REPORT ON THE RESULTS OF THE INQUIRY INTO ALLEGATIONS OF MARINE MAMMAL IMPACTS SURROUNDING THE USE OF ACTIVE SONAR BY USS SHOUP (DDG 86) IN THE HARO STRAIT ON OR ABOUT 5 MAY 2003

9 February 2003

Commander, U.S. Pacific Fleet

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Overview

On 6 May 2003, Commander, U.S. Pacific Fleet (COMPACFLT) was made aware of allegations concerning possible marine mammal impacts associated with the use of active sonar by USS SHOUP (DDG 86) on 5 May 2003 while transiting the Haro Strait. Initially centered on the resident orca, these allegations ranged from the orca having been injured, deafened, disturbed, confused, or disoriented, to having "behaved very peculiarly." COMPACFLT convened this inquiry, the focus of which was a detailed acoustic analysis of SHOUP's use of mid-range active sonar on 5 May 2003. As part of this inquiry into the allegations surrounding SHOUP's use of active sonar on 5 May 2003, the Naval Research Laboratory (NRL) performed an in depth analysis to determine the received sound levels likely to be present at the known locations of the orca J-Pod in Haro Strait on 5 May 2003. Additionally, this inquiry incorporates the results of necropsies that were conducted by National Marine Fisheries Service (NMFS), Northwest Region on 11 harbor porpoise specimens alleged to have been affected by SHOUP's use of sonar.

Pacific Fleet investigators concluded that there was no indication that SHOUP's sonar use on 5 May 2003 either killed or injured any marine mammals or was responsible for any subsequent marine mammal strandings. This report reviews the evidence and scientific analysis that led to these conclusions. All technical terms used in this report are defined in a Glossary at the end. The major findings of each part of the Pacific Fleet's inquiry are summarized below.

The Environment

The Haro Strait is a passage of the eastern North Pacific, lying between Vancouver and Saturna Islands of the province of British Columbia, Canada (west), and San Juan and Stuart islands of the State of Washington, United States (east). Part of the United States–Canadian border passes down the center of the strait, which extends north to the Strait of Georgia and south to Strait of Juan de Fuca. Mid-channel depths average 600–900 feet (180–275 meters), but at its southern end submerged islands reduce the depth to 60–300 feet. Vessels leaving the city of Victoria heading north follow Haro Strait through the islands to the Strait of Georgia.

There are four species of marine mammals inhabiting Haro Strait that were alleged to have been effected by SHOUP's use of sonar on 5 May 2003. These are orca (*Orcinus orca*), Dall's porpoise (*Phocoenidae dalli*), minke whale (*Balaenoptera acutorostrata*), and harbor porpoise (*Phocoena phocoena*). Accurate and precise numbers of the various marine mammal species present in Haro Strait on 5 May 2003 could not be determined.

There are three distinct stocks of orca in the Pacific Northwest: Residents, Transients, and Offshore. All of these stocks may be present in the same general area, as they were in Haro Strait a few days prior to 5 May 2003 (Orca Network 2003b). Those orca south of mid-Vancouver Island, and which frequent Puget Sound, are known as the Southern Resident community and consist of the J, K, and L pods. From April through September each year, the three Southern Resident pods usually travel throughout the inland waters of Puget Sound, the Northwest Straits, and the Georgia Strait. SHOUP is alleged to have impacted Southern Resident orca of J-Pod on 5 May 2003.

The survival rates of the Southern Resident orca have shown a significant downward trend in the past 26 years. Declines in the 1960s were primarily the result of collection for aquariums. A recent decline since 1996 further reduced the population from 97 to the present count of 83 whales (68 FR 31980, May 29, 2003). Degradation of habitat and a reduction in salmon stocks, which is the main prey of the resident orca, are cited by National Marine Fisheries Service as likely causes for the more recent decline. Others have suggested that unregulated whale watching and increased vessel traffic may also have contributed to the declining population (Ford 2000:100; Erbe 2002). Orca also have been found to have high concentrations of organo-chlorine pollutants in their body fat. The effects on the orca are not known, but in other marine mammals there is evidence these pollutants cause reproductive impairment, skeletal abnormalities, immunotoxicity, and endocrine disruption (Ross et al. 2000:505).

USS SHOUP (DDG 86)

USS SHOUP is the eighth OSCAR AUSTIN-class Guided Missile Destroyer, a sub-class of the ARLEIGH BURKE class. SHOUP was placed in commission on 22 April 2002. SHOUP's operational chain of command flows from SHOUP to Commander, Naval Surface Group Pacific Northwest, to Commander, THIRD Fleet.

Relevant to this inquiry, SHOUP's active sonar systems include the AN/SQS-53C(V)4 Hull Mounted Sonar with Kingfisher mine avoidance system. Active sonar is the best acoustic method for detecting submerged submarines and objects such as mines. To this end, SHOUP employs the tactical mid-range frequency AN/SQS-53C sonar. This sonar is designed to emit sounds that will be reflected by nearby surface ships, submarines, and mines and thus detected by the ship's passive sonar sensors. This system is referred to as tactical mid-range sonar to distinguish it from other sonar systems, such navigational, side-scan, and fish-finding sonar systems.

The manner in which SHOUP operated its AN/SQS-53C on 5 May 2003 was the central aspect of this inquiry. The AN/SQS-53C sonar is actually an array of several individual sound sources arranged in a curved geometry. The AN/SQS-53C sonar operates at center frequencies of 2.6 and 3.3 kHz and a nominal source level of 235 dB. SHOUP's use of sonar on 5 May 2003 involved the conduct of Swept Channel and Surface Ship Small Object Avoidance exercises. SHOUP's AN/SQS-53C sonar was used as an integral component of the Swept Channel and Surface Ship Small Object Avoidance exercise.

The object of these exercises is to navigate in a confined area in a condition of heightened readiness, coordinate use of and reporting of sensor information, and to detect and avoid mines and other submerged objects. Specifically, the goal is to train the ship's personnel in conducting small object avoidance operations. Ships engaged in this exercise must demonstrate the ability to conduct operations and effective mission planning to include, but not limited to, small object avoidance search, detection, classification, tracking, and localization and communication. Inherent in the conduct of this exercise is the operation of the ship's mid-range tactical sonar system. The impetus for this training was the damage caused to USS PRINCETON (CG 59) and two other ships by mines in the Arabian Gulf during Operation Desert Storm in 1991. As a result of lessons learned from these incidents, all U.S. Navy surface ships are required to conduct a Swept Channel exercise at least once every three months to maintain this basic readiness skill. As would be the case in a real-world tactical situation, the skills associated with this exercise are best practiced in a channel having the restricted maneuverability and oceanographic characteristics that make mine identification and avoidance difficult.

On 5 May 2003 at 0855[1], SHOUP got underway from the pier at Naval Station Everett, Washington. SHOUP then transited from Everett through Admiralty Inlet to the west side of Whidbey Island, where at 1033 it began the Swept Channel Exercise. Weather that morning consisted of partly cloudy skies, a temperature of 53 degrees, and winds averaging 8 mph. Visibility was ten miles and the seas were calm. SHOUP's AN/SQS-53C mid-range tactical sonar was activated at 1040, operating at the nominal source level of 235 dB with a ping approximately every 25 seconds. At 1420, SHOUP entered the Haro Strait at a speed of 18 knots. SHOUP terminated active sonar use at 1438.

From the information available, it appears that SHOUP's closest point of approach to the orca J-Pod in Haro Strait was approximately 1.5 nautical miles occurring at 1434. At the point of closest approach, there were approximately six motor vessels in the vicinity of the orca J-Pod. Many of these motor vessels appeared to be engaged in whale watching activities. Each of these vessels was closer to the J-Pod than was SHOUP. Videotape recordings made by Mr. Ken Balcomb and Ms. Candice Emmons and provided to Navy by NMFS show that at least two of the vessels were maneuvering towards the J-Pod at approximately this time, with SHOUP clearly visible in the distance. Following the cessation of pinging at 1438 and the securing of its sonar operations at 1440, SHOUP continued its northerly transit of the Haro Strait, exiting at approximately 1500 on 5 May 2003.

Recordings of the sonar, as picked up by hydrophones set up for The Whale Museum as part of Project SeaSound, were made by Dr. Val Viers contemporaneous with SHOUP's training exercise and transit of Haro Strait on 5 May 2003. Dr. Viers provided copies of these recordings to NMFS for use in this inquiry.

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[1] All references to time throughout this investigation are in Pacific Standard Time (PST) using the military twenty-four hour clock.

Allegations of Harm and Injury to Marine Mammals

It was not until the following day, 6 May 2003, that the Navy learned about allegations of interaction between SHOUP and marine mammals from various media and Internet reports. On 9 May 2003, NMFS Northwest Region officials met with three local researchers, each of whom provided an account alleging that SHOUP's use of sonar on 5 May caused unusual behaviors in marine mammals located in Haro Strait. Also provided were videotape recordings made independently and contemporaneous with SHOUP's transit of Haro Strait depicting orca behaviors and vessel traffic, including numerous whale watch boats.

After 5 May 2003, there were no recorded observations indicative of any effect, temporary or permanent, on any marine mammals related to SHOUP's use of sonar on 5 May 2003 (Orca Network 2003b).

Space and Naval Warfare Systems (SPAWAR) Analysis of Videotaped Orca Behaviors

To assess the behaviors shown on the videotape, COMPACFLT requested review by expert marine mammal scientists associated with the Navy Marine Mammal Program (NMMP) centered in the Biosciences Division of SPAWAR in San Diego, California.

Marine mammal scientists involved in the review of the videotape included Dr. Samuel Ridgway, Dr. Randal Brill, Dr. Donald Carder, and Dr. John Sigurdson, noted scientists involved in marine mammal research and critical participants in the development of the Navy's Marine Mammal Program. These scientists determined the behaviors of the orca as recorded on the video were within the species' normal range of behaviors and there were no immediate or general overt negative behavioral reactions depicted. These scientists further opined that the reported behaviors judged by on-site observers to be unusual, but which were not evident on the videotape recording of the event, were possibly the result of the numerous small motor vessels maneuvering in close proximity to the orca.

The U.S. Navy's Marine Mammal Program had its origin in the acquisition, in 1960, of a Pacific white-sided dolphin for hydrodynamic studies. Navy scientists designing torpedoes had heard accounts of the hydrodynamic efficiency of dolphins, and were interested in determining whether dolphins did in fact have special characteristics that might be applied to the design of the underwater missiles. Although discontinued in the 1960s, a new program is underway using modern technologies. Early Navy marine mammal work centered around Point Mugu, California, where the primary interests were in the study of the marine mammals' specially developed senses and capabilities (such as sonar and deep diving physiology) and also how dolphins and sea lions might be used to perform useful tasks. A major accomplishment was the demonstration that trained dolphins and sea lions could be worked untethered in the open sea with great reliability.

In 1967, the Point Mugu facility and its personnel relocated to San Diego and were placed under a newly formed organization which has since undergone a number of name changes, including Naval Undersea Center; Naval Ocean Systems Center; Naval Command, Control and Ocean Surveillance Center Research, Development, Test and Evaluation Division; and, currently, Space and Naval Warfare Systems Center San Diego. Shortly after the headquarters move to San Diego, a laboratory was established in Hawaii at the Marine Corps Air Station on Kaneohe Bay. Some of the personnel and animals at Point Mugu transferred to the Hawaii Laboratory, and later the rest of the operation moved to a new facility on Point Loma in San Diego. Here the research and development program begun at Point Mugu continued. This has included further studies of the capabilities of marine mammals; development of improved techniques for diagnosis and treatment of health problems; neurophysiological studies, using behavioral and other non-invasive techniques, to gain a better understanding of how the large dolphin brain functions; development of instrumentation for determining, by brain wave activity, the hearing range of a cetacean; and investigation of how dolphins produce the sounds they make.

In its operational systems, the Navy employs dolphins and sea lions to perform underwater surveillance for object detection, location, marking and recovery, working under the close supervision of their Navy handlers. The Navy also uses dolphins in operational programs for swimmer defense--to detect swimmers, divers and swimmer delivery vehicles, and, if the handler determines the situation warrants, to mark them; and mine countermeasures--to detect bottom mines and moored mines. Dolphins are used for these tasks because their extraordinary natural biological sonar capabilities enable them to find objects in waters where hardware sonars do not work well due to poor acoustic environmental conditions.

In the past, SPAWAR System Center (SSC) San Diego has investigated possible uses of whales to meet Navy research and operational requirements. In Project Deep Ops, a pilot whale and two killer whales demonstrated their ability to recover objects from significant depths, attaching a special recovery device with a hydrazine gas generator to raise objects to the surface. Using this device, the pilot whale successfully recovered an object from a depth of 1,654 feet. Although much was learned from the project, work with pilot and killer whales, the largest of the dolphins, has not been continued. This research required extensive understanding of the whales' behavior patterns.

The capabilities of white whales have also been investigated by SSC San Diego for similar recoveries in colder and deeper waters. In Project Deephear, white whales were trained to dive to sound generation platforms at varying depths down to 1,000 feet. There the animals stationed while scientists conducted hearing tests from the surface, generating sounds at various frequencies to determine the whales' hearing range. Using this method researchers were able to determine their hearing sensitivity in deep water was very similar to that in shallow water. Later research combined white whales and dolphins in studies of the effects of loud sounds on the animals' hearing.

The National Marine Fisheries Service, which has regulatory responsibility for the Marine Mammal Protection Act, reported findings in scientific literature that showed the Navy's dolphin survival rate is the highest among all organizations holding large numbers of marine mammals. This was attributed by the researchers conducting the study to "superior husbandry." Dolphin survival rate in the wild is reported in the scientific literature as 92-95 percent; the Navy's dolphin survival rate for more than 10 years has been 95-97 percent, and during one period some years ago the Navy maintained an unprecedented 100 percent survival rate for its 140 marine mammals for more than a year and a half.

The Navy's marine mammal systems are subject to the same rigorous test and evaluation process required of any Navy system prior to fleet acceptance. Developed capabilities failing to meet acceptable standards of effectiveness and reliability are rejected by the Navy. As a result, the Navy's operational marine mammal systems are efficient, reliable, and accomplish tasks that are nearly impossible by other means.

Harbor Porpoise Necropsies

On 13 May 2003, new allegations surfaced in the media suggesting SHOUP's use of sonar on 5 May 2003 could have led to the stranding of harbor porpoise in the region. SHOUP has been subsequently linked in the media to all of these strandings (erroneously reported in various media stories as involving as few as 13 and as many as 17 strandings).

Between 2 May to 2 June 2003, approximately 16 strandings involving 15 harbor porpoise and one Dall's porpoise were reported to the Northwest Marine Mammal Stranding Network. According to NMFS, the number of strandings in 2003 is one below the previously recorded high (NMFS 2003b:5). The annual stranding of harbor porpoise in Puget Sound is a known and expected seasonal phenomenon, with strandings occurring more frequently in May, and 70% of all annual strandings occurring between the months of March and June. Other cited causes of strandings include toxins (such as "red tide") and contaminants (NMFS 2003; e.g., release of 40 tons of raw sewage in Admiralty Inlet on 3 May 2003 by a cruise liner; AP 2003).

For a historical perspective, since 1992 the San Juan Stranding Network has documented an average of 5.8 porpoise strandings per year. In 1997 there were 12 strandings in the San Juan Islands with over 30 strandings throughout the general Puget Sound area. On 20 May 2003, Dr. Richard Osborne, Research Director for The Whale Museum on San Juan Island wrote that he believed that he was observing a normal pattern of porpoise strandings (Osborne 2003a).

While this data and trends analysis from Dr. Osborne appears to conflict with the NMFS necropsy report abstract which noted a higher rate of strandings in 2003 than the six per year, they can be reconciled when accounting for several factors (NMFS 2003b:2). First, Dr. Osborne and NMFS point to the repeated and intense level of media attention focused on the strandings which increased reporting efforts (Osborne 2003a; NMFS 2003b:55).

NMFS noted in its report that the “sample size is too small and biased to infer a specific relationship with respect to sonar usage and subsequent strandings (NMFS 2003b:55). In addition, although NMFS has characterized 2003 as having “an abnormally high number” of strandings, it is actually less than the maximum previously recorded (15 strandings in 2001; NMFS 2003b:5). Finally, given the reported average of 6.0 (strandings annually) and the standard deviation of 6.1, a large variation in the number of annual strandings should be expected (NMFS 2003b:5).

Of the 16 strandings SHOUP was accused of potentially having caused, seven mammals died prior to SHOUP departing the pier at Everett on 5 May 2003. Of these seven, one, discovered on 5 May 2003 was in a state of moderate decomposition indicating it died well before 5 May 2003. It’s cause of death was salmonella septicemia and no evidence of acoustic trauma. Another porpoise, discovered at Port Angeles on 6 May 2003, was in a state of moderate decomposition indicating that this porpoise died prior to 5 May 2003. One stranded harbor porpoise discovered fresh at Dungeness on 6 May 2003 is the only animal that could potentially be linked in time to SHOUP’s 5 May 2003 active sonar use. Necropsy results for this porpoise found no evidence of acoustic trauma. Both the Port Angeles and Dungeness locations are known common harbor porpoise stranding sites. The remaining eight strandings were discovered one to three weeks after SHOUP’s 5 May 2003 Haro Strait transit and, therefore, cannot be causally linked in time. Two of the eight died from blunt trauma injury. A third suffered from parasitic infestation possibly contributing to its death (NMFS 2003b: Appendix F). Of the remaining five, NMFS was unable to identify the causes of death.

