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Acoustic and Visual Survey of Cetaceans in the Waters of Puerto Rico and the Virgin Islands: February – March 2001

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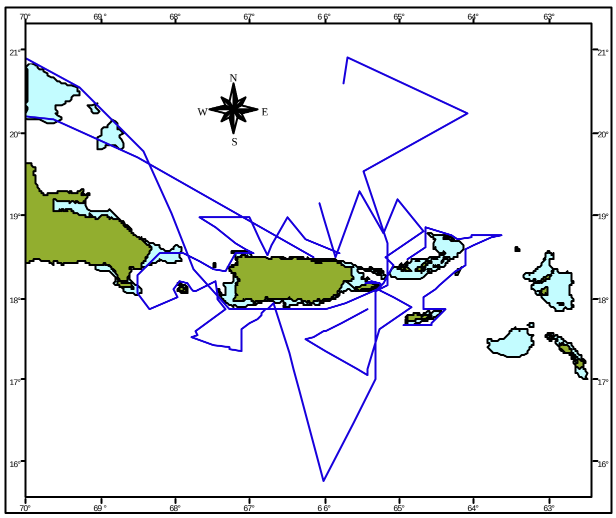
Carolyn Burks, and Antonio A. Mignucci-Giannoni



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Summary

A visual and acoustic survey for humpback whales and other cetaceans was conducted from 12 February to 8 March 2001 in the waters to the east of the Bahamas and around Puerto Rico and the Virgin Islands. The survey utilized passive acoustic techniques (directional sonobuoys and a towed hydrophone array) to augment traditional visual surveys for cetaceans. Several previously unreported areas of humpback whale aggregation were discovered around Puerto Rico, off the east coast of the Dominican Republic, and east and southeast of the Virgin Islands. Samples of humpback whale song were obtained for stock analysis. Additional recordings from sperm whales, other cetaceans, and Atlantic thump trains were obtained. Lists of the species encountered and their distributions, and sounds recorded are presented in 4 tables and 24 figures that accompany the text.

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Acoustic and Visual Survey of Cetaceans in the Waters of Puerto Rico and the Virgin Islands: February – March 2001

INTRODUCTION

Marine mammals are protected in U.S. waters (State, Territorial, and U.S. Exclusive Economic Zone) under the Maine Mammal Protection Act (MMPA, 16 U.S.C. 1361 et seq.), and the Endangered Species Act (ESA, 16 U.S.C. 1531 et seq.). The 1994 Amendments to the MMPA require NOAA Fisheries (NMFS) to monitor trends in abundance and distribution of all marine mammals in U.S. waters. Similarly, the ESA requires monitoring of endangered and threatened marine mammal populations in U.S. waters until such time as their populations recover and are removed from the list of endangered and threatened wildlife. The NMFS' Southeast Fisheries Science Center (SEFSC) developed a scientifically based survey program to provide statistically reliable information on the status of these protected living marine resources on a long-term basis to implement the status of stocks requirement of the 1994 amendments to the MMPA. This information is needed to detect and identify significant changes in the seasonal abundance and distribution of marine mammals that may be indicative of human related disturbance and natural population cycles.

This report presents the findings of a vessel based visual and passive acoustic survey for cetaceans conducted from February 12, 2001 to March 8, 2001 in the waters of the northeastern Caribbean including Puerto Rico and the Virgin Islands.

BACKGROUND

At least 13 species of odontocete and four species of mysticete cetaceans are found in the waters of the Puerto Rican bank, which includes Puerto Rico and the U.S. and British Virgin Islands (Erdman, *et al.* 1973, Mignucci-Giannoni 1998). The seasonal abundance and distribution for most of these species in the northeastern Caribbean are poorly known (Roden and Mullin 2000, Mignucci-Giannoni 1989, Mignucci-Giannoni et al. 1999).

One exception is the endangered North Atlantic humpback whale (*Megaptera novaeangliae*) which migrates in winter to breeding grounds in and around the Greater and Lesser Antilles (Clapham and Mead 1999, Swartz *et al.* 2001). The North Atlantic humpback population as recovered from commercial exploitation to an estimated 10,500 animals (Smith *et al.* 1999), however it remains listed as endangered under the ESA. The largest known and best studied winter concentrations of humpback whales presently occur in the waters of Silver and Navidad Banks off the northeastern coast of Dominican Republic and northern part of the Antillean chain. There, hundreds of humpbacks gather from January to March each year to breed and give birth to their calves (Balcomb and Nichols 1982, Whitehead and Moore 1982, Winn *et al.* 1975, Whitehead 1982, Mattila *et al.* 1989). Lower densities of humpbacks have been reported in adjacent areas immediately to the east, including the Mona Passage (Puerto Rico), and the Virgin Bank and Anguilla Bank (Mattila and Clapham 1989).

The endangered sperm whale (*Physeter macrocephalus*) is the second large cetacean most frequently seen in the northeastern Caribbean (Roden and Mullin 2000). Like humpback whales, sperm whales are distributed in all of the world's oceans. For management purposes the International Whaling Commission defines four stocks: the North Pacific, the North Atlantic, the Northern Indian Ocean, and Southern Hemisphere, however, there is no clear picture of the worldwide stock structure of sperm whales. In general, females and immature sperm whales appear to be restricted in range, whereas males are found over wider ranges and appear to make occasional movements across and between ocean basins (Dufault *et al.* 1999). Females and juveniles form pods that are restricted mainly to tropical and temperate latitudes (between 50/N and 50/S) while the solitary adult males can be found at higher latitudes (between 75/N and 75/S) (Reeves and Whitehead, 1997). In the western North Atlantic they range from Greenland to the Gulf of Mexico and the Caribbean.

Some 20 living species of beaked whales (*Ziphiidae* spp.) are distributed worldwide, rank second only to the delphinids in diversity, and remain the most poorly-known family (Rice 1998). Sightings and strandings of beaked whales (Ziphius cavirostris and *Mesoplodon* spp.) have been reported from many locations in the Caribbean, suggesting that these species may be fairly common (Mullin and Roden 2000, Mignucci-Giannoni 1998, Mignucci *et al.* 1999). Their distribution in the northern Caribbean appears to be limited to tropical and warm-temperate waters. They are generally found off the continental and insular shelves over deep water where they are believed to feed on cephalopod prey.

Because they spend large amounts of time at depth and use low-to-high frequency sound for communication and echolocation, humpback, sperm, beaked, and other whales and dolphins are likely to be vulnerable to any negative effects of anthropogenic sound in the ocean (Richardson *et al.* 1995). While many whales and dolphins are abundant on a world-wide scale, their potential rate of reproduction is relatively low and many regional populations are believed to be small resident stocks. The potential cumulative effects from long-term exposure to noise resulting from activities associated with human industrial activities are of concern, and could include changes in whale and dolphin seasonal abundance and distribution. Reliable baseline information on the seasonal abundance and distribution of whales and dolphins is required to detect and evaluate any demographic changes that could be the result of exposure to noise or other factors in the ocean habitat.

To investigate the current abundance and distribution of cetaceans wintering in the Lesser and Greater Antilles a combined passive acoustic and visual vessel survey was conducted by SEFSC during February and March 2001. The specific objectives of that survey were to:

1. Conduct visual line-transect and passive acoustic surveys to determine the winter distribution and abundance of cetaceans in the waters around Puerto Rico and the Virgin Islands.

2. Collect recordings of vocalizations and other sounds from all cetacean species encountered for reference and comparison among regions.

3. Collect associated environmental data (*i.e.*, sea surface temperature and temperature at depth, wind profiles, and ambient noise measurements) at designated sites within the study area.

4. Deploy and retrieve two acoustic bottom recorders to test the feasibility of utilizing such devices for long-term acoustic monitoring at designated sites.

METHODS

The combined passive acoustic and visual survey was conducted on the NOAA ship *Gordon Gunter*, a 75 m long oceanographic research vessel designed to support surveys for cetaceans in pelagic and coastal waters 11 m or deeper (Fig. 1). The vessel is powered by diesel-electric engines, which are acoustically quiet and produce minimal low-frequency background noise during survey operations.

Survey Track and Timing

The survey consisted of two legs comprising a total of 6,945 km of track line. Total visual survey effort was 3,518 km, and total acoustic monitoring effort was 6,044 km. The first survey leg began on 12 February 2001 and concluded on 19 February 2001. This leg began south of Abaco Island in the Bahamas chain and continued southward along the eastern side of the Bahamas past Caicos, Mouchoir, Silver and Navidad Banks. This leg then continued southward through the Mona Channel, eastward along the southern side of Puerto Rico to Vieques Island, then continuing northward through the Virgin Passage and surveyed the insular shelf waters to the northeast of Puerto Rico, and concluded at the Port of San Juan (Fig.2). The second survey leg began in San Juan on 21 February 2001 and included the insular and offshore waters to the north of Puerto Rico including the southern portion of the Puerto Rico Trench (21-23 February 2001), the insular shelf and offshore waters south of Puerto Rico (24-25 February 2001), the Mona Channel including the coastal waters of the Dominican Republic, the insular shelf waters along the northwestern side of Puerto Rico (26 February to 6 March 2001), and insular shelf waters around the Virgin Islands and St. Croix (7-8 March 2001).

Visual Survey

This survey was designed to provide a general picture of the relative abundance and distribution of cetaceans in specific locations. Thus, survey track lines were developed to circumnavigate the coastlines of the islands and offshore banks surveyed, except for the insular waters around Puerto Rico. The survey track line around Puerto Rico was designed to allow estimation of the most abundant marine mammal species; however, the survey plan had to be modified to accommodate ongoing military operations in the area. As a result, survey coverage of the insular waters around Puerto Rico and the estimation of marine mammal abundance was limited.

Visual survey operations for cetaceans were conducted following standard NMFS survey protocols (Barlow 1995). On-effort survey mode switched to off-effort mode when either visual conditions deteriorated (due to sea state > Beaufort 5), or if the ship left the trackline to locate cetaceans for group size estimation, or to record humpback song or other cetacean vocalizations. Visual observations were normally conducted from 0630 hrs to sunset (approximately 1930 hrs) each day. Two teams of three experienced observers operated rotating 2-hr shifts during daylight hours, weather permitting (*i.e.*, no rain, Beaufort sea state ≤ 5, winds below approximately 22 kts.). Observers rotated through each of three observer positions every 30-min. to reduce fatigue. Observations were made from the flying bridge, located approximately 14 m above the sea surface. A port and a starboard observer each searched for cetaceans using 25X "big eye" binoculars within a 90^0 quadrant from the bow to the beam on each side of the ship (Fig. 3) . A third observer recorded data and maintained a search of the area near the ship using unaided eye and/or 7X hand-held binoculars.

When cetaceans were sighted, the ship broke from its track and approached the cetaceans to confirm species and to estimate group size. Sighting data were recorded on a laptop computer using a data acquisition and logging software program that interfaced with the ship's global positioning system (GPS). Cetacean sighting data included species, group-size, presence of calves, bearing from the bow, linear distance from the ship when detected, and behavioral observations. Each night, observers filled out sighting forms, and these were checked for errors and reconciled with the day's computerized data log. Environmental data were recorded every half-hour with the rotation of observer positions, when conditions changed during a shift, and at the time of each sighing. Environmental data included sea state, surface temperature, water depth, weather, visibility, wind direction and speed, and sun glare in the observer's field of view. A continuous record of the ship's position, sea surface temperature (SST) and water depth was collected via the ship's onboard Scientific Sensor Collection System (SSCS).

Acoustic Survey

Many cetaceans produce sounds that are detectable at substantial distances, and thus pasive acoustic methods are useful for determining presence and distribution of cetaceans, especially in conditions where visual survey methods have limited effectiveness (Noad and Cato 2001). The survey platform, the NOAA ship *Gordon Gunter*, is well suited for both visual and acoustic surveys. It is a former U.S. Navy vessel engineered to support passive acoustic operations. The ship is powered by deisel-electric engines which are acoustically quiet relative to power plants in other vessels, and produced minimal low-frequency background noise during survey operations. Monitoring to detect humpback whale song and other cetacean sounds was conducted throughout the primary survey area and opportunistically in other areas with the use of directional sonobuoys and a towed hydrophone array.

Sonobuoys: The AN-SSQ-53D directional (DIFAR) sonobuoy were used to detect and obtain directional in formation from calling whales. These sonobuoys contain a compass in the sensor head and transmit three types of continuous signal back to the ship on a VHF radio carrier in an analog multiplexed format (Fig. 4). These signals are acoustic sound pressure, east/west particle velocity and north/south particle velocity. The frequency range is from approximately 10 Hz to 4,000 Hz, which is well suited for large whale vocalizations that have their greatest sound energy concentrated below 1,000 Hz. These sonobuoys could be set to broadcast for up to 8-hrs. A second type of sonobuoy, the AN-SSQ-57-A, had a frequency range from approximately 50 Hz to 20,000 Hz and were also used to obtain non-directional sound recordings from other cetaceans, particular the odontocete species encountered that vocalize in higher frequency ranges. All these data contribute to location and species specific library of signature calls for cetaceans, which will allow species identification when visual data are not available.

The VHF radio signal from the sonobuoys was received by a pair of antennas mounted on the aft mast of the ship located at 26 m above waterline. Each antenna was tuned for optimal reception over a range of radio frequencies. Sonobuoy radio broadcast frequencies were chosen near the frequency band of one or the other antenna, depending on the level of radio interference present on a specific frequency band. Radio reception ranges from the sonobuoys averaged 11-13 N.M. which, when the ship was running at survey speed (approximately 10 kts), allowed each sonobuoy to be monitored for approximately one hour and ten minutes before the ship moved out of radio reception range. The signals from the radios were recorded at a 48 kHz sampling rate on two-channel DAT tape recorders for processing and for archival purposes, and were monitored in real time on PC computers running SpectraPlus[1], a commercial signal-analysis software program.

The magnetic bearing (or azimuth to the signal source relative to the position of the sonobuoy) to calling animals was determined by selecting a segment of the humpback song from the sonobuoy signal using the signal-analysis software program's spectrogram display computed on the computers using standard sound cards. This signal was then stored as a binary file, de-multiplexed using custom software designed by Greeneridge Scientific, and the three de-multiplexed signals were processed to yield a magnetic bearing to the sound source using another custom software program written for this project by M. McDonald. This software produces a plot showing signal intensity as a function of frequency and bearing angle from 0^0 to 360^0 relative to the position of the sonobuoy (Fig. 5). The bearing accuracy to a sound source using these buoys had a standard deviation of two degrees. Magnetic bearing angles to calling animals from the sonobuoys were plotted as true bearings on navigational charts to determine the direction to the calling whale relative to the position of the ship. The vagaries of acoustic propagation in the ocean made it impossible to accurately estimate range to a calling whale by received signal amplitude alone. However, when the same singing whale or whales were detected on two or more sonobuoys with a sufficient baseline separation, it was possible to precisely locate the calling whales by crossing two or more bearings to determine the source.

[1] The use of commercial trade names does not imply endorsement by the authors.

Towed Hydrophone Array: The Southeast Fisheries Science Center's 5-element towed array is a 100-meter long Kevlar reinforced cable assembly with five high gain hydrophones, spaced at two-meter intervals along the cable (Fig. 6). Each element is a piezoelectric ceramic striped cylinder with the cable assembly and strength member passing through the center. Each sensor, along with its associated signal conditioning, filtering and line drive electronics, is contained within a hydrodynamically shaped tow body assembly. The frequency response is essentially flat at -127 dB from about 2 kHz to 15 kHz then climbs to a resonance peak at about 35 kHz with a level of -121 dB, then drops off at roughly -15 dB per octave after resonance. Below 1.5 kHz, the sensors roll off at roughly 6 dB per octave to help reduce low frequency tow and impulse noise. The first element is located approximately 17 meters behind the forward underwater connector. The aft end of the array is terminated with another underwater connector, which allows for testing of the array wiring and for attachment of an additional array or sensor package. This entire assembly is connected to an 800-meter tow cable made from the same cable as found in the array. This constitutes the wet end of the assembly and it is deployed from and rewound onto a hydraulically powered winch/drum with a diameter of 1.2 meters. A deck cable running into the acoustics laboratory completes the assembly and allows for the transfer of power to and signal from the array.

As with the sonobuoys, the signals from each of the five hydrophone elements in the array were recorded in the laboratory at a 48 kHz sampling rate on 8-track DAT tape recorders for processing and for archival purposes. The incoming hydrophone signals were monitored in real time on PC computers running a custom software program "Ishmael" developed by D. Mellinger. This program allowed real-time signal monitoring and calculations of magnetic bearings to the sources of whale calls relative to the orientation of the ship.

Each evening following the termination of the visual surveys, the hydrophone array was deployed and towed at approximately 4 kts to minimize self noise and turbulance for optimum recording of ambient and biological sounds. A number of times during the survey DIFAR sonobuoys could not be used to record sounds near the shores of Puerto Rico due to radio and other electronic interference emanating from the island. In these instances, the vessel's speed was reduced to approximately 7 kts from 10 kts for visual surveys, and the hydrophone array was used as a substitute for the sonobuoy to collect data on whale calls and ambient noise during visual surveys. While the reduction in speed was a compromise for the visual survey that is normally conducted at 10 kts, it provided a reasonable reduction in flow noise and turbulence from the array to allow for detection and recording of biological sounds from cetaceans.

Autonomous Acoustic Recorders: The Bioacoustics Research Program (BRP) at the Cornell University Laboratory of Ornithology provided two autonomous acoustic recorders (Pop-Ups) to monitor for whale sounds and ambient noise in the survey area. Each pop-up consists of a 17" Benthos glass sphere that contains batteries, communications electronics, and data collection electronics (DSP system with 25GB hard drive) (Figs. 7 and 8). A continuous sampling schedule was programmed for each recorder through a serial interface and PC software. Sampling rate range was set from 100 - 8,000 Hz to allow detection of low frequency whale calls as well as higher frequency dolphin and small toothed whales.

RESULTS

Visual Surveys

A total of 142 cetacean groups representing 11 species of cetaceans were sighted during during both legs 1 and 2 of the survey, with the highest number of groups sighted per day being 38 (Tables 1 and 2). Sightings included: humpback whales (n=72) (Fig. 9), sperm whales (*Physeter macrocephalus*, n=6), beaked whales, (*Ziphius cavirostris*., n=3, and *Mesoplodon spp*., n=3), false killer whales (*Pseudorca crassidens,* n=1), pilot whales (*Globicephala cf. macrorhynchus*., n=8), rough-toothed dolphin (*Steno bredanensis,* n=1), bottlenose dolphin (*Tursiops truncatus,* n=2), pantropical spotted dolphin *(Stenella attenuata* (n=3), Atlantic spotted dolphin (*Stenella frontalis,* n=10), spinner dolphin (*Stenella longirostris*, n=2), unidentified dolphin (n=11), unidentified small whale (n=3), and unidentified large whale (n=13) (Figs. 10 and 11).

