SWSS 85186: Final D-tag Cruise Report (02G11)

Compiled by Matt Howard and Ann Jochens in consultation with Science Teams on *R/V Gyre* and *M/V Rylan T.* (see **Table 1**).

Introduction

The second leg of the year 2002 Sperm Whale Seismic Study (SWSS), funded through the Minerals Management Service (MMS), the Office of Naval Research (ONR), and the International Association of Geophysical Contractors (IAGC), took place between 19 August and 15 September 2002 aboard the Texas A&M University research vessel *Gyre* (cruise designator 02G11) in the north central Gulf of Mexico. This leg, reported on here, is referred to as the D-tag experiment after the digital-recording tags used. The first leg of SWSS, conducted 20 June - 8 July 2002, is referred to as the S-Tag experiment because of the satellite tags used.

The IAGC provided funding for the seismic source and technical support crew for the D-tag controlled-exposure experiments. This consisted of the Atlas Boats vessel, *Rylan T.*, with the Fairfield Industries seismic vessel, *Speculator,* mounted on the back deck of the *Rylan T.* Fairfield Industries arranged for the boat modifications and support personnel under contract to the IAGC. Seamap Inc. contributed a prototype passive acoustic system for use on the *Rylan T.*, including hydrophone array, computers/software, and technical team. The *Rylan T.* left Texas City, TX, on 29 August and rendezvoused with *Gyre* on 31 August 2002. The seismic source vessel departed the survey area on 11 September to return to port.

The goals of the D-tag experiment were: to locate and tag sperm whales and monitor their behavior in the presence of controlled exposures to specific sounds, to collect skin and biopsy samples for genetic study, to take photographs of flukes for identification of individuals, and to make oceanographic measurements to characterize the marine habitat. The specific sounds to be presented included foreign and familiar whale codas (called "playbacks") and sounds produced by air guns used in marine seismic surveys. Monitoring included recording the time history of the tagged animal's 3-D location, orientation (roll-pitch-heading), and any sounds produced by or impinging upon the animal.

Despite lost days due to delays and weather, the experiments were an unqualified success. Nineteen sperm whales were tagged. All tags were recovered yielding over 77 hours and 14 Gbytes of digital data. Several notable events occurred including the longest D-tag deployment to date (15hrs), a synchronized dive by a pair of tagged whales, and three whales tagged at the same time. Foreign whale codas were played to tagged animals but, although two attempts were made, uncertainty in the position of the tagged whales precluded the opportunity to playback familiar codas. Most importantly, two controlled-exposure experiments of whales to an operating seismic vessel were achieved, including one with three simultaneously tagged whales. Seventeen fluke photographs were taken of 13 animals for photo-identification and three frame-sets (measured length of animals) were made. Fourteen sperm whale skin samples were collected, thirteen from D-tag suction cups and one from biopsy sampling equipment. The visual team enjoyed 13 days of good visual working conditions and the acoustics team recorded data on 20 of 25 days from two hydrophone arrays aboard the *Gyre*, as well as numerous days from the array aboard the *Rylan T.*/*Speculator*. Thirty-eight XBT probes were dropped, eight CTD casts were taken, and chlorophyll concentrations were measured from 75 water samples. Continuous vertical profiles of horizontal currents were collected whenever whales were not present, and continuous near-surface measurements of temperature, salinity, and fluorescence were recorded whenever the vessel was underway. Daily summaries of each day's events were written by

Matthew Howard and posted to the SWSS website (http://seawater.tamu.edu/SWSS/) by Ann Jochens.

All D-tag and biopsy/genetic typing activities were conducted in accordance with federal permits from the US National Marine Fisheries Service (NMFS) to Peter Tyack/Woods Hole Oceanographic Institution (permits 981-1578-01 and 981-1578-02) and to Dan Engelhaupt/University of Durham (permit 909-1465-01).

D-Tag Cruise (02G11): People and Study Region

The 24 members of the science and support staff are listed in **Table 1a**. Dr. Mark Johnson (WHOI) was the Field Party Chief (FPC) whenever Dr. Peter Tyack (WHOI) was not onboard. Sarah Tsoflias (MMS) joined the *Gyre* at sea. The science team aboard the *Rylan T.* consisted of Dr. Bill Lang and Carol Roden of MMS, Natacha Aguilar de Soto (WHOI), Sandy Sawyer of Fairfield Industries, and Craig Douglas and Tim Pinnington of Seamap, Inc. **Table 1b** lists the personnel and their tasks participating on the *Rylan T*. Natacha Aguilar de Soto was in charge of permit compliance monitoring for the seismic vessel and worked aboard the *Rylan T.* whenever there was a chance that whales would be approached by the *Rylan T.* when the *Speculator*'s air guns were operating. When not on the *Rylan T.*, she assisted with the acoustics work on *Gyre*.

The study was conducted between the 700-m and 1500-m isobaths, mainly in on or near the 1000-m isobath, between 93°W and 88°W in the northern Gulf of Mexico. This region includes the continental slope south of the Mississippi River delta between the Mississippi and DeSoto Canyons. Based on historical sightings and recent reports from satellite-tagged (S-Tag) whales, we knew there was a high-probability of encountering pods of sperm whales in this area.

Mobilization for the D-tag cruise began on 18 August. Due to flooding and bad weather in Galveston the week before, the completion and testing of the launch ramp system for the 5000^+ pound MMS R2 tag boat was delayed until the 19th and 20th. On the 20th, the science team requested that the Oregon State University tag boat be outfitted with a back brace and mount for the tagging pole in case this boat would be needed as a back-up; these were constructed and added to the boat before the cruise departed. The Gyre left the dock at Galveston at 0200 on September 21. Additional time was lost during the cruise due to two unforeseeable events: a crew family emergency and an engine failure. A total of 3 days out of 28 were effectively lost for the above reasons. A further 10 days were lost to poor weather leaving a total of 15 days for the transit to-and-from Galveston and for the tagging project. Tagging was attempted on 11 out of 13 fair weather days and tags were deployed on 10 days.

Figure 1 shows the ship track for three periods. The first panel shows the transit from Galveston to Mississippi Canyon where we first encountered sperm whales and tagged four of them (sw235a,b,c & 236a; see **Table 2**). On 25 August we moved northwest to 28.6°N and 89°W, a location we would revisit several times later in the cruise. Nine whales (sw237a-sw240c) were tagged in the vicinity over a 5-day period. We transited to DeSoto Canyon on 29 August, but found few whales there. Due to a family emergency we put the deck engineer ashore in Gulfport, MS, on 30 August.

The second panel of **Figure 1** covers the middle period of the cruise from 30 August to 8 September. During this time we rendezvoused with the *Rylan T.* (31 August) and worked whales between the Main Pass and DeSoto Canyon. Weather and sea-state hampered operations (see under Tagging below for additional information). On 5 September, after tagging one whale (sw248a) we followed a group of whales south, overnight, into the western edge of a cold-core eddy. There we tagged one whale (sw249a) before *Gyre* and *Rylan T.* were chased by bad weather to an area west of the Mississippi. The ships remained anchored there for two and a half days to avoid the remnants of Tropical Storm Edouard to the east and the growing Tropical Storm Fay to the west.

The third panel of **Figure 1** shows the track for the third period covering 9-15 September. During this period, we returned to the region near 28.6°N and 89°W with the *Rylan T.*/*Speculator* and achieved several successes including the controlled-exposure of one (sw253a) and three tagged whales (sw254a,b,c) to the air gun sounds. These crucial controlled exposures were made possible by a two-day extension of the *Rylan T.* contract by the IAGC. After the departure of the *Rylan T.* on 11 September we steamed westward looking for smoother water. On 14 September the tag team approached a large male, but was not able to get close enough for tagging operations. The biopsy/photography team then went out for a few hours. After they finished we headed for Galveston, TX, arriving at 8:30pm local time on 15 September.

General Operations

Operations generally were conducted in accordance with the D-tag cruise plan of 9 August 2002. Upon reaching the study area, a combination of visual and acoustic searches were made to locate whale pods and to follow individuals. The visual search comprised two watches on two-hour rotations using high-power (x25), large-format "BigEye" binoculars. The acoustic search effort comprised two watches, each using one or two hydrophone arrays in conjunction with custom software to determine relative bearing to individual whales. When whales were located, the visual and acoustics team worked together to track the group and collect pre-exposure observations. During daylight hours, the range and relative bearing to each whale was collected visually using Big-eye binoculars and these data were entered into custom software to resolve and record the whale's locations in geographic coordinates. The acoustics team recorded bearings to whales and the start-times and end-times of dives (as determined by the regular clicking of sperm whales). Digital tape recorders captured continuous records of the sound fields detected by the hydrophone arrays. The acoustics search and tracking effort operated day and night. Similar acoustic operations were conducted onboard the *Rylan T.* The success of the search effort is demonstrated by the fact that whales were located and tracked on 12 out of 13 fair weather days.

