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FINAL REPORT

MARINE MAMMAL OBSERVATIONS AND MITIGATION ASSOCIATED WITH USGS SEISMIC-REFLECTION SURVEYS IN THE SANTA BARBARA CHANNEL 2002

Final Report Prepared for

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EXECUTIVE SUMMARY

From 14 to 28 June 2002, the U.S. Geological Survey conducted seismic-reflection surveys in the Santa Barbara Channel area off of southern California. As a part of this project, Cascadia Research was contracted by the USGS to monitor marine mammals from the survey platform and provide mitigation on impacts on marine mammals by requesting shutdown of the sound sources when marine mammals were close to the operations. This report summarizes the results of the marine mammal mitigation and monitoring program conducted in conjunction with this USGS surveys. In addition to mitigating from the survey ship there was an effort to tag large whales ahead of the research vessel and monitor both their behavior and the levels of sound received by the animal from the survey vessel.

A small two-chamber generator-injector (GI) airgun was used during daylight hours only. The GI gun of the size we used has a sound-pressure level (SPL) of about 220 dB re 1 µPa-m RMS with a sound pulse duration of 10 ms. Problems with the airgun on 22 June required that it primarily be used with only a sleeved single chamber. This reduced capacity from 70 in^3 down to 24 in^3 and reduced pressure (3000psi to 2000psi). Other lower-power sound sources were also used including a high-resolution Huntec™ boomer system, an Edgetech 512i Chirp sub-bottom profiler, and a minisparker. Two sets of safety zones were used, one for the airgun and a smaller one when only the lower power sound sources were in use.

The primary objectives of the marine mammal study were to: 1) help mitigate impacts on marine mammals by providing immediate information on the presence of any marine mammals close enough to the sound source to risk injury so that the sound source can be turned off, 2) document the presence and number of marine mammals present in the vicinity of USGS survey operations, and 3) document reactions of marine mammals to the survey ship and sound sources. We also had secondary objectives to attach tags to blue and humpback whales in the vicinity of the seismic-reflection survey as well as examine changes in distribution of whales in reaction to the passage of the survey vessel.

The research effort was primarily conducted directly from the seismic-reflection survey vessel (*Auriga*). Observers conducted 24-hour-a-day observations from the survey ship during all seismic-reflection operations. There was a total of 289.3 hours of observation during day and night in the study area including 85.7 hours of observation while the airgun was firing.

The mammal observers requested shut-down of sound source operations for marine mammals 83 times, 64 during the day and 19 at night. A total of 38 shutdowns called while the airgun was in operation (termed high power) and 45 shutdowns occurred while the airgun was not in use but one of the other low power sources were in use. The principal species triggering shut-downs (45%) were common dolphins. Observers made 504 sightings of 6,537 marine mammals representing 11 species over the course of the survey. California sea lions were the most common followed by common dolphins and humpback whales. Marine mammals were observed exhibiting a variety of behaviors during the period of observation with no clear indication of distress or problems related to sound source operation. Animals tended to be oriented away from the ship more often than toward the ship in all types of operation modes.

We deployed suction-cup attached tags with acoustic recorders to blue and humpback whales in the general vicinity as the seismic-survey operations. Unfortunately it proved difficult to opportunistically get these tags on animals directly ahead of the path of the survey ship. Despite these problems we did place tags on several animals within a few km of the ship while the ship was operating the single-chamber airgun. While these tag deployments did not allow an evaluation of changes in whale behavior in response to specific received sound levels from the *Auriga*, we did obtain useful data on whale behavior and the tags on two occasions obtained recordings of the airgun in the distance.

We were able to evaluate any changes in blue whale distribution in response to the single-chamber airgun on one day where we conducted repeated transects with a 2nd vessel through an area of blue whale concentration before, during, and after passage of the survey vessel. These did not indicate any dramatic shift in blue whales away from the area where the ship operated.

There has been heightened concern in recent years about the potential impacts of underwater sounds on marine mammals. This concern has been heightened by recent evidence of strandings of marine mammals in relation to operation of mid-frequency sound sources by the military. In 2002, the stranding of several beaked whales was documented in the Sea of Cortez in close proximity to operation of a large air-gun array. The sound sources involved in the current study were dramatically smaller (less than 100 in^3 compared to several thousand in^3). While animals seemed to orient away from the survey vessel and in general were sighted farther away when the airgun was firing, we did not see any signs of distress or shifts in overall distribution in response to this survey.

INTRODUCTION

From 14 to 28 June 2002, the U.S. Geological Survey conducted seismic-reflection surveys in the Santa Barbara Channel area off of southern California. As a part of this project, Cascadia Research was contracted by the USGS to monitor marine mammals from the survey platform and provide mitigation on impacts on marine mammals by requesting shutdown of the sound sources when marine mammals were close to the operations. This report summarizes the results of the marine mammal mitigation and monitoring program conducted in conjunction with this USGS surveys. Cascadia has performed similar mitigation services off of California in 1998, 1999, and 2000, however this was the first mitigation project in the Santa Barbara Channel. In addition to mitigating from the survey ship there was an effort to tag large whales ahead of the research vessel and monitor both their behavior and the levels of sound received by the animal from the survey vessel.

BACKGROUND AND SOUND SOURCE DESCRIPTION (FROM USGS)

The USGS collected seismic-reflection data using a number of different instrument systems described in detail below.