Estimation of Abundance: As noted in the methods section, the original survey track around Puerto Rico was designed to allow for the estimation of abundance of humpback and other whale species, however, the trackline and the sequence that each portion of the trackline were executed had to be modified to accommodate naval exercises that were ongoing in the area. As a result, the survey coverage around Puerto Rico and the Virgin Islands did not completely cover the entire insular shelf, and the sightings of most marine mammal species were too few to allow meaningful statistical analyses. There were, however, sufficient visual sightings of humpback whales within the insular shelf waters (n= 31 groups) to allow the calculation of a preliminary abundance estimate of 532 (CV 0.36, 95% CI 260-1,088) humpback whales on the Puerto Rico Bank during the February-March time frame. This estimate is likely negatively biased, as the findings of the 2000 acoustic and visual survey for humpback whales in the Eastern Caribbean (Noad and Douglas 2001, Swartz *et al.* 2001) suggested that acoustic detections outnumbered visual detections by a factor of as much as 8:1.

Acoustic Surveys

A total of 135 sonobuoys were deployed during the survey along approximately 6, 044 km of trackline (Fig. 12). Approximately 270 hours of 2-track DAT tape recordings were obtained from the sonobuoys and approximately 40 hours of 8-track DAT tape recordings of ambient sounds and whale calls were obtained during hydrophone array tows. While analysis of the hydrophone array tapes is ongoing, cetacean sounds recorded from the array included humpback whales, sperm whales, pilot whales, false killer whales, and a variety of dolphin calls (Table 3).

Humpback Whale Acoustic Detections: The northern most detection of a singing humpback whale was obtained from a sonobuoy deployed east of Samana Cay in the Bahamas on February 14, 2001 (Fig. 13). The signals detected from the sonobuoy suggested that the calling whale was located a few kilometers to the north of Samana Cay. As the survey proceeded south, additional calling humpbacks were detected in increasing numbers off the east and southern end of Mayaguana Island, to the east of the Turks and Caicos, and east of Mouchoir Bank. These initial acoustic detections of humpback whales were not accompanied by visual detections due to strong winds and high sea states that limited visibility. The number of singing whales detected acoustically increased from one or a few individuals to choruses of many individual singers as the survey approached the well-known humpback aggregation sites of Silver and Navidad Banks. The first visual detections of humpback whales occurred on 15-16 February 2001 off the eastern sides of Silver and Navidad Banks along with continuous acoustic detections of many singers. The number of singing whales was so great in these locations that it was not possible to localize on the direction of an individual singer; rather, bearings to the general direction of the "chorus" of singing whales were obtained from the sonobuoy signals. Notably, a few sonobuoy bearings obtained off the eastern side of the Turks and Caicos and off Silver Bank suggested that some calling whales were located offshore to the northeast over very deep water (> 5,000 m). Similarly, during the last portion of the survey on 11-12 March 2001 choruses of singing whales were detected along the southern sides of Navidad, Silver, and Mouchoir Banks. In addition, sonobuoy detections indicated that additional whales were located along the northern shore of the Dominican Republic and Haiti. The last acoustic detection of singing humpbacks were from whales located along the southwestern shore of Great Inagua Island, Bahamas on 12 March 2001.

Surveys over the deep water of the Puerto Rican Trench northeast of Puerto Rico detected calls from singing humpback whales presumable located to the northwest in the direction of Navidad Bank, and also from whales located to the northeast and east over deep water (> 6,000 m) and far from any banks or islands (Fig. 14). The presence of humpback whales in this deep water was confirmed by visual sightings on 22-23 February 2001, along with sightings of sperm and pilot whales. Additional acoustic bearings suggested that singers were located to the southeast toward the islands of Anguilla, St. Martin, and St. Barthélemy, and from whales located on the northern side of the insular shelf of the Virgin Islands. Multiple acoustic and visual detections of humpback whales were obtained along the shelf waters of the Virgin Bank to the northwest and north of the Virgin Islands on 17-18 February and on 7 March 2001. Groups of many chorusing humpback whales were detected east and southeast of Anegada Island on 7-8 March 2001. Here the numbers of individually singing whales created a chorus of songs similar in amplitude to that detected off of Silver and Navidad Banks, suggesting high densities of whales were located on the coastal banks to the east and southeast of Anegada Island.

The survey conducted on 8 March 2001 traversed the channel between the Virgin Islands and St. Croix (Fig. 15). Humpback whales were detected visually and acoustically on Barracuda Bank southeast of the British Virgin Islands and off the east end of St. Croix. Surface active groups of presumably mating humpbacks along with lone individual whales were seen in these areas. Acoustic detections suggested that additional singing whales were located to the southeast in the direction of Saba Bank, St. Kitts and Nevis. Surveys of the insular shelf waters southeast of Puerto Rico resulted in no visual sightings of humpbacks, but singing humpback whales were acoustically detected in all directions except to the north in the direction of Vieques Island and the Puerto Rican mainland. Similarly, surveys of the offshore waters south of Puerto Rico on 26-27 February 2001 resulted in no visual sightings of humpback whales. Acoustic detections of humpback whales from sonobuoys placed in this area resulted in bearings to singing whales located to the northeast toward Saba Bank and St. Croix, and to the northwest in the direction of Cabo Rojo (southwest Puerto Rico) and the Mona Channel. A few bearings obtained in this deep-water area suggested that some distant callers were located to the south of Puerto Rico at some yet to be determined location.

Surveys off the southwestern coast of Puerto Rico on 1-2 March 2001 resulted in no visual sightings of humpback whales, however, multiple acoustic detections suggested that singers were located to the north and northeast in the region of Cabo Rojo and Mona Island in the southern end of Mona Channel (Fig. 16). It should be noted that all the acoustic bearings to singing whales were to the north, and there was no indication that additional singing humpback whales were located to the south of the southernmost sonobuoys. Humpback whales were sighted to the west of Cabo Rojo along the edge of the insular shelf, and to the west around the northern shores of Mona Island. The frequency and numbers of calling humpback whales in the Cabo Rojo area and along the northern shore of Mona Island were comparable to that detected off Silver and Navidad Banks to the north suggesting that dense aggregations of humpback whales occupied these locations. In contrast, the survey of the area to the west of Mona Island and along the southeastern shore of the Dominican Republic off Isla Saona detected no humpback whales is this region. All the bearings from sonobuoys deployed in this area suggested that singing whales were those previously detected to the east and northeast in the Mona Channel.

The survey from the southeast corner of the Dominican Republic north to Cabo Engaño and Engañno Bank on 3 March 2001 revealed no sightings of humpback whales, but acoustic detections pointed to sources of whale songs to the east toward Mona Island and to the north at Engaño Bank. As the survey approached Engaño Bank, visual sightings of humpback whales increased along with acoustic detections (Fig. 17). The number of chorusing humpback whales detected on Engaño Bank were similar to that recorded on Silver and Navidad Banks to the north, suggesting that this area was a significant aggregation area for humpback whales. The survey crossed the northern Mona Channel toward Puerto Rico on March 4, 2001. Visual and acoustic detections indicated that concentrations of humpbacks were located on the insular shelf off the northwestern coast of Puerto Rico. As the survey moved to the northwest away from the Puerto Rican coast into deep offshore water, visual sightings of humpback whales declined. Acoustic detections in this area produced bearings to singing whales off toward Samaná Bay in the Dominican Republic to the west (a well documented humpback aggregation area), and to Navidad Bank to the northwest. Similarly, acoustic detections of singing humpbacks obtained off the northern coast of Puerto Rico pointed to whales located to the east in the vicinity of the Virgin Islands and to the west in the northern Mona Channel.

Sperm Whale Acoustic Detections: Classic “clicks” and “codas” from sperm whales were detected on

12 (9%) of the 135 sonobuoys deployed around Puerto Rico (Fig. 18). Most of these sperm whale detections were located to the southwest of Puerto Rico over relatively deep water and in the Mona Channel to the southwest of Mona Island.

Atlantic Thumptrain Detections: Atlantic "thumptrain" calls were the second most frequently detected biological sounds next to humpback whale calls. “Thumptrains” are believed to be attributed to minke whales (*Balaenoptera acutorostrata*) (Mellinger *et al.* 2001), although no minke whales were visually detected during this survey (Fig.19). Multiple thumptrains were detected on 79 (58%) of 135 sonobuoys. These thumptrains consist of a series of repetitive pulses approximately 1.0-1.5 seconds apart with a major center of energy between 200 HZ and 400 Hz that continue for 20 seconds to over one minute in length (Fig. 20). As the thumptrain proceeds, the rate of the individual pulses increases or speeds up to a crescendo and an abrupt termination of the signal. Thumptrains were frequently recorded in the presence of humpback whale calls.

Anthropogenic Noise: A total of 50 percussive “explosion-like” sounds were recorded on 7 sonobuoys (n=43) and during 6 hydrophone array tows (n=7)(Table 4). The first instance was recorded during array tow TA-01 on 22 February 2001 near the eastern edge of the outer northern naval operations range. Additional percussive sounds were subsequently recorded on sonobuoys and during array tows between 25 February and 1 March 2002 south of Puerto Rico. Magnetic bearings calculated from sonobuoy numbers SB-95, SB-96, SB-99, SB-100, and SB-102 suggested that the sources of these percussive sounds were centered within the southern inner naval operations range at Latitude 17^0 48.4 N Longitude 65^0 48.4 W approximately 91-163 km from the sonobuoys (Fig. 21). Additional sounds recorded on sonobuoy SB-108 on 1 March 2001 suggested that their source was the area to the south of Vieques Island approximately 252 km from the sonobuoy. We were not equipped to make quantitative measurements of recieved sound levels, however, we could compare relative sound level to prevailing ambient noise at the time these percussive sounds were recorded. A spectral power analysis of one of these percussive sounds recorded from the towed hydrophone array on 27 February 2001 (TA-06) indicates that between 100 Hz and 20 kHz the received sound level at the array averaged approximately 26.86 dB (re. 1 ： Pa-m) above the ambient noise level in the area just prior to the occurrence of the percussive sound (Fig. 22). At that time the array was approximately 98 km from the center of the southern inner operations range.

Sound from commercial ships was frequently encountered all around Puerto Rico except off the southeast corner of the island. Shipping noise was characteristically broadband with major energy components between 20Hz to 600Hz or higher. A total of 22 (16%) of 135 sonobuoys detected noise from commercial ships (Fig. 23). Active sonar pings were also recorded on 6 occasions: once on a sonobuoy (SB-48) and 5 times during towed hyrdophone arrays (TA-08, TA-09, TA-12, TA-14, and TA-18).

Autonomous Acoustic Recorders

Two "pop-up" autonomous sea-floor recording devices provided by Cornell University were deployed in two locations off Puerto Rico to monitor for cetaceans and collect ambient sound data. Data from both units were downloaded, converted into AIF files and archived on several large disk drives. Converted files were scanned for humpback whales on an ad hoc basis. In both locations there was considerable vessel noise as well as occasional humpback singing.

The first recording device was placed in the northern Mona Channel, approximately 15 km southwest of Desecheo Island, on 16 February 2001 in approximately 300m depth (Fig.17). The second device was placed approximately 8 km south of Vieques Island on February 17, 2001 in approximately 538m depth (Fig. 15). The recorder deployed off Vieques Island was recovered on February 25, 2001 having recorded for 8.3 days, however, usable recordings were obtained for only approximately 47 hours (8 GB of data) beginning on February 23, 2001. Sperm whale clicks were recorded along with various instances of manmade sound during the period the unit operated. Most of the manmade sounds consisted of vessels moving past this area. Other sounds that are assumed to be manmade have yet to be identified. Unfortunately, the quality of recorded sound from this buoy was marginal and a more thorough analysis is required to determine the complete nature of the sounds recorded.

The recorder located off Desecheo Island was recovered on March 2, 2001 having recorded for 14 days. The quality of recorded sound from this device was much better than the device placed off Vieques Island. Sounds from several species of cetaceans were present on recordings, including humpback whales which account for most of the marine mammal sounds recorded. There are also various instances of delphinid whistles that have not been identified to a species. Vessels in transit account for the bulk of manmade sounds recorded, and are seen a peaks in the spectoral data in the low-noise band (10-100 Hz) and mid-noise band (100-300 Hz) recorded over several days (Fig. 7). There are humpback whale calls and other cetacean sounds embeded in these data along with a few instances of what appears to be active sonar pings.

DISCUSSION

Visual and Acoustic Detections

The sightings of cetaceans obtained during this survey were typical for the region and consistent with published species accounts from previous surveys of the area (Erdman, *et al.* 1973, Mignucci-Giannoni 1998, Roden and Mullin 2000). While the eleven of the 13 species of cetaceans observed in this survey were representative of the odontocete and mysticete cetaceans found in the waters of the northeast Greater Antilles around Puerto Rico and the Virgin Islands, the encounter rates were lower than expected, and precluded statistically meaningful estimation of abundance.

The exception was the humpback whale. The provisional abundance estimate of 532 (CV 0.36, 95% CI 260-1,088) for humpback whales on the Puerto Rican-Virgin Island insular shelf is based on sightings of 31 groups of whales, and is likely an underestimate of the number of humpbacks that utilized these areas as winter aggregation sites. The 8:1 ratio of acoustic detections to visual detections of humpback whales observed in the Eastern Caribbean (Swartz *et al.* 2001) suggests that visual methods alone greatly underestimate humpback whale density (Noad and Douglas 2001). Ongoing analyses of the findings from this survey include developing acoustic based estimates of relative density and abundance of singing and other age/sex classes of humpback whales that frequent the aggregating areas described in this study. The goal of these analyses is to develop a correction factor for this region that will allow a more precise estimation of humpback whale density and abundance during the February-March time frame. Future surveys will need to expand the coverage of this survey to adjacent areas within the Greater Antilles to confirm the absence and/or presence of humpback whale aggregations during the winter breeding seasons, and to provide a context in which to evaluate trends in humpback whales and other cetacean species around Puerto Rico and the Virgin Islands.

Humpback whales were the most frequently sighted cetacean, and they were the species most frequently detected acoustically. Clearly the use of passive acoustic methods to detected singing humpback whales contributed to a clearer and more complete determination of their winter distribution and relative density is specific areas in and around the Puerto Rican and Virgin Island insular shelf than would have been obtained by visual methods alone. Over time, the continued use of sonobuoys and towed hydrophone arrays will add new information on the signature vocalizations and calls of specific to all species of cetaceans. Ultimately these species specific sounds will allow the identification, presence or absence, and distribution of these species on a seasonal basis from acoustic information alone. In the long-term, a network of bottom mounted acoustic sensors could provide real-time or near-real time monitoring of the acoustic environment around Puerto Rico and adjacent waters on a seasonal basis. Periodic vessel based surveys employing both visual and passive acoustic survey methods could be used to validate such data gathered over the long-term by these acoustic devices.

<u>Humpback whale distribution</u>: The findings of this survey reaffirmed the continued use of previously identified winter aggregation areas of humpback whales including Silver and Navidad Banks off the northeast coast of the Dominican Republic (Whitehead and Moore 1982, Mattila *et al.* 1989), Samaná Bay (Mattila *et al.* 1989), Rincon and Borinquen bank (Mattila 1984, Mignucci-giannoni 1998) and Virgin and Anguilla Bank (Mattila and Clapham 1989). This survey also identified additional locations in the northeastern Greater Antilles that appear to host densities of humpback whales similar to those detected in better known aggregation areas during the peak of the winter breeding season for this species. These include concentrations of humpback whales off the Turks and Caicos, Great Inagua Island, along the northern coast of Haiti and the Dominican Republic, on the shallow banks to the east and southeast of Anegada Island in the British Virgin Islands, the easternmost banks off St. Croix, and Engaño Bank off the east coast of the Dominican Republic south of the well known aggregation area of Samaná Bay (Mattila et al 1994). The conspicuous absence of humpback whales off the southeastern coast of the Dominican Republic, the nearshore southern Coast of Puerto Rico, and the offshore waters to the south of Puerto Rico remain to be explained.
Mattila and Clapham (1989) reported low densities of humpback whales in the Mona Passage

compared to the Virgin and Anguilla Banks at peak season, and concluded that the Virgin Bank may be a more important breeding ground than Mona Passage, but considerably less important than Silver Bank. The frequency of acoustic and visual detections of humpback whales observed in this survey in the Mona Passage around Cabo Rojo, Mona Island and Engaño Bank were comparable to those obtained from Silver Bank a few weeks earlier, suggesting that the densities of humpback whales utilizing these areas in the Mona Passage are significant. Similarly, the frequency of acoustic and visual detections of humpback whales to the east and southeast of Anegada Island in the British Virgin islands and to the east of St. Croix suggest that these areas are also utilized by humpback whales in densities similar to those found on Silver Bank. Additional calls were detected to the southeast presumably from whales located on Saba Bank. The 2000 acoustic and visual survey of the waters around St. Kitts and Nevis (Swartz *et al.* 2001) documented humpback whale calls emanating from the Saba Bank area, further suggesting that this bank may also serve as an aggregation area for wintering humpback whales.

While humpback whales are known to aggregate in the shallow nearshore insular waters and banks of Eastern Caribbean islands, we documented numerous detections of humpback whale calls that appeared to originating from whales located far offshore, over relatively deep water, and not in proximity to any islands or shallow oceanographic features (*e.g.*, sea mounts). Such detections were obtained from sonobuoys deployed along the eastern side of the Turks and Caicos and to the north of the Virgin Islands. We can only speculate that these calling whales were migrating to and/or from the winter aggregation areas in the Greater Antilles, suggesting that humpback singing occurs during migration as well as on aggregation areas near or adjacent to islands. Similar bearings to singing whales apparently far at sea over deep water were obtained south of Puerto Rico. The only land south of Puerto Rico is the small island of Isla Aves located approximately 15^0 N and 66^0 W in the middle of the Venezuela Basin. It is not known if humpback whales aggregate at or near this small island or follow the Aves Ridge to the east when migrating up and down the Eastern Caribbean island chain.

<u>Thump Trains</u>: The second most common sound recorded during this survey were Atlantic "thumptrains" or "pulse trains" attributable to minke whales. Such "pulse trains" have been reported by previous researchers (Winn and Perkins 1973) and were recently reviewed by Mellinger *et al.* (2000) who concluded that the source of these calls were minke whales. We note that while minke whales have been reported from the waters north of Puerto Rico (Mattila and Clapham 1989, Mignucci-Giannoni, 1998, Mullin and Rodin 2000), there have been no recent strandings or observations of minke whales in this region despite the common occurrence of thumptrain calls in recordings made during this survey and other surveys (B. Mase, pers. comm.). Additional thumptrains were frequently recorded during a 2000 survey of the Eastern Caribbean islands of the Lesser Antilles south to Trinidad-Tobago and the North Venezuelan coast (Swartz *et al.* 2001), and no minke whales were observed during that survey. Given the frequent detections of thumptrains, the number of observer hours achieved during these recent surveys, the lack of observations of minke whales, and the lack of stranded minke whales reported from the Greater and Lesser Antilles, we speculate that the source of these thumptrains is something other than minke whales.