Additional information on sperm whale locations was available through daily reports provided by Oregon State University on S-tagged whales. During leg 1 of the SWSS cruise (20 June - 8 July 2002), 18 sperm whales were tagged. **Figure 19** shows a composite of locations of S-tagged whales on 4, 7-8, 11, and 13 September 2002, as reported to the D-tag team by Tomas Follett of Oregon State University. During the D-tag leg, several of the S-tagged whales were sighted.

During daylight hours, when whales were present and the sea-state acceptable, an attempt was made to place a digital-recording tag (D-Tag) on the animals using a 46-ft carbon fiber spar mounted on one of two small boats. The tag **(Figure 2)** contains a 3-axis accelerometer, pressure sensor, compass, hydrophone, VHF beacon, 2.2Gb of solid-state memory and a pair of active suction cups. Playback of recorded whale codas was done by playing a CD through a projector suspended beneath the tagging boat. Air gun sounds were provided by the seismic vessel *Speculator*, mounted on the back deck of the *Rylan T.* **(Figure 3).** These sounds also are called "seismic playbacks", even though they are made directly by the seismic vessel's actual air guns. The *Speculator* hosts a 1680 cubic-inch air gun system, which produces an acoustic signature nearly identical to that of a deepwater 3D airgun array at the distances required to be maintained from the whales on this cruise.

Habitat characterization was achieved by measuring temperature, salinity, fluorescence, chlorophyll, and currents on a not-to-interfere-with-tagging basis. The flow-through systems were run continuously and XBTs were dropped at will. The ADCPs were operated primarily during long straight runs to new locations. CTD casts were taken when the acoustic arrays were onboard and time permitted the ship to stop for sampling.

Biopsy/genetics sampling was dependant on obtaining skin samples. Most of the tags had fragments of skin stuck in the suction cups. One biopsy sample was taken by Dan Engelhaupt, on the last day of operations, using the dart method of sampling.

Both the *Gyre* and the *Rylan T.* passed over EARS acoustic buoys deployed by the Navy near 28.5°N 89.0°W. This will provide some quantification of sound emissions from the two vessels.

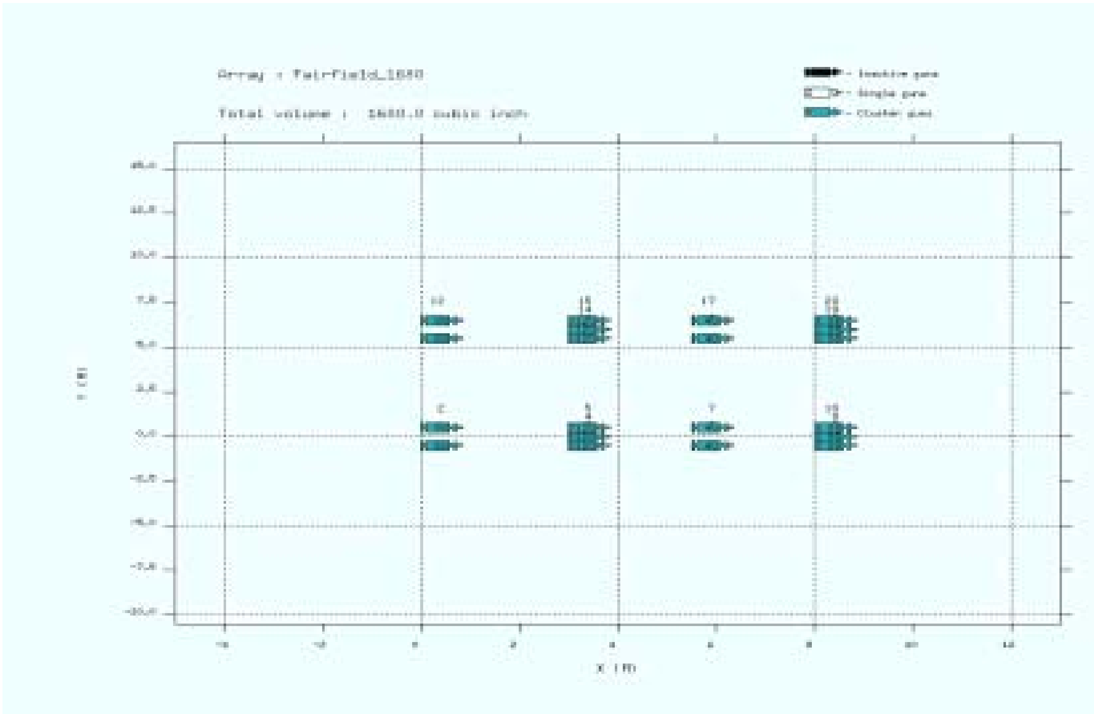
Fairfield 1680 in^3 Airgun Array

During the D-tag portion of the SWSS 2002 project, the IAGC provided a representative airgun source for use in the controlled exposure experiments conducted by the WHOI research group. This airgun array consisted of 20 external sleeve type airguns arranged on two separate gun strings (10 guns per string). The array volume totaled 1680 in^3 and had areal dimensions of 8m long by 7m wide. It produced a nearly identical acoustic signature as that of a deepwater 3D airgun array at the distances required to be maintained from the whales on this cruise. Airguns were towed at a depth of 6m. A schematic of the system is shown in **Figure 20**.

The array and the required air compressors, air-lines, control electronics, and electrical connections were rigged out on Fairfield Industry's shallow water vessel *Speculator*. In order for the array to be used in the deep water research area, Fairfield arranged for the *Speculator* to be piggybacked on the deep water service vessel *Rylan T*.

The array produced a vertical far-field signature with a theoretical point source response of around 252 dB re 1μPa in the 3 to 800 Hz frequency band, as shown in **Figures 21 and 22**.

Because of the areal dimensions of the array, the pressure signal varied as a function of azimuth and emission angle (i.e., angle from the vertical). In order to predict maximum acoustic pressure levels at various distances from tagged whales a set of signatures were modeled for emission angles for various distances corresponding to a tagged whale at a depth of 1,000 m. **Table 3** was then complied to guide the researchers in controlling the source exposure within the limits of the scientific permit allowing these tests.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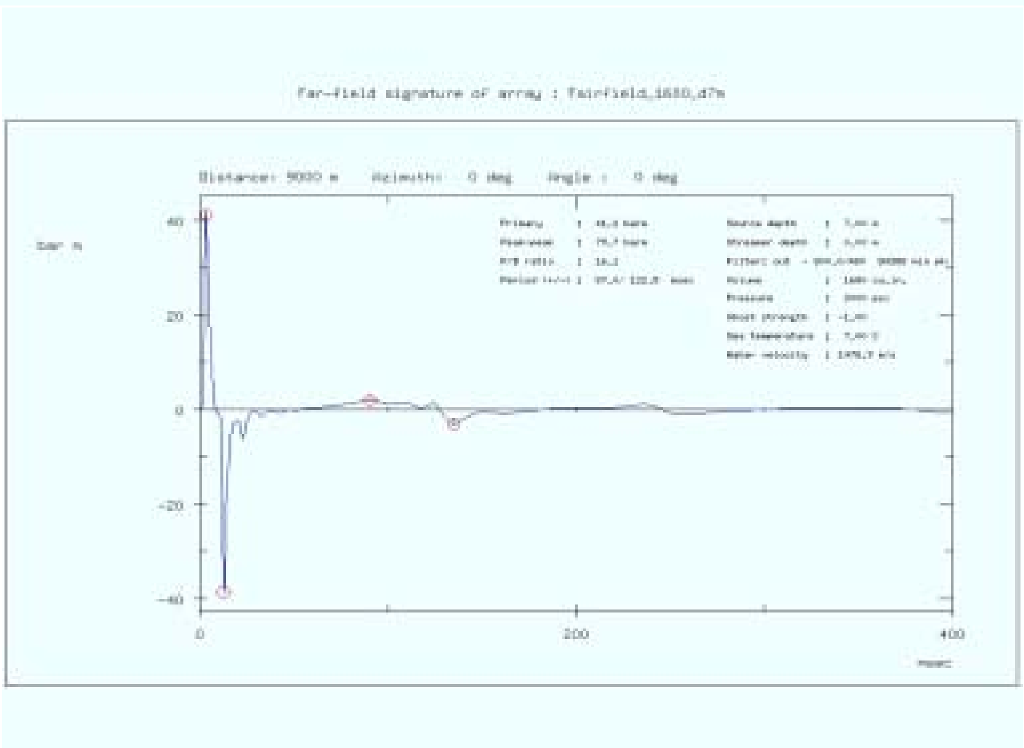
Total volume : 1680.0 cubic inch
X (m)