GI Airgun

A small airgun of special type called a generator-injector, or GI gun (trademark of Seismic Systems, Inc., Houston, TX) was used during daylight hours only. This type of airgun consists of two small airguns within a single steel body. The two small airguns are fired sequentially, with the precise timing required to nullify the bubble oscillations that typify sound pulses from a single airgun of common type. These oscillations impede detailed analysis of fault structure. For arrays consisting of many airguns, bubble oscillations are cancelled by careful selection of airgun sizes. The GI gun is a mini-array that is carefully adjusted to achieve the desired bubble cancellation. Airguns and GI guns with similar chamber sizes have similar peak output pressures. The GI gun for this survey had two chambers of equal size-35 cubic inches-and was fired every 12 seconds. Compressed air delivered to the GI gun had a pressure of about 3000 psi. The gun was towed 12 meters behind the vessel and suspended from a float to maintain a depth of about 1 m.

The manufacturer's literature indicates that a GI gun of the size we used has a sound-pressure level (SPL) of about 220 dB re 1 µPa-m RMS. The GI gun's output sound pulse has a duration of about 10 ms. The amplitude spectrum of this pulse, as shown by the manufacturer's data, indicates that most of the sound energy is at frequencies below 500 Hz. Field measurements by USGS personnel indicates that the GI gun produces low sound amplitudes at frequencies above 500 Hz.

Problems with the GI airgun occurred at 1700 on 22 June. After this time the airgun was primarily used with only a sleeved single chamber. This reduced capacity from 70 in^3 down to 24 in^3 The airgun was also operated at a reduced pressure (3000psi to 2000psi). There were only brief tests of the gun at larger capacity after that. Safety zones were not altered from those initially prescribed even with the reduced capacity of the airgun.

Other sound sources

Huntec. The Huntec system was used intermittently during the cruise whether as the instrument of choice or as a backup for other systems that malfunctioned. The high-resolution Huntec™ boomer system uses an electrically powered sound source that is towed behind the ship at depths between 30 m and 160 m below the sea surface. The hydrophone arrays for listening are attached to the tow vehicle that houses the sound source. The Huntec™ was primarily used in water depths greater than 300 m. The system was triggered at 0.5 to 1.25 second intervals, depending upon the source tow depth. This system provides detailed information about stratified sediment, so that dates obtained from fossils in sediment samples can be correlated with episodes of fault offset. The sound pressure level (SPL) for this unit is 205 dB re 1 µPa-m RMS. The output-sound bandwidth is 0.5 kHz to 8 kHz, with the main peak at 4.5 kHz.

Chirp. In the shallow water parts of the survey area, typically in water depths from 20 m to 300 m, an Edgetech 512i Chirp sub-bottom profiler was used. The source level for the Chirp was 198 dB re 1 microPa-m RMS and the frequency band of the Chirp was 1 kHz-12 kHz. Firing occurred generally at 0.5 to 1 s interval.

Mini-Sparker. The sound source used for multichannel seismic-reflection (MCS) profiling during night operations or within the state three-mile limit was an SIG '2 mille' minisparker. The sparker electrodes are mounted on a small frame in a 'herring-bone' pattern with 50 electrodes on each side. The minisparker power was 2 kJ for MCS work: at this power level, the source had an SPL of 204 dB re 1 µPa-m RMS as measured prior to the cruise. The manufacturer suggests energy produced at 2 kJ is in the frequency range of 890 to 1020 Hz with a pulse duration of one millisecond. For the multichannel seismic-reflection survey, the minisparker was discharged every 2 seconds. When used with a single-channel streamer, at 400 J, the fire rate varied from 300-750 ms, depending on water depth. Additionally, the Huntec towfish had a sparker source that was used during the cruise when other sound sources failed. The 0.5 kJ sparker source produces usable energy from 1 kHz to 6 kHz with peak power at about 1 kHz.

Periodically during the survey, a sidescan-sonar system was used to obtain a high-resolution image of the seafloor. The sidescan system has a sound pressure level (SPL) of about 210 dB re 1 µPa-m RMS with a frequency bandwidth of the outgoing signal of 100khz to 500 kHz. Given the low power output and high frequency, this instrument was not included for marine mammal mitigation.

OBJECTIVES

The primary objectives of the marine mammal study were as follows:

1. Help mitigate impacts on marine mammals by providing immediate information on the presence of any marine mammals close enough to the sound source to risk injury so that the sound source can be turned off.

2. Document the presence and number of marine mammals present in the vicinity of USGS survey operations.

3. Document reactions of marine mammals to the survey ship and sound sources

Secondary objectives were as follows:

1. Attach tags to blue and humpback whales in the vicinity of the seismic-reflection survey vessel to monitor vocalizations, depth of dives and levels of received sound level.

2. Obtain identification photos of whales in the vicinity and compare them to an existing catalog of known animals.

METHODS

General Approach

The research effort consisted of observations made directly from the seismic-reflection survey vessel (*Auriga*) to provide mitigation, document marine mammals exposed to the sound source during hours of investigation, and monitor reactions of marine mammals close to the seismic-reflection survey vessel. Five observers conducted 24-hour-a-day observations from the survey ship during all seismic-reflection operations, with one observer monitoring forward from a platform in front of the bridge and one observer monitoring aft, towards the stern of the ship from a platform just behind the bridge or roaming the aft deck at night. At all times the bow observer was 6.4 m above the water, 5.8 m aft of the bow and 40.9 m from the stern of the vessel. During daytime operations the stern observer was 9.9 m above the water, 11.6m aft of the bow and 35 m from the stern of the vessel. Due to visibility problems during night operations it was more effective for the aft observer to leave the aft platform and roam the stern of the vessel.

In conjunction with the surveys from the *Auriga*, we also opportunistically conducted photo-ID and tagging of humpback and blue whales in the vicinity of the ship. The tagging was designed to gather behavioral data on humpback and blue whales with small suction-cup attached tags that recorded underwater behavior as well as received sound level. We also conducted some opportunistic repeated transects from the Scripps Institutes of Oceanography vessel *Robert Gordon Sproul* in a region of high blue whale abundance before, during, and after passage of the *Auriga* through the area.

