Final report, OGP/JIP 22 06/01, Project 3.7.1: Testing of potential alerting sound playbacks to sperm whales

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SUMMARY

This report reviews the behavioral reactions of depredating sperm whales (*Physeter macrocephalus)* to a variety of acoustic playbacks generated at relatively low source levels, as measured by instrumented bio-acoustic tags. The goal of the study was to determine whether these signals might elicit a "mild alerting response," such as avoidance and surfacing behaviors, for potential incorporation into mitigation efforts during seismic surveys. The tests were conducted in 2009 off a fishing vessel near Sitka, AK, in conjunction with a study, funded by the North Pacific Research Board (NPRB), to learn whether sound can act as an acoustic deterrent to sperm whales depredating longline gear in the area (Thode *et al*., 2007a; Thode *et al*., 2007b; Thode *et al*., 2007c). The region provided a convenient testing ground for sperm whales; the close shelf break off Sitka provided accessibility to the animals, and a history of collaboration exists between the local fishing industry and marine mammal researchers.

Four distinct trips with a total of 11 longline hauls were conducted between June 4 and July 4, 2009, off Sitka, AK; playbacks were conducted during ten of these hauls. The trips were punctuated by shore stops due to weather, the need to recover tags still attached to whales, and the need to refuel and offload fish. A total of 12 bioacoustic "B-probe" and DST (Starr-Oddi Data Storage) tags were deployed during the month, which recorded a total of 229 hours of animal depth, pitch and roll data at 5 second sampling intervals, as well as 79 hours of B-Probe acoustic data recorded on the animals themselves. The B-probe and DST tags were often deployed simultaneously on the same animal. Nine distinct animals were successfully tagged and identified, and two animals

were tagged twice, with one tagged two weeks apart. At least one tagged animal was within a couple of kilometers of a playback during at least seven of the playback sessions, and acoustic tag data was obtained for four playback sessions. Every hauling site was encircled by at least four autonomous acoustic recorders sampling at 50 kHz. Satellite location tags and GPS-based tags were deployed as well.

Roughly speaking, a playback commenced midway through a three-hour haul, in order to provide a baseline for visual, acoustic, and tag observations. During the first two trips, five different types of signals were played: FM sweeps, continuous white noise, white noise bursts, transient orca calls, and sperm whale creaks. The third trip played FM sweeps only, and the final trip played transient orca sounds only. The final two trips also altered the durations and intervals between playbacks. The tagging data were processed to distill parameters about dive, acoustic, and orientation behavior during fishing hauls with and without acoustic playback. A two-sided Kolmogorov-Smirnov test found statistically significant differences between haul-only and haul-playback situations, in terms of the acoustic and rotational behavior of the animals. Specifically, during playbacks animals clicked and "creaked" less, and the relative decrease in "pauses" following creak events suggest that the animals were not as successful in capturing prey. No significant changes in dive depths or durations were found, however. The sample size for playbacks was not large enough to determine which particular acoustic signal type was responsible for the observed differences, and the results may be confounded by differences in the behavior of animals between the start and end of a fishing haul.

No HSE issues were encountered during the work. Lessons learned and suggested changes in fieldwork procedure are discussed.

I. INTRODUCTION
A. Motivation and previous work

The specific objective of JIP 08-02 was “to determine a variety of low power acoustic signals that [would] best elicit mild alerting responses in many species of marine mammals in the wild,” preferably demonstrated from a vessel moving at 5 knots. The motivation of the effort was to determine whether a seismic airgun survey vessel (or associated support infrastructure) could deploy and broadcast acoustic signals that would elicit “mild” avoidance behaviors of marine mammals in the region, thus encouraging them to migrate at least 500 m away from the airgun sources and thus outside the expected exclusion zone for physical trauma. The playback signals themselves would be generated at source levels that would not be expected to engender temporary or permanent hearing threshold shifts when detected by the animals. Instead, low-level signals may exist that accomplish one of the following: (1) produce a novel stimulus that cautious animals would attempt to avoid; or (2) mimic biologically relevant sounds that could initiate a behavioral avoidance response, regardless of the actual received level of the signal. Such signals could include playbacks of social or aggressive sounds naturally produced by a given species, or distinctive sounds made by predators.

Acoustic playbacks have been conducted on marine mammals for at least 40 years. An excellent review of 46 playback studies on marine mammals prior to 2006 is given in (Deecke, 2006), with a more selective review of playbacks in the context of controlled exposure experiments in (Tyack, 2009). Only a few studies have been conducted to specifically test “alerting” signals for management purposes(Nowacek *et al*., 2004); many more studies sought to gain insight into the function of certain calls made by the target species, while others sought to evaluate the potential impact of various types of anthropogenic sounds on specific species. A few studies, relevant to “alerting” studies, sought to determine sounds that would deter animals from depredating fishing gear (Fish and Vania, 1971; Shaughnessy et al., 1981). Specific types of signals used in the “alerting” and “depredation” studies include narrowband pulses (Carlstrom et al., 2002; Johnston, 2002; Morton and Symonds, 2002), tonals (Kastelein et al., 2001; Nowacek et al., 2004; Kastelein et al., 2006a; Kastelein et al., 2006b), FM sweeps (Nowacek *et al*., 2004), or various types of killer whale sounds (Cummings and Thompson, 1971; Fish and Vania, 1971; Shaughnessy *et al*., 1981; Deecke *et al*., 2002).

Signal characteristic	*Frequency range (Hz)*	*Goal source level*	*Duration/Interval*	*Reference*
10 kHz windowed pulse	10 kHz	175 dB re 1uPa SEL	2.5 ms and 400 ms/R [1-4] sec interval	Carlstrom J (2002) Johnston, D.W. (2002) Morton, A.B. (2002)
Tonal	2-50 kHz, 10 evenly spaced frequencies	175-196 dB re 1uPa rms	R[0.5-3] sec/ R [5-20]sec	Kastelein, R.A. (2001, 2006)
Tonal	1500 and 2000 Hz	150 dB re 1uPa rms	1 s/ R [1-4] sec	Nowacek, D.P. (2004)
Logarithmic FM sweep	1-4.5 kHz up/downsweep	150-196 dB re 1uPa rms	1-5 sec/5 sec	Nowacek, D.P. (2004)
Transient orca calls from NE Pacific	1-12 kHz (pulsed call)			Deecke (2002) Cummings(1971) Fish(1971) Shaughnessy(1981)

Table I: Examples of signals used in previous “alert” and “depredation-avoidance” studies.

Sounds from transient killer whales (Deecke *et al*., 2005) have attracted much attention because this subspecies preys on many marine mammal species, and thus playbacks of these sounds might be expected to elicit a response from a wide variety of species. Killer whale sounds used by *Deecke* et al. (Deecke *et al*., 2002) will be one of the primary signals used in this study. Table I summarizes playback sounds used in previous alerting and depredation-reduction studies.

While the selection of a general type of signal is an important consideration in playback studies, an equally important concern is ensuring that multiple versions of a given type of signal are used in playbacks, both to avoid potential habituation effects and to address concerns about "pseudoreplication". The latter topic has received much attention in the playback literature (Kroodsma, 1989; 1990; Deecke, 2006). The term refers to a tendency to generalize conclusions about playback responses that are greater than what is warranted. For example, a common scenario in past studies has been to play the exact same stimulus signal to different individuals, and then claim that the responses observed are representative of responses to the general type of sound, when in reality the responses are relevant only to a single specific stimulus signal (Kroodsma, 1990). This project spent considerable effort to avoid pseudoreplication and habituation issues, as will be detailed in Section II.A.

B. Background on sperm whales

Sperm whales (*Physeter macrocephalus*) are a cosmopolitan species distributed throughout the world's oceans (Whitehead, 2003; Lyrholm, 1998; Rice, 1989). While females and immature individuals generally reside at low latitudes, adult males travel and forage at more extreme latitudes (Whitehead, 1992; Teloni, 2008). In U.S. waters these whales are listed as an endangered species, and their current population in the North Pacific is unknown.

A deep-diving species, sperm whales regularly descend to depths greater than 400 m, for periods ranging between 30 and 45 minutes, and rest at the surface for periods ranging between 5 and 10 minutes (Wahlberg, 2002; Watwood, 2006; Papastavrou, 1989). The few data available from higher latitudes indicate dives there are shallower than what has been measured in temperate or tropical latitudes (Whitehead, 1992; Teloni, 2008).

Sperm whales are vocally active underwater, and during a single dive an individual can generate thousands of impulsive sounds, called clicks (Worthington, 1957; Goold, 1995; Wahlberg, 2002; Madsen, 2002a,b). Measurements in other regions of the world indicate that a whale typically falls silent about 10 to 15 minutes before it returns to the surface (Madsen, 2002a; Douglas, 2005), so by passively monitoring an animal's clicks, the animal's dive cycle can be estimated. Furthermore, under certain circumstances these clicks generate multipath returns from the ocean surface and bottom that can be used to derive the animal's depth and range from the hydrophone, provided that the local ocean bathymetry is known. The technique has been previously used in the Gulf of Mexico to track the dive profiles of females (Thode, 2002) and males in the Gulf of Alaska (Tiemann, 2004), as well as in the Mediterranean Sea (Zimmer, 2003). In the Gulf of Alaska (GOA) click sounds from sperm whales have been detected throughout the year on bottom-mounted recorders, revealing a year-long presence in the region (Mellinger, 2004) .

Another distinctive acoustic feature of sperm whales is the existence of ”creak” (or ”buzz”) sounds, a sequence of pulses produced at a rate of 10 per second or faster (Madsen, 2002a), and often characterized by a decrease in the pulse interval over the five-to-ten second duration of the sound (Whitehead, 1990; 2003). Bio-acoustic tagging work on sperm whales has shown that most creaks occur at foraging depth and are often associated with changes in the orientation of the animal (Watwood, 2006; Miller, 2004b).

Creaks are occasionally followed by periods of silence, before the animal resumes ”usual” clicking again. Analogous signals observed in bats, dolphins, and beaked whales suggest that creaks are echolocation signals (Wahlberg, 2002; Madsen, 2002b; Jaquet, 2001), and periods of time where creaks are detected have been described as prey capture attempts (Watwood, 2006). One component of ongoing echolocation studies is to determine whether creaks followed by a pause in clicking are indicative of prey capture success. Thus the duration of creaks, the rate at which they are produced, and the fraction of creaks that are followed by a period of silence are all variables of interest in characterizing sperm whale acoustic dive behavior.

The diet of sperm whales generally consists of various cephalopod species, based on an analysis of stomach contents (Whitehead, 2003; Rice, 1989; Kawakami, 1980). However, in certain regions fish seem to comprise part of the diet as well (Rice, 1989; Kawakami, 1980), including off the eastern Gulf of Alaska (Okutani, 1964), but it is unknown what fraction of this population’s diet consists of fish.

C. Background of sperm whale depredation in the Gulf of Alaska, and SEASWAP

Questions about the sperm whale diet have attained practical importance in Alaska, because sperm whales are known to take fish from fishing gear, a behavior known as ”depredation”. While killer whales are much more commonly associated with depredation, sperm whale interactions with demersal long-line operations occur at a number of locations around the globe. In the eastern Gulf of Alaska (GOA) an active longline fishery for sablefish (*Anoplopoma fimbria*) occurs about 8.5 months a year. Sablefish (also called blackcod and butterfish) reside on the continental slope, and most commercial longliners operate in water depths between 400 m and 1000 m. The continental shelf off Kruzof, Baranof and Chichagof islands, conveniently located near Sitka, AK, is very narrow; consequently, the sablefish grounds are within 6-12 miles of shore. In the GOA sperm whale longline depredation has been documented since at least 1978 in the domestic U.S. fishery, and observers on Japanese longline vessels in the GOA reported depredation occurring in the mid 1970s. The fishery occurred year round until the early 1980s, when fleet expansion resulted in a shortened season. By 1994, the entire quota was being caught in two weeks, so in 1995 individual fishing quotas (IFQs) were implemented, reducing overall effort expanding to an 8.5-month fishery, from March to November. An unintended consequence of this fishery change is that the extended season apparently provided more opportunities for sperm whales to access longline gear, and by 1997, reports of depredation had increased substantially from pre-IFQ seasons (Hill, 1999). A domestic sablefish survey in the GOA looked at catch rates from 1999 to 2001 for all sets with sperm whales present; they compared boats with and without physical evidence of depredation and found a 5% lower catch rate in boats with depredation (Sigler, 2008). Perez (Perez, 2006) estimated that the impact of marine mammal depredation on the combined longline fisheries in Alaska was about 2.2% of the total fishery groundfish catch during 1998-2004.