As a result of the allegations regarding SHOUP, NMFS initiated a necropsy study involving 11 of the stranded animals discovered between 2 May and 2 June 2003. The purposes of these examinations were to provide scientific data on the causes of death and to investigate whether physical evidence could be found to link the stranding events to “naval sonar activity” (Norberg 2003b; NMFS 2003b). The necropsies took place at the National Marine Mammal Laboratory in Seattle.

NMFS’ overall finding was that none of the 11 necropsied harbor porpoise showed signs of acoustic trauma (NMFS 2003b:55). NMFS identified causes of death for five of the porpoise. Two of the five had perimortem blunt trauma injury with associated broken bones in their head (NMFS 2003b:55). The remaining three died from illnesses including pneumonia, salmonellosis, and peritonitis (NMFS 2003b:2). A cause of death could not be determined in the remaining six cases, which is consistent with the expected percentage in most marine mammal necropsies from the region (NMFS 2003b:57).

Acoustic Analysis

Three independent acoustic analyses were performed. Naval Undersea Warfare Center Newport experts performed an initial assessment of potential acoustic propagation. Based upon this initial assessment, U.S. Pacific Fleet Anti-Submarine Warfare experts conducted an acoustic analysis using a computer based modeling program normally used on board naval vessels for tactical computation of sound propagation. The Naval Research Laboratory (NRL) then performed a detailed in depth analysis to confirm the results of the first two analyses. Ultimately, these three analyses corroborated each other in terms providing a determination as to received sound levels likely to be present at the known locations of the orca J-Pod in Haro Strait.

The NRL analysis predicts sound levels approximately 1-10 dB higher than the hydrophones recorded (where comparisons are possible) on 5 May 2003. The NRL acoustic analysis sound levels therefore represent worst-case determinations. The results of NRL's acoustic analysis indicates that at approximately the point of closest approach between SHOUP and the orca, the J-Pod could have experienced two seconds of a maximum mean received sound pressure level of 171 dB. At all other times during SHOUP's transit, the J-Pod received sound levels from the short pings were lower than this maximum.

The analysis also concluded that the prolonged reverberation, evident on the videotape and hydrophone recordings, reached the orca at approximately the point of closest approach, with a maximum mean sound pressure level of 144 dB. At all other times during SHOUP's transit, sound from the reverberation reaching the orca would have been less than or equal to approximately 130 dB. This is the same approximate sound level recorded by the hydrophones in five instances when the sound from other motor vessels in close proximity to the orca reached mean levels as high as 120-130 dB over-shadowing the reverberation from SHOUP's sonar.

Recent research in Haro Strait has demonstrated that whale watch boats generally have a source level between 159-168 dB when moving at speed. Superimposed noise levels of five boats circulating around or following the whales were modeled as close to the critical level assumed to cause a permanent hearing loss over prolonged exposure (Erbe 2002). The increased vessel traffic is also argued to be creating increased disturbance in the resident whales' core areas, including Haro Strait (Ford 2000:100). Researchers have reported that the ambient background noise of Haro Strait to be approximately 90 dB over a broadband of frequencies. This level of ambient noise in Haro Strait was also consistent with the findings of acoustic analyses undertaken for this inquiry

By way of comparison, orca produce sounds for echolocation in the 200-225 dB range and their vocalization whistles are in the range of 131-168 dB (Au et al. 2000; Miller 2000; Viers 2003b). In April 2003, J-Pod orca were recorded in Haro Strait vocalizing at source levels calculated to be between 159-167 dB (Viers 2003b). A study of auditory thresholds in two captive orca indicated that there was no behavioral reaction to 1-2 kHz sounds at 150 dB (Szymanski et al. 1999). Puget Sound commuter ferries, tugboats, and other mid-sized motor vessels produce sound in the range of 160-170 dB in low range frequencies. Zodiac outboard motor whale watch boats in Haro Strait were found to produce broadband sounds at a source level as high as 168 dB. A modern-day supertanker cruising at 17 knots produces sound in the low frequency band (below 500 Hz), at source levels as high as 190 dB.

In addition to anthropogenic (i.e., man-made) sound sources, natural sources include lightning strikes, which hit the ocean surface creating underwater sound with source levels around 260 dB (67 FR 46712, July 16, 2002). Underwater earthquakes, landslides and volcanic eruptions exceeding 230 dB occur annually in the Pacific Ocean.

It should be noted that due to the characteristic impedance of water being about 3600 times that of air and because of the differences in reference measurements, 100 dB in air is not the same as 100 dB in water. As a general rule, to convert from water to air, simply subtract the 62 dB from the sound level in water; however, this is an approximation, since the source level often changes with the frequency component of the sound. Thus, a Puget Sound ferry generating a 170 dB sound level underwater would be roughly equivalent to a 108 dB sound generated in air.

Conclusions and Recommendations

SHOUP operated its sonar on 5 May 2003 in a manner consistent with established guidelines and procedures. Based on the evidence and scientific review, SHOUP's 5 May 2003 sonar operations did not kill, injure, or otherwise harm resident J-Pod orca. Based on the evidence and scientific review, SHOUP's sonar operations on 5 May 2003 did not kill, injure or otherwise harm other marine mammals, and was not responsible for any subsequent harbor porpoise strandings.

None of the 11 necropsied harbor porpoise had signs of acoustic trauma (NMFS 2003b:55). Five of the porpoises had a known cause of death. Two of the five had perimortem blunt trauma injury with associated broken bones in their head (NMFS 2003b:55). The remaining three died from illnesses including pneumonia, salmonellosis, and peritonitis (NMFS 2003b:2). A cause of death could not be determined in the remaining six cases, which is approximately the expected percentage of unknowns in most necropsied animals from the region (NMFS 2003b:57).

Allegations that harbor porpoise strandings resulted from SHOUP's use of sonar on 5 May 2003 ignore the historic record of annual strandings occurring with the same relative frequency and at the same locations as occurred in 2003. For the nine strandings discovered after 5 May 2003, any acoustic impacts other than physical injury would have resulted in a transitory "flight response," with animals frightened into stranding immediately. It is not possible that strandings occurring days to weeks after 5 May 2003 could have resulted from a sustained flight response. These strandings, therefore, had no relationship to the use of sonar by SHOUP on the date in question.

Although, the precise sonar frequency levels transmitted by SHOUP on 5 May 2003 are classified information, the sonar frequency used was at the lower range of the hearing spectrum for orca. SHOUP's sonar, therefore, should not have interfered with echolocation or communication vocalizations that are centered in a range of higher frequencies than SHOUP's sonar was transmitting on 5 May 2003.

Observer opinions regarding orca behaviors are inconsistent, ranging from the orca being "annoyed" to their being "at ease with the sound," and from the orca having low rates of activity to the orca having displayed their entire behavioral repertoire (Bain 2003; Balcomb 2003; Balcomb and Emmons 2003; Orca Network 2003a). A review of videotape by Navy marine mammal experts showing the orca during SHOUP's transit of Haro Strait indicates the orca behaviors displayed were within the normal range of behaviors and there were no immediate or general overt negative behaviors depicted. Subsequent to 5 May 2003, there were no recorded observations indicative of any effect, temporary or permanent, on any marine species from the SHOUP's use of sonar on that date (Orca Network 2003b).

No further investigation or action related to SHOUP's sonar operations on 5 May 2003 is warranted.

Introduction

This report sets forth of the results of the U. S. Pacific Fleet's inquiry into the allegations of marine mammal impacts surrounding the use of active sonar by USS SHOUP (DDG 86) in Haro Strait on or about 5 May 2003. Following the report is a glossary that provides the definitions and discussion of important, often technical terms used throughout this report. The glossary also provides a rudimentary discussion of Navy sonar operations that may prove useful to the lay reader of this report.

As part of this inquiry into the allegations surrounding SHOUP's use of active sonar on 5 May 2003, three independent acoustic analyses were performed. Naval Undersea Warfare Center Newport (NUWC) experts performed an initial assessment of potential acoustic propagation. Based upon this initial assessment, U.S. Pacific Fleet Anti-Submarine Warfare experts conducted an acoustic analysis using a computer based modeling program normally used aboard naval vessels for tactical computation of sound propagation. The Naval Research Laboratory then performed an in-depth analysis to confirm the results of the first two studies. As discussed below in that portion of this report that addresses the acoustic analysis of the 5 May 2003 events, these three analyses corroborate each other in terms providing a determination as to received sound levels likely to be present at the known locations of the orca J-Pod in Haro Strait. The relevance of this corroboration is discussed in this report's section addressing conclusions and recommendations.

The Environment

The Haro Strait is a passage of the eastern North Pacific, lying between Vancouver and Saturna Islands of the province of British Columbia, Canada (west), and San Juan and Stuart Islands of the State of Washington, United States (east). Part of the United States–Canadian border passes down the center of the strait, which extends north to the Strait of Georgia and south to Strait of Juan de Fuca. Mid-channel depths average 600–900 feet (180–275 meters), but at its southern end seamounts and shoal areas reduce the depth to 60–300 feet. Vessels leaving the city of Victoria heading north follow Haro Strait through the islands to the Strait of Georgia.

There are four species of marine mammals inhabiting Haro Strait that were alleged to have been affected by SHOUP's use of sonar on 5 May 2003. These are orca (*Orcinus orca*), Dall's porpoise (*Phocoenidae dalli*), minke whale (*Balaenoptera acutorostrata*), and harbor porpoise (*Phocoena phocoena*). Accurate and precise numbers of the various marine mammal species present in Haro Strait on 5 May 2003 could not be determined.

The orca and the two porpoise species that were present are odontocetes (toothed whales) and the minke is a mysticete (baleen whale). These two taxonomic suborders of whales have general anatomical differences (e.g., in odontocetes - the presence of a melon and the ear canal being vestigial) that result in different auditory capabilities and hearing thresholds.

The orca (a.k.a. killer whale) is the largest species in the dolphin family. Orca live in small, close-knit, life-long pods. Orca grow to be about 27 to 33 feet long, and can weigh between 8,000 to 12,000 pounds. They can swim up to 30 mph in bursts in order to catch prey. The male orca is larger than the female. An orca's skin is mostly black with distinctive white patches. Orcas have stocky bodies and a rounded head with a distinctive beak. The orca dorsal fin is relatively tall and there is sexual dymorphism with the females having a smaller dorsal fin (up to 4 feet) as compared to the males (up to six feet). Orca have 10-13 pairs of large three inch long, one inch diameter teeth that curve inwards and backwards. Members of a pod frequently cooperate in hunts, and in this respect orca have been compared with terrestrial wolf packs.

There are three distinct stocks of orca in the Pacific Northwest: Residents, Transients, and Offshore. All of these stocks may be present in the same general area, as they were in Haro Strait a few days prior to 5 May 2003 (Orca Network 2003b). Those orca south of mid-Vancouver Island, and which frequent Puget Sound, are known as the Southern Resident community and consist of the J, K, and L pods. From April through September each year, the three Southern Resident pods usually travel throughout the inland waters of Puget Sound, the Northwest Straits, and the Georgia Strait.

As recently noted by the National Marine Fisheries Service (“NMFS”) in May 2003 in the promulgation of its regulations concerning the status of the Southern resident orca, the survival rates of these orca have shown a significant downward trend in the past 26 years. NMFS noted that declines in the 1960s were primarily the result of collection for aquariums, with 68 animals having been removed from the population (68 FR 31980, May 29, 2003). A recent decline since 1996 further reduced the population from 97 to the present count of 83 whales (population levels were at or below the present count from 1976-1986). Degradation of habitat and a reduction in salmon stocks, which is the main prey of the resident orca, are cited by NMFS as likely causes for the more recent decline (68 FR 31980, May 29, 2003). Others have suggested that unregulated whale watching and increased vessel traffic may also have contributed to the declining population (Erbe 2002; Ford et al. 2000:100). Orca also have been found to have high concentrations of organo-chlorine pollutants in their body fat. The effects on the orca are not known, but in other marine mammals there is evidence that these pollutants cause reproductive impairment, skeletal abnormalities, immunotoxicity, and endocrine disruption (Ross et al. 2000:505).

On 1 July 2002, NMFS determined that the stock of Southern Resident orca was below its Optimal Sustainable Population, and was therefore “depleted” as defined in the Marine Mammal Protection Act (MMPA) (68 FR 31980, May 29, 2003). NMFS has begun efforts to develop a Conservation Plan (i.e., an orca recovery plan) for the stock as required under the MMPA.

Transient killer whale pods, which are not the subject of the 5 May 2003 allegations, inhabit the same general area as the resident pods. Transient orca generally occur in groups of three or four individuals comprised of an adult female and two or three of her offspring. This stock of orca consists of carnivorous "mammal-eaters," preying upon seals, sea lions, other whales, porpoise, and dolphins (Ford et al 1998:1461). On 15 October 2002, local Canadian newspapers reported that a number of transient orca were observed by 200 onlookers as they attacked and consumed a minke whale in Ganges Harbor, Vancouver, British Columbia (AP 2002). Given this predatory nature, transient orca, if present, could have affected the behavior of other marine mammal in their vicinity. Both Transients and Offshore orca were observed in the area a few days prior to and in the days following SHOUP's transit of Haro Strait on 5 May 2003.

Offshore orca generally reside in the open ocean, but occasionally enter Juan de Fuca and the inland waters of Puget Sound, including Haro Strait. Like the Transients, Offshore orca also prey upon other marine mammals.

Dall's porpoise were observed on 5 May 2003 moving north in Haro Strait when SHOUP was approximately 10 miles distant (Everett Herald 2003). A 1996 NMFS survey of Washington inland waters resulted in an abundance estimate of 900, while the stock has a total abundance estimate of 99,517 (Caretta et al. 2003). Dall's porpoise have a stocky, black body with large white sections on the flanks and belly**,** a small triangular dorsal fin, and the posterior margin of the tail flukes are fringed with a grayish-white band. The head is small and beakless. They are generally six to eight feet long and weigh up to 400 pounds. Dall's porpoise are the fastest swimmers of all marine mammals, reaching speeds of up to 35 mph. When they surface to breath moving at their normal rate of travel, they produce a characteristic "rooster tail" of spray. Dall's porpoise feed on a wide variety of small fish, squid, and crustaceans. They generally occur in pods of 5 to 20 individuals, although larger temporary congregations are not uncommon.

The behavior of Dall's porpoise may be affected by the presence of orca. Observed "harassments" of Dall's porpoise by Resident orca have involved, "whales chasing, pushing, or ramming the porpoises" (Ford et al. 1998:1460; Orca Network 2003b). For Transient orca, seven of 18 witnessed predation events involving Dall's porpoises ended in a confirmed kill by the orca with nine of the 11 harassments being "high speed chases in which the porpoise appeared to escape." (Ford et al. 1998:1461).

Whale watchers in Haro Strait observed a single minke whale on 5 May 2003 during SHOUP's transit. The number of minke whales in the local stock is estimated by NMFS as 1,015 (Caretta et al. 2003). The minke is the smallest and most numerous of the baleen whales in the rorqual family. Minke can grow to a length of 26 to 36 feet long and can weigh up to 10 tons. Their life spans may stretch for 50 years. Minke whales have a slender streamlined body with a pointed head. The minke whale's coloring is dark gray to black on the back, lightening to white on the belly and undersides of the flippers. Their relatively long flippers have a characteristic white band or patch across them. The dorsal fin is small and there is a series of small ridges along its back near the tail. Minke whales feed on plankton, small crustacea, and small fish. They travel alone or in pods of 2-3 whales. Minke whales can dive for up to 20-25 minutes, but usually make shorter dives, lasting about 10-12 minutes. Because they start to exhale before they reach the surface, the spout of the minke whale is low and inconspicuous. Minke whales normally travel at speeds between 3 to 16 mph, but can reach speeds of 18 to 21 mph over short distances.

Harbor porpoise are among the smallest and shortest-lived cetacea, having a lifespan of about 10-17 years. There were no recorded observations of harbor porpoise on 5 May 2003. They generally inhabit coastal waters with a depth of less than 500 feet, and their common name is derived from their regular appearance in bays and harbors. NMFS reports there are approximately 39,586 harbor porpoise in the coastal Oregon and Washington waters (Caretta et al. 2003). The harbor porpoise is a small, stocky animal. Fully grown harbor porpoise average five feet in length. The most common coloration is brown or dark gray, converging to a lighter gray on the flanks. There is a black stripe that runs from the edge of the mouth or eye to the flipper on either side. There is no noticeable forehead or beak on this species. The triangular dorsal fin is located in the middle of the back. Harbor porpoise are found in coastal waters where they prey on small schooling fish and crustacea. Harbor porpoise are difficult to study because they are widely dispersed, spend little time at the surface, are skittish, and generally occur in small groups of one to three individuals, although larger groups have also been observed on occasion. This inquiry found no recorded sightings of harbor porpoise on 5 May 2003 by any observers.

USS SHOUP (DDG 86)

SHOUP's Sonar Systems

USS SHOUP is the eighth OSCAR AUSTIN-class Guided Missile Destroyer, a sub-class of the ARLEIGH BURKE class. SHOUP was placed in commission on 22 April 2002. SHOUP's operational chain of command flows from SHOUP to Commander, Naval Surface Group Pacific Northwest to Commander, THIRD Fleet.

SHOUP's sonar systems include the AN/SQS-53C(V)4 Hull Mounted Sonar with Kingfisher mine avoidance system. Active sonar is the best acoustic method for detecting submerged submarines and mines. To this end, SHOUP employs the tactical mid-range frequency AN/SQS-53C sonar. This sonar is designed to emit sounds that will be reflected by nearby surface ships, submarines, and mines and thus detected by the ship's passive sonar sensors. This system is referred to as tactical mid-range sonar to distinguish it from navigational sonar systems, fish-finding sonar systems, etc.