Anthropogenic Noise

Ship noise, percussive “explosions”, active sonars, and mechanical sounds of unknown origin were pervasive around Puerto Rico and the Virgin Islands during this survey. It is a well accepted fact that, since the industrial revolution and with the development of steam and fossil fuel driven vessels, the levels of low frequency noise introduced to the marine environment by human industrial and commercial activities has increased above natural sources of low frequency sound (*e.g*., seismic activity, wind, rain, *etc*.) by some yet to be measured level (Richardson *et al*., 1995). It is also generally unknown what the potential long-term effects of chronic exposure to this noise may be on marine life and particularly cetaceans.

Cetaceans evolved sophisticated capabilities to use both passive and active sounds for communication with conspecifics and to explore and navigate in their marine environment. Sensitivity to sound is regarded as the cetaceans’ most highly evolved sensory process (Richardson et al., 1995, Wartzog and Ketten 1999). Humpback whales, for example, have evolved complex acoustic sexual displays that play an important role in their reproductive behavior and biology (Darling 2001), and it is reasonable to consider that some level of background noise would interfere with their ability to communicate and render this aspect of their reproductive behavior ineffective. Similarly, sperm whales and other odontocete cetaceans continuously emit broadband clicking sounds presumably to echolocate while diving to forage for prey and to navigate. At some level, background noise could impede their ability to echolocate effectively.

It will require many years of field observations and other research to determine the levels and duration of exposure to such noise that can be permanently detrimental to cetaceans. In this survey, we were not prepared to measure source levels from such sounds, nor were we able to quantitatively measure recieved sound levels at the hydrophone array or sonobuoys. The sound levels measured relative to the ambient noise field reported in this survey represents an initial starting point with which to document future trends in the use of the waters around Puerto Rico and the Virgin Islands and the kinds and levels of noise in those waters. In the future it will be necessary to undertake additional surveys at regular intervals to develop a baseline of cetacean seasonal distribution and relevant noise levels in the habitats they occupy. To this end, future surveys will need to include the use of calibrated acoustic measurement equipment and employ specific sound measurement methods to document and quantitatively characterize the noise environment in which cetaceans occur, and how that noise environment changes over time.

Autonomous Acoustic Recorders

The two autonomous sea floor recording devices demonstrated a potential for long-term recording to supplement vessel based visual and acoustic survey data. The large magnitude of the acoustic data obtained from these devices, however, will require automated analysis procedures to achieve the maximum benefit from the capabilities of such devices. Manually browsing the continuous stream of files searching for species specific sounds of interest is a time consuming and inefficient process. In the case of blue and fin whales automatic detectors have been developed and work reasonable well. However, in the case of species with more variable calls *(e.g.*, humpbacks), especially in the presence of vessel noise and transient sounds, the operator must go through file by file to pick out the specific sounds to be identified

These results indicated that autonomous recording devices are a viable tool for monitoring over periods of days to months within the region around Puerto Rico and other areas. In the future, units with both higher recording capacity and longer battery life than those used in this survey will be available. Onboard processing (*e.g*., scheduled sampling rates rather than continuous recording) and increased power efficiency of the electronics circuits will allow for longer recording periods as well as a greater frequency range of acoustic coverage. For example, a unit with a 25GB drive, recording for a total of 12h/day (50% duty cycle) at a sampling rate of 10 kHz can record for almost 20 days. A unit recording at a sampling rate of 5 kHz can record for almost 40 days, while a unit recording at a sampling rate of 2 kHz can record for 90 days. Thus, a suite of 6-10 units deployed around Puerto Rico could provide circum-island coverage for over a month, depending on the sampling rate and duty cycle. If numbers and distributions of animals in a specific area were of interest, sets of recording devices could be deployed in arrays, where array spacing is primarily determined by the frequency and source level of the primary species of interest. A minimum of three recording devices are needed for such an array, however four or more units are recommended. For example, with fin whales spacing on the order of 5 miles can be used since sounds from the same fin whale are readily detected out to ranges of tens of miles. For higher frequency species, such as pilot whales or dolphin, array spacing would need to be on the order of 500-1000m.

Ultimately autonomous bottom recorders will provide a relatively cost effective mechanism for sampling a broad area for an extended period of time. A drawback to this technique is that one must wait until the units are recovered and the data analyzed before one learns anything from the effort. If real-time results are not critical, and one knows the time period and the area of interest, a dispersed set of recording devices is a very effective mechanism for acoustic data collection. Real-time or near real-time monitoring could be achieved by integrating autonomous recording devices with various types of sea-buoys that gather oceanographic and weather data and transmit those data by radio to a shore based laboratory, much like a sonobuoy.

Future Surveys

The low sighting rates for some of the cetacean species could be the result of the reduced length of the survey track necessitated to accommodate active naval exercises in many of the areas to the north and south of Puerto Rico. The original survey design was based on estimates of encounter rates for the most common species, and should have resulted in sufficient sightings of those species to serve as the basis for statistical estimation of abundance with coefficients of variation ranging from 0.20-0.30. Future survey effort (*i.e.*, km of trackline searched) of this region should be based on the sighting rates obtained in this survey and be of sufficient length to allow an increase in encounter rates to achieve the desired statistical precision for estimates of abundance. Such a survey would involve increasing the tracklines to approximately 6,400 km to cover the areas from nearshore to the 5000 m bathymetric depth contour around Puerto Rico. Based on the results from the 2001 survey, this effort estimate should result in at least 82 primary humpback whale group sightings compared to 31 sightings on the Puerto Rican Bank in this survey, and an abundance estimate based on these sightings would have an expected coefficient of variation of 0.20 or less (Fig. 24). Aerial surveys flown during the vessel survey could provide additional estimates of group size and expand the range of the vessel survey and verify both acoustic and visual detections of whales.

The sounds recorded from various cetacean species during this survey established the beginning of species specific sound archive. Future surveys will contiribute additional species specific calls and sounds as these are obtained and verified by visual observations. These data will be the foundation for idenifying sounds of unknown origin, and for identifying and enumerating cetacean sounds recorded when visual observations are not possible (*e.g.*, during poor weather, at night, and data from autonomous recording devices). To achieve this capability, additional resources need to be devoted to onging archiving of species specific sounds recorded in specific locations, and the development of "recognition" software to compare and match sounds of unknown origin with those from known sources. Ideally, year round acoustic monitoring of key locations on the Puerto Rican Bank (e.g., the Mona Passage, the Virgin Passage) would provide presence and absence information for specific cetacean species that could serve as an index of their seasonal arrival, residence, and departure from this region. Such acoustic monitoring could be conducted from small vessels, from bottome mounted recorders or hydrophone arrays cabled to shore, or some combination of acoustic montioring methods.

Similarly, anthropogenic sound and noise recorded during this survey will surve as a baseline measurement of the variety and location of this noise with which to monitor the acoustic environment in future years as trends in commercial shipping and other human activities continue.

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Figure 9. Sightings of humpback whales (triangles, n=72) during visual surveys (solid black lines) along the eastern and southern sides of the Bahamas south to Puerto Rico and the Virgin Islands.

Figure 10. Sightings of dolphins during visual surveys (black lines): *Steno bredanensis* (star, n=1), *Tursiops truncatus* (triangle, n=2), *Stenella attenuata* (circles, n= 3), *Stenella frontalis* (squares, n=10), and *Stenella longirostris* (diamonds, n=2).

Figure 11. Sightings of odontocete whales during visual surveys (black lines): *Physeter macrocephalus* (circles, n=5), *Ziphius cavirostris* (triangles, n=3), *Mesoplodon* spp. (squares, n=3), *Pseudorca crassidens* (star, n=1), and *Globicephala cf. macrorhynchus*. (diamonds, n=8).

Figure 12. Survey track lines along the eastern side of the Bahamas, around Puerto Rico and the Virgin Islands (black line) showing location of sonobuoy drops (circles with radials) and hydrophone array tows (bold lines).

Figure 13. Survey track lines along the eastern side of the Bahamas, the Turks and Caicos, Mouchoir, Silver and Navidad Banks (thin line) showing location of sonobuoy drops with magnetic bearings to calling humpback whales (circles with radials).

Figure 14. Acoustic detections of humpback whales during surveys to the north of Puerto Rico and the Virgin Islands showing the location of sonobuoy drops and magentic bearings to singing humpback whales (circles with radials).

Figure 15. Acoustic detections of humpback whales during surveys to the south of Puerto Rico and the Virgin Islands showing the location of sonobuoy drops with magnetic bearings to singing humpback whales (circles with radials), and the location of one autonomous acoustic recording device is idicated by a **i** .

Figure 16. Acoustic detections of humpback whales during surveys to the west, and southwest of Puerto Rico showing the location of sonobuoy drops with magnetic bearings to singing humpback whales (circles with radials).

Figure 17. Acoustic detections of humpback whales during surveys to the west, northwest of Puerto Rico showing the location of sonobuoy drops with magnetic bearings to singing humpback whales (circles with radials), and the location of one autonomous acoustic recording device is idicated by a **i** .

Figure 18. Location of acoustic detections of sperm whales (n = 12) made by sonobuoys and during hydrophone array tows around Puerto Rico and the Virgin Islands.

Figure 19. Location of 79 of 135 sonobuoys (circles) that detected Atlantic thumptrains throughout the study area between 12 February and 12 March 2001.

Figure 20. Spectrogram of a typical Atlantic "thumptrain" recorded during the February-March marine mammal survey around Puerto Rico and the Virgin Islands. The thumptrain consists of a 1-2 minute series of discrete repetitive pulses that increase in intensity and frequency, and terminate abruptly. Major sound energy is centered between 250 Hz and 650 Hz.

Figure 21. Locations where percussive "explosion-like" sounds were detected by sonobuoys and during towed hydrophone array sampling (circles). Radials from circles indicate magentic bearings to the sources of the percussive sounds.

Figure 22. A spectrogram of a percussive "explosion-like" sound recorded off the south coast of Puerto Rico on 27 February 2001. Sound energy between 100 Hz and 20 kHz (upper line) averaged approximately 26.86 dB above the ambient noise level (lower line) in the area just prior to the occurrence of the percussive sound.

Figure 23. The location along the survey trackline (thin line) where commercial ship noise was detected (circles) by sonobuoys and during towed hydrophone array sampling (bold lines).

Figure 24. A proposed track line around Puerto Rico for future acoustic and visual surveys based on the marine mammal sighting rates and acoustic detections obtained during the Febraury-March 2001 survey.

Table 1. Number of cetacean groups (n), mean group size, water depth, and sea surface temperature for sightings along the eastern Behamas, Puerto Rico, and the Virgin Islands from 12 February to 8 March 2001.

		Group Size			Water Depth (meters)			Sea Surface Temperature (^0C)		
Species	n	Mean	(SE)	Range	Mean	(SE)	Range	Mean	(SE)	Range
Megaptera novaeangliae	72	1.8	(0.15)	1 - 10	1395	(167)	34 -6948	26.2	(0.43)	25.3 - 27.7
Physeter macrocephalus	6	3.3	(0.98)	1 - 7	2531	(802)	680 - 4817	26.0	(0.31)	24.6 - 26.7
Ziphius cavirostris	1	3.0			2872			26.5		
Mesoplodon spp.	3	1.6	(0.66)	1 - 3	2515	(1145)	537 -4506	26.5	(0.21)	26.3 - 27.0
Pseudorca crassidens	1	9.0			3103			26.8		
Globicephala macrorhynchus	8	12.5	(1.88)	6 - 20	2556	(770)	806 -7041	25.9	(0.26)	24.2 - 26.8
Steno bredanensis	1	3.0			7226			26.0		
Tursiops truncatus	2	6.0	(3.0)	3 - 9	1662	(1210)	452 -2872	26.8	(0.30)	26.5 - 27.1
Stenella spp.	1	2.0			1019			26.9		
Stenella attenuata	3	12.6	(3.9)	5 - 18	3655	(1916)	663 -7226	26.1	(0.37)	25.5 - 26.8
Stenella frontalis	10	22.3	(4.6)	1 - 54	2547	(548)	452 -4499	26.7	(0.13)	26.0 - 27.4
Stenella longirostris	2	95.0	(35.0)	60 - 130	805	(36)	768 -841	26.7	(0.25)	26.5 - 27.0
Unidentified dolphin	11	11.6	(8.7)	1 - 99	1768	(655)	51 -7041	26.5	(0.13)	26.0 - 27.1

		Group Size			Water Depth (meters)			Sea Surface Temperature (^{0}C)		
Species	n	Mean	(SE)	Range	Mean	(SE)	Range	Mean	(SE)	Range
Unidentified small whale	3	1.0		1 - 1	3451	(952)	1760 -5054	26.6	(0.32)	26.2 - 27.3
Unidentified large whale	13	1.2	(0.1)	1 - 2	1451	(348)	340 -4280	26.4	(0.14)	25.7 - 27.9
Unidentified ziphiid	2	1.0		1 - 1	4091	(2579)	1512 -6670	26.6	(0.30)	26.3 - 26.9
Unidentified odontocete	3	1.3	(0.3)	1 - 2	1565	(479)	628 -2206	27.1	(0.33)	26.8 - 27.7

Table 2. Summary of cetacean sightings during NOAA Ship *Gordon Gunter* Cruise GU-01-01 in the Atlantic and Caribbean Sea, Legs 1 and 2 February 6 - March 14, 2001 (S = effort status of sighting, SST = Sea surface temperature).

Date	Species	Group	Position (N,W)	SST (^{0}C)	Depth (m)
2001 Feb 10	*Physeter macrocephalus*	1	26°03' 78°29'	24.6	672
2001 Feb 11	*Globicephala cf. macrorhynchus*	19	24°41' 77°39'	24.2	1244
2001 Feb 15	*Megaptera novaeangliae*	1	21°06' 70°14'	25.9	4141
2001 Feb 15	*Megaptera novaeangliae*	1	21°04' 70°09'	25.9	3157
2001 Feb 15	*Megaptera novaeangliae*	1	21°00' 70°01'	25.9	2086
2001 Feb 15	*Megaptera novaeangliae*	2	21°00' 70°00'	26.0	2086
2001 Feb 15	*Megaptera novaeangliae*	2	21°00' 70°01'	26.0	2086
2001 Feb 15	*Megaptera novaeangliae*	2	20°58' 69°58'	26.0	2086
2001 Feb 15	*Megaptera novaeangliae*	1	20°58' 69°57'	26.0	2086
2001 Feb 15	*Megaptera novaeangliae*	1	20°58' 69°56'	26.0	2086
2001 Feb 15	*Megaptera novaeangliae*	2	20°57' 69°56'	26.0	2086
2001 Feb 15	*Megaptera novaeangliae*	1	20°55' 69°51'	26.0	1281
	Megaptera novaeangliae	1			
2001 Feb 15	*Megaptera novaeangliae*	1	20°55' 69°50'	26.0	1281
2001 Feb 15	*Megaptera novaeangliae*	1	20°54' 69°49'	26.0	1281
2001 Feb 15	*Megaptera novaeangliae*	1	20°54' 69°49'	26.0	1281
2001 Feb 15	*Megaptera novaeangliae*	2	20°54' 69°48'	26.0	1281
2001 Feb 15	*Megaptera novaeangliae*	1	20°53' 69°48'	26.0	1281
2001 Feb 15	*Megaptera novaeangliae*	1	20°53' 69°48'	26.0	1281
2001 Feb 15	*Megaptera novaeangliae*	2	20°52' 69°45'	26.0	1601
2001 Feb 15	*Megaptera novaeangliae*	1	20°50' 69°41'	26.0	1491
2001 Feb 15	*Megaptera novaeangliae*	1	20°50' 69°40'	26.0.	1669
2001 Feb 15	Unidentified large whale	1	20°48' 69°37'	26.0	1669
2001 Feb 15	*Megaptera novaeangliae*	1	20°46' 69°34'	26.1	3020
2001 Feb 15	*Megaptera novaeangliae*	1	20°46' 69°32'	26.1	3221
2001 Feb 15	*Megaptera novaeangliae*	1	20°38' 69°18'	26.1	2626
2001 Feb 15	*Megaptera novaeangliae*	1	20°38' 69°16'	26.1	2626

Date	Species	Group	Position (N,W)	SST (^{0}C)	Depth (m)
2001 Feb 15	Unidentified large whale	1	20°32' 69°10	26.0	2582
2001 Feb 15	*Megaptera novaeangliae*	4	20°32' 69°10'	26.0	2582
2001 Feb 15	*Megaptera novaeangliae*	2	20°29' 69°08'	26.0	2167
2001 Feb 15	*Megaptera novaeangliae*	1	20°28' 69°06'	26.1	185
2001 Feb 15	*Megaptera novaeangliae*	4	20°27' 69°05'	26.1	185
2001 Feb 15	*Megaptera novaeangliae*	2	20°22' 69°00'	26.3	1610
2001 Feb 15	*Megaptera novaeangliae*	1	20°14' 68°51'	26.3	1098
2001 Feb 15	Unidentified large whale	1	20°13' 68°49'	26.3	1098
2001 Feb 15	Unidentified large whale	1	20°12' 68°49'	26.0	1034
2001 Feb 15	Unidentified large whale	1	20°11' 68°47'	26.3	1007
2001 Feb 15	Unidentified large whale	1	20°11' 68°48'	26.3	1007
2001 Feb 15	*Megaptera novaeangliae*	1	20°11' 68°48'	26.3	1007
2001 Feb 16	Unidentified large whale	2	18°21' 67°44'	26.6	337
2001 Feb 16	*Megaptera novaeangliae*	1	18°18' 67°41'	26.5	2776
2001 Feb 16	Unidentified large whale	2	18°14' 67°37'	26.5	377
2001 Feb 16	*Megaptera novaeangliae*	1	18°04' 67°28'	26.6	293
2001 Feb 16	*Stenella attenuata*	5	18°01' 67°25'	26.8	655
2001 Feb 17	Unidentified dolphin	2	18°29' 65°09'	26.0	51
2001 Feb 17	*Megaptera novaeangliae*	2	18°31' 65°08'	26.0	55
2001 Feb 17	*Megaptera novaeangliae*	2	18°33' 65°05'	26.1	68
2001 Feb 17	Unidentified dolphin	1	18°45' 64°47'	26.0	68
2001 Feb 17	*Physeter macrocephalus*	7	18°59' 64°48'	26.5	3294
2001 Feb 17	*Tursiops truncatus*	3	18°58' 65°07'	26.5	2837
2001 Feb 18	*Globicephala cf. macrorhynchus*	7	19°01' 65°18'	26.1	3660
2001 Feb 18	*Stenella attenuata*	18	19°14' 65°27'	26.0	7137
	Steno bredanensis	3			
2001 Feb 18	Unidentified Ziphiidae	1	19°15' 65°31'	26.3	6588
2001 Feb 22	*Megaptera novaeangliae*	2	20°34' 64°43'	26.1	5033