In 2003 the Southeast Alaska Sperm Whale Avoidance Project (SEASWAP) was created with fishermen to quantify the issue and recommend ways to reduce depredation. A collaborative study between fishermen, scientists and managers, SEASWAP worked with the coastal fishing fleet to collect various quantitative data on longline depredation. Initially photo-ID and biopsy tissue sample data were gathered to estimate the size, sexes and genetic structure of the population involved in depredation. This initial phase proved successful in finding sperm whales near fishing vessels and evaluating the magnitude of the depredation. SEASWAP also learned that sperm whales have been feeding along the shelf edge with no vessels in close proximity, indicating that sperm whales in this area are feeding normally on deepwater prey, presumably including sablefish and other deepwater fishes, in concordance with historical whaling data. Between 2003 and 2006 genetic results determined that all 19 whales sampled were males. A total of 106 sperm whales have been individually photo-identified with 12 different whales re-sighted between years. Bayesian mark-recapture analysis estimated 123 ([94-174]; 95% credible interval) depredating whales in the GOA study area (Thode *et al*, 2006).

In 2004 passive acoustic monitoring studies of sperm whale depredation began and determined that sperm whales would respond to acoustic cues made by fishing activities at ranges of several kilometers or greater (Thode *et al*., 2007b). Then, in 2007 and 2009, SEASWAP conducted a bioacoustic tagging program. Besides measuring acoustic activity on tagged animals, data from bioacoustic suction cup tags have yielded a wealth of high-resolution information on the dive depths and spatial orientation of many marine mammal species (Johnson, 2009), including sperm whales (Miller, 2004a; 2009). Dive profiles of male sperm whales have been obtained via multiple types of tags in the Mediterranean (Pavan, 1997; Drouot, 2004), off Norway (Madsen, 2002a) and off New Zealand (Douglas, 2005), but until recently little to no information existed on the dive profiles, acoustic activity, or spatial orientation of foraging northeast Pacific sperm whales.

This report details the results of the 2007 and 2009 bioacoustic tag deployments on sperm whales during acoustic playback studies off the continental shelf of Sitka, AK. Section II describes the equipment used, including the playback device, autonomous recorders, and bioacoustic tags, while Section III details the deployment schemes, playback protocols, and analysis methods used to process the tagging data. Section IV provides examples of tag data and playback signals, and presents the statistical analysis of the dive, acoustic, and orientation parameters of tagged whales during fishing hauls with and without playbacks.

II. EQUIPMENT

A. Acoustic playback device

1. Hardware

The autonomous playback device was built by May 2009 and tested in an enclosed pool at the Scripps Institution of Oceanography. The device was designed to be activated, deployed, and charged by non-technical personnel, including fishermen, by simply attaching or removing an "on" or "off" dummy underwater connection plug. Rechargeable batteries sealed in a pressure case, surrounded by an aluminum cage, powered the device. The entire assembly stood 1.2 m high and weighed about 70 lb out of water.

The playback device could store up to 4 Gb of playback data, sampled at 125 kHz, and broadcast the signal between a frequency bandwidth of 2-50 kHz. The output signal was split between three different transducers, each optimized over different frequency ranges: an ITC-4004A for components between 2 and 5 kHz; an ITC-1032 for components between 20 and 50 kHz, and an ITC-1001 between 10 and 35 kHz. The entire device was encased in a steel cage to protect all components from collisions with fishing gear and the hull.

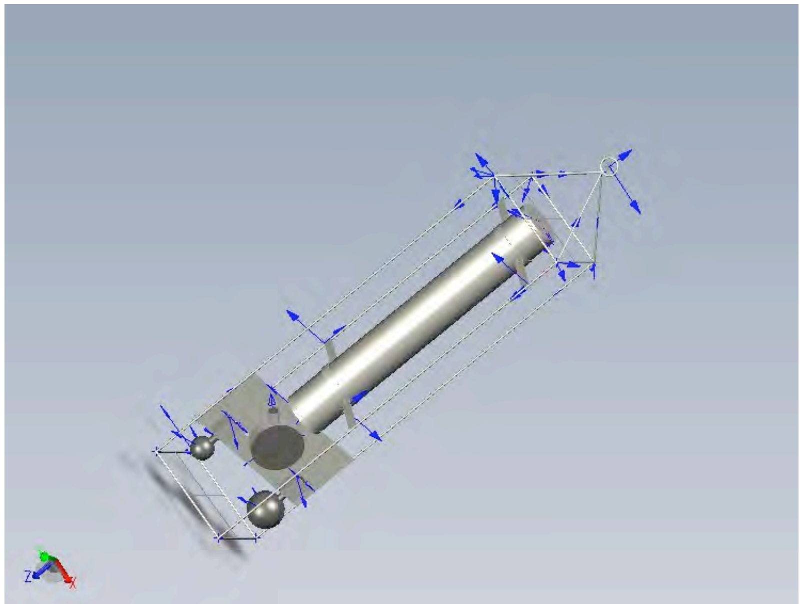

Figure 1: External configuration of playback device. Long dimension of cage is 1.2 m from top ring to bottom base.

The device was calibrated in two ways: first a series of tones were played in the pool to provide an approximate calibration, and then white noise was broadcast in 1 km deep water off the coast of Sitka, AK, with a HTI-96 min hydrophone monitoring and recording the signal at a distance of 2 m from the source, at 10 m water depth. We found that between 2 and 6 kHz the device could output a tone up to 178 dB re 1uPa pk-pk @ 1m (~174 dB re 1uPa rms @ 1 m), and thus the signal level would be expected to drop to the NMFS recommended limit of 160 dB re 1uPa rms within 10 m from the source. The goal of the project was to make a signal that was clearly audible above background noise levels, and a review of hydrophone data collected 1-2 km from the source indicates this goal was achieved (see Section IV.C).

The output spectrum of the device was not flat, so a white noise signal input into the device would become "colored" when transmitted. This output spectrum, recorded by the monitoring hydrophone in deep water, was used to design a set of finite impulse response (FIR) filters that would “equalize” signals once they were generated by the device.

2. Playback signals

Six different types of signals were broadcast into the water. For most signal types, four different instances of each type were available for playback, in order to compensate for pseudoreplication and habituation concerns. Thus there were four different instances of FM sweeps, each with different start and end frequencies and durations, and so forth. Table II summarizes the playback signals and the range of variation of their appropriate parameters. A request was issued by the PI for a single airgun recording, and the JIP/IAGC generously provided the signal midway through the field effort; however, it was decided in the field that it was best to focus on FM sweeps and orca sounds for the final playbacks, in order to ensure a larger sample size for a fixed number of signal types.

Signal	*Trips used*	*Instances*	*Source*	*Variable Parameters*	*Parameter Ranges*
Continuous white noise	1,2,3	1	Synthesized		
FM Sweeps	1,2,3,4	4	Synthesized	Start and end frequency, duration	
White noise bursts	1,2,3	4	Synthesized	Pulse duration, pulse interval	Pulse duration 8-15 msec, Pulse interval 0.05-0.2 seconds

Orca transient calls-continuous sequence	1,2,3	4	Volker Deecke, SMRU, via Chris Clark, Cornell University	Start time in WAV file deecke-05-07-27.wav	3:30, 10:40, 19:40,23:20 minutes into file
Sperm whale creaks	1,2,3	1	Spliced from 2006 longline video camera data	None	none
Orca transient calls-"cherry-picked" calls	5	5	Volker Deecke, SMRU, via Chris Clark, Cornell University	Five high SNR calls randomly concatenated	none

Table II: Signal types used for 2009 playbacks

B. Bioacoustic tags

The acoustic behavior, dive profiles, and spatial orientation of sperm whales in response to the playbacks were investigated using both high-resolution digital acoustic sampling tags (Greeneridge Sciences) and a comp-tilt Data Storage Tag (DST) (Star-Oddi). The Bioacoustic Probe, or "B-probe," measures 25cm by 6cm, and incorporates a HTI-96-MIN/3V hydrophone with a sensitivity of -172 dB re 1 V/Pa and flat response between 5 Hz and 30 kHz, encased in epoxy along with various electronics and 1 Gb of flash memory. The B-probe also contains a pressure sensor and a two-axis accelerometer (MXA2500GL, Memsic Inc., North Andover, MA 01845). The latter is orientated so that one axis is parallel to the longitudinal axis of the probe. Data from the depth gauge and accelerometers are sampled at 1 Hz and stored within the tag. The acoustic data analyzed in this paper were sampled at 4096 Hz, a relatively low sampling frequency for sperm whale sounds, but sufficient for detecting regular clicks and creaks. The tag had a high failure probability at higher sampling rates. Section III.D describes the acoustic analysis in detail. The DST comp-tilt tag, with dimensions of 46 by 15 mm, measures temperature, depth, and compass heading with respect to magnetic north, as well as local acceleration along three orthogonal axes. No calibration of the magnetic sensors was conducted in the field, and none of the magnetic data were used in this analysis. While the sampling rate of these data can be adjusted, in this paper the tag data were digitally recorded once every 10 sec. The B-probe was attached to 2 silicon suction cups with zip-ties, and the end cap was bolted to a syntactic foam float designed by Cetacean Research Technology, which also contained a radio beacon. The DST tag was small compared with the B-probe assembly, and so was simply taped onto the syntactic float, which had sufficient buoyancy to lift the entire assembly to the surface when detached from the whale. Once on the surface, the tag assembly could be detected and located using the radio beacon.

C. Autonomous acoustic recorders

During every fishing haul and playback session at least three autonomous passive acoustic recorders were deployed on "anchorline" fishing gear, at depths between 200 and 500 m, about 2 km from the midpoint of the fishing deployment. The recorders sampled acoustic data at 50 kHz in ten-hour batches, then transferred the data to hard disk for about one hour. The electronics and batteries were encased in 12 cm diameter acrylic cylinders 0.75 m long. Although not analyzed extensively during this project, these instruments were used to independently confirm the transmission loss characteristics of the playback signals (Section IV.C).

III. PROCEDURE

A. Personnel, tag deployment and visual observation protocols

The fieldwork participants included Aaron Thode and Delphine Mathias of MPL/SIO; Jan Straley and Lauren Wild of the University of Alaska, Southeast (UA); Kendall Folkert, master of the F/V Cobra; and John Calambokidis and Greg Schorr of Cascadia Research Collective, who conducted all tagging work. Health, Safety and environmental aspects of the F/V Cobra were assessed consistent with the International Association Oil & Gas Producers (OGP) Joint Industry Program (JIP) on Sound and Marine Life. All tagging work was conducted under NOAA NMFS Permit 473-1700-02.

The SEASWAP tagging effort used a 16 foot rigid-hulled inflatable boat(RHIB), which loitered in the vicinity of cooperating fishing vessels in order to spot tagging opportunities. In both 2007 and 2009, a local fishing vessel (the F/V Cobra) would depart from Sitka and deploy longline gear at a site, followed by the RHIB. If whales visited the gear, observers on the fishing vessel would help direct the RHIB toward potential tagging candidates. If no whales were sighted around the gear the RHIB would traverse along the continental shelf break. At the end of each day the RHIB would retire to a sheltered harbor in Symmonds Bay, while the F/V Cobra would drift in the vicinity of the deployed gear.

The tags were deployed using a 10 m modified windsurfing mast from an inflatable RHIB. Through trial and error it was discovered that the animals were best approached from the side, rather than from behind. The time of deployment was noted, and photographs taken of the relative orientation of the tag on the animal. Once tagged, a whale was identified and followed via both visual sightings and monitoring the radio beacon. During a fishing haul whales activity foraging around the vessel were consistently within 500 m of the observers, and often less than 50 m. Distances beyond 500 m could not be estimated consistently or accurately. The tag usually stayed attached to an animal for several hours before the suction cups detached; attachment times greater than 12 hours were not uncommon. Once free of the animal, the tag assembly floated to the surface and was recovered by converging on the radio beacon. Upon tag recapture, the data were downloaded for analysis via either infrared transmission for the B-probe data or via serial port for the DST tag.

The tagging team was active mostly in the early morning (i.e. before the beginning of a haul) with the goal of deploying tags on animals before the start of a haul by the F/V Cobra. After a haul began, the tagging boat drifted away from the fishing vessel to avoid unduly influencing animal behavior. During a fishing haul visual observations were conducted from the vessel's upper deck. The visual observers noted times and distances of surfacing animals relative to the vessel, recorded subsequent orientation and surface movements, and noted times of 'fluke ups,' indicative of deep diving. Individuals could be consistently identified when surfacing, due to the presence of distinctive profiles, scars, and coloring on all sides of the whale. Photos were taken of each individual surfacing within 500 m of the vessel, and often individuals were identified by photo-ID after the encounter. Distances were estimated by a laser range-finder, when possible; otherwise, the range was marked as being greater than or less than 500 m range from the vessel.

