MARINE MAMMAL AND SEA TURTLE SURVEY AND DENSITY ESTIMATES FOR GUAM AND THE COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

FINAL REPORT

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LIST OF ACRONYMS AND ABBREVIATIONS

°	Degree(s)
AIW	Antarctic Intermediate Water
BSS	Beaufort Sea State
C	Celsius
CDW	Circumpolar Deep Water
CI	Confidence Interval
CREEM	Centre for Research into Ecological and Environmental Modelling
CV	Coefficient of Variation
CNMI	Commonwealth of the Northern Mariana Islands
D	Animals per 1,000 km^2
dB	Decibel
DON	Department of the Navy
E	East
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FDM	Farallon de Medinilla
$f_i(0)$	Detection Function
ft	Foot/feet
$g(0)$	Probability of Detecting an Animal on the Survey Trackline
GPS	Global Positioning System
GMI	Geo-Marine, Inc.
Gt	Giggatonne
hr	Hour(s)
Hz	Hertz
IWC	International Whaling Commission
kHz	Kilohertz
km	Kilometer(s)
kt	Knot(s)
lb	Pound
LCPW	Lower Circumpolar Water
m	Meter(s)
min	Minute(s)
MISTCS	Mariana Islands Sea Turtle and Cetacean Survey
ml	Milliliter
MRA	Marine Resources Assessment
MMPA	Marine Mammal Protection Act
N	North or Number of Animals
n	Number of Groups Sighted
Navy	United States Navy
NEC	North Pacific Equatorial Current
NEPA	National Environmental Policy Act
nm	Nautical Mile(s)
nm^2	Square Nautical Miles
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDW	North Pacific Deep Water
NPSG	North Pacific Subtropical Gyre
NWFSC	Northwest Fisheries Science Center
PSD	Perpendicular Sighting Distance
PSU	Practical Salinity Units
ODV	Ocean Data View
OPAREA	Operating Area

RPM	Revolutions per Minute
RUWPA	Research Unit for Wildlife Population Assessment
S	South or Mean Group Size
SBE	Sea-Bird Electronic
SE	Standard Error
spp.	Species
SSC	Sea Surface Conductivity
SSS	Sea Surface Salinity
SSSV	Sea Surface Sound Velocity
SST	Sea Surface Temperature
SWFSC	Southwest Fisheries Science Center
TSG	Thermosalinograph
UID	Unidentified
U.S.	United States
USFWS	United States Fish and Wildlife Service
W	West
$\bar{x}$	Mean
XBT	Expendable Bathythermograph

EXECUTIVE SUMMARY

The United States (U.S.) Navy (Navy) is committed to demonstrating environmental stewardship while executing its national defense mission. The Navy is responsible for compliance with a suite of Federal environmental and natural resources laws and regulations, including the National Environmental Policy Act (NEPA), the Marine Mammal Protection Act (MMPA), and the Endangered Species Act (ESA). To comply with these mandates, up-to-date, area-specific marine mammal density estimates for the Navy's Operating Areas (OPAREAs) were desired. For Guam and the Commonwealth of the Northern Mariana Islands (CNMI), the data needed to calculate marine mammal density estimates did not exist and little was known of the occurrence of marine mammals in the area. The objective of Mariana Islands Sea Turtle and Cetacean Survey (MISTCS) was to conduct the first systematic line-transect visual survey of the waters around Guam and the Northern Mariana Islands and generate density estimates for those species which had adequate data.

The MISTCS cruise area was defined by the boundaries of 10° – 18° N Latitude and 142° – 148° E Longitude and encompassed an area approximately 170,500 square nautical miles (nm^2) including the islands of the Mariana archipelago. The systematic line-transect survey effort was conducted from the 185-foot long *M/V Kahana* using standard line-transect protocols developed the National Marine Fisheries Service (NMFS)/Southwest Fisheries Science Center (SWFSC). Visual survey effort was along predetermined tracklines with the ship traveling at 14.2-17.7 kilometers per hour (8-10 knots). Visual survey effort was conducted from the flying bridge (10.5 meters above the water), beginning at sunrise and continuing until sunset each day (weather-permitting). The daily watch consisted of six experienced marine mammal observers who rotated between stations every 40 minutes. Observers rotated through a port-side 25x150 binocular station, a data recorder position, and a starboard-side 25x150 binocular station. Each observer would work a 2-hour (hr) shift followed by a 2-hr rest period.

Passive acoustic monitoring was used to detect and locate cetaceans in the study area as a supplement to visually-based observations. A two-element towed hydrophone array (frequency response from approximately 100 Hertz (Hz) to 45 Kilohertz (kHz)) was monitored and recorded continuously during daylight hours concurrent with the visual effort. The acoustic system consisted of hardware and software used for signal acquisition, conditioning, processing, recording and geographic plotting of bearings to cetacean vocalizations.

Although not a part of the original research plan, sonobuoys were deployed opportunistically and occasionally at night to supplement the towed array system. Two types of sonobuoys were deployed: the AN/SSQ-53D (directional with frequency response of 10 Hz to 2.5 kHz) and AN/SSQ-57B (omnidirectional with an effective frequency response of 10 Hz to 20 kHz) with the latter type predominantly deployed. Sonobuoy signals were monitored by an operator and recordings were made if sounds of interest were detected. No attempt was made to localize acoustic detections made with sonobuoys.

Temperature data were collected using a Thermosalinograph (TSG), Expendable Bathythermograph (XBT) and a hand-held thermometer. Sea surface salinity data were gathered using the TSG, while water samples for chlorophyll *a* analysis were collected using a Fiedler Bucket. The TSG continually sampled during visual observation effort (daylight hours), while chlorophyll *a* sampling, sea surface thermometer readings, and XBT operations were conducted three times a day.

Observers visually surveyed 11,033 km (6,063 nm) of trackline during the MISTCS cruise. On-effort kilometers ranged from 2,200 km (Leg 3) to 3,300 km (Leg 4). Survey effort was stopped at Beaufort sea state (BSS) $\geq$7. The original intent was to stop visual effort at BSS>5; however, the poor sea conditions would have prevented any survey effort on several days during Legs 1 and 2. All survey effort and sightings in BSS≤6 were included in density estimation analyses.

There were 148 total sightings of 12 marine mammal species and one sea turtle species, the hawksbill turtle (*Eretmochelys imbricata*). The sperm whale was the most frequently seen species (n = 21) followed by the Bryde's and sei whales (n = 18 and 16, respectively). The pantropical spotted dolphin was the most frequently encountered delphinid species (n = 16) followed by the false killer whale and the striped dolphin (both n = 10). Group size varied by species and ranged from 1 to 115 individuals. Range of bottom depth for sightings was highly variable (144-9,874 m) and was species-dependent. There were also three sightings of beaked whales (two *Mesoplodon* spp. and one ziphiid whale).

The high Beaufort sea states and low number of marine mammal sightings were taken in account in the approach used to calculate marine mammal densities. The method of calculating densities, including the assumptions and limitations, and are given in detail in the methods chapter. In addition, the methodology used was reviewed and determined to be appropriate by the Research Unit for Wildlife Population Assessment (RUWPA) within the Centre for Research into Ecological and Environmental Modelling (CREEM) at St. Andrews University.

In calculating the densities of marine mammals, the probability of detecting an object that is on a transect line, $g(0)$, is very important to generating reliable abundance estimates. We assumed $g(0) = 1$, because estimates of $g(0)$ were not calculated during this survey. In fact, most systematic surveys of cetaceans do not estimate $g(0)$ due to the associated expenses of additional observers and equipment needed to perform this task. It should be noted, however, that there has been an increasing effort to address this concern. A $g(0)$ value of 1 indicates that 100 percent (%) of the animals are detected; it is rare that this assumption holds true. By assuming $g(0) = 1$ for these analyses, the density and abundance estimates for most of the species are underestimated.

Species with similar sighting characteristics (*e.g.*, body size, group size, surface behavior, blow visibility) were pooled to estimate $f_i(0)$ for three categories: *Balaenoptera* spp., Blackfish, and Delphinids. This was done because there were insufficient numbers of sightings for all other species to model the detection function (<20 sightings) independently.

Figure ES-1. Summary of Marine Mammal Sightings and Calculated Densities

Species	n	S	CV(S)	D	N	CV	95% CI
Sperm Whale *Physeter macrocephalus*	11	5.1	40.2	--------	705	60.4	228-2181
				1.23	--------		0.40-3.80
***Balaenoptera* spp.**	24	------	--------	--------	499	32.8	265-941
				0.88	--------		0.46-1.64
Sei Whale *Balaenoptera borealis*	8	1.3	13.1	--------	166	48.7	67-416
			--------	0.29			0.12-0.73
Bryde's Whale *Balaenoptera edeni*	10	1.4	11.7	--------	233	45.0	99-546
			--------	0.41	--------		0.17-0.95
Sei or Bryde's Whale *Balaenoptera borealis/edeni*	2	1	--------	--------	33	100.2	6-175
				0.056	--------		0.01-0.31
Unidentified Balaenoptera	4	1	--------	--------	67	53.6	25-181
				0.12	--------		0.04-0.32
Blackfish	12	------	--------	--------	4079	93.8	1650-10085
				7.12	--------		2.9-17.6
False Killer Whale *Pseudorca crassidens*	5	9.8	42.9	--------	637	74.3	164-2466
				1.11	--------		0.29-4.3
Short-finned Pilot Whale *Globicephala macrorhynchus*	4	17.5	50.1	--------	909	67.7	230-3590
				1.59	--------		0.40-6.26
Melon-headed Whale *Peponocephala electra*	2	94.5	15.3	--------	2455	70.2	695-8677
				4.28	--------		1.2-15.10
Pygmy Killer Whale *Feresa attenuata*	1	6	0.0	--------	78	88.1	17-353
				0.14	--------		0.03-0.62
Delphinids	33	------	--------		19269	49.8	7286-50959
				33.6			12.7-88.90
Pantropical Spotted Dolphin *Stenella attenuata*	11	64.2	57.6	--------	12981	70.4	3446-48890
				22.6	--------		6.0-85.3
Striped Dolphin *Stenella coeruleoalba*	7	27.4	34.4	--------	3531	54.0	1250-9977
				6.16	--------		2.18-17.4
Pacific Bottlenose Dolphin *Tursiops truncatus*	3	2.2	80.7	--------	122	99.2	5.0-2943
				0.21	--------		0.001-5.10
Spinner Dolphin *Stenella longirostris*	1	98	--------	--------	1803	95.8	361-9004
				3.14	--------		0.63-15.7
Rough-toothed Dolphin *Steno bredanensis*	1	9	--------	--------	166	89.2	36-761
				0.29	--------		0.06-1.33
Bottlenose or Rough-toothed Dolphin *Tursiops/Steno*	1	3	--------	--------	55	91.8	12-262
				0.09	--------		0.02-0.46
Unidentified delphinid	9	3.7	33.0	--------	612	47.8	242-1550
				1.07	--------		0.42-2.70

Towed array effort was conducted for 70 out of 71 (99%) of surveyable days at sea for a total of 762 hours and 11,478 km of total survey effort for the entire 3-month cruise. On average, towed array effort was conducted for 10.9 hours/day, for all survey days. A total of 55 sonobuoys were deployed of which 36 (65%) were functional. Nine unique species and two unidentified species groups were detected including sperm whales, sei whales, minke whales, humpback whales, false killer whales and melon-headed whales. Although minke whales were never sighted by visual observers, they were the second most frequent acoustically-detected species. Sperm whales were the most common large whale encountered by both visual and acoustic methods, but acoustic encounter rates were over three times higher than visual encounters. Beaked whales, Bryde's whales and *Kogia* spp. were expected to be encountered in the study area, but were not detected acoustically (not expected to be detected acoustically). Bryde's whales were detected visually.

For all temperature data collected across the survey area between the months of January and April 2007, a mean of 27.18°C was observed. The highest temperature recorded was 29.8°C, while 25.0°C was the lowest, denoting a range of 4.8°C. These temperatures are consistent with the North Equatorial Current, in which the Mariana Islands are located.

The Navy is required by the ESA and MMPA to use the "best available data" for the preparation of environmental planning documents. Prior to this survey, there were no marine mammal abundance or density estimates for this area and data for environmental documents used densities extrapolated from other geographical locations (*e.g.,* Hawaii) where density estimates existed. While this approach meets federal requirements, it has obvious limitations and a more proactive approach was initiated with this survey. Although sighting conditions were difficult, the number of species and overall sightings recorded were greater than expected. Due to the sighting conditions and the assumptions made in the calculations, the marine mammal abundance and densities are most likely an underestimate of animals in the area but the survey provides the first direct and best scientific data available to use in the assessment of environmental effects for the area.

1 INTRODUCTION

The Department of the Navy (DON) is committed to demonstrating environmental stewardship while executing its national defense mission. There is responsibility for compliance with a suite of federal environmental and natural resources laws and regulations, including the National Environmental Policy Act (NEPA), the Marine Mammal Protection Act (MMPA), and the Endangered Species Act (ESA). To comply with these mandates, up-to-date, area-specific marine mammal and sea turtle density estimates for the United States (U.S.) Navy's (Navy) Operating Areas (OPAREAs) were desired. For the Guam and Commonwealth of the Northern Mariana Islands (CNMI), data needed to calculate density estimates did not exist.

The objective of Mariana Islands Sea Turtle and Cetacean Survey (MISTCS) was to conduct the first systematic line-transect visual survey of the waters around Guam and the Northern Mariana Islands and generate density estimates for those species which had adequate data. Geo-Marine, Inc. (GMI), Bio-Waves, Inc., and Aquatic Farms, Ltd. were contracted by ManTech SRS Technologies, Inc. to design and implement this survey. This document represents the Navy's first comprehensive effort to provide density estimates of cetaceans and sea turtles for the Marianas study area. The Marine Resources Assessment (MRA) for the Marianas Operating Area (DON, 2005) serves as the foundation reference document upon which this document is built. The density estimates are needed to aid in the planning of military operations, to assist in the determination of the potential impacts of scheduled military operations on marine mammal and sea turtle species in the area, and aid in the preparation of associated take permit applications and Section 7 consultations.

1.1 DESCRIPTION OF SURVEY AREA

The islands of the Mariana archipelago lie between latitude 13 degrees (°) North (N) and 20°N and are approximately 5,800 kilometers (km) west (W) of Hawaii, 2,250 km south of Japan, and 7,600 km north of Sydney, Australia (**Figure 1-1**; DON, 1998; 2003a; 2003b; 2005). The archipelago extends roughly 800 km from Guam in the south to the uninhabited island of Farallon de Pajaros in the north (DON, 1998). The MISTCS cruise area was defined by the boundaries of 10 – 18° N Latitude and 142 – 148° East (E) Longitude and encompassed an area approximately 170,500 square nautical miles (nm^2).

The seafloor of the study area is characterized by the Mariana Trench, the Mariana Trough, ridges, numerous seamounts, hydrothermal vents, and volcanic activity. The bathymetry of the study area can be divided into three main areas: the Mariana Trough, the Mariana Ridge, and the Mariana Trench. The Mariana Trench is the major physiographic feature of the study area. The bottom depth ranges from 5,000 to 11,000 meters (m) with the deepest locations being southwest of Guam and becoming shallower northward (Fryer *et al*., 2003).

Two volcanic arcs, the West Mariana Ridge (a remnant volcanic arc than runs from approximately 21°N 142°E to 11°30'N 141°E) and the Mariana Ridge (an active volcanic arc) are separated by the Mariana Trough (Baker et al., 1996). The West Mariana Ridge is a series of seamounts lying 145 to 170 km west of and parallel to the main island chains of the CNMI.

Very little is known of the general oceanographic circulation surrounding the study area, as few studies have investigated the major current patterns around the islands (Eldredge, 1983). Circulation patterns that influence the area include sea surface circulation, deepwater circulation, and the North Pacific Subtropical Gyre (DON, 2005).

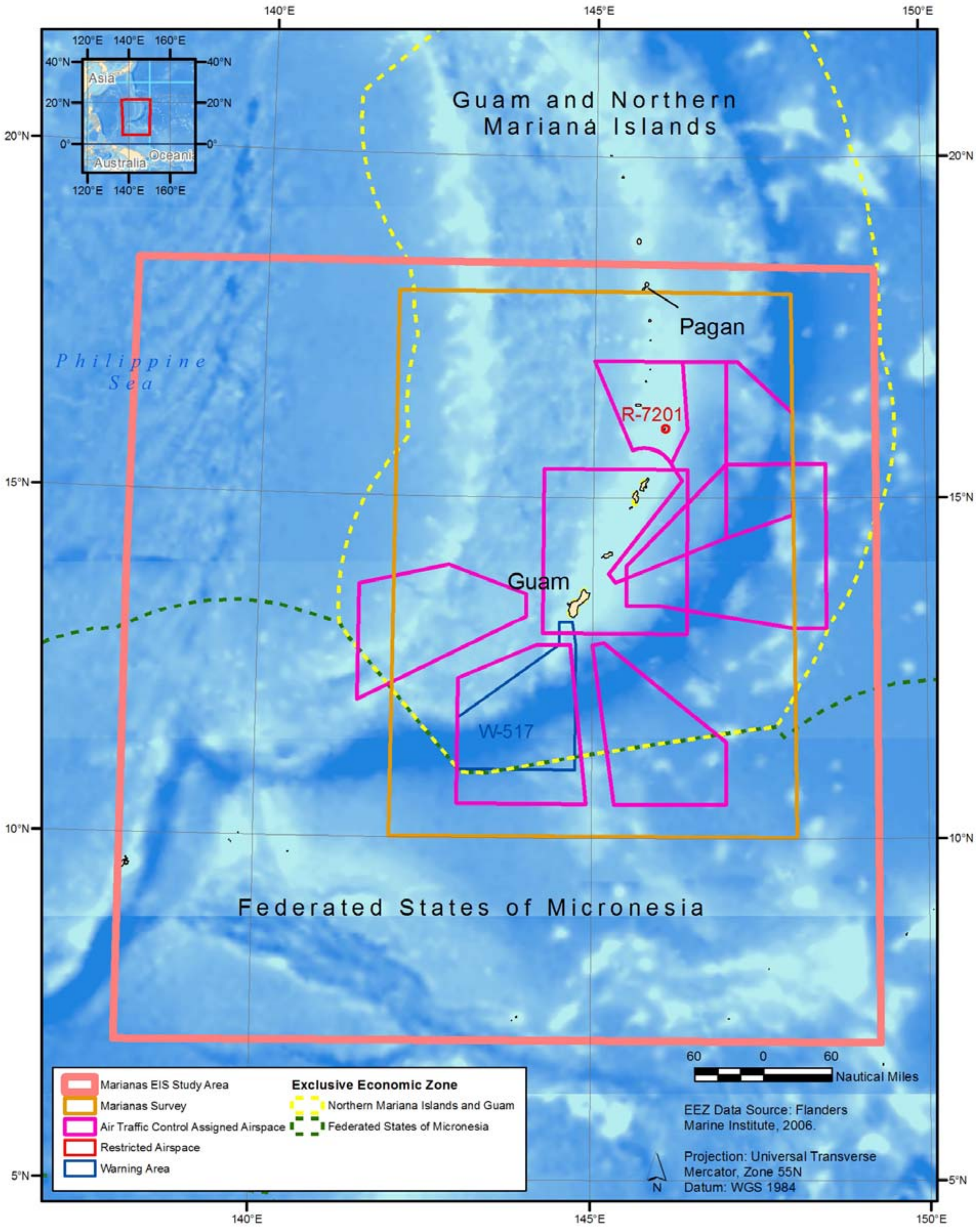


Figure 1-1. Mariana Island Study Area in Waters off Guam and the Commonwealth of the Northern Mariana Islands

1.2 MARINE SPECIES BACKGROUND

Marine mammals are not well-documented in Micronesia. The first compilation of available information for 19 species of marine mammals from Micronesia was provided by Eldredge (1991) with additional records in Eldredge (2003). Taking into consideration marine mammal distribution and habitat preferences, DON (2005) expanded the list to 32 marine mammal species with confirmed or possible occurrence records in Guam and CNMI (**Table 1-1**). The vast majority (29) are cetaceans (whales, dolphins, and porpoises).

The green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), leatherback (*Dermochelys coriacea*), and olive ridley (*Lepidochelys olivacea*) sea turtles have documented occurrence in the waters around Guam and the CNMI (*e.g.*, Pritchard, 1995; DON, 2005; Kolinski *et al*., 2001; 2006). The loggerhead turtle (*Caretta caretta*) is also known to occur in the North Pacific Ocean, but has never been sighted in the Marianas region (National Marine Fisheries Service [NMFS] and U.S. Fish and Wildlife Service [USFWS], 1998). However, due to this species' wide-ranging nature, there is a slight possibility that it could occur in this region (DON, 2005).

Table 1-1. Marine Mammal Species of the Mariana Island Study Area

Order Cetacea	Scientific Name	Status
Suborder Mysticeti (baleen whales)		
Family Balaenidae (right whales)		
North Pacific right whale	*Eubalaena japonica*	Endangered
Family Balaenopteridae (rorquals)		
Humpback whale	*Megaptera novaeangliae*	Endangered
Minke whale	*Balaenoptera acutorostrata*	
Sei whale	*Balaenoptera borealis*	Endangered
Fin whale	*Balaeonptera physalus*	Endangered
Blue whale	*Balaenoptera musculus*	Endangered
Bryde’s whale	*Balaenoptera edeni/brydei*	
Suborder Odontoceti (toothed whales)		
Family Physeteridae (sperm whales)		
Sperm whale	*Physeter macrocephalus*	Endangered
Family Kogiidae (pygmy sperm whales)		
Pygmy sperm whale	*Kogia breviceps*	
Dwarf sperm whale	*Kogia sima*	
Family Ziphiidae (beaked whales)		
Cuvier’s beaked whale	*Ziphius cavirostris*	
Blainville’s beaked whale	*Mesoplodon densirostris*	
Gingko-toothed beaked whale	*Mesoplodon ginkgodens*	
Hubb’s beaked whale	*Mesoplodon carhubbsi*	
Longman’s beaked whale	*Indopacetus pacificus*	
Family Delphinidae (dolphins)		
Rough-toothed dolphin	*Steno bredanensis*	
Common bottlenose dolphin	*Tursiops truncatus*	
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	
Pantropical spotted dolphin	*Stenella attenuata*	
Spinner dolphin	*Stenella longirostris*	
Striped dolphin	*Stenella coeruleoalba*	
Short-beaked common dolphin	*Delphinus delphis*	
Risso’s dolphin	*Grampus griseus*	
Melon-headed whale	*Peponocephala electra*	
Fraser’s dolphin	*Lagenodelphis hosei*	
Pygmy killer whale	*Feresa attenuata*	
False killer whale	*Pseudorca crassidens*	
Killer whale	*Orcinus orca*	
Short-finned pilot whale	*Globicephala macrorhynchus*	
Order Carnivora	**Scientific Name**	**Status**
Suborder Pinnipedia (seals, sea lions, walruses)		
Family Phocidae (true seals)		
Hawaiian monk seal	*Monachus schauinslandi*	Endangered
Northern elephant seal	*Mirounga angustirostris*	
Order Sirenia	**Scientific Name**	**Status**
Family Dugongidae (dugongs)		
Dugong	*Dugong dugon*	Endangered

Taxonomy follows International Whaling Commission (IWC, 2006) for cetaceans and Rice (1998) for pinnipeds.
Source: DON, 2005.

2 SURVEY METHODS

2.1 VISUAL OBSERVATIONS

2.1.1 Survey Design

Visual survey effort was conducted from the 185 feet (ft) M/V *Kahana* using standard line-transect protocols (Buckland *et al*., 2001, 2004). The vessel traveled at 8-10 knots (kt) through the water along the designated trackline. Survey methodology established by the National Oceanic and Atmospheric Administration (NOAA)/Southwest Fisheries Science Center (SWFSC) to collect cetacean and sea turtle distribution and abundance data was followed. Visual survey effort was along predetermined tracklines drawn to maximize visual effort and was not stratified; given there was little information on the region upon which to base stratification of effort. Survey lines were determined based on the dominant wind, waves, and swell direction in a manner to uniformly cover the entire study area. These tracklines were at an approximate heading of 222° and 315°. Start location within the area of operation (north or south) was determined by a flip of a coin at the beginning of the survey and alternated each leg. Some original tracklines had to be abandoned and redrawn due to the prevailing winds, swell, and waves. Tracklines were also sometimes modified depending on the effect of the vessel's ride (pitch, yaw, and roll) to improve observer stability on the flying bridge.

Visual survey effort was conducted from the flying bridge (10.5 meters [m] above the water), beginning at sunrise and continuing until sunset each day (weather-permitting). The daily watch consisted of six observers (trained in Eastern Tropical Pacific species identification) who rotated between stations every 40 minutes (min). Observers rotated through a port-side 25x150 binocular station, a data recorder position, and a starboard-side 25x150 binocular station. Each observer would work a 2-hour (hr) shift followed by a 2-hr rest period.

Alterations to the ship course or speed were conveyed to the bridge by the visual observer team. The ship was not diverted more that 10 nautical miles (nm) from the trackline for sea conditions, glare and/or exhaust fumes. If sea states were too high, observers would switch to hand-held binoculars, naked-eye effort, or in worst case scenarios, one person would rotate as a bridge watch. The *Mariana Island Sea Turtle and Cetacean Survey (MISTCS) Cruise Report* is included as **Appendix D**.

2.1.1.1 Data Logging

Visual sighting data was recorded in WinCruz (a program developed by NOAA/SWFSC). The data recorder was responsible for recording visual effort (on or off), sightings, sea conditions (Beaufort sea state [BSS], wave and swell height, glare, etc.), wind direction and speed, and to ensure the Global Positioning System (GPS) was functioning properly. Ship's position was recorded via an integrated, stand-alone GPS unit on the flying bridge.

2.1.1.2 Sightings

In the event of an "on-effort" cetacean sighting, the visual team would go "off-effort" and the ship was diverted off course to confirm species identification, estimate group size, and determine the group's composition (*i.e*., presence of calves). "On-effort" means that both the visual observers were in place and actively searching for cetaceans and/or sea turtles and that the observation platform (vessel) was on its trackline. This decision was made by the lead marine mammal observer on watch. When the ship approached the animals, the observers made independent estimations of group size (best, maximum and minimum). The ship was directed to make course and speed changes as deemed appropriate to maximize the viewing and photography of the groups. In accordance with NOAA/National Marine Fisheries Service (NMFS) Office of Protected Resources letter dated 10 January 2007, animals were not approached closer than 100 meters to avoid harassment. Once the group size estimates, species identifications, and photography were completed, the ship was directed to return to original course and speed.

2.1.1.3 Calculation of Survey Effort

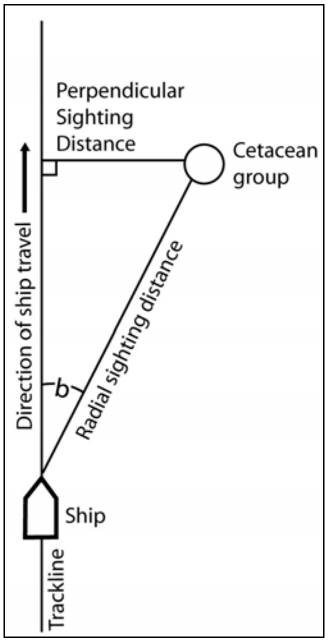
Ship survey data were collected as a series of latitude and longitude points every 10 min. Only "on-effort" portions of the survey tracklines, conducted in BSS≤6 were used for analyses. Daily survey effort was calculated as a summation of the distance between each successive point, after the coordinates were converted to radians. To accomplish this, the latitude and longitude coordinates were converted from degrees to radians. Once in radians, the coordinates were then used to calculate the great circle distance in kilometers between successive latitude and longitude positions. All of the individual distances between points were summed for each day to produce an estimate of daily effort. These, in turn, were summed to provide a total estimate of effort for the entire survey.

2.1.1.4 Calculation of the Perpendicular Sighting Distance

The method used for calculating the perpendicular sighting distance (PSD) for each sighting was in accordance with Lerczak and Hobbs (1998), the bearing and reticle of the sighting were used in combination with the height of the platform above the water's surface (**Figure 2-1**).

2.1.1.5 Preparation of the Sighting Data

During the MISTCS survey, up to three separate species could be recorded for each sighting event. All sightings were identified to the lowest possible level (species). If identification to species level was not possible, then the observation was recorded at the next possible category (*e.g.*, bottlenose dolphin, *Balaenoptera* species (spp.), unidentified (UID) delphinid, UID large whale, etc.).



B= angle between trackline and cetacean group

Figure 2-1. Diagram of PSD and Other Sighting Parameters for Shipboard Survey

2.1.1.6 Estimating Bias – *g(0)*

The probability of detecting an object that is on a transect line, *g(0)*, is very important to generating reliable abundance estimates. Departures of *g(0)* from 1 can be attributed to either a) perception bias (when observers fail to detect an animal on the trackline), or b) availability bias (from animals being submerged while on the trackline and unable to be detected). For the purpose of this report, we assumed *g(0)* = 1, because estimates of *g(0)* were not available for the MISTCS cetaceans and could not be calculated during this survey. In fact, most systematic surveys of cetaceans do not estimate *g(0)* due to the associated expenses of additional observers and equipment needed to perform this task. It should be noted, however, that there has been an increasing effort to address this concern. The application of *g(0)* values from other surveys or regions was not considered advisable since this was the first systematic cetacean survey in Guam and the CNMI. Assuming *g(0)* = 1 is probably unrealistic, particularly for those species with long dive times (*i.e.*, sperm whale) or that are difficult to detect as a result of their size or behavior (*i.e.*, minke whale). A *g(0)* value of 1 indicates that 100 percent (%) of the animals are detected; it is rare that this assumption holds true. Various factors are involved in estimating *g(0)*, including: sightability/detectability of the animal (species-specific behavior, school size, blow characteristics, dive characteristics, and dive interval); viewing conditions, (sea state, wind speed, wind direction, sea swell, and glare); observers (experience, fatigue, and concentration), and platform characteristics (pitch, roll, yaw, speed, and height above water). Thomsen *et al*. (2005) provides a complete and recent discussion of *g(0)*, factors which affect the detectability of the animals, and current thoughts on how to account for detection bias. Failure to address *g(0)* results in abundance and/or density estimates which are biased and underestimated. By assuming *g(0)* = 1 for these analyses, the density and abundance estimates for most of the species are underestimated.

2.1.2 Data Analysis

For each species, genus, or unidentified category (*i*) and stratum (*j*), abundance ($N_{i,j}$) was estimated with line-transect methods using the program DISTANCE (Thomas *et al*., 2006) by:

$$N_i = \sum_{j=1}^{3} \frac{A_j n_{i,j} S_{i,j} \hat{f}_i(0)}{2 L_j g(0)}$$

where A_j = area of stratum j,

$n_{i,j}$ = number of group sightings of species *i* in stratum *j*;

$S_{i,j}$ = mean group size of species *i* in region *j*;

$f_i(0)$ = sighting probability density function at perpendicular distance zero for species *i*;

L_j = total length of transect line in stratum *j*; and

$g(0)$ = probability of seeing a group on the transect line.

Abundance estimates were negatively biased, because observers, without doubt, missed groups on the transect line at the surface, and some groups were underwater while in the observation area; therefore $g(0)<1$. However, as stated above in Section 2.2.6, the parameter *g(0)* was not estimated and *g(0)* = 1 was used for each abundance estimate. The log-normal 95% confidence interval (CI) was computed for each abundance/density estimate because it was a product of estimates and tends to have a skewed distribution. The variance of $N_{i,j}$ was estimated as:

$$var(N_{i,j}) = N_{i,j}^{\ 2} \cdot \left\{ \frac{var(n_{i,j})}{n^2_{i,j}} + \frac{var(S_{i,j})}{S^2_{i,j}} + \frac{var\left[\hat{f}(0)\right]}{\left[\hat{f}(0)\right]^2} \right\}$$

The sampling unit was the length of the transect completed on-effort each day with BSS≤6. The formula used to estimate each component of the variance followed Buckland *et al*. (2001, 2004). Var($n_{i,j}$) was length-weighted and based on the variation in the number of on-effort group sightings between sampling units that ranged up to 239 km/day. Coefficients of variation (CV) were estimated as CV($N_{i,j}$) = $[\mathrm{var}(N_{i,j})]^{1/2}/N_{i,j}$ and CV(N_i) as:

$$CV(N_i) = \left\{ \sum_{j=1}^{3} CV(N_{i,j})^2 \right\}^{1/2} \Bigg/ \sum_{j=1}^{3} N_{i,j}$$

The perpendicular distance, *y*, for each sighting was estimated using bearing and reticle measurements. The reticle readings were converted to radial sighting distances (R) by the method of Lerczak and Hobbs (1998), using the formula y = R *sin(b)*, where b = angle between the sighting and the transect line. Estimates of $f_i(0)$ were made using a uniform, or half-normal model with exact PSD. Hazard-rate models were not included in the analysis due to their tendency to provide unreliable density estimates (Gerrodette and Forcada, 2005). Model selection was determined using Akaike's Information Criterion (AIC; Buckland *et al*., 2001, 2004).

Where abundance was estimated with a pooled $f_i(0)$, if the individual detection functions of each species within a category were indeed very similar, by pooling, var[$f_i(0)$] was probably underestimated, because var[$f_i(0)$] was based on an artificially high sample size. On the other hand, if the true detection functions of the species within a category are highly variable, var[$f_i(0)$] for an individual species may be overestimated.