Far-field signature of array : Fairfield_1680_d7m
Distance: 9000 m Azimuth: 0 deg Angle : 0 deg
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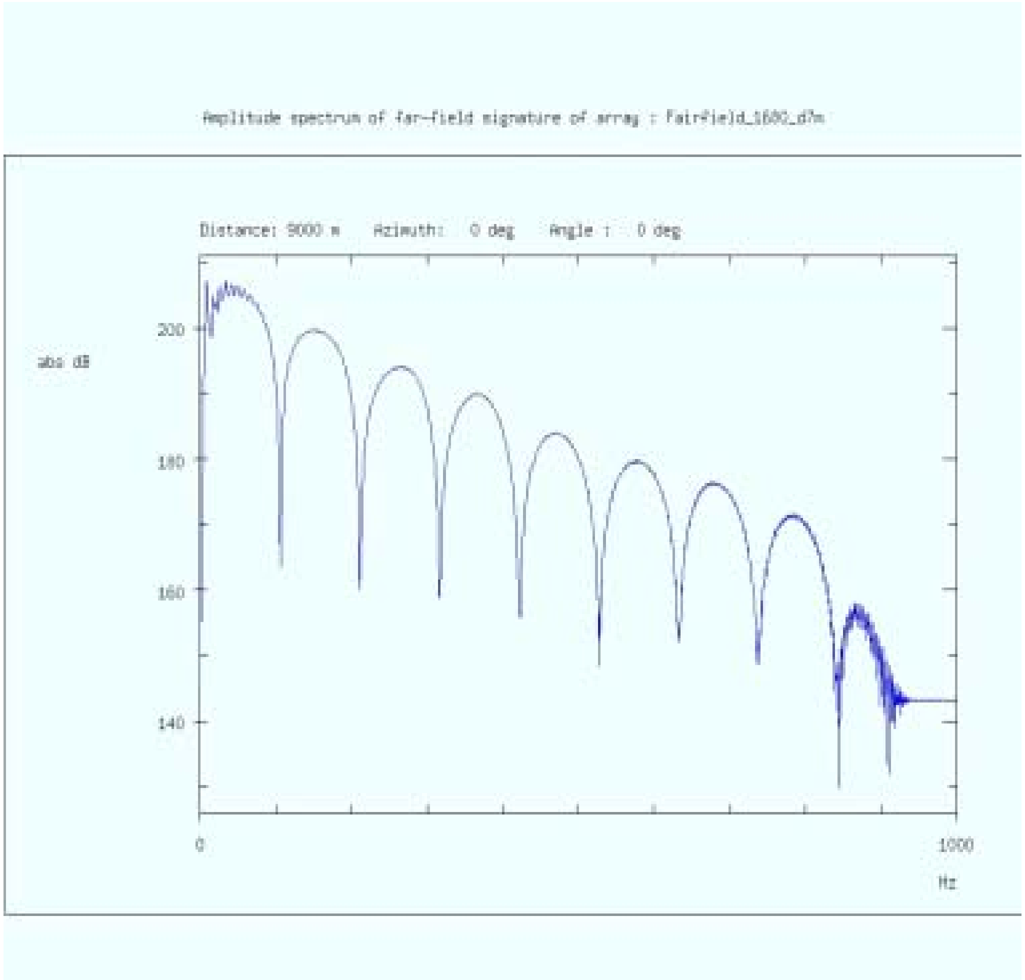
20
0
-20
-40
0
200
400



Visual Survey and Monitoring

Visual survey operations were similar to those described in the D-tag cruise plan. During the day, the visual team controlled the direction of the *Gyre*. Two teams of four visual observers kept watch from the flying bridge from dawn to dusk. Their job was to locate sperm whales, keep track of the location and time of "blows" (breathing at the surface) and "fluke-ups" (a behavior indicative of the initiation of a deep dive), to guide the tagging team into proximity of targeted animals, and to keep track of the D-tags after they were deployed. This last item is the notable distinction between operations during the S-tag cruise and the D-tag cruise. Once an animal was tagged with an S-tag, it received no further special attention by the visual team. On the D-tag cruise, however, when one or more whales were tagged, both visual teams went on watch. One team continued normal operations while the other team focused on following the tag. Although sightings of other marine mammals were noted and logged, the emphasis of the work was on sperm whales.

Three sets of BigEye binoculars were available to measure distance and relative bearing from the ship to animals. Distance was computed via geometry using the known altitude of the binoculars in conjunction with reticule markings in the eye-pieces. From the flying bridge of the *Gyre*, the horizon was approximately 12km away which yields a searchable area of approximately 450 km^2. As each animal was sighted, the observer relayed the reticule and relative bearing information to the data entry person. These data were entered into the "Logger 2000" software along with information such as animal behavior (blow, fluke-up) and heading (the data collection software, "Logger 2000", was developed by the International Fund for Animal Welfare to promote benign and non-invasive research). Eddie Webb (TAMU) provided a custom navigational data string, updated every second, containing ship's heading and location to the Logger software. This information, when combined with the relative bearing and distance from the binoculars, produced a latitude and longitude fix for each animal. **Figure 4** shows the locations of sperm whale sightings by date. **Figure 5** shows a typical plot of the relative bearing vectors to the sighted animal along the *Gyre* ship track. This information is stored in a Microsoft Access database. In practice, about 12 animals at a time can be followed visually using this system.

When one or more animals have been tagged, the second watch comes up to the flying bridge to follow the tag. They do this visually and by means of radio beacon tracking equipment designed to receive the VHF signal from the tag. The beacon can only be heard when the tag antenna is out of the water. The tagging team tries to place the tag high on the animal near the dorsal fin because this area of the animal is frequently out of the water when the animal is at the surface. The tag is designed to float with the antenna in the air when it is not attached to an animal. Thus, an intermittent signal usually indicates the tag is still on the animal while a continuous signal usually indicates the tag is off the animal and is floating at the surface. Often, the tag will remain on after dark, sometimes almost to dawn. The task of monitoring the radio equipment after dark was primarily borne by the visual team. The beacon frequency is different for each tag. When two or more tags were deployed, two or more VHF units and monitors were needed. At one point, three tagged animals were being worked. This would appear to be the practical limit both for the visual observers and the VHF monitors given the equipment and personnel available.

Tagging

A typical sperm whale dive cycle begins with a 10-15 minute period at the surface followed by a 40-50 minute dive. During the dive the animal may move laterally some 500 to 1000m. Therefore, the tagging team, which normally operates within the large visual survey region, needs timely information to intercept whales at the surface. Often they will arrive in the vicinity just as the whale dives. The tag team then stays in the general area using acoustic tracking equipment on the tag boat so as to be close to the whale at the next surfacing. Some whales were skittish and difficult to approach. At such times the whales either speed up or execute a series of shallow dives changing direction as they do. Other whales were unperturbed by the boat's approach. The triple tagging was accomplished on such a day.

The tag team consisted of Mark Johnson, Patrick Miller, and Alessandro Bocconcelli. On days when tagging was possible they usually departed between 8 and 9am, returned once between noon and 3pm for a few hours to service a recovered tag, and went out again returning for the day around dusk (~7:15pm). If a tag stayed on for more than a few hours Mark and Patrick frequently worked quite late, often between 1-4 am, recovering and downloading tags. Three D-tags were available for use, but once used, each required several hours to download and refurbish.

Nineteen whales were tagged during the D-tag experiment as shown in **Table 2**. Fourteen animals completed at least one dive before the tag came off. A total of 65 deep dives were recorded. **Figure 6** shows a map of the locations where whales were tagged. **Figure 7** shows a 2-D representation of the 3-D trajectory of two tagged whales that dove together. The record shows the animals dove to 500m depth and traveled horizontally some 1500m before surfacing.