B. Acoustic playback protocols

When directed by the skipper, the autonomous playback device was deployed by the fishing crew off the port bow of the fishing vessel at a depth of approximately 10 m

(30 feet). Each signal was played back with 125kHz sampling rate, usually midway through a fishing haul. A monitoring hydrophone was placed two meters above the playback device cage. The vessel's 25 kHz echo-sounder was active at all times when outside the harbor, including during all playbacks, as is typical during a fishing haul. No other sound sources were active during the hauls. The full experimental protocol is provided in Appendix A.

When activated, the device would remain silent for five minutes, then select a signal to play, with a finite probability of playing back a "zero" signal, an input file that was uniformly zero amplitude. Once a signal type had been selected, a particular instance of that signal was then selected. The signal would then be played back at -20 dB below maximum attainable output (MAO), then after a certain pause time, the same instance is replayed at -10 dB below MAO, and then finally replayed at MAO. For convenience, this set of three playbacks will be defined as a "playback set" for the rest of this report. After a playback set is finished, an "extended pause time" elapses before the cycle repeats, with a new signal type possibly being selected. A "playback session" is defined as a collection of playback sets broadcast during a single fishing gear recovery haul. There were a total of 48 playback sets conducted over 10 sessions. Table II summarizes all the playback sessions. A "logfile" failure indicates that the device failed to internally log the signal types played, a problem that occurred during the first two trips, before the software bug was fixed. The exact signal types played can be reconstructed from the monitoring hydrophone data. Unless otherwise mentioned, all playbacks took place in the vicinity of tagged whales.

At the end of the second trip the playback device became entangled in fishing gear. Although the cage protected the playback device from damage, it was decided that the playback device needed to have 30 kg of weight added to the cage to keep the deployment vertical, even when the vessel was moving forward slightly. A winch and davit was added to the bow of the vessel to facilitate deployments, which followed standard HSE procedures.

C. Tag dive profile analysis

The pressure sensor data on both the B-probe and DST tags permitted recovery of dive profiles during all types of behavior. Whenever both tags were deployed together, the data could be cross-checked between the instruments to confirm proper calibration and to evaluate the effect of potential sensor drifts arising from temperature changes. The start and end of a given dive were defined as times when the animal's depth became deeper or shallower than 10 m. Within that dive, a set of dive "inflections" are defined as points where the vertical velocity of the whale (the time derivative of the pressure) changed sign, consistent with the definitions used in (Miller, 2004a). After an inflection is identified, an ensuing net vertical change of at least 10 m (approximately 2/3 of a body length) was required to transpire before a new inflection could be flagged.

Dividing the number of inflections in a dive by the total dive duration, yielding a rate of dive inflections per hour, normalized the number of inflections logged during each dive. The surface, dive, and bottom durations (T_s , T_d ,T_b), as well as the maximum depth attained (D_{max}) were also logged for every dive.

D. Tag acoustic analysis

Sperm whale "regular" clicks were automatically detected in the tag records by generating a series of overlapping 256 pt Fast-Fourier Transforms (FFTs), overlapped

75%, and then integrating the power spectral density between 1200 and 1900 Hz. If a value exceeded the estimate of background noise level by 20 dB, the presence of a click was flagged; otherwise, the information was used to update a running average of the background noise levels (Mathias, 2009). The output of this automated click detector was manually spot-checked to confirm that clicks produced by other nearby non-tagged whales have not been incorporated into the results.

Detecting creaks was more difficult, because their signal-to-noise ratio (SNR) is generally much lower. The inter-click intervals (ICI) during a creak decrease from 0.2 sec to 0.02 sec (Goold, 1995) and the creak amplitude decreases with time, with clicks at the end of a creak often 20dB or more lower in level than at the beginning (Madsen, 2002b). Creak sounds are also almost always preceded by a set of regular clicks with steadily decreasing ICI, which eventually transition into a creak.

Creak detection was thus semi-automated. The first step in the process was to use automated click processing to note ”gaps” in regular click trains, with a gap defined as a pause in detected clicks that exceeds 5 s but is shorter than 60 s. Each gap was reviewed manually and aurally for the presence of a creak, and then categorized as a silence, creak-only, or creak-pause event. After a creak-only event, the whale starts producing regular clicks within two seconds after the audible end of a creak, while creak-pause events contain at least two seconds of silence between the end of a creak and the onset of a click train. As discussed in Section I.B, this latter category is generally considered to be a sign of prey capture (e.g., Miller, 2004b; Watwood, 2007), although this distinction has not been emphasized in the literature. Thus, the ratio of creak-pause events divided by the total number of creak events will be dubbed the “success ratio” F_{crP}. Special effort was made to ensure that no creaks were missed, due to the relatively low acoustic sampling rate of the tag. Whenever a gap was first categorized as a silence but preceded by a decrease in the ICI of a regular click sequence, the sample was reviewed aurally and usually categorized as a creak-only creak-pause. Only 2% of silent gaps preceded by a decrease in the regular click ICI provided no evidence of a creak.

Every tag record is decomposed into a set of dive profiles, with the beginning and end of each dive defined according to the criteria of Section II.C. The following acoustic parameters are then extracted from each dive:

a) Timing of first click (TC_{l1}): the time difference in minutes between the start of the dive and when the first click is detected on the tag;

b) Click rate (Cl): the total number of clicks produced during a dive, divided by the total dive duration in seconds;

c) Mean Inter-Click-Interval (ICI): the mean interval in seconds between successive clicks within the same click train. Note that this quantity will differ from Cl if the whale is silent during substantial portions of the dive;

d) Creak-only (Cr) and creak-pause (CrP) rates: the number of creak events produced during a dive, all divided by the dive duration in seconds;

e) Fraction of creak-only (F_{cr}) and creak-pause (F_{crP}) events: the relative fraction of each creak event for each dive;

f) Creak/dive inflection time separation (δT cr/infl) and creak-pause/dive inflection time separation (δT crP/infl) : the difference in seconds between the beginning of a creak and the nearest dive inflection time.

E. Tag orientation analysis

1. *Angular definitions*

a. Acceleration vector

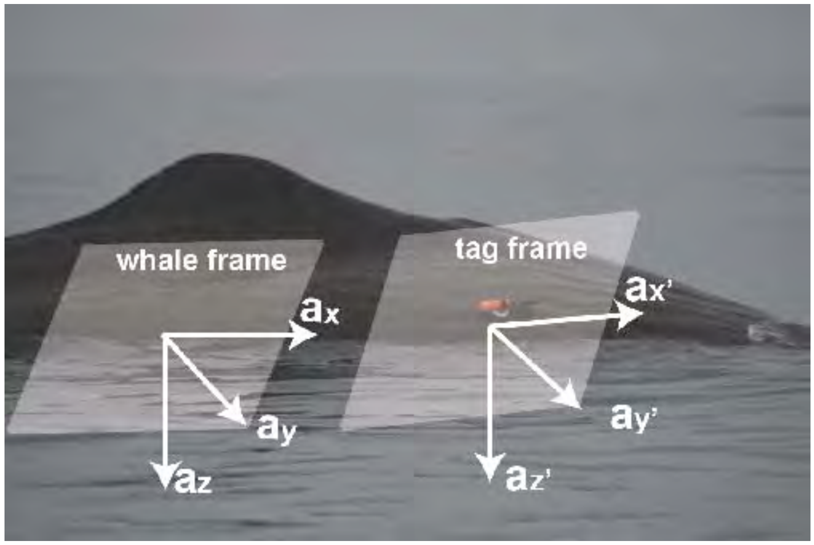

Figure 2: Picture of B-probe tag with associated reference axes (primed), along with whale reference axes (unprimed).

Figure 2 displays the reference frames discussed here. The ”whale reference frame” is defined such that the positive x-axis points toward the rostrum of the animal, while the positive z-axis points ventrally. The ”tag reference frame” defines the axes relative to the inertial frame of the instruments. Both the B-probe and DST tag provide measurements of gravitational acceleration along at least two orthogonal axes, and so an acceleration vector a can be defined with components (a'_x,a'_y,a'_z), expressed in units of gals (1gal =9.8m/s^2) in the tag reference frame. Each raw measurement $a_{i,raw}$ obtained from the tag was normalized into gals by measuring the full-scale maximum value a^* output from a tag along each axis, after correcting for bias, and then computing

$a'_i = a_{i,raw}/|a^*_{i,raw}|$.

The DST tag measures all three components of **a** every 10 seconds, while the B-probe only measures two components, but sampled every second. However, if one assumes that the magnitude of **a** is dominated by the static gravitational acceleration, and not by accelerations from the animal's motion or wave action slapping on the tag at the surface, then the three components are not independent, and the third component of **a** on the B-probe can be derived from the other two. To test the robustness of this assumption, the distribution of $|\mathbf{a}|$ was computed from all 229 hours of DST records collected in 2009. It was found that 95% of the samples yielded $|a|$ within 2.5% of 1 gal, consistent with a previous detailed analysis of the dynamics of tagged sperm whales, which found that the animals' acceleration was generally less than 0.01 m/s (Miller, 2004a). Thus the assumption that $|\mathbf{a}| \sim |1|$ gal is generally valid, and the third vector component of a on the B-probe can be safely estimated, permitting higher-resolution time measurements of the animals' motion.

b. Coordinate transformations

During most deployments the major axes of the tag assembly are slightly misaligned with the whale's reference frame. Thus the coordinates of the acceleration measured in the tag frame (a'_x,a'_y,a'_z) must be transformed into the whale-centered coordinate system (a_x,a_y,a_z) displayed in Figure 2.

Using the angular definitions and matrix notation of (Johnson, 2003), if the pitch, roll, and heading of the tag with respect to the whale frame are θ_t, ψ_t , and ϕ_t, then the relationship between **a** and **a**' is as follows:

$$\mathbf{a} = (\mathbf{H}^\mathrm{T}\mathbf{P}^\mathrm{T}\mathbf{R}^\mathrm{T})\mathbf{a}' \tag{1}$$

where

$$\mathbf{H^T} = \begin{pmatrix} \cos(\phi_t) & -\sin(\phi_t) & 0 \\ \sin(\phi_t) & \cos(\phi_t) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\mathbf{P^T} = \begin{pmatrix} \cos(\theta_t) & 0 & -\sin(\theta_t) \\ 0 & 1 & 0 \\ \sin(\theta_t) & 0 & \cos(\theta_t) \end{pmatrix}$$

$$\mathbf{R^T} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(\psi_t) & -\sin(\psi_t) \\ 0 & \sin(\psi_t) & \cos(\psi_t) \end{pmatrix}$$

Estimates for all three correction angles were made during times when a tagged animal was surfacing to breathe, as per previous tagging studies (Johnson, 2003; Miller, 2004b) . The magnitude of a specific accelerometer measurement a_0 taken at these times was found to be typically 1 gal. By assuming that the z-axis of the whale frame at these times is aligned with the local gravitational acceleration, Eq. (1) becomes

$$\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = (\mathbf{H^T P^T R^T})\mathbf{a}'_0 = (\mathbf{P^T R^T})\mathbf{a}'_0 \tag{2}$$

The second equality arises from the definition for H^T, which indicates that the x and y-elements of $\mathbf{a}'_0$ must be zero after the first two rotations for the equation to be solved.

Stated another way, data from the accelerometer alone are insufficient to determine the heading of the tag relative to the whale. Solving Eq. (2) yields

$$\theta_t = \arcsin(a'_{x,0}) \tag{3}$$

$$\psi_t = \arctan(\frac{a'_{y,0}}{a'_{z,0}}) \tag{4}$$

Finally, photographs of a tagged animal while surfacing were used to estimate φ_t. Specifically, a yaw angle was estimated, γ_t, that would rotate the a'_x axis into the a_x axis aligned with the whale. Substituting **a** =$[1\ 0\ 0]^T$ into Eq. (1) and using the relationship $\hat{a}_x \bullet \hat{a}'_x = \cos(\gamma_t)$ one obtains

$$\cos(\phi_t) = \frac{\cos(\gamma_t)}{\cos(\theta_t)} \tag{5}$$

In general, a large majority of tag deployments were nearly parallel with the tagged whale's longitudinal axis, and Eq. (5) was used infrequently.