The group sizes for some species tended to be related to *y*, because in many cases, larger groups are easier to see than small groups with increasing *y*. In general, the arithmetic mean of group size may be an overestimate of the true mean group size and could lead to positively biased density and abundance estimates. Therefore, a regression of group size by *y* was used to estimate an ''expected mean group size'' (program DISTANCE). The expected mean group size was used in the abundance estimate if it was significantly (P<0.15) smaller than the arithmetic mean group size. Var($S_{i,j}$) was the analytical variance for mean group sizes based on arithmetic means or was estimated as in Buckland *et al*. (2001, 2004) for expected mean group sizes.

2.2 ACOUSTIC SURVEY

The primary goal of the passive acoustics component of the MISTCS project was to detect and in some cases, localize vocalizations of cetaceans in the study area as a supplement to visually-based, line-transect methods. The passive acoustic techniques were designed to complement, but not interfere with visual line-transect methods. Acoustics are of particular value when sighting conditions are poor for example, during periods of bad weather, rough sea conditions, poor lighting conditions, and at night. Passive acoustic methods can be effective at detecting individual or small groups of animals for those species of cetaceans that are not easily detectable, or are easily missed by visual methods. Furthermore, passive acoustic methods can provide additional information about species identification, population identity, relative abundance, and distribution patterns. Finally, acoustically-based information about bearings and locations of animals can be useful when trying to visually locate, or relocate sightings. As the summaries of acoustic data in this report indicate, the towed hydrophone array effort and occasional sonobuoy deployments provided important additional information about cetacean distribution, relative abundance and species identity which would not have been possible with visual methods alone.

2.2.1 Acoustic Survey Methodology

2.2.1.1 Towed Array System

The 'wet-end' of the acoustic system consisted of a primary two-element hydrophone array and a secondary four-element array that were deployed behind the *M/V Kahana*. The two hydrophone elements located at the end of the primary array were spaced 3 m apart with approximately 400 m of lead-in cable (**Figure 2-2**). Both elements had an effectively flat (+/- 5 decibel [dB]) frequency response from approximately 100 Hertz (Hz) to 45 Kilohertz (kHz). The secondary four-element array had similar frequency-response characteristics with 3 m spacing between two pairs of elements situated near the front and back of the array, with 300 m spacing between the two pairs of hydrophones. Both towed arrays were spooled onto a hydraulically powered winch with spools that could be operated independently so that each array could be deployed and retrieved separately. Approximately 12-15 pounds (lbs) of lead weight were attached approximately 200 m from the tail end of the array to sink it to a suitable depth during towing. The hydrophone array was connected to a deck cable at the winch using a weatherproof electrical connector. The deck cable was fed into the acoustics lab situated where the dry-end (*i.e.* the processing and monitoring system) of the system was situated.

The two-element towed hydrophone array was deployed the majority of the time. Occasionally, it was supplemented with the secondary four-element hydrophone array. When both arrays were deployed, they were towed side-by-side approximately 3-4 m apart. This 'dual array' system allowed a variety of configurations resulting in greater receiving, processing, and localization capabilities.

The 'dry end' of the acoustic system consisted of hardware and software used for signal acquisition, conditioning, processing, recording and geographic plotting of bearings to detections (**Figure 2-2**). The components of this system are described below.

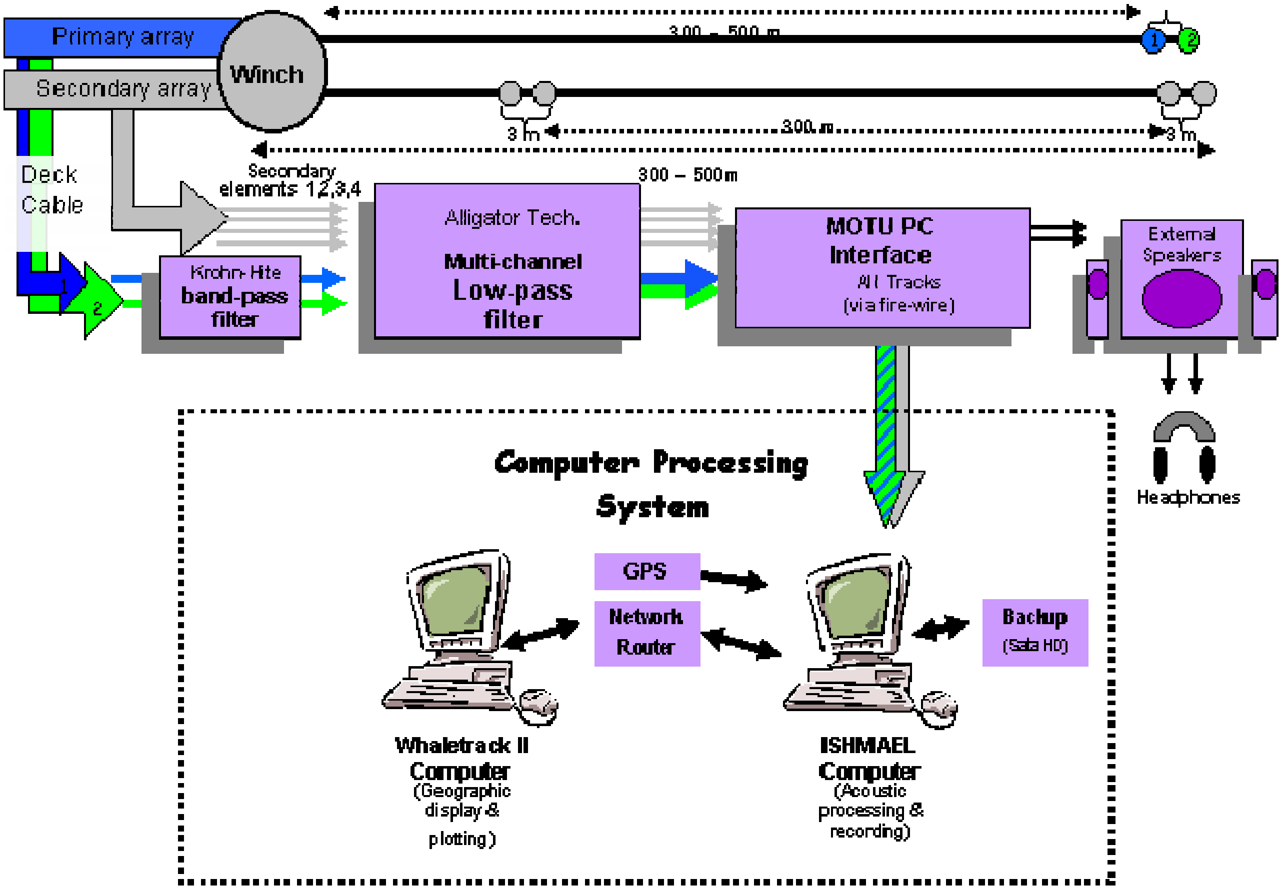


Figure 2-2. MISTCS Passive Acoustic Processing and Monitoring System

Signal Acquisition and Conditioning System

All channels of analog acoustic data from the hydrophones were passed through a low-pass filter system (Alligator Technologies, AAF-1 model) with a 48 kHz corner frequency (for anti-aliasing). A tuneable high-pass filter (Krohn-Hite model 3382) was used to reduce flow and self-vessel noise thereby increasing the effective dynamic range of the system. Corner frequencies of the high pass filter were set between 100 Hz and 500 Hz, depending on noise conditions. A PC digital audio interface (MOTU Traveler Model) was used to digitized the filtered hydrophone signals (@ 96 kHz sample rate) and pass them to a desktop computer via a fire-wire cable.

Signal Processing System and Recording System

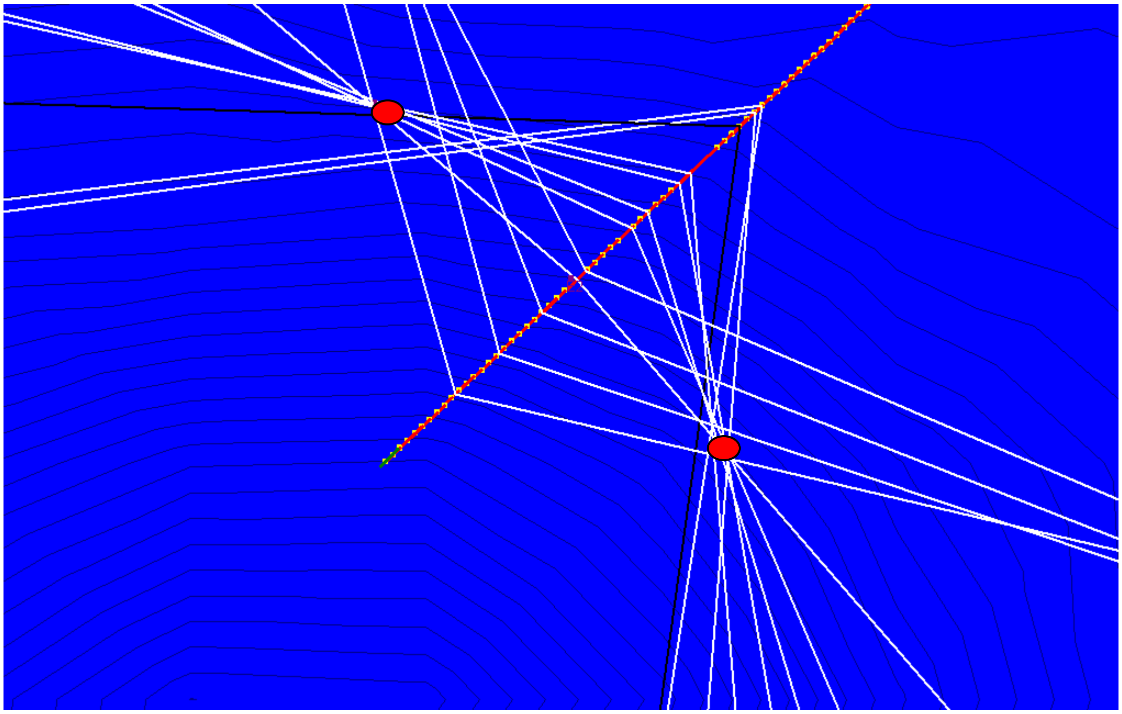
A desktop PC computer was dedicated for acoustic data acquisition recording and processing using ISHMAEL (Mellinger, 2001) sound localization and digital recording software. The version used for this project was modified specifically for use with our system and version of Whaletrack II software. Whaletrack II is geographic plotting and data-logging software developed by G. Gailey (Texas A&M University at Galveston, TX) and was customized for our system. A second laptop computer was dedicated to running Whaletrack II. Both the ISHMAEL and Whaletrack II computers were connected via an Ethernet router which was used to pass data between the two computers (**Figure 2-2**).

ISHMAEL was used to process, record, and estimate bearings of the acoustic data. ISHMAEL works by estimating the bearing to a signal (*e.g*. a whale call) that it is manually selected by a computer operator by drawing a window with a pointing device. Bearing estimates are relative to the location of the research vessel (or array location). Upon review by the operator, bearing and other relevant information is passed to Whaletrack II via the Ethernet connection.

During on-effort acoustic status, acoustic data from each hydrophone (typically 2) were recorded in real-time to computer hard-drives. This system is capable of real-time recording six channels acoustic data at the 96 kHz sample rate used in this study. Recordings were made continuously during all on-effort periods with file durations limited to 10 minutes to keep file sizes manageable. The times and dates of each file were saved in the filename to facilitate file management.

Whaletrack II software was used to plot bearings to animal calls that were passed from ISHMAEL. Whaletrack II also served to log geographic-location data that were acquired via a serial connection to a portable GPS (Garmin Map-76). Ship, location, track history, current heading and speed and an estimated position of the array were geographically displayed and logged by Whaletrack II using an MS Access database. Information about effort, acoustic contacts, settings of acoustic equipment (*e.g*. gain and filter cutoffs), and general comments were entered manually by the operator into Whaletrack II. All bearings plotted in Whaletrack II were saved in the databases with associated ancillary information. Bearings that were mistakenly sent by ISHMAEL to Whaletrack II were removed or edited by the operator as necessary. This useful feature allowed near real-time review and quality control of the data.

Bearings to the calls of an individual or a compact group of animals were plotted in the Whaletrack II geographic display window. A “sequential-bearing fix” technique (also called ‘target motion analysis’ Lewis, *et al*., 2007) was used to localize the animal or animal group. This technique involves sequentially plotting several bearings to a target (i.e. a calling animal) while moving past it on a linear course (**Figure 2-3**). The location of the animal(s) could then be estimated by the computer operator by visually assessing the point where the bearing lines converge. Using a pointing device, points were placed on the locations where the bearing lines to mark and save them to the database.



Example of left/right ambiguous acoustic localization of a sperm whale (Detection #144). Note that bearing lines converge on 2 points on either side of trackline. Red dots were manually placed by the software operator to indicate the two possible whale positions. Additional information (*e.g.*, from a second array) is necessary to resolve the left/right ambiguity.

Figure 2-3. Screen Capture of Localization

2.2.1.2 Towed Array Operations

The towed array system was operated by a team of two bioacousticians. Towed array operations typically were conducted from a few minutes after sunrise until a few minutes before sunset, coincident with the visual effort. In some circumstances, it was necessary to retrieve the array to allow greater maneuverability of the vessel when visually monitoring animals, but typically the array(s) remained deployed even when closing on animals. Occasionally, equipment maintenance or hardware problems resulted in slight delays in deployment.

2.2.1.3 Sonobuoy System

Two types of Navy surplus sonobuoys were available for deployment: AN/SSQ-53D (53D) and AN/SSQ-57B (57B). The 53D sonobuoys have an effective frequency response of 10 Hz to 2.5 kHz and transmit a multiplexed signal that includes the bearings of each signal. The 57B sonobuoys are omnidirectional with an effective frequency response of 10 Hz to 20 kHz. Both buoys were deployed, but the 57B's were the main type of sonobuoy used on this project.

Sonobuoy signals were received with a calibrated ICOM radio receiver (model types IC-PCR1000 or IC-R100). In some instances, two receivers were used to make two channel recordings from the same sonobuoy. This procedure was used to increase the probability of signal reception and also allowed different antennae types to be used. An omnidirectional (Cushcraft ringo-ranger model) radio antenna was used as the primary receiving antenna. This was supplemented with a directional multi-element yagi antenna. A pre-amp was placed inline at the receiver end of the antennae cable but was determined to be ineffective on the first leg, so was not used for the remainder of the cruise.

Sonobuoys were deployed during sighting events for "species of interest" (*e.g*. balaenoptrid whales, blackfish, and rarely encountered species). Occasionally, night operations were conducted in which sonobuoys were deployed to listen for animals while the research vessel was drifting or slowly motoring. There was no rigid protocol or sampling design for sonobuoy deployments. Each deployment was decided on a case-by-case basis depending on weather and sighting conditions, whether or not the animal had been positively identified, the “priority” of the species sighted, and other factors. In general, the sonobuoy was deployed as close to the target animal(s) as possible, taking into consideration the animal’s behavior, speed and direction of movement, as well as the ship’s course and the marine mammal observer activity.

Typically, sonobuoys were deployed during or near the end of an approach to a sighting in which the research vessel departed from the designated trackline to more closely investigate the sighting, usually for species identification or confirmation. Once the sighting was confirmed, or lost, the research vessel would return back to the designated trackline to resume visual observer effort. During this period, the vessel would steam away from the deployed sonobuoy usually at a speed of ~7-10 knots providing a brief opportunity to record vocalizations without excessive ship noise. In some instances, a request was made to turn or slow the vessel to better position it for sonobuoy deployment and reduce vessel noise during the monitoring and recording period. Whenever possible, a bioacoustician monitored the signals in real-time and took notes on the occurrence of biological signals of interest. Species identities were made to the highest taxonomic level possible.

2.2.2 Data Analysis

All acoustic detections from the towed array were reviewed and summarized daily at sea. They were again reviewed after the cruise was complete to confirm detections were unique and in some cases, to confirm species identifications. “Unique detections” were defined using the following criteria:

- How much time had passed between consecutive acoustic detections for a given encounter? Generally, 1 hour was used as a minimum time period.
- Were localizations to the sounds source made? If so, how far apart were they?
- If bearing angles were determined, were they different?
- Was the ship track straight, or was the ship off the trackline to investigate a sighting?
- Were any comments made (by the bioacoustian on watch) to indicate the detection was unique from the previous one?

There were no hard and fast rules for determining when a detection was unique as each encounter had different circumstances which needed to be considered. Localized sources were considered unique detections unless localizations were not geographically distinct.

2.3 OCEANOGRAPHY

Temperature data were collected using three instruments; a Thermosalinograph (TSG), Expendable Bathythermographs (XBTs) and a hand-held thermometer. Sea surface salinity data were gathered using the TSG, while water samples for chlorophyll *a* analysis were collected using a Fiedler Bucket. The TSG continually sampled during visual observation effort (daylight hours), while chlorophyll *a* sampling, sea surface thermometer readings, and XBT operations were conducted three times a day. During Leg 1, these operations were initially held at 0900; 1200 and 1500 local time but, due to TSG equipment issues, the 0900 and 1500 sampling times were soon shifted to include sunrise and sunset; congruent with visual observation effort. The oceanographic sampling rate is presented in **Table 2-1** below, showing the depth strategy of each operation.

Table 2-1. Oceanographic Sampling during the MISTCS Cruise

Sampling Rate	Operation	Sample Depths and Comments
~0640 until ~1815	MicroTSG Sampling	Continuous sea surface temperature and salinity sampling
~0640, 1200, ~1815	XBT (T10)	Temperature probes sampling the water column down to 200 meters
~0640, 1200, ~1815	Chlorophyll *a*	Surface "Fiedler" bucket samples
~0640, 1200, ~1815	Sea Surface Temperature reading	Surface water samples tested using a hand-held thermometer

2.3.1 Oceanography Methodology

2.3.1.1 Thermosalinograph (TSG)

For this survey the Sea-Bird Electronic (SBE) 45 MicroTSG Conductivity and Temperature Monitor was used. The SBE 45 MicroTSG is an externally powered, high-accuracy, conductivity and temperature monitor, designed for shipboard determination of sea surface (pumped-water) conductivity and temperature. Communication with the MicroTSG is over an internal, 3-wire, RS-232C link, providing real-time data transmission. Raw data are collected using the Sea-Bird SEASAVE (data acquiring) and SEATERM (instrument communication) programs.

The *M/V Kahana* is not equipped with a secure seawater intake system necessary for the TSG. Therefore one was constructed on the outside of the hull, which led onto the deck, through the railing, under the CONEX box and into the weather-protected TSG unit. Unfortunately, a temporary solution such as this was not adequate for the generally high sea state of the cruise and the pipe intake failed continually, which hampered the TSG data collection. In addition, when operable, the pipe was introducing air into the system, which interfered drastically with the conductivity measurements of the surface water. Nonetheless, when operable, the temperature and salinity of the surface waters were sampled every 10 seconds during visual observation effort.

2.3.1.2 Expendable Bathythermograph (XBT)

The Lockheed Martin Sippican, Inc. WinMK21 v2.7.1 program was used to collect XBT data. T10 XBT probes were used, surveying the water column between the surface and 200 m. These drops occurred at the beginning of effort, 1200, and end of effort, local time. For accurate drops, the ship needs to be moving at a constant speed and in a non-deviating direction. During simultaneous marine mammal sightings, these factors necessitated the delay of a few XBT drops until after a simultaneous mammal sighting.

2.3.1.3 Chlorophyll Surface Samples

Surface water samples were collected with the "Fiedler bucket" (a bucket attached to a rope and dropped into the sea over the side of the research vessel). These samples were collected in conjunction with an XBT.

The extractive non-acidification analysis method was used to determine chlorophyll *a* levels. Upon collection, the water sample was filtered through a Whatman glass fiber filter to collect the algal cells. The filter was then immersed in 10 milliliters (ml) of 90% acetone and stored in the refrigerator for 24 hours. These samples were subsequently analyzed using a Turner Design 10-AU Fluorometer and associated secondary solid standards. Incorrect filters were used during Leg I, resulting in incorrect chlorophyll values.

2.3.2 Data Analysis

2.3.2.1 Thermosalinograph (TSG)

As mentioned above, the Sea-Bird Electronic Inc. programs SEASAVE and SEATERM were used to collect and save the raw data. The SBE 45 TSG outputs data in engineering units that need to be changed to an ASCII format for analysis. Using the Sea-Bird Electronics Inc. Data Conversion module, the data is converted into the desired ASCII output. Applicable data [and units] converted using this module are temperature [ITS-90, deg C], conductivity [S/m] and salinity (practical salinity units [PSU]). Data filters were used to remove erroneous data caused by aeration in the shallow seawater intake system. However, such was the extent of bubbles entering the system that the filters were used conservatively to retain data. For this reason, little confidence should be placed in the salinity data gathered during this cruise.

No GPS interface box was incorporated into the TSG system. Therefore position coordinates were added post data collection. Procedures used were manual importing (Leg 1), SAS programming (Leg 2) and Matlab (Legs 3 and 4). GPS addition in this external way negated the use of the SBE SeaPlot module. Data were plotted using Reiner Schlitzer's Ocean Data View (ODV), Version 1.4 (AWI, 2003 http://www.awi-bremerhaven.de/GEO/ ODV).

2.3.2.2 Expendable Bathythermograph (XBT)

The WinMK21 v2.7.1 (Lockheed Martin Sippican, Inc., Marion, MA) program contains a data processing feature that allows for immediate data processing. Drops are confirmed by the user and visually checked for errors.

During post-processing, two WinMK21 modules may be used. The Noise Reduced module scans each individual data point for inconsistency of value between the data point and the previous data point. A user-defined noise spike threshold value ('4.0' as recommended by Lockheed Martin Sippican, Inc.) determines the acceptable difference between the relevant two points. Successive data points are compared to the last acceptable data point, and removed if their differences exceed the threshold. The Profile Averaging module is used to remove erroneous values from the data. Again the averaging range may be determined by the user and is 9.0 in this case, as recommended by Lockheed Martin Sippican, Inc. More importantly, no post-processing modules affect the raw data files.

However, during the MISTCS cruise, no data processing was necessary for the XBT data. All collected data points fell within the acceptable noise and averaging ranges, allowing for clean sea column profiles. These profiles were overlain over each other for comparison. As allowed by the Lockheed Martin Sippican, Inc. WinMK21 program, XBT drops were grouped in portion of 10 drops per display.

2.3.2.3 Chlorophyll Surface Samples

A recently developed chlorophyll sampling method (Welschmeyer, 1994), minimizes interferences from chlorophyll b and pheopigments and requires one fluorometric measurement and no acidification. The non-acidification method was chosen for this cruise because Arar and Collins (Revision 1.2, 1997) have documented it to be less susceptible to the above mentioned interfering compounds. Therefore discrete chlorophyll *a* samples were analyzed using the Welschmeyer method, documented as U.S. Environmental Protection Agency (EPA) Method 445.0 No Acidification extraction method. (See Welschmeyer, 1994; Turner Designs website at http://www.turnerdesigns.com/t2/esci/chlqa.html).

Analysis was completed using a Turner Design 10-AU Fluorometer, which was set to *Auto* read to allow for potential fluctuations in the chlorophyll levels. During each daily analysis, the fluorometer accuracy was confirmed using a Turner Design secondary solid standard and blank acetone sample used for control purposes.

After the recommended 24-hour extraction period, the sample filters, contained within 10 ml of 90% acetone, were removed from the refrigerator. The vials were allowed to return to within

±2°C of 20°C (68°F), in this case actual room temperature of the ship's lab. Once warm, the sample was decanted into the appropriate cuvettes for analysis in the fluorometer.

The following equation for this method (EPA Method 445.0, 1997) was used to calculate the actual chlorophyll *a* concentrations from the fluorometric data:

$$\text{chl } a = (F_o \times v)/V$$

Where:

F_o = fluorescence signal of sample

v = extract volume (L)

V= volume filtered (L)

Data were plotted using Reiner Schlitzer's Ocean Data View (ODV), Version 1.4 (2003 – http://www.awi-bremerhaven.de/GEO/ ODV).

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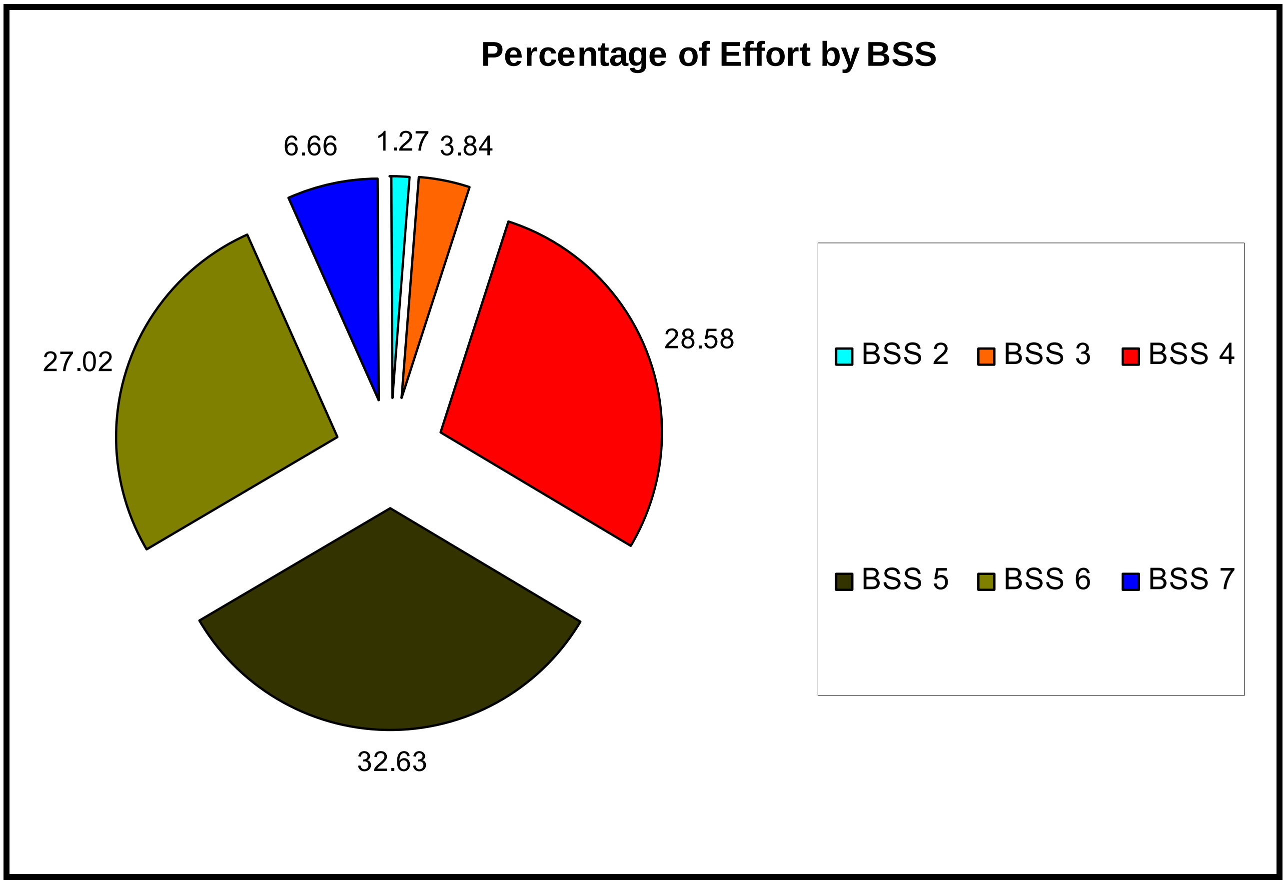
3 SURVEY RESULTS

3.1 VISUAL OBSERVATIONS

3.1.1 Survey Effort

Observers visually surveyed 11,033 kilometers (km) (6,063 nautical miles [nm]) of trackline during the Mariana Island Sea Turtle and Cetacean Survey (MISTCS) cruise. On-effort kilometers ranged from 2,200 km (Leg 3) to 3,300 km (Leg 4). The survey trackline coverage was adequate given the high sea states (**Figures 3-2 through 3-6**). **Figure 3-1** provides the percentage of overall survey effort by Beaufort sea state (BSS). Survey effort was stopped at BSS≥7. The original intent was to stop visual effort at BSS>5; however, the poor sea conditions would have prevented any survey effort on several days during Legs 1 and 2. Leg 3 was stopped after 2 days due to BSS>7; we returned to Guam during the poor weather and resumed the survey after 4 days. Leg 4 was affected by Typhoon Kong-Rey, but effort continued in the western portion of the study area to avoid the typhoon's greatest impacts. All survey effort and sightings in BSS≤6 were included in density estimation analyses.

Figure 3-1. Percentage of Survey Effort Separated by Beaufort Sea State (BSS)



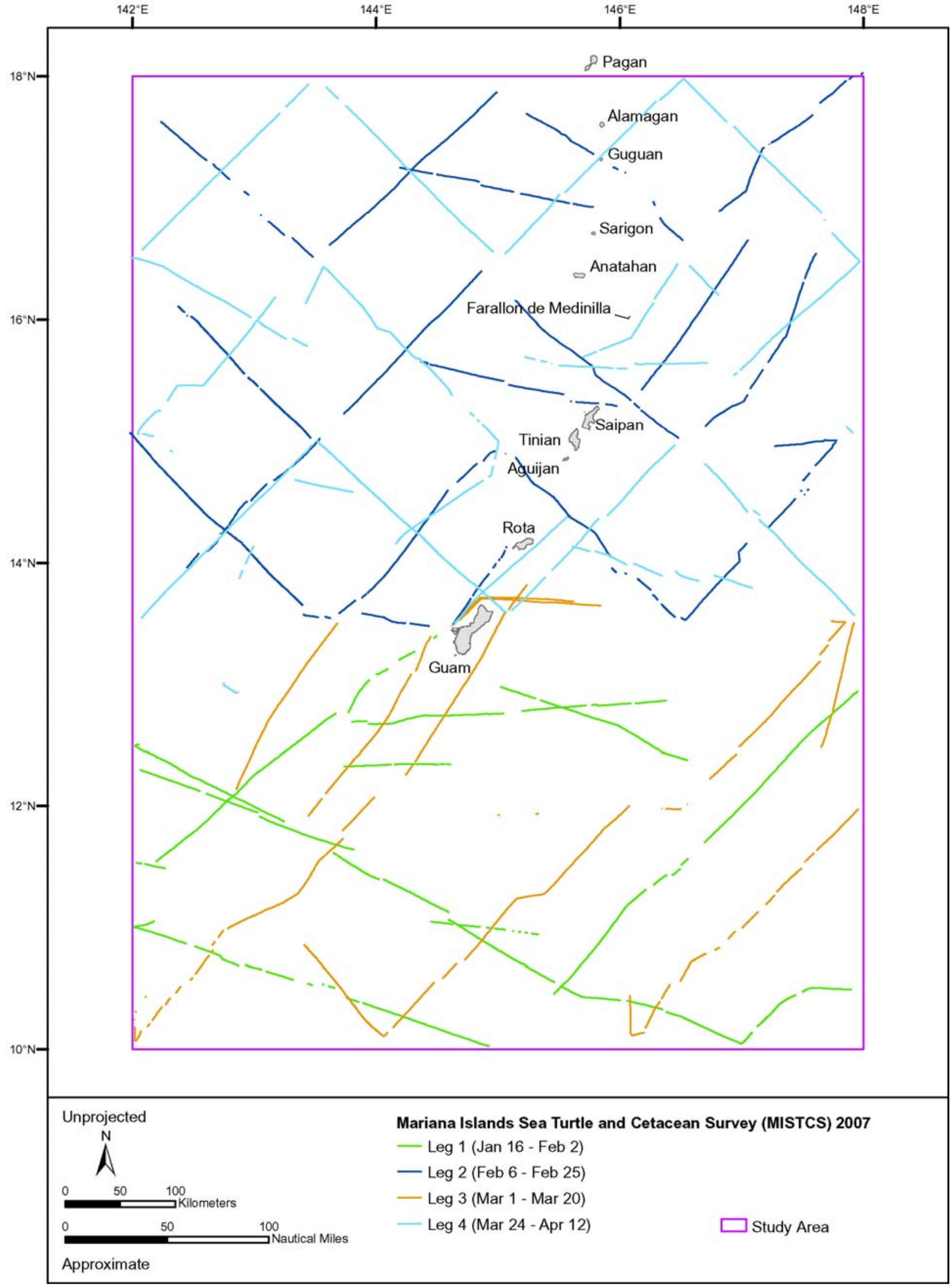


Figure 3-2. All On-Effort Survey Tracklines (11,033 km) Conducted for the MISTCS Cruise