A key goal of this cruise was to conduct controlled-exposure experiments using a seismic source. The seismic source vessel, the *Rylan T.* with the *Speculator* on deck, rendezvoused with *Gyre* on 31 August. Whales were in the area, but so was at least one other seismic vessel and efforts were made to move away from that vessel. Weather also became a significant problem as two tropical cyclones, Edouard and Fay, impacted the survey area. During the time the *Rylan T.* was at sea, weather conditions were generally poor to bad, making tagging operations difficult. Personnel were not transferred between the *Rylan T.* and *Gyre* until the evening of 2 September. Natacha Aguilar de Soto was transferred to the *Rylan T.* and Peter Tyack and Sarah Tsoflias were transferred to *Gyre*. Much of 3 September was spent trying to locate whales acoustically, with the visibility too poor for successful visual operations. The tagging efforts on 4 September were curtailed due to rising seas, after two unsuccessful tagging approaches to whales by the tag boat. On 5 September, no whales were found until late afternoon. One whale was tagged (sw248a), but the tag did not stay on long enough to conduct experiments. A whale was successfully tagged on 6 September (sw249a), but the tag came off just as the *Rylan T.* began to prepare for a seismic test; skittish whales prevented additional tagging that day. Tropical Storm Fay prevented all activities for two days, as both vessels anchored in shelter. On 9 September, the *Gyre* and *Rylan T.* returned to the survey area and located whales acoustically in the afternoon. September 10 provided the first successful controlled-exposure experiment using the seismic source; the tagging (sw253a) was done in sea state conditions that were becoming marginal for small boat operations and with rain and squalls in the area. September 11th provided another successful experiment, with three whales tagged (254a-c) for a period extending well beyond the seismic source testing. After the seismic source test on the 11th, the *Rylan T.* headed into port. On **Figure 8** are shown the relative positions of the *Gyre* (coinciding with the black cruise track) and the *Rylan T.* during the ramp up of the air guns and the seismic test. The locations and air gun transmission levels for 10 September are in browns and for 11 September are in blues; the scale is shown on the right, with 1680 in^3 being maximum. **Table 4** shows the ramp-up/mitigation timeline for the two controlled-exposure experiments using the air guns. During these experiments, there was visual and acoustic monitoring on the *Rylan T.* to ensure no sea turtles or sperm whales were in the immediate area of the vessel during ramp-up and firing operations per permit requirements. The experience between 31 August and 11 September indicates that future cruises should be conducted earlier in the hurricane season to increase the likelihood that the weather conditions will be more amenable to tagging efforts.

Two tag boats were available to use during tagging activities. The MMS tag boat (R2) was intended to be the primary vehicle. However, during pre-tagging activities (radio range checks and calibration of the acoustic arrays) the check engine light came on first on one and then both of the Mercury 135hp Optimax gasoline engines. The boat was brought on board and an attempt was made to diagnose the reason for warning lights. The fuel system was checked by Captain Dyer and found to be in good condition. Numerous calls were made to the Mercury repair centers on shore but nothing was resolved, so a decision was made to use the Oregon State University diesel-powered tag boat. The OSU boat was used until the end of August at which time the starter motor on it failed. Although the cause of the engine light on the MMS boat was not resolved the engines started easily and ran acceptably, albeit noisily at high rpm. Left with no alternative, the MMS boat was put in service and all further tagging operations were conducted from this boat. The OSU boat was deployed from the port side of the *Gyre* using the ship's crane while the R2 was deployed from a custom launch ramp over the fantail. Both deployment/recovery methods were usable in all sea conditions appropriate for tagging. Despite the more cramped fore-deck on the OSU boat, its low noise diesel engine and simple deployment method made it the preferable boat to use from the *Gyre*.

Acoustics Monitoring

Two watches staffed the acoustics lab aboard the *Gyre* rotating day and night. At night when whales were present, the acoustics team dictated the course of the *Gyre*. Two acoustic arrays were available, each with different acoustic characteristics. The first was the Ecologic acoustic array. The second array was the WHOI array, which had a "towfish" sometimes called a "batfish" depressor that pulled the end of the array into a somewhat vertical orientation with the bottom at a depth of 140m or so. In principle, the Ecologic array could be towed faster as it had no depressor and was allowed to stream out horizontally behind the vessel. Both hydrophone arrays were used during the experiment and both fed their signals into the software package called "Rainbow Click," written by Douglas Gillespie of the International Fund for Animal Welfare (to promote benign and non-invasive research), and "Ishmael," written by David Mellinger of Oregon State University. These programs have many features, but primarily allowed the acoustic team to determine the relative bearing to many whales at once **(Figure 9)**. There is a left-right ambiguity in the relative bearing which is resolved by turning the ship to different bearings and following the change in relative bearing. **Figure 10** shows the portion of cruise track where each array was used. The number of acoustic contacts by geographic location are indicated by **Figure 11.**

During the S-tag cruise a noise was reported in the Ecologic array at a frequency of 19kHz. This noise was observed on the D-tag cruise as well. It was ruled out that this might be due to sub-harmonics of the 38kHz ADCP system because the noise was at 18.45kHz and was a continuous signal, whereas the ADCP has a pulse signal that makes a distinctive discrete signal resembling a vertical array of short horizontal lines when displayed in Rainbow Click. Aaron Thode worked with the ship's engineer to try to locate a shipboard electrical source for the noise but none was found. Eventually, it was noticed that the noise did not show up in the WHOI array at all. On the S-tag cruise, the problem had been eliminated by using a different top-end amplifier/conditioner unit. The offending amplifier was returned to the manufacturer and the "quiet" amplifier left for use on the D-tag cruise. However, when the same noise was present on the D-tag cruise, it was eventually cured by replacing one of the hydrophones and preamplifiers in the streamer suggesting that a faulty hydrophone preamplifier was the cause. A further problem developed when the cable was damaged, apparently through being towed with a kink in it. Initially this limited the tow speed to 3knots but eventually the cable failed completely. To cure this the cable will be either replaced or respliced. The WHOI array proved more reliable but restricted the vessel speed to 4.5kts. This was useful for monitoring whales already known to be in the area but was too slow to search for whales over large areas.

Twice during the cruise ranging experiments were performed to estimate the detection range of the arrays. On 29 August, during a time when no sperm whales were present, a small workboat was deployed from the *Gyre* and driven to points 1.5 and 2.6 nautical miles from the ship. At these two points light bulbs were imploded underwater to generate an impulsive sound roughly like a sperm whale click. The implosions were clearly heard at 1.5 nm on the WHOI array, but barely heard, if at all, at 2.6 nautical miles, suggesting an effective detection range of 4 km, much lower than the 10 n.m. range or higher reported in the Pacific (Barlow and Taylor 1998).

An additional detection test was performed on a sperm whale group using the Ecologic array on 3 September, when the seismic source vessel *Rylan T.* was present. While the *Rylan T.* remained in the vicinity of the pod, the *Gyre* drove directly away from the group until sperm whale sounds could no longer be heard, then turned around and determined when the click sounds became audible again. At a speed of 3.3 knots the Ecologic array had a detection range of about 3.5 km, very close to the WHOI array performance.

One reason behind the limited detection range was ship noise. When the *Gyre* was commissioned in 1973 it was not designed to be acoustically silent. The WHOI array, in particular suffered from ship noise contamination, as the towfish pulled the array not only deeper, but closer to the ship. It was found that whenever the ship traveled slower than around 2 knots, one of the engines would have to be disengaged, creating a large amount of noise. Even at higher speeds the WHOI array was effectively awash in prop noise.

However, previous acoustic D-tag work in the Gulf on a different ship with different arrays has produced similar results, suggesting that propagation conditions in the Gulf are fundamentally poor for long-range acoustic propagation. XBT and CTD data collected during the cruise show that the effective vertical sound-speed profile in the study region showed a very strong decrease in sound speed with depth, a feature that would be expected to refract acoustic energy into the ocean bottom, away from the surface. **Figure 12** below shows an example of an average sound speed profile (red line), as well as the largest perturbation from the mean profile observed, created after a week of rough weather and storms had mixed the upper 50 m of the ocean (blue line).