Date		Species	Group	Position (N,W)		SST (^{0}C)	Depth (m)
2001	Feb 23	*Physeter macrocephalus*	1	20°25'	64°20'	26.1	4758
2001	Feb 23	Unidentified dolphin	3	19°46'	65°02'	26.0	6954
		Globicephala cf. macrorhynchus	10				
2001	Feb 23	*Megaptera novaeangliae*	2	19°43'	65°09'	26.2	6863
2001	Feb 24	*Stenella frontalis*	12	17°22'	66°07'	26.6	4443
2001	Feb 26	*Mesoplodon* sp.	1	16°04'	65°46'	26.4	4451
2001	Feb 27	*Stenella frontalis*	25	16°19'	66°11'	26.4	4357
2001	Feb 27	*Stenella frontalis*	22	16°45'	66°19'	26.6	4379
2001	Feb 27	*Physeter macrocephalus*	5	17°03'	66°24'	26.7	4575
2001	Feb 27	Unidentified dolphin	2	17°05'	66°21'	26.6	4548
2001	Feb 28	*Stenella frontalis*	37	17°33'	66°33'	26.5	3338
2001	Feb 28	Unidentified Ziphiidae	1	17°44'	66°36'	26.9	1493
2001	Feb 28	Unidentified dolphin	1	17°46'	66°37'	26.9	1493
2001	Feb 28	*Tursiops truncatus*	9	17°51'	66°39'	27.1	447
		Stenella frontalis	1				
2001	Feb 28	*Stenella frontalis*	20	7°52'	66°43'	26.9	1007
		Stenella attenuata	2				
2001	Feb 28	*Stenella frontalis*	15	17°49'	66°48'	27.2	1135
2001	Feb 28	Unidentified small whale	1	17°45'	66°52'	27.3	1739
2001	Feb 28	Unidentified dolphin	1	17°43'	66°53'	26.0	2233
2001	Feb 28	*Stenella attenuata*	15	17°38'	67°00'	25.5	3038
2001	Mar 01	*Globicephala cf. macrorhynchus*	6	17°33'	67°06'	26.0	3825
2001	Mar 01	Unidentified large whale	1	17°26'	67°07'	25.7	3488
2001	Mar 01	*Stenella frontalis*	12	17°20'	67°15'	26.4	3967
2001	Mar 01	*Pseudorca crassidens*	9	17°30'	67°43'	26.8	3065
2001	Mar 01	*Mesoplodon* sp.	1	17°43'	67°28'	27.0	2471
2001	Mar 02	*Megaptera novaeangliae*	3	17°57'	67°25'	26.5	717
2001	Mar 02	*Stenella longirostris*	130	17°57'	67°25'	26.5	831
2001	Mar 02	*Megaptera novaeangliae*	3	18°03'	67°26'	26.4	210
2001	Mar 02	*Megaptera novaeangliae*	1	18°05'	67°26'	26.4	179

Date		Species	Group	Position (N,W)		SST (^{0}C)	Depth (m)
2001	Mar 02	Unidentified large whale	1	18°03'	67°42'	26.7	699
2001	Mar 02	Unidentified large whale	1	18°04'	67°45'	27.9	578
2001	Mar 02	*Stenella frontalis*	25	18°04'	67°45'	26.0	699
2001	Mar 02	*Megaptera novaeangliae*	2	18°07'	67°48'	26.7	518
2001	Mar 02	*Megaptera novaeangliae*	1	18°10'	67°53'	26.8	273
2001	Mar 02	Unidentified large whale	1	18°07'	68°00'	26.7	536
2001	Mar 02	*Physeter macrocephalus*	4	18°06'	68°01'	26.6	798
2001	Mar 02	*Physeter macrocephalus*	2	18°01'	67°59'	26.0	904 -
2001	Mar 02	Unidentified large whale	2	17°56'	68°05'	26.6	4227
2001	Mar 03	*Megaptera novaeangliae*	4	18°30'	68°14'	26.0	110
2001	Mar 03	*Megaptera novaeangliae*	1	18°32'	68°11'	26.5	178
2001	Mar 03	*Megaptera novaeangliae*	3	18°32'	68°11'	26.4	178
2001	Mar 03	*Megaptera novaeangliae*	2	18°32'	68°03'	26.6	86
2001	Mar 03	*Megaptera novaeangliae*	10	18°32'	68°08'	26.6	59
2001	Mar 04	*Globicephala cf. macrorhynchus*	20	18°21'	67°35'	26.0	796
2001	Mar 04	Unidentified dolphin	4	18°20'	67°27'	26.7	844
2001	Mar 04	Unidentified dolphin	9	18°20'	67°23'	27.1	604
2001	Mar 04	*Megaptera novaeangliae*	3	18°23'	67°17'	26.6	254
2001	Mar 04	*Megaptera novaeangliae*	3	18°32'	67°10'	26.6	59
2001	Mar 04	*Megaptera novaeangliae*	1	18°32'	67°07'	26.4	55
2001	Mar 04	*Megaptera novaeangliae*	1	18°35'	67°03'	26.5	361
2001	Mar 04	*Megaptera novaeangliae*	1	18°39'	67°09'	26.3	1098
2001	Mar 05	Unidentified small whale	1	18°49'	67°23'	26.2	4992
2001	Mar 05	*Ziphius cavirostris*	3	18°52'	66°56'	26.5	2837
2001	Mar 05	*Megaptera novaeangliae*	2	18°47'	66°53'	26.0	2681
2001	Mar 05	*Globicephala cf. macrorhynchus*	15	18°36'	66°43'	26.0	1336
2001	Mar 06	*Globicephala cf. macrorhynchus*	14	18°38'	66°42'	26.3	1546
2001	Mar 06	Unidentified odontocete	1	18°46'	66°18'	26.8	2180
2001	Mar 06	Unidentified odontocete	2	18°44'	66°16'	27.7	1837
2001	Mar 06	*Megaptera novaeangliae*	4	18°42'	66°11'	27.7	1636

Date	Species	Group	Position (N,W)	SST (^{0}C)	Depth (m)
2001 Mar 06	*Stenella frontalis*	54	18°39' 66°06'	27.4	1385
2001 Mar 06	Unidentified dolphin	4	18°39' 66°01'	27.1	1290
2001 Mar 06	*Megaptera novaeangliae*	2	18°37' 65°58'	27.1	1096
2001 Mar 06	*Stenella longirostris*	60	18°33' 65°48'	27.0	759
2001 Mar 06	*Megaptera novaeangliae*	2	18°32' 65°48'	27.0	728
2001 Mar 06	Unidentified odontocete	1	18°31' 65°47'	27.0	620
2001 Mar 07	*Megaptera novaeangliae*	2	18°33' 64°44'	26.0	46
2001 Mar 07	*Megaptera novaeangliae*	2	18°38' 64°38'	26.3	37
2001 Mar 07	*Megaptera novaeangliae*	2	18°40' 64°38'	25.3	37
2001 Mar 07	*Megaptera novaeangliae*	2	18°42' 64°38'	26.3	34
2001 Mar 07	*Megaptera novaeangliae*	1	18°49' 64°37'	26.3	732
2001 Mar 07	*Megaptera novaeangliae*	1	18°47' 64°17'	26.6	487
2001 Mar 07	*Megaptera novaeangliae*	1	18°45' 64°14'	26.6	408
2001 Mar 07	Unidentified dolphin	2	18°44' 64°07'	26.5	366
2001 Mar 07	*Megaptera novaeangliae*	1	18°43' 64°03'	26.5	739
2001 Mar 07	Unidentified small whale	1	18°46' 63°53'	26.5	3495
2001 Mar 07	*Megaptera novaeangliae*	1	18°46' 63°42'	26.4	6101
2001 Mar 08	*Megaptera novaeangliae*	5	18°23' 64°06'	26.3	441
2001 Mar 08	*Mesoplodon* sp.	3	18°20' 64°11'	26.3	531
2001 Mar 08	*Megaptera novaeangliae*	1	18°11' 64°23'	26.6	1373
2001 Mar 08	Unidentified dolphin	1	18°09' 64°25'	26.7	763
2001 Mar 08	*Megaptera novaeangliae*	1	17°50' 64°31'	26.8	822
2001 Mar 08	*Megaptera novaeangliae*	2	17°50' 64°29'	26.8	818
2001 Mar 08	*Megaptera novaeangliae*	3	17°47' 64°25'	26.9	897
2001 Mar 08	*Megaptera novaeangliae*	2	17°45' 64°28'	26.8	1135
2001 Mar 08	*Globicephala cf. macrorhynchus*	9	17°40' 64°33'	26.8	840

Table 3. Acoustic data obtained from sonobuoys and during hydrophone array tows from February 12 to March 8, 2001 along the eastern side of the Bahamas, and around Puerto Rico and the Virgin Islands.

Buoy No.	Date	Time (UTC)	DAT Tape	Depth (M)	Depth (M)	LAT (DD)	LONG (DD)	Bearing No. 1	Bearing No. 2	Bearin g No. 3	Thump . Tr.	MM Species	Anthro. Noise
SB-07	2/13/01	1439	01-06	303	4800	25.0173	-75.3982				1		
SB-08	2/13/01	1833	01-07	303	4600	24.6873	-74.9740				1		
SB-09	2/13/01	2213	01-08	121	5151	24.3829	-74.5812				1	10	
SB-10	2/14/01	857	01-09	303	4400	23.2450	-73.5380	267			1	9	
SB-11	2/14/01	943	01-09	303	4400	23.1569	-73.4674				1	9	
SB-12	2/14/01	1110	01-10	27	3000	22.9881	-73.3287				1	9	
SB-13	2/14/01	1328	01-10	121	3800	22.7272	-73.1126	127	134	145	1	9	
SB-14	2/14/01	1645	01-11	27	2900	22.4715	-72.7037	205	198		1	9	
SB-18	2/14/01	1953	01-12	27	4000	22.2485	-72.2868				1	9	1
SB-19	2/14/01	2149	01-13	27	3220	22.1124	-72.0303	190	105	58	1	9, 60	
SB-22	2/14/01	29	01-13	27	2500	21.9240	-71.6765				0	9	1
SB-25	2/14/01	359	01-14	27	1400	21.7095	-71.1915	190	176	259	1	9	
SB-26	2/15/01	929	01-14	27	4000	21.2627	-70.4859	204	170	240	0	9	
SB-27	2/15/01	1125	01-15	27	4000	21.1092	-70.2279	170	228	300	1	9	
SB-30	2/15/01	1618	01-15	27	3475	20.7705	-69.5409	10	280	310	1	9	
SB-31	2/15/01	1953	01-16	27	1500	20.4456	-69.0815	100	235	195	1	9	
SB-32	2/15/01	138	01-17	27	4200	19.8333	-68.4367	340	272	20	1	9	
SB-33	2/16/01	448	01-17	27	6500	19.3854	-68.2217	80	160	225	1	9	1
SB-34	2/16/01	713	01-18	27	1870	19.0421	-68.0549	200	67		1	9	1
SB-35	2/16/01	1144	01-18	27	232	18.4154	-67.7582	280	225	80	0	9	
SB-37	2/16/01	1522	01-20	27	239	18.2252	-67.6147				0		
SB-39	2/16/01	1709	01-21	27	100	18.0250	-67.4330	8	14		1(?)	9, 60	
SB-40	2/16/01	1751	01-21	27	243	17.9436	-67.3634				0		
SB-41	2/17/01	753	01-22	27	450	18.0932	-65.2937				0		
SB-43	2/17/01	915	01-22		34	18.1524	-65.2191				0		
SB-44	2/17/01	1100	01-23	27	80	18.3916	-65.0887	40	302	330	1	9	
SB-46B	2/17/01	1401	01-24		300	18.6998	-64.8681	31			0	9	
SB-47	2/17/01	1648	01-25	121	2900	18.9719	-64.7969	360			1	9, 10, 60	
SB-48	2/17/01	1909	01-25	121	3630	19.2136	-65.0182	343	280		1	9, 60	1, 4
SB-49	2/17/01	1958	01-26	27	2835	19.0637	-65.0850	173	125	200	1	9, 60	

SB-50	2/17/01	129	01-27	27	84	18.5276	-65.3209	165	205	244		9	1
SB-51	2/18/01	1008	01-28	27	2650	18.8995	-65.2633	155	238	195	1	9	
SB-52	2/18/01	1146	01-28	27	2000	19.0463	-65.3432				1	9, 10, 26	
SB-54	2/18/01	1438	01-29	27	6584	19.2420	-65.5588				1	9	1
SB-55	2/18/01	1524	01-29	121	3650	19.1397	-65.5950	350			1	9	
SB-56	2/18/01	1745	01-30	27	2000	18.7706	-65.7470				1		
SB-57	2/18/01	106	01-30	27	5500	19.1878	-66.0708	145	36		1	9, 60	
SB-57B	2/18/01	215	01-31	27	5500	19.1878	-66.0708	10	350		0	9	1
SB-58	2/22/01	1319	01-33	27	5000	20.9835	-65.6354	330	20	270	1	9	
SB-59	2/22/01	1415	01-33	27	5000	20.9205	-65.4938	323			0	9	3
SB-60	2/22/01	1502	01-33/3	27	5000	20.8725	-65.3785	310	22	260	0	9, 10	
SB-61	2/22/01	1630	01-34	27	5000	20.7771	-65.1606	330	273	63	1	9	
SB-62	2/22/01	1827	01-35	27	5000	20.6437	-64.8656				1	9	
SB-63	2/22/01	2121	01-35	27	5000	20.4713	-64.5086	270	90	345	1	9	
SB-64	2/23/01	1128	01-37	27	5500	20.4167	-64.3167				0	9, 10	
SB-65	2/23/01	1240	01-37/3	27	5500	20.3003	-64.0795	20	50	150	1	9, 60	
SB-66	2/23/01	1517	01-38/3	27	5500	20.0932	-64.4917	120	148	280	1	9	3
SB-67	2/23/01	1730	01-39	27	5500	19.9068	-64.8545	65	310		0	9	3
SB-73	2/23/01	2010	01-40		2900	19.7429	-65.1358	345	20	194	0	9	
SB-74	2/23/01	2228	01-41	27	6590	19.5840	-65.4727	226	22	192	0	9	
SB-75	2/24/01	1048	01-42	27	3800	17.8260	-65.4310	184	155	192	0	9	
SB-76	2/24/01	1249	01-42	27	1200	17.6710	-65.7623	145	191		0	9, 10	
SB-77	2/24/01	1424	01-43	121	2900	17.5635	-66.0260				1	9	
SB-78	2/24/01	1512	01-44/4		3657	17.4963	-66.1535	117	121	139	1	9	
SB-79	2/24/01	1756	01-45	27	5000	17.3148	-65.9815	94	138		1	9	
SB-80	2/24/01	1944	01-45/4	27	4750	17.1568	-65.7057				0	9	
SB-81	2/24/01	2134	01-46	27	4575	17.0086	-65.4349	301	17		1	9	5
SB-82	2/25/01	1104	01-47	27	1600	17.6130	-65.2113	282	24		0	9	5
SB-83	2/25/01	1229	01-47/4	27	1000	17.7346	-65.0341				0	9	
SB-84	2/25/01	1327	01-48	121	2500	17.8157	-64.9116				0		
SB-85	2/25/01	1344	01-48	27	3300	17.8392	-64.8764				0		
SB-86	2/25/01	1450	01-48	27	4300	17.9283	-64.9712				0	10	5
SB-87	2/25/01	1528	01-49	27	4200	17.9814	-65.0737	44	270		1	9	5
SB-88	2/25/01	1852	01-50	27	22	18.1672	-65.2732				0		
SB-89	2/25/01	218	01-50	27	2000	17.5340	-65.2888	290	93	140	1	9	3, 5
SB-91	2/25/01	449	01-52	27	4400	17.3179	-65.3101				?	?	

SB-91B	2/25/01	1047	01-53	27	4400	17.0000	-65.0000				?	?	
SB-92	2/26/01	1200	01-53/5	27	4900	16.9765	-65.3154	165			0	9	5
SB-93	2/26/01	1439	01-54	27	5400	16.5800	-65.5214	80			1	9	3, 5
SB-94	2/26/01	1741	01-55	27	5500	16.1249	-65.7588				1	9	3, 5
SB-95	2/26/01	1807	01-55	121	6000	16.0682	-65.7905				1	9	2, 3
SB-96	2/26/01	2103	01-56	27	5500	15.6612	-65.9960	55	26	195	1	9	2
SB-97	2/27/01	1256	01-57	27	5400	16.1382	-66.1447	70	50		1	9	
SB-99	2/27/01	1735	01-58	27	5000	16.8028	-66.3195	330			0	9	2
SB-100	2/27/01	2043	01-59/6	27	5000	17.1006	-66.3807	325	90		0	9, 10	2
SB-101	2/28/01	1115	01-61	27	5000	17.0042	-66.2530	65	85	335	0	9	5
SB-102	2/28/01	1331	01-62	27	5000	17.2771	-66.4778	95			0	9, 10, 36	2, 3
SB-103	2/28/01	1612	01-62	27	3336	17.6317	-66.5830	100	291		0	9	1
SB-104	2/28/01	2123	01-63	27	2210	17.7250	-66.9067	110			1	9	
SB-105	3/1/01	1125	01-64	27	3200	17.5575	-67.1158	70	330		1	9	2
SB-106	3/1/01	1249	01-64	121	3300	17.3853	-67.1220				0	9	
SB-107	3/1/01	1304	01-64/6	27	5000	17.3453	-67.1233	350	336	110	1	9	1
SB-108	3/1/01	1550	01-66	27	3500	17.3981	-67.4799	350	345	5	1	9	2
SB-109	3/1/01	1730	01-67	121	3000	17.0000	-68.0000				1	9	1
SB-110	3/1/01	1740	01-67	27	3000	17.4833	-67.7602	10	355	5	1	9	
SB-111	3/1/01	1905	01-67/6		2700	18.0000	-68.0000	4			1	9, 10, 36	1
SB-112	3/1/01	2055	01-69	27	2700	17.6428	-67.5875	355	10		0	9	1
SB-113	3/2/01	1106	01-70	27	1636	17.8382	-67.3233	355	340	320	1	9	
SB-114	3/2/01	1206	01-70/7	27	825	17.9717	-67.4346	331	136	345	0	9	1, 3
SB-115	3/2/01	1437	01-71/7	27	311	18.1853	-67.4614	331	325	342	0	9	3
SB-116	3/2/01	1623	01-72/7	27	400	18.0651	-67.7275	320	297	120	1	9	3
SB-117	3/2/01	1902	01-73/7	27	70	18.1782	-67.9567	120	335	280	0	9	
SB-118	3/2/01	2028	01-74/7	27	1100	17.9758	-67.9820	79	360	355	0	9, 10	
SB-119	3/3/01	1015	01-75	27	790	18.0972	-68.0563	14	75	345	0	9	
SB-120	3/3/01	1318	01-76	27	2300	17.8544	-68.3570	60	90	20	1	9	
SB-121	3/3/01	1545	01-76/7	27	750	18.2157	-68.5002	90	100	125	1	9	
SB-123	3/3/01	1835	01-77	27	60	18.5469	-68.1896	160	325	275	1	9	
SB-127	3/3/01	2204	01-80/8	27	460	18.4789	-67.7338	312	280	360	0	9	
SB-129	3/4/01	845	01-82	27	350	18.4363	-67.8734	307	111	280	1	9	
SB-130	3/4/01	1255	01-83	27	235	18.3731	-67.7416	355	115		1	9	
SB-131	3/4/01	2202	01-84/8	27	1100	18.6752	-67.1749	215	20	120	0	9	
SB-135	4/5/01	1222	01-86	27	5050	18.8699	-67.4661	265	120	257	1	9	