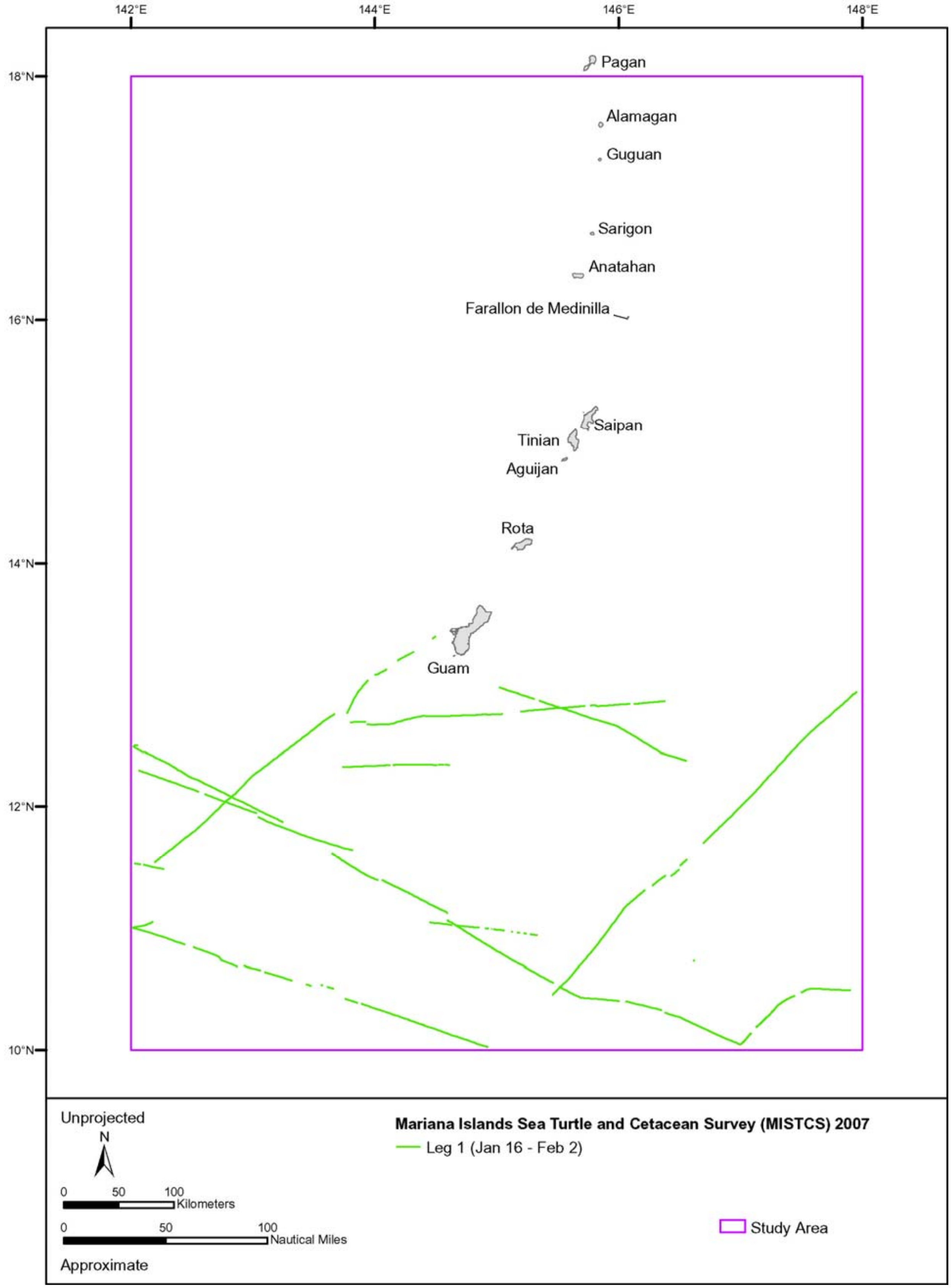


Figure 3-3. Leg 1 On-Effort Survey Tracklines (2,535 km) Conducted for the MISTCS Cruise

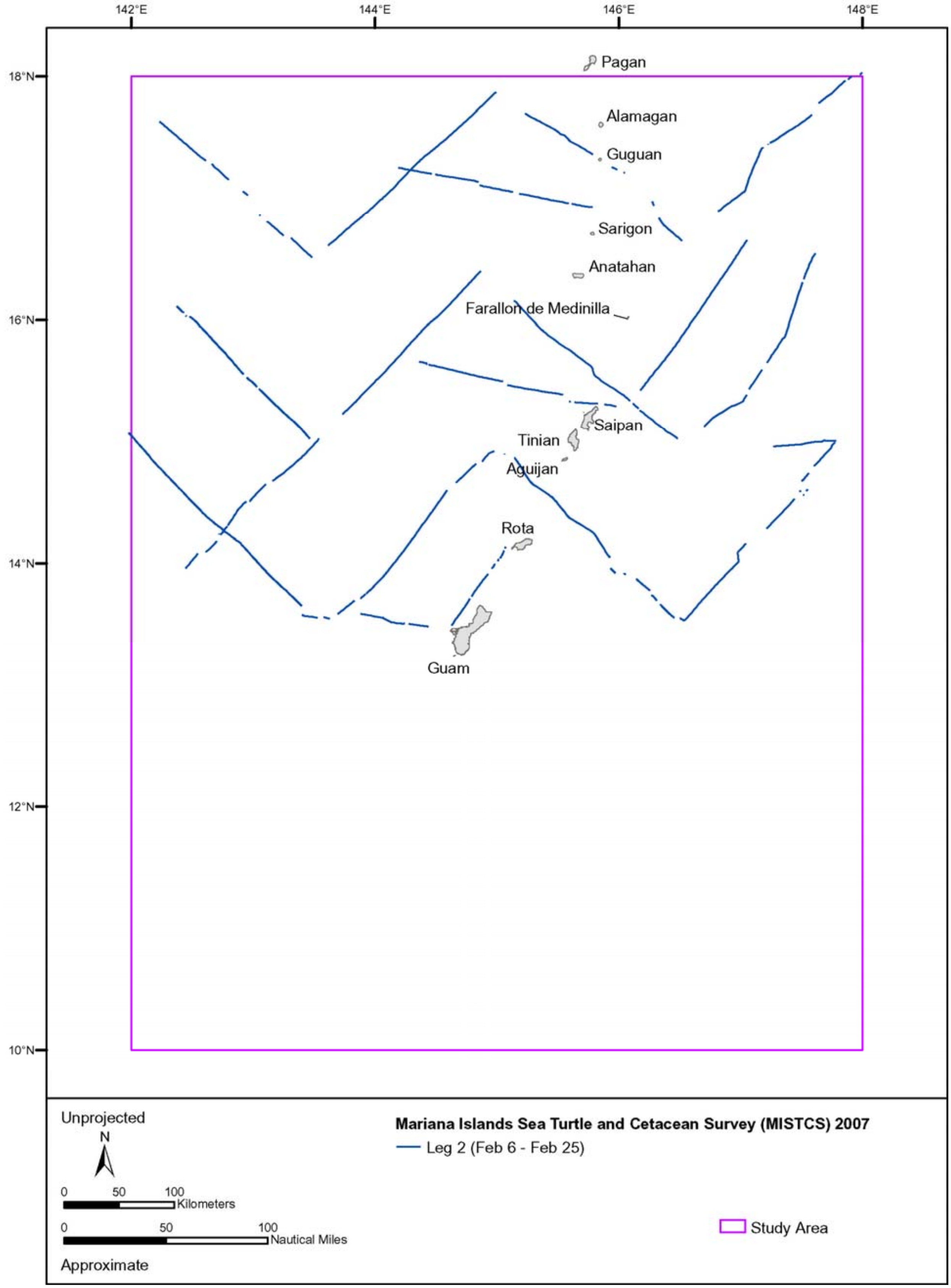


Figure 3-4. Leg 2 On-Effort Survey Trackline (2,999 km) Conducted for the MISTCS Cruise

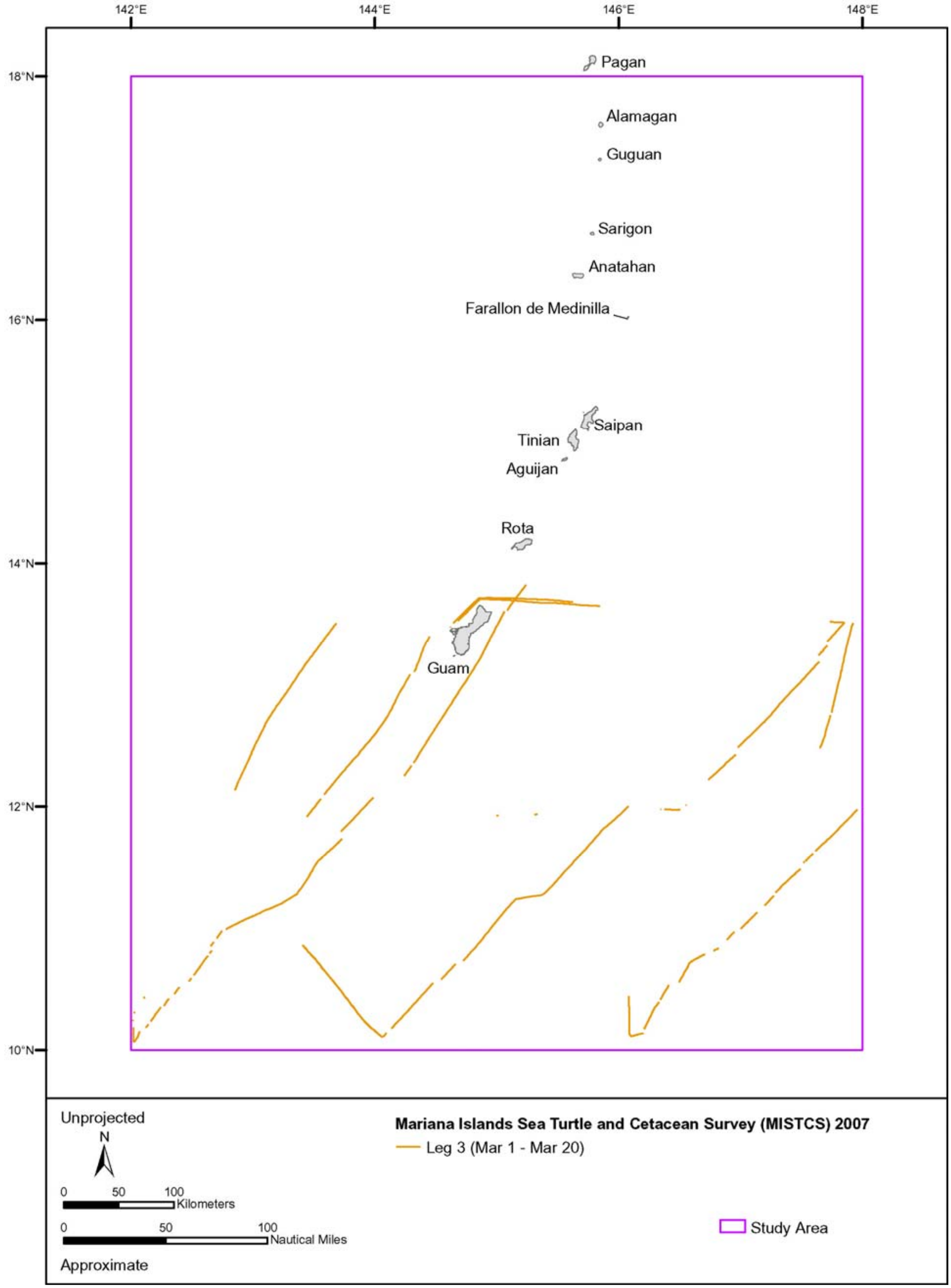


Figure 3-5. Leg 3 On-Effort Survey Tracklines (2,200 km) Conducted for the MISTCS Cruise

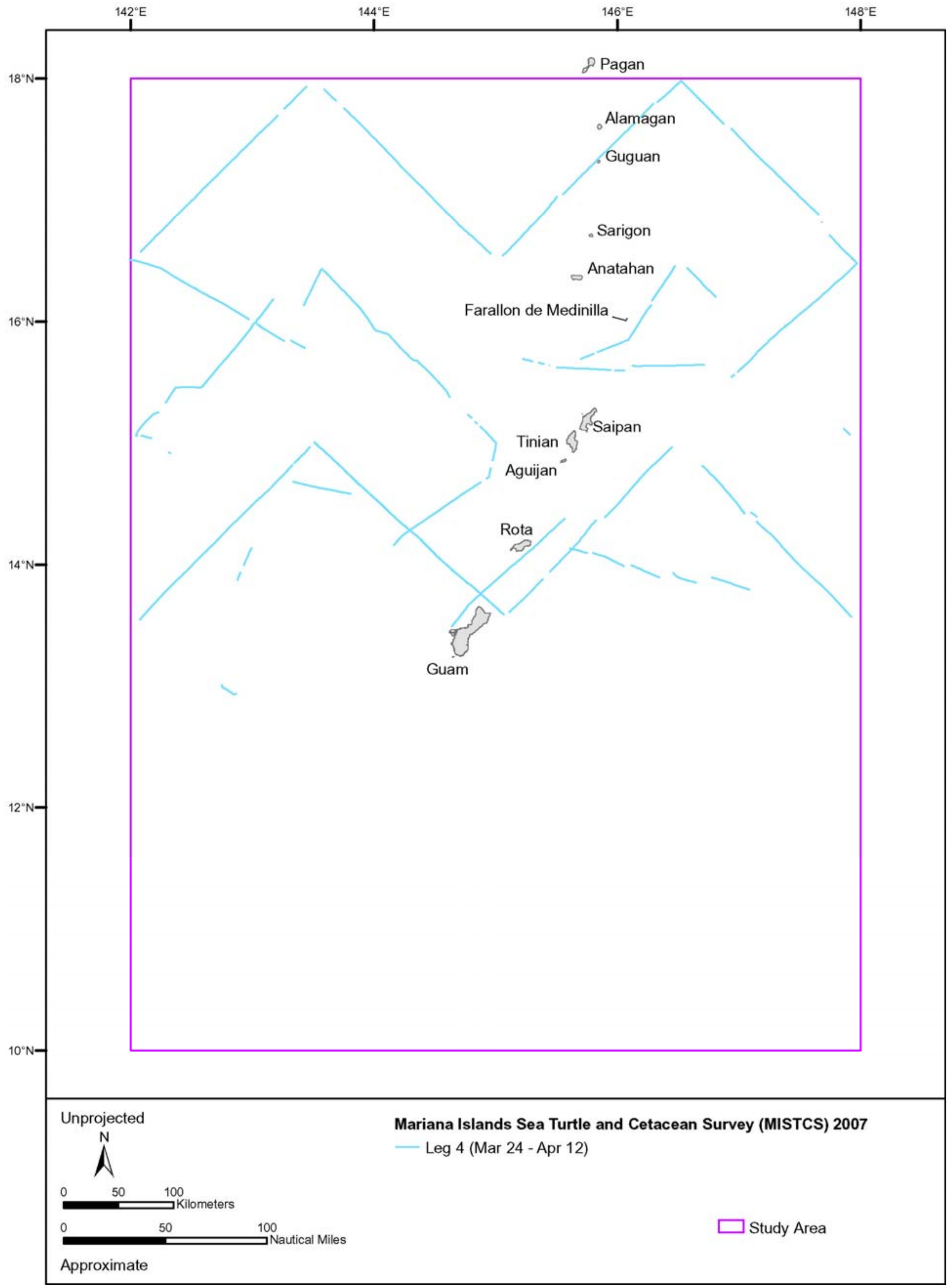


Figure 3-6. Leg 4 On-Effort Survey Tracklines (3,300 km) Conducted for the MISTCS Cruise

3.1.2 Sightings

There were 149 total sightings of 13 individual species; 148 of the sightings were of cetaceans (12 individual species). Only one sea turtle species, the hawksbill turtle (*Eretmochelys imbricata*) was sighted on Leg 4. Out of the 148 cetacean sightings, 121 were on-effort (**Table 3-1**). The sperm whale was the most frequently seen species (n = 21) followed by the Bryde's and sei whales (n = 18 and 16, respectively). The pantropical spotted dolphin was the most frequently encountered delphinid species (n = 16) followed by the false killer whale and the striped dolphin (both n = 10). Other cetaceans (including beaked whales and unidentified [UID] cetaceans) were sighted throughout the study area (**Figures 3-7 – 3.13**) and are summarized in **Table 3-1.**

Table 3-2 provides a summary of all marine mammals sighted during the survey. The table includes the GPS location, species description, behavior, group size, reaction and attitude to the vessel, direction relative to the travel of the ship, distance (in meters) from the ship, and comments. **Appendix A** provides a comprehensive summary of all information recorded for each sighting.

Group size varied by species and ranged from 1 to 115 individuals (**Table 3-3**). Range of bottom depth for sightings was highly variable (144-9,874 m) and was species-dependent (**Table 3-3**). Several sightings occurred over or in the near vicinity of the Mariana Trench (**Figures 3-8 – 3-13)**.

There were also three sightings of beaked whales (two *Mesoplodon* spp. and one ziphiid whale; **Figure 3-14**). On 18 February 2007, we did a focal study off Saipan of humpback whales (that included photo-identification efforts) that had been acoustically-detected the previous night. This day was considered off-effort and included two additional sightings of sperm whales, one sighting of pantropical spotted dolphins, and a sighting of unidentified small delphinids (**Table 3-1; Figure 3-14**). **Appendix A** provides a detailed discussion of the distribution and habitat preferences of the marine species sighted during the survey.

A single hawksbill turtle was sighted on Leg 4, 285 km WSW off the island of Anatahan (north of Farallon de Medinilla [FDM]) (**Figure 3-15**). The sighting took place over the West Mariana Ridge (an area of seamounts), with a bottom depth of 2,716 m.

Table 3-1. Summary of Visual Sightings by Species

Scientific Name	Common Name	On-Effort	Off-Effort	Total
*_Balaenoptera borealis_	Sei Whale	11	5	**16**
Balaenoptera edeni	Bryde's Whale	16	2	**18**
Balaenoptera borealis/edeni		3	0	**3**
Balaenoptera spp.		8	2	**10**
*_Physeter macrocephalus_	Sperm Whale	19	2	**21**
Globicephala macrorhynchus	Short-finned Pilot Whale	4	1	**5**
Peponocephala electra	Melon-headed Whale	2	0	**2**
Feresa attenuata	Pygmy Killer Whale	1	0	**1**
Peponocephala/Feresa		1	1	**2**
Pseudorca crassidens	False Killer Whale	6	4	**10**
Stenella attenuata	Pantropical Spotted Dolphin	13	3	**16**
Stenella coeruleoalba	Striped Dolphin	10	0	**10**
Stenella longirostris	Spinner Dolphin	1	0	**1**
Steno bredanensis	Rough-toothed Dolphin	1	1	**2**
Tursiops truncatus	Common Bottlenose Dolphin	3	1	**4**
Tursiops/Steno		1	0	**1**
Mesoplodon spp.	Beaked Whale	2	0	**2**
Ziphiid whale	Beaked Whale	1	0	**1**
UID small delphinid		11	2	**13**
UID medium delphinid		1	0	**1**
UID large delphinid		1	0	**1**
UID dolphin		0	1	**1**
UID small whale		1	0	**1**
UID large whale		1	3	**4**
UID whale		1	0	**1**
UID cetacean		1	0	**1**
*_Eretmochelys imbricata_	Hawksbill Turtle	1	0	**1**
Total		**121**	**28**	**149**

Sightings (off-effort) from the Humpback Whale Focal Study on 18 February 2007

Scientific Name	Common Name	Leg 2
*_Megaptera novaeangliae_	Humpback Whale	**1**
*_Physeter macrocephalus_	Sperm Whale	**2**
Stenella attenuata	Pantropical Spotted Dolphin	**1**
UID small delphinid		**1**

*Asterisk indicates species protected under the Endangered Species Act.
All on- and off-effort sightings are included. Multi-species sightings are not delineated.

Table 3-2. Marine Mammal and Sea Turtle Sighting Record

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
1	1/18/07	2	UID small delphinid	3	6	90	200	3	5	11.41	142.57	
2	1/18/07	2	*B. borealis*	3	5	0	50	1	2	11.34	142.83	
3	1/20/07	2	*B. borealis*	5	5	170	100	1	2	10.67	147.02	
4	1/20/07	2	*B. borealis*	1			75	1	2	10.56	147.66	
5	1/21/07	1	*B. borealis*	1	4	90	18	1	2	10.47	147.50	
6	1/21/07	1	*P. macrocephalus*	1	4	180	125	5	5	10.19	147.13	
7	1/21/07	2	UID rorqual	1	5	180	1,000			10.16	147.11	
8	1/22/07	1	UID cetacean	1	4	130	1,500			10.52	145.51	
9	1/23/07	2	*S. attenuata*	25	6	140	40	1	3	11.76	143.42	
10	1/23/07	2	*T. truncatus*	12			1	1	2	11.84	143.28	
11	1/24/07	1	*S. attenuata*	2.3	2	270	1	1	2	12.21	142.56	
11	1/24/07	1	*P. electra*	112.7	2	270	1	1	2	12.21	142.56	
12	1/25/07	1	*B. borealis*	3			20	1	2	12.70	143.92	
13	1/25/07	1	UID whale	1			2,000			12.76	145.04	Acoustics had minke whales in area
14	1/26/07	1	*P. macrocephalus*	1			50	1		12.84	146.09	
15	1/27/07	1	*S. attenuata*	25	4	200	50	1	5	11.70	146.09	Porpoising, low swimming, leaping
16	1/28/07	1	*B.edeni*	1			70	3	3	11.52	146.51	
17	1/28/07	1	*B. borealis*	1			100	1	2	11.43	146.43	
18	1/28/07	1	*B. borealis*	1	4	270	50	1	2	11.35	146.28	
19	1/29/07	1	*S. attenuata*	85	5	120	150	3	1	10.38	1438.9	Splashing, changed directions at 1.6 kms
20	1/29/07	1	*B.edeni*	1	4	300	400	2	3	10.42	143.76	
21	1/29/07	2	UID dolphin	1	2	180	300	3	6	10.52	143.60	Animal was first seen close to ship; unknown if animals approached or not; evasive after turn
22	1/29/07	1	*B. edeni/borealis*	1			500	3	5	10.53	143.57	
23	1/30/07	1	*B.edeni*	1			50	2	3	10.56	143.40	
24	1/30/07	1	*B. borealis*	1			100	1	2	10.64	143.10	Not as interested in the ship as past sei whales
25	1/30/07	2	*S. attenuata*	175			50	1	1	10.70	142.90	Animals leaping; change direction at 2,000-300 m
26	1/30/07	1	UID small delphinid	10	5	30	920	3	5	10.84	142.51	Low-swimming animals

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
27	1/31/07	1	*P. macrocephalus*	1			2,000			11.91	143.05	
28	1/31/07	1	UID small delphinid	3			920			12.10	142.60	
29	2/1/07	1	*B. borealis*	1	8	0	50	1	2	12.34	144.51	
30	2/1/07	1	*B. borealis*	2			100	1	2	12.34	144.56	Approached the ship, then followed the array
31	2/8/07	1	UID large whale	1			8,200			18.03	148.00	
32	2/8/07	1	*P. macrocephalus*	1	4	280	100			17.98	147.88	
33	2/8/07	1	UID small delphinid	0			8,300			17.78	147.64	
34	2/8/07	1	*P. macrocephalus*	3			400			17.45	147.23	Tail-slapping, spy-hopping, breaching, multiple whales visual and acoustics
35	2/9/07	2	*S. bredanensis*	7	5	90	40	1	2	17.29	145.83	Approached boat at about 250 m
36	2/9/07	1	*P. macrocephalus*	4			300			17.47	145.60	Mom/calf pair; maybe other animals
37	2/9/07	1	UID ziphiid	2	2	160	1,500			17.53	145.53	
38	2/11/07	1	*S. coeruleoalba*	39	3	270	100	1	1	16.67	143.31	Low swimming – ran from boat at ~1,300 m
39	2/11/07	1	*Mesolplodon* spp.	2	3	160	920			16.67	143.27	
40	2/11/07	1	*S. attenuata*	14	6	20	150	1	1	16.81	143.12	Evasive movement at ~2,100 m
41	2/11/07	2	*G. macrorhnychus*	25	0	0	40	3	3	17.11	142.85	Animals milling about and when approached, appeared relaxed and indifferent
42	2/11/07	1	UID small delphinid	6			3,400			17.28	142.66	
43	2/12/07	1	*P. macrocephalus*	4	2	90	150			17.05	145.13	Large and small animals; only large one fluked
44	2/12/07	2	*P. macrocephalus*	5	3	180	920			17.03	145.25	
45	2/12/07	1	*T. truncatus*	3	4	250	3,000	3	4	15.44	147.07	Animals were leaping
46	2/14/07	1	*Tursiops/Steno*	2	3	270	50	1	4	15.26	146.17	Low swimming and approached boat at ~300 m
47	2/14/07	1	*S. coeruleoalba*	31	4	350	100	2	3	15.96	145.32	
48	2/15/07	1	*Peponocephala/Feresa*	17	2	190	2,300	2	4	16.05	144.54	Low swimming
49	2/16/07	1	*S. coeruleoalba*	10	5	180	100	1	1	16.03	142.48	Stealthy behavior animals reacted at ~920 m
50	2/16/07	1	*S. coeruleoalba*	14	5	90	100	2	1	16.03	142.45	Tail slaps
51	2/16/07	1	*Mesolplodon* spp.	2	2	200	600			16.06	142.43	

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
52	2/16/07	1	*P. crassidens*	10	4	160	1	2	4	16.11	142.37	Animals approached boat at ~300 m; may have initially ran from boat at 2,800 m and low swimming
53	2/17/07	1	UID med. delphinid	2	2	180	800	2	5	15.65	144.42	
54	2/17/07	1	UID small delphinid	1	3	290	1,450			15.50	145.04	
55	2/17/07	1	*P. macrocephalus*	25	2	0	300			15.39	145.04	Possible mom/calf pairs; not approached close enough; smaller animals did not fluke
56	2/17/07	1	*S. longirostris*	135	5	90	1	2	2	15.31	145.83	Animals leaping/spinning. Approached boat and rode bow; spinning juveniles in group
57	2/18/07	2	UID small delphinid	8	5	45	6,000			15.38	145.91	
58	2/18/07	2	*M. novaeangliae*	8	2	90	200			15.39	145.89	
59	2/18/07	2	*S. attenuata*	5	5	100	1	1	2	15.13	145.64	
60	2/18/07	1	*P. macrocephalus*	11.5			40			15.08	145.56	At least 2 cow/calf pairs in the group
61	2/18/07	1	*P. macrocephalus*	16			2,000			15.02	145.45	
62	2/19/07	1	*S. coeruleoalba*	13	6	200	6,400	2	1	14.68	147.51	Aerial activity, porpoising; running from boat at about 5,400 m
63	2/19/07	2	*B. borealis*	1			50	3	2	14.64	147.56	
64	2/19/07	2	UID rorqual	1			3,700			14.64	147.57	
65	2/19/07											Deleted record
66	2/19/07	1	*P. crassidens*	5			50	2	2	14.59	147.49	Milling, foraging? Checking out array; animals approached boat at 2,600 m
67	2/20/07	1	*B.edeni*	2			100		4	14.09	146.98	Cow/calf pair; small calf; swimming in calf position
68	2/20/07	2	*P. crassidens*	6.02	6	320	100	2	2	13.74	146.27	
68	2/20/07	2	*B. borealis*	0.98				2	2	13.74	146.27	
69	2/20/07	1	*B.edeni*	1	4	240	40		3	13.87	146.15	
70	2/20/07	1	*S. coeruleoalba*	35			1,360	3	1	13.92	146.05	Reaction strongest at 1,360 m; began running at ~4,000m
71	2/21/07	1	*P. macrocephalus*	6			0	1	1	14.86	145.14	This is the group which had the animal that rammed us.
72	2/21/07	1	*P. macrocephalus*	1			600			14.90	145.06	
73	2/21/07	1	*B. borealis*	1			40	1	2	14.84	144.88	
74	2/21/07	1	UID large delphinid	5	2	300	2,800			14.66	144.67	

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
75	2/22/07	1	UID rorqual	1			7,200			14.02	144.17	
76	2/22/07	1	*B.edeni*	2	2	180	150	2	3	13.72	143.88	Very small calf
77	2/22/07	1	UID rorqual	1			400			13.60	143.71	
78	2/22/07	1	*S. coeruleoalba*	50	4	320	200	1	1	13.56	143.58	Low swimming 1,000m; run from boat 400 m; split 400 m; 400 m strongest response
79	2/22/07	1	Unid large whale	1			4,400			13.58	143.40	
80	2/24/07	1	*S. attenuata*	30	2	90	100	1	1	14.68	143.17	Strongest reaction 400 m; run from boat at 100 m; low swimming 300 m
81	2/24/07	1	*S. attenuata*	40			250	2	4	14.51	142.97	Low swimming 1,500 m; run from boat at 300 m; milling moderate travel
82	2/24/07	1	UID rorqual	1	6	110	5,800			14.31	142.79	
83	2/24/07	1	*S. attenuata*	26	6	270	200	1	1	14.30	142.79	Ran from boat at 920 m
84	2/24/07	2	*B.edeni*	1	4	180	800		3	14.23	142.73	
85	2/24/07	1	*S. coeruleoalba*	30	4	270	300	2	1	14.24	142.72	Animals porpoising, leaping; reacted to ship at 1,400 m; low swimming not sure if due to vessel
86	2/24/07	1	*B.edeni*	3			50		3	14.10	142.61	Animals appeared to be feeding by skimming the surface
87	2/24/07	1	*B.edeni*	2			50		3	13.96	142.45	Cow/calf pair
88	2/25/07	1	*B. edeni/borealis*	1			40			13.55	144.07	
89	2/25/07	1	UID small delphinid	1	6	350	6,000			13.49	144.36	
90	2/25/07	1	*P. crassidens*	14			1	1	4	13.48	144.42	Animals seen outside Apra Harbor on way into port
91	3/3/07	2	UID small delphinid	0			600			12.51	147.38	
92	3/8/07	1	*P. macrocephalus*	9			500			13.48	144.62	Animals seen 2 miles from shore
93	3/8/07	1	UID small delphinid	1	6	90	2,900			13.65	145.82	
94	3/9/07	1	*S. coeruleoalba*	15	2	280	300	2	1	13.36	147.72	Light evasion; ran from boat at 1,600 m slow; fast at 760 m
95	3/9/07	1	*S. coeruleoalba*	12	5	100	350	2	1	13.25	147.64	Ran from boat at 200 m; school slip at 1,000 m
96	3/9/07	1	UID small delphinid	8	7	250	760	1	1	12.49	146.98	Evasive movement at ~2,600 m
97	3/11/07	1	*P. electra*	135	3	350	1	3	2	13.11	144.33	Animals approached the boat at ret. 8
98	3/13/07	2	*P. crassidens*	7	8	0	50	1	2	11.63	147.61	

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
99	3/13/07	2	*P. crassidens*	5	3	140	30	1	2	11.55	147.53	
100	3/13/07	1	*P. crassidens*	2	4	200	2,900	2	5	11.55	147.52	Low swimming 4,660
101	3/13/07	1	*P. crassidens*	11	4	240	10	2	2	11.29	147.29	Milling, associated swimming; approach, strongest reaction 300 m
102	3/13/07	1	*B.edeni*	1.98			50	1	4	11.19	147.20	Animals within 100 m or each other began approaching boat at ~500 m
102	3/13/07	1	*B. borealis*	1.02			50	1	4	11.19	147.20	Animals within 100 m or each other began approaching boat at ~500 m
103	3/13/07	1	*B.edeni*	2			100	3		11.00	147.00	
104	3/13/07	1	*B.edeni*	1			70			10.92	146.90	Large shark with associated tuna breezer
104	3/13/07	1	*B. edeni/borealis*	1			70			10.92	146.90	Large shark with associated tuna breezer
105	3/14/07	1	*B. borealis*	2			40	3	2	10.81	146.78	
106	3/14/07	1	*S. attenuata*	95.04			920	2	3	10.56	146.50	
106	3/14/07	1	UID rorqual	0.96			2,000			10.56	146.50	
107	3/14/07	1	UID small whale	1			560			10.42	146.35	
108	3/14/07	1	*B.edeni*	1			50		3	10.18	146.21	
109	3/14/07	1	*P. crassidens*	5	4	30	100	1	2	10.50	146.08	Animals approached boat at 200 m and were also low swimming, milling slow travel
110	3/16/07	1	*S. attenuata*	45			70	2	3	10.58	144.54	Behavior change to slow travel moderate travel milling and approaching at 300 m; split 100 m
111	3/16/07	1	*G. macrorhynchus*	15.2						10.18	144.14	
111	3/16/07	1	*S. bredanensis*	4.8	3	220	40	1	2	10.18	144.14	Steno split at 300 m; group approached at 5.2 ret, pilot and bottlenose stayed together
111	3/16/07	1	*T. truncatus*	60						10.18	144.14	
112	3/17/07	1	*P. crassidens*	7	2	250	0	2	2	11.80	143.72	Animals rode bow and approached boat at 300 m, low swimming; 0.8 ret
113	3/17/07	1	*P. macrocephalus*	1	2	300	1,770			11.00	142.80	
114	3/17/07	1	Unid small delphinid	4	5	270	560			10.92	142.70	
115	3/18/07	1	*P. macrocephalus*	6	2	0	2,800			10.57	142.48	
116	3/18/07	1	*S. attenuata*	25	4	190	0	1	2	10.55	142.42	Approached boat at 1,100 m

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
117	3/18/07	1	*P. macrocephalus*	8						10.48	142.37	
118	3/18/07	2	*S. attenuata*	20	3	270	150	2	3	10.46	142.35	Low swimming at 300 m
119	3/18/07	2	*B.edeni*	1			200			10.36	142.27	
120	3/18/07	1	*P. macrocephalus*	1			6,800			10.24	142.16	
121	3/18/07	1	*S. attenuata*	9	5	270	1,000	2	1	10.18	142.12	Low swimming
122	3/18/07	1	*B. edeni/borealis*	1						10.18	142.02	
123	3/18/07	1	UID rorqual	1						10.25	142.01	
124	3/18/07	1	*B.edeni*	2			40	2	1	10.31	142.03	Low swimming underwater blowing near ship (80 m)
125	3/18/07	2	*P. macrocephalus*	2			920			10.39	142.10	
126	3/18/07	1	*T. truncatus*	11.88			0	1	2	10.43	142.11	
126	3/18/07	1	*P. macrocephalus*	24.12			80	1	2	10.43	142.11	Both of these groups exhibited spy-hopping, breaching, and were closely associated – very calm
127	3/20/07	1	*G. macrorhnychus*	7	3	180	50	2	3	13.62	145.08	
128	3/20/07	1	*F. attenuata*	6			150	2	3	12.37	144.32	Approach 200 m briefly, low swimming 200 m
129	3/25/07	1	UID small delphinid	3	5	90	4,400			16.71	147.74	
130	3/26/07	1	*P. macrocephalus*	3			1,100			16.82	147.68	
131	3/26/07	1	UID rorqual	1			4,150			17.59	146.94	
132	3/27/07	1	*B.edeni*	1			400			17.05	145.55	
133	3/28/07	1	*G. macrorhnychus*	9	3	60	50	3	3	17.76	143.75	Milling; seemed preoccupied with something other than the ship
134	3/29/07	1	*G. macrorhnychus*	7	5	35	1,050			17.75	143.26	
135	3/30/07	1	UID large whale	1			5,800			16.02	142.97	
136	3/30/07	1	*B.edeni*	2	4	240	100			15.84	143.26	Cow/calf pair
137	3/31/07	1	*P. macrocephalus*	14	3	100	200			15.60	146.06	
138	4/2/07	1	*S. attenuata*	20	6	260	400	2	3	16.17	146.29	Rough seas and not able to continue working the animals
139	4/8/07	1	*S. attenuata*	36	6	0	200	1	1	14.10	145.75	Low-swimming animals
140	4/8/07	1	UID rorqual	1			3,930			13.99	146.05	
141	4/8/07	1	UID rorqual	3			2,820			13.99	146.34	
142	4/8/07	1	*B.edeni*	3			20		4	13.85	146.65	3 or 4 animals, lots of underwater blows; mixed characteristics; sei/Bryde's; interested in array

#	Date	Effort	Species	Group Size	Movement	Direction	Distance (m)	Reaction	Attitude	Latitude	Longitude	Comments
143	4/9/07	1	*B. borealis*	2			350	3	4	14.43	147.10	Possible cow/calf pair; maybe 3 animals
144	4/10/07	1	*P. macrocephalus*	1			500			14.39	145.90	
145	4/10/07	2	*Peponocephala/Feresa*	5	6	160	1,470	3	5	14.38	145.87	
146	4/10/07	1	UID small delphinid	10	4	330	3,300	3	5	13.94	145.45	Low swimming at 3,570 m

*Direction is relative to travel of the ship (in degrees)

Behavior Codes:

Effort: 1 = on-effort; 2 = off-effort

Reaction to Vessel: 1 = yes; 2 = no; 3 = unknown/cannot be determined; 4 = other (please explain)

Attitude (Reaction to Vessel): 1 = evasive; 2 = non-evasive – attracted; 3 = non-evasive – indifferent; 4 = both; 5 = cannot be determined; 6 = other.