The agreement of a numerical simulation with the empirically-measured detection range results suggests that poor propagation conditions are a fundamental fact of life in the Gulf, and simplified acoustic propagation assumptions like cylindrical spreading are inappropriate for the region. **Figure 26** is of a numerical propagation with energy reaching the surface between 3-6 km. If a towed array system is well-designed and deployed from a quiet vessel, then the detection range might be extended to about 6 km, a threefold increase in search area. The only way to improve detection range further is not by increasing array depth, but by increasing the array gain by incorporating additional hydrophones into an array system. For example, the *R/V Alliance*, a quiet ship using a 128 element hydrophone array, is able to achieve detection ranges in excess of 20 n.m. in summer-stratified conditions in the Mediterranean Sea.

Acoustic monitoring on the *Rylan T.*

The passive acoustic system onboard the *Rylan T.* was provided by Seamap Inc. (http://www.seamap.com). The system consisted of an oil filled passive acoustic listening array, 56 meters long, which was connected to the vessel via a 300m tow cable. The array was deployed astern of the *Rylan T.* such that the head of the array was 250m from the stern. The array was ballasted to maintain 40 meters depth when towed at 5 knots. At this tow speed, the array was able to detect sperm whale vocalizations out to a range of 5-6 km. During transit between areas, the *Rylan T.* steamed at speeds between 7 and 8 knots. At this higher speed the array maintained depths between 8 and 10 meters. During the higher speed steaming, the array was fully functional, but the effective range was reduced from 5-6 km to 3-4 km. Still higher towing speeds could have been supported with the use of supplemental ballasting, which was available on the vessel in the form of hinged weight collars.

The towed array comprised two channels configurable from a selection of any combination of 4 hydrophones. The distance between the outer phones was 50m with the two center phones between these placed at frequency thirds. The onboard system was configured to two of these groups with a hydrophone spacing of 5.55m. This separation was chosen as optimal for sperm whale detection.

The system offered a suite of visualization and detection facilities that monitored audio frequencies in real time from 8Hz to 22000Hz and also recorded acoustic data in a proprietary format that subsequently was exported in "wav" file format. The system also was interfaced to GPS to provide positional information that allowed detections to be plotted on the system's mapping software.

During the trial, a TASCAM recorder was attached to the analogue output from the system to provide continuous recording of acoustic data during critical periods. In addition to this recording, the Seamap Cetacean Monitoring System also recorded more than 6 hours of animal vocalizations. The system automatically buffered the last two minutes of digital audio data in the internal memory for recording to hard drive at any time by a single operator mouse click.

The system was operated by Craig Douglas and Tim Pinnington from Seamap, as well as Natacha Aguilar de Soto in her role as permit monitor onboard the *Rylan T*. Images show a typical Seamap system screenshot (**Figure 23**), a picture of the Fairfield seismic source in operation (**Figure 24**; the Seamap array was deployed to the starboard side and aft of the source), and the back deck configuration of the *Rylan T*. showing the Fairfield *Speculator* and the Seamap array before it was deployed (**Figure 25**). During the cruise, two of the acoustic team members on the *Gyre* worked extensively with the Seamap team and had the opportunity to view the array, recording hardware, and software. The acoustic team concluded the Seamap array and personnel provided considerable help to the acoustics effort.

The system was deployed on 31 August and was in continuous use until 7 September when it was recovered onboard when the *Rylan T*. and Gyre went to anchor west of the Mississippi Delta sheltering from the weather. The streamer was deployed again on 9 September and remained in use until 11 September when the *Rylan T*. left to demobilize in Texas City. The system performed without any downtime for the entire period of the trial.

In conclusion, the Seamap array was able to track sperm whales within 6km of the operation. The positions estimated by the system for the detected whales were confirmed and consistent with those estimated by the visual observers for the fraction of the acoustically detected whales that were sighted.

Tagging and Playback Coordinators

Coordination of the tagging and seismic playback activities was achieved by Dan Engelhaupt and Peter Tyack, respectively. Their task was to maintain situational awareness of the various operations going on with the tag boat and the seismic vessel, merge the information coming from the acoustic and visual team, and communicate with the ship's bridge crew. This can be quite challenging when all players are active. It would appear that 3 tagged whales and 3 vessels are currently the practical limit for such control.

Tissue Collection/Genetic Typing

Tissue sampling during the D-tag cruise was primarily focused on the opportunistic collection of sloughed skin occasionally found attached to the D-tag suction cups placed on sperm whales (**Table 5**). Sloughed skin samples from eleven D-tagged sperm whales were collected during the four-week cruise. Two samples of sloughed skin found free-floating in the water near a group of whales were collected with a dipnet. While sloughed skin obtained from D-tags has proven fairly reliable in the past, sloughed skin in general can be quite difficult to amplify given the DNA's somewhat degraded nature. Due to the extensive weather delays, biopsy sampling was limited to one day with what was thought to be a large sub-adult, or perhaps adult, male based on size estimates from the R2 tag boat. Although this whale proved extremely skittish and evasive to the RHIB, a very minute amount of skin was collected from a biopsy dart that skimmed the whale's back. If this sample provides adequate DNA for analysis, this will mark the largest whale sampled to date throughout the northern Gulf of Mexico and the first free-ranging sperm whale sampled in the western region of the northern Gulf of Mexico. Based on previous and ongoing surveys, large sexually and physically mature males are not common in the northern Gulf of Mexico. Future cruise decisions to biopsy sample, photoID, and incorporate photogrammetry techniques on all 'larger' sperm whales will surely aid the overall goals of this research.

The combination of D-tagging and genetic sampling continues to provide an in-depth examination of sperm whales found throughout the northern Gulf of Mexico. Molecular sexing, microsatellites, and mitochondrial DNA sequencing will provide a rich set of information that can be directly integrated with the dive profiles of D-tagged whales. For example, we obtained skin samples from multiple members of three groups (Group #s 1, 3, and 7; see **Table 5**). An extremely exciting and interesting result was the collection of skin from all three members (Group 7) of the 'triple-dog' tagging session. Preliminary visual results suggest that the tagged members of Group 7 were surfacing in close proximity to each other. Degrees of relatedness will be tested between whales found within all sampled groups. The combination of genetics and WHOI D-tag dive profile data may perhaps shed light on how related and unrelated whales found within groups in the northern Gulf of Mexico coordinate both deep foraging and shallow dives.

In an ideal situation, one would attempt to sample all members that comprise a group. Given this year's primary focus on the D-tagging effort and the inclement weather, this was simply not possible. While our resulting genetic composition of groups will not portray an accurate representation of group structure for free-ranging sperm whales found in the Gulf of Mexico, the benefits of combining skin sampling and D-tagging will surely provide numerous answers to previously unknown questions.

Environmental Characterization

Several kinds of measurements were collected to characterize the physical-biochemical environment during the cruise. Conductivity-Temperature-Depth (CTD) profiles provided the most complete information about temperature, salinity, density, and sound speed structure of the water column. However, CTD casts were only made when the ship was stopped. When hydrophone arrays were deployed, the ship cannot stop or the arrays will sink. Due to these mutually exclusive requirements, only 8 CTD casts were taken **(Figure 13). Table 6** shows the date, time, location, and depth of cast for each CTD cast. Expendable temperature profiles (XBTs) which can be deployed from a moving ship, are the next best alternative for determining sound speed profiles. Thirty-eight XBTs were deployed, with 35 giving profiles to approximately 760m. Because we were following whales, it was never clear where we would be from hour to hour or day to day. This made it somewhat difficult to plan the deployment of the XBTs to get good spatial coverage, but the coverage turned out well **(Figure 14). Table 7** shows for each XBT drop the time, location, and depth of the 15°C isotherm.

Mean sound speed profiles based on the XBT and limited CTD data were provided to Aaron Thode and Mark Johnson for use in their acoustic calculations. These were used to obtain estimates of sound speed profiles to assist in extracting precision information from the D-tags. Furthermore, most whales were found along the rather complex frontal boundaries of the Mississippi River plume. Here is where sound speed profiles are likely to differ most from historical averages.

Because of the sensitive nature of the controlled-exposure experiment to extraneous sound sources, the two ADCPs were turned off whenever whales were present and were operated only when making long (several hour) high speed runs between locations. Upon reaching a new location, the ADCPs were secured as soon as the first whale was sighted. In this regard we were more conservative than the plan required. However, this action makes it clear that the ADCP operations did not interfere with the controlled-exposure experiments because they were not operational during the experiments. The data from the long runs should provide an idea of the general circulation patterns over the area between Mississippi and DeSoto Canyons. Additionally, no good data were lost under this method of operating because whale observations generally were made in a 10km box encompassing the whales we were working with; continuous ADCP records within such boxes would have been unwieldy to process and of limited use.