The AN/SQS-53C is capable of producing a variety of waveforms, each designed for specific tasks. As a consequence, this sonar system will often emit several different signals in rapid sequence before waiting some time to listen to the returning echoes of the different signals. The manner in which SHOUP operated its AN/SQS-53C on 5 May 2003 was a central aspect of this inquiry and is detailed below in an unclassified format. The AN/SQS-53C sonar is actually an array of several individual sound sources arranged in a curved geometry. By operating the individual sources in precise timing relative to each other, it is possible to produce a beam of sound that does not project equally in all directions from a source depth of 26 feet (7.9 meters). The AN/SQS-53C, however, can also radiate sound in a 120-degree arc in front of the ship. This arc can be steered from side to side, but is typically centered in the direction of travel of the ship. The AN/SQS-53C sonar can operate at center frequencies of 2.6 and 3.3 kHz and at a nominal source level of 235 dB as occurred in SHOUP's use of active sonar on 5 May 2003 as discussed below.

The Swept Channel Exercise

SHOUP's use of sonar on 5 May 2003 involved the conduct of a Swept Channel and Surface Ship Small Object Avoidance exercise. SHOUP's AN/SQS-53-C sonar was used as an integral component of the exercise. The object of this exercise is to navigate in a confined area in a condition of heightened readiness, coordinate use and reporting of sensor information, and to detect and avoid mines and other submerged objects. Specifically, the goal is to train the ship's personnel in conducting small object avoidance operations. Ships engaged in this exercise must demonstrate the ability to conduct operations and effective mission planning to include, but not limited to, small object search, detection, classification, tracking, localization, and communication. Inherent in the conduct of this exercise is the operation of the ship's mid-range tactical sonar system.

The impetus for this training was the damage caused to the USS PRINCETON (CG 59) and two other ships by mines in the Arabian Gulf during Operation Desert Storm in 1991.

The 5 May 2003 Haro Strait Transit

On 5 May 2003 at 0855, SHOUP got underway from Naval Station Everett, Washington. SHOUP transited from Everett through Admiralty Inlet to the west side of Whidbey Island, where at 1033 it began the Swept Channel Exercise. Weather that morning consisted of partly cloudy skies, a temperature of 53 degrees, and winds averaging 8 mph. Visibility was ten miles and seas were calm. SHOUP's AN/SQS53-C mid-range tactical sonar was activated at 1040, operating at the nominal source level of 235 dB with a ping every 25 seconds. SHOUP continued active use of the sonar for approximately the next four hours, terminating pinging at 1438.

As the vessel entered more open water at the confluence of Juan de Fuca and Admiralty Inlet northbound in the vessel traffic separation scheme, it increased speed from 7 knots to 20 knots, terminating the Simulated Swept Channel Exercise at 1052. SHOUP continued operation of the AN/SQS 53-C in order to conduct small object avoidance training. SHOUP then continued in a northwesterly direction towards Victoria, Canada where she was to take on a Canadian Pilot for the remainder of the passage to the Nanoose Training Range.

At 1130, while enroute to Victoria, SHOUP commenced a Loss of Steering Control Drill. At 1152, SHOUP secured the Sea and Anchor Detail and completed the Loss of Steering Control Drill. A light rain was falling, reducing visibility to eight miles with no change in sea state. Seas remained calm. At 1233, SHOUP commenced a Damage Control Training Team environment and set a condition of General Quarters. Arriving at Victoria at 1324, SHOUP embarked a Canadian Naval officer who served as the pilot. At 1350, a modified Condition ZEBRA was set, which is a condition of maximum watertight integrity where all hatches are closed and secured. The light rain that had begun at 1150 stopped about this time and mostly cloudy conditions prevailed.

At approximately 1420, SHOUP entered the Haro Strait between Victoria/Vancouver Island and San Juan Island at a speed of 18 knots. Winds were averaging 7 mph, eventually increasing to 12 mph as the sky became overcast over the next hour. At 1426, the vessel secured from General Quarters and again set the Sea and Anchor Detail.

At 1434, Victoria Traffic called SHOUP via Bridge-to-Bridge (BTB) radio on Channel 11 and requested that the ship contact Victoria Canada Coast Guard on BTB Channel 22A. Radio communications were established and Canada Coast Guard informed SHOUP that Victoria Traffic had received complaints about loud underwater noise and asked if sonar operations were ongoing. SHOUP acknowledged that sonar was being used. Based on the receipt of this query, SHOUP unilaterally ceased transmission of sonar at 1438.

At no time during its radio communications with SHOUP did the Canadian authorities relay information regarding the presence of or concerns with marine mammals in the area. Sonar operations were subsequently secured at 1440, meaning that the entire system, including passive monitoring, was turned off and manning of the sonar stations was no longer required. SHOUP exited Haro Strait at approximately 1500 and continued in a northerly direction enroute to the Nanoose Range via the Strait of Georgia.

From the information available, SHOUP's closest point of approach to the orca J-Pod in Haro Strait was approximately 1.5 nautical miles and occurred at 1434. [See Figure 1.]

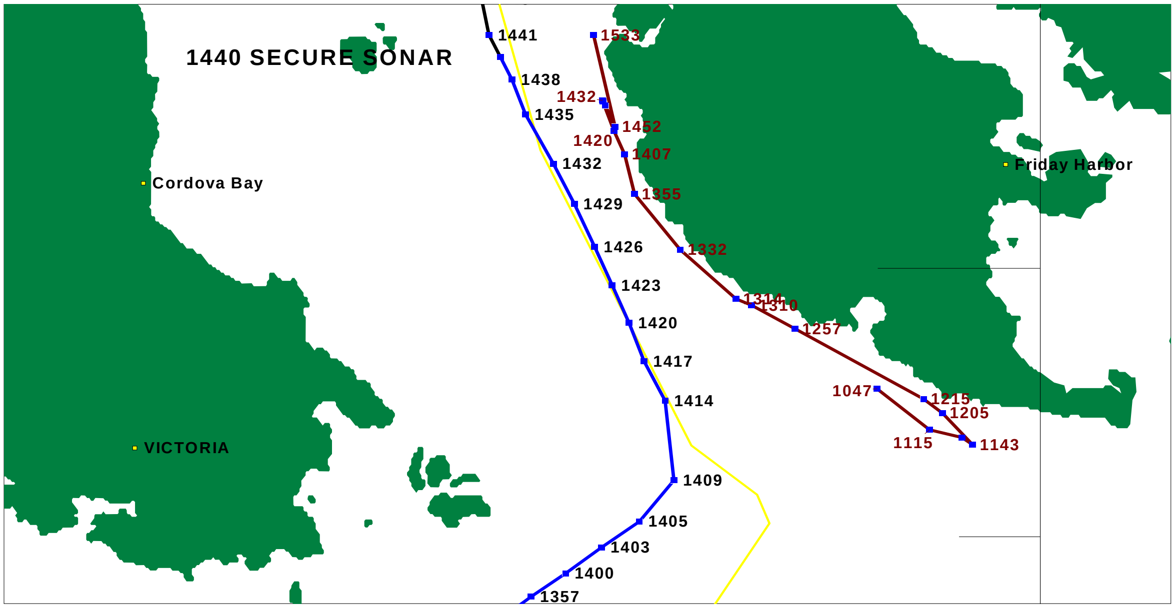

Figure 1: Orca J-Pod movement relative to SHOUP's Haro Strait transit (5 May 03). Blue depicts SHOUP's track, yellow depicts the international border, and maroon depicts the orca J-Pod's track. Times are PST.

Videotape recordings of SHOUP's transit provided to Navy by NMFS show that at the point of closest approach, 1.5 nautical miles, there were approximately six motor vessels in the vicinity of the orca J-Pod. Many of these vessels appeared to be directly engaged in whale watching activities. Each of these vessels was significantly closer to the J-Pod than was SHOUP. At least two of the vessels were maneuvering towards the J-Pod at approximately this time, with SHOUP clearly visible in the distance over a mile away.

Throughout the exercise and subsequent Haro Strait transit on 5 May 2003, SHOUP had numerous lookouts and other personnel on watch at all times, which at a minimum consisted of the Officer of the Deck, Junior Officer of the Deck, Tactical Communications, Master Helmsman, Helm Safety Officer, Navigation Evaluator, Starboard Lookout, Port Lookout, and Aft Lookout. The primary task of lookouts and personnel on watch is to be alert for the presence of surface contacts including marine mammals, discolored water, floating debris, trash, and other small objects; anything unidentified or any disturbances in the water, which in tactical settings can be telltale indicators of mines and submarine masts/periscopes. No marine mammals were reported by the crew or detected by ship’s sensors on 5 May 2003.

Allegations of Harm and Injury to Marine Mammals

It was not until the following day, 6 May 2003, that the Navy learned about the alleged interaction between SHOUP and marine mammals from various media and Internet reports.

On 9 May 2003, NMFS Northwest Region officials met with Mr. Kenneth Balcomb, Executive Director for the Center for Whale Research; Dr. Richard Osborne, Research Director for The Whale Museum (San Juan Island); and Dr. David Bain, Affiliate Assistant Professor at the University of Washington.

Mr. Balcomb reported to NMFS his observations that, " . . . the whales of J-Pod exhibited behaviors in close proximity to each other, including variable speed and surface activity, spyhop and tail slapping, changing and un-coordinated heading, 'logging,' not 'logging,' splitting into groups, and coalescing, etc." (Balcomb 2003). Mr. Balcomb further opined that this exhibition of behaviors was extremely unusual in his experience.

Dr. Bain began observations of J-Pod at 1047 from a vessel located off the southwest corner of San Juan Island on 5 May 2003, which continued until 1557 that afternoon (Bain 2003). According to Dr. Bain, the sonar became audible through the hull of his vessel at 1134. At the time, USS SHOUP was approximately 10 miles to the south transiting the Strait of Juan de Fuca.

It should be noted that for an approximate 45-minute period between 1313 and 1348, the acoustic analysis detailed later in this report determined (and the hydrophone recordings confirmed) that direct path sound from SHOUP's sonar was not reaching the orca J-Pod given the orientation of SHOUP towards Victoria and the interposed islands (e.g., Discovery Island) and shoals between the ship and the orca. Dr. Bain did not record any observations of changes in behavior when the sonar ceased being directly received by the orca of J-Pod at 1313, during this 45-minute period when the faint sonar echo was the only sound received by the orca from SHOUP, nor did he record any changes in behavior when the sonar direct path resumed being received by the orca at 1348.

In general, Dr. Bain reported observing "low rates of surface active behavior" on behalf of the orca J-Pod (Bain 2003). Dr. Bain opined that the behavior was " . . . very unusual, but appeared to be more appropriate for minimizing the received level of the noise and hiding from the source." He reported the orca spread out briefly at various points along San Juan Island, otherwise staying in close proximity to each other while continuing northward. At 1432 off Andrews Bay, Dr. Bain's field notes reflect that J-Pod turned south, heading back toward the approaching SHOUP and the sonar. [See Figure 2.] Dr. Bain then noted that the orca "stopped in Andrews Bay, where they milled back and forth" as SHOUP passed by. Dr. Bain continued to note the movement of J-Pod as they continued to the south until 1452, when the pod resumed travel to the north.

As SHOUP passed the orca of J-Pod, another observer reported that, "Jpod seemed more or less at ease with the sound" (Bates 2003).

Regarding Dr. Bain's observation concerning the orca having turned to the south, the videotape shows approximately six whale watch boats arrayed in an arc potentially blocking the J-Pod's northward line of progress. Previous studies have suggested that measured noise levels in the presence of five whale watch boats within 400 meters were just below the critical sensation level causing permanent threshold shift in human ears for long-term exposures (Erbe 2002:18).

Figure 2 provides an enhanced view of the orca J-Pod's track relative to SHOUP's transit at the time of SHOUP's closest point of approach.

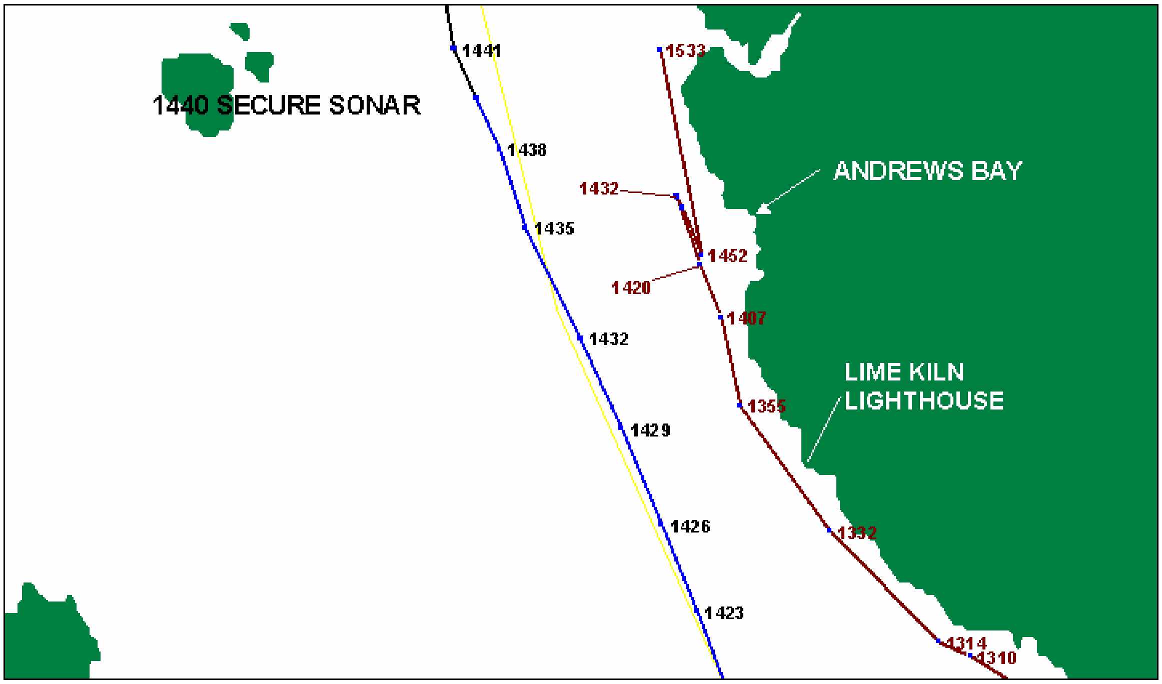

Figure 2: Enhanced view of SHOUP's track relative to orca J-Pod movements at SHOUP's point of closest approach during the Haro Strait transit (5 May 03). Blue depicts SHOUP, yellow depicts the international border, and maroon depicts the orca J-Pod. All times are PST.

Dr. Bain also noted that at 1434 he observed a lone minke whale porpoising repeatedly in a northbound direction (Bain 2003). The videotapes depict the splashes from the minke, which continued running to the north even after being overtaken by SHOUP. Dr. Bain opined that this porpoising behavior was extremely rare as part of a natural repertoire having personally observed a minke porpoising on one previous occasion. An accurate plot of the minke whale's movements relative to SHOUP could not be developed using available information.

Videotape recordings made by Mr. Ken Balcomb and Ms. Candice Emmons, his assistant, depicting whale behaviors and vessel traffic in Haro Strait were shot from two locations along the shoreline using two cameras contemporaneous with SHOUP's passage through Haro Strait (Balcomb and Emmons 2003). An unidentified male voice on the audio track of the videotape recording (Camera 2) made during SHOUP's closest point of approach with the J-Pod (approximately 1433) described the observed behavior as follows: “This is nuts, man. This is nuts. Yeah, well the J’s have turned around, I mean this is definitely behavior, um, well, it’s just annoyed.” Approximately one minute later, the same individual stated, “Whales are just sort of drifting around at the surface here right now, hoping the whole thing will goes [sic] away, I guess.”

An unidentified female voice on the audio track of the videotape recording (Camera 1) can be heard just prior to SHOUP’s closest point of approach with the J-Pod stating, “We have J-pod right up against the shoreline here …. um, well, they’ve been hugging the shoreline kind of resting” (Balcomb and Emmons 2003).

Tom McMillen, a local whale watch boat operator, observed Dall’s porpoise at an unidentified location as “going north” when the SHOUP was estimated by him to be 10 miles away (Everett Herald 2003). The time and location of this observation could not be determined more accurately given presently available information. Potential reasons for the Dall’s movement include the pursuit of a food source, the presence of harassing resident orca or predatory transient orca, vessel disturbance other than SHOUP, or multiple other unknowable reasons.

There were no reported observations of harbor porpoise on 5 May 2003. It was not until 13 May 2003 that allegations were first reported in the media that SHOUP’s use of sonar on 5 May 2003 could have caused the strandings of harbor porpoise in the region.

Navy SPAWAR's Analysis of Videotaped Behaviors

The videotape depicting orca behaviors on 5 May 2003 was forwarded to scientists with expertise in marine mammal behavior who are located at SPAWAR and involved with the Navy Marine Mammal Program (NMMP) centered in the Biosciences Division of the Space and Naval Warfare Systems Center in San Diego. These world-renowned scientists are frequently called upon to provide technical support for environmental compliance and guidelines for Naval operations where marine mammals may be present.

Marine mammal scientists involved in the review of the videotape included Dr. Samuel Ridgway, D.V.M, Senior Scientist, Scientific and Veterinary Support Branch, Dr. Donald Carder, Scientist and Project Manager for the Acoustic Safety Criteria Project, Dr. Randal Brill, Head of the Scientific and Veterinary Support Branch, and Dr. John Sigurdson, Senior Scientist, Scientific and Veterinary Support Branch. Based on their review, these experts concluded that the indicated behaviors of the orca in the video were within the species' normal range of behaviors and there were no immediate or general overt negative behavioral reactions depicted. These scientists further opined that the reported behaviors judged by on-site observers to be unusual, but which are not evident on the videotape recording of the event, were possibly the result of the numerous small motor vessels maneuvering in close proximity to the orca.