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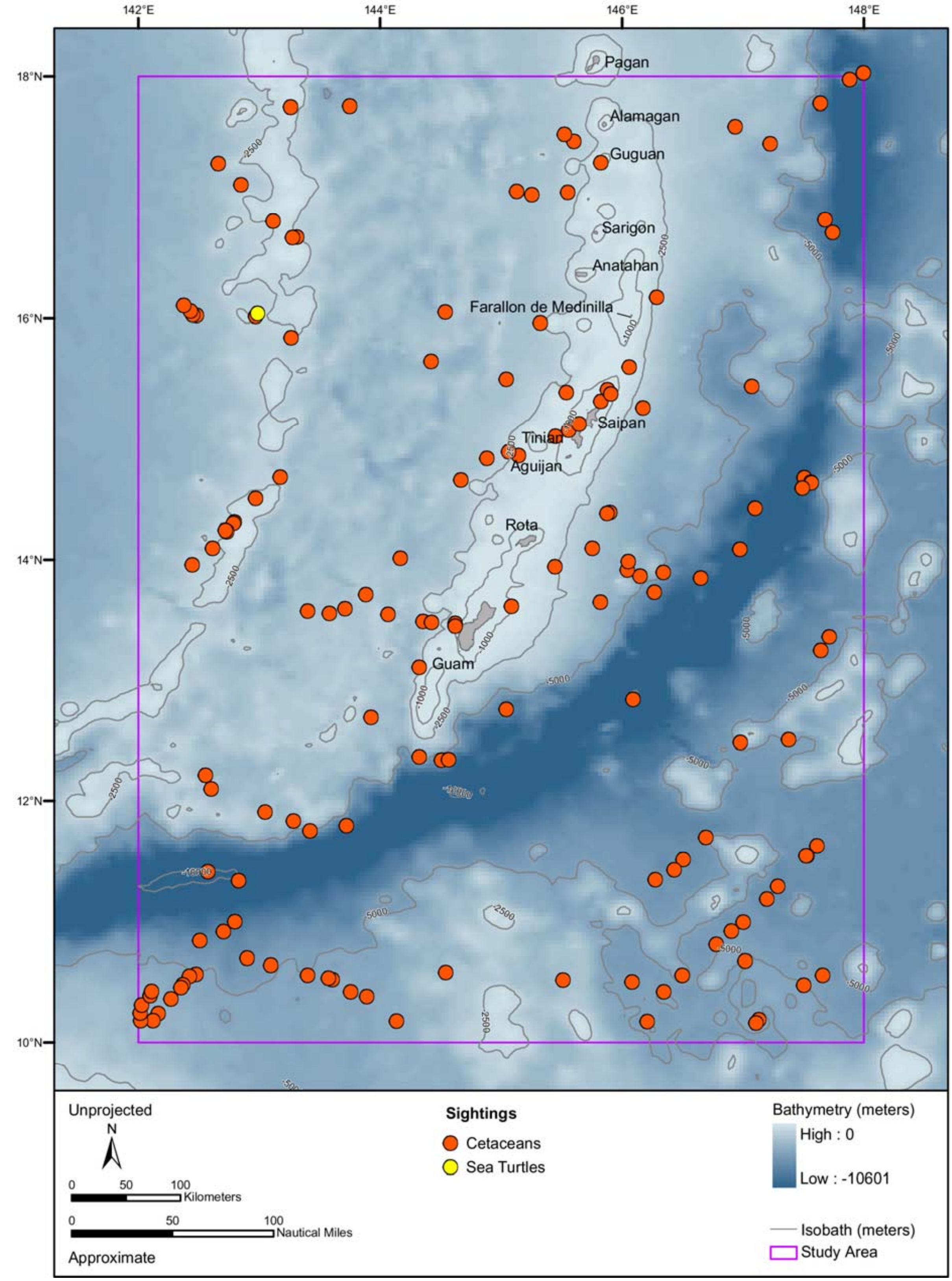


Figure 3-7. All Cetacean and Sea Turtle Sightings (Regardless of Effort Status) for the MISTCS Cruise

Table 3-3. Summary of Species/Species Groups with Group Size Range, Mean Group Size, Depth Range, and Mean Depth for all (On- and Off-effort Sightings)

Species/Species Group	Group Size	Mean Group Size (SE)	Depth Range (m)	Mean Depth (m) (SE)
Physeter macrocephalus	1-25	5.1 (2.03)	809-9874	3925 (440.4)
***Balaenoptera* spp.**				
Balaenoptera borealis	1-4	1.3 (0.16)	3164-9322	5673 (364.2)
Balaenoptera edeni	1-3	1.4 (0.16)	2549-7373	4563 (329.4)
Balaenoptera borealis/edeni	1	1	3435-4885	4531(559.6)
Unidentified *Balaenoptera*	1-3	1	2413-7543	4334 (430.2)
Blackfish				
Pseudorca crassidens	2-26	9.8 (4.2)	3059-8058	5617 (443.3)
Globicephala macrorhynchus	5-43	17.5 (8.8)	927-4490	2949 (705.4)
Peponocephala electra	80-109	94.5 (14.5)	3224-3935	3650 (161.9)
Feresa attenuata	6	6	4439	-
Delphinids				
Stenella attenuata	1-115	64.2 (37.0)	114-5672	3720 (354.0)
Stenella coeruleoalba	7-44	27.4 (9.4)	2362-7570	4207 (514.5)
Stenella longirostris	98	98	426	-
Steno bredanensis	7-15	9	1019-4490	2755 (1735.5)
Tursiops truncatus	3-10	2.2 (1.8)	4241-5011	4554 (162.7)
Tursiops/Steno	3	3	3295	-
UID dolphins	1-7	3.7 (1.2)	2418-9874	4965 (536.8)
Megaptera novaeangliae	8	-	148	-
Beaked whales	1	-	2122-3984	3116.7 (541.3)

SE = Standard Error; depth in meters (m)

Mean group size was calculated from on-effort data used in DISTANCE analyses. Mean group size is not intuitive compared to group size since off-effort sightings were not included in this calculation

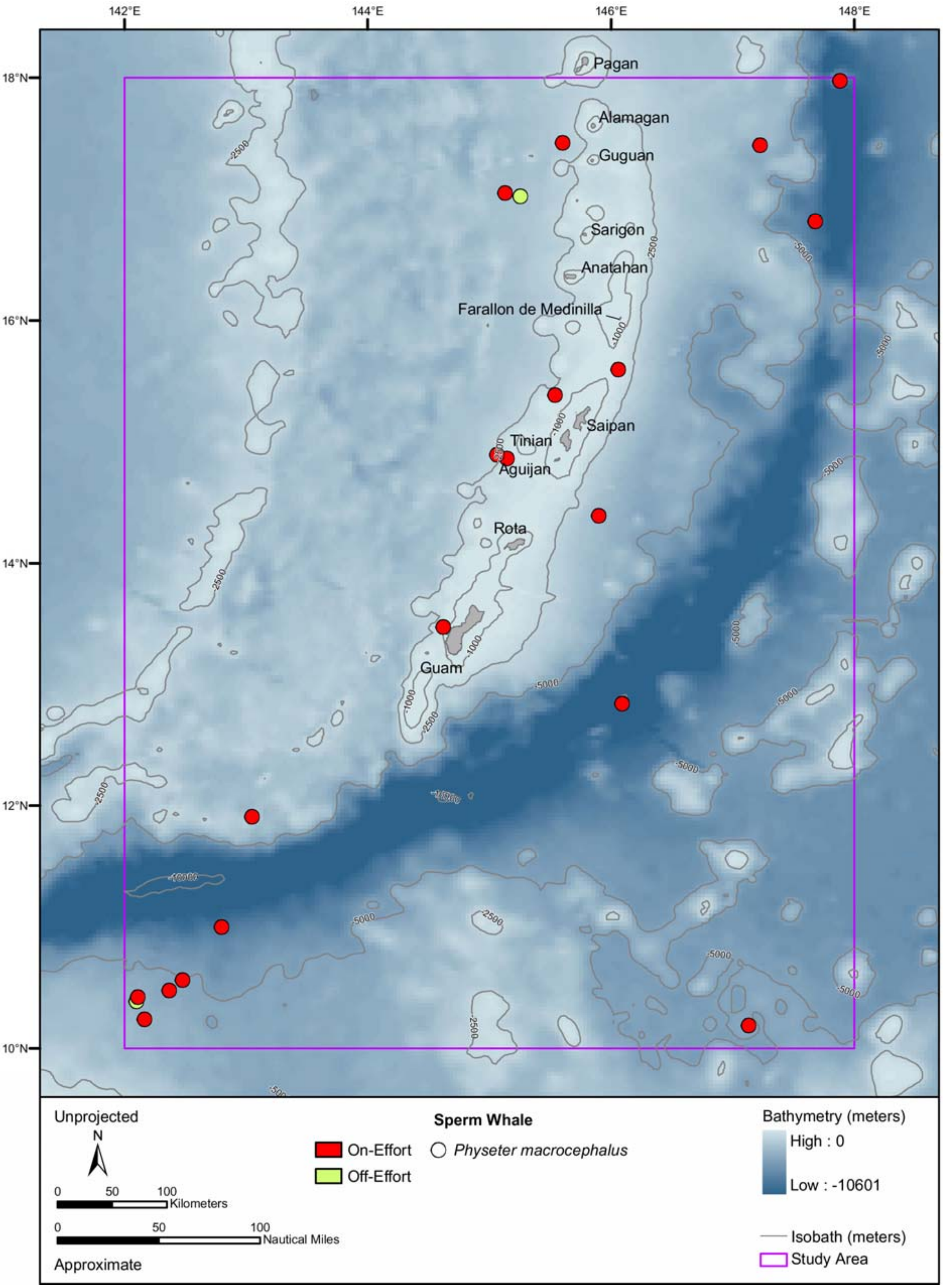
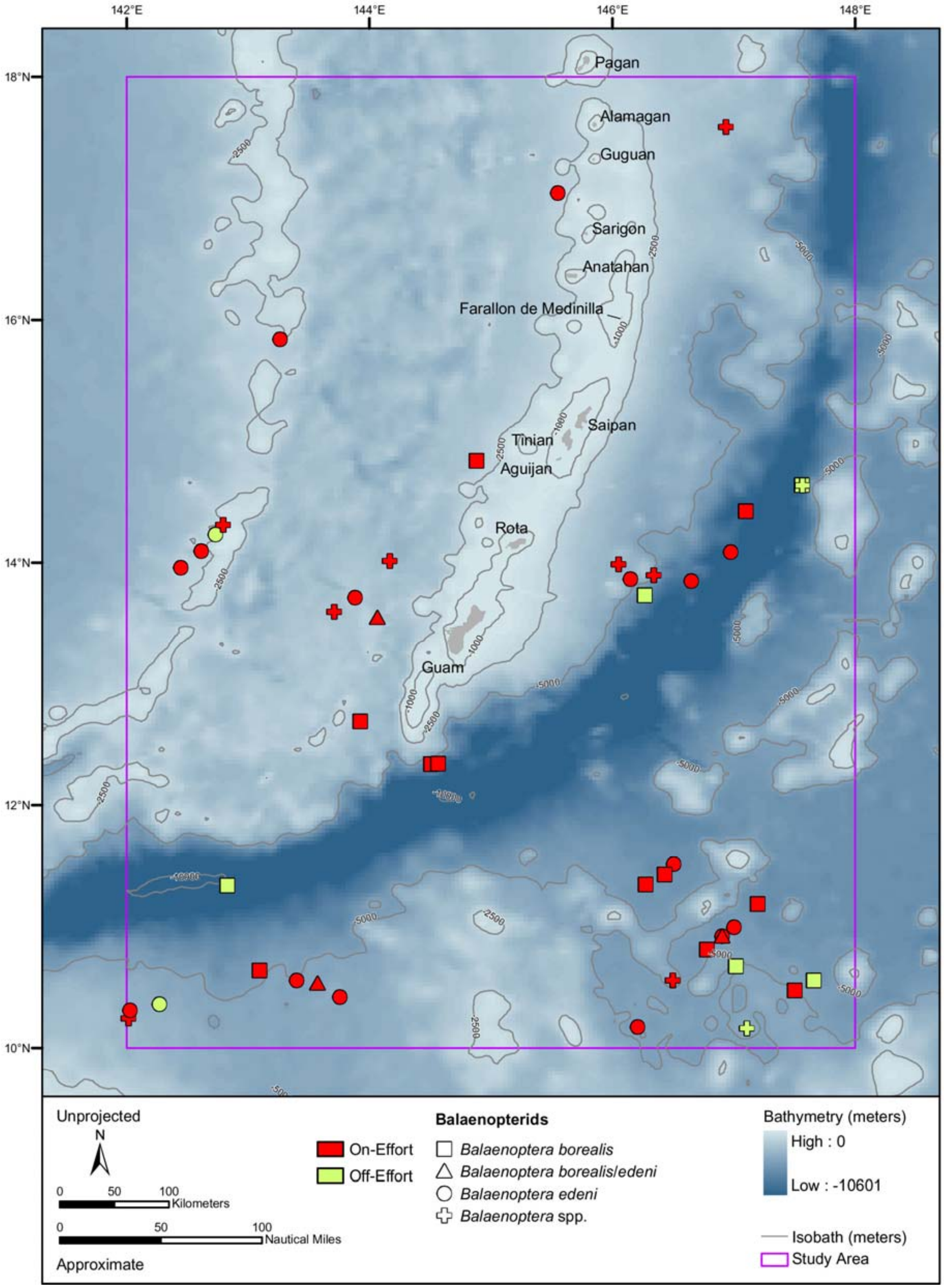
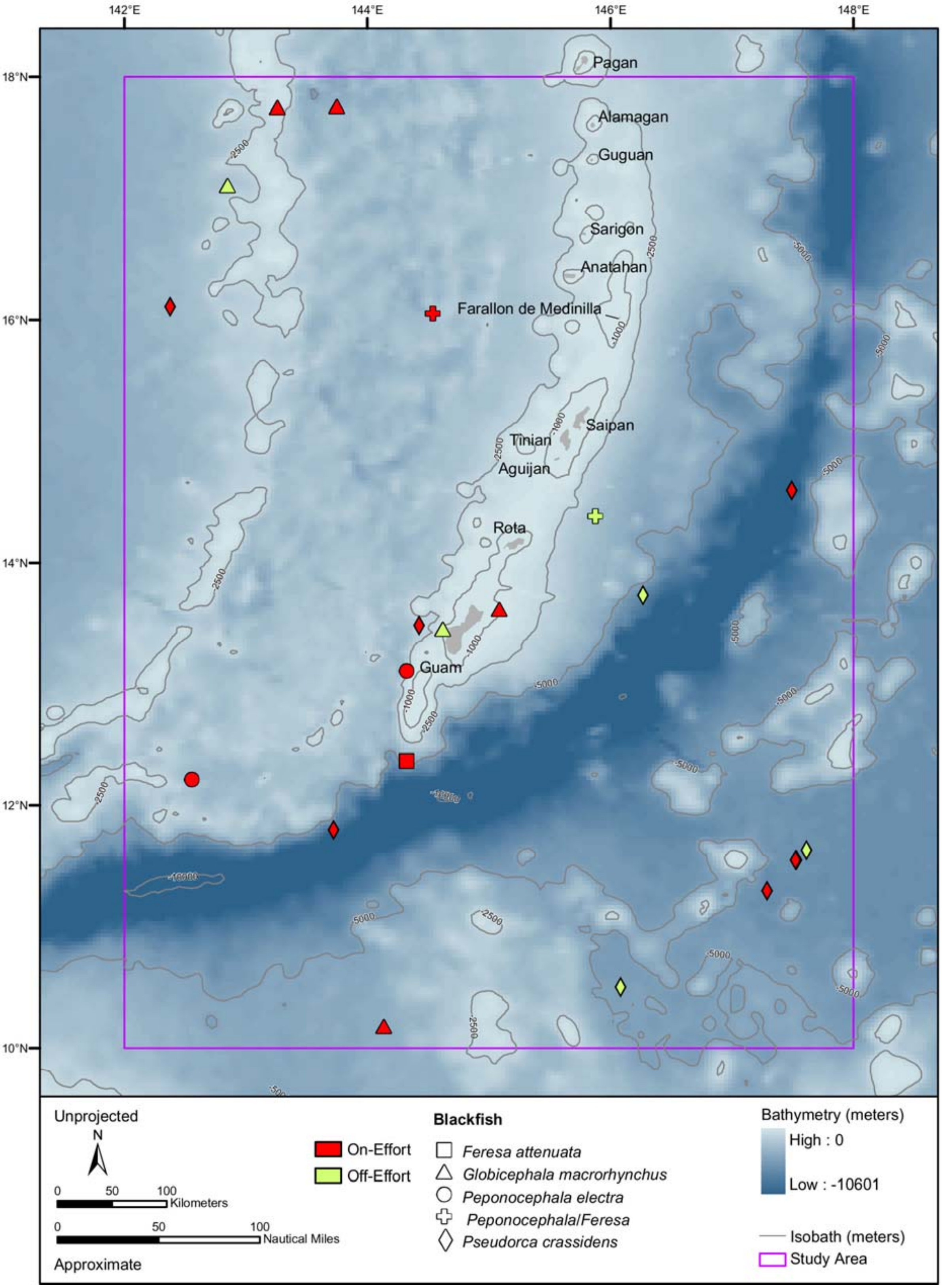


Figure 3-8. All Sperm Whale Sightings (Regardless of Effort Status) for the MISTCS Cruise



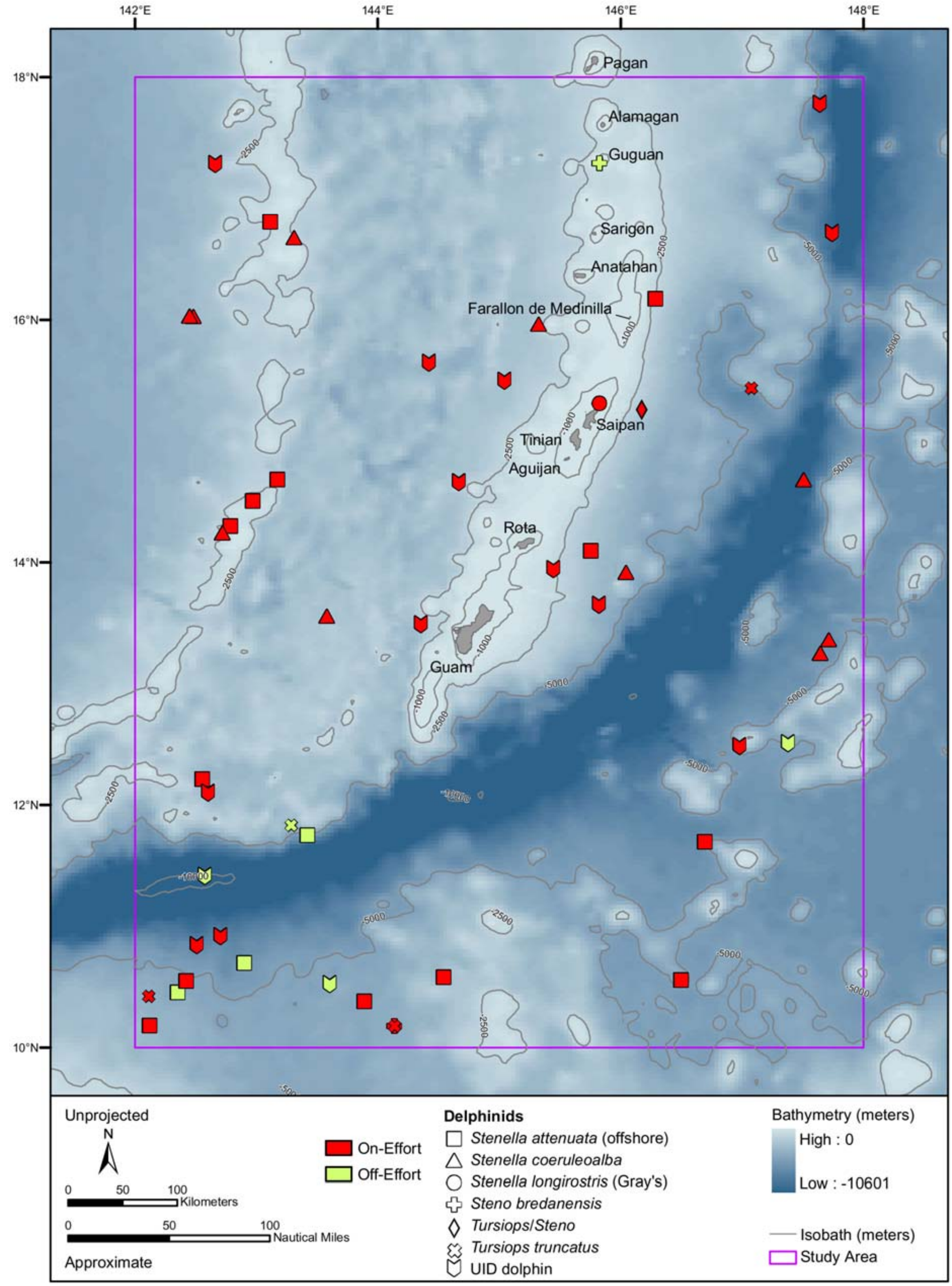
Species which comprised this group are listed.

Figure 3-9. All *Balaenoptera* spp. Group Sightings (Regardless of Effort Status) for the MISTCS Cruise



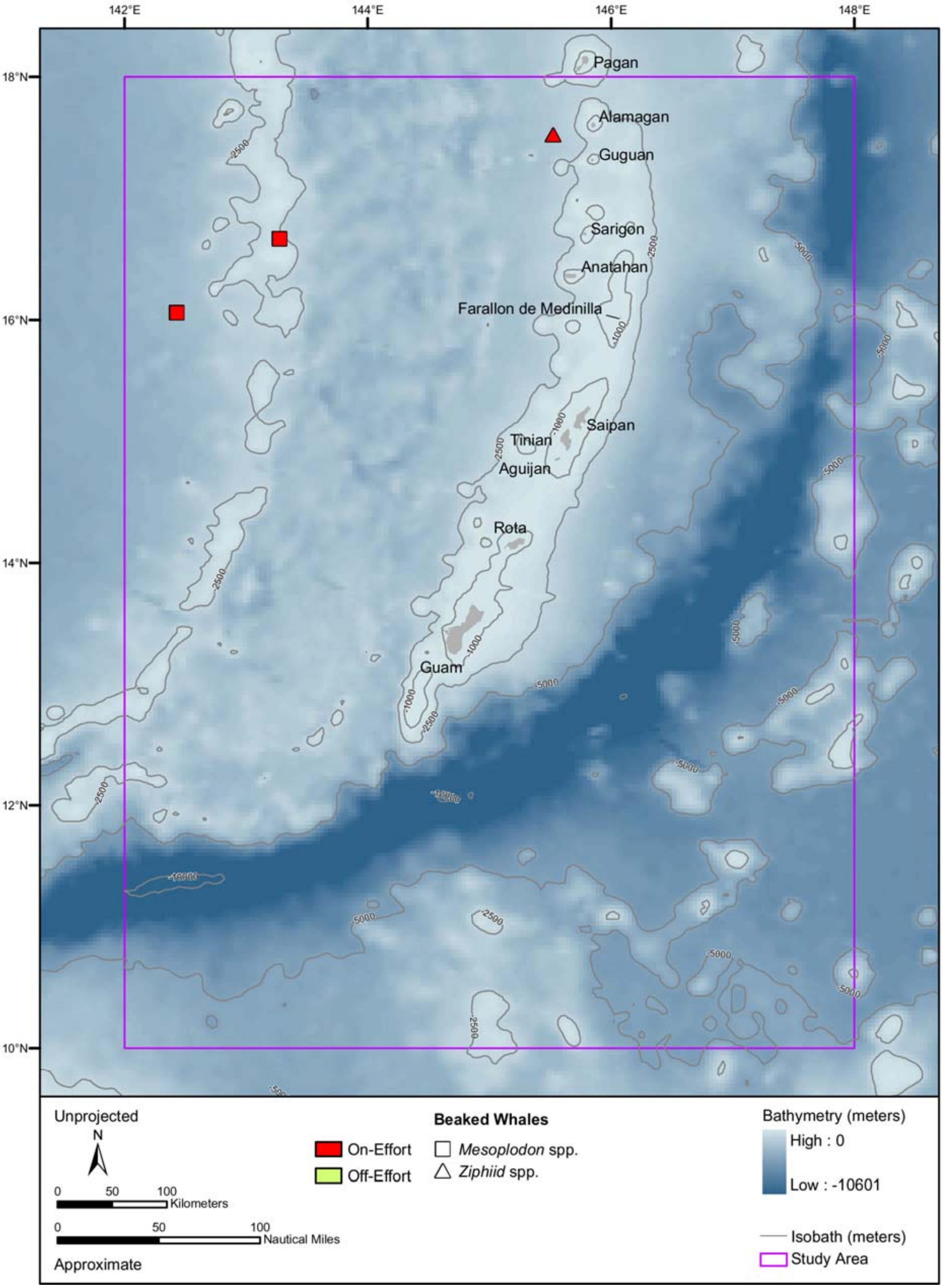
Species which comprised this group are listed.

Figure 3-10. All Blackfish Group Sightings (Regardless of Effort Status) for the MISTCS Cruise



Species which comprised this group are listed.

Figure 3-11. All Delphinid Group Sightings (Regardless of Effort Status) for the MISTCS Cruise



Species which comprised this group are listed.

Figure 3-12. All Beaked Whale Sightings (Regardless of Effort Status) for the MISTCS Cruise

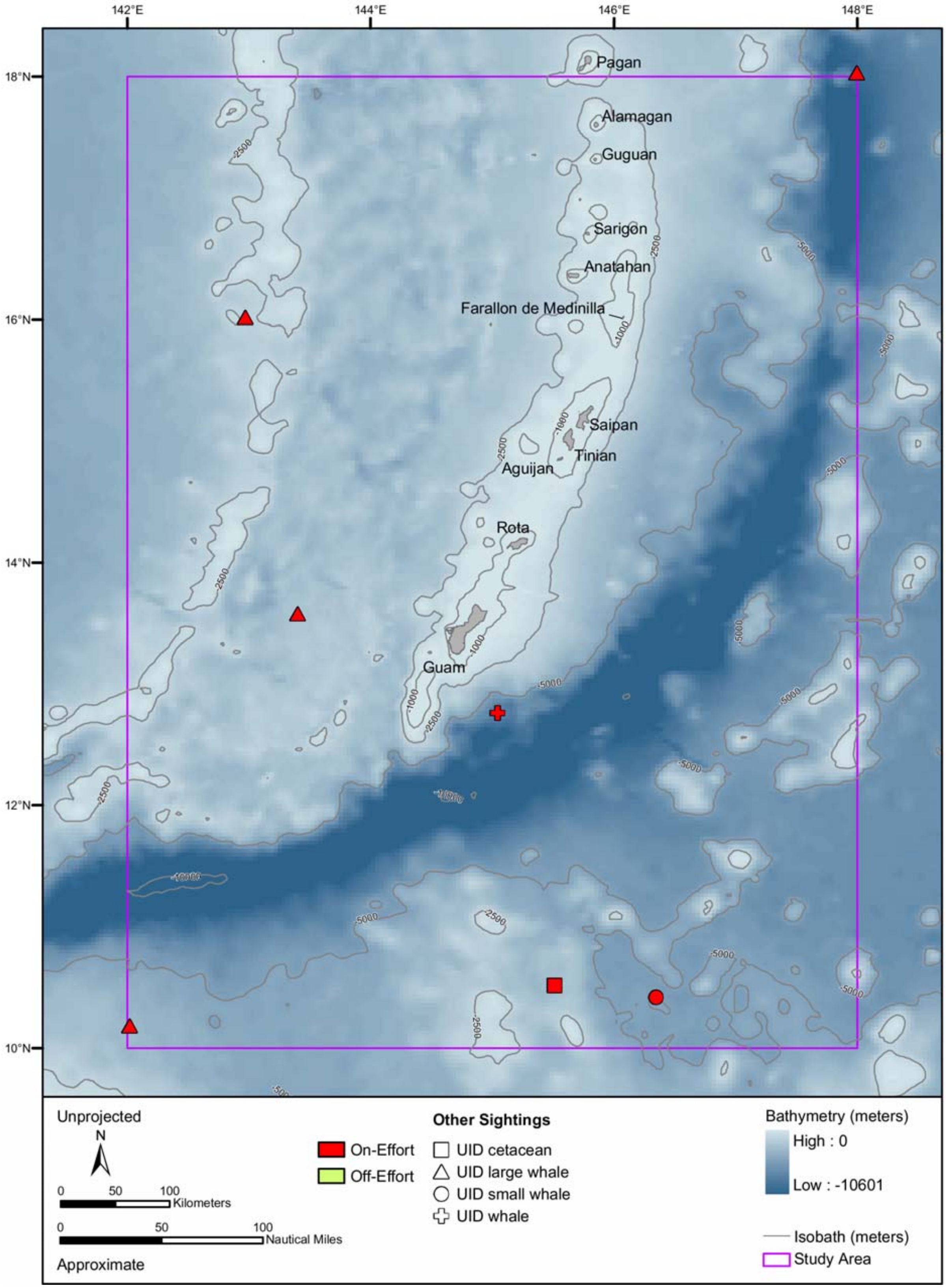
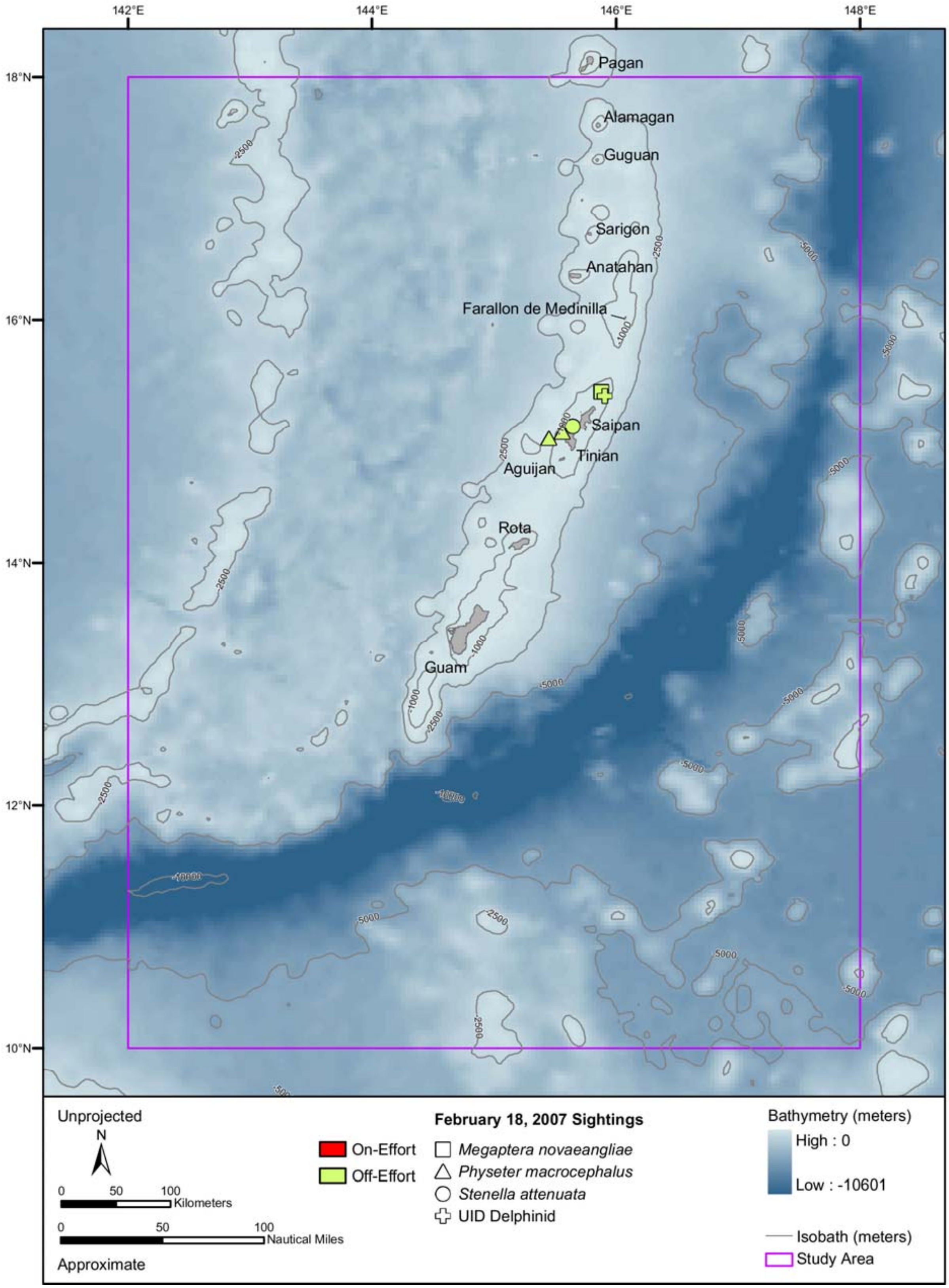


Figure 3-13. All Unidentified (UID) Cetacean Group Sightings (Regardless of Effort Status) for the MISTCS Cruise



Species which were sighted are listed.