The *Gyre* has two continuously-fed flow-through systems that draw seawater in from ~3m depth. One is located in the bow and measures temperature and salinity, and one is mid-ships and monitors temperature, salinity, and fluorescence. These can be merged with DGPS time and location to produce a continuous record of these parameters during the entire cruise. **Figure 15** shows the continuous record from the system for the cruise. Water samples were drawn from the mid-ship flow-through system and measured chemically for chlorophyll concentration. Seventy-five such samples **(Figure 16)** were collected and analyzed by Laurie Sindlinger (TAMU). The date, time, location, concentration, and subjective ocean color observations for each chlorophyll are listed in **Table 8.** The color observations alone show that we were operating in a frontal region between the relatively low-salinity high-chlorophyll regions associated with Mississippi River outflow and the more saline "blue" waters offshore.

While at sea, we received four Sea Surface Height (SSH) images, produced by Robert Leben of the University of Colorado, representing conditions for 21 August, 28 August, 4 September, and 10 September. All four images are similar. Only that for 10 September is shown in **Figure 17**; the others are available for viewing on the SWSS website. The SSH field shows a fairly strong cyclonic flow southeast of the mouth of the Mississippi River separating two moderate regions of anticyclonic flow over the Mississippi and DeSoto Canyons. This configuration should produce offshore flow near 90°W and onshore flow near 88°W. We also received a SeaWiFS image for 24 August, courtesy of Orbimage and NASA and processed by the College of Marine Science of the University of South Florida. **Figure 18** shows the ship track color-coded to reflect near-surface salinity (blue is low salinity, pink is higher) from the flow-through system overlain on this SeaWiFS image, which is indicative of chlorophyll levels in surface waters (red is high, purple is low). The region of blue imbedded in purple south of the delta is a region of apparent cyclonic flow. The image suggests the notion that we were finding whales in the frontal regions. High salinities correlate well with low chlorophyll waters found offshore as do low salinities with high-chlorophyll waters associated with the river plume. Also, the fact that there is some movement of the frontal boundaries is seen in changes with time of salinity from the ship tracks in the same area.

Recommendations

The successes and experiences, including weather-related delays, of this second leg of the 2002 SWSS cruise lead to a number of recommendations and/or action items for the next years' work. Several of these are mentioned briefly here.

- As experienced on the D-tag cruise, work in the Gulf of Mexico in August and September is subject to the likelihood of more tropical storm activity. Thus, the cruise schedule for future SWSS cruises should be set for earlier in the hurricane season to reduce the probability of storm activity that interferes with tagging work.

- The *Gyre* was built in 1973 and was not constructed to be acoustically quiet. The D-tag team found that the level of noise from *Gyre* was too high to make *Gyre* an optimal vessel for controlled-exposure experiments. It is recommended that possible alternative vessels be investigated.

- The Ecologic hydrophone array is more suitable for towing at higher "survey" ship speeds than the WHOI hydrophone array. However, depending on the goals of the array, going faster with reduced detection range may not be the best approach. The Ecologic array is in need of repair for use on the 2003 cruises.

- Alternative arrays, to supplement or replace the WHOI and/or Ecologic arrays, such as the Seamap array, should be investigated for a larger role in future cruises. Compatibility of any alternative array with the software used by the tagging teams should be considered, as should the ability of the array to provide data useful in locating whales if deployed from the *Gyre* and the ability to record full-time the array's data, along with time and position, for later integration. The possibility of the development of real-time three-dimensional spatial capability for an alternative array should be explored, thus allowing the array to possibly serve as a form of behavioral tracking rather than just for location of the animals. Active acoustic monitoring systems should also be explored as a possible alternative or addition to the study.

• Alternative acoustic or other experiments should be planned in advance, at least conceptually, as contingencies if weather does not allow tagging. Consideration should be given to locations of EARS buoys, S-tagged whales, and active seismic vessels, along with communication abilities on all vessels to directly receive updates.

• If possible, it would be helpful in the future to have more D-tags and an additional person able to download and service them. This would allow a separation of the tagging tasks and the D-tag servicing tasks, allowing the tagging team to stay out longer during the day and get more sleep during the night.

• To avoid delays, such as were caused by weather this year, associated with mobilization of the R2 launch ramp, additional dock time for the *Gyre*, exceeding the standard 2 days, should be scheduled before each SWSS cruise.

• The D-tag team would prefer that a crane-based deployment system be used to launch the R2 tag boat. However, the *Gyre* cannot carry a crane of sufficient size to handle the 5000^{+} pounds of that boat. If the tag work for D-tag is carried out from an alternative vessel, the capability of the crane for handling the R2 should be factored in to the ship configuration.

• For future tagging operations, the D-tag team strongly recommends that the R2 be outfitted with quieter 4-stroke engines.

• WHOI observers were concerned that the launch ramp for R2 led to submergence of the engines during many deployments and recoveries, a problem which they believe may have contributed to the warning indications on the engines. TAMU observers noted the engines were not in danger of being submerged and were never in more water than they were designed to handle. The post-cruise diagnostics on the R2 revealed that cylinder compression was low on one engine, that sometime in the past the engines had overheated, and that there was residual moisture in the fuel lines. Either the repair or replacements for the engines will be completed prior to the S-tag cruise in 2003.

• In the future, consideration should be given to taking an XBT whenever animals are tagged since sound speed profiles are important for extracting precision information from the tags and the historical average sound speed profiles do not well-represent those profiles that occur in the frontal boundaries where many whales were found.

References

Barlow, Jay, and Taylor, Barbara L. 1998. Preliminary abundance of sperm whales in the northeastern temperature Pacific estimated from a combined visual and acoustic survey. Southwest Fisheries Science Center Report No. SC/50/CAWS 20.

Table 1a. *R/V Gyre* 02G11 Science Team. Captain Dana O. Dyer III was captain of the *Gyre*.

Field Party Chiefs	Mark Johnson (WHOI) Peter Tyack (WHOI)
Electronics Technicians	Eddie Webb (TAMU) Paul Clark (GERG)
Deck Engineers	Billy Green (TAMUG) Mike Fredericks (GERG)
Tagging Team	Mark Johnson (WHOI) Patrick Miller (WHOI) Alessandro Bocconcelli (UNCW)
Visual teams	Nicoletta Biassoni (WHOI) Maria Elena Quero (WHOI) Dan Engelhaupt (Durham Univ., UK) Todd Pusser Amy Beier Irene Briga Mandana Mirhaj (WHOI) Simon Childerhouse (WHOI) Dee Allen (NMNH Smithsonian)
Acoustics team	Aaron Thode (SIO) Valeria Teloni (WHOI) Matt Grund (WHOI) Natacha Aguilar de Soto (WHOI) Sarah Tsoflias (MMS)
Physical Oceanography	Matthew Howard (TAMU)
Flow through Fluorescence/CHL	Laurie Sindlinger (TAMU)

Table 1b. *M/V Rylan T.* Science Team. Captain Steve Bennett was captain of the *Rylan T.*

Seismic Team - Fairfield Industries	Cliff Smith Tony Edwards Neil Estay
Acoustic Team - Seamap Inc.	Tim Pinnington Craig Douglas
Playback/Permit Team	Natacha Aguilar de Soto (transfer from *Gyre*) Bill Lang (MMS) Carol Roden (MMS) Sandy Sawyer (Fairfield Industries)

Table 2. List of 19 D-Tag placements on sperm whales showing date, reference number (Julian day plus letter), the D-Tag used (D-Tag identification number), the number of complete deep dives made by the animal while tagged, and the number of hours of digital data recorded by the D-Tag while on the animal. The total number of hours for all tags is 77.12hrs.

