied between 80 dB and 100 dB over the 100–2000 Hz frequency range that was measured. At Fire Island, maximum (100%) sound levels exceeded the 120 dB threshold between 100 and 450 Hz with a peak at 630 Hz and the maximum peak over 130 dB, while median levels (50%) ranged between 75 and 90 dB over the entire 100–2000 Hz frequency range that was measured. This data suggests that either extreme tidally-induced sounds or anthropogenic sounds skewed maximum sound levels at Fire Island, while the stronger current velocities at East Foreland led to higher overall ambient sound levels. Interestingly, at East Foreland, the shorter term data set collected between September 26, 2012 and October 21, 2012 also showed higher maximum sound levels (100%) and slightly higher average (50%) sound levels than the long-term data set at the East Foreland site. Again, this could be due to several factors, including anthropogenic sounds (such as increased human activity around East Foreland during the ice-free season compared to months with heavy ice) or possibly differences in the acoustic environment where the short-term deployment was located versus the long-term deployment that was 1 km further north. Unfortunately, an analysis of the maximum received sound levels and their specific sources was not possible under the scope and budget of this project, but it is likely that the peak levels experienced at both sites were comprised of natural tidally-induced noise and anthropogenic sounds. Figure 15 shows the correlation between the peak received sound levels recorded by DASAR SN101 deployed at Fire Island between December 5, 2010 and December 7, 2010 compared to predicted tidal flows at that time. The strong correlation between sound levels and tidal flows was evident here. Similarly, Figure 16 showed a relationship between predicted tidal heights and received sound level of DASAR SN 103 deployed at East Foreland between September 26, 2012 and October 21, 2012. Peaks in this data can be seen increasing to above the 120 dB level at times of peak tidal exchange within the deployment month. As illustrated in Figure 17, some anthropogenic sources at East Foreland were also identified that contributed to maximum sound levels; in this case, vessel noise and airgun seismic surveys, although an in-depth analysis of peak received levels from these sources and how they ultimately impacted overall ambient sound levels were not completed under this Project.

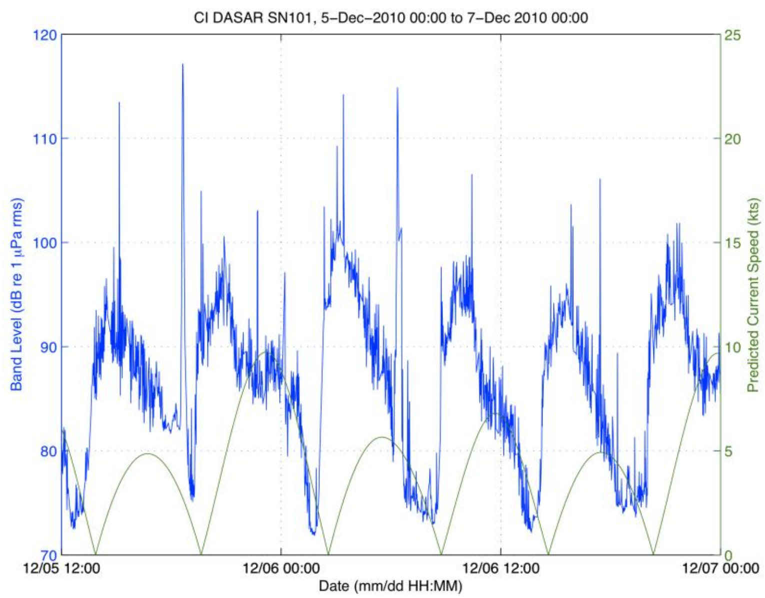


Figure 15. Band level (blue) and tidal current (green) as a function of time for DASAR SN101 deployed at Fire Island for the two-day period of December 5–7, 2010.