Observations

Mammal observations were conducted during transit periods before and after the survey (June 14 and 28) and 24 hours a day during all sound source operations. At least one half hour of observations was conducted before the start up of any equipment to make sure the area was clear of mammals.

Daytime operations began about a half hour before sunrise and continued until about a half hour after sunset. Daytime sighting data was gathered using *Tasco 7x50* reticle binoculars or handheld clinometers. Night observations began when conditions became too dark for sightings to be made within the mitigation zone. In years past all night operations were conducted with the forward observer using night vision goggles. This year we experimented by using the ship's powerful sodium lights at night. Night vision goggles were used when it was not possible to keep the ship's sodium lights on.

Data on survey effort and sightings were recorded on a datasheet recording information to track survey effort, which includes observers on duty, and weather conditions (Beaufort sea state, cloud cover, swell height, precipitation, visibility, etc.). For each sighting the time, bearing and reticle, degree, or estimated distance to the sighting, species, group size, surface behavior orientation and travel direction were recorded.

Distances to sightings were calculated using the vertical angle to the animal (based on either the reticle reading through the binoculars for distant sightings or a hand held clinometer for close sightings) and the known elevation above the water. This was then used to evaluate whether a sighting was within the mitigation safety zones.

Mitigation and safety zones

To allow a quick determination of a mammal's status, safety zones were calculated in three arcs around the ship and the safety distance was applied using the closest part of the ship or array: 1) 0-60 degrees off the bow or ahead of the ship, 2) 60-120 degrees off the bow or to the side of the ship, and 3) 120 to 180 degrees off the bow or astern of the ship. Observers used a polaris (angle board) to determine which of the three arcs the sighting occurred in (Table 1). The cut-off vertical angle, which represented each of the safety zones, was also written on the polaris allowing observers to quickly see whether the animal was inside the safety zone or not.

Observers were instructed to call for a shutdown when a marine mammal was seen inside the safety zone or close enough to the safety zone that given measurement-error, it could be within the safety zone. Shut-down was also considered when animals were ahead of the vessel path outside the safety zone, but appeared likely that the direction of travel of the survey vessel would result in the marine mammal being within the safety zone shortly. Following a shutdown of sound-source equipment, marine mammals were tracked until they were outside the safety zone at which time sound source operations resumed.

Under the NMFS incidental harassment authorization permit marine mammals were classified into two groups:

Group 1 (non-endangered): bottlenose dolphins (*Tursiops truncatus*), common dolphin(*Delphinus delphis*), killer whale (*Orcinius orca*), pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Risso's dolphin (*Grampus griseus*), pilot whales (*Globicephala macrorhynchus*), Dall's porpoise (*Phocoenoides dalli*), gray whale (*Eschrichtius robustus*), minke whale (*Balaenoptera acutorostrata*), harbor seal (*Phoca vitulina*), elephant seal (*Mirounga angustirostris*), California sea lion (*Zalophus californianus*), and northern fur seal (*Callorhinus ursinus*). Sea turtles were also included in this group.

Group 2 (endangered): mysticete whales not listed in group 1, and sperm whales (*Physeter macrocephalus*)

Three mitigation safety zones were created by NMFS under the mitigation permit for the two groups of animals depending on which sound source was in use. The safety zones were:

1. 250 m from sound source while the airgun was in use for mammals in group 2 above.
2. 100 m from sound source while the airgun was in use for mammals in group 1, or 100 m from sound source with the non-airgun equipment in use for animals in group 2.
3. 30 m from sound source while the non-airgun equipment was in use for mammals in group 1.

Tagging

Two types of tags were attached to humpback and blue whales in the Santa Barbara Channel during the time period that the USGS surveys were being conducted. These were part of a separate study but tag deployments were attempted when possible close to the survey vessel. The two tag systems are described below.

Greeneridge acoustic tag: This tag developed by Bill Burgess with ONR support recorded underwater sound and dive depth. The tag was potted in resin and was much smaller than in previous tag deployments. The tag sampled acoustics with 16-bit resolution at bandwidths up to 14 kHz, as well as temperature and depth with 12-bit resolution. Constant acoustic sampling at 2 kHz fills the 576-MB solid-state flash disk in 41 hours. Low-power three-volt electronics allow a single half-AA-cell lithium battery to power the entire tag.

WHOI(Woods Hole Oceanographic Institute) **digital tag**: The WHOI digital tag has been developed in recent years and successfully tested on a number of species. A graduate student at WHOI, Becky Woodward, collaborated with us in conducting deployments in the Santa Barbara Channel. The digital tag consists of:

- a hydrophone (acoustic) channel with a 12-bit analog-to-digital converter, and a programmable gain filter. The typical acoustic sampling rates are 16kHz or 32 kHz.
- additional sensors, sampled at 12 bits and roughly 23 Hz (when audio sampling is 16 kHz), including
- a pressure sensor to measure depth, 0-2000m, resolution of 0.5m.
- a thermistor both for water temperature and to correct the pressure sensor readings.
- 3-axis accelerometers to measure pitch and roll.
- 3-axis solid-state magnetometers to measure heading.
- a salt water switch to detect surfacings and to trigger the initial recording of data.
- depending on the tag version, from 400 megabytes to 1.6 gigabytes of flash memory to record up to 20 hours of acoustic and sensor data when sampling at 16 kHz. Lossless compression will be investigated.
- a nichrome wire release mechanism, which can be triggered to corrode away slowly and release the tag from the animal after a set amount of time. When the nichrome wire has corroded away, a small valve is opened, flooding the suction cups and allowing it to float to the surface.