Figure 3-14. All Off-Effort Sightings from 18 February 2007 for the MISTCS Cruise

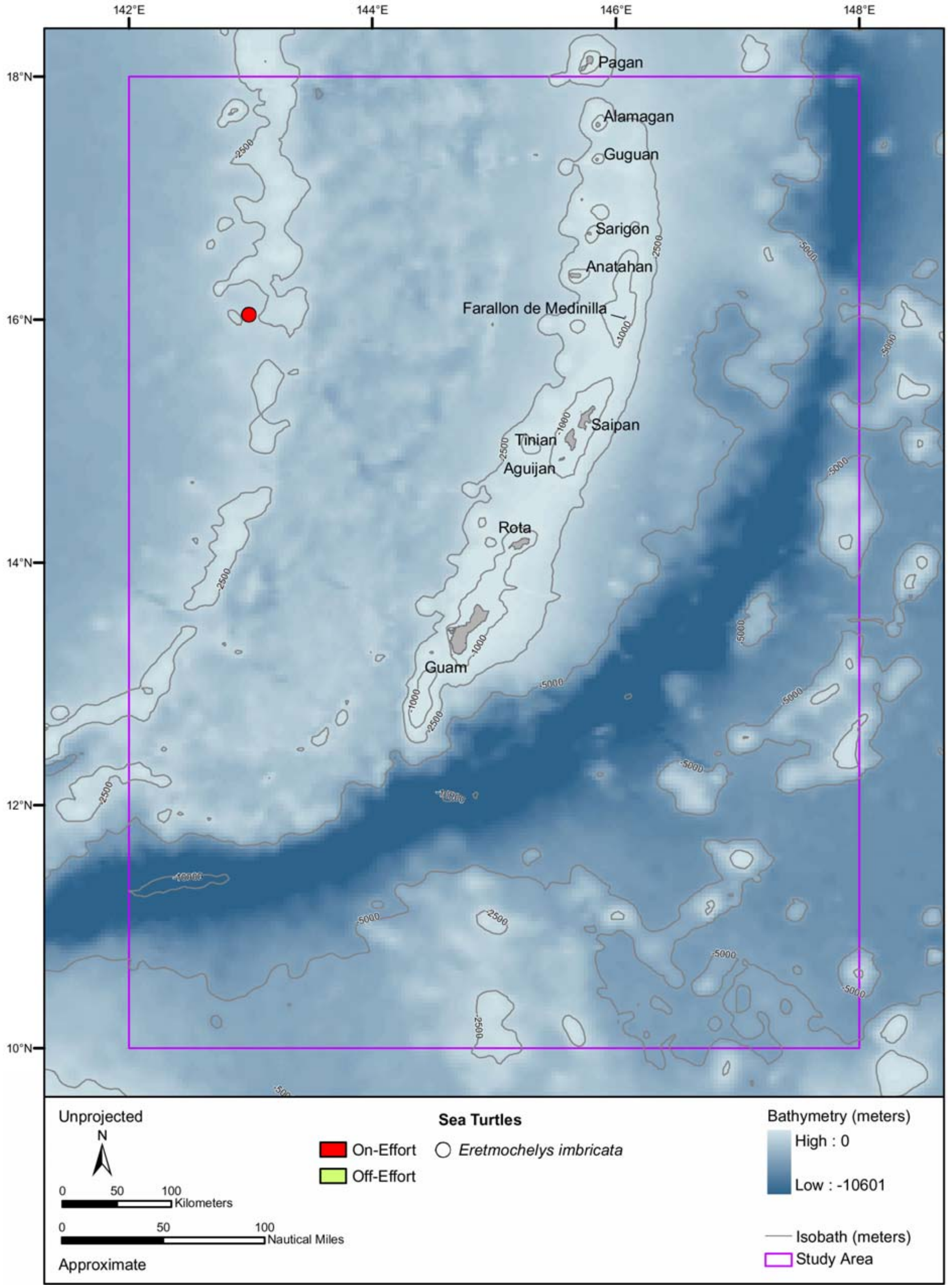


Figure 3-15. Hawksbill Turtle Sighting during the MISTCS Cruise

3.1.3 Density Estimation

Species with similar sighting characteristics (*e.g.*, body size, group size, surface behavior, blow visibility) were pooled to estimate $f_i(0)$ for three categories: *Balaenoptera* species (spp.), Blackfish, and Delphinids (**Table 3-4; Figures 3-16 to 3-19)**. This was done because there were insufficient numbers of sightings for all other species to model the detection function (<20 sightings) independently.

- The group *Balaenoptera* spp. includes the sei whale, Bryde's whale, sei whale/Bryde's whale, and *Balaenoptera* spp. Sei whale/Bryde's whale category reflects sightings where the species identification could not be confirmed, because these two species are so close in physical appearance, making identification extremely difficult on some occasions (see Reeves *et al*., 2002 for more information). The *Balaenoptera* spp. sightings were cases where the gradation of even sei/Bryde's could not be determined.
- Blackfish species (false killer whale, melon-headed whale, pygmy killer whale, short-finned pilot whale) were separated from the group Delphinids based on their similar physical appearance and behavior.
- In Delphinids, the species category of *Tursiops/Steno* reflects the similar physical appearance of these two genera, particularly from a distance (see Reeves *et al*., 2002 for more information).

Table 3-4. Estimate of $f_i(0)$ for Each Species and Species Categories

Species/species group	n	Truncation (m)	$f_i(0)$ (km-1)	Model	CV[$f_i(0)$]	ESW (m)
Physeter macrocephalus	11	4000	0.858E-3	Half-Normal	17.6	2053
***Balaenoptera* spp.**	24	3500	0.640E-3	Uniform	20.6	1562
Balaenoptera borealis						
Balaenoptera edeni						
Balaenoptera borealis/edeni						
Unidentified Balaenoptera						
Blackfish	12	4000	0.500E-3	Uniform	16.8	2000
Globicephala macrorhynchus						
Peponocephala electra						
Feresa attenuata						
Pseudorca crassidens						
Delphinids	33	2500	0.708E-3	Uniform	9.9	1412
Stenella attenuata						
Stenella coeruleoalba						
Tursiops truncatus						
Stenella longirostris						
Steno bredanensis						
Tursiops/Steno						
UID dolphins						
Total	**80**					

Species pooled to estimate $f_i(0)$ for species categories (*e.g.,* Blackfish) are listed (ESW = effective half-strip width, 1/ $f_i(0)$).

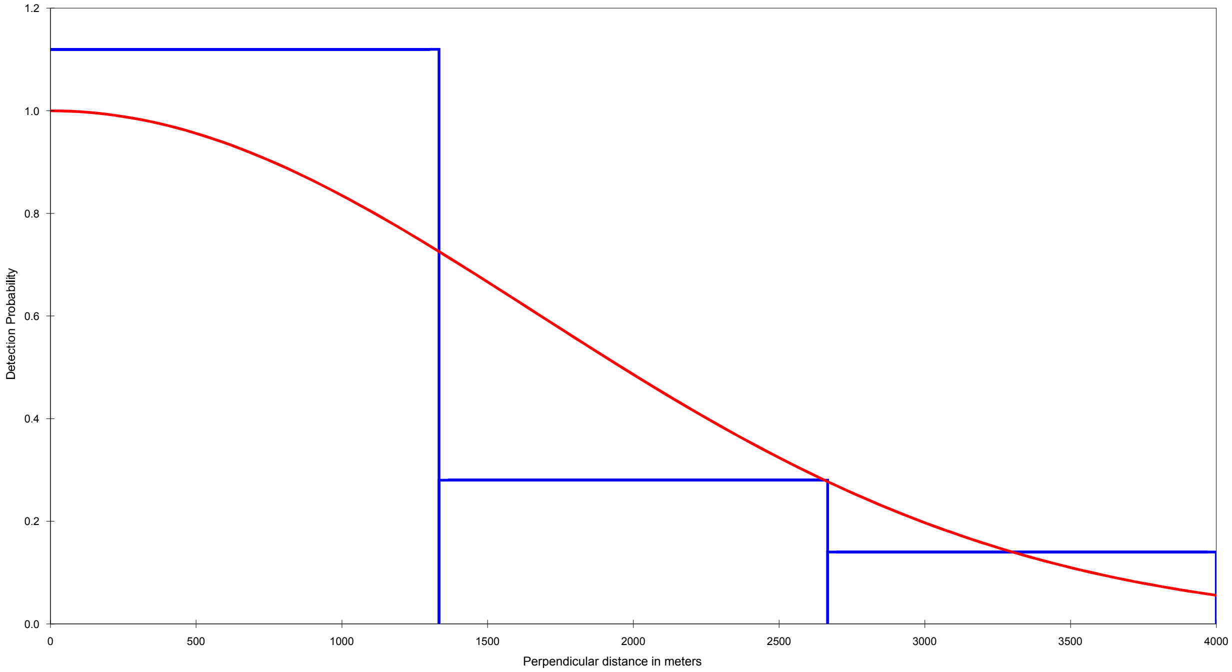


Figure 3-16. Plot Detection Function for the Sperm Whale

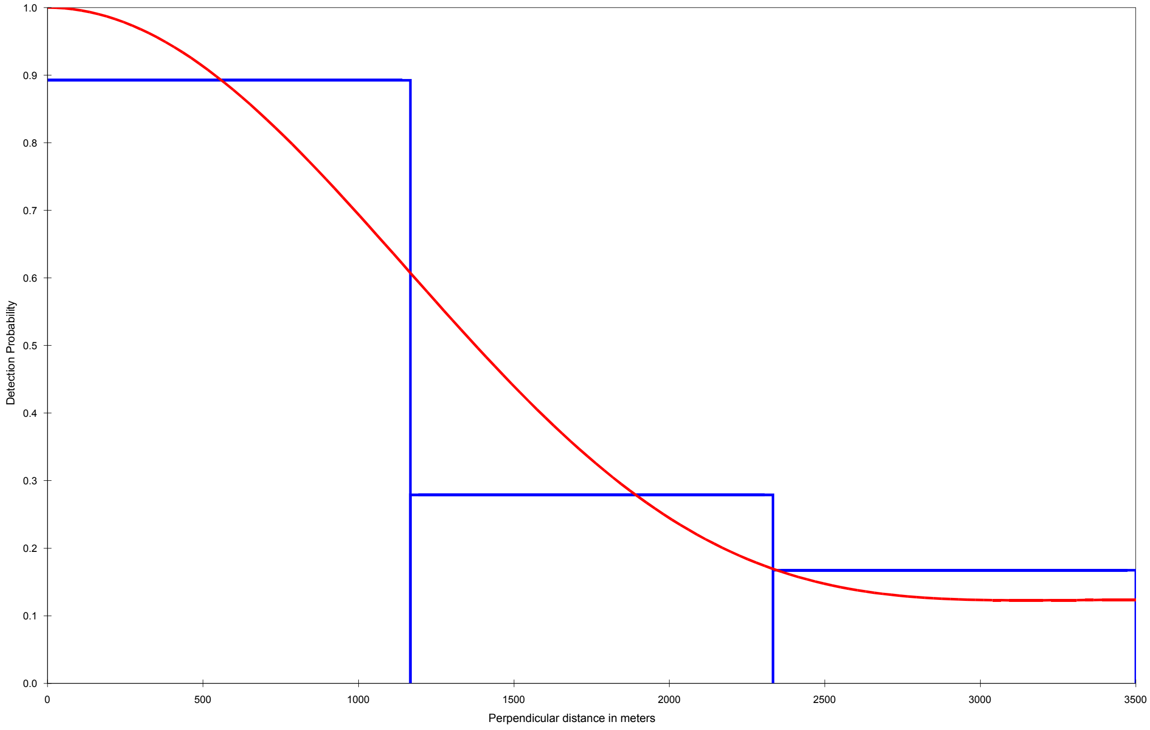


Figure 3-17. Plot of the Detection Function for the Pooled Species within Species Group *Balaenoptera* spp.

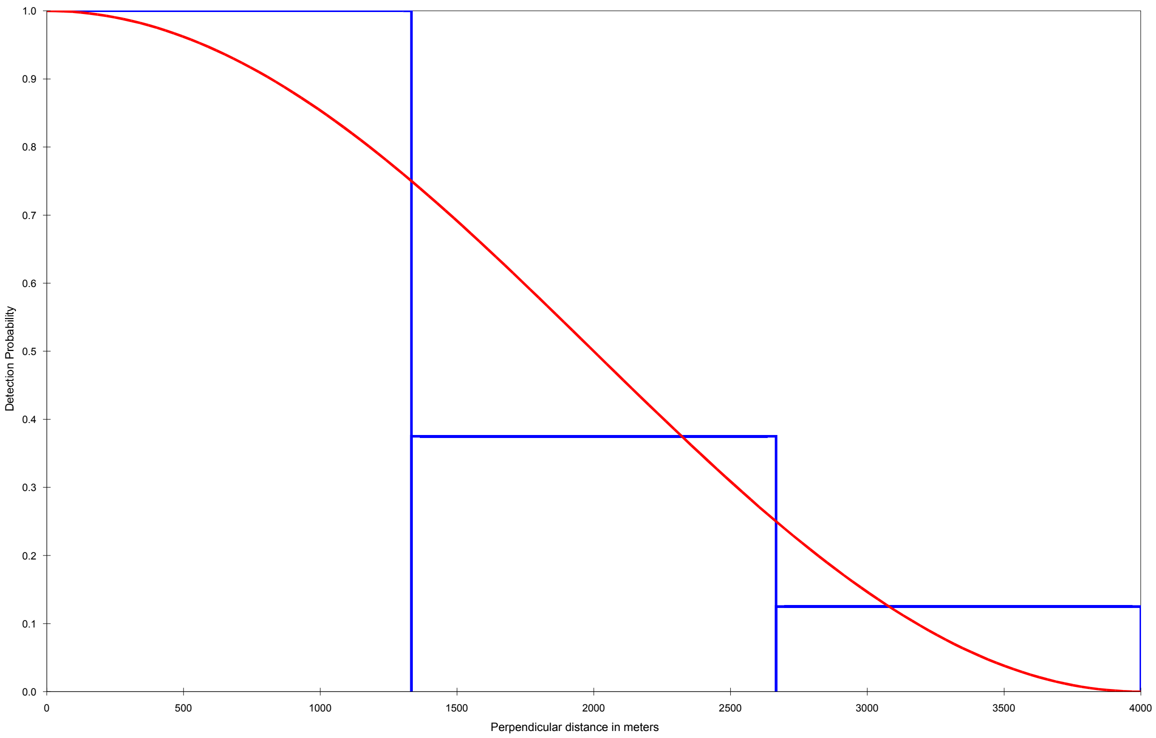


Figure 3-18. Plot of the Detection Function for the Pooled Species within Species Group Blackfish

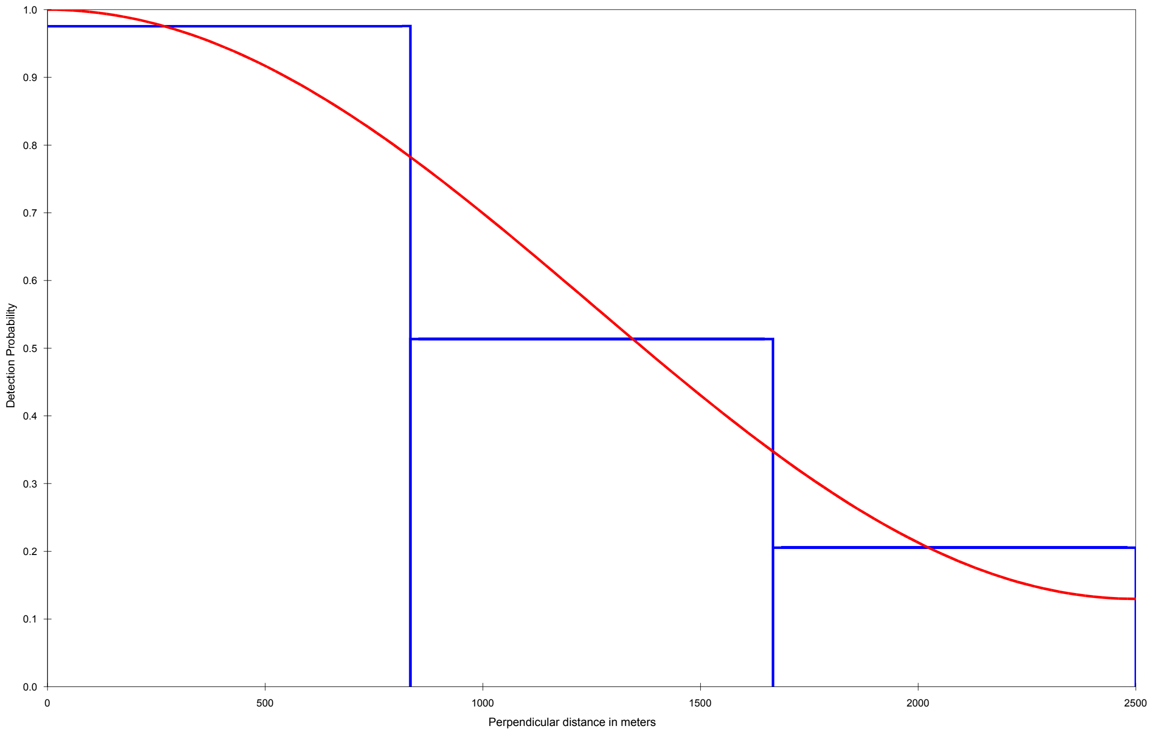


Figure 3-19. Plot of the Detection Function for the Pooled Species with Species Group Delphinids

Minimum abundance and density estimates were based on 80 sightings comprised of 20 species/species groups (**Table 3-5**). The sperm whale was the only species which initially had enough sightings (>20) to generate an independent detection function (estimate $f_i(0)$). Therefore, this is the only species analyzed independent of all other sightings. Sperm whales were not pooled with any other whale species due to their propensity for long dive intervals (Barlow, 1999; Barlow and Taylor, 2005), general behavioral patterns, and large body size.

The precision of the abundance/density estimates (expressed as CV) were large, highly variable, and dependent on the number of sightings. CVs ranged from 32.8 (*Balaenoptera* spp.) to 102.2 (*Balaenoptera borealis/edeni*). Because the CVs of most of the estimates were generally poor (<0.30), the power to detect statistically significant differences in estimates was low (Gerrodette, 1987). This is not unsuspected given that this is the first dedicated line-transect survey of this region. Poor precision of these estimates is a result of the low number of sightings, high BSS and the reduced amount of survey trackline used for analysis. Regardless of these shortcomings, and given the lack of any other line-transect data for this region, the estimates provided in this report are the “best available scientific data.”

Table 3-5. Density and Abundance Estimates and Group Size for Cetaceans in Guam and CNMI Waters

Species	n	S	CV(S)	D	N	CV	95% CI
Physeter macrocephalus	11	5.1	40.2	--------	705	60.4	228-2181
				1.23	--------		0.40-3.80
***Balaenoptera* spp.**	24	------	--------	--------	499	32.8	265-941
				0.88	--------		0.46-1.64
Balaenoptera borealis	8	1.3	13.1	--------	166	48.7	67-416
			--------	0.29			0.12-0.73
Balaenoptera edeni	10	1.4	11.7	--------	233	45.0	99-546
			--------	0.41	--------		0.17-0.95
Balaenoptera borealis/edeni	2	1	--------	--------	33	100.2	6-175
				0.056	--------		0.01-0.31
Unidentified Balaenoptera	4	1	--------	--------	67	53.6	25-181
				0.12	--------		0.04-0.32
Blackfish	12	------	--------	--------	4079	93.8	1650-10085
				7.12	--------		2.9-17.6
Pseudorca crassidens	5	9.8	42.9	--------	637	74.3	164-2466
				1.11	--------		0.29-4.3
Globicephala macrorhynchus	4	17.5	50.1	--------	909	67.7	230-3590
				1.59	--------		0.40-6.26
Peponocephala electra	2	94.5	15.3	--------	2455	70.2	695-8677
				4.28	--------		1.2-15.10
Feresa attenuata	1	6	0.0	--------	78	88.1	17-353
				0.14	--------		0.03-0.62
Delphinids	33	------	--------		19269	49.8	7286-50959
				33.6			12.7-88.90
Stenella attenuata	11	64.2	57.6	--------	12981	70.4	3446-48890
				22.6	--------		6.0-85.3
Stenella coeruleoalba	7	27.4	34.4	--------	3531	54.0	1250-9977
				6.16	--------		2.18-17.4
Tursiops truncatus	3	2.2	80.7	--------	122	99.2	5.0-2943
				0.21	--------		0.001-5.10
Stenella longirostris	1	98	--------	--------	1803	95.8	361-9004
				3.14	--------		0.63-15.7
Steno bredanensis	1	9	--------	--------	166	89.2	36-761
				0.29	--------		0.06-1.33
Tursiops/Steno	1	3	--------	--------	55	91.8	12-262
				0.09	--------		0.02-0.46
Unidentified delphinid	9	3.7	33.0	--------	612	47.8	242-1550
				1.07	--------		0.42-2.70

n= number of groups sighted; S=mean group size; D= animals per 1,000 km^2; N = number of animals; CV = coefficient of variation

3.2 ACOUSTIC SURVEY

Extremely poor sea and sighting conditions hampered visual efforts but had little effect on the acoustics effort. A two-element towed hydrophone array was monitored and recorded continuously during daylight hours concurrent with the visual effort. Sonobuoys were deployed opportunistically on sightings and areas of interest and at night.

3.2.1 Towed Hydrophone Array Effort

Towed array effort was conducted for 70 out of 71 (99%) of surveyable days at sea for a total of 762 hours and 11,478 km of total survey effort for the entire 3-month cruise (**Table 3-6**; **Figure 3-20**). There were no major malfunctions of the acoustics system during the duration of the cruise. On average, towed array effort was conducted for 10.9 hours/day, for all survey days and 11.6 hours/day for “whole” survey days (*i.e*. days not shortened due to weather, port calls, or non-acoustics related issues; **Table 3-6**). These totals include 12 hours of nighttime effort conducted to detect and localize singing humpback whales encountered off the north coast of Saipan on 17 and 18 February.

Table 3-6. Towed Array Survey Effort by Leg

	Leg 1	Leg 2	Leg 3	Leg 4	All Legs
Total Hours	188.4	209.4	153.9	210.2	761.9
Total Days (includes partial days)	18	19	14	19	70
Avg Hours/Day	10.5	11	11	11.1	10.9
Whole Days	17	17	12	16	62
Avg Hours/Day (whole only)	11	11.9	11.6	11.9	11.6
Distance (km)	2,209.8	3,230.8	2,407.5	3,577	11,477.6

Nighttime survey effort during Leg 2 (12 hrs; 192.24 km) is included in totals.

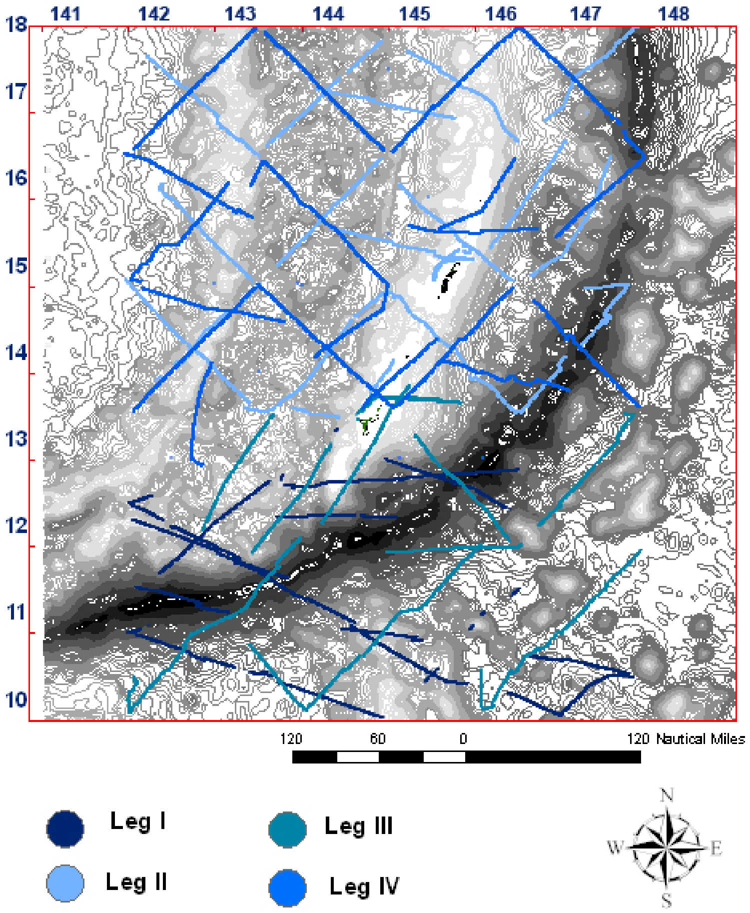


Figure 3-20. Acoustic Towed Array Effort by Leg

Approximately 207 “unique detections” were made during the entire cruise (**Table 3-7**). Of this total, 141 (68%) were identified to 12 different species (using both acoustic and visual means). Of the remaining 62 detections that could not be identified to species, 46 (74%) were classified as “unidentified delphinids.” Bearings were obtained for 148 (71%) of all detections and acoustic localizations were determined for 48 (23%) of all detections (**Table 3-8**).

A comparison of unique acoustic detections to visual sightings indicates that the total for acoustic methods (207 detections) was greater than for visual methods (148 sightings) (**Table 3-8**). Forty-nine (49) of all the encounters detected by both visual and acoustic methods, were detected acoustically first, and 36 encounters were sighted by visual observers before they were detected acoustically (**Table 3-9**). Of the 207 total acoustic detections made, 122 (59%) were not detected by visual observers. Alternatively, 61 (42%) of visual sightings were not detected by acoustic methods. It is important to note that for various reasons acoustic and visual data are not directly comparable (see Section 4).

Table 3-7. Summary of Acoustic Detections from the Towed Array by Leg

Species	Leg 1	Leg 2	Leg 3	Leg 4	Total
Physeter macrocephalus	15	24	12	10	61
Balaenoptera acutorostrata	11	1	10	7	29
Balaenoptera borealis	3	1	-	-	4
Megaptera novaeangliae	-	10	-	1	11
Pseudorca crassidens	-	4	6	-	10
Globicephala macrorhynchus	-	1	-	1	2
Peponocephala electra	-	-	1	-	1
Stenella attenuata	4	4	3	-	11
Stenella coeruleoalba	-	6	3	-	9
Stenella longirostris	-	1	-	-	1
Steno bredanensis	-	1	-	-	1
Tursiops truncatus	-	1	-	-	1
Mixed species group (see maps for species)	1	1	1	1	4
Unidentified delphinid	24	13	6	3	46
Unidentified odontocete	1	4	1	4	10
Unidentified cetacean	1	3	1	1	6
Total	**60**	**75**	**44**	**28**	**207**

Table 3-8. Summary of Acoustic Detection Localizations and (Bearings) from Towed Array

Species	Leg 1	Leg 2	Leg 3	Leg 4	Total
Physeter macrocephalus	5 (142)	13 (173)	4 (105)	3 (62)	25 (482)
Balaenoptera acutorostrata	3 (107)	8	1 (47)	1 (38)	5 (200)
Megaptera novaeangliae	-	3 (38)	-	(27)	3 (65)
Pseudorca crassidens	-	1 (9)	1 (50)	-	2 (59)
Globicephala macrorhynchus	-	-	-	(1)	(1)
Peponocephala electra	-	-	(4)	-	(4)
Stenella attenuata	1 (24)	-	(4)	-	1 (28)
Stenella coeruleoalba	-	(6)	(5)	-	(11)
Steno bredanensis	-	(4)	-	-	(4)
Mixed species group	(4)	-	(2)	-	(6)
Unidentified odontocete	1 (1)	-	(4)	1 (10)	2 (15)
Unidentified cetacean	1 (4)	-	(1)	(4)	1 (9)
Unidentified delphinid	4 (95)	3 (58)	(16)	2 (31)	9 (200)
Total	**15 (377)**	**20 (296)**	**6 (238)**	**7 (174)**	**48 (1085)**

Species in mixed species groups are not counted in species totals

Table 3-9. Summary of Acoustic vs. Visual Detection from the Towed Array

Species	AC 1st	Visual 1st	AC Only	Totals
Physeter macrocephalus	16	8	37	61
Balaenoptera acutorostrata	1	-	28	29
Balaenoptera borealis	1	3	-	4
Megaptera novaeangliae	-	1	10	11
Pseudorca crassidens	9	1	-	10
Globicephala macrorhynchus	1	1	-	2
Peponocephala electra	1	-	-	1
Stenella attenuata	3	9	-	12
Stenella coeruleoalba	4	4	-	8
Stenella longirostris	-	1	-	1
Steno bredanensis	-	1	-	1
Tursiops truncatus	1	-	-	1
Mixed species group	2	2	-	4
Unidentified odontocete	2	-	8	10
Unidentified cetacean	-	-	6	6
Unidentified delphinid	8	5	33	46
Total	**49**	**36**	**122**	**207**

3.2.2 Sonobuoy System

A total of 55 sonobuoys were deployed of which 36 (65%) were functional (**Table 3-10**). Excluding Leg 1 (in which there were operational problems with the receiving system), the success rate of sonobuoys increased to 73%. Nine unique species and two unidentified species groups were detected including sperm whales, sei whales, minke whales, humpback whales, false killer whales and melon-headed whales. Review of recorded acoustic data, other than the real-time monitoring and note-taking that occurred at sea, was not conducted due to funding and time constraints.

Table 3-10. Summary of Sonobuoy Deployments and Species Detected by Leg

	Leg 1	Leg 2	Leg 3	Leg 4	Total
Sonobuoy Deployments	(11)	10	6	28	44(55)
Sonobuoy Type 57B	(9)	10	5	28	43(52)
Sonobuoy Type 53D	(2)	-	1	-	1 (3)
# Functioning	(4)	7	5	20	32(36)
% Functioning	(36)*	70	83	71	73(65)
Recordings/Detections					
Physeter macrocephalus	-	1	3	2	6
Balaenoptera acutorostrata	1	-	-	5	6
Balaenoptera borealis	1	1	-	-	2
Balaenoptera borealis/edeni	2	-	-	-	2
Megaptera novaeangliae	-	2	-	-	2
Globicephala macrorhynchus	-	-	-	-	-
Pseudorca crassidens	-	-	-	-	-
Peponocephala electra	-	-	-	-	-
Tursiops truncatus	-	1	1	-	2
Unidentified large whale	-	0	2	1	3
Unidentified delphinid	-	2	-	2	4
Total	**4**	**4**	**3**	**7**	**18**

*Leg 1 totals for functioning sonobuoys likely were under-represented because several sonobuoys that were recorded as non-functional may have been functional but could not be received because initial problems with the receiver system set-up prevented good signal reception. Therefore only Legs 2, 3 and 4 were used in total for the number (#) functioning and percent (%) functioning, (with Leg 1 results in parentheses).