	Tagging Event Reference Number	D-Tag Identification Number	Number of complete deep dives	On-animal data-hours
August 23, 2002	235a	10	0	0.18
August 23, 2002	235b	12	0	0.46
August 23, 2002	235c	10	1	1.32
August 24, 2002	236a	10	0	0.49
August 25, 2002	237a	10	2	3.51
August 25, 2002	237b	12	0	0.56
August 26, 2002	238a	10	3	4.44
August 26, 2002	238b	12	3	2.11
August 27, 2002	239a	10	12	12.36
August 27, 2002	239b	12	1	0.89
August 29, 2002	240a	12	1	0.73
August 29, 2002	240b	12	0	0.37
August 29, 2002	240c	10	5	5.22
September 5, 2002	248a	10	1	0.89
September 6, 2002	249a	12	2	1.92
September 10, 2002	253a	12	3	5.41
September 11, 2002	254a	10	11	11.54
September 11, 2002	254b	12	10	12.36
September 11, 2002	254c	11	10	12.36

Table 3. Emission angles for various distances corresponding to a tagged whale at a depth of 1,000 m.

V1680 Array

	Range	500.0	1000.0	2000	3000	4000	5000	6000
Emission Angle								
45		192.6289	186.6083	180.5877	177.0659	174.5671	172.6289	171.0453
63		191.0777	185.0571	179.0365	175.5146	173.0159	171.0777	169.494
72		188.366	182.3454	176.3248	172.803	170.3042	168.366	166.7824
76		188.1648	182.1442	176.1236	172.6018	170.103	168.1648	166.5812
79		187.8187	181.7981	175.7775	172.2557	169.7569	167.8187	166.2351
82		187.6042	181.5836	175.563	172.0412	169.5424	167.6042	166.0206

Table 4. Timeline for ramp-up of air guns on *Speculator* for D-tag controlled-exposure experiments on 10 and 11 September 2002. Mitigation observations are noted.

Time	Latitude (°N)	Longitude (°W)	Comments
9/10/02			
16:40	28° 27.5	88° 58.46	Tag on
17:10	28° 25.55	89° 00.36	gun deployment started
17:20	28° 25.25	89° 00.89	
17:25	28° 24.92	89° 01.54	guns in water
17:35	28° 24.29	89° 01.28	
17:40	28° 24.08	89° 01.09	
17:50	28° 25.52	89° 00.09	
17:55	28° 23.18	89° 00.38	first shot attempt – boot failure
17:59	28° 22.98	89° 00.26	first shot large grain ship at 4.8 nm
18:04			80ci
18:13			grain ship at 3.4 nm
18:14			340 ci
18:18			turn to cut past grain ship stern
18:19	28° 22.63	89° 01.30	640ci
18:29	28° 21.94	89° 00.92	1680 ci full array power
18:34	28° 21.58	89° 00.69	Gyre radios 145db level
18:54	28° 20.31	89° 59.68	course change to close slightly
19:15–19:19			dolphin shut-down
19:29	28° 19.22	88° 57.17	END
9/11/02			
10:14	28° 42.80	88° 56.3	TAG ON 28° 39.89 88° 59.2 3.4 nm away
10:28	28° 42.06	88° 57.5	TAG 2 ON
10:33	28° 39.81	88° 59.92	TAG 3 ON
10:57			Gyre estimates about 20 whales around them
11:10	28° 42.54	89° 00.77	observers to flying bridge
11:19	28° 42.89	89° 01.71	Gyre due west at 4.4 nm
11:33			gun deployment begun
11:40	28° 43.11	89° 03.90	guns out
12:10	28° 41.57	89° 05.28	Gyre at 4.5nm platform at 4.0 nm
12:16	28° 44.14	89° 05.58	ramp-up begun
12:26	28° 40.47	89° 05.82	160 ci 4.3 nm to Gyre
12:31	28° 40.08	89° 05.86	320 ci
12:35	28° 39.69	89° 05.86	640 ci
12:41	28° 39.30	89° 05.83	1280 ci platform at 3.25 nm
12:46	28° 38.92	89° 05.79	full power at 4nm to Gyre
12:48	28° 38.72	89° 05.78	approach starts to 2.5 nm
12:51			3.8 nm
12:56			3.6 nm
13:12	28° 36.81	89° 05.61	3.25 nm
13:20	28° 36.17	89° 05.67	3.1 nm
13:22			Tuna off bow
13:26			Bottlenose 2-6 off bow SHUTDOWN
13:43	28° 34.27	89° 05.96	half-ci start-up
13:50	28° 33.74	89° 06.17	full power on guns
13:51			Tuna off bow
13:53	28° 33.44	89° 06.37	order to close mile
13:56			more tuna
14:01	28° 33.05	89° 06.57	2.25nm
14:13	28° 32.21	89° 06.73	2.0nm
14:20	28° 31.73	89° 06.78	END

Table 5. Tissue Collection/Genetic Typing samples collected during D-tag fieldwork. Sample number code gives the date (yymmdd) followed by the consecutive number for multiple samples taken on any given day (01 to 04).

Sample #	Tag #	Group #	Approx. # Whales in Area	Latitude (N)	Longitude (W)
02082301		1	20	28º14.321	89º33.708
02082302		1	20	28º18.085	89º31.133
02082303	SW235B	1	20	28º19.820	89º39.840
02082304	SW235C	1	20	28º18.085	89º31.133
02082401	SW236A	2	7	28º13.250	89º24.320
02082501	SW237A	3	15	28º46.800	88º41.580
02082502	SW237B	3	15	28º47.443	88º42.610
02082601	SW238A	4	5-10	28º41.176	88º56.667
02082801	SW239A	5	10	28º39.065	89º00.313
02082901	SW240B	6	10	28º49.911	88º35.970
02091101	SW254A	7	15-20	28º39.867	88º58.976
02091102	SW254B	7	15-20	28º39.702	88º59.543
02091103	SW254C	7	15-20	28º39.673	88º59.716
02091401		8	2	27º39.019	92º45.425

Table 6. Listing of location, time, cast depth and bottom depth for SeaCat CTD casts taken on the D-Tag Cruise.

Cast Number	Lat Deg	Lat Min	Lon Deg	Lon Min	MM	DD	YYYY	HH:MM	Cast Depth(m)	Bottom Depth(m)
01	28	18.4000	89	30.0000	08	22	2002	18:20	920.	925.
02	28	12.3421	89	22.3709	08	25	2002	10:30	990.	1000.
03	28	39.9072	88	55.8300	08	28	2002	06:33	940.	0000.
04	28	52.2807	88	39.3820	08	29	2002	05:16	662.	674.
05	28	46.8734	88	27.0311	09	04	2002	22:48	1325.	1360.
06	28	55.7659	88	30.8538	09	12	2002	13:14	715.	745.
07	27	33.8876	91	06.8500	09	13	2002	12:47	934.	940.
08	27	38.9720	92	45.4565	09	14	2002	22:38	700.	720.

Table 7. List of XBT probe deployment time, location, thermograph temperature and salinity, and depth of 15°C isotherm. Counter starts at 02. Probes 9, 19, and 27 were bad.