C. Pitch and roll

If only acceleration data are available to estimate the sperm whale's orientation, and not heading information, a yaw motion of the animal cannot be distinguished from a roll, and so only the animal's pitch (θ) and roll (ψ) can be derived from **a**:

$$\theta(t) = \arcsin(a_x(t)) \tag{6}$$

$$\psi(t) = \arctan(\frac{a_y(t)}{a_z(t)}) \tag{7}$$

Alternatively one can use the formula used in (Goldboggen, 2006), which links the roll directly to a_x and a_y without requiring estimation of a_z:

$$\psi(t) = [\frac{1}{1-(\frac{a_x(t)}{a_x^*})}] \quad [cos(asin(\frac{a_x(t)}{a_x^*}))]^2 \quad [asin(\frac{a_y(t)}{a_y^*})] \tag{8}$$

Figure 3 shows a comparison between data from a DST tag, using Eqs. (6) and (7), and data from a B-probe deployed simultaneously, using Eqs. (6), (7) and (8). The results indicate that Eq. (8) is generally less accurate than Eq. (7), when compared with the measurements of a full three-axis accelerometer.

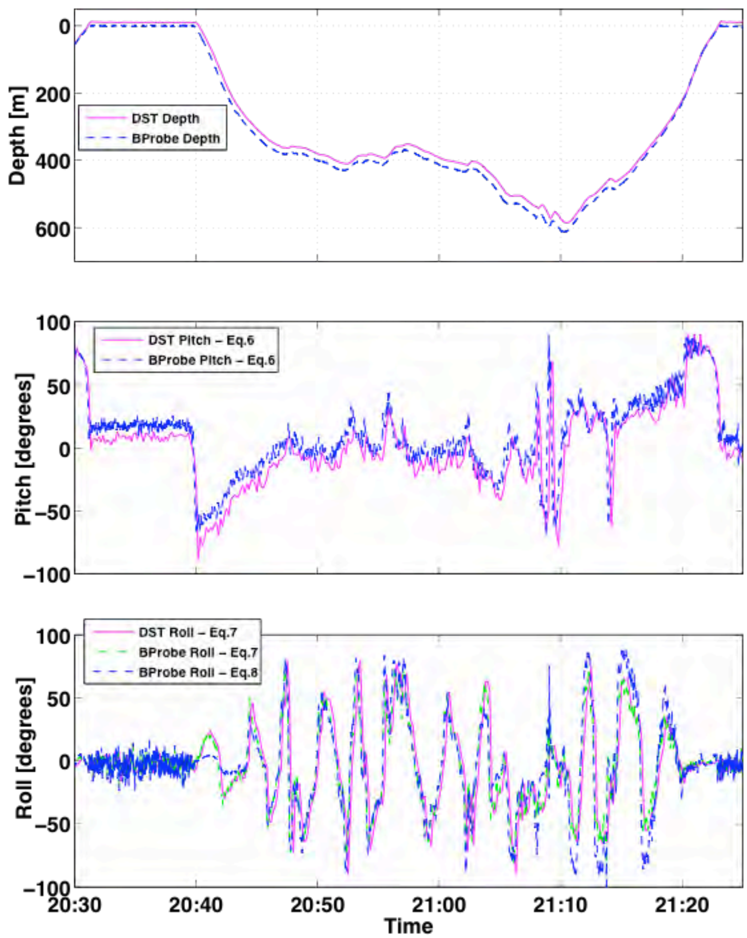

Figure 3: Comparison of pitch and roll measurements between DST (solid magenta lines) and B-probe (dotted blue lines and dashed-dotted green line) when both tags were deployed simultaneously on 21 June 2009 : (a) dive profile; (b) pitch; (c) roll. For the B-probe data, the pitch was computed using Eq. (6); the roll was computed using both Eq. (7) and Eq. (8).

d. Angular displacement and angular velocity definitions

In this paper a "combined angular displacement" η_{all} is defined as the angular change in the direction of the acceleration vector over a fixed time interval δt. Thus if the acceleration at two distinct times is $[a_x(t), a_y(t), a_z(t)]$ and $[a_x(t+\delta t), a_y(t+\delta t), a_z(t+\delta t)]$ then η_{all} is defined by :

$$\cos(\eta_{all}(t)) = \frac{a_x(t)a_x(t+\delta t) + a_y(t)a_y(t+\delta t) + a_z(t)a_z(t+\delta t)}{|a(t)||a(t+\delta t)|} \tag{9}$$

A ”combined angular velocity” Ω_{all} is defined as a combined angular displacement per second :

$$\Omega_{all}(t) = \frac{\eta_{all}}{\delta t} \tag{10}$$

Two additional angular displacements and velocities can be defined in terms of pitch and roll :

$$\eta_{pitch}(t) = |\theta(t+\delta t) - \theta(t)| \quad ; \quad \Omega_{pitch}(t) = \frac{\eta_{pitch}}{\delta t} \tag{11}$$

$$\eta_{roll}(t) = |\psi(t+\delta t) - \psi(t)| \quad ; \quad \Omega_{roll}(t) = \frac{\eta_{roll}}{\delta t} \tag{12}$$

The three angular displacements are not independent; any one can be derived from the other two. The combined velocity is a useful quantity to estimate in that its values are independent of a particular coordinate reference frame. In the following analyses, angular displacements are estimated over 3 s increments, shifting the measurement window by 1 s for subsequent estimates. The angular displacements and thus the angular velocities will always be non-zero because the tag readings fluctuate randomly around the presumed steady-state value. Low-pass filtering the time series to reduce fluctuations was not practical, because the timescale of interest for an animal’s rotation was on the order of ten seconds or less.

2. Analyzing relationships between angular velocities, dive inflections, and creak events

The relationships between a given animal's depth profile, acoustic behavior, and angular velocity were examined by creating "velocity plots" that display the details of the animal's motion during certain key times (e.g. Fig. 6 in Section IV.B). Possible key times include times during which the animal generates creaks, or times when the animal produces a dive inflection. A review of all tag records found that 81% of creak events occurred within 30 s of a dive inflection. The remaining 19% of creaks, not associated with dive inflections, occur during descent and ascent, with 90% of them being creak-only events. However, no precise relationship was found between the timing of the whale's angular motions and the start of creak within a 30 s time window. By contrast, consistent relationships were always found between angular rotations and dive inflections. It is hardly surprising that a relationship exists between pitch velocity and dive inflections – after all, a change in pitch is needed to generate changes in depth – but consistent relationships between roll and inflection were found as well. Thus in the following sections the time origins of the velocity plots will be defined with respect to dive inflection times.

To generate a velocity plot, each tag record is first decomposed into a sequence of dives, with the beginning and end of each dive defined according to the criteria of Section II.C. Then, for each dive, the angular velocities of pitch, roll, and combined angle [Eqs. (10) through (12)] are computed starting 30 s before the start of every dive inflection, and recomputed every second, using a sliding 3 s window, until 30 s after the inflection, generating an "angular velocity time series" (AVTS). The complete set of AVTS curves from the tag record are then grouped according to whether a playback was present, as well as whatever type of creak event was detected within a given velocity time series window. For every group, the mean and standard deviation of the velocities at every second are then computed. By plotting the mean values as a line and the bounds of the standard deviations as vertical bars, a final velocity plot is created, summarizing the angular motion of the animal over multiple types of creak events and playback states (Fig. 6).

Dive inflections not associated with creak events are used to generate ”control plots” during subsequent discussion, under the assumption that these angular motions are unrelated to prey capture events. Because the number of dive inflections not associated with any creak events is generally much larger than the number of dive inflections associated with creaks, the control plots are generated using a random sub sample of dive inflections not associated with creaks, such that the sample size used is the same as the one used for dive inflections associated with creaks. A ”deviation” is defined as the difference between a control plot and any other velocity plot.

For every velocity plot the following parameters are extracted:

a) time of maximum roll deviation (T_{dev}): relative time of the maximum deviation in roll velocity in seconds;

b) maximum pitch deviation (P_{dev}): value of the maximum pitch velocity deviation in $^{\circ}$/s;

c) maximum roll deviation (R_{dev}): value of the maximum roll velocity deviation in $^{\circ}$/s;

d) maximum combined deviation (C_{dev}): value of the maximum combined velocity deviation in degrees/s.

F. Hypothesis testing

The distributions of the dive, acoustic, and orientation parameters derived from haul-only and haul-playback dives were non-Gaussian, characterized by large tails that indicated relatively infrequent but significant events that could not be discounted as outliers. Thus a two-sided Kolmogorov-Smirnov (KS) test was used to evaluate the probability that two sample parameter distributions, one obtained from the haul-only and one obtained from the haul-playback categories, could have been drawn from the same underlying cumulative probability distribution. The null hypothesis is that various parameters measured from both categories were drawn from the same underlying distribution. KS p-values of less than 0.05 led to the rejection of the null hypothesis.

IV. RESULTS

A. Playback and tag summary

Figure 4 displays the locations of playback trials conducted. A total of ten playbacks were conducted during hauls between June 12 and July 2, 2009. Three playbacks took place when no tagged whales were present. Table III summarizes the dates, times, durations, and signal types played during each playback session. During the first two offshore trips, five different types of signals were played: FM sweeps, continuous white noise, white noise bursts, transient orca calls, and sperm whale creaks. The third trip played FM sweeps only, and the final trip played transient orca sounds only. When the results of the four trips were combined, a total of 48 playback sets (as defined in Section III.B) were conducted. A “logfile” failure indicates that the playback device failed to internally log the signal types played, a problem that occurred the first two trips, before the software bug was fixed. The playback device did get caught in fishing gear during one haul, midway through the field effort. No equipment was damaged, but extra weight was added to the playback cage to reduce the chance of entanglements.

In 2009 twelve tag assemblies were deployed: two B-probes only, nine combined B-probe/DST assemblies, and one GPS Mark-10/DST deployment. All DST tags recorded data, but only 3 B-probes recorded acoustic data for any length of time. However, the duration of the successful B-probe tag records was quite long, with mean, median, and mode durations of 22.3, 27.0, and 12.0 hours, collected on 6/11, 6/12 and 6/21. Dive depth information was obtained from DST and B-probes for 32 dives during hauls without playbacks, and 18 dives during playbacks. Acoustic data were obtained from three tags, covering eight non-playback dives and seven playback dives, during four playback sessions. Appendix B lists the details of twelve tag deployments conducted during the project.

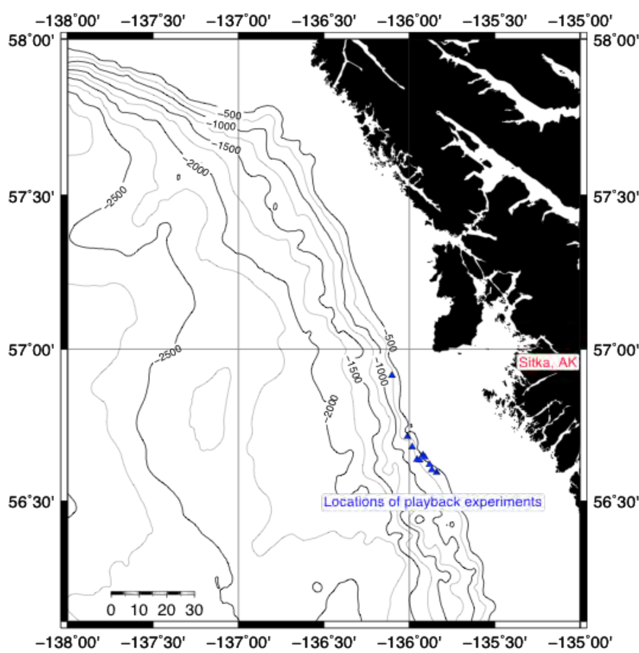

Figure 4: Locations of 2009 playback experiments off Sitka, AK.

Date	Time	Signals	# sets	Duration (minutes)	Set interval (minutes)	Comments
6/12	9:15-10:50					Logfile failure, Bprobe tag present.
6/12	16:19-17:35	FM sweeps, orca continuous	3	2	10	Two "zero" sets. Bprobe tag present.
6/13	12:42-14:15	White noise + sperm creaks, white noise bursts		2	10	Logfile failure, no tags on animals
6/14	14:32-15:14	Sperm creaks, white noise bursts	4	2	10	One "zero" set; tagging boat drifts nearby
6/15	12:16-13:20	FM sweep, white noise bursts	5	2	10	One "zero" set; Device caught in fishing gear
6/21	18:00-20:28	FM sweeps, continuous white noise, white noise bursts	10	2	5	B-probe tag success.
6/25	20:00-21:38	FM sweeps, continuous white noise	8	2	5	
6/30	13:26-14:05	Concatenated orca calls	4	1	5	
7/1	13:18-14:37	Concatenated orca calls	8	1	5	No tags on
7/2	14:23-15:18	Concatenated orca calls	6	1	5	No tags on

Table III: Playbacks conducted in June 2009.