SB-136	3/5/01	1405	01-87	27	3000	19.0032	-67.6012	150	95	235	1	9	1
SB-137	3/5/01	1550	01-88	27	4345	18.9973	-67.3100				0	9	1
SB-138	3/5/01	1744	01-88	27	4056	19.0000	-67.0002	330	170	257	1	9	
SB-140	3/5/01	1949	01-89	27	1900	18.7137	-66.8556	300	190	296	0	9	
SB-141	3/6/01	1108	01-89/9	27	1700	18.6625	-66.6964	255	80	297	1	9	
SB-142	3/6/01	1325	01-90	27	4500	18.9870	-66.5070	70	250	120	1	9	
SB-143	3/6/01	1643	01-91	27	1240	18.6789	-67.1511	266	122	165	1	9	3
SB-144	3/7/01	1047	01-92	27	55	18.4952	-64.8620	225	195	204	0	9	
SB-145	3/7/01	1209	01-92/9	27	50	18.6197	-64.6541	20	5	193	1	9	1
SB-146	3/7/01	1348	01-93	27	1209	18.8659	-64.6077	105	300	38	1	9	
SB-147	3/7/01	1504	01-94	27	1692	18.8254	-64.4350				1	9	1
SB-148	3/7/01	1524	01-94/9	27	500	18.7903	-64.2870	120	47	103	1	9	1
SB-149	3/7/01	1600	01-94/9	27	500	18.7650	-64.2617	150	110	160	1	9	
SB-150	3/7/01	1659	01-95/9	27	750	18.7445	-64.0570	240	343	302	1	9	
SB-151	3/7/01	2107	01-97/9	303	6000	18.7698	-63.6692	45	340	212	1	9, 10	3
SB-152	3/7/01	24	01-98	27	6100	18.7561	-63.7684				0	9	3
SB-153	3/7/01	24	01-99	303	1600	19.0000	-64.0000				1	9	3
SB-155	3/8/01	1059	01-100	27	1600	18.5453	-64.1140	255	213	225	1	9	
SB-156	3/8/01	1258	01-101	27	50	18.3346	-64.1939	308	284	315	1	9	1
SB-157	3/8/01	1324	01-101	27	1300	18.3140	-64.2598	45	305	56	1	9	
SB-158	3/8/01	1615	01-102	27	2788	18.0195	-64.6330	56	297	31	1	9	
SB-159	3/8/01	1705	01-102		2500	17.8936	-64.6632	50	65	265	1	9	
SB-160	3/8/01	1915	01-103	27	1100	17.8299	-64.3845	3	55	215	1	9	
SB-161	3/8/01	2051	01-103		800	17.6436	-64.5778				1	9, 10, 26	
SB-162	3/8/01	2145	01-104	27	800	17.6349	-64.6315	114	134	160	0	9	
SB-163	3/11/01	20	01-105	27	6000	19.4704	-67.9657				1	9	1
SB-164	3/11/01	331	01-106	27	3600	19.7522	-68.4936	341	127	50	1	9	3
SB-166	3/11/01	738	01-108	27	4500	20.0559	-69.1917				0	9	
SB-167	3/11/01	959	01-109	27	28	20.2262	-69.6034				0	9	
SB-169	3/11/01	1452	01-111	27	2000	20.3392	-70.5500				0	9	
SB-170	3/11/01	1714	01-111	27	3689	20.4096	-71.0101				1	9	3
SB-171	3/11/01	1741	01-111	27	3700	20.4240	-71.1082	176	61	66	1	2	3
SB-172	3/11/01	1943	01-112	27	3000	20.4871	-71.5172	340	175	193	1	2	1, 3
SB-173	3/12/01	0	01-113	27	4180	20.6122	-72.3159				0	2	
SB-174	3/12/01	236	01-114	27	1500	20.6954	-72.8292				0		
SB-175	3/13/01	541	none	27	500	20.7800	-72.4120						

SB-176	3/13/01	1000	01-115	27	2800	21.0000	-74.2230	78	89		1	2	1
TA-01	2/22/01	2354	A01		5000	20.3890	-64.3350	90	150		0	7	1, 2
TA-02	2/23/01	2252	A02		6590	19.5419	-65.4604				0	2(?)	
TA-03	2/24/01	2340	A03		3000	17.1028	-65.4013				0		
TA-04	2/25/01	137	A04		2000	17.5680	-65.2847				0		2
TA-05	2/26/01	1	A05		5000	15.8703	-66.0619				0		2
TA-06	2/27/01	1935	A06		5000	17.0933	-66.4217				0		2
TA-07	2/27/01	2154	A07		5000	17.0552	-66.3380				0	1(?)	
TA-08	2/28/01	910	A08		5000	17.0000	-66.0000				0	1(?)	
TA-08B	2/28/01	1733	A08		20	17.8815	-66.6232	90	180	10R	1	4	1
TA-09	2/28/01	1833	A09		1000	17.9173	-66.6701				1	2,4	1
TA-10	2/28/01	2058	A10		2000	17.7472	-66.8750				1	2	2
TA-11	3/1/01	137	A11		2700	17.5911	-67.6332	102	139	167	0	2	2
TA-12	3/2/01	1702	A12		400	18.0888	-67.7670	135	168	29	0	1,2,4,5	
TA-13	3/3/01	939	A13		2300	18.0401	-68.0050				0	2	
TA-14	3/4/01	1607	A14		150	18.3375	-67.3633				0	2,4	
TA-15	3/4/01	1818	A15		75	18.4980	-67.2095				1	2	
TA-16	3/5/01	2121	A16		400	18.5523	-66.7545	28			0	2,3	
TA-17	3/6/01	1555	A17		2000	18.7277	-66.2570	94/266	128/232	16/344	0	2,4	
TA-18	3/6/01	2113	A17		800	18.5545	-65.8313				0	1(?),2,4	
TA-19	3/7/01	52	A18		5500	18.7698	-63.6692	105/255	10/350		0	5	
TA-20	3/8/01	2050	A18		886	18.7416	-63.8015	271	36/324		0	?	3

Sound Source / Species Codes:

1 = Ship noise
2 = Percussive / Explosions
3 = Light bulb implosions
4. = Active Sonar
5. = Other

7 = Balaenoptera edei
8 = Balaenoptera acutorostrata
9 = Megaptera novaeangliae
10 = Physeter macrocephalus
11 = Kogia sp.

17 = Mesoplodon sp.
23 = Feresa attenuata
24 = P. crassidens
26 = G. macrorhynchus
29 = Steno bredanensis

35 = D. delphus
36 = T. truncatus
37 = G. griseus
38 = Stenella sp.
39 = S. attenuata

40 = S. frontalis
41 = S. coeruleoalba
42 = S. longirostris
43 = S. clymene
45 = Unid. Dolphin

46 = Unid. Small whale
47 = Unid. Large whale

48 = Ziphius sp.
54 = Unid. odontocete

60 = Bloops

Table 4. Percussive "explosion-like" sounds detected on sonobuoys and during hydrophone array tows from February 12 to March 8, 2001 around Puerto Rico and the Virgin Islands.

	Date	Time/UTC	DAT / Array Tape	Lat (DD)	Long (DD)	Bearing 1	Bearing 2	Bearing 3	Bearing 4	Bearing 5
Sonobuoy No.										
SB-95	02/26/2001	1807	01-55	16.0682	65.7905	183	177	180	185	182
SB-96	02/26/2001	2103	01-56	15.6612	65.9961	158	189			
SB-99	02/27/2001	1735	01-58	16.8028	66.3195	47	40	43	32	29
SB-100	02/27/2001	2043	01-59	17.1006	66.3807	112	56	65		
SB-102	02/28/2001	1331	01-62	17.2771	66.4778	78	80	82	83	86
SB-105	03/01/2001	1125	01-64	17.5575	67.1158					
SB-108	03/01/2001	1550	01-66	17.3981	67.4799	75	76	70	66	72
Array Tow No.										
TA-01	02/22/2001	2354	A-01	20.3891	64.3351					
TA-04	02/25/2001	0137	A-04	17.5681	65.2847					
TA-05	02/26/2001	0000	A-05	15.8703	66.0619					
TA-06	02/27/2001	1935	A-06	17.0933	66.4217					
TA-10	02/28/2001	2058	A-10	17.7472	66.8751					
TA-11	03/01/2001	0137	A-11	17.5911	67.6332					

Figure 1. NOAA ship *Gordon Gunter.*

Figure 2. Survey trackline from Abaco Island, Bahamas south to Puerto Rico and the Virgin Islands (solid black line).

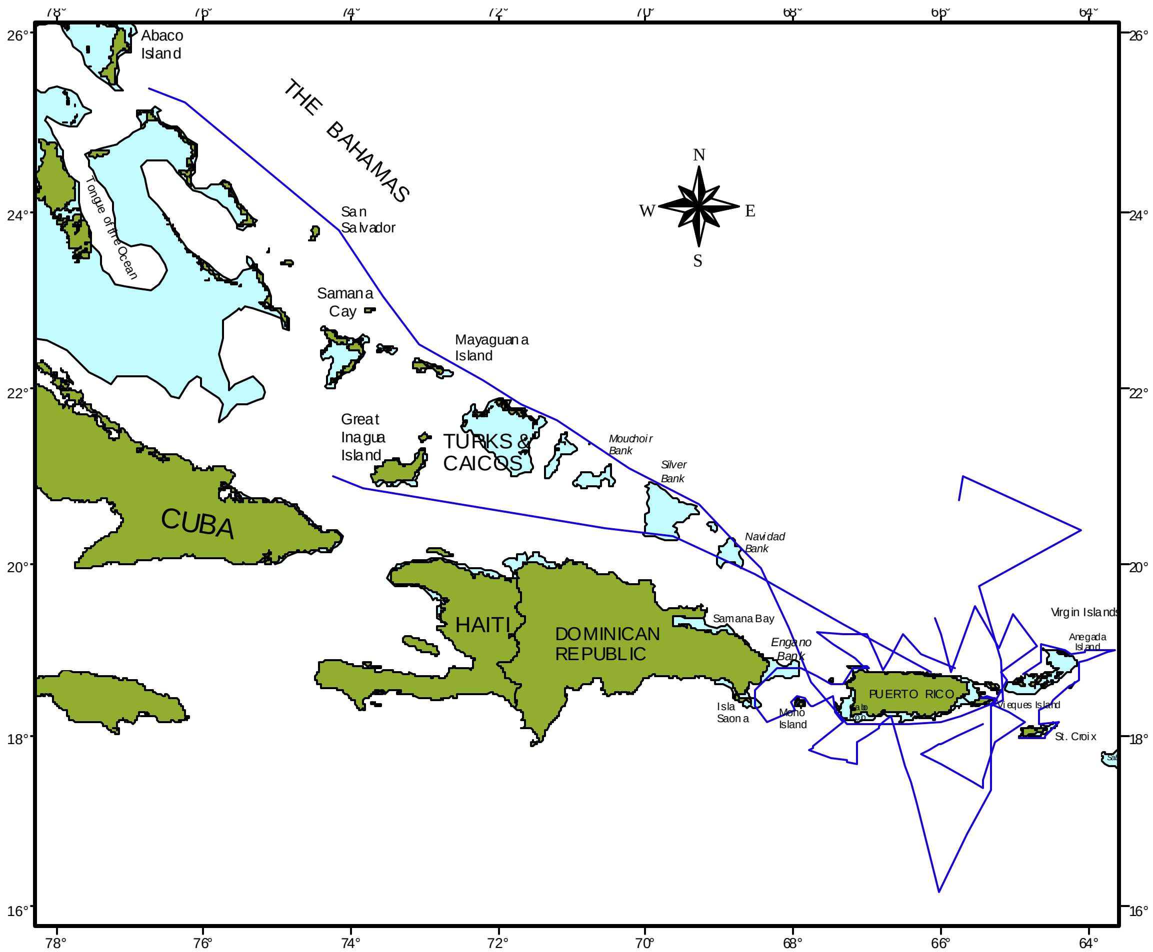


Figure 3. Marine mammal observers at the “big-eye” 25x binoculars.

Figure 4. Illustration of a typical DIFAR sonobuoy utilized in the survey.

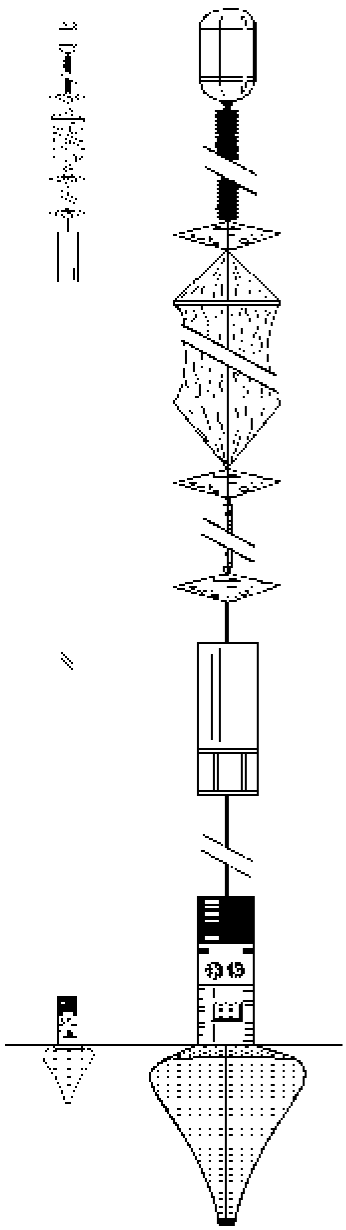


Figure 5. A 3-D plot showing signal intensity as a function of frequency and bearing angle from 0^0 to 360^0, showing a single calling whale at a bearing of 101^0 magnetic from the sonobuoy's location and major acoustic energy between 450 Hz to 650 Hz.

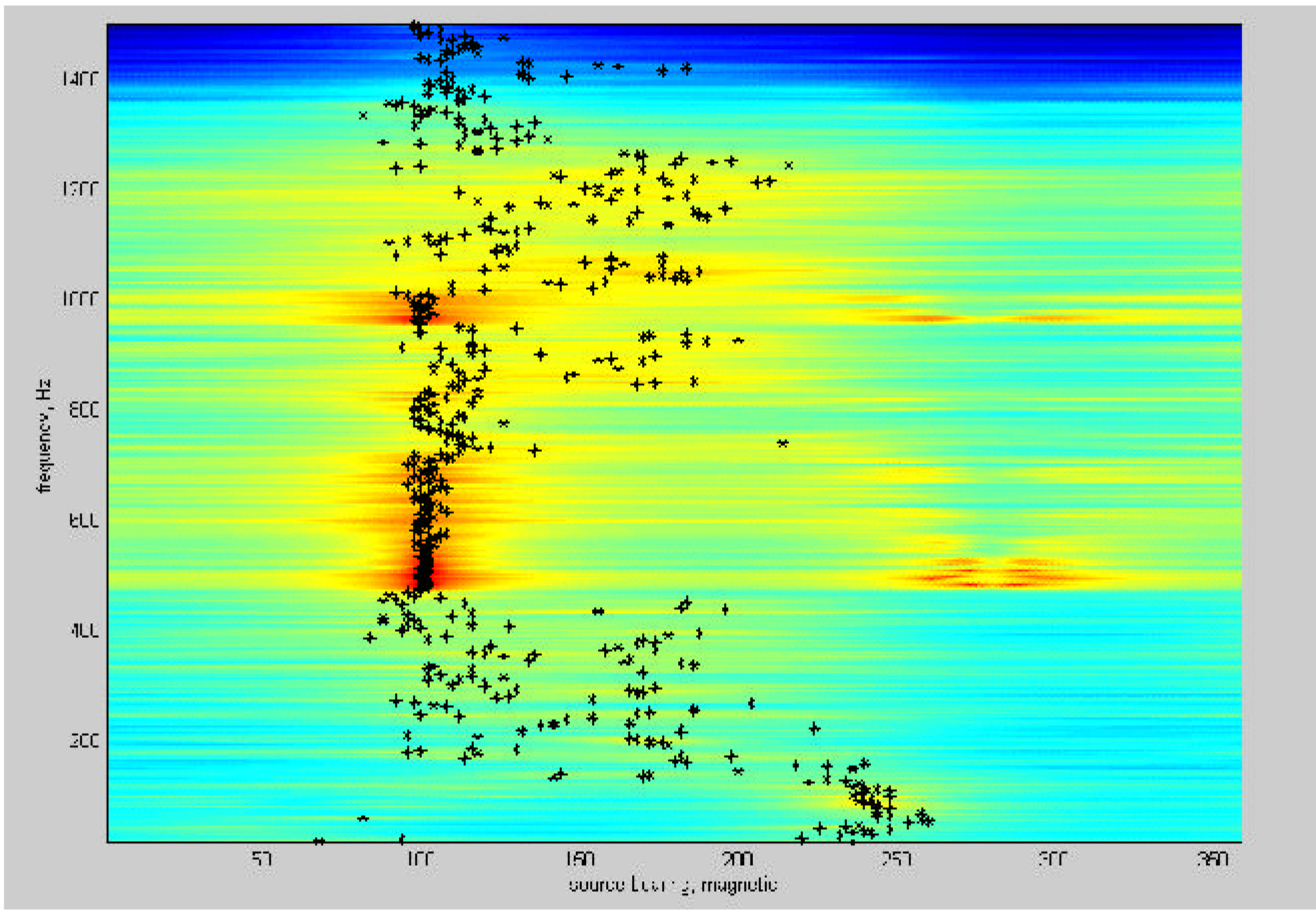


Figure 6. Illustrations of the towed 5-element hydrophone array and signal monitoring and tracking laboratory utilized in the survey.