#	Lat Deg	Lat Min	Lon Deg	Lon Min	mm	dd	yyyy	hhmm	Temp (°C)	Salinity	Depth of 15°C isotherm
02	28	25.8680	88	59.9944	08	25	2002	05:32	29.959	33.382	241
03	28	36.8786	88	49.9769	08	25	2002	09:09	29.967	35.938	261
04	28	39.8444	88	59.3799	08	27	2002	18:18	30.270	31.910	248
05	28	56.4789	88	24.8853	08	29	2002	07:26	30.448	34.828	191
06	29	02.5834	87	59.9864	08	29	2002	10:02	30.125	35.643	244
07	29	08.0921	87	44.8688	08	29	2002	11:38	30.178	35.347	220
08	29	17.2742	87	27.7217	08	29	2002	16:38	29.790	35.480	224
09	28	40.0751	88	55.6494	08	31	2002	14:20	29.981	34.684	215
10	28	40.0751	88	56.6494	08	31	2002	14:36	29.994	34.692	208
11	28	54.8906	88	16.0584	09	03	2002	19:44	29.647	34.687	213
12	28	51.8351	88	34.3918	09	04	2002	08:41	29.347	30.034	222
13	28	39.9474	88	45.0082	09	05	2002	02:02	29.170	32.140	235
14	28	32.9960	89	04.2988	09	05	2002	04:38	29.840	34.093	249
15	28	28.1815	89	15.0052	09	05	2002	06:10	29.342	31.705	228
16	28	22.4908	89	30.0054	09	05	2002	08:13	29.779	34.913	223
17	27	42.5096	88	55.7609	09	06	2002	18:56	29.351	34.990	215
18	27	40.7323	88	57.8281	09	06	2002	20:13	29.369	35.242	206
19	27	39.9529	89	00.8025	09	06	2002	21:10	29.351	35.483	230
20	27	39.8729	89	01.0642	09	06	2002	21:16	29.351	35.488	237
21	27	40.0583	89	03.1173	09	06	2002	22:46	29.333	35.540	237
22	27	50.2973	89	04.3178	09	07	2002	12:04	29.360	35.529	233
23	27	55.4485	89	04.9768	09	07	2002	12:44	29.249	35.417	237
24	28	00.0018	89	05.7525	09	07	2002	01:19	29.156	35.562	235
25	28	10.0151	89	07.4952	09	07	2002	02:36	29.369	35.242	226
26	28	40.1067	88	55.4663	09	09	2002	20:05	29.130	33.652	222
27	28	38.5874	89	00.4361	09	11	2002	16:10	24.702	31.704	200
28	28	38.5503	89	01.1051	09	11	2002	16:22	24.819	31.663	202
29	28	32.4093	88	59.0466	09	12	2002	08:26	28.592	311.24	220
30	28	42.4263	88	46.1104	09	12	2002	10:42	28.716	31.776	200
31	28	40.1118	88	47.4352	09	12	2002	19:11	28.983	32.297	207
32	28	29.1303	89	00.4456	09	12	2002	21:04	28.966	31.822	208
33	28	13.2673	89	16.3342	09	12	2002	23:41	29.285	34.697	252
34	28	00.3606	89	32.0999	09	13	2002	01:57	29.285	34.697	243
35	27	51.1844	90	00.0334	09	13	2002	05:16	29.258	35.926	250
36	27	43.0995	90	30.4608	09	13	2002	08:46	29.369	36.004	274
37	27	34.8757	91	00.0109	09	13	2002	11:57	29.400	35.874	244
38	27	37.8418	91	29.9993	09	13	2002	16:50	29.085	35.835	248
39	27	39.3546	92	01.0672	09	13	2002	21:21	29.466	35.658	228

Table 8. List of dates and locations for Chlorophyll samples collected during R/V Gyre cruise 02G11.

Sequence	Lat (°N)	Longitude (°W)	Ch µg/L	Date (CTD)	CDT	GMT	Ocean Color
1	28.30	89.50	0.29	8/22/2002	13:01	18:01	blue
2	28.30	89.65	0.36	8/23/2002	10:43	15:43	very blue
3	28.25	89.60	0.28	8/24/2002	11:08	16:08	very blue
4	28.32	89.47	0.27	8/24/2002	12:48	17:48	very blue
5	28.20	89.38	0.25	8/24/2002	14:25	19:25	very blue
6	28.20	89.37	0.32	8/24/2002	19:29	00:29	very blue
7	28.37	89.10	0.23	8/24/2002	20:33	01:33	very blue
8	28.55	88.85	0.18	8/24/2002	23:40	04:40	very blue
9	28.75	88.63	0.37	8/25/2002	10:36	15:36	blue
10	28.68	88.87	0.18	8/25/2002	18:14	23:14	blue
11	28.67	88.92	1.28	8/26/2002	10:06	15:06	green
12	28.65	88.98	0.81	8/26/2002	12:29	17:29	green
13	28.65	89.00	1.66	8/26/2002	16:38	21:38	green
14	28.65	88.98	0.77	8/27/2002	11:09	16:09	green
15	28.65	88.97	0.6	8/27/2002	16:25	21:25	green
16	28.65	88.98	0.46	8/27/2002	19:47	00:47	green
17	28.87	88.47	0.59	8/28/2002	08:03	13:03	green
18	28.88	88.48	0.26	8/28/2002	11:28	16:28	green
19	28.88	88.52	1.28	8/28/2002	13:45	18:45	green
20	28.82	88.68	0.40	8/28/2002	20:56	00:56	green
21	29.18	87.60	0.27	8/29/2002	07:38	12:38	very blue
22	29.22	87.57	0.35	8/29/2002	08:47	13:47	very blue
23	29.30	87.43	0.31	8/29/2002	11:42	16:42	very blue
24	29.23	87.47	0.27	8/29/2002	15:15	20:15	very blue
25	29.20	87.65	0.25	8/29/2002	18:03	23:03	very blue
26	29.63	88.25	0.77	8/30/2002	02:47	07:47	green
27	29.95	88.67	0.47	8/30/2002	06:08	11:08	green
28	28.93	88.87	0.51	8/30/2002	20:00	01:00	green
29	28.73	88.88	0.27	8/31/2002	07:02	12:02	very blue
30	28.82	88.73	0.35	8/31/2002	10:56	15:56	very blue
31	28.82	88.73	0.23	8/31/2002	17:48	22:48	very blue
32	28.97	88.40	0.27	9/01/2002	12:18	17:18	blue
33	28.98	88.37	0.28	9/01/2002	17:42	22:42	blue
34	28.88	88.57	0.85	9/02/2002	08:44	13:44	green
35	28.92	88.57	1.83	9/02/2002	10:42	15:42	green
36	28.87	88.50	0.44	9/02/2002	14:43	19:43	blue
37	28.97	88.32	0.27	9/03/2002	08:12	13:12	green
38	28.90	88.23	0.18	9/03/2002	12:23	17:23	blue
39	28.92	88.40	4.04	9/03/2002	18:20	23:20	very green
40	28.80	88.58	2.42	9/04/2002	08:38	13:38	green
41	28.85	88.42	1.15	9/04/2002	14:33	19:33	blue-green
42	28.77	88.45	1.19	9/04/2002	18:29	23:29	blue-green
43	28.63	88.83	0.68	9/04/2002	21:42	02:42	blue-green
44	28.53	89.10	0.51	9/05/2002	23:45	04:45	blue-green
45	28.38	89.45	0.36	9/05/2002	02:47	07:47	blue-green
46	28.33	89.57	0.33	9/05/2002	07:33	12:33	blue-green
47	27.92	89.42	0.33	9/05/2002	16:43	21:43	blue-green
48	27.65	88.93	0.32	9/06/2002	10:31	15:31	blue
49	27.68	88.95	0.50	9/06/2002	14:42	19:42	blue
50	27.65	89.02	0.28	9/06/2002	16:30	21:30	blue
51	27.72	89.05	0.33	9/06/2002	17:42	22:42	blue
52	27.85	89.07	0.29	9/06/2002	19:07	00:07	blue
53	28.11	89.12	0.37	9/06/2002	21:47	02:47	blue
54	28.47	89.02	0.51	9/07/2002	02:20	07:20	blue
55	28.70	88.93	0.89	9/09/2002	12:32	17:32	blue-green

Table 8. List of dates and locations for Chlorophyll samples collected during R/V Gyre cruise 02G11 (continued).

Sequence	Lat (°N)	Longitude (°W)	Ch μg/L	Date (CTD)	CDT	GMT	Ocean Color
56	28.68	88.95	0.85	9/09/2002	15:46	20:46	blue-green
57	28.63	88.95	0.42	9/09/2002	19:44	00:44	blue-green
58	28.68	88.88	0.64	9/10/2002	09:57	14:57	green
59	28.50	88.88	0.29	9/10/2002	15:52	20:52	green
60	28.42	88.87	0.35	9/10/2002	20:28	01:28	green
61	28.67	88.88	3.77	9/11/2002	08:01	13:01	green/brown
62	28.50	89.07	2.83	9/11/2002	13:28	18:28	green/brown
63	28.43	89.12	0.51	9/11/2002	17:26	22:26	green
64	28.65	88.83	1.19	9/12/2002	05:06	10:06	blue-green
65	28.92	88.50	1.49	9/12/2002	05:40	10:40	blue-green
66	28.93	88.48	0.64	9/12/2002	08:11	13:11	blue-green
67	28.23	89.25	0.15	9/12/2002	18:27	23:27	azure blue
68	28.08	89.42	0.25	9/12/2002	20:01	01:01	azure blue
69	27.83	90.03	0.15	9/13/2002	00:32	05:32	azure blue
70	27.78	90.23	0.14	9/13/2002	01:59	06:59	azure blue
71	27.70	90.52	0.12	9/13/2002	03:53	08:53	azure blue
72	27.60	90.88	0.14	9/13/2002	06:18	11:18	azure blue
73	27.55	91.10	0.16	9/13/2002	07:48	12:48	azure blue
74	27.62	91.57	0.17	9/13/2002	12:19	17:19	azure blue
75	27.65	92.07	0.13	9/13/2002	16:54	21:54	azure blue