3.3 OCEANOGRAPHY

3.3.1.1 Thermosalinograph (TSG)

TSG data analysis shows sea surface temperatures ranging between 26.10 to 29.31ºC, with a mean of 27.67 ºC. **Table 3-11** shows the interpolated change in sea surface temperatures with location. Salinity values ranged between 32.53 and 34.91 psu (practical salinity units), with a mean of 34.26 psu as shown in **Figure 3-21**. **Table 3-11** shows the mean sea surface temperature (SST), sea surface conductivity (SSC), sea surface salinity (SSS) and sea surface sound velocity (SSSV) observed per Leg. **Figures 3-22 and 3-23** show the linear change in SST and SSS levels along the total survey track. Due to the shallow intake pipe that was constructed immediately prior to the cruise, numerous erroneous salinity data points were recorded as air was introduced into the pipe and affected the conductivity of the water in the TSG unit. The temperature data for Leg 2 may also have been subjected to these inconsistencies. **Figure 3-24** shows an average of salinity data bins to determine the true salinity value; however, since it was necessary to apply conservative filters, little reliability should be attached to these data. **Appendix C, Figures C-1 and C-2** contain a geographical representation of the sea surface temperature and salinity per Leg.

Table 3-11. Mean Sea Surface Temperature (SST), Sea Surface Conductivity (SSC), Sea Surface Salinity (SSS), and Sea Surface Sound Velocity (SSSV) as per MISTCS TSG Data

Mean	SST	SSC	SSS	SSSV
Leg 1	28.23	5.52	34.09	1540.86
Leg 2	26.53	5.41	34.52	1533.98
Leg 3	27.64	5.40	33.69	1536.99
Leg 4	27.52	5.49	34.41	1539.17

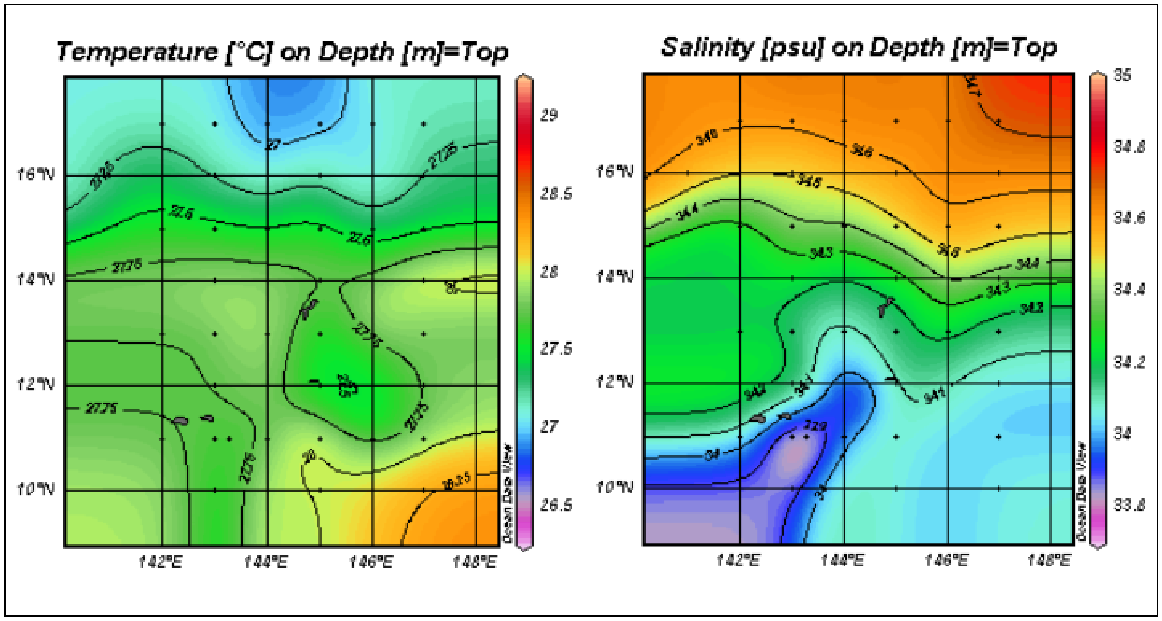


Figure 3-21. Temperature and Salinity Levels Across the MISTCS Study Area

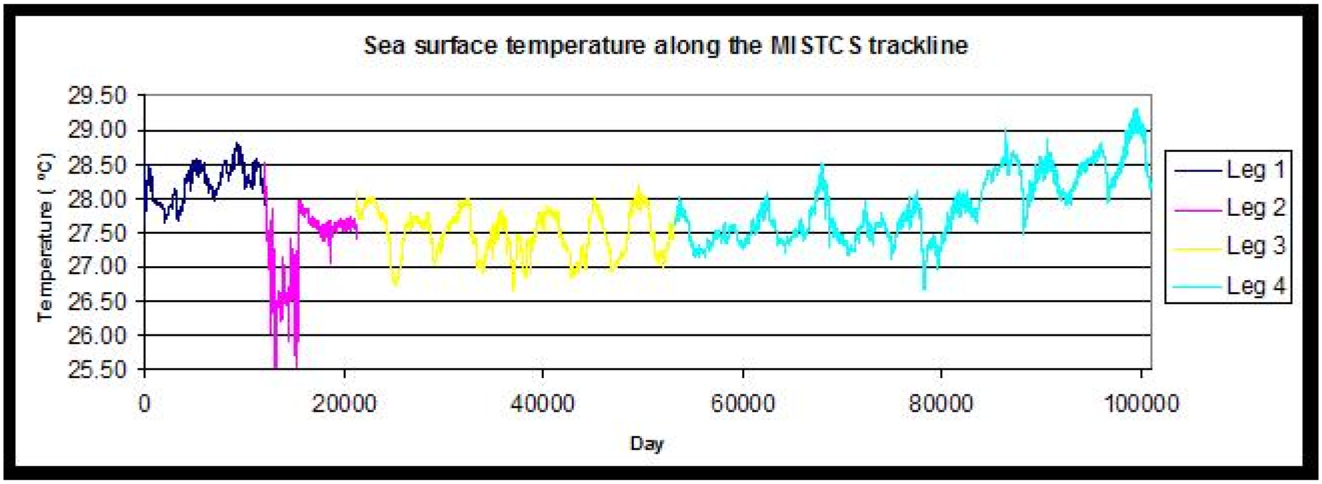
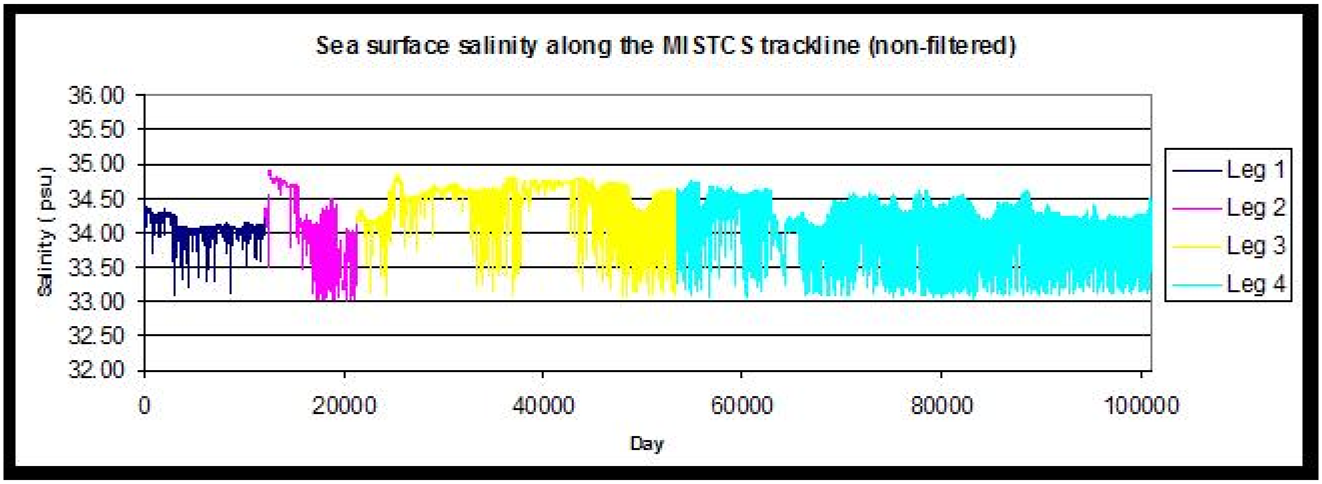
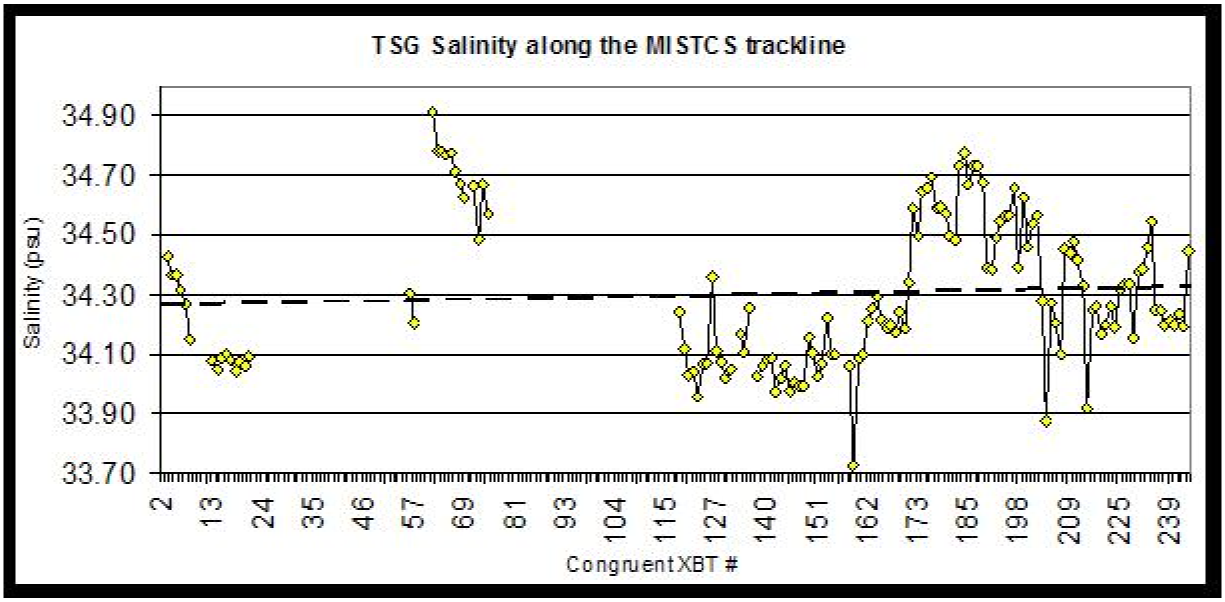


Figure 3-22. TSG Temperature and Associated Trendline along the MISTCS Trackline



Note: Aeration in the shallow intake pipe during rough seas resulting in the collection of numerous erroneous salinity data points.

Figure 3-23. TSG Salinity along the MISTCS Trackline



Note: Gaps are caused by: a) the loss of the seawater intake pipe due to rough seas; and b) aeration in the shallow intake pipe during rough seas resulting in the collection of erroneous salinity data.

Figure 3-24. Averaged TSG Salinity and Associated Trendline along the MISTCS Trackline

3.3.1.2 Expendable Bathythermograph (XBT)

In total, 225 XBT drops were conducted during the cruise. Bearing in mind that in tropical waters the 20°C isotherm is considered to be the indicating temperature for the depth of the thermocline; within the MISTCS study area the 20°C isotherm was found to range between 115.2 – ~240.0 m, averaging at 189.23 m. Unfortunately the T10 XBT probes only reached an official depth of 200 m, although extra wire within the probes allows the software to be manipulated to gather data to a depth of 240 m. However, data gathered between 200 – 240 m is prone to wire stretching as the probe reaches its maximum deployment and data becomes unreliable. Data in this range were carefully analyzed for false information. **Figure 3-25** depicts the changing thermocline depth with location. A uniform change of thermocline depth is clearly shown with change in latitude. **Appendix C, Figure C-3** contains the thermocline 20°C isotherm depth per Leg.

The end of the surface mixed layer ranged between 53.4 and 153.0 m, with an average of 102.88 m. The temperature of the end of the surface mixed layer varied between 25.91 and 28.8°C, averaging at 27.33°C. **Figure 3-26** shows the temperature and depth of the end of the mixed layer with position. While the temperature at the bottom of the mixed layer is relatively uniform in accordance with latitude, the depth of the bottom of the mixed layer is more random in occurrence.

Figure 3-27 shows an example of the first ten XBT drops, as depicted by the Lockheed Martin Sippican, Inc. WinMK21 v2.7.1 program. **Appendix C, Figures C-5 through C-26** show the profiles of the rest of the drops conducted during the MISTCS cruise.

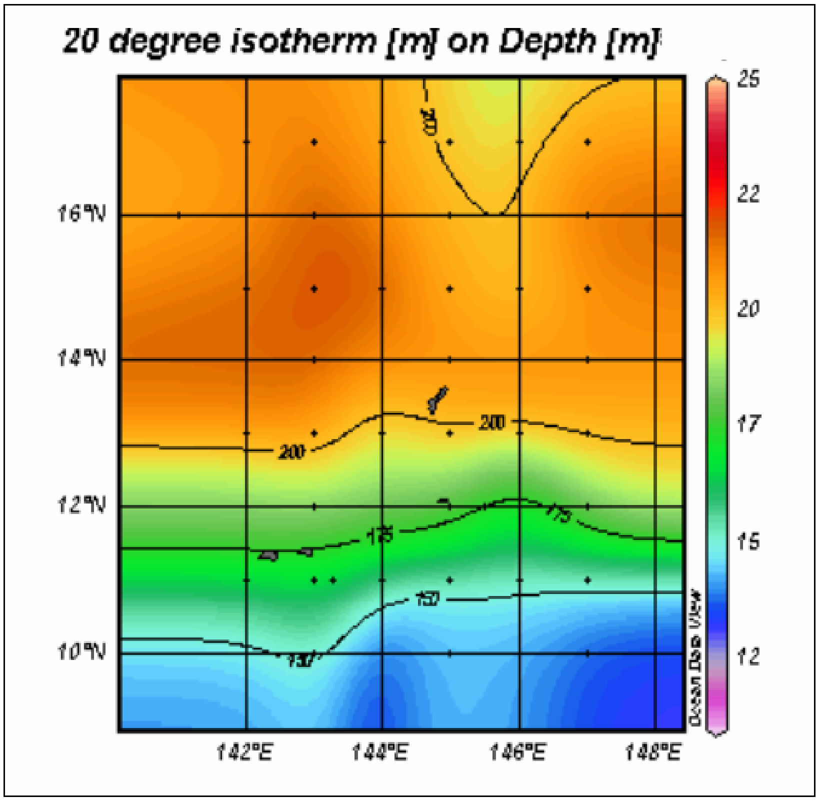


Figure 3-25. The 20°C Isotherm Depth (m) as Found within the MISTCS Study Area

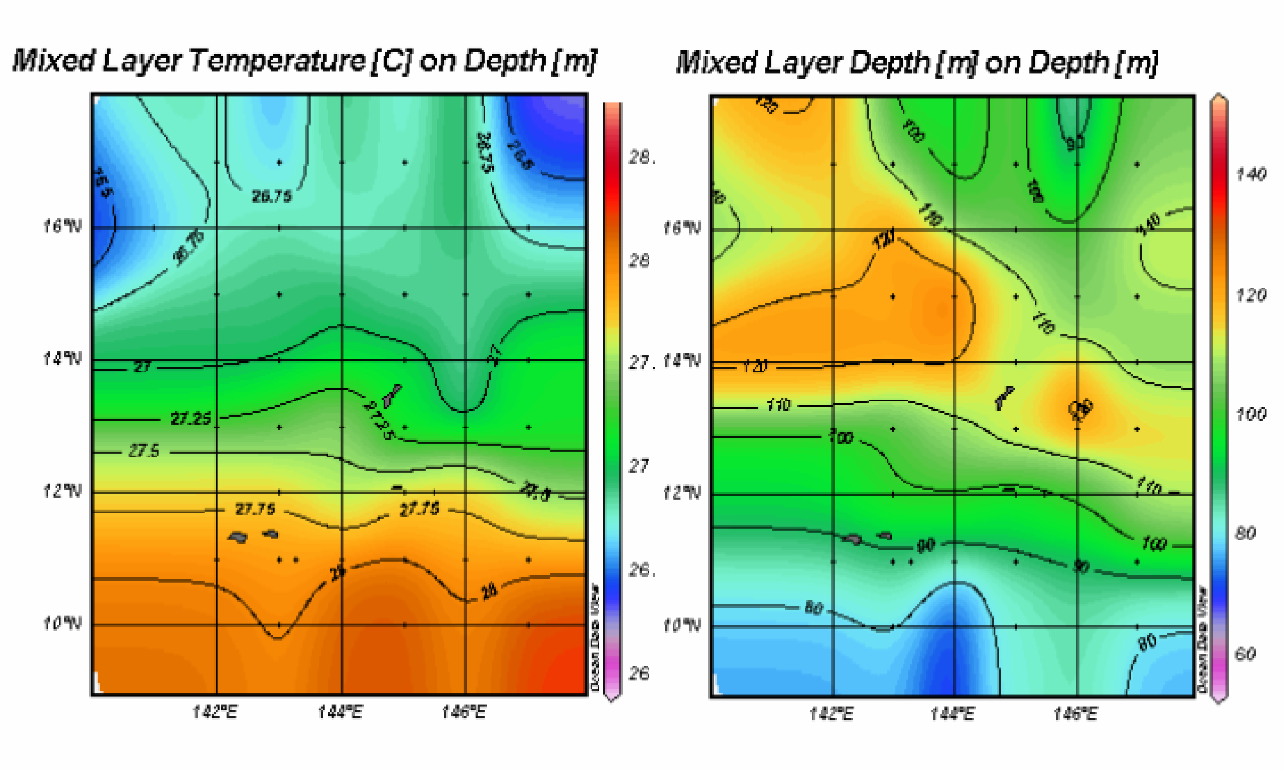
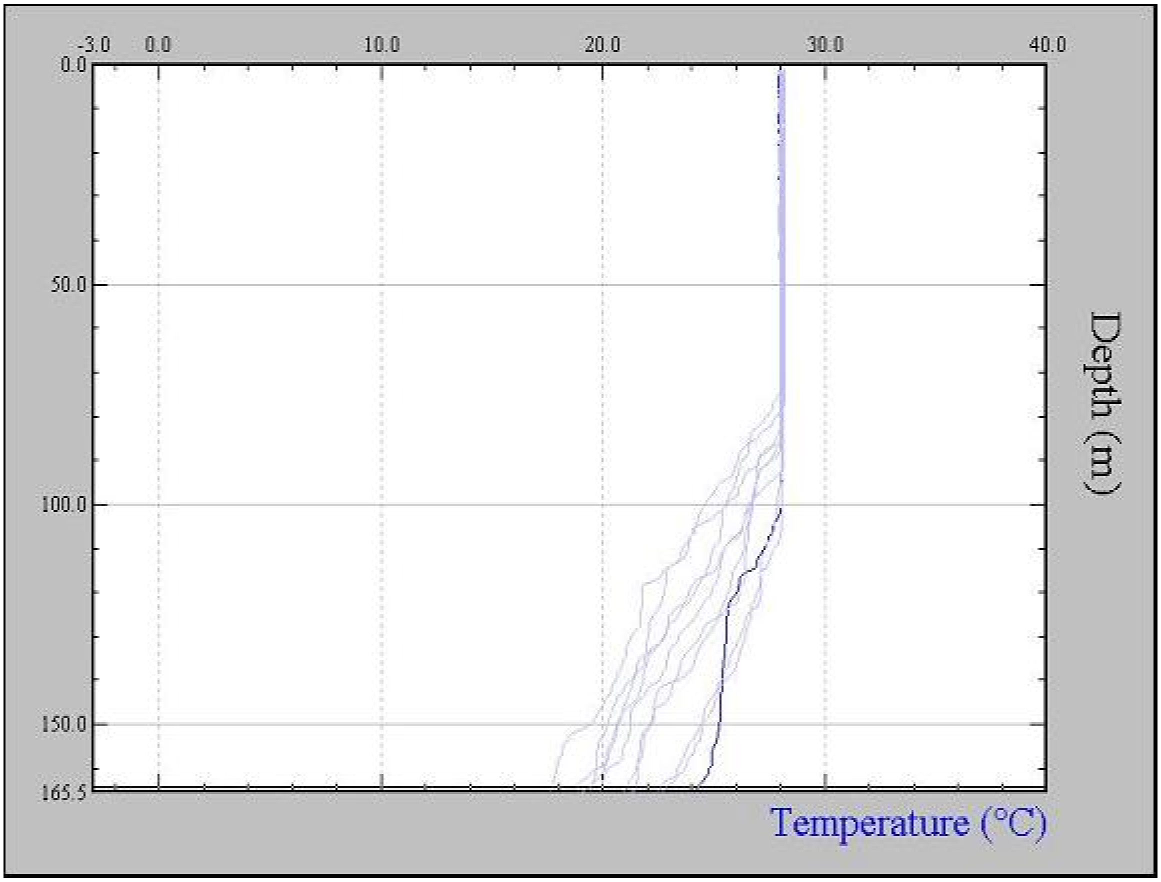


Figure 3-26. Bottom of the Surface Mixed Layer Depth and Temperature as Determined by XBT Drops across the MISTCS Study Area



Notice the uniform surface mixed layer ending with the beginning of the thermocline.

Figure 3-27. MISTCS XBT Drops #002 – 012 as depicted by the Lockheed-Martin Sippican Inc. WinMK 12 Program

3.3.1.3 Chlorophyll Surface Samples

Incorrect filters available during Leg 1 caused a potential bias in chlorophyll *a* values, hence Leg 1 data were discarded to ensure validity of the remaining data. The mean chlorophyll *a* concentration during Legs 2 through 4 of the cruise was 0.0150 µgl^{-1}. However, the range was considerable as the maximum chlorophyll value was over five times greater than the minimum value (0.0060 - 0.052 µgl^{-1}). As shown graphically in **Figure 3-28**, the lowest region of productivity seen during the survey was to the southeast of the island of Guam at approximately 13°N, 145 – 145.5°E. The highest chlorophyll *a* concentration was found to the north of the study area between 16 – 18°N and 143.5 – 145°E, with another relatively high patch found between ~10 – 11.5°N and 143.8 – 145.5°N. When comparing chlorophyll values collected from three of the four legs of MICSTS, a decreasing trend in mean values with each subsequent Leg is observed (**Figure 3-29**). Mean chlorophyll a was 0.0216 µgl^{-1}, 0.0189 µgl^{-1}, and 0.0152 µgl^{-1} during Legs 2, 3, and 4, respectively. **Appendix C, Figure C-4** contains a graphical representation of the sea surface chlorophyll *a* levels per Leg.

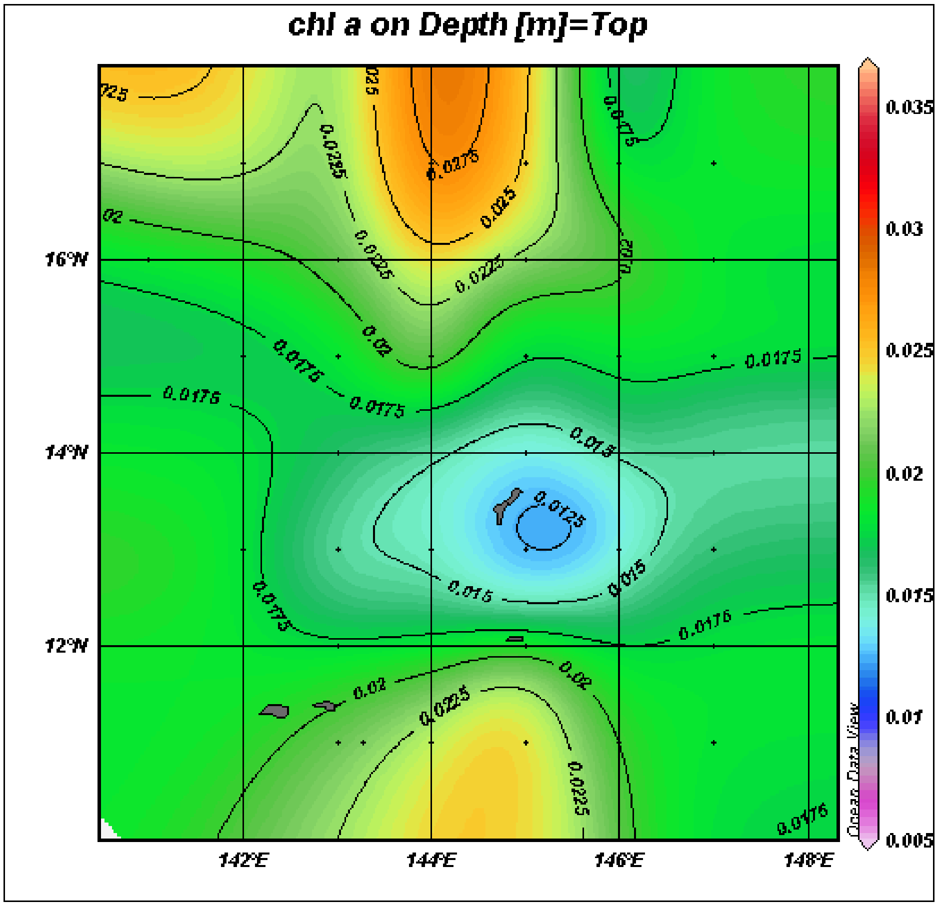
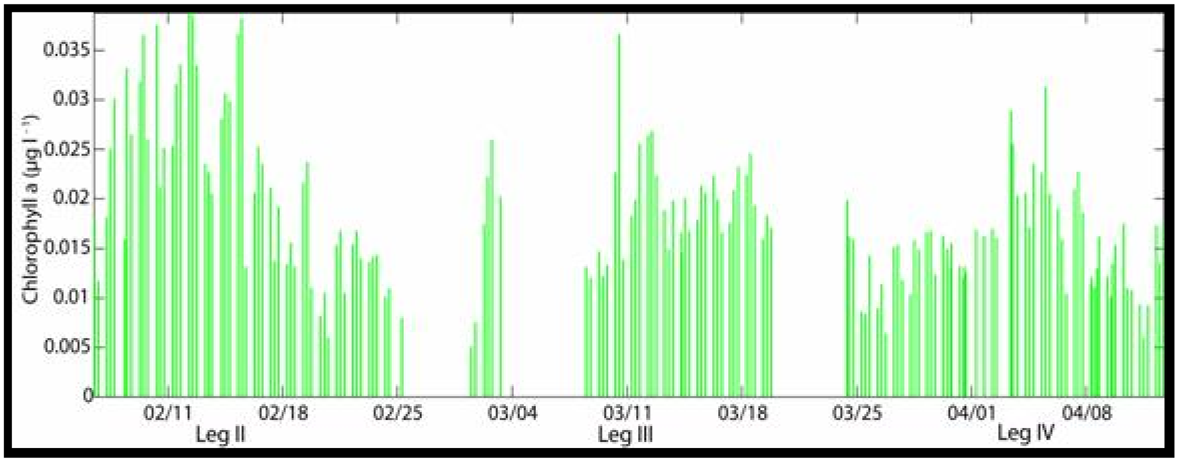


Figure 3-28. Chlorophyll *a* Levels as Found within the MISTCS Study Area



Note: Figure created by Jamie Gove, 2007

Figure 3-29. Surface Chlorophyll *a* Concentrations during Legs 2, 3, and 4 of MISTCS

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4 DISCUSSION

4.1 VISUAL OBSERVATIONS

4.1.1 Density Estimation Caveats

The goal of this survey was to provide baseline data that would serve as the best available information for Navy environmental planning purposes. This document represents the United States' first comprehensive effort to provide density estimates in the region of Guam and CNMI. The density estimates will assist with determining any potential impacts of military operations to marine mammal and sea turtle populations and aid in the preparation of associated consultations under ESA and MMPA.

In the absence of any real offshore occurrence data, aside from anecdotal reports, MISTCS proved to be invaluable. For example, based on recent assessments of available occurrence data for the region (Eldredge, 2003; DON, 2005), the sei whale was not expected to occur south of 20° N, however, a number of confirmed sightings were made. Essentially, in the absence of a systematic survey program conducted year-round for a number of years, MISTCS should be considered the currently best available information on cetaceans in the region.

We recognize that MISTCS is a snapshot of cetacean occurrence in the region during only one 4-month period of time, and does not necessarily reflect the real occurrence (*i.e*., seasonal and species variability) in this region. As a result, as a baseline survey, the analysis using DISTANCE was not overly robust (*i.e*., extensive use of covariates could not be applied due to the low sighting rate and CVs were very high).

The year-round high sea states that are endemic to the Mariana Islands made this a difficult cruise to execute. The poor sea conditions made detection of all, but either the largest cetaceans or cetaceans occurring in large, gregarious groups, extremely difficult. This resulted in a "less than optimal" number of sightings for density estimation. To address this, we pooled species based on their sighting characteristics (see Chapter 2) and in some cases; the numbers of sightings were still below 20.

For the purpose of this report, we assumed *g(0)* = 1. This is an unrealistic assumption for many of the species addressed in this report, particularly those with long dive times (*i.e*., beaked whales and the sperm whale) or that are difficult to detect as a result of their size or behavior (*i.e*., minke whale and *Kogia* spp.) (Barlow, 1999). However, estimates of *g(0)* could not be calculated during this survey. In fact, most systematic surveys of cetaceans do not estimate *g(0)* due to the associated expenses of additional observers and equipment needed to perform this task. It should be noted, however, that there has been an increasing effort to address this concern.

As stated previously, by assuming *g(0)* = 1 for these analyses, the abundance and density estimates for those species analyzed are underestimated, since it does not include a correction for animals below the water's surface and/or not detected. The magnitude of the bias is species-, area-, and platform-specific. The magnitude of *g(0)* variation from other regions (where *g(0)* has been estimated) is provided in Table 4-1. This table is meant to provide a range of reported *g(0)* values. Methodology of how those *g(0)* values were derived are found in the complete references found in Table 4-1.

Density analyses performed for this report were reviewed by researchers at the University of St. Andrews, Centre for Research into Environmental and Ecological Modelling (CREEM) while under contract to GMI. This research group (a non-governmental organization) is at the forefront of abundance estimation and provide the software DISTANCE; used to generate the density numbers for this report.

Table 4-1. Range of Estimates for *g(0)* for Each Cetacean Species Sighting in the MISTCS Study Area

g(0)	Location	Platform	Source
Threatened/Endangered Cetacean Species			
Sei whale (*Balaenoptera borealis)*			
0.32-0.94	U.S. Atlantic Coast	Shipboard	Palka, 2006
0.19-0.29	U.S. Atlantic Coast	Aerial	Palka, 2005a
0.90-1.00	U.S. West Coast	Shipboard	Barlow, 1995; 2003a
0.97	U.S. West Coast	Aerial	Forney and Barlow, 1993; Forney *et al.,* 1995
0.90	Hawaii	Shipboard	Barlow, 2003b
Sperm whale (*Physeter macrocephalus)*			
0.28-0.57	U.S. Atlantic Coast	Shipboard	Palka, 2005b; Palka, 2006
0.19-0.29	U.S. Atlantic Coast	Aerial	Palka, 2005a
0.53-1.00	U.S. West Coast	Shipboard	Barlow, 1995; Barlow and Gerrodette, 1996; Barlow and Sextron, 1996; Barlow, 2003a; Barlow and Taylor, 2005
0.95-0.98	U.S. West Coast	Aerial	Forney and Barlow, 1993; Forney *et al.,* 1995
0.87	Hawaii	Shipboard	Barlow, 2003b; 2006
0.32	Antarctica	Shipboard	Kasamatsu and Joyce, 1995
Non-Threatened/Non-Endangered Cetacean Species			
Bryde's whale (*Balaenoptera edeni)*			
0.90-1.00	U.S. West Coast	Shipboard	Barlow, 1995; 2003a
0.90	Hawaii	Shipboard	Barlow, 2003b; 2006
Bottlenose dolphin (*Tursiops truncatus)*			
0.62-0.99	U.S. Atlantic Coast	Shipboard	Palka, 2005b; 2006
0.58-0.77	U.S. Atlantic Coast	Aerial	Palka, 2005a
0.74-1.00	U.S. West Coast	Shipboard	Barlow, 1995; 2003a
0.67-0.96	U.S. West Coast	Aerial	Forney and Barlow, 1993; Forney *et al.,* 1995
0.74-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
Spinner dolphin (*Stenella longirostris)*			
0.61-0.76	U.S. Atlantic Coast	Shipboard	Palka, 2006
0.77-1.00	U.S. West Coast	Shipboard	Barlow, 2003a
0.77-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
Pantropical spotted dolphin (*Stenella attenuata)*			
0.37-0.94	U.S. Atlantic Coast	Shipboard	Palka, 2006
0.77-1.00	U.S. West Coast	Shipboard	Barlow, 2003a
0.76-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
Striped dolphin (*Stenella coeruleoalba)*			
0.61-0.77	U.S. Atlantic Coast	Shipboard	Palka, 2005b; 2006
0.77-1.00	U.S. West Coast	Shipboard	Barlow, 1995; 2003a
0.76-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
Rough-toothed dolphin (*Steno bredanensis)*			
0.74-1.00	U.S. West Coast	Shipboard	Barlow, 2003a
0.74-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
False killer whale (*Pseudorca crassidens)*			
0.74-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006

g(0)	Location	Platform	Source
Pygmy killer whale (*Feresa attenuate)*			
0.74-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
Killer whale (*Orcinus orca)*			
0.90	U.S. West Coast	Shipboard	Barlow, 2003a
0.95-0.98	U.S. West Coast	Aerial	Forney *et al.,* 1995
0.90	Hawaii	Shipboard	Barlow, 2003b; 2006
0.96	Antarctica	Shipboard	Kasamatsu and Joyce, 1995
Melon-headed whale (*Peponocephala electra))*			
0.74-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
Pilot whale (*Globicephala* spp.*)*			
0.48-0.67	U.S. Atlantic Coast	Shipboard	Palka, 2005b; 2006
0.19-0.29	U.S. Atlantic Coast	Aerial	Palka, 2005a
0.74-1.00	U.S. West Coast	Shipboard	Barlow, 2003a
0.74-1.00	Hawaii	Shipboard	Barlow, 2003b; 2006
0.93	Antarctica	Shipboard	Kasamatsu and Joyce, 1995

These numbers were either determined by the source or applied by the source for abundance/density estimation analyses in the particular geographic location.