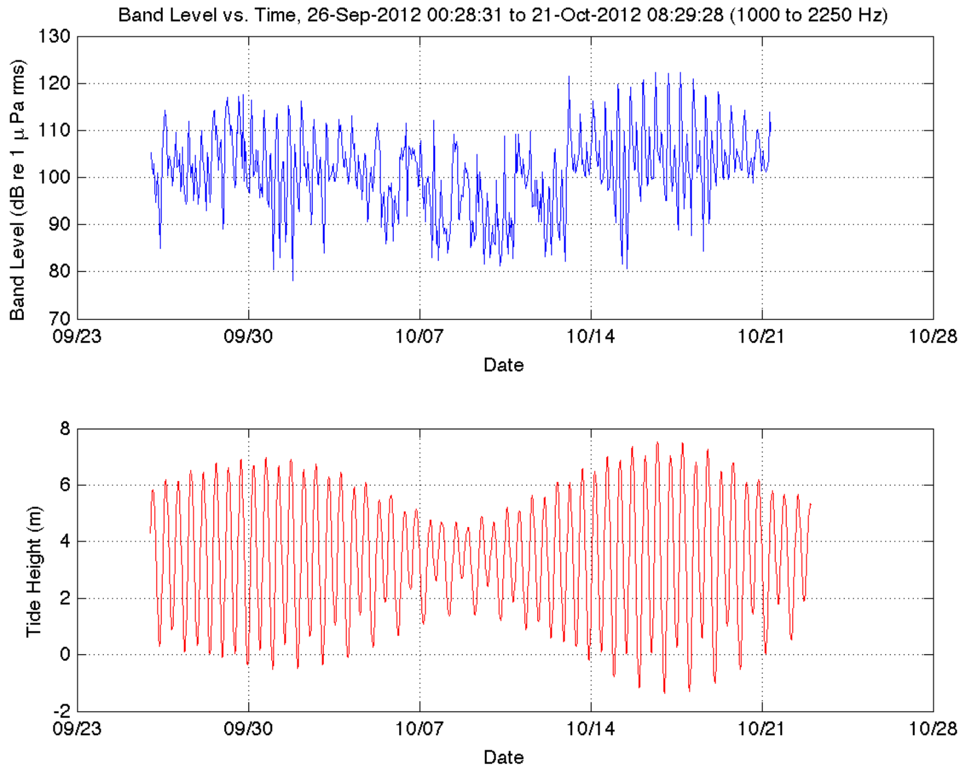
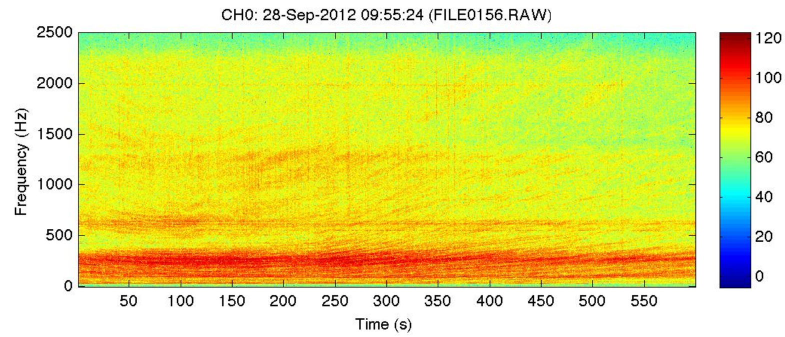
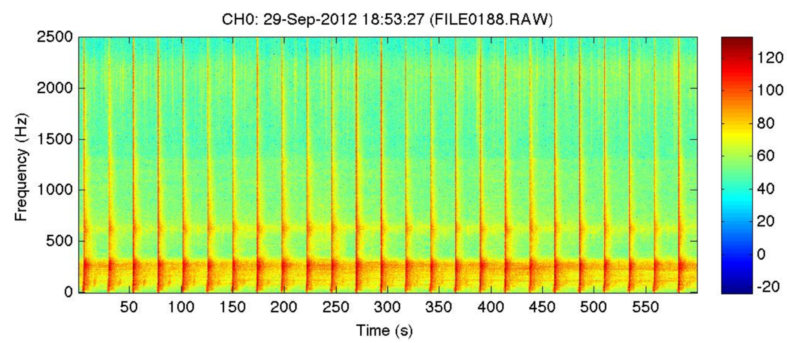


Figure 16. Band level for DASAR SN103 deployed at East Foreland between September 26, 2012 and October 21, 2012 (blue, upper plot) and tidal height (red, lower plot) as a function of time across the one-month test deployment period.



(a) Vessel noise



(b) Impulsive noise (airguns)

Figure 17. Anthropogenic sound sources at East Foreland recorded by DASAR SN103 in September 2012

Problems Encountered

ORPC overcame and adapted to several unforeseen challenges to achieve success in completing the Project objectives:

- Logistical challenge of performing visual observations at remote locations
- Challenges with reliable long-term deployment and successful retrieval of PAM devices
- Analysis of large amounts of data
- Difficulties in successfully using a new design of DASAR to localize beluga calls

Visual observation logistics

Difficulties in performing visual observations at Fire Island included getting observers out to the remote site and positioning them at a vantage point with an adequate field of view. To accomplish this ORPC and LGL organized a charter flight service to fly observers to and from Fire Island on a daily basis and established an overnight camp in case weather or daylight conditions made flying back on the same day imprudent. This arrangement included a mile long walk to the observation site each day and proved effective for the duration of the Project allowing 122 days of successful visual observations to be performed. To allow observations to be effective and not inhibited by vegetation or landscape interference, a site was chosen atop a bluff overlooking the Project site, and a tower was erected to elevate the observers to sufficient height. This provided observers with an ample field of view to observe the project site (see Figure 1 and Attachments A and B for a detail of the field of view). Construction and placement of a tower required a Land Access Permit from the U.S. Coast Guard (License HSCG-Z71117-09-RP-054L).