Review of the videotape also demonstrates that notations of orca behaviors detailed by on-site observers as being "unusual" in statements to NMFS are inconsistent with the orca behaviors and movements depicted in the videotape recording, the statements are inconsistent between observers, and the behaviors depicted are within the normal repertoire of behaviors for the J-Pod orca.

The scientists in the NMMP are the Navy's marine mammal experts given their continuing role in conducting research in development, training, veterinary care, and marine mammal physiology, which previously included work with orca. The NMMP is the single largest contributor to the open literature on marine mammals with over 800 technical publications to date including results of research aimed at understanding marine mammal bioacoustics and the potential effects of human-generated sound on marine mammals. The U.S. Navy's Marine Mammal Program had its origin in the acquisition, in 1960, of a Pacific white-sided dolphin for hydrodynamic studies. Navy scientists designing torpedoes had heard accounts of the hydrodynamic efficiency of dolphins, and were interested in determining whether dolphins did in fact have special characteristics that might be applied to the design of the underwater missiles. Although discontinued in the 1960s, a new program is underway using modern technologies. Early Navy marine mammal work centered around Point Mugu, California, where the primary interests were in the study of the marine mammals' specially developed senses and capabilities (such as sonar and deep diving physiology) and also how dolphins and sea lions might be used to perform useful tasks. A major accomplishment was the demonstration that trained dolphins and sea lions could be worked untethered in the open sea with great reliability.

In 1967, the Point Mugu facility and its personnel relocated to San Diego and were placed under a newly formed organization which has since undergone a number of name changes, including Naval Undersea Center; Naval Ocean Systems Center; Naval Command, Control and Ocean Surveillance Center Research, Development, Test and Evaluation Division; and, currently, Space and Naval Warfare Systems Center San Diego. Shortly after the headquarters move to San Diego, a laboratory was established in Hawaii at the Marine Corps Air Station on Kaneohe Bay. Some of the personnel and animals at Point Mugu transferred to the Hawaii Laboratory, and later the rest of the operation moved to a new facility on Point Loma in San Diego. Here the research and development program begun at Point Mugu continued. This has included further studies of the capabilities of marine mammals; development of improved techniques for diagnosis and treatment of health problems; neurophysiological studies, using behavioral and other non-invasive techniques, to gain a better understanding of how the large dolphin brain functions; development of instrumentation for determining, by brain wave activity, the hearing range of a cetacean; and investigation of how dolphins produce the sounds they make.

In its operational systems, the Navy employs dolphins and sea lions to perform underwater surveillance for object detection, location, marking and recovery, working under the close supervision of their Navy handlers. The Navy also uses dolphins in operational programs for swimmer defense--to detect swimmers, divers and swimmer delivery vehicles, and, if the handler determines the situation warrants, to mark them; and mine countermeasures--to detect bottom mines and moored mines. Dolphins are used for these tasks because their extraordinary natural biological sonar capabilities enable them to find objects in waters where hardware sonars do not work well due to poor acoustic environmental conditions.

In the past, SPAWAR System Center (SSC) San Diego has investigated possible uses of whales to meet Navy research and operational requirements. In Project Deep Ops, a pilot whale and two killer whales demonstrated their ability to recover objects from significant depths, attaching a special recovery device with a hydrazine gas generator to raise objects to the surface. Using this device, the pilot whale successfully recovered an object from a depth of 1,654 feet. Although much was learned from the project, work with pilot and killer whales, the largest of the dolphins, has not been continued. This research required extensive understanding of the whales' behavior patterns.

The capabilities of white whales have also been investigated by SSC San Diego for similar recoveries in colder and deeper waters. In Project Deephear, white whales were trained to dive to sound generation platforms at varying depths down to 1,000 feet. There the animals stationed while scientists conducted hearing tests from the surface, generating sounds at various frequencies to determine the whales' hearing range. Using this method researchers were able to determine their hearing sensitivity in deep water was very similar to that in shallow water. Later research combined white whales and dolphins in studies of the effects of loud sounds on the animals' hearing.

The National Marine Fisheries Service, which has regulatory responsibility for the Marine Mammal Protection Act, reported findings in scientific literature that showed the Navy's dolphin survival rate is the highest among all organizations holding large numbers of marine mammals. This was attributed by the researchers conducting the study to "superior husbandry." Dolphin survival rate in the wild is reported in the scientific literature as 92-95 percent; the Navy's dolphin survival rate for more than 10 years has been 95-97 percent, and during one period some years ago the Navy maintained an unprecedented 100 percent survival rate for its 140 marine mammals for more than a year and a half.

The Navy's marine mammal systems are subject to the same rigorous test and evaluation process required of any Navy system prior to fleet acceptance. Developed capabilities failing to meet acceptable standards of effectiveness and reliability are rejected by the Navy. As a result, the Navy's operational marine mammal systems are efficient, reliable, and accomplish tasks that are nearly impossible by other means.

Harbor Porpoise Strandings

On 13 May 2003, new allegations surfaced in the media suggesting SHOUP’s use of sonar on 5 May 2003 could have led to the stranding of harbor porpoise in the region. Between 2 May to 2 June 2003, approximately 16 strandings involving 15 harbor porpoise and one Dall’s porpoise were reported to the Northwest Marine Mammal Stranding Network. This number of strandings has been erroneously reported in the media as involving as many as 17 strandings. NMFS considered only strandings that occurred in Washington waters south of the Canadian border as part of their necropsy report and historical database, and they therefore count and deal with only 14 strandings (NMFS 2003b). The NMFS 2003 stranding total of 14 is below the maximum of 15 occurring in 2001 and within the expected range of variation from the average of 6.0 given the standard deviation of 6.1 (NMFS 2003b:5). Only 12 of the strandings occurred in inland waters.

Of the 16 strandings, 15 could not be causally linked to SHOUP’s sonar use on 5 May 2003 based upon relative locations, times of discovery, and states of decomposition. Of the 15 not causally linked to SHOUP’s sonar use, six strandings occurred on or before 5 May 2003. Eight strandings occurred one week to three weeks after SHOUP completed its transit. One porpoise was discovered on 5 May 2003 in a moderate state of decomposition. This state of decomposition indicates that it died well before 5 May 2003. Its death was attributed to salmonella septicemia and the computerized tomography scan did not identify any overt lesions consistent with acoustic trauma (NMFS 2003b:20). Two other strandings were discovered on 6 May 2003; however, one of these strandings was in a moderately decomposed state indicating that the stranding occurred before 5 May 2003. The other stranded harbor porpoise discovered on 6 May 2003 is the only animal that could potentially be linked in time to SHOUP’s 5 May 2003 active sonar use. However, it was discovered at a common harbor porpoise stranding location, the stomach was empty as is typical for strandings in the region, and there was no evidence indicative of acoustic trauma (NMFS 2003b:54-55).

Of the remaining 8 strandings were discovered between one and three weeks after SHOUP’s 5 May 2003 Haro Strait transit. Necropsies identified perimortem blunt force trauma as the causes of death for two of the porpoise (NMFS 2003b:5). A third necropsy identified parasitism as the most likely cause of death. The remaining three necropsies were unable to identify causes of death. Figure 3 depicts the locations of the strandings and dates of discovery relative to SHOUP’s 5 May 2003 movements.

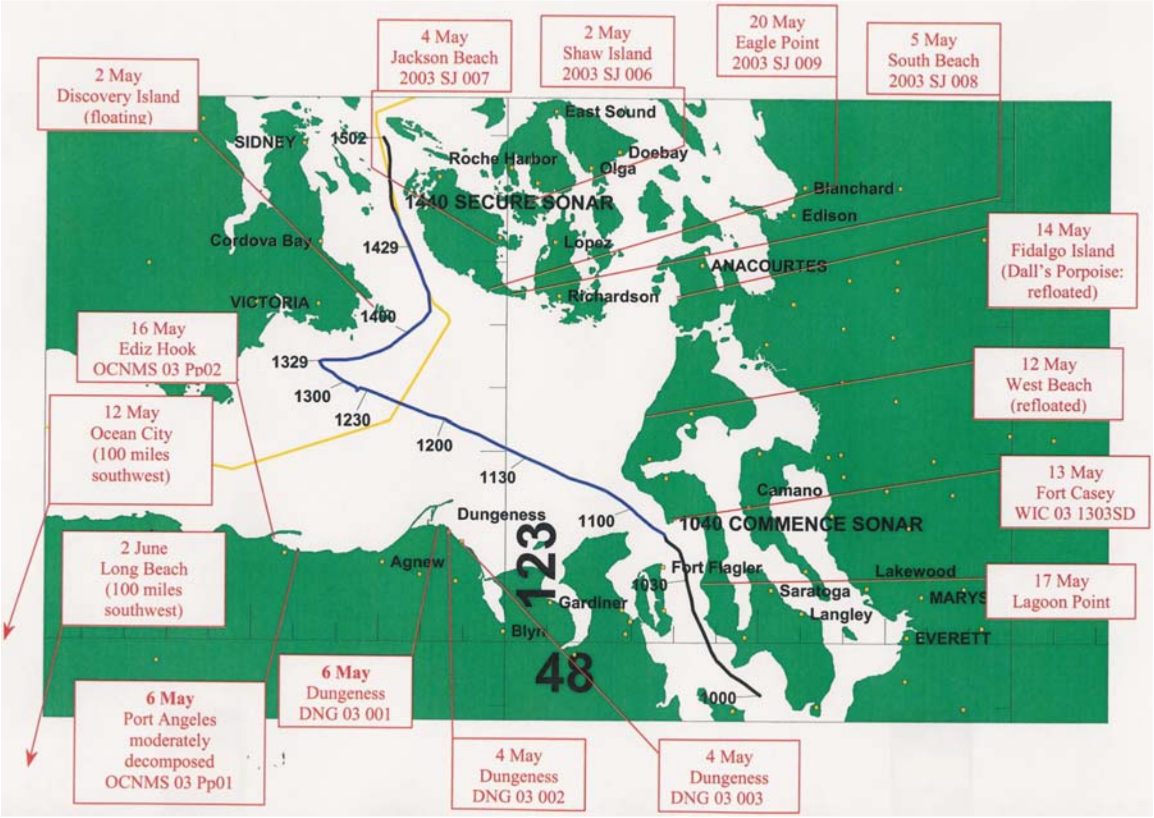

Figure 3: 2 May to 2 June 2003 – Puget Sound harbor porpoise strandings locations. The blue line depicts SHOUP's 5 May 2003 movements. The yellow line depicts the United States-Canadian border.

All of the 16 strandings are from locations and in numbers consistent with stranding data from prior years for which there is data. As noted previously, the annual strandings of harbor porpoise in Puget Sound are a known and expected seasonal phenomenon, with strandings occurring more frequently in May, and with 70% of all recorded annual strandings having occurred between March and June (Osborne 2003a; NMFS 2003b). Given the 39,586 harbor porpoise in the local stock (Caretta et al. 2003), many of these annual strandings are likely the result of normal mortality.

Other cited causes of strandings include toxins (such as "red tide") and contaminants [e.g., release of 40 tons of raw sewage in Admiralty Inlet on 3 May 2003 by a cruise liner (AP 2003)]. In a recent scientific report concerning the strandings of 17 bottlenose dolphins in the Atlantic, the reported causes of death included infectious/inflammatory disease, cachexia, asphyxiation, degenerative central nervous system disease, traumatic injury and dermatologic disease (Bossart et al. 2003).

For a historical perspective, since 1992 the San Juan Stranding Network has documented an average of 5.8 porpoise strandings per year. In 1997 there were 12 strandings in the San Juan Islands with over 30 strandings throughout the general Puget Sound area. On 20 May 2003, Dr. Richard Osborne, Research Director for The Whale Museum on San Juan Island wrote that he believed that he was observing a normal pattern of porpoise strandings (Osborne 2003a).

While this data and trends analysis from Dr. Osborne appears to conflict with the NMFS necropsy report abstract which noted a higher rate of strandings in 2003 than the six per year, they can be reconciled when accounting for several factors (NMFS 2003b:2). First, Dr. Osborne and NMFS point to the repeated and intense level of media attention focused on the strandings which increased reporting efforts (Osborne 2003a; NMFS 2003b:55). NMFS noted in its report that the "sample size is too small and biased to infer a specific relationship with respect to sonar usage and subsequent strandings (NMFS 2003b:55). In addition, although NMFS has characterized 2003 as having "an abnormally high number" of strandings, it is actually less than the maximum previously recorded (15 strandings in 2001; NMFS 2003b:5). Finally, given the reported average of 6.0 (strandings annually) and the standard deviation of 6.1, a large variation in the number of annual strandings should be expected (NMFS 2003b:5).

As a result of the allegations regarding SHOUP as being causally linked to the strandings, NMFS initiated a necropsy study involving porpoise carcasses discovered between 2 May to 2 June 2003 that were in sufficient condition to establish if evidence of acoustic trauma was present or if another cause of death could be determined.

NMFS undertook necropsy studies on 11 harbor porpoise specimens in its custody. The necropsies took place at the National Marine Mammal Laboratory in Seattle. The specimens were sorted for the freshest condition and specimens in sufficient condition were x-rayed using high-resolution Computerized Tomography (CT) imaging (a.k.a. "CAT scanning" or Computed Axial Tomography) to examine for evidence of acoustic trauma. Interpretation of the CT images as they relate to the morphology of marine mammal hearing is extremely specialized. To assist with its efforts, NMFS retained the services of Dr. Darlene Ketten, of the Woods Hole Oceanographic Institution Biology Department and Harvard Medical School Department of Otology and Laryngology, to undertake interpretation of the CT images. Dr. Ketten is considered by many to be the world's foremost authority in this regard.

Summary of NMFS' Findings

The dissection and scanning portions of the necropsies began on 22 July 2003 and were completed on 24 July 2003. Laboratory analysis of approximately 300 tissue samples and review of CT scans followed thereafter. Tissue samples from the harbor porpoise necropsies were submitted to a Canadian lab that focused on bacteriological analysis and also to the Armed Forces Institute of Pathology that focused on a toxicological and heavy metal analysis. The results are summarized as follows.

None of the 11 necropsies revealed definitive signs of acoustic trauma that could be associated with the SHOUP's sonar operations on 5 May 2003 (NMFS 2003b:55). Of the five for which definitive causes of death determined, two suffered perimortem blunt trauma injury with associated broken bones in their head (NMFS 2003b:55). The remaining three died from illnesses including pneumonia, salmonellosis, and peritonitis (NMFS 2003b:2). A cause of death could not be determined in the remaining six cases, which is approximately the expected percentage in most necropsied animals from the region (NMFS 2003b:57). No freshly consumed prey were present in any of the examined stomachs as is typical for porpoise strandings from the region (NMFS 2003b:54-55).

Acoustic Analysis

Contemporaneous hydrophone recordings of SHOUP's sonar were made from San Juan Island by Dr. Val Viers, Professor of Physics and Environmental Science at Colorado College, at a location north of Andrews Bay (Veirs 2003a). NMFS NW Region subsequently received copies of a portion of those recordings (as 370 sound files on two CDs) and made them available to Navy authorities on 5 June 2003. Additional data used in this analysis included historical databases containing water temperature readings from the Haro Strait area for 5 May 2003 and data detailing the complex bathymetry in and around SHOUP's track on this date.

NUWC Newport's Initial Acoustic Propagation Loss Approximation

As part of the initial inquiry, Navy Undersea Warfare Command (NUWC) Newport generated estimates of the potential received sound decibel levels at ranges of one, two, and three miles from SHOUP. Initial reports from witnesses were that SHOUP was in the middle of the channel and estimated to be about three miles from the orca at their closest point of approach (this was later determined to be in error based on precise tracking of both SHOUP and the orca J-Pod; 1.5 nm was the approximate closet point of approach). The NUWC first order approximation for a received level at three miles was 180 dB.

U.S. Pacific Fleet Analysis

On 29 May 2003, U.S. Pacific Fleet Anti-Submarine Warfare (ASW) experts conducted an analysis of SHOUP's use of sonar on 5 May 2003. Noting that NUWC Newport's initial calculation was only an approximation, these experts used a Personal Computer version of the Interactive Multisensor Analysis Training System (PC-IMAT). PC-IMAT is a tactical decision aid for the conduct of submarine, surface and air ASW as well as the U.S. Navy training system for oceanography and acoustics. Within PC-IMAT, the program offers two major types of applications: structured interactive lessonware, and environmental acoustic modeling. PC-IMAT was selected for this analysis given that it is the tactical decision tool of choice for the fleet ASW operators, it was easily accessible, and the analysis was producible in a timely manner at no additional cost.

Relevant to this report, the current basis for the Environmental and Acoustic modules are the Navy's standard environmental databases and range-dependent propagation loss models. With these modules, a user can choose an arbitrary geographic location and time of year, extract and view environmental data, display ray trajectories or propagation loss as a function of depth, distance and azimuth from a sonar sensor or threat.

The PC-IMAT analysis was undertaken by an individual assigned to the U.S. Pacific Fleet ASW directorate and a member of the Fleet's IMAT Mobile Training Team, which inspects and trains fleet sonar technicians on the operation of the AN/SQS-53C sonar and on the use of the PC-IMAT as a tactical decision-making tool. The results of the Pacific Fleet's analysis indicated that marine mammals experienced at various times and locations maximum sound levels in the range of 160-170 dB as a result of SHOUP's sonar operations on 5 May 2003.