- a VHF radio beacon to enable tracking and focal observations of the whale when it surfaces, and to find the tag for recovery when the suction cups release from the animal.
- a real-time clock to give an accurate time base and to trigger events such as the nichrome wire release.
- an infrared serial port for menu-based user interface and for data transfer. LEDs (active only before deployment) also provide the user with the tag state (armed for recording).
- a low-power digital signal processor capable of 100 million instructions per second, enabling complex compression and detection routines.
- a lithium ion polymer rechargeable battery pack, 2 Watt-Hours. Power consumption when recording is about 150 mW.

Two ship experiment

On 27 June, with the use of nearby Scripps vessel *Robert Gordon Sproul* we were able to collect data on blue whale distribution before, during and after the *Auriga* ship transited through an area while firing the airgun (reduced chamber airgun). Concurrent with this experiment, the Cascadia RHIB (ridged hull inflatable boat) was also trying to deploy instrument packages onto the backs of blue whales.

Starting at 0737 on the morning of the 27th, and continuing through 1546 the *Sproul* surveyed repeatedly along an east-west transect on 34°07N between 120°00W and 120°08W. This was an area the *Auriga* was scheduled to travel through and in which we anticipated from surveys the previous day would contain high numbers of blue whales. Observations aboard the *Sproul* were made and recorded using similar methods to those employed on the survey *Auriga*. Including turnaround time, each transect was about an hour in duration and except for small deviations were conducted at consistent course and speed.

RESULTS

Marine mammal mitigation

There was a total of 289.3 hours of observation during day and night in the study area (Table 2). Daylight operations totaled 188.0 hours and included 85.7 hours of observation while the airgun was firing (High Power), 53.7 hours while the airgun was not firing but one of the other sound sources (Huntec, Chirp, or minisparker) was operating (Low Power) and 48.6 hours where none of these were operating (no power). Night operations did not include any operations of the airgun.

The mammal observers requested shut-down of sound source operations for marine mammals 83 times, 64 times during daylight observations, and 19 times during night observations. There were 38 shutdowns called while the airgun was in operation (termed high power) and 45 shutdowns occurred while the airgun was not in use but one of the other low power sources were in use (Table 3). Forty five percent of shut downs requested were in response to groups of common dolphins (short or long beak) swimming into or near the safety zone. California sea lions and Pacific white-sided dolphins were responsible for 23% and 22% of shutdowns, respectively. Shutdowns were requested on 8 occasions for whales, six times for humpback and twice for blue whales. One of the two blue whale shutdowns was a mistake, after a resight was made it was determined that the animal was well outside the safety zone and the shut-down should not have been called.

Weather conditions were worse during the early part of the survey during operations outside the Santa Barbara Channel. From 15-22 June the sea state was above a Beaufort 5, reducing the distances at which marine mammals could be sighted; 74% of the daylight sightings during the worst period (17-21 June) were made within 200 m of the survey vessel.

A total of 101.5 hours of observation were conducted at night over the duration of the cruise. There were 19 shutdowns called during night operations from just 68 sightings of marine mammals. This reflected the close distance at which marine mammals were sighted at night. The distance of initial sightings at night was 55.4 m compared to 585 m during daylight. During this particular cruise the observation team used the *Auriga's* sodium lights to illuminate the safety zones for 10 nights and the night vision goggles for 3 nights (June 15-16, June 19-20 and June 20-21) when it was not possible to use the sodium lights. Sightings per hour were 0.24 with sodium lights and 0.03 without the use of the sodium lights.

Marine mammal sightings

Observers identified 11 species over the course of the survey. There were a total of 504 marine mammal sightings (not including re-sightings), comprised of 6,537 animals (Table 4). Of the above sightings, the observers were able to make 409 "resightings" following the initial documentation of animals. California sea lions were the most abundant species in the study area, accounting for 56% of the total initial sightings. Common dolphin and humpback whale were the second and third most common species sighted over the mitigation period with 12% and 10% of the initial sightings, followed by Pacific white-sided dolphins, blue whales, Risso's dolphin, Dall's porpoise, harbor seal, sea otter and elephant seal. Humpback whales, Dall's porpoise and Risso's dolphin were also observed during the transit periods to and from the study area.

A wide range of marine mammal species were sighted during all types of sound source operations (Table 5). During daylight operations, sighting rates of large whales and small cetaceans were higher and pinniped sightings lower during airgun operations compared to when lower power sound sources or no sound sources were operating (Table 6). This was likely a result of the different areas that these operations occurred. Daylight operations outside of the Santa Barbara Channel did not involve use of the airgun, while daylight operations inside the Santa Barbara Channel (where whale and small cetacean densities are higher) generally did involve use of the airgun.

There were differences in distances at which some marine mammal groups were initially sighted depending on the sound source operating (Table 7). The differences in distance were statistically significant among these three groups (high power, low power, or no sound source) for pinnipeds ($F= 6.98$, $p=0.001$) but not for small cetaceans ($F=0.83$, $p>0.05$). The results for large whales were more ambiguous with the overall Analysis of Variance being not significant ($F=2.26$, $p>0.05$) among the three groups but among the pair-wise comparisons sightings during air-gun operation were at significantly greater distances than during no sound source operations (t-test, ,<0.05). For pinnipeds as well the initial sightings were made at distances greatest from the ship when the airgun was operating and closest to the ship when no sound source was operating.

Orientation and behavior of marine mammals

Marine mammals were observed exhibiting a variety of behaviors during the period of observation (Table 8). The most common behaviors observed were classified as fast travel and slow travel. Other common behaviors were milling, which can indicate foraging or feeding activity, porpoising, and stationary or hauled behavior (pinnipeds). Less common behaviors included feeding and breaching. Dive behaviors were categorized separately since they can reflect a reaction to the survey vessel following the initial sighting (Table 9). For initial sightings the dive behavior "fast roll/porpoising" was observed 46% of the time where dive behavior was noted. "Slow roll" was observed 32% of the time. Fluke up dive, splash and vertical sink were also observed on a few occasions. Rooster tail and stationary behaviors were seen infrequently.