PAM device deployment and retrieval at sites with strong tidal currents
Deployment and retrieval of scientific equipment moored in Cook Inlet has long been a challenge. The request from NMFS that data be collected throughout the year establishing presence or absence of beluga whales within the Project areas required that PAM devices be in place and recording throughout the winter. Due to heavy ice floe activity in Cook Inlet during winter months from November to April that precluded small vessel operations for recovery or deployment of PAM devices, the PAM device deployments had to last up to 6 months, further complicating this challenge.

Based on experience from deployments of other scientific equipment and acoustic recorders in Cook Inlet and the deployment and retrieval of DASARs in the Beaufort Sea, the Project team chose to use redundant recovery methods for the DASARs deployed at Fire Island that included an acoustically-releasable pop-up buoy as well as a ground line attached to an auxiliary anchor that could be grappled in the case that the pop-up buoy retrieval failed. This approach proved prudent as the pop-up buoy mechanism on both DASARs failed when excessive abrasion of the chains that attached the pop-up buoys to the DASAR moorings caused the chains to part and the buoys to be lost during the course of the overwinter deployment. Fortunately, grappling for the ground lines proved successful, though challenging and time-consuming. Both DASARs were eventually recovered by this method although the ground lines sustained significant damage during the duration of the deployment due to abrasion with the seafloor. Grappling may not have been a viable recovery mechanism at a more energetic site or over a longer deployment.

Based on experience with the deployment of other scientific equipment at the site, ORPC knew that the site was highly energetic with a challenging bottom that included numerous boulders that would make the pop-up buoys and ground lines likely ineffective for overwinter deployments. The Project team redesigned the recovery system to utilize an abrasion resistant steel cable tethered to a permanent anchor at the MLLW line to allow the line to avoid abrasion and interactions with winter ice as much as possible and to be recoverable from shore at extreme low tides. However, over the course of the winter, the steel cable attached to each DASAR parted, and the recovery crew resorted to grappling for these cables off shore. One DASAR was successfully recovered by this method though it had sustained significant damage over the course of the deployment and had ceased functioning on January 27, 2014, i.e., 99 days into the deployment (Figure 18). The other DASAR was not recovered.

Figure 18. DASAR SN 101 after recovery on June 24, 2013, eight months after deployment at East Foreland showing damages including lost ABS cover, missing two of three hydrophones and bent mooring frame.

Based on these experiences, ORPC will consider alternative and redundant systems in highly energetic and challenging sites such as the East Foreland:

- Alternative and redundant pop-up buoy systems
- Buoys tethered to become accessible only at the lowest tides (a technique used with relative success by local commercial fishermen)
- Housing recording systems within the buoyant sections of pop-up buoys or utilizing acoustic release mechanisms in conjunction with positively-buoyant recorders, either equipped with tracking devices should they release prematurely (Figure 19)

Figure 19. EAR and C-Pod in prototype mooring used by Team CIBA in Cook Inlet with PAM devices housed in buoyant portion of pop-up buoy system.

Data analysis

The continual recording of the DASAR devices generated huge amounts of data that made manual analysis unfeasible. To address this, Greeneridge Sciences applied a whistle detector algorithm developed previously for delphinid vocalizations which allowed automated detection of beluga vocalizations. The algorithm was designed for cetaceans with distinctly different call characteristics and was not optimized for belugas. Thus, despite adjusting the algorithm's input parameters to try to represent beluga vocalizations, the automated detector produced an inordinately large percentage of false detections. Consequently, significant time was required to manually review all of the detections to discern actual beluga whale vocalizations from other sounds.

After filtering the results of the automated detector, the initial report on beluga detections from Fire Island later proved to be highly inaccurate, as 44% of the reported detections (by detection duration) and 70% of the reported detections (by number of detection events) were later identified as sounds generated from ice movement, not beluga vocalizations. The results presented in this final report have been verified by acousticians familiar with ice noise to ensure that all beluga detections were classified correctly. (See Attachment E for a revised report from the Fire Island data set after reanalysis of the data.) These results significantly affected the earlier interpretation of the data, which informed subsequent data collection, and highlights the importance of effective and robust data analysis.