B. Example of tagging data from 12 June 2009: Resting, natural foraging, depredation, and haul

In this section a single B-probe tag record (SC-09-3) is described in detail, in order to provide examples of the various parameters measured from the tag that are subjected to the statistical analyses in the following section. The tag record discussed here is among the longest available, spanning across two fishing hauls and two playback sessions. The whale displaying this tag record had been following the F/V Cobra since 11 June 2009, before being tagged close to the vessel at 13:53 on 12 June 2009. Subsequently the first longline haul began at 14:00 and ended four hours later, accompanied by a 75 min playback. The vessel began its second haul the following day (13 June) at 11:15, finishing at 14:30, after conducting a 90 min playback session. Visual observers sighted three whales during the first haul: the tagged whale and another animal consistently surfaced within 200m of the vessel throughout the haul, while a third whale arrived an hour into the haul and consistently surfaced within 400m of the vessel. Six whales were sighted during the second haul: four of them were present just before the haul, and two joined an hour into the haul. During this haul all whales consistently surfaced within 400m of the vessel. The tagged whale performed dives between 200m and 700m depth throughout the tag record, except for one resting dive that occurred just after the completion of the second haul. The tag detached around 18:00 on 13 June.

Figure 5 summarizes key features of the tag record, with the start and end of the fishing hauls respectively indicated by the solid and dotted vertical lines, and shaded areas representing playback sessions. The labeled horizontal bar along the top of the figure displays an interpretation of the animal's behavioral state:

(1) *resting* occurs between 14:30 and 15:20 on 13 June: as can be seen, the animal remains at less than 30 m depth, and its inflection rate and click rate are at levels much lower than natural foraging conditions. The resting period occurs just after the end of the fishing haul. When resting the animals produced no creaks.

(2) *natural foraging behavior* between 18:00 on 12 June and 11:25 on 13 June, and between 15:20 and 18:00 on 13 June: the animal shows considerable variation in dive

depth, with the animal systematically shallowing and deepening between 250 and 750 m throughout the night and morning. The normalized creak rate also varies between 5 and 20 creaks/h. During the natural foraging state 54% of creaks detected were labeled as creak-pause (F_{crP}=0.54).

(3) *deep depredation during haul,* during both hauls: during the first haul, all depth and acoustic behaviors displayed by the animal lie within the range of normal foraging behavior, with the exception of a high creak rate of over 30 creaks/h for one dive. During this phase 43% of detected creaks were labeled as creak-pause. During the second haul, the animal's depth range and usual click parameters also lay within normal bounds; however, the dive inflection rate is slightly greater than average, and the creak rate attains or exceeds 30 creaks/h through half the haul, then drops off to nothing for one dive. Only 30% of creaks were labeled as creak-pause.

The water depth at both haul locations was 720 m, so the tagged whale occasionally descended all the way down to the ocean floor during deep depredation and perhaps during natural foraging, although the water depth underneath the animal during the latter state is unknown. Dive inflections and creak rates are highly correlated, with a correlation coefficient of 0.78 .

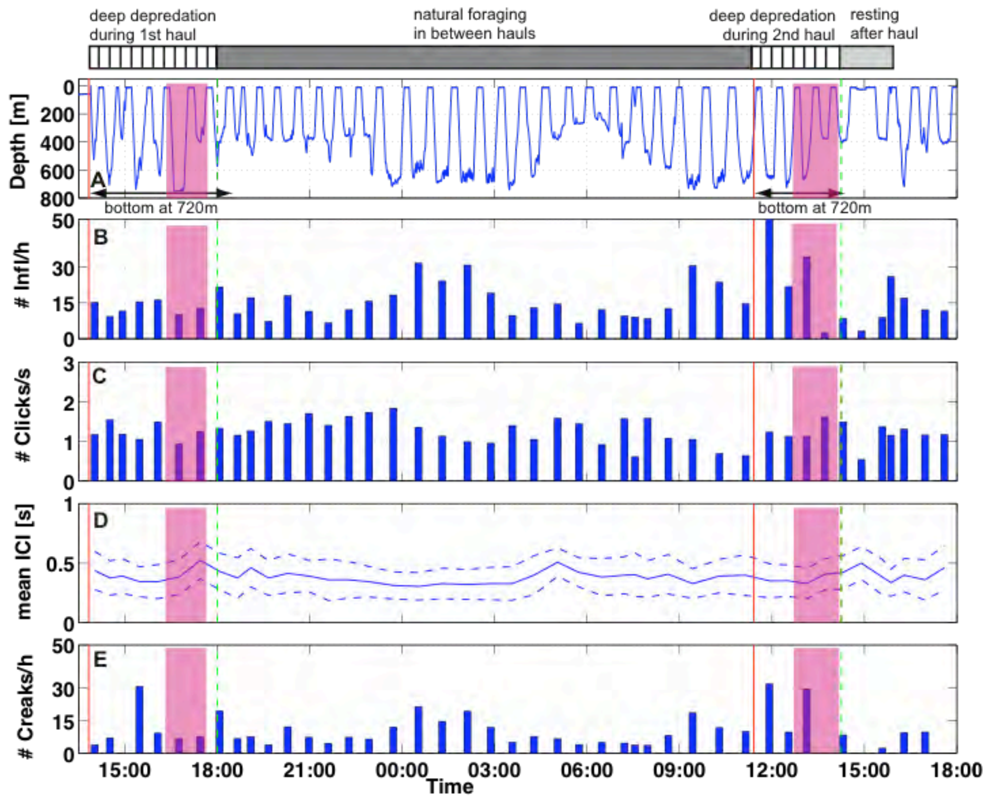

Figure 5: Example of tagging parameters obtained from whale SC-09-3 over two fishing hauls and playbacks, conducted on 12/13 June 2009. A: dive profiles; B: normalized dive inflections per hour; C: mean click rate; D: mean inter-click interval (ICI); E: normalized creak rate per hour. All parameters are defined in Section III.D. A vertical solid line indicates the start of a haul; vertical dashed lines show the end of the haul; shaded areas (pink) indicate playback trials. Top timeline indicates interpreted behavioral mode of the animal.

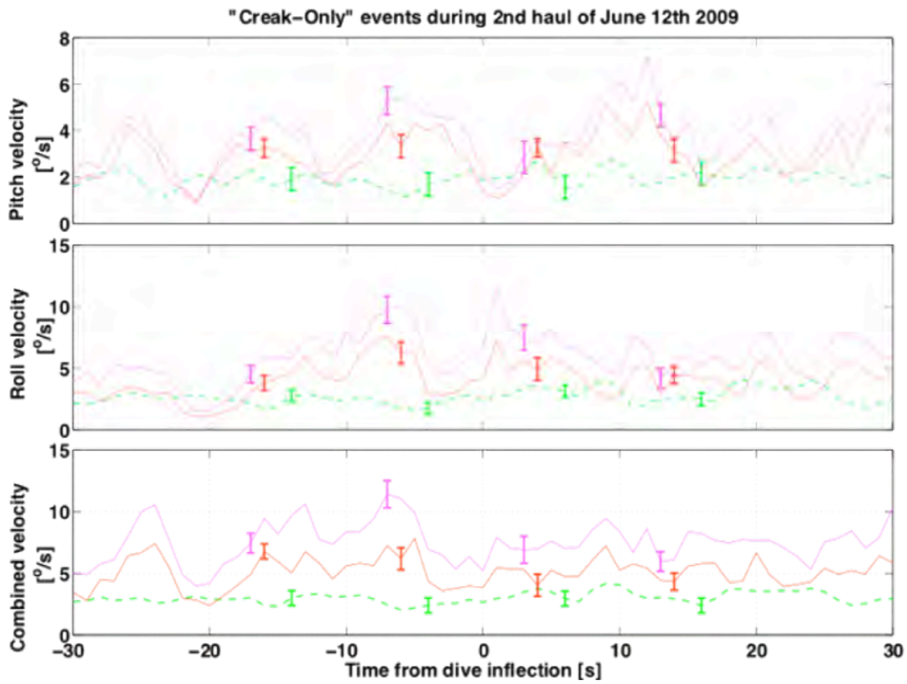

Figure 6: Pitch, roll, and combined angular velocities of 12/13 June 2009 tagged whale SC-09-03, in the vicinity of dive inflections associated with "creak-only" events. Green lines are control periods when animal is not creaking; magenta lines are angular velocities during creak times during hauls with no playbacks; red lines are angular velocities during hauls during playbacks. Green vertical bars indicate standard deviations of the control velocity time series at -15, -5, 5, and 15 s relative to the time of the inflection; other vertical bars show standard deviations of other time series, offset by 1 s for visual clarity.

Figure 6 displays the tag record velocity plots (Section III.E.2) associated with creak-only events, separated by behavioral state. Plots show angular velocities associated with the hauls during playback and non-playback periods, along with control periods. Deviations from the control curve are visible for all angles and for all situations, with the maximum deviations occurring between 5 s and 10 s before the dive inflection.

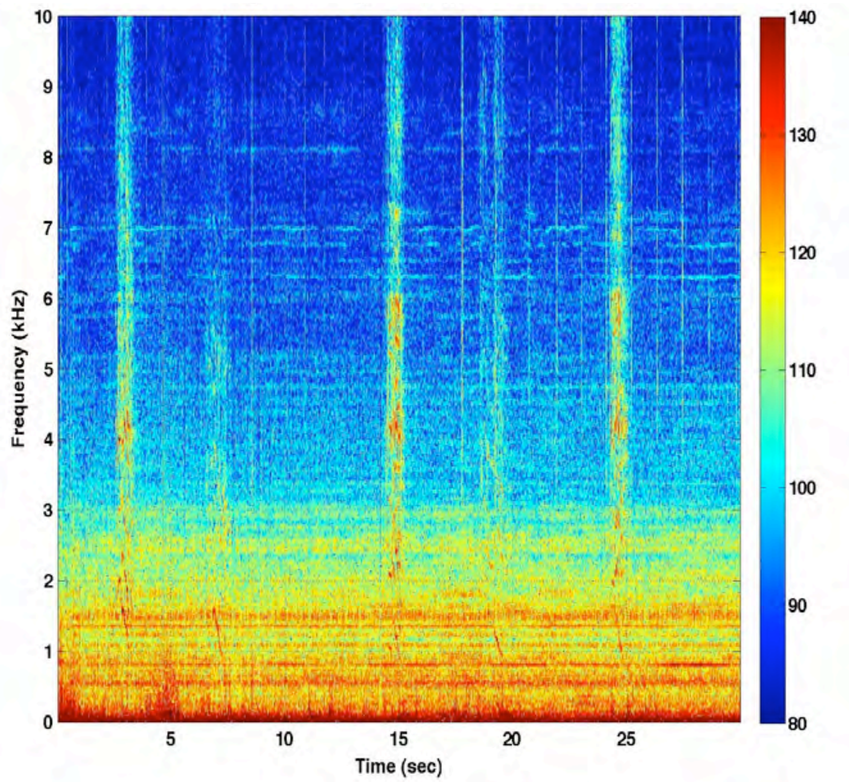

Figure 7: Transient killer whale playbacks detected 2 m away from playback device on 30 June 2009, 13:39:50, at 13 m depth. Fishing vessel haul noises dominate below 1.5 kHz. Color units are in terms of power spectral density (dB re 1uPa^2/Hz)

C. Examples of playback signals, with estimated source levels

Here examples of two types of playback signals in the field are presented: killer whale calls and FM sweeps. Figure 7 displays killer whale sounds recorded 2 m away from the playback projector by the monitoring hydrophone. The peak source power spectral density (PSD) is around 125 dB re 1uPa^2/Hz @ 1 m, (where 3 dB has been added to Figure 7 to convert a 2 m to 1 m range). Between 1 and 6 kHz the total source level is thus roughly $125 + 10*\log_{10}(5000)= 161$ dB re 1uPa @ 1m.