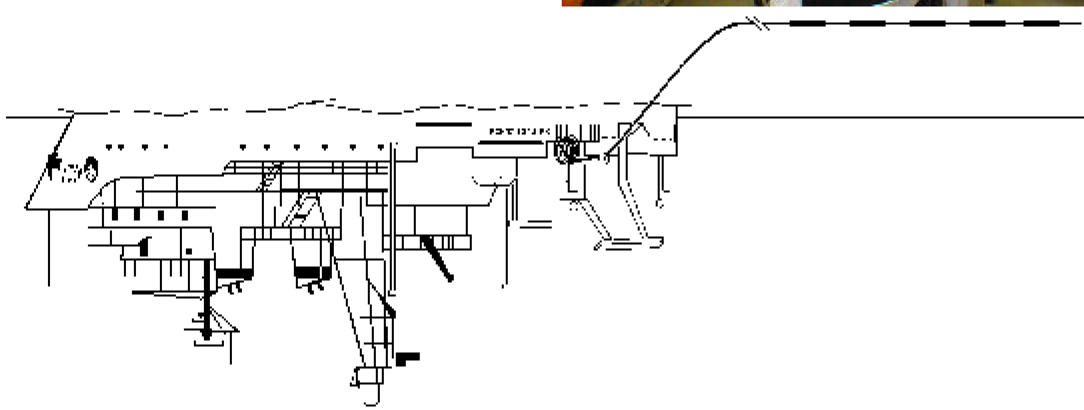
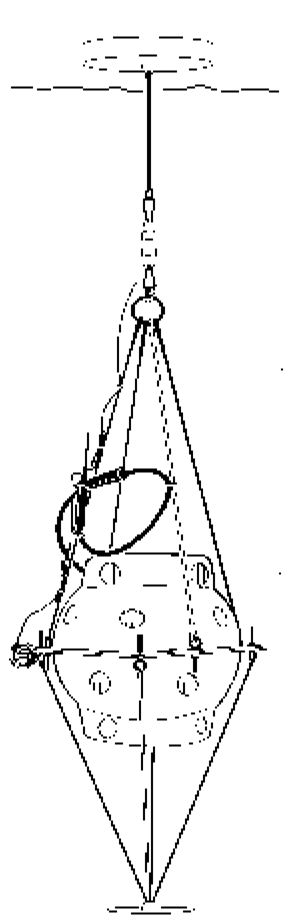


Figure 7. An autonomous bottom acoustic recording device or “pop-up” buoy developed by C. Clark of Cornell University and deployment operations for one device placed in the Mona Channel.



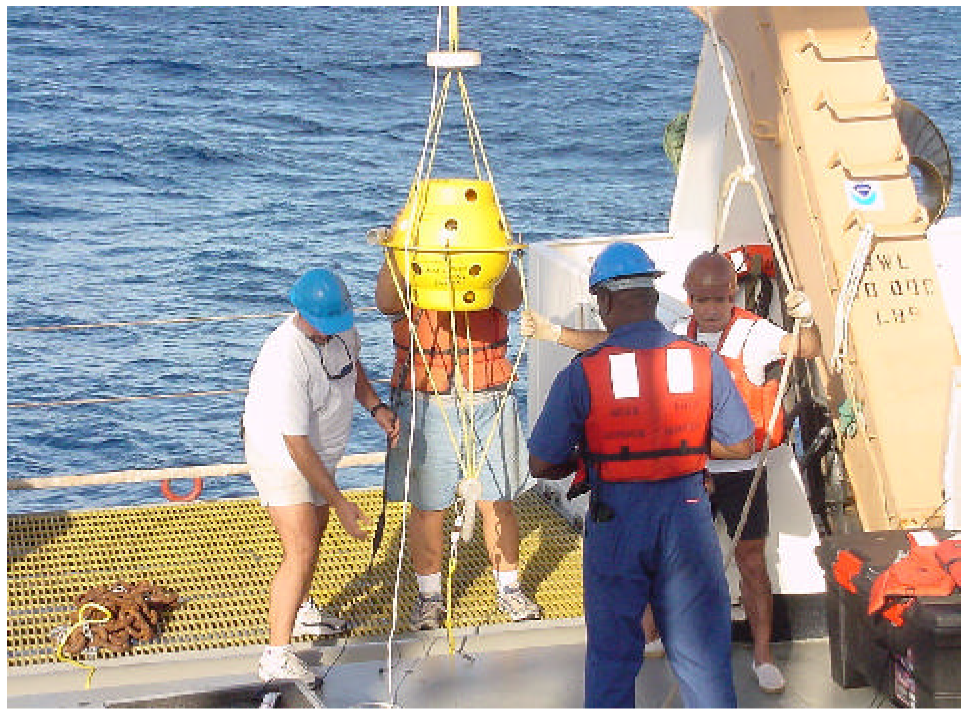


Figure 8. An example of the recordings from one autonomous bottom acoustic recording device or "pop-up" buoy developed by C. Clark of Cornell University. The spectrogram shows sound energy (spectrum level) versus time of day (GMT) recorded on February 19, 2001 in Mono Channel. The sound energy peaks represent close approaches by passing vessels. Marine mammal sounds, mostly humpback whale calls are also embedded in these data.

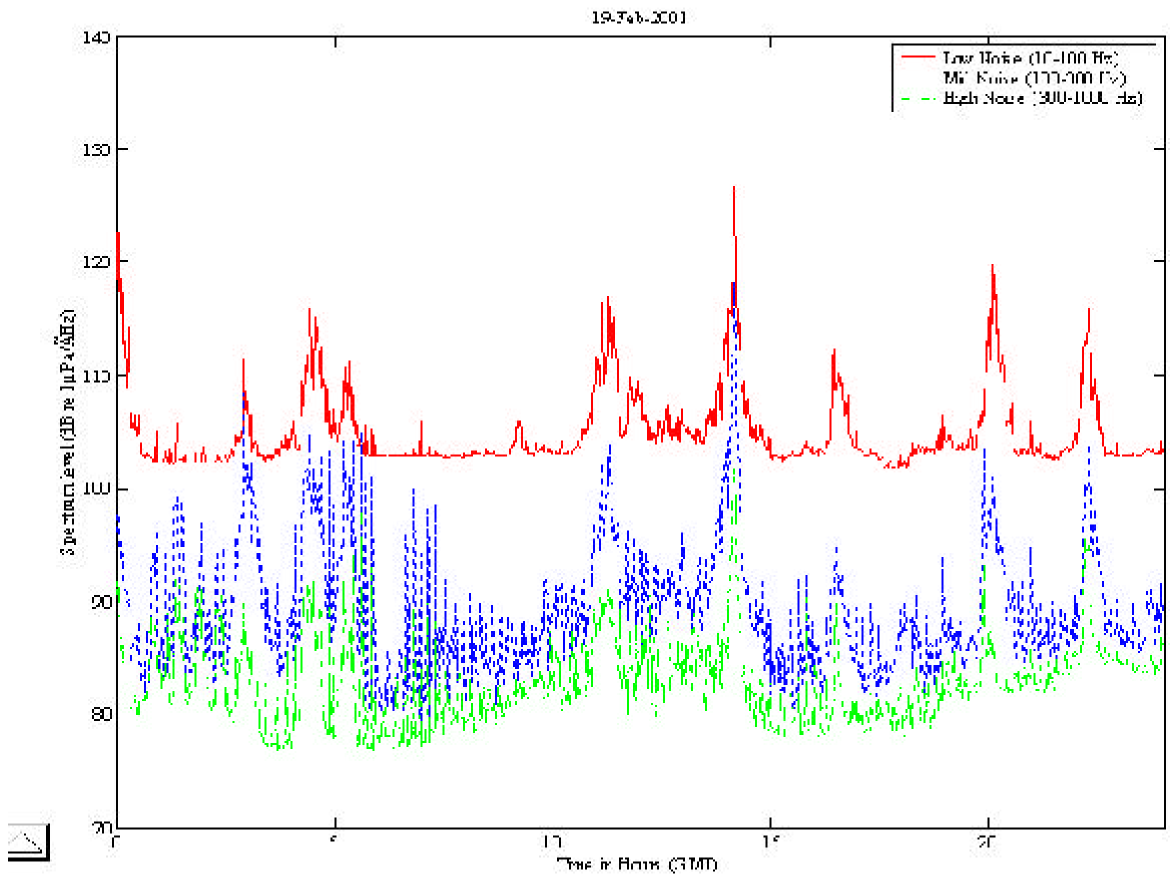


Figure 9. Sightings of humpback whales (triangles, n=72) during visual surveys (black line) along the eastern and southern sides of the Bahamas south to Puerto Rico and the Virgin Islands.

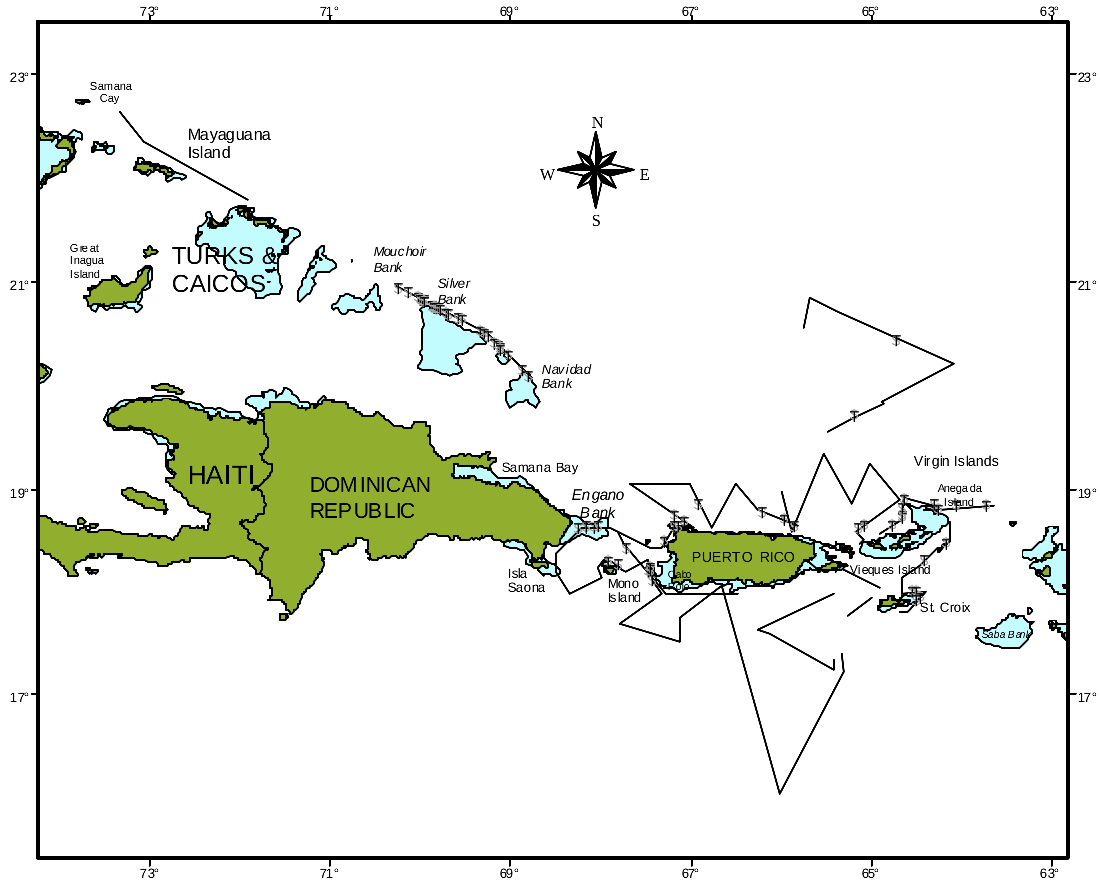


Figure 10. Sightings of dolphins during visual surveys (black lines): *Steno bredanensis* (star, n=1), *Tursiops truncatus* (triangle, n = 2), *Stenella attenuata* (circles, n = 3), *Stenella frontalis* (squares, n = 10), and *Stenella longirostris* (diamonds, n = 2).

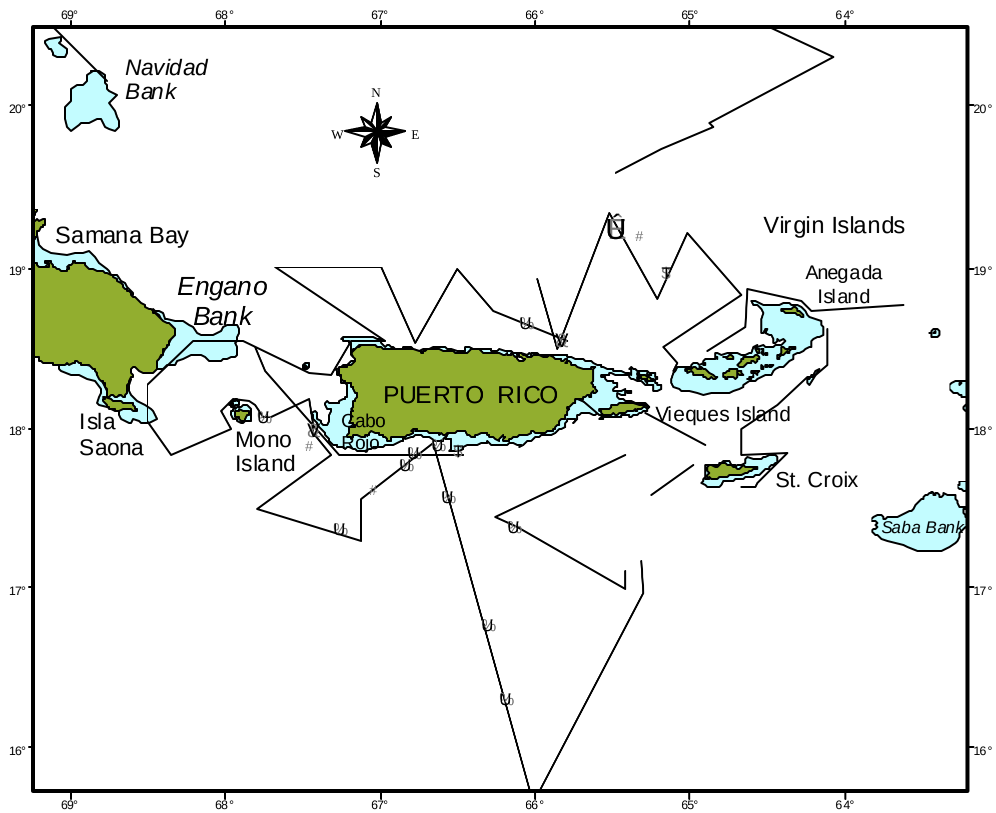
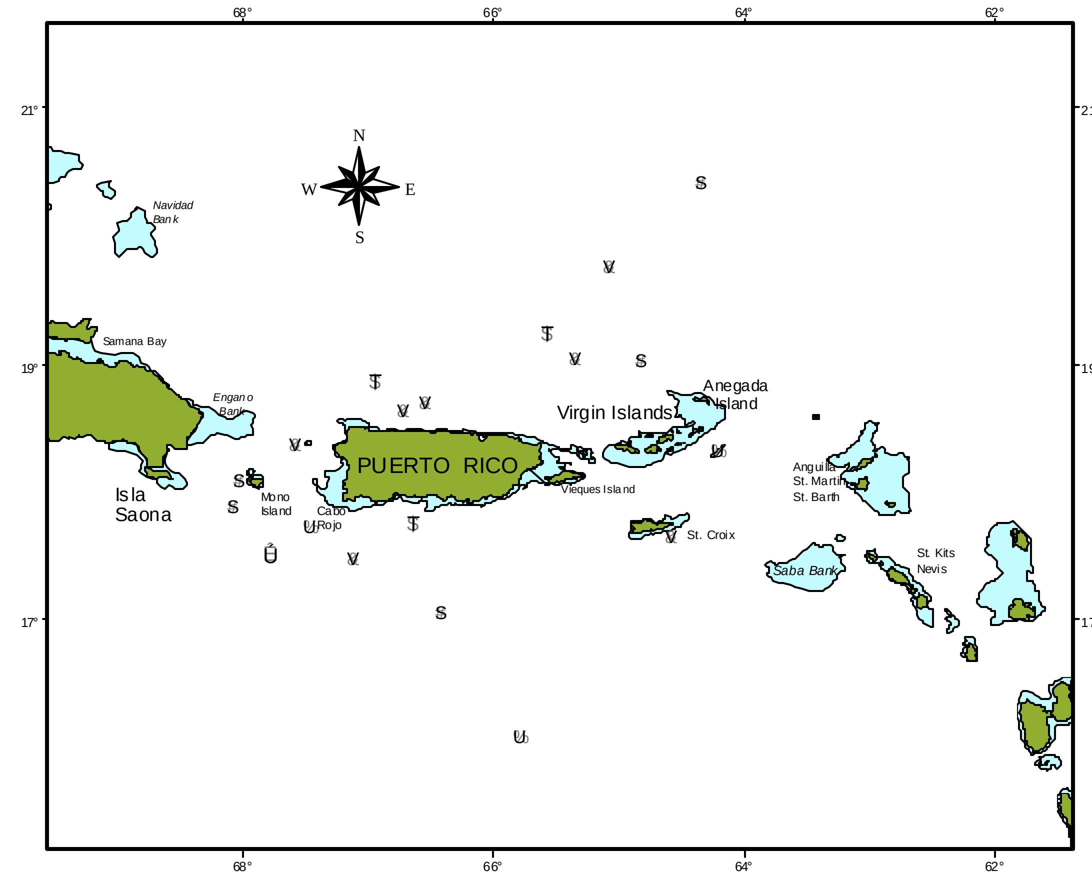


Figure 11. Sightings of odontocete whales during visual surveys (black lines): *Physeter macrocephalus* (circles, n = 5), *Ziphius spp*. (triangles, n = 3), *Mesoplodon spp*.(squares, n = 3), *Pseudorca crassidens* (star, n = 1), and *Globicephala spp*. (diamonds, n = 8).



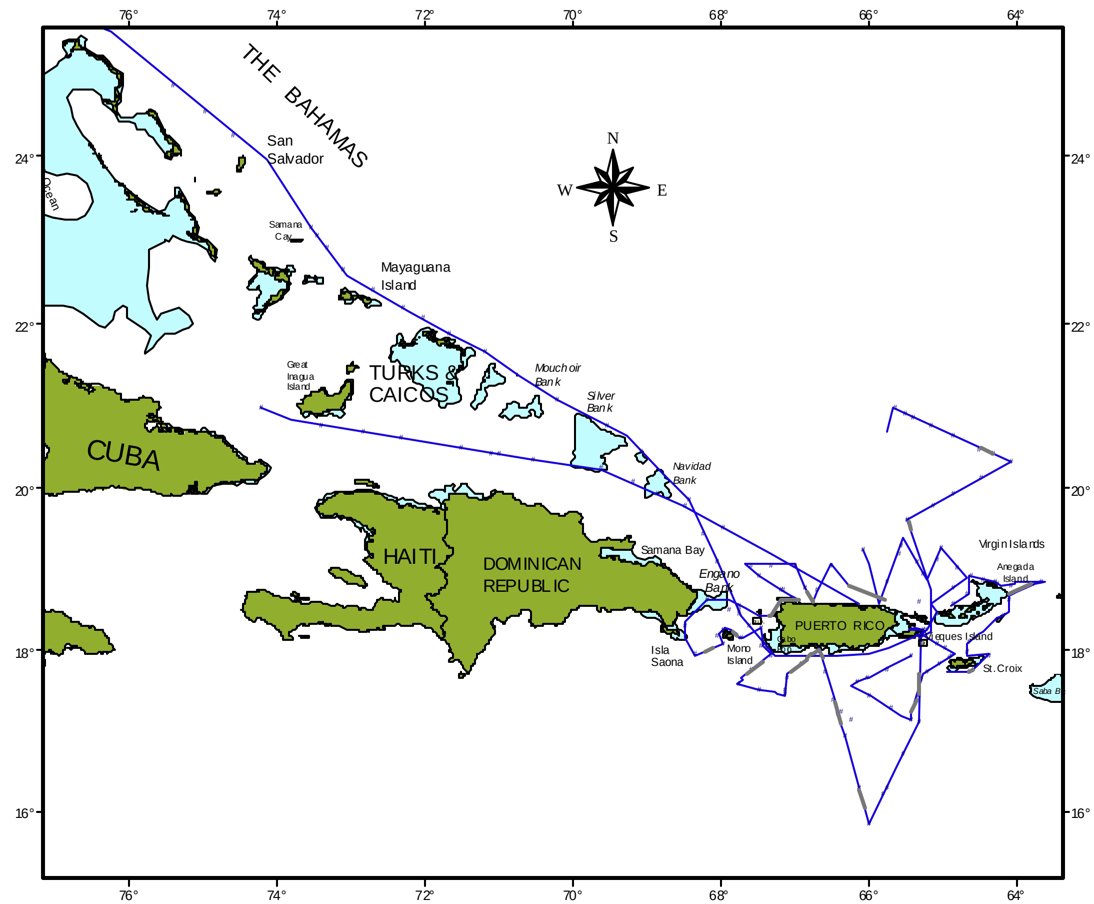


Figure 12. Survey track line along the eastern side of the Bahamas, around Puerto Rico and the Virgin Islands (black line) showing location of sonobuoy drops (circles) and hydrophone array tows (bold lines).