4.1.2 Species/Species Group Summaries

4.1.2.1 Physeter macrocephalus

There were an estimated 705 (CV = 60.4; 95% CI = 228-2,181) sperm whales in the MISTCS study area and density was estimated as 1.2 animals per 1,000 km^2 (95% CI = 0.40-3.8) (**Table 3-5**). Sperm whale group size ranged from 1 to 25 individuals ($\bar{x}$ = 5.1; Standard Error [SE] = ±2.03). There were multiple sightings that included young calves and large bulls, suggesting that this area is part of a breeding ground for the species. These observations support a sighting reported in DON (2005) of a sperm whale calving event in these waters. One sighting in particular is noteworthy where at least three large bulls were seen with rake mark scars suggesting male-male intra-specific interactions (Kato, 1984; Whitehead, 2003).

Sperm whales were sighted in deep waters, ranging from 809 to 9,874 m ($\bar{x}$ = 3,925 m; SE = ±440.4 m) in bottom depth (**Table 3-3**; **Figure 3-8**). These findings match the known preference of this species for very deep waters (see **Appendix A** for more information). There were several sightings over the Mariana Trench and concentrated sightings in the southwest corner of the MISTCS study area. The closest sighting to shore was 2.5 km off the mouth of Apra Harbor (Guam); this sighting included several calves and a large bull. On the humpback whale focal study day (18 February), there were two sightings off Tinian within 5 and 14 km from shore (800-1,200 m in bottom depth).

4.1.2.2 *Balaenoptera* spp.

Sei and Bryde's whales can be difficult to distinguish from one another by physical appearance and behavior (see Reeves *et al*., 2002); however, many of the sightings during MISTCS involved sei whales closely approaching the vessel, facilitating quality identification photographs that confirmed the presence of the sei whale in these waters.

- *Balaenoptera borealis*—There were an estimated 166 (CV = 48.7; 95% CI = 67-416) sei whales in the MISTCS study area and density was estimated as 0.29 animals per 1,000 km^2 (95% CI = 0.12-0.73) (**Table 3-5**). Sei whale group size ranged from one to four individuals ($\bar{x}$ = 1.3; SE = ±0.16). There was only one incident when calves were noted. Multi-species aggregations were noted on a few occasions. Noteworthy is an encounter with a mixed-species aggregation of one sei whale with two Bryde's whales, further illustrating difficulties in confirmation of species identity. There was also an aggregation that included melon-headed whales.

Sei whales were sighted in deep waters, ranging from 3,164 to 9,322 m ($\bar{x}$ = 5,673 m; SE = ±364.2 m) in bottom depth (**Table 3-3**; **Figure 3-9**). There were several sightings in waters over and near the Mariana Trench. Most sightings though were associated with bathymetric relief (*e.g.*, steeply sloping areas), including sightings adjacent to the Chamarro Seamounts east of CNMI. All confirmed sightings of sei whales were south of Saipan (approximately 15°N) with concentrations in the southeastern corner of the MISTCS study area.

Prior to this survey effort, it was expected that the sei whale would be extralimital to the study area, based on the available distribution information and known habitat preferences of the species (DON, 2005), however, the MISTCS cruise resulted in a total of 16 recorded sightings.

- *Balaenoptera edeni*—There were an estimated 233 (CV = 45.0; 95% CI = 99-546) Bryde's whales in the MISTCS study area and density was estimated as 0.41 animals per 1,000 km^2 (95% CI = 0.17-0.95) (**Table 3-5**). Bryde's whale group size ranged from one to three individuals ($\bar{x}$ = 1.4; SE = ±0.16). Several sightings included calves, suggesting that the MISTCS study area is part of the breeding ground for the Bryde's whale. Multi-species aggregations with sei whales were observed on a few occasions. Noteworthy were observations of Bryde's whale associations with schools of what were believed to be skipjack tuna (*Euthyunnus pelamis*) and seabirds; one of these involved lunge-feeding by the whales on the fish.

  Bryde's whales were sighted in deep waters, ranging from 2,549 to 7,373 m ($\bar{x}$ = 4,563 m; SE = ±329.4 m) in bottom depth (**Table 3-3**; **Figure 3-9**). There were several sightings in waters over and near the Mariana Trench. Most sightings though were associated with bathymetric relief (*e.g.*, steeply sloping areas and seamounts), including sightings adjacent to the Chamarro Seamounts east of CNMI and over the West Mariana Ridge. There were also concentrations in the southeast corner of the MISTCS study area.

4.1.2.3 Blackfish

- *Globicephala macrorhynchus*—There were an estimated 909 (CV = 67.7; 95% CI = 230-3,590) short-finned pilot whales in the MISTCS study area and density was estimated as 1.59 animals per 1,000 km^2 (95% CI = 0.40-6.26) (**Table 3-5**). Short-finned pilot whale group size ranged from 5 to 43 individuals ($\bar{x}$ = 17.5; SE = ±8.8). A mixed-species aggregation involved common bottlenose dolphins with short-finned pilot whales and rough-toothed dolphins. No calves were seen.

  Short-finned pilot whales were sighted in waters with a bottom depth, ranging from 927 to 4,490 m ($\bar{x}$ = 2,949 m; SE = ±705.4 m) in bottom depth (**Table 3-3; Figure 3-10**). Pilot whales associate with seamounts in some geographic locales, such as the eastern tropical Pacific (see **Appendix A**). Similar observations were made in the Mariana Islands; there were three sightings over the West Mariana Ridge, an area of seamounts (see **Appendix A** for more information). Noteworthy are some sightings relatively close to shore in the MISTCS study area. One on-effort sighting was 13 km off the northeast corner of Guam, just inshore of the 1,000 m isobath. There was also an off-effort sighting of a group of 6 to 10 pilot whales near the mouth of Apra Harbor between Legs 3 and 4. This sighting is also depicted in **Figure 3-10**.

- *Peponocephala electra*—There were two sightings of melon-headed whales in the MISTCS study area, both southwest of Guam. There were an estimated 2,455 (CV = 70.2; 95% CI = 695-8,677) melon-headed whales in the MISTCS study area and density was estimated as 4.28 animals per 1,000 km^2 (95% CI = 1.2-15.1) (**Table 3-5**). Melon-headed whale group size ranged from 80 to109 individuals ($\bar{x}$ = 94.5; SE = ±14.5). A mixed-species aggregation with pantropical spotted dolphins was observed.

Melon-headed whales were sighted in waters with a bottom depth, ranging from 3,224 to 3,935 m ($\bar{x}$ = 3,650 m; SE = ±161.9 m) in bottom depth (**Table 3-3; Figure 3-10**). One of the two sightings was in the vicinity of the West Mariana Ridge.

- *Feresa attenuata*—There was only one sighting of the pygmy killer whale. Based on this one sighting, the best estimate of abundance was 78 individuals (CV = 88.1; 95% CI = 17-353). Density was estimated as 0.14 animals per 1,000 km^2 (95% CI = 0.03-0.62) (**Table 3-5; Figure 3-10**). The group size was six individuals.

  The sighting was made near the Mariana Trench, south of Guam, where the bottom depth was 4,439 m. This is consistent with the known habitat preferences of the species for deep, oceanic waters (see **Appendix A** for more information).

- *Pseudorca crassidens*—There were an estimated 637 (CV = 74.3; 95% CI = 164-2,466) false killer whales in the MISTCS study area and density was estimated as 1.11 animals per 1,000 km^2 (95% CI = 0.29-4.3) (**Table 3-5**). False killer whale group size ranged from 2 to 26 individuals ($\bar{x}$ = 9.8; SE = ±4.2). Several sightings contained calves.

  False killer whales were sighted in waters with a bottom depth ranging from 3,059 to 8,058 m ($\bar{x}$ = 5,617 m; SE = ±443.3 m) in bottom depth (**Table 3-3; Figure 3-10**). Several sightings over the Mariana Trench were made, as well as several in the southeast corner of the study area, in waters with a bottom depth greater than 5,000 m (**Figure 3-8**). There was also a sighting in deep waters west of the West Mariana Ridge. Noteworthy is a sighting relatively close to shore, 20 km off the mouth of Apra Harbor in waters with a bottom depth greater than 1,000 m.

4.1.2.4 Delphinids

- *Stenella attenuata*—There were an estimated 12,981 (CV = 70.4; 95% CI = 3,446-48,890) pantropical spotted dolphins in the MISTCS study area and density was estimated as 22.6 animals per 1,000 km^2 (95% CI = 6.0-85.3) (**Table 3-5**). Pantropical spotted dolphin group size ranged from 1 to 115 individuals ($\bar{x}$ = 64.2; SE = ±37.0). There were multiple sightings that included young calves, and one mixed species aggregation with melon-headed whales and another with an unidentified *Balaenoptera* spp. These pantropical spotted dolphins were identified as the offshore morphotype (see **Appendix A** for more information).

  Pantropical spotted dolphins were sighted throughout the study area in waters with a variable bottom depth, ranging from 114 to 5,672 m ($\bar{x}$ = 3,720 m; SE = ±354 m) in bottom depth (**Table 3-3; Figure 3-11**). The vast majority of the sightings (65%; 11 of 17 sightings) were in deep waters (>3,000 m); these findings match the known preference of this species for oceanic waters (see **Appendix A** for more information). There was only one shallow-water sighting; this sighting was made on 18 February, 2.5 km north of Tinian during the humpback whale focal study, in waters with a bottom depth of 114 m.

- *Stenella coeruleoalba*—There were an estimated 3,531 (CV = 54.0; 95% CI = 1,250-9,977) striped dolphins in the MISTCS study area and density was estimated as 6.16 animals per 1,000 km^2 (95% CI = 2.18-17.4) (**Table 3-5**). Striped dolphin group size ranged from 7 to 44 individuals ($\bar{x}$ = 27.4; SE = ±9.4). Several sightings contained calves.

  Striped dolphins were sighted throughout the study area in waters with a variable bottom depth, ranging from 2,362 to 7,570 m ($\bar{x}$ = 4,207 m; SE = ±514.5 m) in bottom depth (Ta**ble 3-3; Figure 3-11**). There was at least one sighting over the Mariana Trench, southeast of Saipan. There were no sightings south of Guam (approximately 13°N).

- *Tursiops truncatus*—There were an estimated 122 (CV = 99.2; 95% CI = 5.0-2,943) common bottlenose dolphins in the MISTCS study area and density was estimated as 0.21 animals per 1,000 km^2 (95% CI = 0.001-5.1) (**Table 3-5**). Common bottlenose dolphin group size ranged from 3 to 10 individuals ($\bar{x}$ = 2.2; SE = ±1.8). Calves were seen during several sightings.

Common bottlenose dolphins were sighted throughout the study area in very deep waters with a bottom depth ranging from 4,241 to 5,011 m ($\bar{x}$ = 4,544 m; SE = ±162.7 m) in bottom depth (**Table 3-3; Figure 3-11**). There were a total of only three sightings of the species - two of the sightings were in the vicinity of Challenger Deep, one of the deepest locations of the Mariana Trench, while the other sighting was east of Saipan near the Mariana Trench. One of the sightings near the Challenger Deep was a mixed-species aggregation that included sperm whales (with calves) logging at the surface; social behaviors were observed. Another mixed-species aggregation involved common bottlenose dolphins with short-finned pilot whales and rough-toothed dolphins.

- *Stenella longirostris*—There was only one sighting of spinner dolphins. They were identified as subspecies Gray's. There were an estimated 1,803 (CV = 95.8; 95% CI = 361-9,004) spinner dolphins in the MISTCS study area and density was estimated as 3.14 animals per 1,000 km^2 (95% CI = 0.63-15.7) (**Table 3-5**). The best estimate of group size was 98 animals.

  Spinner dolphins were sighted northeast of Saipan in waters with a bottom depth of 426 m (**Table 3-3; Figure 3-11**).

- *Steno bredanensis*—There were only two sightings of the rough-toothed dolphin made during the MISTCS cruise. There were an estimated 166 (CV = 89.2; 95% CI = 36-761) rough-toothed dolphins in the MISTCS study area and density was estimated as 0.29 animals per 1,000 km^2 (95% CI = 0.06-1.33) (**Table 3-5**). Rough-toothed dolphin group size was nine individuals. A mixed-species aggregation involved common bottlenose dolphins with short-finned pilot whales and rough-toothed dolphins. There was one sighting of rough-toothed dolphin that included calves.

  Rough-toothed dolphins were sighted in deep waters, ranging from 1,019 to 4,490 m ($\bar{x}$ = 2,755 m; SE = ±1,735.5 m) in bottom depth (**Table 3-3; Figure 3-8**). One sighting was off the island of Guguan, while the other was at the southern edge of the study area (**Figure 3-11**).

4.1.2.5 Beaked Whales

There were only three sightings of beaked whales made during the MISTCS cruise: two *Mesoplodon* spp. and one ziphiid whale. No estimate of abundance or density was possible due to the low number of sightings and the inability of pooling this group of species with other cetaceans due to their cryptic behavior. Only single individuals were sighted. The high BSS associated with the MISTCS cruise made visual detection of these cryptic animals extremely difficult.

The beaked whales were all sighted in deep waters; bottom depth ranged from 2,122 to 3,984 m ($\bar{x}$ = 3,116.7 m; SE = ±541.3 m). These findings match the known habitat preferences of beaked whales for deep, oceanic waters (see **Appendix A** for more information). The closest sighting to land was 33 km WSW of the island of Alamagan of a ziphiid whale (**Figure 3-12**). The two *Mesoplodon* spp. sightings were over the West Mariana Ridge, an area of seamounts.

4.1.2.6 Megaptera novaeangliae

A group of humpback whales was acoustically detected on 17 February and visually detected on 18 February, 15 km off the northeast coast of Saipan (**Figure 3-14)**. Bottom depth of this sighting was 148 m. As mentioned earlier, a day was set aside for a focal study of humpback whales in the area, to include photo-identification efforts. Fluke photographs will be compared with established catalogues from other geographic areas.

No estimate of abundance or density was possible since only one sighting (off-effort) was made of humpback whales in the MISTCS study area. The best estimate of group size was eight individuals; no calves were sighted. Social behaviors observed included tail-slapping, breaching, and chin-slapping which are behaviors frequently observed on the breeding grounds of the species (*e.g.*, Hawaii, Caribbean) (DON, 2005).

4.1.2.7 Eretmochelys imbricata

A single hawksbill turtle was sighted on Leg 4, 285 km WSW off the island of Anatahan (north of Farallon de Medinilla (FDM).

4.2 ACOUSTIC SURVEY

The acoustic monitoring effort provided information about cetacean distribution and abundance that could not have been gathered using visual methods alone. For example, minke whales were never sighted by visual observers, but were the second most frequent species acoustically-detected. Sperm whales were the most common large whale encountered by both visual and acoustical methods, but acoustic encounter rates were over three times greater than visual encounters. Incorporation of the sperm whale acoustic data in the abundance estimation analysis is possible (see discussion of sperm whales), but beyond the scope of this report. Due to the high acoustic encounter rates, distribution patterns can be readily assessed.

Acoustic methods are extremely effective for some species of cetaceans, but not necessarily for all species encountered during these surveys. Most delphinids are easily detected acoustically, but species identification and differentiation remains problematic and usually requires visual methods (Oswald *et al*., 2003; In Press). Beaked whales, fin whales, Bryde's whales and *Kogia* species (spp.) were expected to be encountered in the study area (DON, 2005), but were not detected acoustically (Bryde's whales were detected visually). The reasons relating to these differences in the probability of acoustic detections of cetaceans are discussed in greater detail below.

Current passive acoustic methods are generally ineffective at precisely determining group sizes of cetaceans, especially when more than a few (~3-4) individuals are present. Therefore, species that frequently occur in groups must be counted visually. Techniques are now being developed that will allow differentiation of individuals in groups based on 3-D locations and track for some species such as sperm whales (Thode, 2004; 2005).

Perhaps the greatest advantage of acoustic methods for oceanic surveys is that they are relatively unaffected by poor sighting or sea conditions. Also, they can be easily conducted at night. In this study, towed array effort was conducted for a total of 762 hours (99%) of the available days at sea[1.] Acoustic effort was conducted for an average of 10.9 hours per day for all survey days, and 11.6 hours per day for "whole" survey days (**Table 3-7**). The cumulative distance surveyed using the towed hydrophone array was approximately 11,448 km. By comparison, for the 71 days in which visual effort was conducted, approximately 11,033 km of survey effort was completed. Much of the visual effort consisted of marginal or unusable sighting conditions of Beaufort 5 or more (**Figure 3-1**). These differences highlight one of the primary advantages of using passive acoustic monitoring for surveys of marine mammals and is the reason they have recently become standard practice for many cetacean line-transect surveys (Barlow and Taylor, 2005; Barlow and Rankin, 2007; Lewis *et al*., 2007).

Encounter rates for acoustic methods (207/11,478 = 0.018 or ~1.8 animals/100 km) were greater than for visual methods (148/11033=1.3 animals/100km). These rates are not independent and are possibly biased upwards for acoustic detections (as discussed below) but we believe the differences are real. Forty-nine (58%) of all the encounters detected by both methods, were detected acoustically first (**Table 3-9**), whereas, only 36 (42%) of those encountered by both methods were sighted by visual observers first. Of the 207 total acoustic detections made, 122 (59%) were not detected by visual observers. Alternatively, there were only 61 visual sightings that were not detected acoustically.

It is important to stress that the acoustic and visual data are not directly comparable for several reasons. For acoustic methods, "unique detections" are determined using somewhat subjective criteria which likely resulted in cases of "double-counting" detections of the same individual or

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[1] One day was intentionally taken off to allow bio-acousticians to sleep after a 24 hr day/night survey.

groups. Also, totals for visual sightings were counted exclusively from on-effort data, whereas acoustic detection totals were tallied from both on effort and off effort modes for visual search effort, and possibly resulted in an upward bias for acoustic detection totals. This was an artifact of the sighting protocols, which did not require visual observers to allow a sighting to pass the beam before going off-effort to investigate. Isolated island groups like the Mariana Islands also have very high sea states year-round, which hampers visual observations of marine mammals.

Other protocols may have resulted in biased encounter rates for visual or acoustic methods. For example, visual observers were allowed to notify the bioacousticians when a sighting was made, potentially resulting in a positive bias for acoustic monitoring. However, the acoustics team was not supposed to notify the visual observers of any acoustic detections until the animals were well past the ship's beam (> 90 degrees from the bow). This protocol might be expected to result in a bias towards more acoustic detections, but we do not think observer bias is an issue for bioacoustic monitoring because signals with good signal-to-noise are unlikely to be missed regardless of whether or not cues are given by visual observers. A more significant issue is the fact that visual observers can direct the ship off-track once they have made a sighting. On numerous occasions, the research vessel was instructed to leave the trackline to investigate or pursue a sighting before the animals passed the ship's beam. This could result in an increase or decrease probability of acoustic detections depending on how animals respond to the pursuit (*e.g*. if they are more or les vocally active; or are attracted to or flee from the vessel) and any related changes in ship noise caused by turning the vessel and changing engine revolutions per minute (RPMs).

Perhaps the most important issue relating to comparing these data directly are that visual and acoustic methods are effectively searching different areas, and at slightly different times. The visual observers are instructed to scan from 0-90 degrees (bow-to-beam) and "guard" the track-line ahead of the ship. Due to the directivity of the towed hydrophone array, it has limited ability to "look" ahead, but is most effective "looking" at regions directly abeam. In addition, the array is towed 300 m behind the stern of the ship, resulting a slight (few minutes) delay of the same area searched by the visual team. These factors act to reduce or most likely, delay the likelihood of detecting animals that have already been detected by visual means.

Noise from the ships machinery and propeller cavitation can significantly affect signal detection probability by reducing the received signal-to-noise ratio at the array, especially from signal sources near or in the vessel. Perhaps the most important and least understood factor affecting probability of acoustic detections are vocalization rates and beam-patterns of cetaceans. Vocalizations for some species and signal types are highly directional (Zimmer, *et al*., 2005; Lammers *et al*., 2003) affecting the ranges and relative directions from which they can be detected. Finally, vocalizing is not an obligate behavior (as is surfacing to breathe) so for some species it is possible, even probable, that they do not vocalize (or do not do so loud enough) effectively making them undetectable using passive acoustic methods.

In spite of these constraints, passive acoustic detection methods have proven to be quite effective in this and other ship-based surveys of cetaceans. Acoustic detections by species and species groups are summarized in detail below. **Appendix B-1** provides the acoustic detection log detailing all acoustic detections during MISTCS.

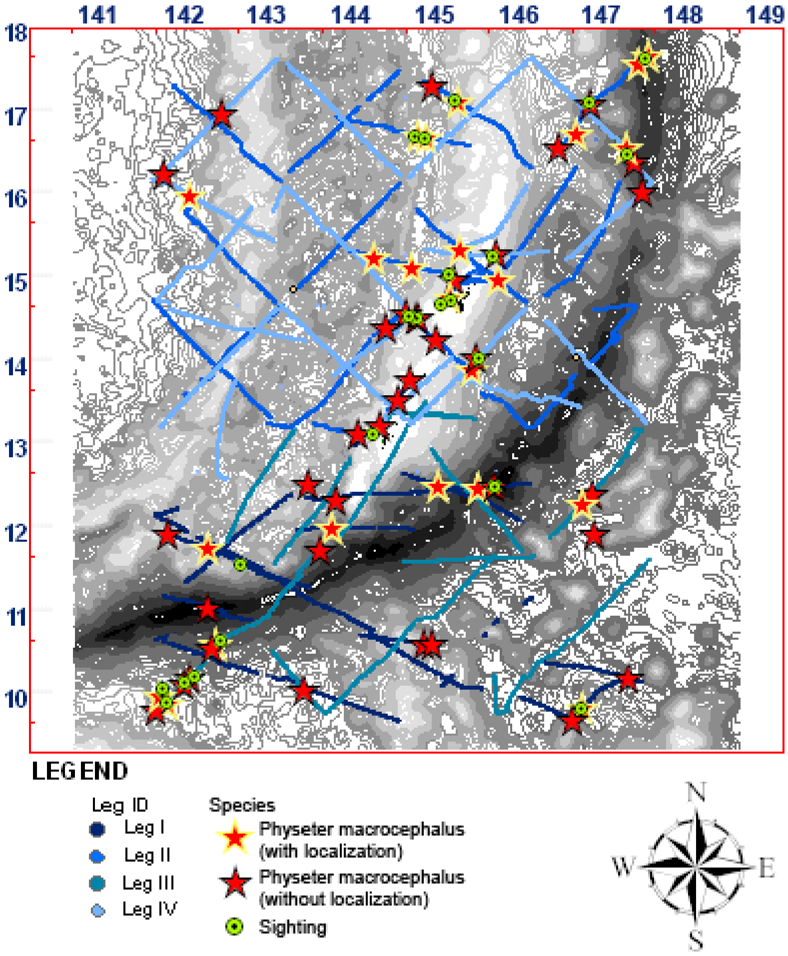
4.2.1 Summary of Acoustic Detections by Species/Species Groups

4.2.1.1 Family Physteridae

Sperm Whales

Sperm whales were the most commonly detected large whale during the survey, with a total of 61 unique acoustic detections (**Table 3-7**) of which 25 sperm whales groups were localized (**Table 3-8**). Sperm whale encounter rates were more than twice as high during Leg 2 (~ 7.4 /1000 km) as Leg 4 (2.8 /1000 km) with an average encounter rate of 5.3 detections per 1,000 km for the entire survey. The reason for this large difference in sighting rates for the different legs is not known.

Some obvious distribution patterns are evident from visual examination of a map of all sperm whale acoustic detections (**Figure 4-1**). The most striking is that there appears to be greater densities of sperm whale detections off the western side of the main Mariana Islands. Interestingly, sperm whales do not appear to be strongly associated with the deepest parts of the Marianas trench (with the possible exception of the northwest corner of the study area), although they often were detected within a 100 km of the trench axis. These patterns should be considered very preliminary and qualitative in nature; verification would require quantitative statistical analysis of locations in relation to bathymetry features.

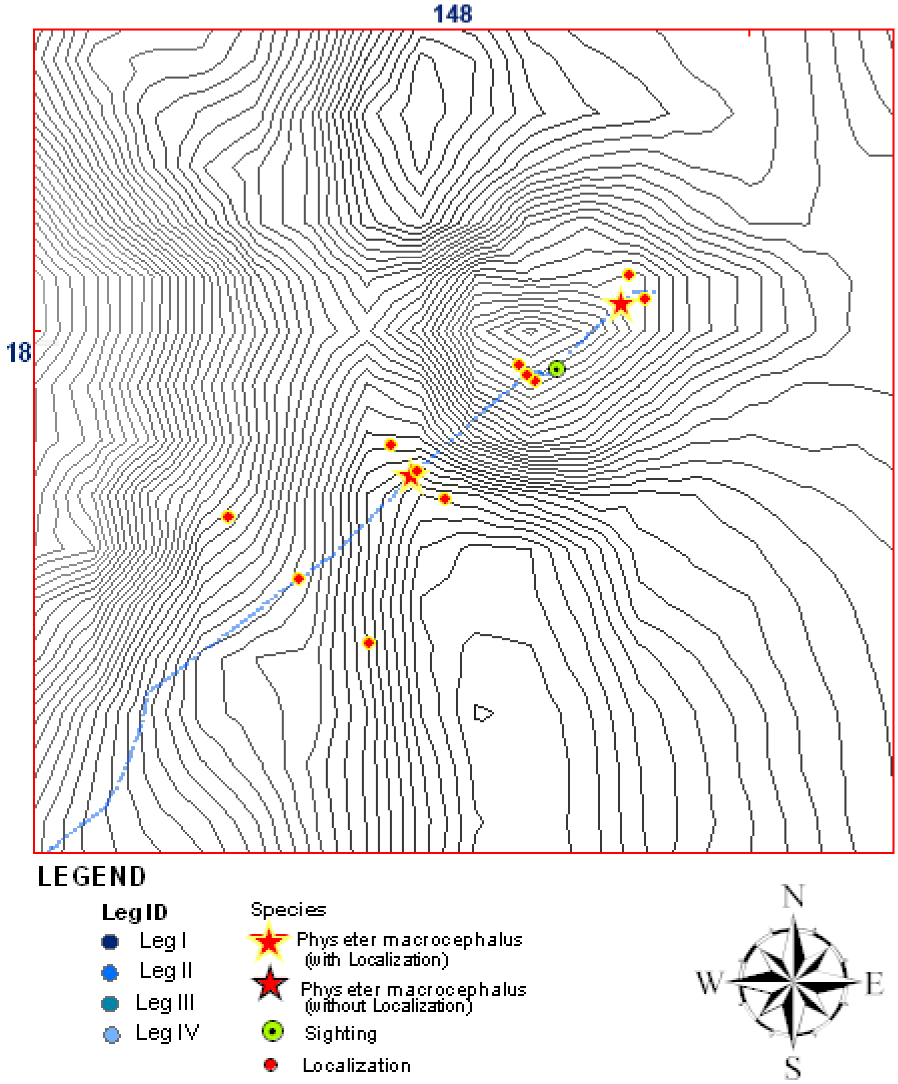


Sperm whale acoustic detections (red stars) and visual sightings (green bulls-eyes)

Figure 4-1. Physteridae Acoustic Detections

Over 40% of all sperm whale detections were localized. Sperm whales are among the easiest species of cetacean to localize, due in part to their nearly continuous vocalization behavior, slow movements, as well as the acoustic characteristics of their clicks with closely spaced hydrophone pairs. An example of several localizations over a relatively small area is provided in (**Figure 4-2**). The three clustered dots for each localization represent the left, right and center (*i.e.* trackline) estimated positions as determined from the convergence of bearings. **Figure 2-3** provides an example of the convergence of bearings at a left/right ambiguous location. Incorporation of the sperm whale acoustic data into abundance estimation is possible and has been attempted in several studies with varying success (Barlow and Taylor, 2005; Lewis *et al*., 2007). The simplest approach is to use acoustic localizations to estimate a detection function and, with a (visually-based) estimate of average group size, calculate an abundance estimate (Barlow and Taylor, 2005), similar to the approach used with visual sighting data (Buckland *et al*., 2003). Estimating bias in *g(0)* can be problematic, as it is with many species of marine mammals for visual data (for a discussion, see Appendix A in Mellinger and Barlow, 2003).

A variety of sperm whale sounds were recorded including codas, 'slow clicks', produced by sexually mature males, 'usual clicks', produced by females and sexually immature males, and creaks, produced by foraging whales (Weilgart and Whitehead, 1988; Miller *et al*., 2004). Codas are important for defining population structure (Rendell and Whitehead, 2003). Although there is much information that could be determined from recordings of sperm whale sounds, additional analysis of these sounds is beyond the scope of this report.

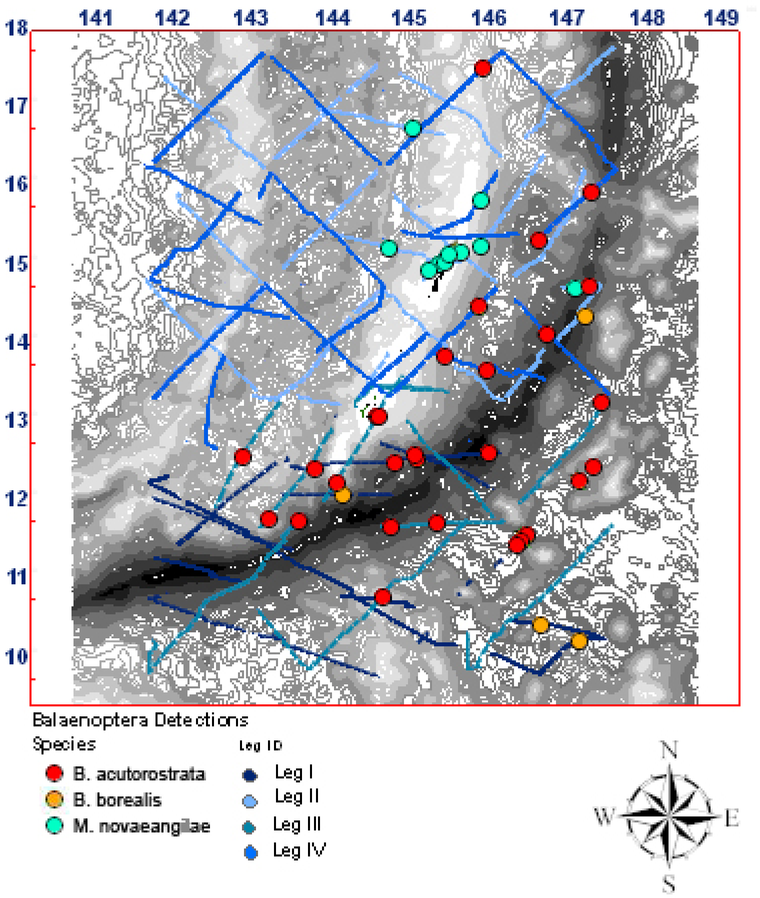


Ship direction of travel is from NE to SW. Red stars with yellow border are locations of first detection (on trackline). Red dots represent estimated left, right, and trackline intersection positions of sperm whale localization, based on convergence of bearings. Note that the four localizations have only two unique detections associated with them. This is due to the fact that unique detections were, in part, defined as those with at least an hour's separation in time between detection events. In this case, it is likely that each localization is a separate group, but they were grouped with the prior acoustic detection as a conservative approach to defining unique detections.

Figure 4-2. Sperm Whale Localization

4.2.1.2 Family Balaenopteridae

There were 44 unique acoustic detections of balaenopterid whales representing about 20 percent of all detections made. Based on visual review of a map with all balaenopterid detections plotted, the distribution appeared to be clumped by species with humpback whales mostly associated with the island of Saipan and minke whales scattered across the southwestern part of the study area (**Figure 4-3**). Interestingly, the northwestern quadrant of the study area was largely devoid of baleen whales.



Humpback whales are generally clustered near the island of Saipan, whereas minke whales occur in the general vicinity of the Marianas Trench slope. Note that northwest corner of the study area is generally devoid of detections.

Figure 4-3. Balaenoptera Acoustic Detections

Minke Whales

Minke whales were the most frequently detected species of baleen whale with a total of 29 unique acoustic detections made during the cruise (**Table 3-7**). Of this total, five localizations were possible (**Table 3-8**). As previously stated, there were no visual sightings of minke whales, a result which was not unexpected due to the cryptic behavior of this species in tropical waters, and the poor sighting conditions experienced during the cruise. In spite of enormous visual search effort very few sightings of this species have been documented in tropical Pacific waters (Balcomb, 1987; Barlow, 2006; Wade and Gerrodette, 1993).

Visual review of the distribution of minke whales acoustic detections reveals a possible association with the Marianas Trench, but not necessarily the deepest parts of the trench (**Figure**

4-4). This assessment should be considered very preliminary. Additional localizations and statistical analysis of these possible trends are needed to verify any associations with bathymetry or habitat features.