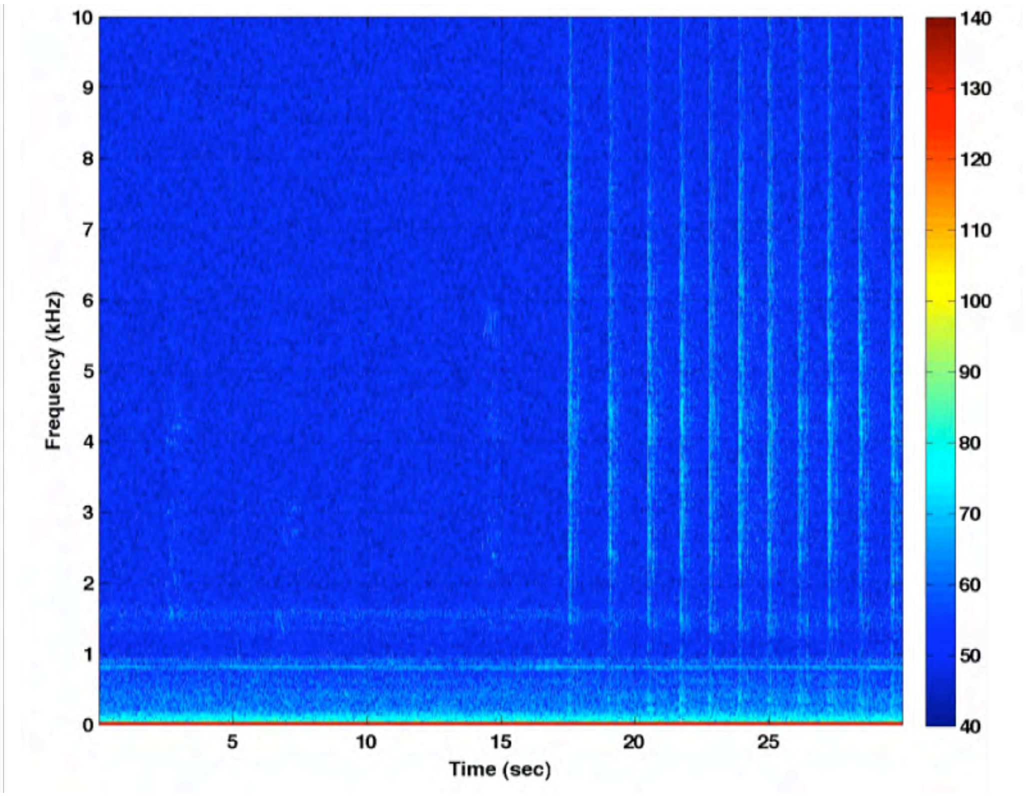

Figure 8: Transient killer whale playbacks detected on an autonomous recorder (Unit7) on 30 June 2009, 13:39:50, deployed 1.3 km away from playback device, at a depth of 200 m. The impulses after 17 s are sperm whale echolocation clicks.

Figure 8 illustrates the same signal as detected by an autonomous recorder mounted on a fishing anchorline 1.3 km away from the playback device. The measured peak PSD is around 65 dB re 1uPa^2/Hz, and by assuming a spherical spreading transmission loss one obtains a source level PSD of 65+ $20\log_{10}(1300\text{ m})$=127 dB re 1uPa^2/Hz @ 1 m, consistent with what was measured by the source. Thus the received levels from the killer whale playbacks have nearly faded to background levels within 2 km of the source.

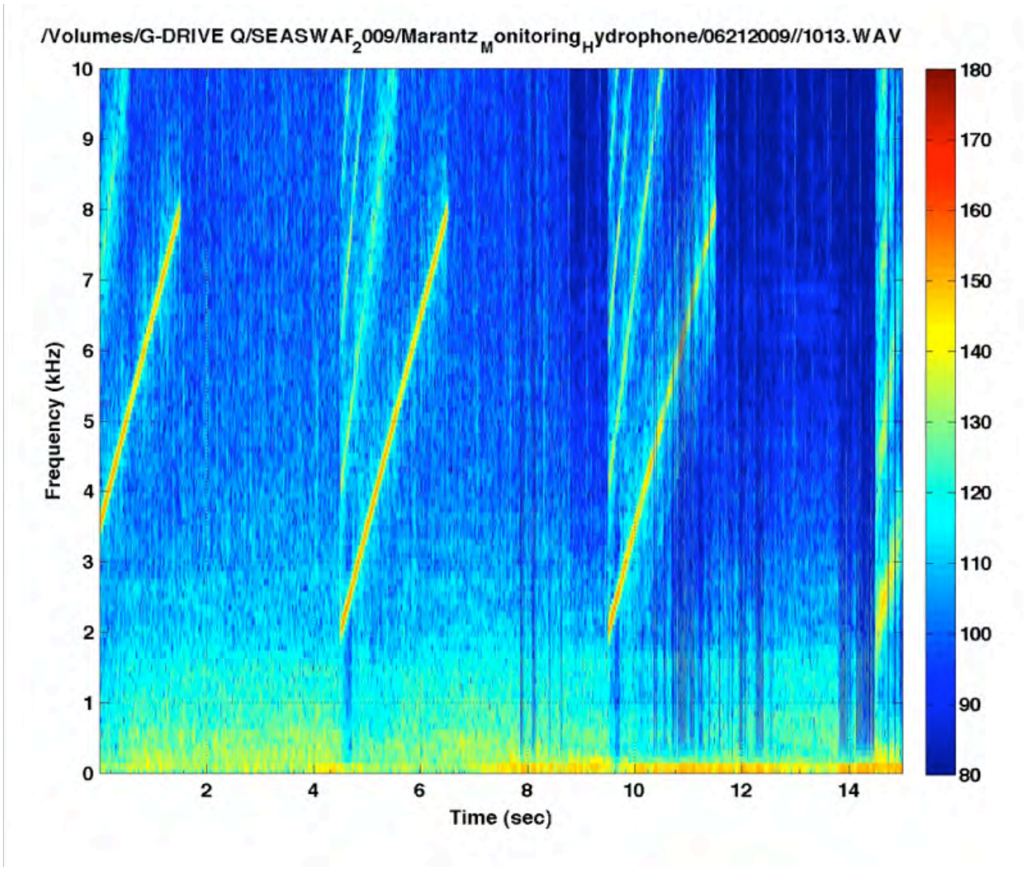

Figure 9: Example of randomized FM sweep played at 19:09:00 21 Jun 2009 1t 15 m depth, measured at 2 m range. Instantaneous source level is 156 dB re 1uPa.

Figures 9 and 10 show the outputs of one of the four FM sweeps synthesized from random selections of bandwidth and duration, played during a time when a whale with a working acoustic tag (SC-09-10) was present. Figure 10 was detected at essentially the same range as Figure 8 and the clarity of the signals demonstrates how narrowband FM sweeps propagated farther than the killer whale sounds, since all the output power of the device has been concentrated into a single frequency bin for the FM sweeps. Instantaneous source levels of the FM sweeps were about 156 dB re 1uPa.

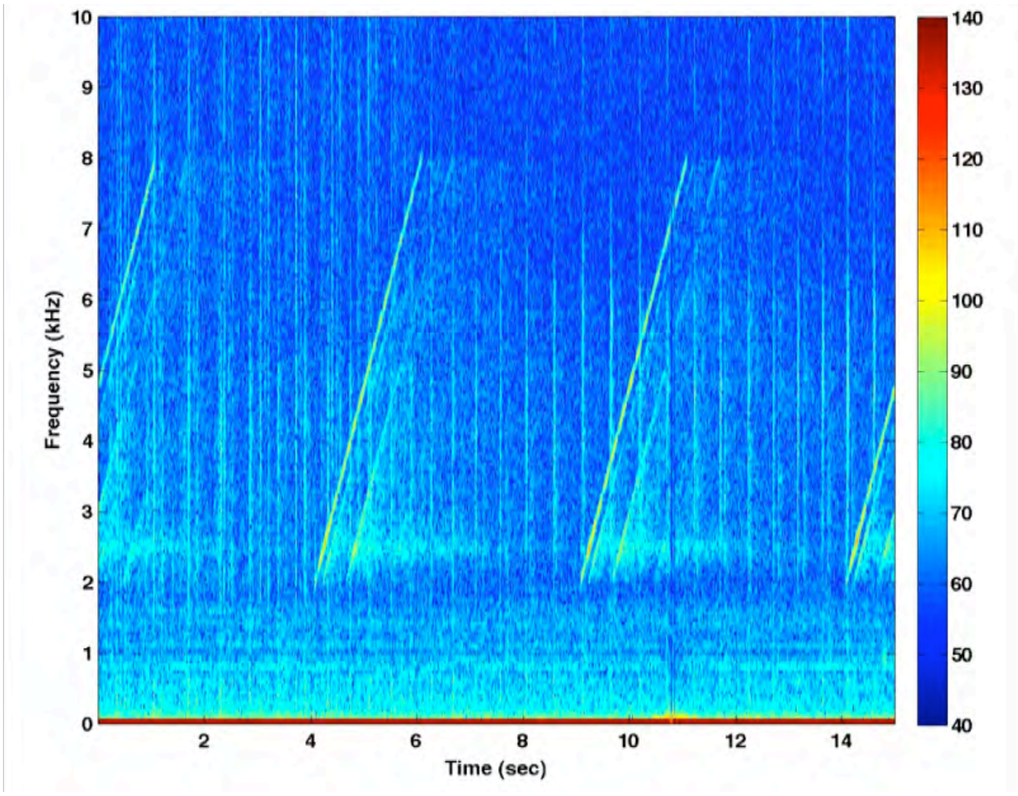

Figure 10: Signal in Figure 9, received at 1.3 km at 250 m depth on Unit 5. Mulitpath arrivals are also visible. The received level of the playback is around 100 dB re 1uPa at this range. Vertical lines are sperm whale clicks.

D. Statistical analysis of overall dive, acoustic, and orientation behavior during haul alone and playbacks during hauls

Tables IV-VI summarize the mean and standard deviations of all tag parameters measured during haul-only and haul-playback conditions. Due to small sample sizes the playback trials could not be subdivided by playback signal type. The significance values of the two-side K-S test are also displayed, with values below the 5% level italicized, indicating rejection of the the null hypothesis that no difference in the statistical distributions exists.

	D_{max} (m)	T_s (min)	T_d (min)	T_b (min)	Infl (h^{-1})	N_d	N_{tag}	N_{ind}
No Playbacks	382.4 ± 149.9	9.3 ± 3.8	28.3 ± 13.3	12.1 ± 5.7	21.1 ± 12.5	32	11	9
Playbacks	440.0 ± 143.3 p=0.26	9.2 ± 2.7 p=0.17	34.3 ± 9.2 p=0.32	14.7 ± 3.9 p=0.28	21.2 ± 13.1 p=0.17	18	8	7

Table IV: Differences in dive parameters of tagged animals between playback/no-playback situations, during times of a fishing haul. Definitions of parameters are provided in Section III.C. N_d: Number of distinct dives used to compute mean and standard deviation; N_{tag}: Number of B-probe tag deployments available; N_{ind}: Number of individual animals available.

D_{max}: Maximum dive depth attained; T_s: surface time; T_d: Dive time; T_b: bottom time; I_{nfl}: normalized number of inflections per hour.

The p-value shows the probability that the distribution for *Playbacks* is drawn from the same cumulative empirical distribution as the *No Playbacks* distribution, using the two-sided K-S statistical test. Italic p-values indicate the rejection of the null-hypothesis of a common underlying distribution (p<0.05).}

Table IV summarizes features of the animals' dive profiles, as defined in Section III.C. Because both DST and B-probe dive profiles exist, dive sample sizes (32 for haul-only and 18 for haul-playback conditions) are larger than the acoustic measurements in Table V. None of the dive profile parameters show significant differences between haul-only and haul-playback conditions.

	T_{Cl1} (min)	$\dot{C}l$ (s^{-1})	ICI (s)	$\dot{C}r + \dot{C}rP$ (h^{-1})	F_{crP}(percent)	N_d	N_{tag}	N_{ind}
No Playbacks	0.3 ± 0.1	1.1 ± 0.3	0.4 ± 0.1	20.1 ± 6.2	62.7 ± 8.1	8	3	3
Playbacks	0.4 ± 0.1 p=0.21	0.8 ± 0.2 *p=0.04*	0.5 ± 0.1 p=0.11	12.2 ± 4.0 *p=0.01*	45.1 ± 6.9 *$p=8.7\times10^{-3}$*	7	3	3

Table V: Differences in acoustic parameters of tagged animals between playback/no-playback situations, during times of a fishing haul. Definitions of parameters are provided in Section III.D. N_d: Number of distinct dives used to compute mean and standard deviation; N_{tag}: Number of B-probe tag deployments available; N_{ind}: Number of individual animals available.

T_{Cl1}: Time of first usual click, relative to start of dive; C_l: mean click rate; ICI: inter-click interval; C_r+ C_{rP}: combined normalized creak and creak-pause rate; F_{crP}: percentage of creak events that are followed by pauses.