Observers noted the direction of travel in relation to the *Auriga* for all sightings except when the animal was too far away to determine heading or the animal was stationary (Table 10). The majority of marine mammals were observed traveling on a tangent to the direction towards the vessel (left or right from the observers perspective). For both humpback and blue whales, animals were initially observed oriented away from the vessel much more than oriented toward the vessel (12 times away and only 1 time toward). This encompassed periods of all types of sound source operation and could have reflected a reaction to the ship itself. Dolphin species were most commonly observed headed toward the survey vessel compared to away (Table 10) and reflected their tendency to approach to vessel to bowride even when sound sources were operating.

Tagging

Both types of tags were attached to humpback and blue whales in the Santa Barbara Channel during the period of the USGS surveys (Table 11). Unfortunately it proved difficult to opportunistically get these tags on animals directly ahead of the path of the survey ship so that there would be a close approach during the period the tag was on: This difficulty stemmed from a number of factors:

1. The concentration of whales in most areas the ship was operating was not high enough to reliably be able to find and place tags on animals ahead of the ship.

2. The humpback whales encountered through most of the survey period were engaged in fish feeding with unpredictable and erratic surface intervals and movements making tagging approaches harder.

3. We did not have control over where and when the survey ship was operating and often could not anticipate its direction of travel, this made it difficult to insure that we found animals and deployed tags in the right area.

4. Weather was not cooperative for much of the study period

5. The dual chamber GI gun was not functioning for the latter half of the survey period when blue whales were present in larger numbers and deployments were made near the ship.

Despite these problems we did place tags on several animals within a few km of the ship while the ship was operating the lower power single chamber airgun (Table 11). The deployments made when the survey ship was closest were all on 27 June in the same area as the two-ship experiment described below.

The three deployments on blue whales conducted on 27 June stayed on the whales from a few minutes to 1.5 hours (Table 11). The initial deployment was on a single blue whale ahead of the path of the approaching survey ship. The tag was only on for 12 minutes and recorded a single dive series to about 120 m before coming off. The longest deployment of the three was as the survey ship was just heading out of the area. During the 1.5 hours this tag was on the whale it recorded seven dive series down to about 160 m and showing repeated underwater feeding lunges. While these tag deployments did not allow an evaluation of changes in whale behavior in response to specific received sound levels from the *Auriga*, we did obtain useful data on whale behavior and the tags on two occasions obtained recordings of the airgun in the distance.

Two-ship experiment

The repeated transects through the area of blue whale concentration during the passage of the *Auriga* did not indicate any dramatic shift in blue whales away from the ship (Figure 1). This was after the malfunction of the GI airgun and so the sound source was only the single-chamber lower-power airgun. The repeated transects showed that while the concentration of blue whales tended to shift slightly mostly east and west through the morning and into the early afternoon, these shifts did not appear to coincide with any avoidance or attraction to areas where the sound sources was operating. There did not appear to be any decrease in overall number of whales or any shift in distribution of whales away from the areas the sound source has traversed.

DISCUSSION

Species encountered during this survey is consistent with what would be expected in the region at this time of year. Both common dolphins and California sea lions are considered the most common marine mammals in near shore waters of Southern California. Over a 12-day survey we would expect to sight more baleen whales in the Santa Barbara Channel Islands than were sighted by the observers on the *Auriga* in 2002. Lower numbers of sightings are most likely due to challenging sighting conditions over the first week of the survey.

Species sighted and behaviors exhibited in this study were similar to those seen in past USGS surveys in this region (Calambokidis et al. 1998, Calambokidis and Chandler 2000). “Distress” behavior (fluke slapping, pec slapping, head slapping, continuous breaching) was not observed.

Unlike the animals sighted in this report, a USGS survey off of Southern California in 1998 reported twice the number of animals traveling away from the survey vessel as in any other direction. This difference could not be explained by a difference in species between the two years, but it could be dependent on number of sightings and different regions of study. Animals sighted in 1998 were in the Southern California Bight and perhaps more likely to avoid ships than animals in the Channel Islands where there is less vessel traffic. The 1998 survey had 133 sightings, whereas the 2002 survey had almost four times that number of sightings. The orientation of animals sighted headed away from the survey vessel increased from initial sighting to resighting from 17% to 27%. The reversal of travel direction may be explained by the animals reaching a sound threshold upon approaching the vessel, but the trend was seen with all sound sources and no sound source in operation.

Night observations have been a source of frustration for observers in past years due to low visibility and the possibility of not being able to detect marine mammals within the safety zones. In 1998 and 2000 observers used night vision goggles for night observations with varying sighting numbers that were highly dependent on weather. For the 1999 USGS cruise night time mitigation was unnecessary, but observers spent 6 hours over the course of the survey evaluating the quality of available night vision equipment. Observers found in 2002 that sighting rates were higher when using the sodium lights and unanimously felt they were more effective at detecting marine mammals than with the night vision equipment and the lights off. Sodium lights gave the forward observer greater peripheral vision and greatly enhanced the “roaming” aft observers’ ability to see animals at greater distances. Even with the sodium lights to illuminate the water, the observers still lack an effective method for judging distance from the survey vessel.

The tagging effort conducted opportunistically in association with these cruises demonstrated the promise of this approach but also the difficulty in getting animals, weather, the survey vessel, and a successful tag deployment to all occur at the same place. This was complicated by the relatively low power sound source in use during the latter half of the survey. Control of the survey vessel would be required to improve the chances of getting data on the underwater behavior of whales in relation to received sound level.