Given the disparity between the initial approximation from NUWC and the PC-IMAT analysis results, NUWC Newport was asked to re-verify the Fleet's PC-IMAT analysis. Based on similar ongoing work for the U.S. Pacific Fleet, NUWC Newport Engineering, Test and Evaluation Department was chosen to undertake this re-analysis.

A review of the area using the tools within PC-IMAT showed a complicated bathymetric environment, so an approximation of 15 * logR (range) was used for the transmission loss modeling to approximate a received level of sound at the likely location of the whales. The 15 * logR is an approximation for Urick's formula for transmission loss at intermediate ranges (Urick 1983). The calculated transmission loss for each range of interest was subtracted from the sonar source level to produce an estimate of the received level in the approximate vicinity of the orca.

Shortly thereafter, a refined ship location was obtained by review of SHOUP's deck logs. Again using PC-IMAT, sound velocity profiles near this location were obtained. Very small movements from the location showed differences in the sound velocity profiles (i.e., surface duct or no surface duct). The presence of a surface duct would allow the sound to propagate farther resulting in a louder received level at a given point. Using the different sound velocity profiles and an approximation of the bottom topography, the Comprehensive Acoustic System Simulation (CASS) model option was run within PC-IMAT to generate transmission losses. These values were then used to compute received levels. It was noticed that depending on range, the surface duct case had receive levels that were 3.4 to 13.9 dB louder than the non-surface duct case. It was also noted that both of the surface duct and non-surface duct cases had lower received levels than the initial approximation using 15*logR (range). The results of NUWC Newport's re-analysis using PC-IMAT and worst-case assumptions indicated that marine mammals experienced at various times and locations maximum received sound levels in the range of 160-170 dB as a result of SHOUP's sonar operations on 5 May 2003.

Naval Research Lab Analysis

During the course of the Pacific Fleet inquiry, outside queries posed the question as to whether the 5 May 2003 allegations and conditions were similar to the 15-16 Mar 2000 Bahamas marine mammal stranding event. Although the two events were found to be dissimilar by researchers involved in and/or familiar with both events, after consultation with the Chief of Naval Operation's environmental staff the determination was made to arrange for the Naval Research Laboratory to conduct an acoustic analysis using the same methodology that had been used in the Bahamas investigation (NOAA and Navy 2000). This was done notwithstanding the dissimilar nature of the two events as the Bahamas report acoustic analysis had been peer reviewed and found to be comprehensive. It was noted at this time that an independent analysis using this approach could also serve as a measure for the validity of PC-IMAT as a predictive tool.

Important to this analysis were the recorded locations of the J-Pod orcas at known times and the hydrophone acoustic recordings that were made while SHOUP was transiting the area (Vires 2003a; Tables 1-3). Because of this knowledge, it was possible to create a detailed reconstruction of the event that relates the location of SHOUP, the J-Pod, and the monitoring hydrophones during the time period of SHOUP's sonar operations. Using this reconstruction, the NRL analysis sought to quantify the received sound levels in the immediate vicinity of the J-Pod occurred during SHOUP's sonar operations using worst-case assumptions.

The Acoustic Propagation Model

The research-quality acoustic propagation model, RAM (Collins, 1995; Collins, 1993), was used to calculate transmission loss as a function of range and depth. This model, which is based upon the parabolic equation, has been widely benchmarked and is considered by the underwater acoustics community to be a validated state-of-the-art model. It was also the primary model used for the Bahamas analysis.

The system inputs to the RAM model are the frequency, depth, and relative phasing (for beamforming purposes) of the source array elements. The primary environmental inputs are the bathymetry, the sound speed in the water column, and the geoacoustic properties of the bottom. No single propagation code, including RAM, routinely and directly accounts for all the environmental processes that can potentially impact predictions. Reasons vary from the underlying assumptions or approximations used by the model, to the environmental processes not being adequately described or measured. Examples of these processes are internal waves, biological scattering, and sub-surface bubbles. The RAM model does not routinely account for intrinsic (volume) absorption or for the loss of acoustic energy resulting from repeated interaction with the rough sea surface interface (surface loss). In the NRL analysis, intrinsic absorption in the water column was estimated using a simple model of absorption as a function of range (Urick, 1983). Due to weather conditions (described below), the sea surface was sufficiently calm as to not be a factor. The consequences of these and other phenomena will be discussed later in this report.

Environmental Inputs: Bathymetry

Bathymetry was constructed from various Naval Oceanographic Office (NAVOCEANO) databases including the NOAA Soundings Database. The merged bathymetry data was corrected and sampled to a 0.1-min resolution at NAVOCEANO. This resolution corresponds to a depth point approximately every 185 meters in latitude and 123 meters in longitude. For input to the models, bathymetry for a given bearing was extracted using bilinear interpolation every 0.1 kilometer (until a maximum range of 40 kilometers or the edge of the database) along radials from SHOUP's location to either the location of the marine mammal class's boat or the monitoring hydrophones.

Environmental Inputs: Sound Speed Field

Characterizations of physical parameters during SHOUP's Haro Strait transit were derived from archived data sets for the Haro Strait obtained from the U.S. Navy Oceanographic Office and other sources, as there was no bathythermograph data from 5 May 2003 available. This historical data did not display great variability that would have otherwise significantly have altered the outcome of the analysis. This increases the confidence level that the inputs to the models have captured the actual conditions during the SHOUP's transit of Haro Strait.

SHOUP did not retain the *in situ* sound speed information measured during the 5 May 2003 sonar training exercise. Sonar operators often consider information such as ambient noise and sound speed "perishable" and common practice is to discard it after leaving the area for which it was measured. This necessitated the use of models to predict the sound speed field present in the vicinity of the Haro Strait on 5 May 2003. Two different models were used – the Modular Ocean Data Assimilation System (MODAS) and the Navy Coastal Ocean Model. MODAS is a modular toolkit for estimating present and future conditions in the oceans. It presently consists of over 100 individual programs to: (1) acquire and quality-control input data of various types (including satellite remote sensed information); (2) use satellite data to refine climatological temperature and salinity in the oceans; (3) merge *in situ* measurements with a "first guess" field to produce a "best guess" of the present conditions in the ocean; and (4) provide a short-term forecast of the ocean, including currents and tides.

One of the most significant components of MODAS is its "dynamic climatology." Climatologies normally represent historical averages of ocean conditions. For example, at a particular time of year and location in the ocean, we can expect the temperature and salinity in the water column to have a mean and variability that can be estimated by summarizing all the historical data available in the area. Conventionally, the historical data is condensed into an average "profile" but additional information can be extracted from the historical profiles in the area. In particular, the surface temperature and dynamic height (quantities which can be estimated from satellites) are correlated to variations in the subsurface temperature. Further, relationships may be derived to estimate salinity from temperature at each depth. This allowed the development of a dynamic climatology that starts with a simple mean profile of temperature and salinity but then corrects this mean using height and temperature measurements from space-borne satellites. Once the remote sensing is used to produce an estimate of the 3-D temperature and salinity fields for a given day, *in situ* profile measurements of temperature and salinity can be assimilated, using those fields as initial background estimates. Problems with altimetry corrections near land prevented the remote-sensed height anomalies from being used in the case of the Haro Strait area, and very few Multichannel Sea Surface Temperature (MCSST) measurements were available there, resulting in a daily MODAS analysis that was not dramatically different from climatology in the specific locations of interest.

The daily global MODAS estimates of temperature and salinity are assimilated into a global implementation of the Navy Coastal Ocean Model (NCOM, running at a resolution of approximately 1/8 degree and undergoing operational testing and evaluation for transition to the Naval Oceanographic Office. Higher resolution Princeton Oceanographic Model (POM) (Mellor, 1996) and NCOM models can be initialized from the global model, and a 1 km resolution NCOM model was run for the Haro Strait area. Wind forcing was provided by the 27 km resolution Coupled Ocean/Atmosphere Mesoscale Prediction System wind model.

Initially predictions were made using a single sound speed profile characteristic of the deep section of the Haro Strait, and using the MODAS and NCOM sound speed fields. Since the primary differences in the results were in the details of the acoustic field and not the peak or mean levels, the model results presented in this report use the NCOM sound speed field.

Environmental Inputs: Geoacoustic Properties of the Ocean Bottom

The region of interest is primarily composed of glacial moraine sediments, which covers the gamut from rock dust to boulders. A simple model for the geoacoustics at the frequencies used by SHOUP is to assume everything except the deep channel next to San Juan Island is composed of sand-gravel-diatomaceous material (Fulford 2003). Thus, a half-space description is given by a sound speed ratio of 1.1, a density of 1.9 gm/cc, and an attenuation of 0.7 dB per wavelength. In the channel adjacent to San Juan Island the half-space description is given by a sound speed ratio of 1.04, a density of 1.6 gm/cc and an attenuation of 0.2 dB per wavelength.

Initially, predictions were made using each half-space description separately. As with the different sound speed fields, the differences in the results were primarily in the details of the acoustic field. The channel half-space did result in a slight reduction in the overall levels despite lower attenuation because of increased penetration into the bottom due to the lower sound speed ratio and density.

Originally, given the time required and difficulty of constructing a range-dependent geoacoustic database, and given the small differences in the predictions using the individual half-space descriptions, the model results presented below use the first half-space given above.

Later, after the acoustic recordings were calibrated, data/model comparisons indicated that the predicted levels were high. The geoacoustic parameters were adjusted within the given range to maximize the loss into the bottom. The resulting predictions for received SPLs are still generally higher than the phone data, but where comparisons are possible, nominally within 1 to 10 dB. The problem is that actual geoacoustics are much more complicated than the simple half-space model assumed here, but these model predictions will suffice as a worst-case estimate.

Environmental Inputs: Weather

Wind speeds ranged from 5 to 10 mph during and for 48 hours preceding the event. The consequence is that the sea surface was relatively calm, as is evident in various published photographs and videotape recordings showing SHOUP on 5 May 2003. This also results in little or no bubble generation and subsequent entrainment. The lack of surface roughness and near-surface bubbles removes a potential scattering and loss mechanism from the analysis. Light winds also means there is little mixing of the top layers of water. During the day, such conditions can result in warming of the top of the water column causing a sound speed gradient that tends to keep the sound away from the surface. Except for a few hours in the morning of 5 May, conditions were generally overcast for the preceding 48 hours resulting in little or no warming of the sea surface due to the sun. Finally, rain/light-rain was reported in the area at 1153, 1253, and 1353. Rain is a well-known source of noise in underwater acoustics, and may have contributed to the overall ambient noise level.

Modeling Assumptions and Approach

The NRL analysis predicts sound levels approximately 1-10 dB higher than the hydrophones recorded (where comparisons are possible) on 5 May 2003. The NRL acoustic analysis sound levels therefore represent worst-case determinations. The predictions of SPL do not include all the environmental processes and operational procedures that could, at least potentially, impact acoustic propagation resulting in greater attenuation of the sonar sound and reducing the received level of sound reaching the orca. Time, the lack of accurate information, and in some cases, incomplete knowledge or modeling of the physics involved prevented more precise predictions.

An important environmental mechanism that is not explicitly handled by the version of the RAM model used in this analysis is intrinsic volume absorption. Absorption is accounted for in the numerical modeling through a multiplicative term of exponential decay versus range (Urick 1983). Absorption of sound in the ocean was a focus of investigation in underwater acoustics through the 1970s. By that time, all significant absorption mechanisms had been identified and quantified (except possibly at very low frequencies). In the mid-frequency band of interest here, absorption is due primarily to the chemical relaxation processes in the ocean associated with magnesium sulfate and boric acid (Fisher and Simmons, 1977). Simplified expressions are commonly used, such as the formula by Thorp (Thorp, 1967), to provide approximate estimates of absorption as a function of frequency.

However, to more precisely estimate sound absorption, the temperature, salinity, and pressure in the ocean where the chemical reactions occur must be included. In addition, the pH of the water column provides a measure of the amount of boric acid present. The absorption model used in the numerical modeling is that of Francois and Garrison (Francois and Garrison, 1982a & b). The inputs to the intrinsic absorption model were obtained from the NCOM data for temperature and salinity and a pH of 7.7, which is nominal for the North Pacific. The resulting average absorption rate is 0.128 dB/km at 3.0 kHz.

If Thorp's formula is used, the average absorption rate would be 0.1766 dB/km at 3.0 kHz. If this value for the absorption had been used in the modeling, the received SPLs in the reconstruction would have been reduced by about 0.5 dB, 1.0 dB and 2.0 dB at ranges from SHOUP of 10 km, 20 km, and 40 km respectively.

A major mechanism for damping sound propagation as a function of range is surface loss, the loss of acoustic energy resulting from repeated interaction with the rough sea surface interface. Near surface bubbles, if present, have long been known to have a significant impact on propagation of sound (Urich, 1983) and on the scattering of sound (Gilbert, 1993). The dependence on incidence angle of the backscattering strength of the sea surface at low grazing angles is thought to be due to a near-surface bubble layer (Urick, 1979). Bubbles not only scatter and absorb sound, but also cause an appreciable decrease in effective sound speed at the lower frequencies. In addition, their effect on sound propagation at mid frequencies is difficult to model and is an active area of present-day research. Again, due to the weather conditions present in the Haro Strait at the time of SHOUP's transit, these processes were determined to be negligible in their effect on propagation and scattering.

The region surrounding the Haro Strait region is well known for having internal wave activity at various times of the year. Due to cloud cover, it is not possible to determine from satellite data if there was internal wave activity. Accurate modeling of acoustic propagation through internal wave fields is an active area of current research. The simplest description of the affect of internal waves is that they cause portions of the sound speed profile to shift up and down. This sound speed shift causes corresponding fluctuations in the acoustic field down range from the internal wave activity. These fluctuations have their largest affect on the one-way direct path transmission between a source and receiver causing variations in the received sound level by as much as plus or minus 5-20 dB. These variations would come and go in the received direct-path data depending on the relative location of the source, receiver, and internal wave. Detecting the affect of internal waves on reverberation is more difficult because reverberation is generally a summation over a large number of scatterers and the fluctuations tend to average out. The peak and mean values for the received SPLs are calculated from the predicted acoustic levels within a box 20m in depth by 500m in range that contains the phones. Because of this sampling/averaging procedure, fluctuations due to internal waves, if they had been included in the modeling, would have had a minimal affect on the results.

Some aspects of the ocean bottom such as its shear velocity, interface roughness, sub-bottom heterogeneity, and detailed layering were not considered for a variety of reasons. These reasons include: lack of data, lack of a robust modeling capability for the phenomena, the phenomena reduces the SPL or affects the reverberation, which is being addressed through the acoustic recording data.

It is evident from the acoustic recordings that reverberation was significant in level and duration, many times lasting as long as 19 seconds after a ping was transmitted. The source of the reverberation is most likely scattering from the bottom. Reverberation from surface scattering is minimal due to the low surface roughness that is the consequence of the low wind speeds. Reverberation due to scattering from biologics such as fish schools were not addressed in this analysis since their possible presence and distribution were completely unknown and their effects were judged likely to be too ephemeral to have an overall impact on the average results. In general, modeling bistatic reverberation is a non-trivial exercise, and the RAM model is not appropriate for the purpose. Although bistatic reverberation models exist, they were not utilized in this report.

Navy Surface Ship Activities and Sonar Parameter/Source Models

The modeling effort was initially executed for 3.0 kHz, primarily because of the consistent received levels in the acoustic recordings at that frequency. There will be differences in the model results as a function of frequency, but for the frequency band under consideration, the variations will be small. Comparing the difference due to just volume absorption for 2.6 kHz (versus 3.0 kHz), the SPL would be 0.33dB higher at 26 km. A full model prediction at 2.6 kHz (versus 3.0 kHz) for the monitoring phones at 26 km resulted in the mean SPL being 1.3 dB higher, but a peak SPL 0.6 dB lower. It was determined that modeling at 3.0 kHz would adequately characterize the SPL.

A sonar source level of 235 dB was used to obtain the SPL estimates and is the *maximum* level that the sonar is capable of producing in the mode it was reported to be operating. For the mode that the sonar was operating in, the first two pings were approximately directed azimuthally toward the port side of the ship, the second two pings were approximately directed azimuthally toward the starboard side of the ship, and the last ping was transmitted omni-directionally. The first four pings were transmitted at a source level of 235 dB and the last ping at 230 dB. All SPL estimates in this report are obtained using the sonar source level of 235 dB and thus all data/model comparisons will be for the first four pings only.

In addition to the azimuthal variation of the transmissions described above, the maximum levels are not broadcast in all vertical directions due to beamforming, which reduces levels outside of the main beam, by at least 13 dB. For this case, the sonar was numerically modeled as an 11-element array of omnidirectional elements with equal element spacing of 0.135 m, center depth 26 ft (= 7.925 m), uniformly shaded, and main beam steered downward from the horizontal by three degrees. The main lobe width in all cases is presumed sufficiently broad, and the ocean surface wave conditions during the transit sufficiently calm, that the pitch-and-roll of the ship is assumed to have negligible effect on the radiated sound field levels.

The Acoustic Recordings

Acoustic recordings were made on monitoring hydrophones deployed by Dr. Val Veirs of Colorado College for his OVAL project. These acoustic recordings, as provided by Dr.

Val Veirs (Veirs, 2003a), comprise a fascinating data set. There are over 370 recordings on four hydrophones spanning the time period that SHOUP was transmitting. The locations and depths of these phones are summarized in Table 2.