Ability to localize vocalizations
The original scope of this Project included utilizing two or more DASARs to localize individual beluga vocalizations that were simultaneously detected by two or more DASARs. This would provide a more rigorous data set on whether belugas were present or absent and whether they were calling from within the Project area. To accomplish this, each DASAR would provide not only a recording of received sounds but also a bearing indicating the direction from which the call originated. By triangulating the bearings from two or more DASARs to a given beluga call, a location of the call could then be estimated. Previous versions of the DASAR utilized in the Beaufort Sea have proven this capability by localizing Bowhead whale calls. However, those DASARS rely upon an accelerometer-based sensor that measures particle velocity rather than acoustic pressure in order to estimate direction to a received sound. Due to the high current velocities in Cook Inlet, it was determined that such a sensor would likely be ineffective since particle velocity sensors are highly sensitive to pressure fluctuations likely to be induced by current flow, in which very small sensor movements overwhelm the signal of interest. Instead, Greeneridge attempted a somewhat novel approach utilizing three hydrophones within each DASAR configured in a short baseline triangular configuration with approximately 1 ft between each hydrophone. The intent was to utilize the short baseline array configuration within each DASAR to discern the difference in phase of the received sound at each hydrophone, allowing the bearing of the received sound to be identified through post-processing of the data. Significant time was spent developing an algorithm based upon this method, but ultimately a successful algorithm proved elusive and further attempts to localize sounds in this manner were abandoned in order to focus project resources where they were most effective.

Departure from Planned Methodology
There were several departures from the planned methodology that the project team worked through.

The first departure was the relocation of ORPC's pilot project in Cook Inlet from Fire Island to East Foreland in the middle of this Project’s performance period. There were a number of factors that influenced this decision: (1) the stronger tidal energy resource, (2) closer access to grid connection and marine infrastructure at the East Foreland, and (3) NMFS’s opinion that the habitat at East Foreland was less utilized by the beluga whale population than that at Fire Island, and was thus a preferable initial pilot project site. Data were therefore collected at both locations and provided a comparison of both the ambient acoustic environment and beluga use of each area. In addition, work at each location provided experience deploying and retrieving hydrophones in different marine environments. Unfortunately, a full year of hydro acoustic data was not collected at either site.

The original proposal included utilizing the directional capability of the DASARs to localize beluga vocalizations. As explained above, the algorithm to do so was not successfully implemented, so localization of the calls did not prove possible during this Project. Discussions with federal agencies made it clear, however, that the presence/absence data collected would meet permitting requirements in lieu of successful localization data for beluga whale vocalizations within the Project area.

The original proposal also included performing data collection before and after installation of a tidal energy device. As a tidal turbine was not installed in Cook Inlet within the performance period of this project, data collection after installation of a tidal energy device was not possible. Comparison of before and after data and assessment of the potential effect of tidal energy device installation and operation on beluga use of the area was thus not possible.

The original proposal did not include development and implementation of pseudo-noise removal from the ambient sound measurements. The addition of this analysis to the data collected at each site was incorporated to increase the rigor of the ambient sound measurements and added an unforeseen and valuable aspect to the Project.

Recommendations on the best practice for future data collection

Visual observations were utilized in this Project as the most tried and true method for data collection on beluga presence in the Cook Inlet area. These methods again proved effective in collecting data during ice-free months and daylight hours. When possible logistically and cost effectively, visual observations added value to marine mammal data collection efforts, and provided information on marine mammal presence, behavior, group size, and relative age-class (i.e., presence of calves) that is largely indeterminable by passive acoustic devices. The data collected in conjunction with PAM monitoring during this Project highlighted the fact that visual observations played a role in detecting marine mammals that were sometimes missed by hydroacoustic devices and expanded the understanding of marine mammal use of an area during times that visual observations were possible. However, it was also clear the visual observations alone cannot be relied upon in a locations where seasonal restrictions did not allow year-round monitoring of a project area.