Observations of the distribution of blue whales before, during, and after passage of the survey vessel using a different ship, proved valuable and allowed an evaluation of any shifts in whale distribution in response to passage of the survey ship. This was successful due to the high density of animals in this region and good information from the USGS survey crew of the anticipated route of the survey vessel.

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FIGURES AND TABLES

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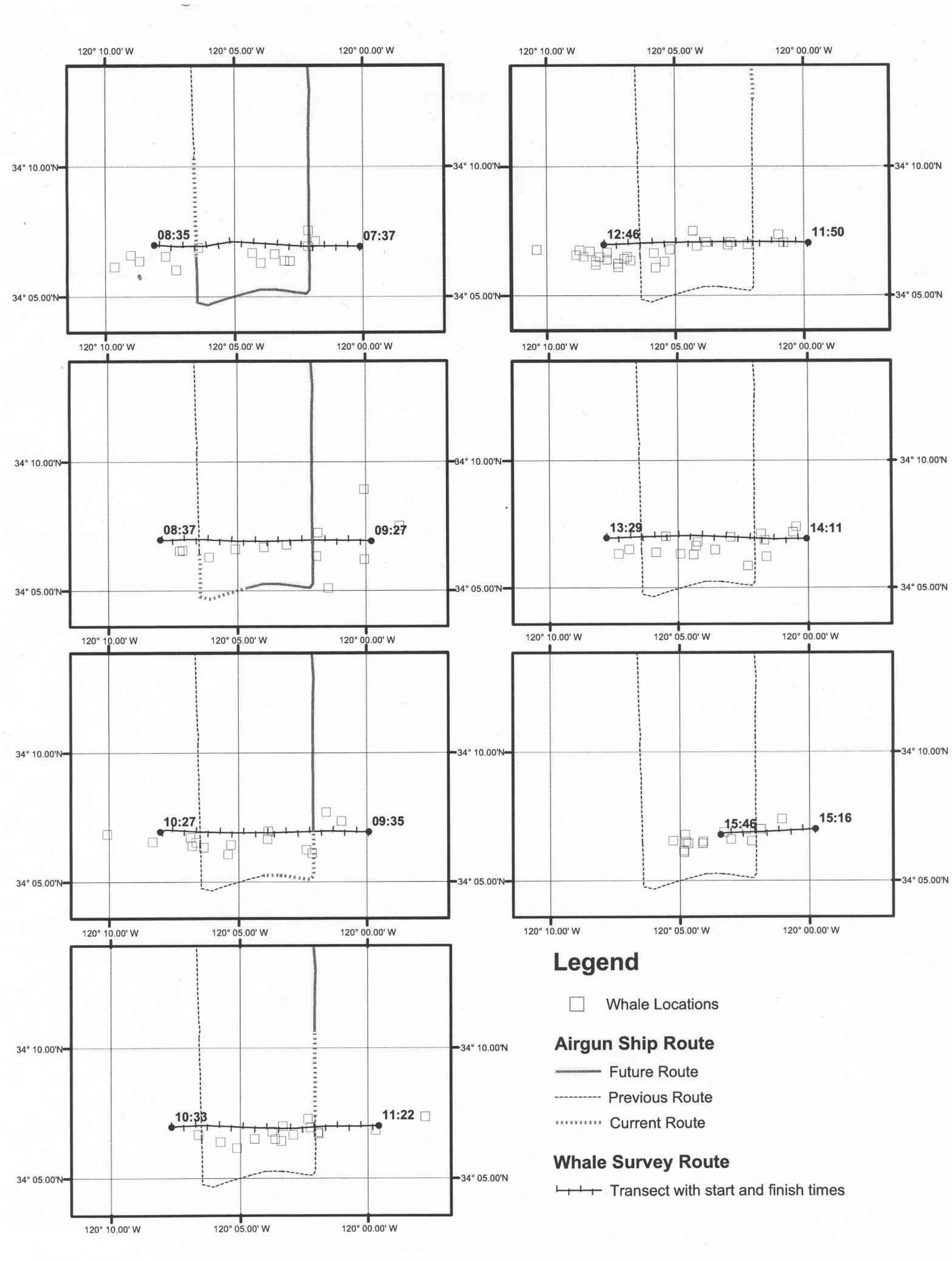

Figure 1. Plots showing the location of blue whales sighted during transects by the *Sproul*, before, during and after passage of the Auriga firing the single-chamber airgun on 27 June 2002 in the Santa Barbara Channel.

Table 1. Safety zone matrix showing the two groups of marine mammals and their vertical angle cutoffs for three arcs around the Auriga. Any vertical angle reading equal to or greater to that shown for each arc warranted a call for shutdown.

	Cut-off	Bow			Aft		
Species	**distance**	**0-60 Deg.**	**60-120 Deg.**	**120-180 Deg.**	**0-60 Deg.**	**60-120 Deg.**	**120-180 Deg.**
Airgun							
Non-endangered	100	3	3	n/a	n/a	3	3
Endangered	250	1	1	n/a	n/a	1.5	1.5
Other sound sources							
Non-endangered	30	10	10	n/a	n/a	4.5	4.5
Endangered	100	3	3	n/a	n/a	4	4

n/a (not applicable) = section not visible from that observation post

Table 2. Sound sources used and hours of operation during the survey. To allow summary of data all modes involving use of the airgun were termed high power. Other sources in the absence of the airgun were considered low power.

	Hours at operation			
Operational seismic equipment	**No Power**	**Low Power**	**High Power**	**Total**
None	61.5			
Chirp		60.9		
Huntec (boomer mode)		6.9		
Mini-Sparker (either SIG or Huntec in Sparker mode)		66.1		
Chirp and Mini-Sparker		8.3		
Chirp and Multi-Chamber airgun			9.3	
Chirp and Single-Chamber airgun			46.2	
Huntec and Multi-Chamber airgun			19.8	
Multi-Chamber airgun			8.0	
Single-Chamber airgun			2.3	
Total hours at power	61.5	142.2	85.6	289.3

Table 3. Shutdowns by species and sound source level during the survey.