The p-value shows the probability that the distribution for *Playbacks* is drawn from the same cumulative empirical distribution as the *No Playbacks* distribution, using the two-sided K-S statistical test. Italic p-values indicate the rejection of the null-hypothesis of a common underlying distribution ($p<0.05$).}

Table V shows the acoustic parameters extracted from the acoustic data recorded on the B-probe tags. Since only three tags recorded successfully, the number of dives available to sample (8 and 7 for haul-only and haul-playback conditions) are much smaller than those with dive profile information, which were able to use additional data from the DST tags. The small sample size also indicates that the acoustic tags recorded during only four playback trials (two on 6/12, one on 6/13 and one on 6/21). Despite this small sample size, the K-S test rejects the null hypothesis for three acoustic parameters: the long-term average click rate, the total creak rate, and the relative fraction of creaks that are followed by pauses. In essence, during playback times the animals are silent for a longer portion of their dive (although when they click, their inter-click interval is relatively unchanged), they make fewer foraging noises, and their “success ratio” F_{crP} falls. Figure 11 compares the success ratio between natural foraging behavior, two different types of depredation behavior encountered when playbacks are not present, and behavior during playbacks. “Shallow depredation” is a form of aggressive depredation where animals dive to relatively shallow depths to (presumably) bite the line directly. No playbacks took place during shallow depredation. The figure indicates that during playbacks the animals' success ratio drops to those of non-depredating (natural foraging) animals.

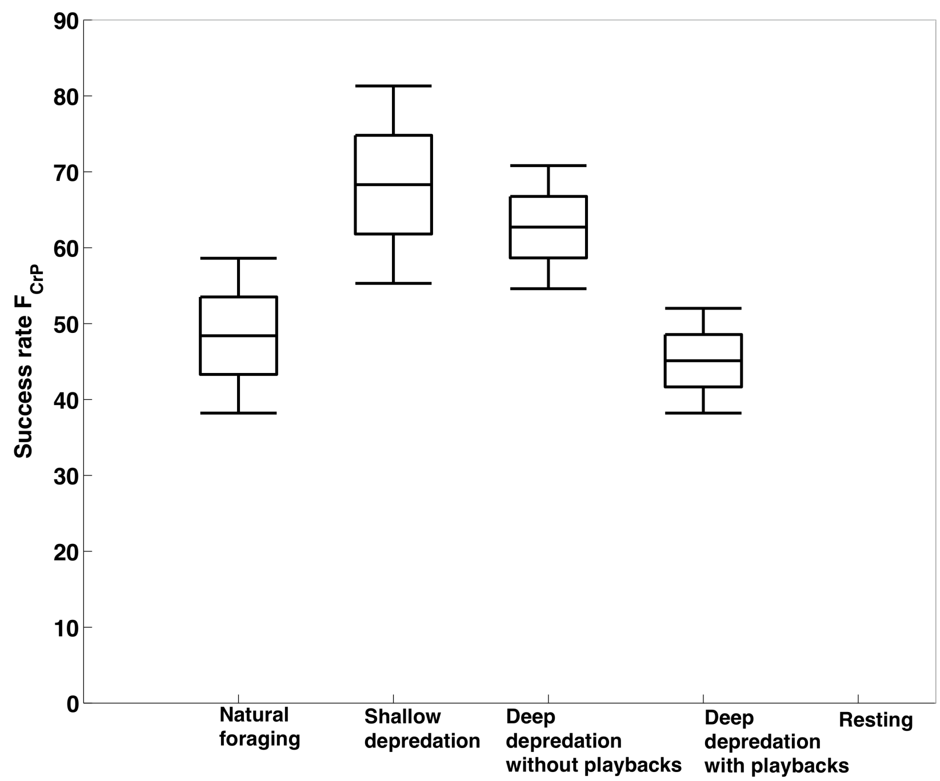

Figure 11: Box plot of F_{crP} for different types of behavior. No creaks were measured during "Resting" behavior. "Natural foraging" behavior is measured when no fishing haul is being conducted. "Shallow depredation" and "deep depredation without playbacks" are behaviors measured during fishing hauls but when playbacks are absent, and "Deep depredation with playbacks" measures behavior during playbacks during a fishing haul. No playbacks occurred to animals displaying shallow depredation behavior.

	T_{dev} (s)	P_{dev} ($^o/s$)	R_{dev} ($^o/s$)	C_{Dev} ($^o/s$)
No Playbacks	6.4±0.7/5.5±0.6 *p=0.07*	5.5±0.4/6.1±0.4 p=0.06	6.2±0.4/7.8±0.6 *p=0.05*	5.9±0.4/7.4±0.5 *p=0.05*
Playbacks	6.5±0.5/5.6±0.5 *p=0.06* p=0.33/p=0.41	5.0±0.4/5.7±0.5 p=0.06 p=0.08/p=0.09	5.2±0.4/6.1±0.5 *p=0.04* *p=0.05/p=0.04*	5.2±0.5/6.0±0.5 *p=0.05* p=0.07/*p=0.05*

Table VI: Differences in rotational parameters of tagged animals between playback/no-playback situations, during times of a fishing haul. Definitions of parameters are provided in Section IIIE. Number of dives, tag records, and individuals used are the same as Table V.

T_{dev}: Time between maximum combined deviation and pitch inflection; P_{dev}: maximum pitch deviation; R_{dev}: maximum roll deviation; C_{dev}: maximum combined deviation.

Each table cell has up to three lines. The first line displays the mean and standard deviation for creak-only/creak-pause events for a given parameter and playback situation. The second line provides a single p-value, displaying the probability that the parameter distributions for creak-only and creak-pause events are drawn from the same cumulative empirical distributions. The third line, if it exists, displays two p-values. The left side indicates the probability that the creak-only distribution for *Playbacks* has been drawn from the same cumulative empirical distribution as the creak-only distribution for *No Playbacks*; the right side is the corresponding result for creak-pause events. All analyses used the two-sided K-S test. Italic p-values indicate when the null-hypothesis that there is the same underlying distribution has been rejected ($p<0.05$).

Table VI shows the analyses of the body rotation of the animals while generating creak sounds, and thus only uses the limited data from the B-probes. The table shows that whales have significantly higher roll rates during creak-pause events than during creak-only events. Furthermore, roll rates during both types of creak events decrease significantly during playback situations. Similar conclusions arise from the combined angular rates, but the pitch rates just miss being significant at the 5% level.

V. DISCUSSION AND CONCLUSION

A. Equipment Issues

One month of field effort yielded a fairly large sample size of tagged animals and acoustic playbacks, but a big disappointment with the fieldwork was the high failure rate of the bioacoustic recording tags. Only three tag deployments recorded, and thus only four of the ten playback trials in Table II are associated with acoustic tag data (although acoustic data from autonomous recorders surrounding the deployment exist for all playbacks). Fortunately, through Cascadia's foresight the bioacoustic tags were also mated with Star-Odi DS tags, which all successfully recorded, providing a solid record of each tagged animals' orientation and depth at ten second intervals.

Several "static" tests of the bioacoustic tags were performed in the field, where the recording tags were dropped to sperm whale foraging depths (300-500 m) and left to record overnight, mimicking the pressures and temperatures of a true deployment. All those tags successfully recorded, so the tag failure cannot be assigned to simply battery failure at cold temperatures. Our best hypothesis as to the source of the problem is that the cold waters of SE Alaska make the tags vulnerable to power spikes caused by the auxiliary sampling (orientation sampling) requirements of the bioacoustic tag. Unfortunately we were not able to test this hypothesis during the fieldwork. We recommend that in the future, all bioacoustic tags should be deployed with auxiliary sampling turned off, relying on the Star-Odi DS tag data for pressure and orientation data instead. Furthermore, we recommend that new generations of bioacoustic tags should have software installed that will automatically reinitiate acoustic recording in case of a temporary power failure.

A second issue with the fieldwork effort was the need to occasionally wait for a day or two for tags to detach after deployment. Cascadia has located suction cups that allow the tag instrument packages to remain attached for more than 24 hours. When hauls can be conducted several days in a row, this long lifetime is not an issue; however, after the last haul is conducted in the presence of a tagged animal, delays in returning to shore of up to two days were experienced, in order to wait for the tags to release. In the future fieldwork should only be conducted when a high likelihood of two or more hauls in short succession is expected.

The playback device performed reliably, and Figures 7-10 indicate that the source levels generated were exactly as predicted. However, the low-frequency transducer (ITC 4004) currently used by the playback device should be replaced. The bandwidth of maximum performance of this transducer is only a few kHz wide on either side of 2 kHz, making it difficult to equalize signals, and to broadcast high-level signals with frequency content between 4 and 10 kHz. A Lubell LL916C underwater speaker has now been substituted for the ITC 4004 in the playback device for future fieldwork.

B. Response to playbacks

Of the various datasets collected during the project--visual surface observations, autonomous acoustic recorders, acoustic tags — only the acoustic tag data were selected for detailed analysis in this report, as those data were expected to produce the highest-resolution data. Unfortunately, the high failure rate of the B-probe tags resulted in a relatively low sample size to analyze, and all playback signal types had to be clumped together into a single “haul-playback” category.

No statistically significant differences were found in the dive profile parameters between haul-only and haul-playback scenarios, including total dive time, foraging time, or mean depth. However, significant differences were found in the acoustic behavior of the animals between playback/no-playback conditions, despite the low sample size. Under playback conditions the relative amount of time the animals spent clicking and creaking decreased. Intriguingly, the “success ratio” of the animals — the relative fraction of creak-pause events (indicating foraging success) to total creak events —

decreased under playback scenarios as well. The results suggest that while the playbacks did not deter the animals from approaching the fishing gear, they potentially decreased the efficacy of the animals in removing fish.

Unfortunately, there are two problems with interpreting this analysis. First, the four playbacks covered by the statistical analysis contained playbacks of FM sweeps, continuous killer whale sound recordings, white noise, and white noise bursts, and at this moment it is impossible to determine whether one particular signal type was responsible for the observed acoustic response. It may be possible to review the autonomous acoustic recordings on the fishing gear for bulk changes of acoustic parameters of all whales detected on the recorders, during all playback sessions, but this is a speculation, as it remains uncertain how reliably creak sounds can be detected amidst the cacophony of several calling whales.

A more fundamental flaw arises from the experimental protocol, in that the playbacks were always conducted during the latter portion of the haul. A possibility exists that as the end of a haul approaches sperm whale acoustic behavior may taper off, even had playbacks not been present. In retrospect, the fishermen should have been asked to begin the playback session at random times throughout a haul. As a precaution the acoustic behavior of two depredating whales during hauls without playbacks (conducted in 2007) were reviewed, to determine whether the success ratio decreases toward the end of a haul. The first whale had six depredation dives during the haul, with success ratios of 0.67, 0.70, 0.78, 0.80, 0.75, and 0.85; the five depredation dives of the second whale had success ratios of 0.86, 0.70, 0.63, 0.89, and 0.67. No evidence exists that the success ratio of depredating animals decreases as a haul progresses.

Regardless of these concerns the fact remains that during playbacks sessions, a measurable acoustic response in the animals was detected. As the animals were highly motivated to remain near the hauling vessel during the playback, it is unsurprising that no change in the animals' dive parameters or location relative to the vessel was detected. A natural follow-on to this work would be to conduct playbacks to sperm whales during times when hauls are not taking place. In all fieldwork with depredating sperm whales we have found that once a haul ends, animals often loiter in the area, but revert to natural dive behavior (e.g. Fig. 5). We suspect that acoustic playbacks during these post-hauling times would generate more substantial responses in dive and positional parameters, especially as the playback sounds would not be masked by vessel noise. Such work requires a scientific permit, which was issued in mid-2010 (NMFS 14122). In 2011 our group plans to mount the playback device on a buoy and conduct further playback tests using the signals described in Table II, using autonomous passive acoustic recorders to observe whether changes in acoustic behavior can be detected without using bioacoustic tags.

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Appendix A: Complete experimental protocol for sperm whale playbacks

Dates: approximately 9 June to 2 July 2009.

Location: Gulf of Alaska offshore of Kruzof and Baranof islands, near Sitka, Alaska.

Vessels: F/V Cobra, skippered by Kendall Folkert, fishing operations

RHIB owned by Cascadia Research, tagging operations

Personnel: F/V Cobra

Fishing-Kendall Folkert and Dean.

Acoustic and visual monitoring, data entry-Aaron Thode, Delphine Mathias, Lauren Wild

RHIB Cascadia

John Calambokidis

Greg Schorr

Jan Straley

Protocol: A single experiment will take place over a two-day period.

<u>Day 1, afternoon/evening:</u>

1. F/V Cobra arrives on fishing grounds between afternoon and evening, prepares to deploy one long set (2-3km) or possibly 2 shorter sets. Tagging vessel monitors location of currently tagged whale, if whale still tagged.
2. Autonomous acoustic instruments deployed around longline in the form of a triangle, one anchorline per instrument. Instruments will sample at 50 kHz. One instrument will be a vertical array.
3. Longline deployed with time-activated cameras (to turn on prior to haul).