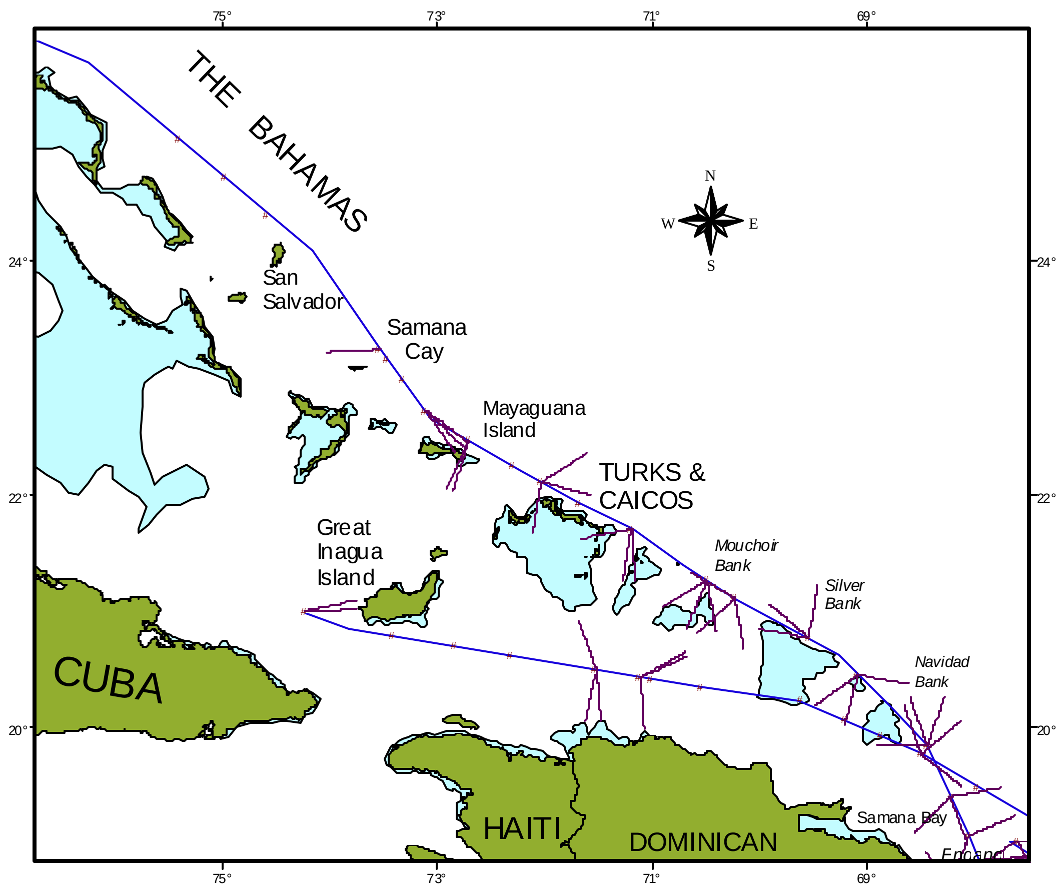


Figure 13. Survey trackline along the eastern side of the Bahamas, the Turks and Caicos, Mouchoir, Silver, and Navidad Banks (black line) showing location of sonobuoy drops with magnetic bearings to calling humpback whales (circles with radials).

Figure 14. Acoustic detections of humpback whales during surveys to the north of Puerto Rico and the Virgin Islands showing the location of sonobuoy drops and magnetic bearings to singing humpback whales (circles with radials).

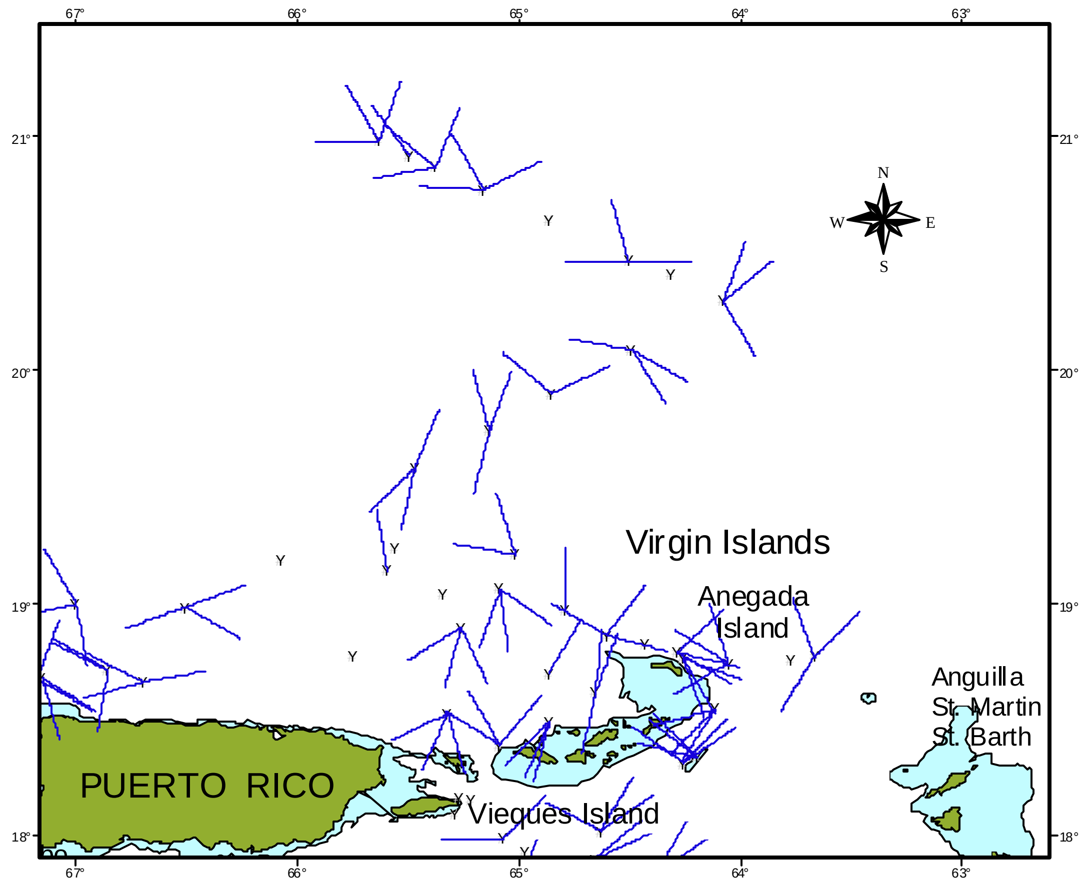


Figure 15. Acoustic detections of humpback whales during surveys to the south of Puerto Rico and the Virgin islands showing the location of sonobuoy drops with magnetic bearings to singing humpback whales (circles with radials). Location of one autonomous acoustic recording device is indicated by a **i** .

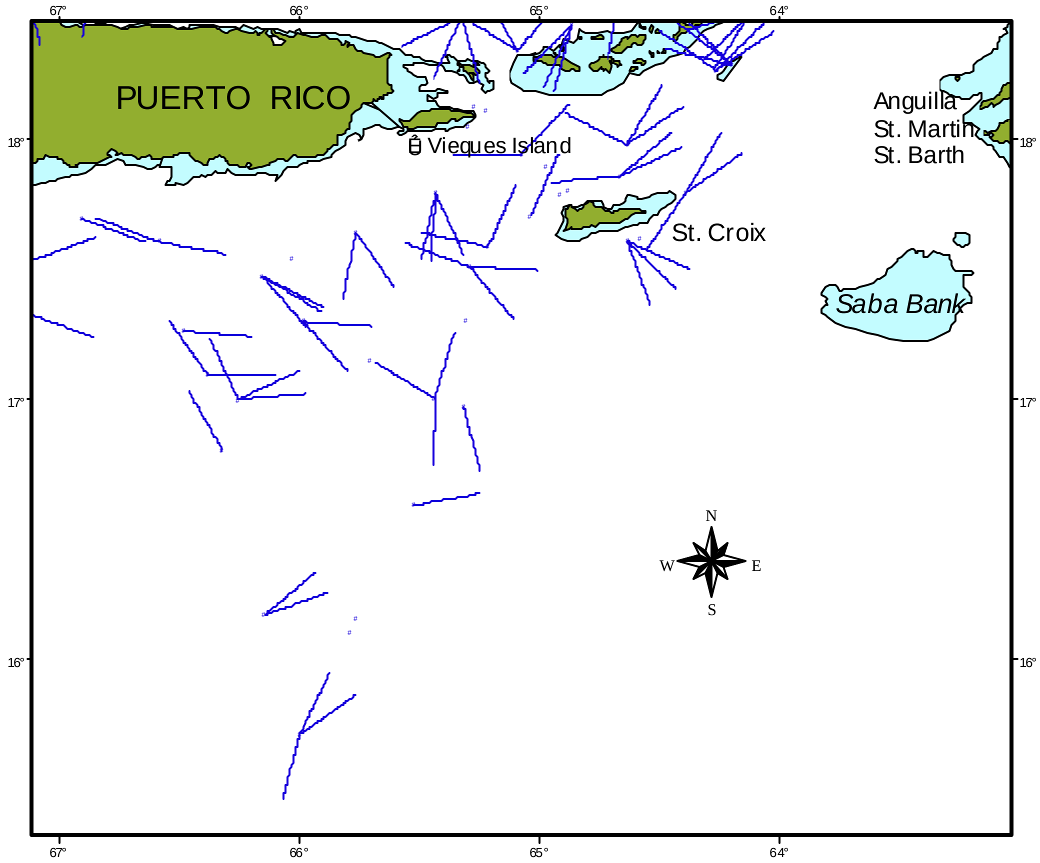


Figure 16. Acoustic detections of humpback whales during surveys to the west and southwest of Puerto Rico showing the location of sonobuoy drops and magentic bearings to singing humpback whales (circles with radials).

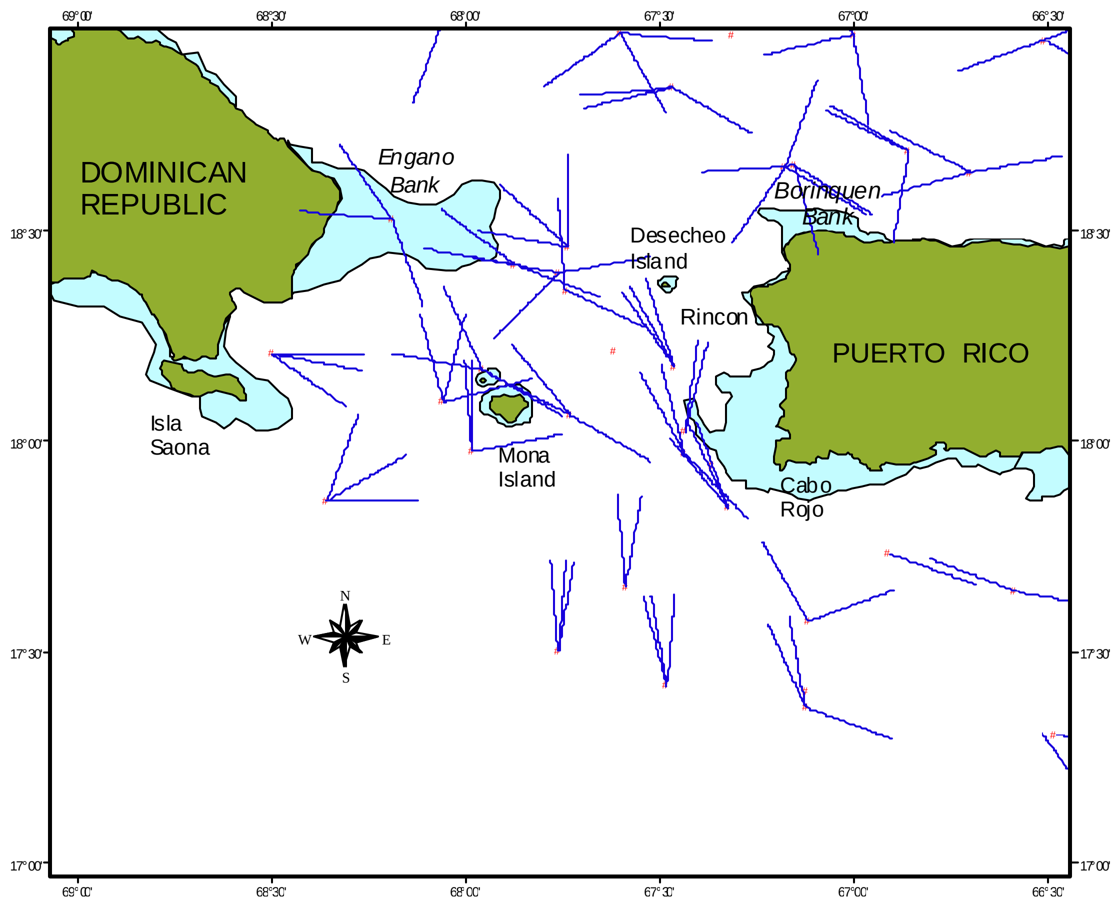


Figure 17. Acoustic detections of humpback whales during surveys to west and northwest of Puerto Rico showing the location of sonobuoy drops and magnetic bearings to singing humpback whales (circles with radials). The location on one autonomous acoustic recording device is noted by a **i** .

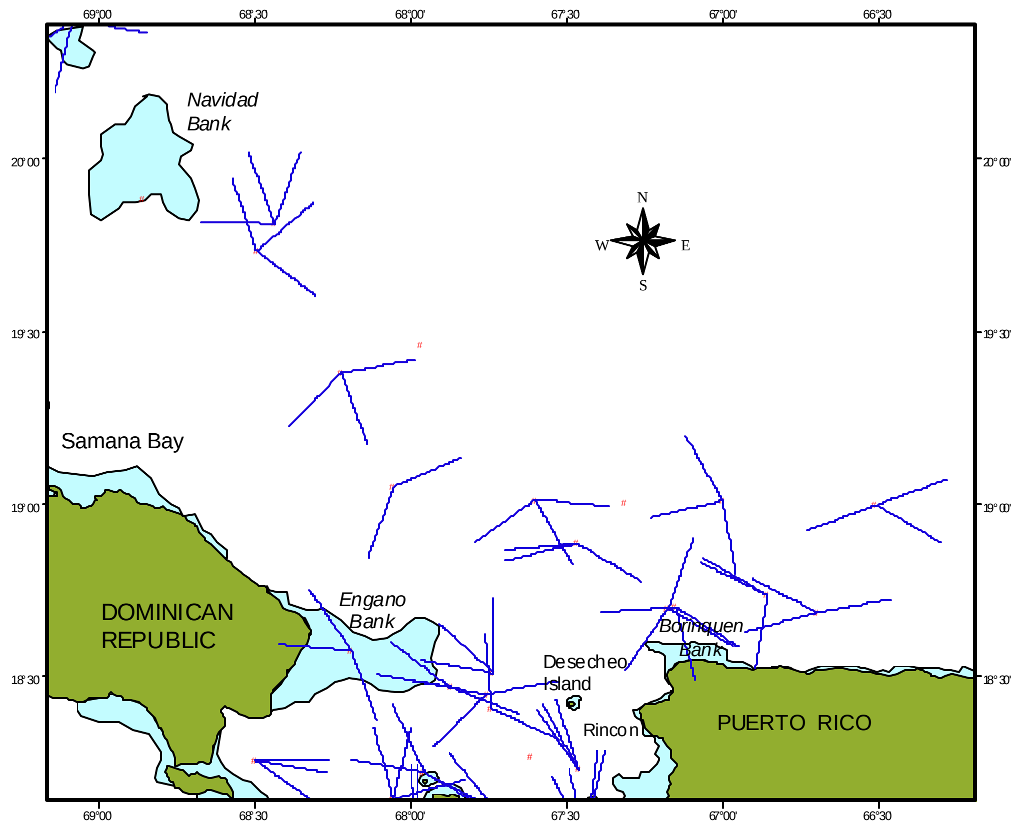


Figure 18. Location of acoustic detections of sperm whales (n=12) made by sonobuoys and during hydrophone array tows around Puerto Rico and the Virgin Islands from February 12 to 8 march, 2001.