The acoustic recordings as originally provided were “autoscaled”. That is, their levels were adjusted to enhance their presentation on screen. Adjusting levels in this manner allows events that are at an overall low level to be as detectable to the observer as an event that has an overall high level. It also means that the received SPLs appear to just as high in level when SHOUP was 35 km away as when it was 3 km away. Fortunately, each sound file contained the scaling factors (Veirs, 2003b). With the “autoscaling” removed, meaningful comparisons can be made between the acoustic recordings. Additionally, calibration factors for each phone were available (Veirs, 2003b), allowing actual received SPLs to be calculated and compared with predicted SPLs.

It should also be noted that with regard to the videotape recordings of the event, that autoscaling of the hydrophones, as well as a likely autogain feature on the video camera volume controls, would have at times resulted in an inaccurately over-loud representation of the actual sound present underwater at the hydrophones and onshore at the locations where the video was filmed.

There are two caveats with respect to the hydrophone data. First, phone #0 was found to have slipped from its mooring and was probably sitting on the bottom as it was coated in mud when recovered (Veirs, 2003b). An inspection of the acoustic data finds that the received levels on phone #0 are generally lower than those on the other phones. This is consistent as phone #0 was probably more shielded on the bottom, especially if covered by mud. For completeness, phone #0 data is included in the results below, but the reader should keep in mind that the data is not comparable to that from the other phones.

The second caveat is that the dynamic range of the recording system limited the maximum SPL that could be accurately recorded to approximately 140 dB. The recordings of received SPLs greater than the dynamic range exhibit a phenomenon known as “clipping”. In addition to the level being incorrect, the frequency content of “clipped” data is usually corrupted. Audio playbacks of “clipped” data will generally sound distorted.

It should be noted that because of these recordings, an extensive effort was made to reconstruct the event. For each sound file, modeling was executed from SHOUP’s location to the location monitoring hydrophones; specifically phone #2, but the phones are sufficiently collocated to make little difference.

Model Results

Results of NRL’s acoustic analysis are characterized in this report using the mean of the predicted sound pressure levels since that is the most representative single value citable. The results of the analysis indicate that at approximately the point of closest approach between SHOUP and the J-Pod, the orca were in a sound field having a maximum mean sound pressure level of 171 dB. This occurred only at approximately the point of closest approach and at all other times during the afternoon of 5 May 2003, the pings of sonar from SHOUP were lower than this maximum.

Because of the mode of operation of the SHOUP's sonar, the first two pings of a transmission were directed toward the port side and the second two were directed toward the starboard side. For most of the transit, the J-Pod received only one second of acoustic energy at the direct path levels. During the period from 1410 until 1429, the J-Pod received 2 seconds of acoustic energy at the direct path levels because the SHOUP's sonar was essentially directed north up Haro Strait and thus toward the J-Pod.

The acoustic recordings allowed prediction of the reverberation sound levels to be estimated in the vicinity of the J-Pod. Prior to SHOUP entering the Haro Strait, the reverberation was generally less than 130 dB. The reverberation in the vicinity of J-Pod was approximately 144 dB at its maximum, just after the sonar ping, occurring approximately at the point of closest approach between SHOUP and the orca.

The precise sonar frequency levels used by SHOUP on 5 May 2003 are classified information; however, the frequency was at a level that falls within the lower range of the spectrum of hearing and vocalizations for orca (Szymanski et al. 1999; Thomsen et al. 2001). SHOUP's sonar use on 5 May 2003, therefore, should not have interfered with orca communication centered in a range of higher frequencies than SHOUP's sonar was transmitting.

Figures 4-8 below depict the received sound levels at both the location of the orca J-Pod and hydrophones that recorded SHOUP's sonar on 5 May 2003. The times depicted relate to the reported times of recorded orca J-Pod observations as reflected in Figures 1 and 2 and detailed in Tables 2 and 3.

On each figure, the map shows the tracks of SHOUP and the J-Pod. Radial lines are drawn from SHOUP to the location of the J-Pod and to the monitoring hydrophones.

The pair of plots in the upper right shows acoustic analysis predicted transmission loss as a function of depth and range for those radial lines.

The pair of plots in the lower right shows the range of predicted sound levels (i.e., the 235 dB sonar source level reduced by the calculated transmission loss) for the immediate vicinity of the phones and that of the J-Pod orca as indicated by the red outlined rectangle. The histograms give the distribution of levels within the red rectangle on each of the received level plots. The histogram for the received sound level at the phones has horizontal red lines indicating the level at which each phone would begin clipping. Finally, each histogram is annotated with the histogram peak and mean predicted sound levels for area of interest inside the red rectangle.

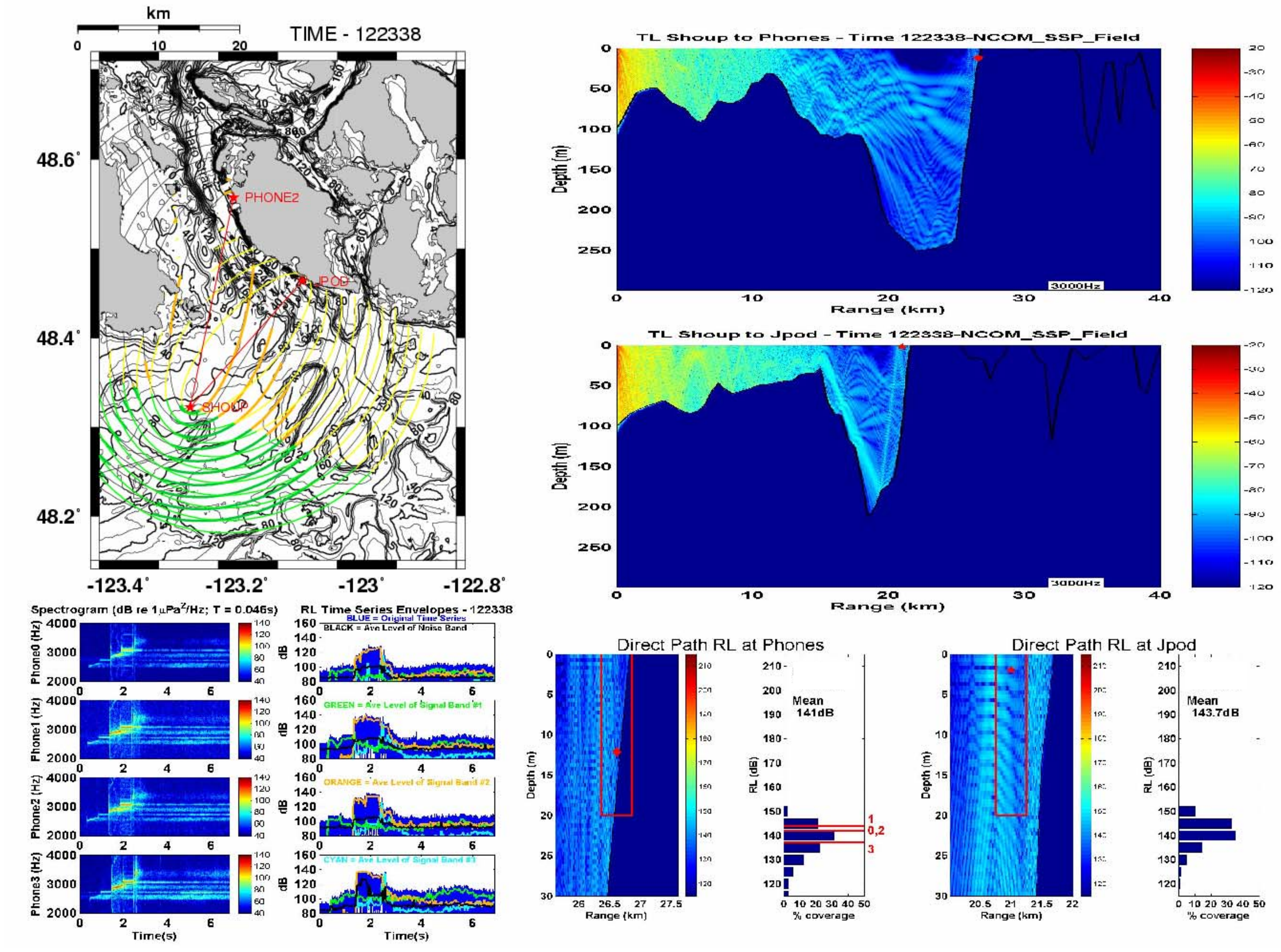

Figure 4. Event reconstruction for time 12:23:38.

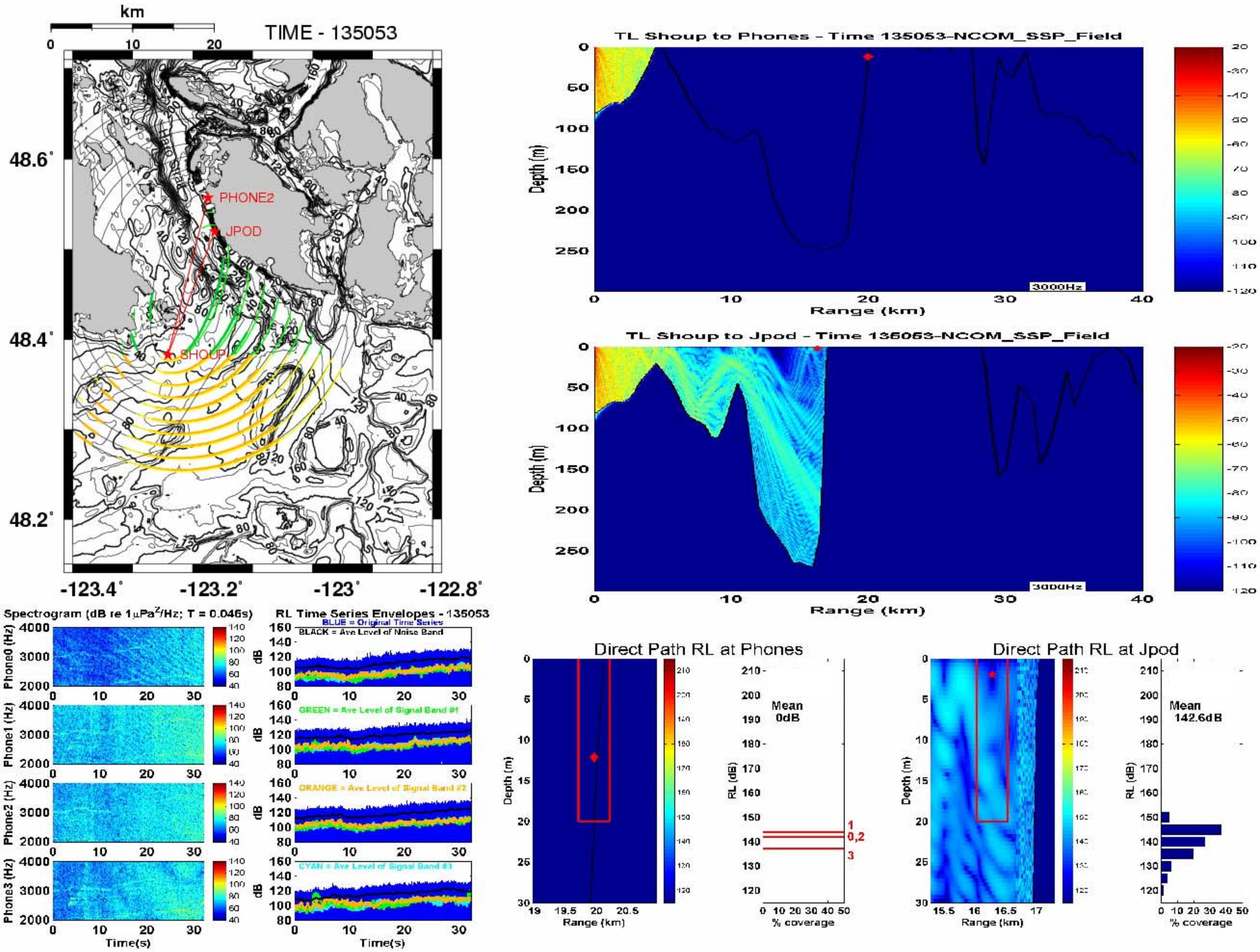

Figure 5. Event reconstruction for time 13:50:53.

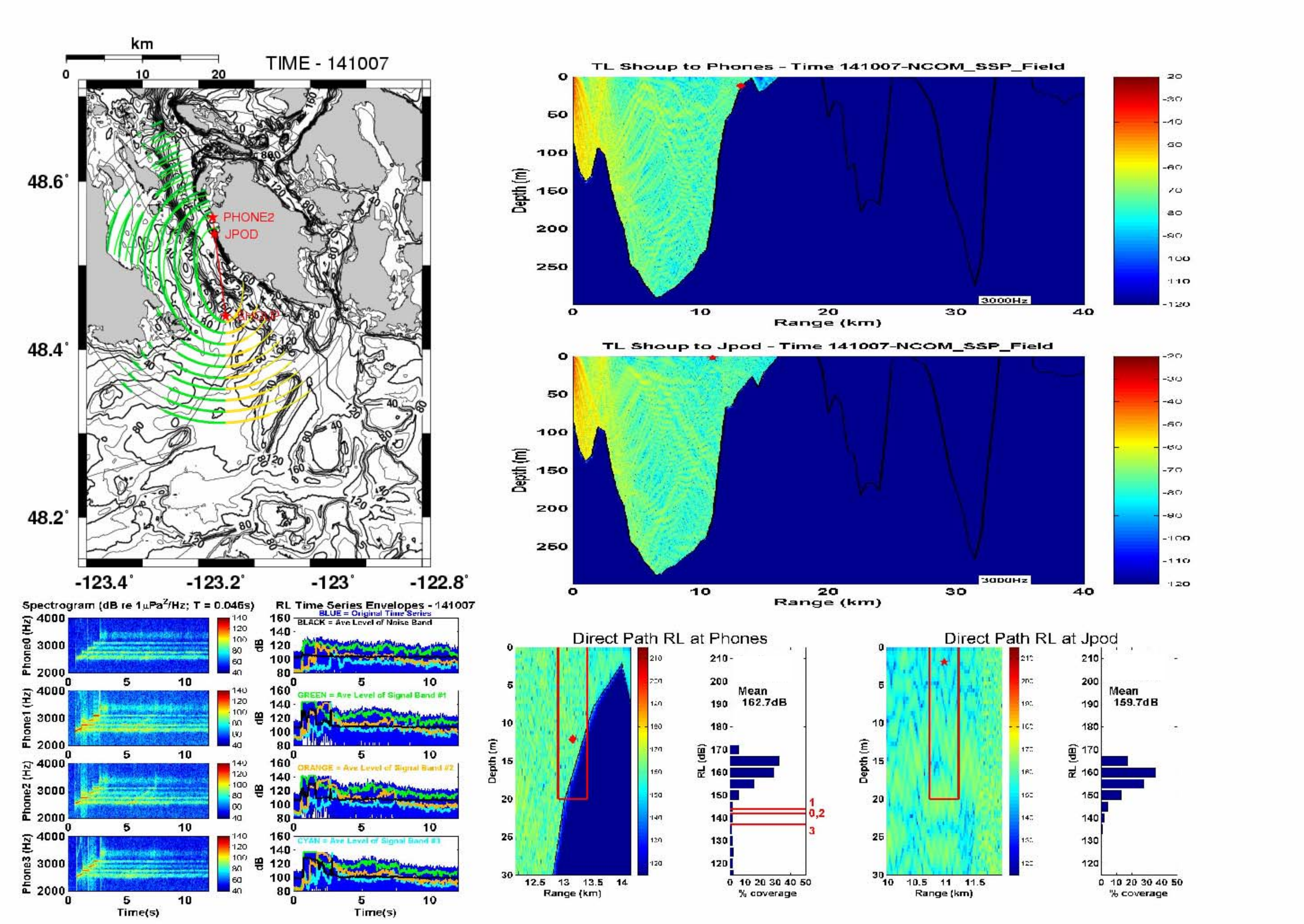

Figure 6. Event reconstruction for time 14:10:07.