For this reason, PAM devices also have a significant role to play in understanding year-round use of an area by marine mammals. For this Project, the three PAM devices investigated for data collection showed differing results in detecting beluga whales. Ultimately, however, the DASAR and C-Pod were effective in detecting beluga whales in all months of deployment while the EAR only detected whales during three of the six months of concurrent deployment with the C-Pod and DASAR. It appears that the EAR alone was not an adequate data collection device in this application as it painted a somewhat incorrect picture by implying that belugas were not present in the Fire Island Project area mid-winter. However, in all Cook Inlet deployments the EAR has been co-deployed with a C-Pod and, in this case, the results that beluga whales were present in all months of deployment would have been similar to those derived from the DASAR. Ultimately, it is apparent that coupling PAM devices that allow detection of both social vocalizations (EAR and DASAR) and echolocations (C-Pod) provided the most rigorous approach to ensuring that accurate presence and absence data is collected. In the case of this Project, it also appeared that the lower frequency range, but continuous recording of the DASAR was a more effective approach to detecting social vocalizations than the larger frequency range using 10% duty-cycling of the EAR alone. It should be noted that the comparison between PAM devices in this Project was limited to a single deployment at one site targeting a specific marine mammal species, it may not be the case that the DASAR outperforms the EAR in detecting vocalizations in other conditions. All of the devices tested proved effective in deployment, retrieval, and reliable operation over long-term deployment at Fire Island.

Overall design and implementation of reliable deployment and retrieval systems proved to be a challenge for this Project and the associated Team CIBA project. Long-term deployments at Fire Island proved effective for all of the PAM devices deployed there, though retrievals were somewhat problematic and introduced risk in securing invaluable overwinter data. At the East Foreland site, by comparison, overwinter deployments were only 50% successful with one of two DASARs being lost. Furthermore, the recovered DASAR sustained damage during its overwinter deployment that shortened the data collection window and may require a follow on deployment in a future field season in order to complete year round data collection efforts. This could be a significant setback to a project, causing a delay of a year or more if a year of continuous data was required for successful project permitting. More work is thus necessary in order to enhance the reliability of deployment and retrieval systems for PAM devices deployed in high energy environments for long-term monitoring in order to better ensure that the valuable data is recovered at the end of the deployment period.

Long-term ambient sound data collection and analysis was successfully completed as part of this project for both the Fire Island and East Foreland sites. The methodology used involved spectral coherence analysis to remove some pseudo-noise from the data and allow a more rigorous approach to ambient sound characterization. While this method appeared effective, it was not completely effective in reducing self-noise such as “drum head” resonance associated with the DASAR housing itself. Another proven approach to collecting ambient sound measurements at tidal sites involved the use of drifting hydrophones such as the DNMS used by ORPC at the Cobscook Bay Tidal Energy Project. This system collected very rigorous data on ambient sound as both self- and pseudo-noise were nearly eliminated by the device floating with the tidal currents. However, this method can only capture short snapshots of ambient sound and would require many repeated deployments to effectively characterize ambient sound levels at different tidal stages for a given site. By coupling the two methods together and comparing their measurements, it would be possible to verify the accuracy of the stationary noise measurement system with the DNMS, and thereby allow the long-term data set to be calibrated and ensure the long-term ambient sound analysis was accurate.

PRODUCTS

Posters

Land-based beluga observations from Northwest Fire Island, Upper Cook Inlet, Alaska, June-November 2009. McGuire, T., Bourdon, M., Kirchner, R., McCann, & M., Worthington, M. Alaska Marine Science Symposium. (2010).

Land-based beluga observations from Northwest Fire Island, Upper Cook Inlet, Alaska, June-November 2009, and May-November 2010. Bourdon, M., McGuire, T., Kirchner, R., Hesselbach, C., Johnson, R., & Worthington, M. Alaska Marine Science Symposium. (2011).

Presentations

McCann, M., ORPC Tidal Energy Projects. Marine Mammals and Renewable Energy Projects Seminar. 18 Biennial Conference, Society of Marine Mammalogy, Quebec City, Canada, October 11, 2009.

McGuire, T. Cook Inlet beluga whale studies: visual and passive acoustic studies of beluga whales around Cook Inlet Tidal Project. Marine Mammals and Renewable Energy Projects Seminar. 18 Biennial Conference, Society of Marine Mammalogy, Quebec City, Canada, October 11, 2009.

Data

All ORPC-AK Cook Inlet Beluga Whale reports are available publically at: http://alaskafisheries.noaa.gov/protectedresources/whales/beluga.htm

COMPUTER MODELING

Not applicable to this project

[i] Deane, G.B. 2000. Long time-base observations of surf noise. **J. Acoust. Soc. Am.** 107(2): 758–770.

[ii] Buck, B.M. and C.R. Greene. 1980. A two-hydrophone method of eliminating the effects of nonacoustic noise interference in measurements of infrasonic ambient noise levels. **J. Acoust. Soc. Am.** 68(5):1306–1308.