Species	Seismic Sound Source Level		
	Low Power	**High Power**	**Total**
Large whales			
Blue whale	1	1	2
Humpback whale	2	4	6
Small cetaceans			
Delphinus species	17	20	37
Pacific white-sided dolphin	8	10	18
Risso's dolphin		1	1
Pinnipeds			
California sea lion	17	2	19
Total	45	38	83

Table 4. Summary of sightings and resightings by species during the 2002 survey. Resightings represent groups seen more than one time. Does not include sightings outside study area during transit to and from region.

	Sighting		Resighting	
Species	**# of sightings**	**# of Animals**	**# of sightings**	**# of Animals**
Large whales				
Blue whale	22	29	46	68
Humpback whale	51	67	164	249
Unidentified large whale	32	44	14	22
Unidentified small whale	1	1		
Total large whales	106	141	224	339
Small cetaceans				
Delphinus species (DD and DC)	62	3,521	97	9,131
Pacific white-sided dolphin	24	155	31	323
Risso's dolphin	3	4		
Dall's porpoise	1	2		
Unidentified dolphin	19	2,013	7	246
Unidentified small cetacean	1	1		
Total small cetaceans	110	5,696	135	9,700
Pinnipeds				
California sea lion	283	695	50	272
Elephant seal	1	1		
Harbor seal	3	3		
Sea otter	1	1		
Total Pinnipeds	288	700	50	272
Grand Total	504	6,537	409	10,311

Table 5. Summary of sightings and total number of animals observed with the operating sound source. Resightings are not included.

	No Power		Low Power		High Power	
Species	**# Sit**	**# Anim**	**# Sit**	**# Anim**	**# Sit**	**# Anim**
Large whales						
Blue whale					22	29
Humpback whale	9	12	20	29	22	26
Unidentified large whale	6	8	7	9	19	27
Unidentified small whale	1	1				
Small cetaceans						
Delphinus species	8	675	23	661	31	2185
Pacific white-sided dolphin	3	15	8	69	13	71
Risso's dolphin					3	4
Dall's porpoise			1	2		
Unidentified dolphin	5	1519	5	117	9	377
Unidentified small cetacean			1	1		
Pinnipeds						
California sea lion	79	278	122	276	82	141
Elephant seal					1	1
Harbor seal	1	1	2	2		
Sea otter			1	1		
Grand Total	112	2509	190	1167	202	2861

Table 6. Day time sighting rate of groups of marine mammals by type of sound source in operation.

		# of sightings			# of sightings per hour		
Sound source level	**Hours**	**Large whales**	**Small cetaceans**	**Pinnipeds**	**Large whales**	**Small cetaceans**	**Pinnipeds**
High	86	63	56	83	0.74	0.65	0.97
Low	54	26	21	77	0.48	0.39	1.43
None	49	16	15	79	0.33	0.31	1.63
Total	188	105	92	239	0.56	0.49	1.27

Table 7. Average distances (in meters) of marine mammals sighted during daylight observations by type of sound source.

Marine mammal	n	Mean	SD
Large whale			
High power	63	1,642	1,048
Low power	26	1,353	1,490
No power	16	1,005	537
Total	105	4,001	3,075
Pinniped			
High power	83	250	294
Low power	77	141	210
No power	79	131	130
Total	239	522	634
Small cetacean			
High power	56	629	806
Low power	21	512	602
No power	15	806	1,212
Total	92	1,947	2,620
Grand Total	436	6,469	6,329

Table 8 . Primary behavior of marine mammals based on type of sound source in operation.

Behavior	**Sightings**				**Resightings**			
	No Power	**Low Power**	**High Power**	**Total**	**No Power**	**Low Power**	**High Power**	**Total**
Fast travel	47	113	84	244	53	33	43	129
Slow Travel	45	56	86	187	49	47	118	214
Hauled		1	3	4			1	1
Milling	4	9	4	17	6	8	15	29
Stationary	8	2	4	14	1		2	3
Breach		1	1	2			3	3
Feed	1	1		2		1		1
Total	105	183	182	470	109	89	182	380

Table 9. Summary of the dive behaviors observed during sightings and resightings during surveys in the Santa Barbara Channel, 2002.

Species	**Dive behavior**								
	Breach	**Fluke Dive**	**Porpoise/Fast roll**	**Rooster tail**	**Stationary**	**Splash**	**Slow roll**	**Vertical rise**	**Vertical sink**
				Sightings					
Large whales									
Blue whale							21		
Humpback whale		11				1	27		
Unidentified large whale		2				1	5		
Small cetaceans									
Delphinus species			42			3	14		
Pacific white-sided dolphin			10				13		
Risso's dolphin							3		
Dall's porpoise				1					
Unidentified dolphin			14				5		
Unidentified small cetacean			1						
Pinnipeds									
California sea lion			164	3	1	8	73	5	6
Elephant seal							1		
Harbor seal									2
Sea otter							1		
Total (sighting)		13	231	4	1	13	163	5	8
				Resightings					
Large whales									
Blue whale		6					31	1	
Humpback whale	2	30	2				107	1	1
Unidentified large whale							4		
Small cetaceans									
Delphinus species			61			5	28		
Pacific white-sided dolphin			13				18		
Risso's dolphin									
Dall's porpoise									
Unidentified dolphin			3			3	1		
Unidentified small cetacean									
Pinnipeds									
California sea lion			34		1		11		1
Elephant seal									
Harbor seal									
Sea otter									
Total (Resighting)	2	36	113		1	8	200	2	2
Grand Total (sighting and Resighting)	2	49	344	4	2	21	363	7	10

Table 10. Orientation and distance to some marine mammal species during intial sighting from the survey vessel.