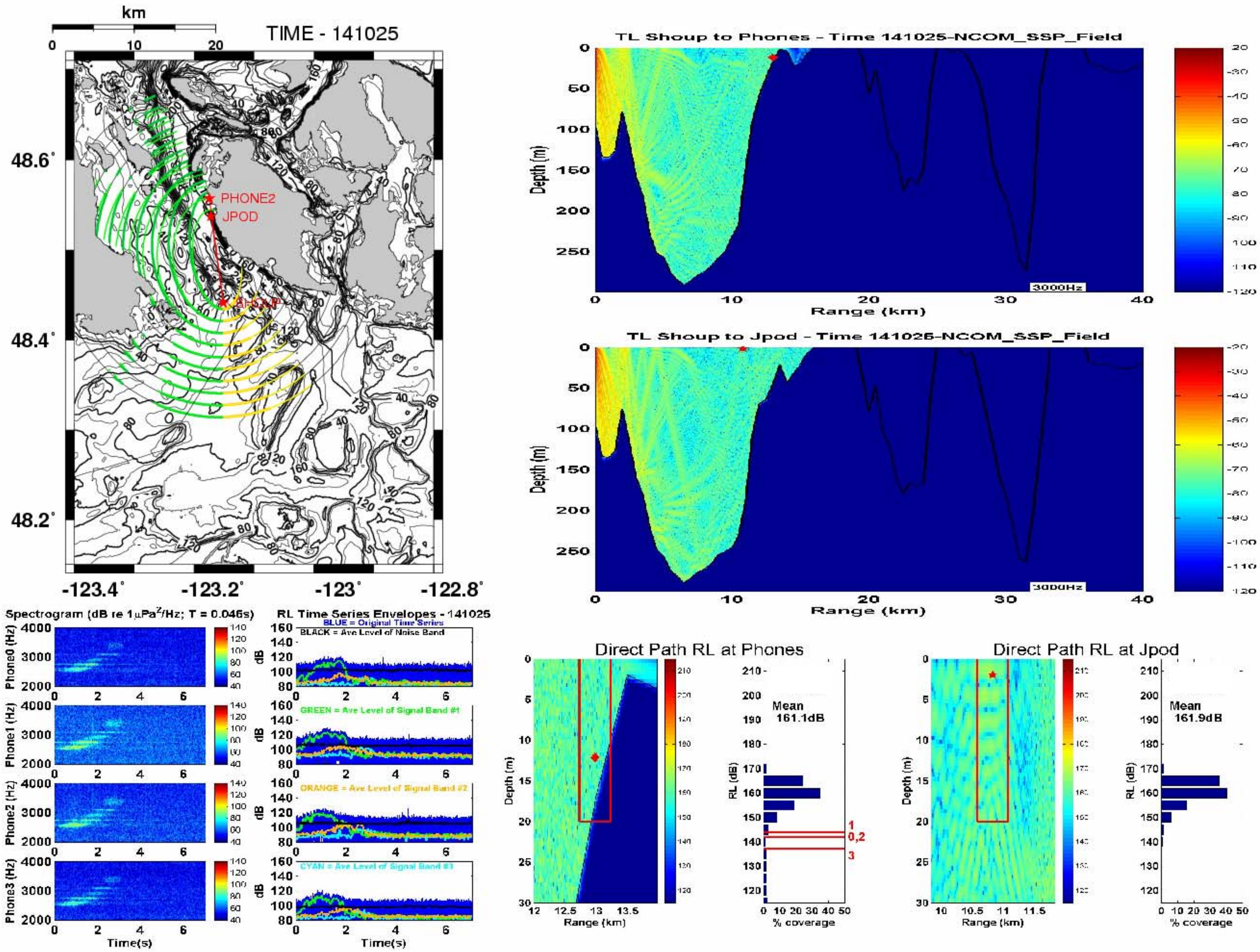

Figure 7. Event reconstruction for time 14:10:25.

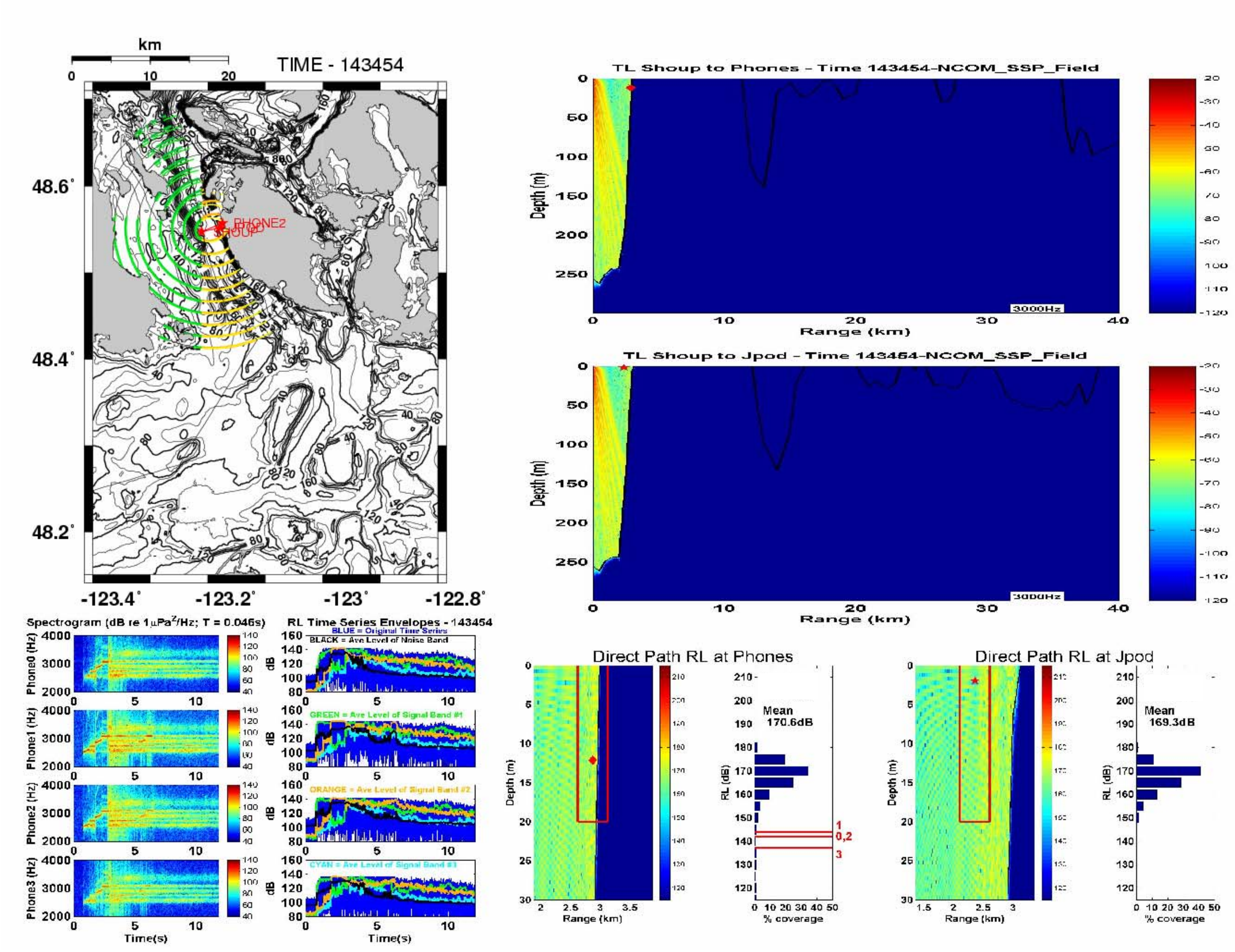

Figure 8. Event reconstruction for time 14:34:54. Approximate closest approach between SHOUP and J-Pod.

Species Auditory Characteristics

For many marine mammals, especially the large cetaceans, there are no established audiograms and the hearing range of many whales is not known with any degree of certainty (NRC 2003; Gisiner 1998, Richardson et al. 1995). It is assumed, however, that animals can generally hear in a portion of the ranges of sounds that they produce. While vocalizations are accepted indicators for audible frequencies, recorded intensity may have little to do with sensitivity. It is also unlikely that samples of vocalizations recorded in field studies have captured the entire range of frequencies and maximum source levels that marine mammals are capable of producing.

In addition, animals and humans commonly produce sounds that would produce discomfort if received at the ear at decibel levels equal to the emitted level. Mammal ears are protected generally from self-generated sounds by both intervening tissues (head shadow and impedance mismatches) as well as active mechanisms (eardrum and ossicular tensors) (Gisiner 1998). It must also be noted that marine mammals are highly evolved for sensing sound energy in an underwater environment and comparisons between human or other mammal hearing is fraught with error.

The vocalization whistles of orca have been measured as ranging from 131-168 dB (Au et al. 2000; Miller 2000; Viers 2003b) with an average dominant frequency of 8.3 kHz (Thomsen 2001). Measured source levels for odontocete echolocation signals having a frequency between 45-80 kHz have been measured as having source levels between 200-225 dB (Richardson et al. 1995). A study of auditory thresholds in two captive orca indicated that there was no behavioral reaction to 1-2 kHz sounds at 150 dB (Szymanski et al. 1999). The most sensitive frequency range was 18-42 kHz. SHOUP's sonar was operating at frequencies of 2.6 and 3.3 kHz and was well below this most sensitive frequency range and should not, therefore, have interfered with orca communication or echolocation.

Dall's porpoise echolocation signals are in the 135-149 kHz range at 165-175 dB and their clicks are 0.04-2 kHz at 120-148 dB (Hatakeyama et al. 1995; Richardson et al. 1995).

Harbor porpoise echolocate at 110–150 kHz at 135-177 dB and have clicks at 2 kHz at 100 dB (Hatakeyama et al. 1995; Richardson et al. 1995)

The sounds produced by minke whales are described as downsweeps, upsweeps, grunts, thump trains or pulse trains, and ratchets. These vary in frequency from 60 Hz –20 kHz at levels of 151-175 dB (Mellinger et al. 2000; Richardson et al. 1995). At the assumed closest point of approach to the single observed minke whale the level of received sound from SHOUP's sonar should not have exceed approximately 171 dB.

Relevant Sound Source Comparisons

The loudest received level the orca experienced was approximately 171 dB at the point of SHOUP's closest approach. For comparison with regard to this maximum received level, Puget Sound commuter ferries, tugboats, and other mid-sized motor vessels produce sound in the range of 160-170 dB in low range frequencies (NRC 2003; see also Veirs 2003b). Zodiac outboard motor whale watch boats in Haro Strait were found to produce sounds across the 1-20 kHz band at a source level as high as 168 dB (Erbe 2002). A modern-day supertanker cruising at 17 knots produces sound in the low frequency band (below 500 Hz), at source levels as high as 190 decibels.

The analysis of the hydrophone recordings documented five instances where the sound from other motor vessels, at mean levels as high as 120-130 dB, over-shadowed the reverberation from SHOUP's sonar. Recent research in Haro Strait has demonstrated that whale watch boats generally have a source level between 145-169 dB (Erbe 2002). Superimposed noise levels of five boats circulating around or following the whales were modeled as close to the critical level assumed to cause a permanent hearing loss over prolonged exposure. The increased vessel traffic is also argued to be creating increased disturbance in the resident whales' core areas, including Haro Strait (Erbe 2000; Ford et al. 2000). Researchers have reported the ambient background noise of Haro Strait to be approximately 90 dB over a broadband of frequencies (Erbe 2000). This measured level of ambient noise in Haro Strait was also consistent with the findings of acoustic analysis undertaken for this inquiry, which further validates the accuracy of the acoustic analysis' predicted sound levels.

In addition to anthropogenic sound sources underwater, natural sources include lightning strikes, which hit the ocean surface producing underwater sound with levels around 260 dB (67 FR 46712, July 16, 2002). Underwater earthquakes, landslides and volcanic eruptions exceeding 230 dB occur annually in the Pacific Ocean. It should be noted that due to the characteristic impedance of water being about 3600 times that of air and because of the differences in reference measurements, 100 dB in air is not the same as 100 dB in water. As a general rule, to convert from water to air, simply subtract the 62 dB from the sound level in water. A Puget Sound ferry generating a 170 dB sound level would be roughly equivalent to a 108 dB sound in air. (Note this is an approximation, since the source level often changes with the frequency component of the sound.) For comparison, a jet at take-off (at 1,000 feet), an outboard motor, lawn mower, and jackhammer (at the source) all produce about 100 dB.

Audibility of Sonar in Air

One of the more interesting phenomena reported by several eyewitnesses was that they could hear the sonar in the air, even when SHOUP was apparently at or over the horizon. It is not unusual for observers on ships participating in underwater acoustic experiments to hear the sonar. The ship acts to reradiate the acoustic energy into the air. In fact, the ship is not necessary as direct transmission is possible through the interface. For a normal incident wave, the intensity of the reflected wave, I_T, is related to the intensity of the incident wave, I_O, by

$$I_T / I_O = 1 - (Z_2 - Z_1) \wedge^2 / (Z_2 + Z_1) \wedge^2$$

Where Z_1 is the impedance of the material on the incident side and Z_2 is the impedance on the transmitted side. Impedance is the product of the material's density and the sound speed in the material. Substituting appropriate values for air and water and converting to dB yields a factor of approximately –65.5 dB.

Thus to calculate the sound level in air, we subtract 65.5 dB from the intensity in the water near the surface. This gives the transmitted intensity in units of "dB re 1 microPascal", which needs to be converted to "dB re 0.0002Bar". This is done by subtracting 26. Using the mean values of the received levels at the phones and J-Pod, and assuming the field is at normal incidence to the surface (it is not), we can estimate a rough maximum level.

These predicted levels are in reasonable agreement with an estimate provided by Dr. Richard Osborne of 40-80 dB (Osborne 2003b). This range corresponds to sounds in air from a low voice up to buses, trucks and motorcycles at a distance of 15m. Dr. Osborne was working at the shoreline near the monitoring hydrophones when SHOUP transited.

There are several other interesting points. First, the predictions are for the direct blast which would occur every 28 seconds, but Dr. Osborne reported that he was hearing a continuous warbling signal which would imply he was also hearing the reverberation. If we assume the received SPLs on the monitoring hydrophones approximate the field at normal incidence to the surface (again, it is not), then the sound in the air due to the reverberation could range from inaudible to as high as 50 dB (noise in a room with a window air conditioner).

Secondly, due to the consequences of refraction at the air-water interface, the sound as it left the surface of the water would have been directed between straight up and 12 degrees off vertical. For Dr. Osborne to hear it, the effect would have to be local or atmospheric conditions caused the sound to refract down towards the ground.

Finally, it is not clear why the effect was so strong. Navy ships have transited this region before using their sonars and this effect was not reported. Perhaps the low wind speed and calm seas combined with specifics of the sound speed profile to cause the effect, but without actual measurements of the environmental conditions and the sounds heard, the answer to this question will have to wait.

Conclusions and Recommendations

Conclusions

SHOUP operated its sonar on 5 May 2003 in a manner consistent with established guidelines and procedures. Based on the evidence and scientific review, SHOUP's 5 May 2003 sonar operations did not kill, injure, or otherwise harm resident J-Pod orca. Based on the evidence and scientific review, SHOUP's sonar operations on 5 May 2003 did not kill, injure or otherwise harm other marine mammals, or was responsible for any subsequent harbor porpoise strandings.

Necropsies on 11 harbor porpoise did not find evidence of acoustic trauma (NMFS 2003b:55). States of decomposition for six of these 11 harbor porpoise precluded NMFS from determining their causes of death. Definitive causes of death were determined for five of the porpoise which is approximately the expected percentage in most necropsied animals from the region (NMFS 2003b:57). Of these five, two had perimortem blunt trauma injury with associated broken bones in their head (NMFS 2003b:55). Of the remaining three, one died from pneumonia, one from salmonellosis, and one from peritonitis (NMFS 2003b:2). No evidence of acoustic trauma was found in any of the necropsied porpoise.

There is no evidence indicating the harbor porpoise were killed, injured, stranded, or otherwise harmed as a result of the SHOUP's active sonar use on 5 May 2003. Between 2 May to 2 June 2003, 16 strandings involving 15 harbor porpoise and one Dall's porpoise were reported to the Northwest Marine Mammal Stranding Network. Allegations surfaced on 13 May 2003 that SHOUP may have caused harbor porpoise strandings in the region. Numerous media reports since 13 May 2003 have repeatedly linked SHOUP's sonar operations with as many as 17 porpoise strandings (although only 16 had stranded) despite the well documented history of expected annual strandings in Puget Sound. Based upon relative locations, times of discovery, and states of decomposition, 15 of the porpoise died either in the time periods before SHOUP left port on 5 May 2003 or between one and three weeks after SHOUP completed the Haro Strait transit.

Eight strandings occurred on or before 6 May 2003. Of these, one was discovered on 5 May 2003 and two strandings were discovered on 6 May 2003. Necropsies did not identify acoustic trauma on any of these porpoise. The porpoise discovered on 5 May 2003 was in a state of moderate decomposition indicating that the stranding occurred before 5 May 2003 and the necropsy identified salmonellosis as the likely cause of death. One of the stranded porpoise discovered on 6 May 2003 was in a state of moderate decomposition. The other stranded harbor porpoise discovered on 6 May 2003 is the only animal that could potentially be linked in time to SHOUP's 5 May 2003 active sonar use. However, it was discovered at a common harbor porpoise stranding location, the stomach was empty as is typical for strandings in the region, and there was no evidence indicative of acoustic trauma. The most likely conclusion given these factors and the history of strandings in the area is that this 6 May 2003 stranding was not caused by SHOUP's sonar operations.

No freshly consumed prey were present in any of the examined stomachs as is typical for porpoise strandings from the region (NMFS 2003b:54-55). If there had been an abnormal cause of strandings, especially associated with a flight response and subsequent stranding, it is unlikely that all examined animals would have been found in this condition. Any acoustic impacts other than physical injury would have resulted in a transitory "flight response," with animals frightened into stranding immediately as has been the case in stranding events alleged to be associated with the use of sonar (NMFS 2003b:55). It is unreasonable to conclude that strandings occurring weeks after sonar operations could have resulted from a sustained flight response. These strandings, therefore, had no relationship to SHOUP's sonar operations on 5 May 2003. It has also been the case in sonar associated stranding events that a percentage of animals strand alive, which is inconsistent with the strandings alleged to be associated with SHOUP's use of sonar on 5 May 2003 (NMFS 2003b:55).

Observer opinions regarding orca J-Pod behaviors were inconsistent, ranging from the orca being "annoyed" to their being "at ease with the sound" or "resting." One witness reported observing "low rates of surface active behavior" on behalf of the orca J-Pod, which is in conflict with that of another observer who reported variable surface activity, tail slapping and spyhopping. Witnesses also expressed the opinion that the behaviors displayed by the orca on 5 May 2003 were "extremely unusual," although those same behaviors are observed and reported regularly on the Orca Network Website and are behaviors listed in general references as being part of the normal repertoire of orca behaviors (e.g., Ford et al. 2000).