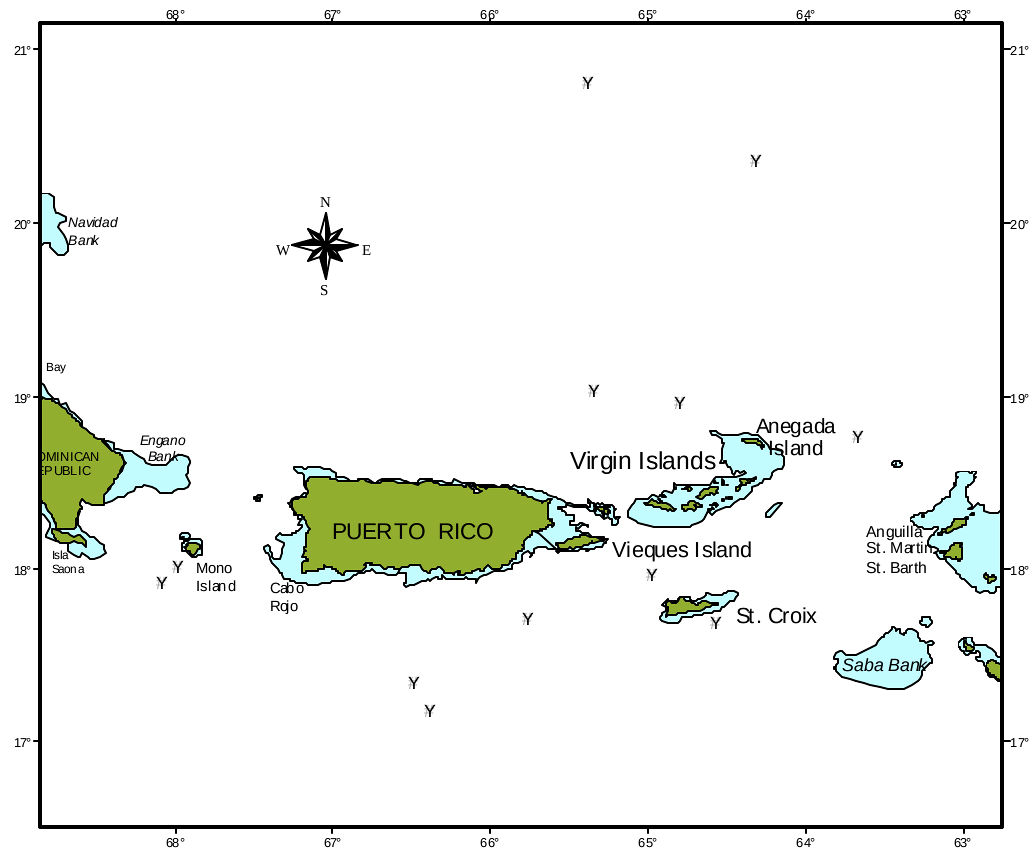


Figure 19. Location of 79 of the 135 sonobuoys (circles) that detected Atlantic "thumptrains" throughout the study area between February 12 and March 8, 2001.

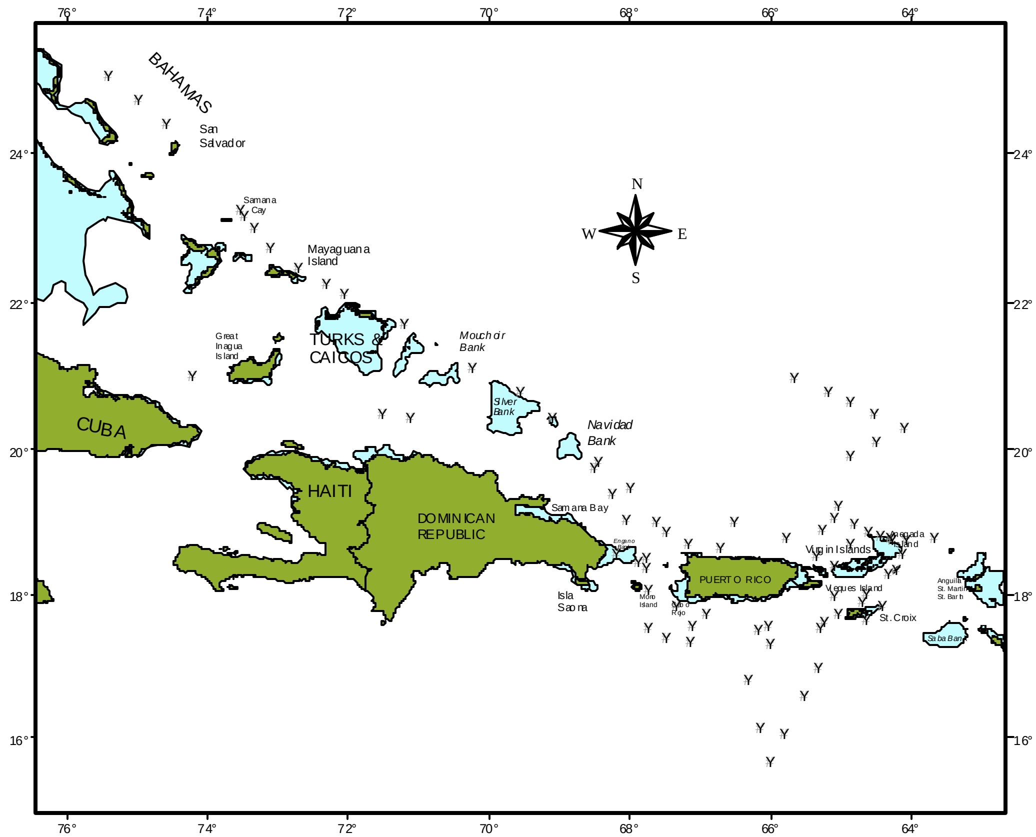


Figure 20. Spectrogram of a typical Atlantic “thumptrain” recorded during the February-March marine mammal survey around Puerto Rico and the Virgin Islands. The thumptrain consists of a 1-2 minute series of discrete repetitive pulses that increase in intensity and frequency, and terminate abruptly. Major sound energy is centered between 100 Hz and 650 Hz.

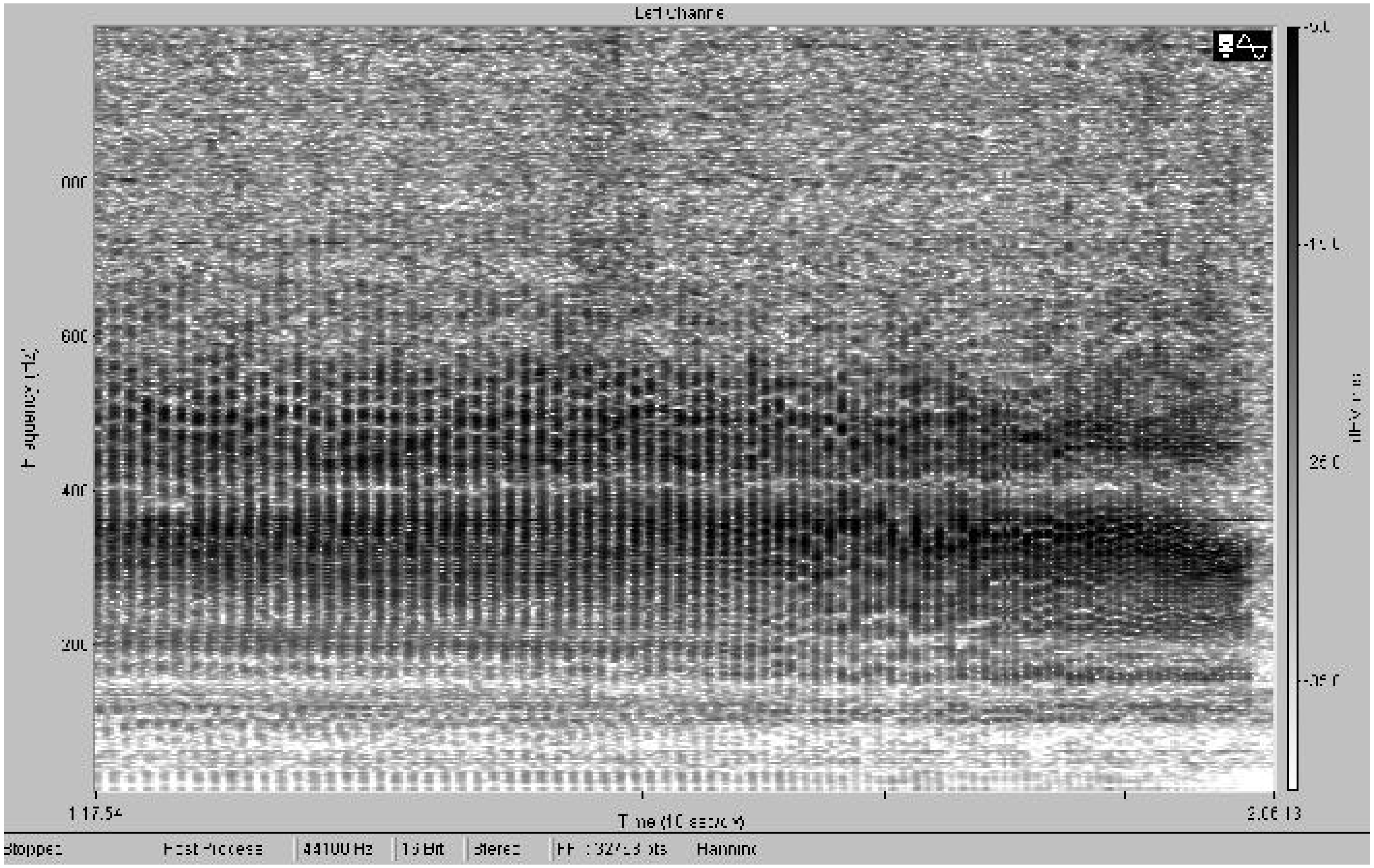


Figure 21. Locations where percussive "explosion-like" sounds were detected by sonobuoys and during towed hydrophone array sampling (circles). Radials from circles indicate magnetic bearings to the sources of the sounds.

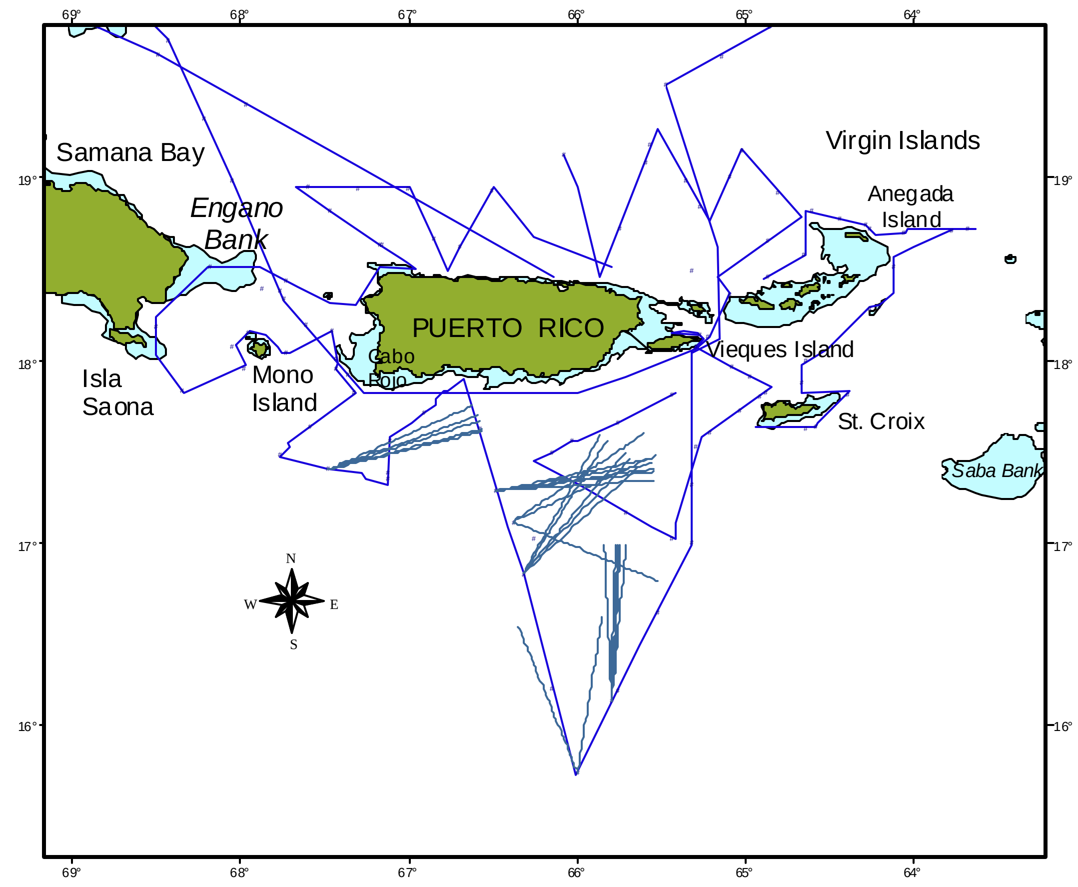


Figure 22. A spectrogram of a percussive "explosion-like" sound recorded off the south coast of Puerto Rico on February 27, 2001. Sound energy between 100 Hz and 20 kHz (upper line) averaged approximately 26.86 dB above the ambient noise level (lower line) in the area just prior to the occurrence of the percussive sound.

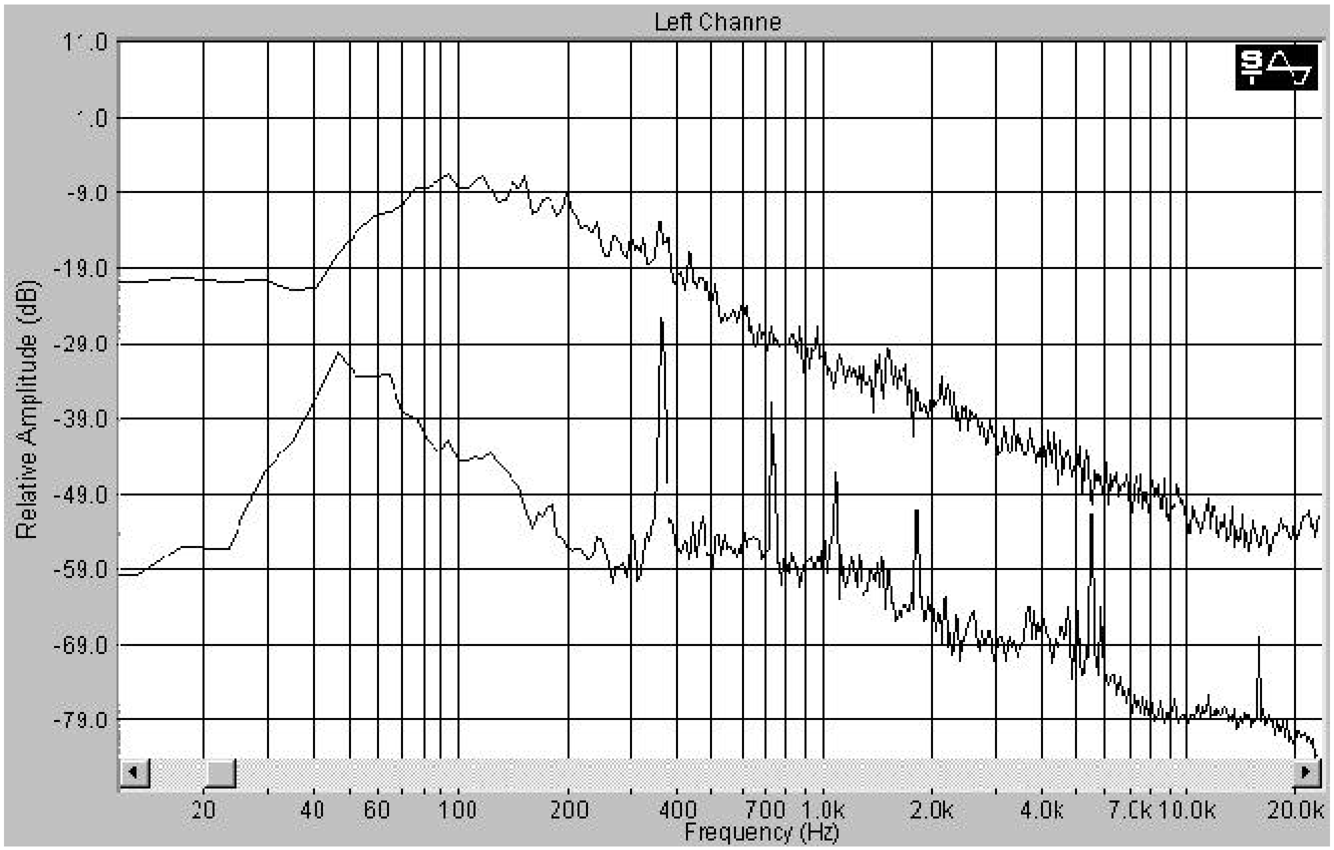


Figure 23. The locations along the survey track line (thin line) where commercial ship noise was detected (circles) by sonobuoys and during towed hydrophone array sampling (bold lines) from February 12 to march 8, 2001.

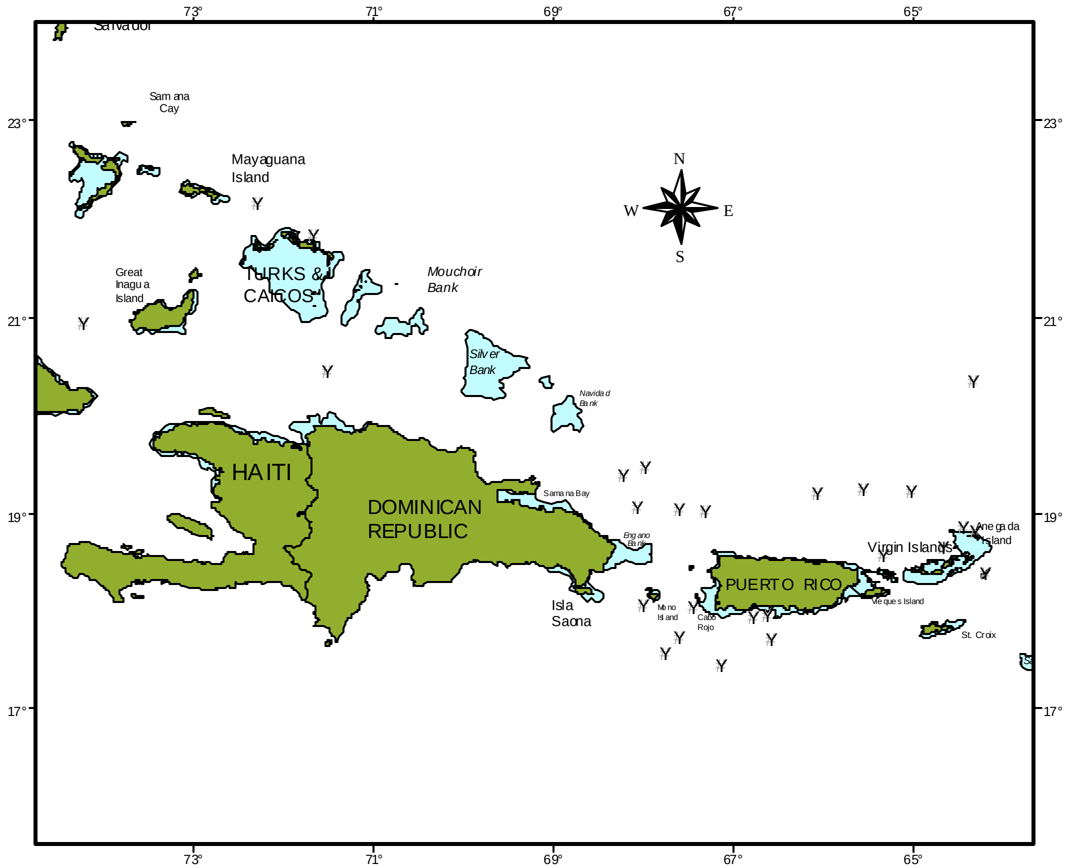


Figure 24. A proposed survey track line around Puerto Rico for future acoustic and visual surveys based on the marine mammal sighting rates obtained during the February-March 2001 survey.