Species	Distance(m)	Orientation to survey vessel			
		Away	Left	Right	Toward
Blue whale	1-200				
	201-500		3	1	
	501-1000		1	1	
	1001-2000	2	2	1	
	>2000	2	5	1	
Total		4	11	4	
Humpback whale	1-200			2	
	201-500	1	4	4	
	501-1000	4	1	2	
	1001-2000	2	5	9	1
	>2000	1	3	2	
Total		8	13	19	1
Delphinus	1-200	10	6		17
	201-500	1	5	3	2
	501-1000		2	1	3
	1001-2000		1	3	3
	>2000				1
Total		11	14	7	26
Pacific white-sided dolpl	1-200	2	4	3	7
	201-500		2	2	1
	501-1000		1		
	1001-2000			1	
	>2000				
Total		2	7	6	8
California sea lion	1-200	35	72	49	63
	201-500	6	13	17	4
	501-1000	1	1	4	2
	1001-2000			1	
	>2000				
Total		42	86	71	69

Table 11. Summary of tag deployments in the Santa Barbara Channel in June 2002 during USGS surveys.

Deploy			Deployment		Detach	Hours	Detach	Recovery											
Date/time	**Tag**	**Sp**	**Latitude**	**Longitde**	**Time**	**on**	**reason**	**Time**	**Latitude**	**Longitde**	**Num**	**SN#**	**Beh**	**Type of deployment**	**Track data**	**Dive**	**Skin**	**Reaction**	**Comments**
6/19/2002 11:06	Burgess	Mn	34 18.77	119 51.43	11:25	0.3	Front gummy gone only rear held suction	6/19/2002 11:25	34 20.25	119 51.87	2	8	Mill	Put tag on whale	Mostly complete	Yes	None	Tail slap	Tag slid back on one cup, acoustic saturation prob from vibration
6/22/2002 10:45	dTag	Mn	34 12.65	119 50.82	10:48	0.0	Failure of front cup to seal	6/22/2002 10:52	34 12.71	119 50.79	1	11	Travel	Attach tag	Short	Yes	None	NR	Out-bound freighter approaching
6/23/2002 11:19	dTag	BM	34 08.01	119 53.21	12:29	1.2	Detached early	6/22/2002 12:30	34 06.52	119 48.59	2	8	Travel	Put tag on trail whale	Good incl. post-tag	Good	010623-1 from robot head	Pos. early termination of SS	Trail animal does not surface next series but appears to be normal pattern
6/24/2002 12:34	dTag	BM	34 08.34	119 56.11	19:51	7.3	Unclear, wire had burned but was set for 2h	6/25/2002 15:00	34 15.82	120 12.42	1	1	Mill - travel	Put tag on single	Ex intil 1900	Good	010624-1 robot 020625-1 tag	Pos. sink and early term. of SS	Tag recovered the next dat
6/25/2002 18:02	Burgess	BM	34 06.98	120 10.21	18:05	0.0	Put on backwards	6/26/2002 18:08	34 06.97	120 10.07	1	3	mill	Tag put on whale	Too short	Dive to 20 m	None	Sink, term. SS	Out of position (1 engine) tag put on backward
6/26/2002 7:58	Burgess	BM	34 07.42	120 00.36	8:02	0.1	Rear gummy was gone (blown out on tagging?)	6/26/2002 8:07	34 07.48	120 00.57	2	2	Mill	Put tag on trail of pair	Too short	Single dive to 60m	None	Sink, accel., term. SS	Used flex head, may not have gotten solid press on, gummies good
6/26/2002 9:03	Burgess	BM	34 06.85	120 04.25	11:54	2.8	Tag slid on whale, gummies intact suction good after	6/26/2002 12:00	34 06.65	120 04.79	1	4	Mill, travel	Put tag on single	9:03-10:20 then lost signal	8 dive seiries to about 165m	020626-2 (sm. Sk from cup)	Accel., extends SS dive	Solid attachment, 2nd appr on SS stayed with animal below surface
6/27/2002 7:27	Burgess	BM	34 06.64	120 05.53	7:39	0.2	Good atchmt. rear gummy blew out	6/27/2002 7:41	34 06.68	120 05.61	1	2	Mill	Put tag on single	Short	One dive series to 120 m	020627-1	Suspend SS, back flex	Lead gummy out, USGS ship appr.
6/27/2002 10:22	Burgess	BM	34 06.84	120 03.84	10:24	0.0	Attached underwater, no good atchmt.	6/27/2002 10:25	34 06.83	120 03..84	1	11	Mill	Brief attach to single	Too short	Comes off on 1st dive	None	Sink	
6/27/2002 10:49	Burgess	BM	34 06.92	120 03.17	12:18	1.5	Gummies intact	6/27/2002 12:21	34 06.59	120 06.02	1	13	Mill	Put tag on single	None	7 feeding dive series to 160m	None	Interupt SS then resume	USGS ship moving away

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6/26/2002 9:03	Burgess	BM	34 06.85	120 04.25	11:54	2.8	Tag slid on whale, gummies intact suction good after	6/26/2002 12:00	34 06.65	120 04.79	1	4	Mill, travel	Put tag on single	9:03-10:20 then lost signal	8 dive seiries to about 165m	020626-2 (sm. Sk from cup)	Accel., extends SS dive	Solid attachment, 2nd appr on SS stayed with animal below surface
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6/27/2002 10:49	Burgess	BM	34 06.92	120 03.17	12:18	1.5	Gummies intact	6/27/2002 12:21	34 06.59	120 06.02	1	13	Mill	Put tag on single	None	7 feeding dive series to 160m	None	Interupt SS then resume	USGS ship moving away