Observations of orca behavior made between 1313 and 1348 on 5 May 2003 are inconsistent with the 6 May 2003 assertion that SHOUP's use of sonar affected the behavior of the J-Pod orca. For approximately 45 minutes, the acoustic analysis determined (and the hydrophone recordings confirm) that direct path sound from SHOUP's sonar did not reach the J-Pod orca. Only the faint sonar reverberation reached the orca given the orientation of SHOUP towards Victoria and the interposed islands and shoals between SHOUP and the J-Pod orca. There were no reported observations of any changes in behavior when the sonar ceased being received by the orca at 1313, the beginning of this 45-minute period. Conversely, there were no reported observations of any changes in behavior when the sonar resumed being directly received by the orca at 1348. If the sonar was affecting the behavior of the orca as alleged, these events should have resulted in some observable phenomena having been reported.

Although the precise sonar frequency levels transmitted by SHOUP on 5 May 2003 are classified for national security reasons, the sonar frequency used was at the lower range of the hearing spectrum for orca. SHOUP's sonar, therefore, should not have interfered with echolocation or communication vocalizations that are centered in a range of higher frequencies than SHOUP's sonar was transmitting on 5 May 2003.

No other marine mammals were killed, injured or stranded as a result of SHOUP's sonar operations on 5 May 2003. A minke whale was reported porpoising in Haro Strait on 5 May 2003, which is a rarely observed behavior. The cause of this behavior is indeterminate given multiple potential causal factors including but not limited to the presence of predatory Transient orca, possible interaction with whale watch boats, other vessels, or SHOUP's use of sonar. Harbor porpoise were not mentioned in any of the observations reviewed.

A review of videotape by Navy marine mammal experts showing the orca during SHOUP's transit of Haro Strait indicates the orca behaviors displayed were within the normal range of behaviors and there were no immediate or general overt negative behaviors depicted (Carder 2003).

Recommendations

The use of PC-IMAT as a real-time predictive tool to determine potential acoustic impact zones should be further explored.

No further investigation into this matter is warranted.

Glossary

Antemortem: Before death.

Cephalopod: Any of the most highly developed class of mollusks, having long, arm-like tentacles around the mouth, a large head, a pair of large eyes, and a sharp, bird-like beak. Many can expel a dark, ink-like fluid. These include: squid and octopus.

Cetacean: Literally it refers to three suborders of marine mammals including ancient whales, baleen whales (which include minke whales), and toothed whales (which include beaked whales, dolphins, and porpoise).

Computed tomography (CT): The creation of images showing anatomic information, each image generated by a computer synthesis of x-ray transmission data obtained in many different directions in a given plane.

Crania (um): The bones of the head.

Cranial: Relating to the cranium or head.

Crustacean: A very large class of aquatic animals (phylum Arthropoda) with a chitinous (hard) exoskeleton and jointed appendages. E.g. Crab, lobster, crayfish, and shrimp.

DeciBel (dB): Decibel is a dimensionless ratio term that can be applied to any two values; temperature, rainfall, the number of jellybeans in a jar, or sound. Decibels are expressed as 10 times the logarithm of the ratio of a value (V) to its reference value (Vref), or:

$$N \text{ decibels (dB)} = 10 * \log (V/Vref)$$

The decibel originated in electrical engineering measurements of transmission line losses, but it is also physiologically significant in that the response of biological ears to sound is logarithmic (Bartberger, 1965). Decibels should always be accompanied by a reference value that defines the ratio being expressed, unless the reference is clearly stated at the start of the paper. In this report, all references to dB that are not accompanied by a specific reference value are dB of sound pressure level (SPL), referenced to 1 micro Pascal of pressure. Other commonly used acoustic measures, such as Sound Energy Level (SEL), also commonly expressed in dB ratio terms, will be specifically stated as being something other than sound pressure, and a different reference term, such as 1 second-second squared, will indicate that a value other than SPL is being discussed. A further distinction that needs to be kept in mind is whether the dB value is a Received Level (RL) or Source level (SL). For acoustic sources, the convention is to express the power of the source in Sound Pressure Level at a distance of 1 meter from the acoustic center of the source. In many cases especially for large sources, this is a theoretical number that never actually exists in the physical world, but is calculated from received levels measured at distances greater than one meter from the source. The source level of a sonar may be 235 dB or more, but the sound pressure at any one point away from the source is affected by the spreading of sound in all directions, and by absorption, reflections, scattering and other phenomena (discussed in more detail in the section of Acoustic Modeling). The physics of the propagation medium will determine whether the received level at a given point is 170, 180 dB, or some other value for a stated source level. While the source levels of the Navy sonars described here were generally 235 dB (sound pressure level), the received sound pressure level at any point more than a meter from the source would have been lower. How much lower is detailed in the section on Acoustic Modeling.

Delphinids: Family or classification of animals within the Order Cetacea and includes dolphins.

Diathetic: A condition of the body where an individual is more susceptible to a disease or physiological anomaly such as hemorrhage than usual.

Epidemiology: The study of the distribution and determinants of health-related states (e.g., diseases) or events (e.g., mortalities) in specified populations, and the application of this study to control or mitigate health problems.

Gross findings: Observations of organs and tissues in carcasses that are large enough to be made with the naked eye.

Growth layer groups: Layers of cementum or dentin of teeth that are deposited in the tooth on a regular basis with age. These layers are counted to estimate age of the species.

Histology: The science concerned with the minute structure of cells, tissues, and organs in relation to their function.

Impulse noise: There are no clear boundaries between impulse sounds and tonal (“continuous”) sounds, but generally speaking impulse sounds are 1) of short duration (less than 0.1 – 0.2 seconds, and usually much shorter), and 2) have an irregular waveform, rather than the smooth sinusoidal waveform generated by most sonars or speech, for example. However, when a tonal sound source like a sonar powers up rapidly to full power in less than 0.1 second, the onset of the sound can have impulse-like effects (see Rise Time). The effects of impulse differ from tonal sounds in that the rapid overpressure, underpressure or combination of both in rapid succession, may exceed the mechanical resilience of structures and cause damage not seen with equal amplitude but slower pressure changes in tonal sounds. And since impulse is characteristically broadband (made up of may frequencies) effects like TTS may be found in unanticipated parts of the inner ear (a low frequency impulse may exhibit high frequency effects) or effects may be distributed across many frequencies. The ear has protective mechanisms against sudden loud noises that often reduce the effect of impulse sounds relative to tonal sounds. But individual differences in impulse sounds and in physiological protective responses mean that predicting the effects of impulse sound on a given individual is more difficult than for tonal sound. Within a population, impulse sounds tend to result in more varied effects between individuals, relative to exposure to tonal sounds.

Interspecific: Occurring or arising between species.

Intracochlear: Within the inner ear or cochlea.

Intra-cranial: Within the skull or more loosely within the head.

Labyrinthine: Relating to the structure of the inner ear comprised of several connected ducts, bony and membranous components. The labyrinth is the canal system within the tympanic bone that houses the inner ear. The labyrinth has a bony component and a membranous component.

Moderate Decomposition: is assessed when a carcass is decomposed but the carcass and organs are basically intact. Bloating is evident (e.g., tongue and penis protruded) and skin cracked and sloughing with possible scavenger damage; characteristic mild odor; mucous membranes dry, eyes sunken or missing; blubber blood-tinged and oily; muscles soft and poorly defined; blood hemolyzed, uniformly dark red; viscera soft, friable, mottled, but still intact; gut dilated by gas; brain soft, surface features distinct, dark reddish cast, fragile but can usually be moved intact.

Morphology: The science concerned with the structure of animals.

Necropsy(ied): (SYN: autopsy)- An examination of the organs of a dead body (whale) to determine the cause of death or to study the pathologic changes present. Is the same as an autopsy performed on humans.

Necrotic: Death of one or more cells or a portion of a tissue, organ, or carcass resulting from irreversible damage.

Nominal Source Level: A calculated level that translates the complex array output into a simplified expression of a single point source. Although no single source within the array ever attains the nominal amplitude, and there is no actual physical point at which the nominal sound level is reached, for the sake of simplicity the output can be characterized as if a single point source at the center of the array and operating at the nominal source level had produced it. In other words, an array such as SHOUP's AN/SQS-53C operated at a nominal level of 235 dB does not in fact attain 235 dB in any place, but the sound propagates as if it were generated by a single point source at 235 dB.

Parasitism: An interaction between two organisms in which the parasite attains most or all the benefit of the close relationship. Parasitism can be considered as a special case of predation.

Pathology: The medical science and specialty practice, concerned with all aspects of disease, but with special reference to the essential nature, causes, and development of the abnormal conditions, as well as the structural and functional changes that result from the disease processes.

Peritonitis: An infection or inflammation of the peritoneum, the membrane that lines the wall of the abdomen and covers the abdominal organs.

Perimortem: Occurring around the time of death.

Physiology: The science concerned with the normal vital functions and activities of life or of living matter, especially as to how things normally function.

Ping-Second: The term ‘ping-seconds’ refers to the number of seconds of sonar sound that would have occurred at a specified site and specified level

Pneumonia: A serious infection or inflammation of the lungs with causes ranging including but not limited to bacteria, viruses, or other infectious agents.

Post-mortem: Pertaining to or occurring during the period after death.

Propagation (sound propagation): Several factors must be considered when reviewing the acoustic propagation reported here. First, there is a difference between Source Level (SL), measured at one meter from the acoustic center the source, and Receive Level (RL), the amount of sound an animal would receive at some distance from the source. Due to spherical spreading of sound, absorption, reflection, scattering, and other phenomena, Receive Levels drop markedly as one moves away from the source. For example, a Source Level of 235 dB one meter from the source dissipates to a Receive Level of 180 dB at a distance of 200m to 1000m from the source, depending on conditions. Second, the rise time of the signal, the time required for the signal to grow from zero to maximum amplitude, can have an impulse like effect if short enough in duration. Although frequency spreading and environmental scattering tend to smear the rise time in question and reduce the potential for impulse like events, they cannot be discounted.

Salmonellosis: A bacterial infection that generally affects the intestinal tract and occasionally the bloodstream.

Sonar: Sonar (Sound Navigating and Ranging) may be active or passive. Active sonar projects a sound and then listens for echoes of that sound returning from underwater objects. Passive sonar does not project a sound, but instead only listens for sounds produced by underwater objects. The Navy uses both active and passive sonar. Active sonar is the most significant sensor for detecting and locating diesel submarines in the complex oceanography of littoral waters. It enables ships to search a larger area more quickly than any other sensor, and it provides the only accurate targeting data for the ship’s antisubmarine warfare (ASW) weapons. However, interpreting sonar data is much more difficult than interpreting radar data because of the complexity of how sound travel under water, especially in littoral waters. Proficiency in these interpretations is gained slowly and lost quickly. Simulators are available for training, but they do not fully replicate the difficulty of detecting and tracking submarine at sea. Ping contact time against actual targets at sea is essential for gaining and retaining ASW proficiency.

Stock: The term 'stock' or 'population stock' means a group of marine mammals of the same species or smaller taxa in a common spatial arrangement that interbreed when mature.

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Table 1: USS SHOUP (DDG 86) Transit Information for 5 May 2003

TIME	LATITUDE	LONGITUDE	COURSE (°T)	SPEED (KTS)	DEPTH (FMS)
1000	47-55.9N	122-29.7W	304	20	69
1002	47-56.3N	122-30.5W	304	20	65
1004	48-56.8N	122-31.5W	304	20	61
1006	47-57.1N	122-32.2W	304	20	47
1008	47-57.5N	122-33.2W	304	20	41
1011	47-58.5N	122-34.7W	330	20	28
1012	47-58.6N	122-34.9W	330	20	30
1014	47-59.3N	122-35.5W	332	20	39
1016	48-00.1N	122-36.0W	332	20	41
1018	48-01.0N	122-36.6W	332	20	73
1024	48-02.5N	122-37.7W	347	20	59
1026	48-03.4N	122-37.9W	347	20	51
1028	48-04.1N	122-38.2W	347	20	58
1030	48-04.9N	122-38.5W	347	7	84
1032	48-05.6N	122-38.6W	347	7	95
1034	48-06.0N	122-38.8W	345	7	69
1036	48-06.3N	122-38.9W	345	7	71
1041	48-07.1N	122-39.3W	310	7	49
1042	48-07.2N	122-39.4W	CRS CHG	7	45
1044	48-07.4N	122-39.7W	295	7	38
1046	48-07.6N	122-40.1W	295	7	24
1048	48-07.8N	122-40.5W	295	7	49
1050	48-08.0N	122-40.9W	CRS CHG	20	58
1052	48-08.5N	122-41-9W	310	20	43
1054	48-09.0N	122-42.5W	310	20	30
1056	48-09.5N	122-43.4W	CRS CHG	20	28
1058	48-10.1N	122-44.5W	309	20	41
1100	48-10.5N	122-45.1W	309	20	26
1102	48-11.1N	122-46.2W	309	20	21
1105	48-11.9N	122-48.1W	293	20	29
1108	48-12.2N	122-49.2W	293	20	24
1110	48-12.5N	122-50.4W	280	15	30
1115	48-12.9N	122-52.4W	295	13	33
1120	48-03.5N	122-54.2W	295	13	41
1125	48-14.0N	122-55.9W	295	13	56
1130	48-14.5N	122-57.6W	295	13	75
1135	48-15.0N	122-59.2W	295	13	64
1140	48-15.4N	123-00.6W	295	5	76
1145	48-15.8N	123-01.8W	295	13	77
1150	48-16.3N	123-03.2W	CRS CHG	13	88
1155	48-16.8N	123-05.3W	293	18	30
1200	48-17.5N	123-07.3W	293	5	49
1205	48-17.8N	123-09.1W	293	12	53
1210	48-18-15N	123-10-44W	293	12	32
1215	48-18-49N	123-12-54W	293	12	48
1220	48-19-00N	123-13-36W	293	12	45
1225	48-19-29N	123-15-20W	293	4	46
1230	48-19-45N	123-16-28W	293	4	38
1235	48-19-55N	123-17-17W	CRS CHG	4	36
1240	48-19-41N	123-17-41W	CRS CHG	4	40

Table 1 (cont.)

1245	48-19-48N	123-17-31W	310	4	39
1250	48-20-01N	123-17-58W	310	4	37
1255	48-20-16N	123-18-40W	310	3	32
1300	48-20-24N	123-19-08W	320	3	28
1305	48-20-36N	123-19-37W	320	3	20
1308	48-20-44N	123-19-55W	320	3	17
1311	48-20-54N	123-20-13W	320	6	17
1314	48-21-06N	123-20-34W	CRS CHG	6	15
1317	48-21-17N	123-21-04W	300	6	8
1320	48-21-30N	123-21-37W	330	5	41
1323	48-21-44N	123-21-55W	340	5	49
1326	48-22-00N	123-22-06W	CRS CHG	10	49
1329	48-22-07N	123-21-39W	090	10	49
1332	48-22-07N	123-20-56W	090	13	51
1335	48-22-08N	123-19-53W	090	13	46
1338	48-22-08N	123-18-59W	090	13	43
1343	48-22-17N	123-17-18W	069	13	49
1346	48-22-34N	123-16-08W	069	13	51
1349	48-22-50N	123-14-57W	069	13	44
1354	48-23-13N	123-13-44W	049	13	37
1357	48-23-53N	123-12-32W	049	18	31
1400	48-24-19N	123-11-41W	049	18	24
1403	48-24-48N	123-10-48W	049	18	37
1405	48-25-17N	123-09-52W	CRS CHG	18	36
1409	48-26-03N	123-09-01W	000	18	43
1414	48-27-32N	123-09-14W	338	18	43
1417	48-28-16N	123-09-45W	338	18	89
1420	48-28-59N	123-10-07W	338	18	108
1423	48-29-41N	123-10-32W	338	18	121
1426	48-30-24N	123-10-58W	337	18	123
1429	48-31-12N	123-11-28W	337	18	125
1432	48-31-57N	123-11-59W	337	18	126
1435	48-32-52N	123-12-40W	CRS CHG	18	35
1438	48-33-31N	123-13-00W	339	18	157
1441	48-34-21N	123-13-34W	339	18	145
1443	48-35-01N	123-13-45W	357	18	131
1446	48-35-56N	123-13-47W	CRS CHG	10	125
1449	48-36-22N	123-13-54W	CRS CHG	5	119
1452	48-36-54N	123-13-56W	000	18	123
1453	48-37-20N	123-13-55W	CRS CHG	18	123
1456	48-38-01N	123-13-52W	357	18	126
1459	48-39-06N	123-14-04W	CRS CHG	18	128
1502	48-39-49N	123-14-38W	332	18	142

Table 2. Locations (in UTM coordinates) and depths of monitoring hydrophones.
Reference location: UTM-E 487209 UTM-N 5378394

	Phone 0	Phone 1	Phone 2	Phone 3
East (m)	487151	487139	487133	487103
North(m)	5378331	5378257	5378226	5378409
Depth(m)	4.95	14.51	12.11	18.59

Table 3: Locations and times for boat containing Dr.David Bain and marine mammal class corresponding to times when SHOUP was transmitting

Time	Longitude		Latitude	
(local)	(deg)	(min)	(deg)	(min)
1047	-123	4.021	48	27.758
1115	-123	2.225	48	26.991
1134	-123	1.931	48	26.849
1143	-123	1.666	48	26.713
1205	-123	2.407	48	27.303
1215	-123	2.874	48	27.567
1257	-123	6.039	48	28.874
1310	-123	7.104	48	29.312
1314	-123	7.491	48	29.43
1332	-123	8.858	48	30.346
1355	-123	9.984	48	31.387
1407	-123	10.229	48	32.126
1432	-123	10.778	48	33.132
1434	-123	10.765	48	33.114
1443	-123	10.701	48	33.032