4. F/V Cobra drifts near set overnight, or when needed (about every three days) the F/V Cobra will anchor near tagging vessel living platform anchored in Symonds Bay, Biorka Island. Rest overnight.

Day 2, morning

5. Next morning, three hours prior to scheduled start of haul (roughly 11 AM), tagging vessel and fishing vessel arrive at the south end of the set (where the haul will begin).
6. Bioacoustic tag deployed on one whale at least an hour prior to haul. One whale to start, second whale tagged if conditions favorable and sufficient animals present. Whale location/movements recorded by tagging vessel.
7. Monitoring hydrophone deployed off F/V Cobra. The hydrophone is a HTI-96min with 30 kHz recording bandwidth, and data will be sampled at 96kHz and stored on a calibrated Fostex-2 and/or Marantz recorder. A signal generator will be used to feed a known-amplitude white noise signal into the recorder before and after the hydrophone deployment.
8. If whale(s) present, monitor whale behavior, at a minimum, 20 minutes prior to start of haul. See "During haul" for observational protocol. If whale tagged, goal is to record one complete dive cycle (average dive time near a longline vessel is 15 minutes).
9. Haul begins with fishing vessel grabbing anchorline of deployment at scheduled time.

Day 2, hauling

10. During haul:
    - F/V Cobra fishing crew deploys acoustic playback device prior to or during haul, most likely off port bow using a 60 lb lead weight. The device has a timer that starts playback 10 minutes after being activated. Playback signals and cycles discussed under separate "Stimulus Plan".
    - Three observers on board, two on duty, one off duty. They will remain on the bridge and upper deck, out of way of fishing activity on deck.
    - Visual monitor role: documents whale behavior with range finder to measure distance/travel speed, bearing relative to tag vessel, orientation to vessel, activity, dive intervals, count blows if possible, photo identification using digital camera and video footage when necessary. Bearing relative to tagging vessel is recorded because fishing vessel spins often while hauling, and land is often not visible, causing disorientation wrt to vessel heading.
    - Data recorder role: enters whale behavior data (data sheets or computer).
    - The off-duty observer will check signal level recorded by monitoring hydrophone every ten minutes, to confirm device is

operating. Observer will not listen to signal, or communicate status of device to other two active observers.
- If visual observer observes reactions that warrant a shutdown, data recorder role will slip deck box hydrophone over side and initiate shutdown broadcast sequence. Deactivated device will likely not be recovered until haul complete, although it might be lifted to a shallower depth by the observers to minimize likelihood of gear entanglement.

11. Post haul:
    - Visual monitor and data recorder document whale behavior for a minimum of 20 minutes as fishing vessel drifts.
    - Tag vessel continues to follow/record locations of tagged whale(s).
    - Initiate recovery of autonomous recorders if needed. One recorder would likely be recovered and shifted per deployment, as new site would likely be adjacent to previous deployment.
    - Restart step one, or return to Sitka if need to sell fish.

Appendix B: Summary of tag deployments for 2009 JIP Project

Spreadsheet summary appears on next page.

Tag #	SC-09-1	SC-09-2	SC-09-3	SC-09-4	SC-09-5	SC-09-6	SC-09-7	SC-09-8	SC-09-9	SC-09-10	SC-09-11	SC-09-12
DateTimeOn	6/11/09 14:21	6/12/09 7:29	6/12/09 13:53	6/13/09 9:09	6/13/09 10:35	6/14/09 13:47	6/14/09 14:14	6/15/09 9:49	6/21/09 12:14	6/21/09 12:48	6/29/09 16:29	6/30/09 8:37
Year	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009
Bprobe turned on									6/21/09 11:14			
TagType	BP2/DST CT	BP2	BP2	BP2/DST CT	BP2/DST CT	BP2/DST CT	Mk10/DST CT	BP2/DST CT	BP2/DST CT	BP2/DST CT	BP2/DST CT	BP2/DST CT
Tag	B030/DST 224-3	B037	B035	B031/DST 224-4	B032/DST 225-1	B037/DST 226-2	Mk10 DST 224-(	B031/DST 225-2	B030/DST 225-3	B035/DST 226-:	B030/DST 225-:	B035/DST 224-(
VHF Ch	164.306	164.287	164.345	164.306	164.287	164.306	164.427	164.287	164.345	164.306	164.306	164.345
Sp	Pm	Pm	Pm	Pm	Pm	Pm	Pm	Pm	Pm	Pm	Pm	Pm
Region	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK	SEAK
OnLat	56 38.62	56 35.17	56 35.76	56 37.41	56 36.75	56 37.7	56 38.51	56 36.88	56 55.42	56 55.2	56 38.83	
OnLong	135 56.46	135 49.95	135 52.92	135 55.41	135 52.54	135 55.45	135 55.87	135 55.45	135 05.94	135 06.2	135 54.08	
OffTime	6/12/09 12:36	6/13/09 6:15	6/13/09 18:00	6/13/09 11:16	6/14/09 6:00	6/15/09 11:00	6/16/09 13:33	6/16/09 14:41	6/22/09 4:01	6/22/09 14:12	6/30/09 11:35	7/1/09 13:55
Bprobe end data	6/12/09 12:36	6/12/09 9:20	6/13/09 18:00	6/13/09 9:14	6/13/09 10:58	6/15/09 11:00	6/16/09 13:33	6/15/09 10:21	6/22/09 12:10	6/22/09 14:12	6/29/09 16:55	6/30/09 8:50
H-on	22.25	22.77	28.12	2.12	19.42	21.22	47.32	28.87	15.78	25.40	19.10	29.30
H Bprobe data	22.25	1.85	28.12	0.08	0.38	0.00		0.53	0	25.40	0.43	0.22
H-DST	22.25			2.12	18.00	21.22	47.32	28.87	15.78	25.40	19.10	29.30
H-Mk10							47.32					
H any tag	22.25	22.77	28.12	2.12	18.38	21.22	47.32	28.87	15.78	25.40	19.10	29.30
RecoveryTime	6/12/09 12:36	6/13/09 6:32	6/13/09 18:16	6/13/09 12:23	6/14/09 7:30	6/15/09 11:24	6/16/09 15:16	6/16/09 16:26	6/22/09 4:58	6/23/09 22:45		
RecLat	56 37.85	56 37.62		56 39.01		56 37.23	56 21.15		56 47.76	56 45.2		
RecLong	135 54.39	135 52.48		135 55.21		135 54.42	135 39.379		136 01.94	135 57.6		
RecDlat	56.63	56.63	56.622.91	56.65	56.28	56.65	56.65	56.50	56.80			
RecDecLong	-135.91	-135.87	-135.93	-135.92	-135.62	-135.92	-135.92	-135.72	-136.03			
SN#	4	1	5	5	3	3	2		5	6		
Photos - JAC	23-49	1-13,31-33,47-84	23-30,34-37,38-4	35-38	22-26,33-34,92-1	4-8, 9-12, 57-69,	53-56,80-86,98-1	1-13,50-62	36-51,84-97	52-65		1-8,34-65,86-93
Photos GSS	1-13	1-17, 86-130	18-85,131-156		71-76		34-53					
Photos JMS						3-7,8-18,	38-41	1-8, 19-24				
Fr: best ID	JAC-49df	JAC-11	JAC-37	JAC-37df	JAC-24	JAC-160	JAC-56	JAC-13	JAC-96	JAC-53df,64F	JAC-120	JAC-106
ID	NO ID	GOA-85	GOA-47	GOA-103	GOA-106	GOA-104	GOA-90	GOA-107	GOA-107	GOA-105	GOA-81	GOA-47
Skin #	20090611-1 sm f	20090612-1	No, Cobra picks	20090613-1 sm f	No, Cobra picks	No	20090614-1	No				
Sex	Male	Male	Male	Male	Male	Male	Male	Male	Male	Male		
Reaction												
Location on whale												
Cup	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT wh	CT front/CRT white back on float		
Comments	DST CompTilt 224 on board, playbacks done by Cobra 11th PM and on 12th AM while animal in area	Playbacks done by Cobra 12th AM and PM while animal in area, Bprobe pwer probalems stops recording	Playbacks done by Cobra 12th PM while animal in area, this whale had been Sat Tagged w/ 85479 at 13:00 12 June 2009 prior to Bprobe, P/Uby Cobra ~1900	DST CompTilt 224 on board, playbacks not done by Cobra until after tag off	DST CompTilt 225 on board, playbacks by Cobra in afternoon, Bprobe fails within 2 hours, DST starts at noon about the time of Bprobe failure	DST 226 records throughout, Bprobe not recording (double red) when picked up appeared to have failed during night, playback on PM of the 14th while whale in area\	DST 224 on 15 0730, 224 battery at end was 73%, tracked south by Cobra then heads N, picked up	DST 225 on at 0730,225 battery at end was 83%, deployed prior to haul and playback by Cobra, whale had been in apparent aggressive pairing with whale frin 1st deployment on 14th, Bprobe recorded sound only	Bporbe fails at about time of deployment so no data, DST records, Cobra recovers	Bprobe and DST both fully record, pick by Cobra (w/ Greg and Delphine)		
SAT			SAT-7			SAT-10						SAT-7

Appendix C: Lessons learned

While the Conclusion of this report provided some recommendations of lessons learned from this effort, it is convenient to review several logistical and operational lessons learned from the effort in a separate appendix.

Problems with bioacoustic tags

In 2009 the bioacoustic tags had a high failure rate. The same instruments were deployed in the same region in 2007 with a lower failure rate that was still near 50%. Several "static" tests of the bioacoustic tags were performed in the field, where the recording tags were dropped to sperm whale foraging depths (300-500 m) and left to record overnight, mimicking the pressures and temperatures of a true deployment. All those tags successfully recorded, so the tag failure cannot be assigned to simply battery failure at cold temperatures. Our best hypothesis as to the source of the problem is that the cold waters of SE Alaska make the tags vulnerable to power spikes caused by the auxiliary sampling (orientation sampling) requirements of the bioacoustic tag. Unfortunately we were not able to test this hypothesis during the fieldwork. We recommend that in the future, all Bprobe tags should be deployed with auxiliary sampling turned off, relying on the Star-Odi DS tag data for pressure and orientation data instead. Furthermore, we recommend that new generations of Bprobe tags should have software installed that will automatically reinitiate acoustic recording in case of a temporary power failure. Finally, we suggest the JIP try to obtain and use D-Tags whenever possible, and only use the Bprobe tags as a backup.

<u>Sample sizes needed to obtain results</u>

The high failure rate of the Bprobe tags required the study to lump all playback signals into one category to achieve a sample size sufficient to determine whether playback activity caused any change in behavior. We found statistically-significant effects could be discerned from three tag records that encompassed a total of 15 dives, evenly split between playback and non-playback situations. We used the two-sample K-S test, which effectively searched for differences in the shapes of the distributions, as opposed to other tests that only searched for significant changes in the means derived from the distributions.

We would recommend that any future playback studies conducted by the JIP attempt to collect at least five tag records, covering at least 15 dives for playback/no-playback scenarios for *each* general type of stimulus presented (as discussed in the introduction, the actual signals broadcast may vary in parameter values in order to reduce the potential effects of habituation and pseudoreplication). We feel that in retrospect we would have reduced the six available stimulus classes to three, most likely the white noise bursts, continuous orca sounds, and segmented orca sounds.

<u>Equipment Issues</u>

Other than the Bprobe failures, the playback equipment worked very well with a minimum of interference with vessel operations. That said, it makes sense to explore attaching an autonomous playback device to a buoy so that the potential complications of entanglement in fishing gear can be avoided. This approach will be attempted in summer 2011. The ability to remotely disable the device is a crucial factor when such an approach is considered; fortunately, the current playback device incorporates such a system.

<u>Length of vessel haul/playback</u>

The general strategy of deploying the device during the last third of the haul seems sound; it would have been better to try to deploy the device at random times throughout the haul, but that approach raises logistical problems if the deployment is conducted from a fishing vessel. Deploying the playback device from an independent buoy could also times of playback to be randomly varied with minimal impact on fishing operations.

<u>Compensating for weather</u>

Given the short time-frame for fieldwork (one month), the demonstrated ability to deploy twelve tag assemblies and conduct ten playback sessions compares favorability to other playback /tagging efforts. Weather only prevented activities for five days. The issue that was a bigger factor in limiting playbacks was the need to wait and recover tags that had been deployed for a previous experiment. Sometimes these tags would not release until 1-2 days after the playbacks occurred. An attachment system with a timed released may be beneficial under such circumstances, and we encourage the OGP/JIP to collaborate with ONR and other U.S. federal agencies in developing improved “active” and timed suction cup attachments.