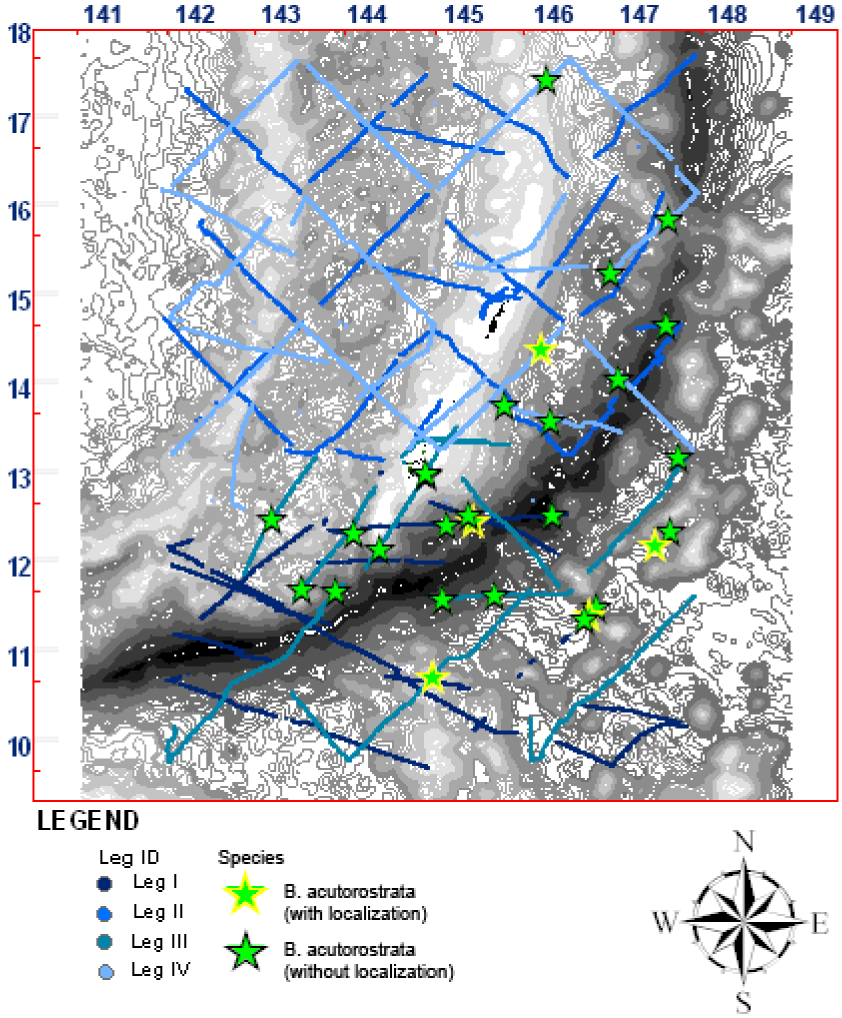
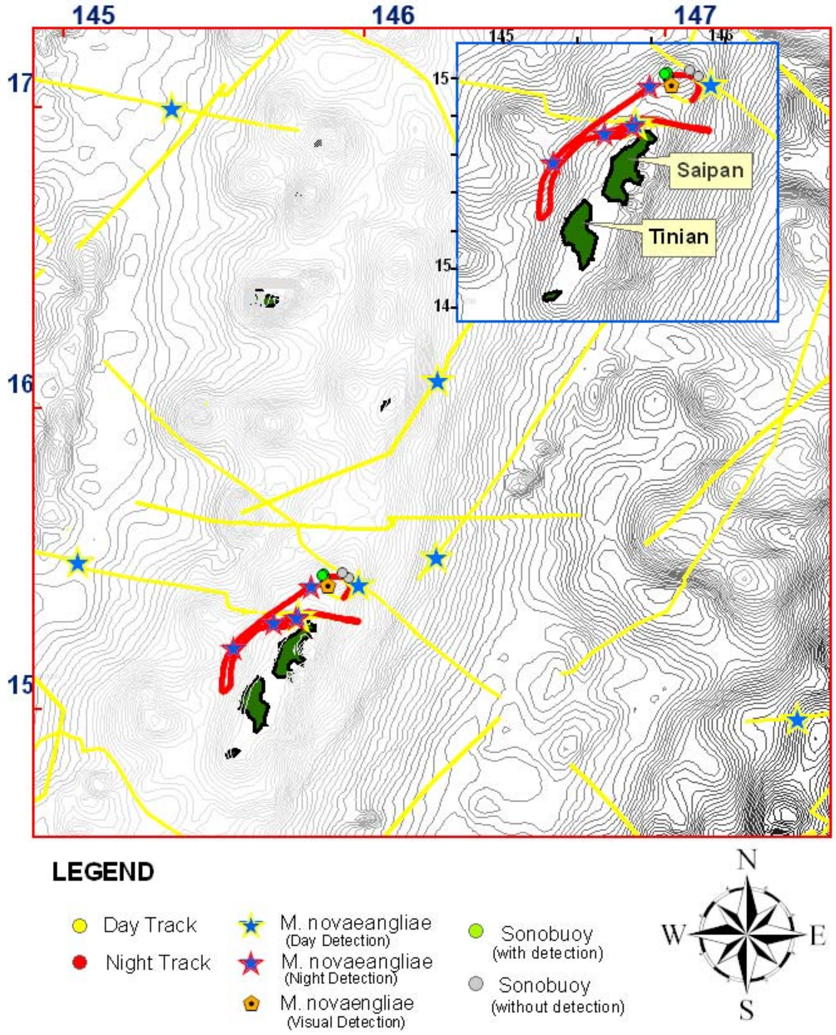


Figure 4-4. Minke Whale Acoustic Detections with Localizations

Minke whales have only recently been identified as the source of the ubiquitous 'boing' sound in the North Pacific Ocean (Rankin and Barlow, 2005). Two types of boings, 'central' and 'western', have been described in the north Pacific, based on acoustic characteristics, primarily pulse repetition rate and duration (Rankin and Barlow, 2005; Wenz, 1964). Preliminary analyses of minke whale boings recorded during the MISTCS surveys indicate that they have acoustic characteristics (*e.g*. pulse repetition rates) consistent to the central Pacific (*i.e*. Hawaii) boing. Statistical analysis of boing call characteristics from the MISCTCS recordings will be necessary to confirm this finding.

Humpback Whales

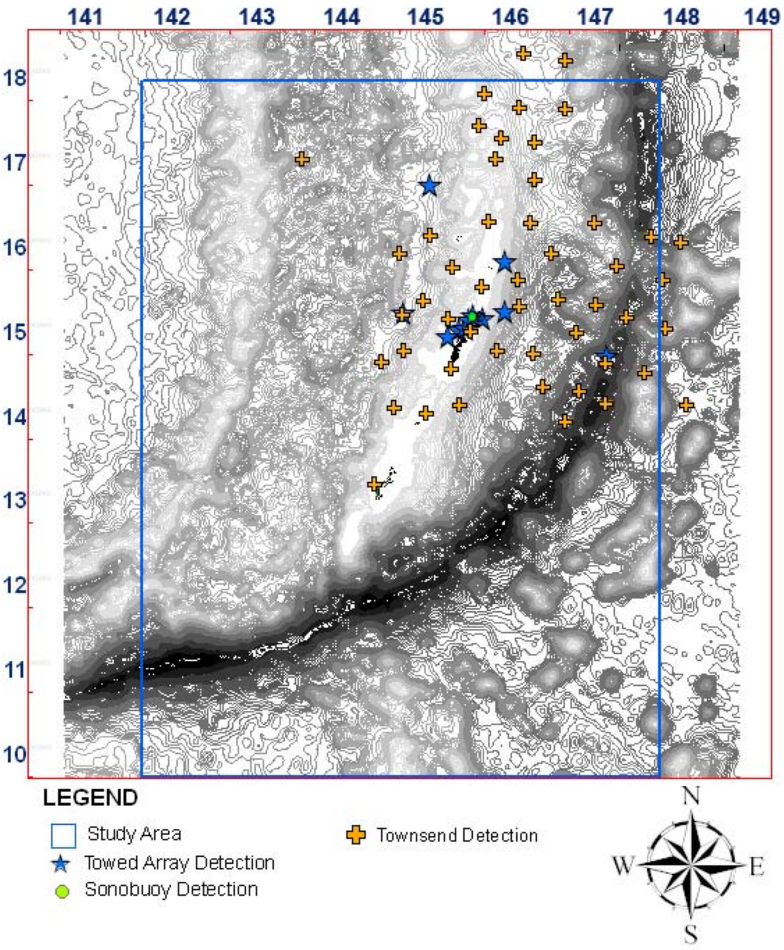
Humpback whales were the second most frequently detected baleen whale during the cruise with a total of 11 unique detections (**Table 3-7**). All of these detections were of singing humpback whales, and therefore, all are considered to be males (Darling, *et al*., 1983; Glockner, 1983). The first detection occurred on 7 February, and the last on 2 April, a span of 54 days. Four of the eleven detections were made during a 12-hour nighttime survey of the northern and western shores of the island of Saipan which occurred on 17 and 18 February. The southern and eastern sides of the islands of Saipan and Tinian were not surveyed. Because the nighttime survey was not part of the line-transect study, the ship's course was opportunistically determined based on the areas of greatest singer concentrations encountered during the survey. A close-up view of the encounters during this survey indicates that singing humpback whales were detected mainly to the north and west of the island of Saipan (**Figure 4-5**). The nighttime survey ended in a pre-dawn acoustic localization and soon thereafter a morning visual sighting of a group of six to nine socially active animals near the site of the localization was observed. It is unknown whether or not this sighting included the singing humpback whale that was acoustically localized earlier However, the presence of numerous singers and a relatively large competitive group suggests that there were probably females in the area that males were competing for access to (Tyack and Whitehead, 1983). These findings suggest that the waters around Saipan are probably an active breeding site for humpback whales.



Acoustic detections with localizations, sonobuoy deployments (with and without detections) and visual sightings of humpback whales. Inset is close-up of 17 and 18 Feb nighttime survey near the island of Saipan.

Figure 4-5. Acoustic Detections of Humpbacks near Saipan, Leg 2

Information about humpback whales around the island of Saipan is limited. Whaling charts that summarize whale kills between 1761 and 1920 indicate historical concentrations of humpback whales around the northern Marianas Islands (Townsend, 1935) (**Figure 4-6**). Later, in 1990, Darling and Mori (1993) listened for singing whales and interviewed residents of the northern Marianas and concluded that humpback whales were not regularly seen in the area. Data from the MISTCS acoustic surveys, along with the visual sighting of a large number of socially active animals indicates that humpback whales may be re-occupying a former breeding site. Additional surveys of this area during the winter-spring breeding season should be conducted to confirm that this area is consistently being used by breeding humpback whales.



Locations of acoustic detections with whaling takes (kills) overlaid. Note: Locations of Townsend Chart animals are of uncertain accuracy and are intended to show historical numbers of animals around the main Mariana Islands.

Figure 4-6. Map of Humpback Whale Acoustic Detections and Historical Townsend Detections

Sei Whales

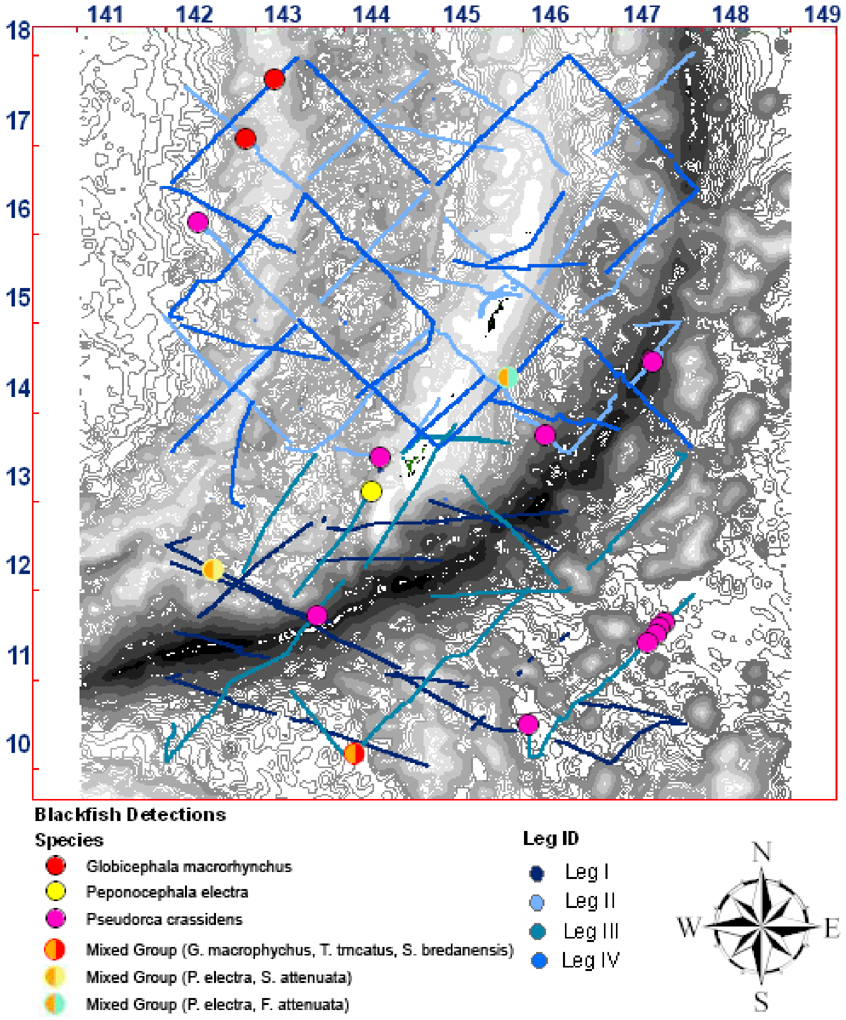
Only four acoustic detections of sei whales were made, the fewest of all balaenopterids (**Table 3-7**; **Figure 4-3**). All of the acoustic detections occurred after visual observers initially detected the animals (and usually approached them to verify species identity). Calls were very brief (generally < 2 seconds), and sporadically produced. There is almost no published information about sei whale calls. Additional analysis is needed to describe and document the acoustic characteristics of the sounds recorded in the presence of sei whales.

4.2.1.3 Family Delphinidae

Blackfish

Three species of blackfish were acoustically detected with false killer whales (*Pseudorca crassidens*) being the most common species with ten groups encountered (**Table 3-7**). Short-finned pilot whales (*Globicephala macrorhynchus*) and melon-headed whales (*Peponocephala electra*) were both detected three times, including one mixed-species school for pilot whales and two mixed-species detections for melon-headed whales (**Figure 4-7**). Species identifications were visually determined for all blackfish detections. Interestingly, all but two detections were encountered acoustically before visual detection.

Numerous recordings of blackfish were not identifiable to species. It is possible that additional analysis of unidentified recordings will allow identification of some species based solely on whistle characteristics. For example, false killer whales have very distinctive mid-frequency (~5-7 kHz) whistles that are relatively easy to differentiate from those of most other species of dolphins (Oswald, *et al*., 2003; In Press).



Mixed species groups are indicated by bi-colored symbols and may include dolphins

Figure 4-7. Blackfish Acoustic Detections

Dolphins

There were 69 acoustic detections of delphinid groups of which one third (23) were identified to species using visual means (**Table 3-7**). The most common species detected was *Stenella attenuata* (11), followed by *S. coeruleoalba* (9). *S. longirostris*, *Steno bredanensis* and *Tursiops truncatus* were detected in single-species schools one time each, with the latter two species also detected in mixed-species school (**Figures 4-7 and 4-8**). Because all species identification was accomplished using visual methods, these data should be considered redundant with the visual sightings[2]. There were 46 unidentified delphinids remaining representing two-thirds of the total delphinid detections (**Table 3-7**; **Figure 4-9**). In all cases, these groups or individuals were either never sighted by the visual observers, or the detection was sufficiently separated in time or space to preclude an association with a visual sighting. It is not currently possible to definitively identify species of dolphins based solely on whistles, however computer algorithms are being developed that allow whistles for a few select species of dolphins to be identified with good probability (Oswald, *et al*., 2003; Oswald *et al*., In Press).

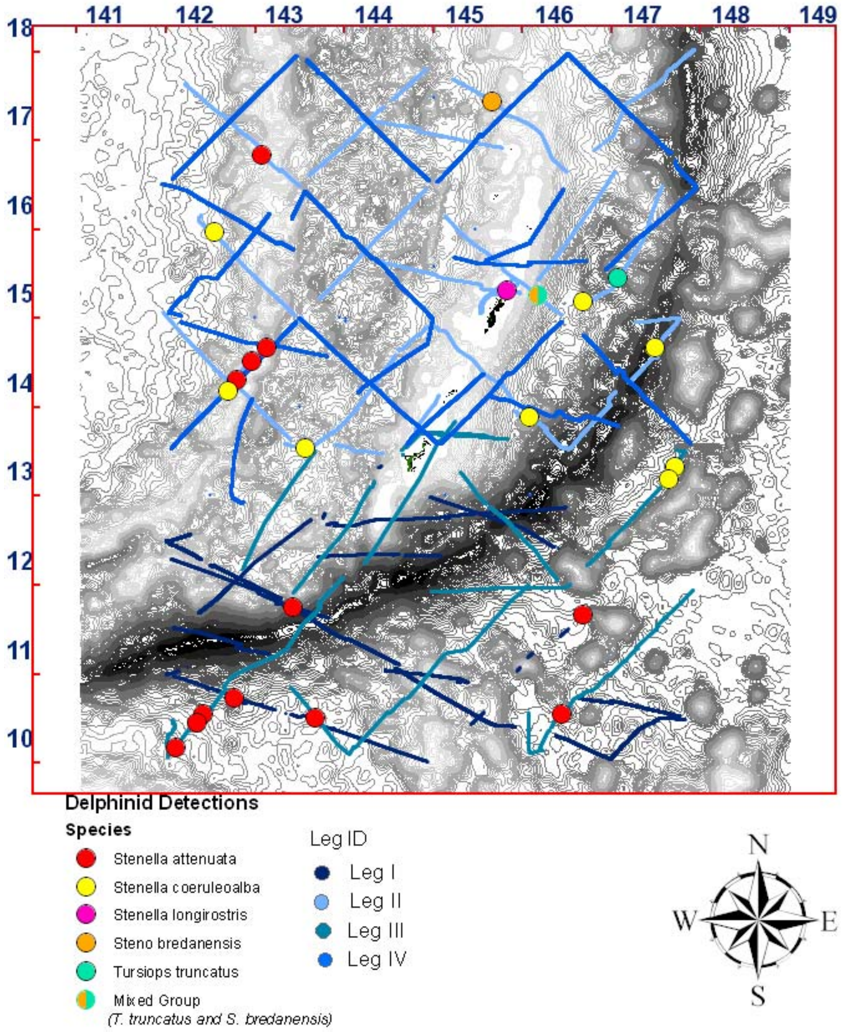


Figure 4-8. Delphinid Acoustic Detections

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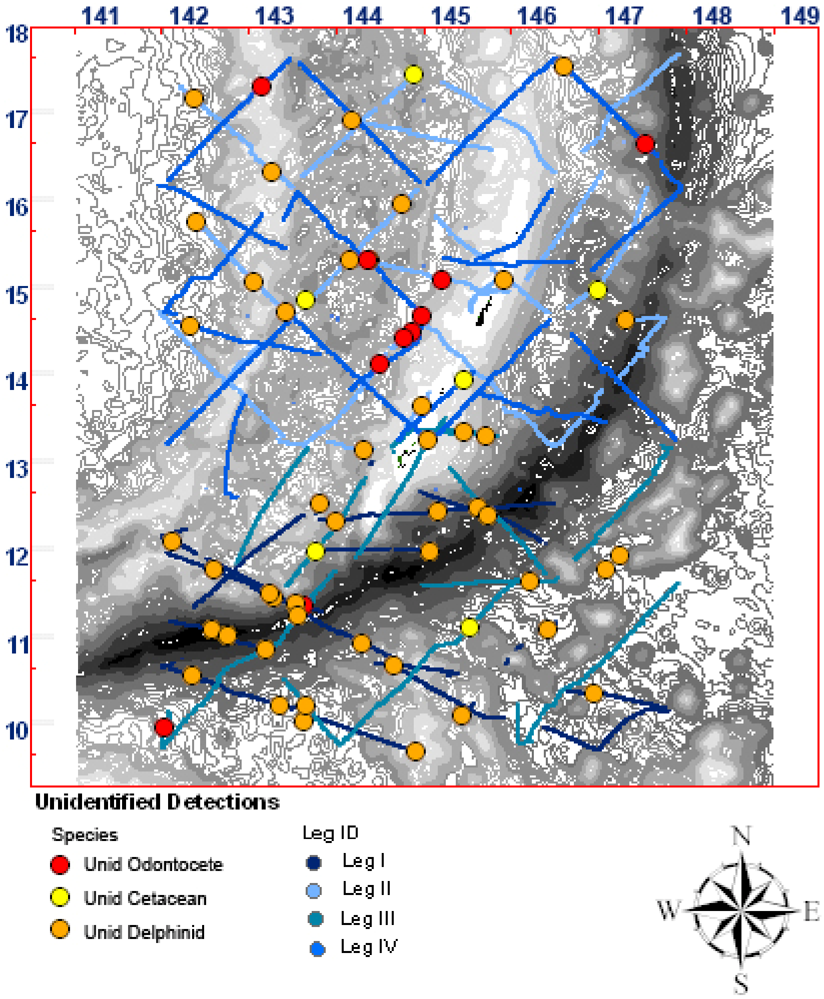
[2] Some of these visual sightings were 'off-effort' sightings.



By highest taxa species could be identified to.

Figure 4-9. Unidentified Acoustic Detections

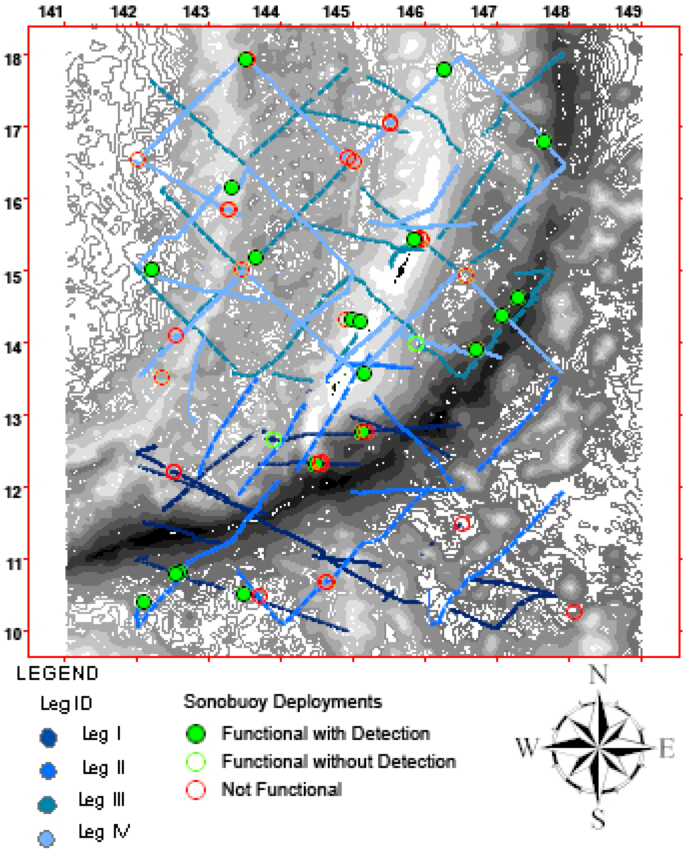
4.2.1.4 Unidentified Odontocetes and Cetaceans

There were numerous detections of ‘Unidentified Odontocetes’ and ‘Unidentified Cetaceans’. These consisted of detections that were considered to be from a cetacean, but could not be attributed to a particular species or species group with any confidence. These types of signals often consisted of unusual whistles, burst pulses, clicks, pulses or other biological sounds that are not commonly heard. It is possible that some of these signals were either not of biological origin (*e.g.*, originated from the survey vessel) or perhaps were from a species that had already been detected but the signal was not ‘typical’ of the known signal types for that species. Further review and analysis might provide better classification of these signals, but is beyond the scope of this effort.

4.2.2 Sonobuoys

The majority of the 53D buoys deployed were non-functional due to float damage (most likely caused by age) and therefore were not deployed often after the first leg. The 57B’s however seemed to perform well and were used almost exclusively for the duration of the cruise (**Table 3-10**). Failure rates of sonobuoys were relatively low (~30%) once the receiver system had been optimized, by relocating the antennas and making adjustments to the receiver settings (see footnote for **Table 3-10**). Maximum sonobuoy reception ranges were 12 km, but were typically less than 4 km.

It should be noted that this component of the project was unfunded and therefore was not considered a priority in relation to the towed array and other acoustic effort. Despite the initial problems with the sonobuoy system, some important detections and useful recordings were made. Sonobuoy coverage of the study area was generally good in all areas except the southwest corner of the study area (**Figure 4-10**). Of particular interest were recordings of humpback whale songs during the night-time survey of the Northern and Western shores of Saipan. Also recorded were sperm whale codas, sei whale calls, minke whale boings and several unidentified low frequency calls from unknown species, but possibly baleen whales. Brief narratives summarizing the highlights of sonobuoy monitoring are provided in **Appendix B-2**).



Sonobuoys were deployed opportunistically during day and night.

Figure 4-10. Sonobuoy Deployment with Detections

4.3 OCEANOGRAPHY

It is a well-documented fact that the physical and biological environment plays a large role in the distribution and behavior of marine mammals (Balance *et al*., 2006; Coyle *et al*., 1992; Hunt and Harrison, 1990). Varying thermohaline properties act as indicators of ocean currents, both vertically and horizontally, whereas chlorophyll *a* levels act as an indication of the productivity of the region, alluding to the presence of the phytoplankton and essential life-supporting nutrients. As few studies of this nature have been conducted within the Mariana Island area, the importance of investigating the physical and biological environment in conjunction with any marine mammal abundance and distribution research becomes apparent.

4.3.1 Physical Oceanography

4.3.1.1 Surface Thermohaline Properties

Sea surface temperature (SST) is one of the most accessible and informative indicators of the surface ocean environment. Various methods are deployed to gather this data, from simple hand-held thermometers to global satellites that orbit the earth. NOAA (2004) reviewed the temperature data for this area between the years of 1984 and 2003. Results from that review determined an annual mean temperature of 27° to 28°C for the years ranging from 1984 to 2003 (NOAA 2004). These results show a relatively small inter-annual temperature flux that is consistent with the classic ideal for tropical region surface temperature.

Sea surface temperature results from the MISTCS match the NOAA review above. For all temperature data collected across the survey area between the months of January and April 2007, a mean of 27.18°C was observed. The highest temperature recorded was 29.8°C, while 25.0°C was the lowest, denoting a range of 4.8°C. These temperatures are consistent with the North Equatorial Current, in which the Mariana Islands are located.

A meridional change in SST is apparent, with cooler temperatures observed towards the northern and central portions of the survey area and warmer temperatures towards the south. The combination of lower winds, smaller seas, and less cloud cover likely resulted in an increased SST in the southern region of the study area, potentially contributing to the observed north-south SST gradient. As evident from **Figure 3-22**, the surface temperature along transect lines show mostly diel variation, where the warmest temperatures were observed during the middle to late part of the day when solar radiation was at its peak.

Salinity, in conjunction with temperature, is considered to be a signature property for ocean mass identification. Pickard and Emery (1982) describe the MISTCS area as a region of low salinity longitudinally flanked by regions of higher salinity, with surface salinity increasing towards the North Pole. This hypothesis is confirmed by the MISTCS TSG salinity data as the southerly Legs 1 and 3 show a lower mean sea surface salinity value than the northerly Legs 2 and 4. **Figure 3-21**, showing sea surface temperature and salinity in Section 3.3 above depicts this meridional shift rather dramatically, accentuated in the northern half of the survey area. A less dense finger of water may be seen to the southwestern region of the survey area, although it is important to note the relatively small scale of the salinity change. In addition, due to the TSG intake pipe aeration problem, salinity data is not as conclusive as expected.

As the cruise was conducted during the region’s dry season, evaporation rates are assumed to be higher than the annual mean. As shown in **Figures 3-23 and 3-24**, diel variation is apparent, hypothesized to be attributed to increased surface evaporation from amplified mid-to late day solar radiation.

4.3.1.2 Water Column Properties

Beyond the surface waters, oceanographers have divided the water column into three horizontal zones: a surface layer; the thermocline; and a deepwater layer (Tomczak and Godfrey, 2002). The top layer, containing uniform hydrographic properties, is known as the surface mixed layer and is driven by climatological events. Theoretically, the bottom of the surface mixed layer must be no more than 0.02–0.1° colder than at the surface (Tomczak and Godfrey, 2002), heralded by a region of rapidly changing thermohaline properties. This surface mixed layer is an essential wind-driven element of heat and freshwater transfer between the atmosphere and the ocean. It usually occupies the uppermost 50 to 150 m or so but can reach much deeper in certain areas in winter when cooling at the sea surface produces convective overturning of water, releasing heat stored in the ocean to the atmosphere.

This study found the survey area surface mixed layer reached a mean depth of 102.88m, with a relatively large range of 53.4 to 153.0 m. While the depth of the bottom of the mixed layer was variable, the temperature range remained between 25.91 and 28.8°C, averaging at 27.33°C.

Figure 3-26, depicting the temperature and depth of the end of the mixed layer, shows that while the temperature at the bottom of the mixed layer is relatively uniform in accordance with latitude, the depth of the end of the mixed layer is more random in occurrence.

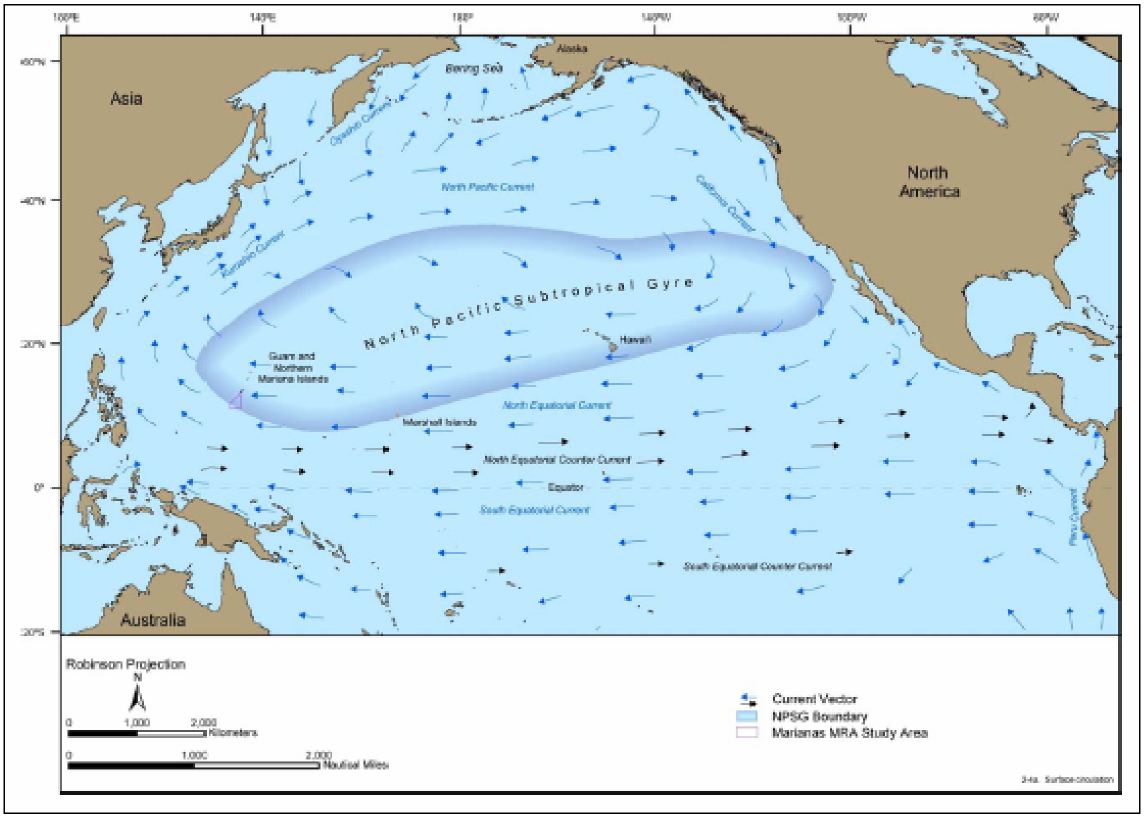
Below the layer of active mixing is a zone of rapid transition, where (in most situations) temperature decreases rapidly with depth. This transition layer is called the thermocline. Because density is closely related to temperature, the thermocline also tends to be the layer where the density gradient is greatest, the pycnocline. Being the bottom of the climatologically-driven surface mixed layer, the thermocline is generally shallow in spring and summer, deep in autumn, and disappears in winter throughout most oceans. However, in the tropics, winter cooling is not strong enough to destroy the seasonal thermocline, and a shallow feature sometimes called the tropical thermocline is maintained throughout the year (Tomczak and Godfrey, 2002).

In the MISTCS area, a strong thermocline was observed throughout the four-month study period. As reported in Section 3, the 225 XBT's deployed during the cruise returned a mean 20°C isotherm (line of constant temperature) of 189.23 m, centering a thermocline range of 115.2. – ~240.0 m for the entire area surveyed. As previously mentioned, due to the shallow T10 XBT probes, data gathered between 200 – 240 m becomes potentially unreliable and was treated as such. **Figure 3-21** clearly depicts the decreasing thermocline depth with increase in latitude. Although there is a large range for the 20°C isotherm over the entire study range, the latitudinal consistency of depth proves that the thermocline is relatively stable and not prone to inverting as in more temperate regions. In essence, this stability acts like an invisible ceiling and caps the deeper, more nutrient rich waters, prohibiting them from mixing with the higher euphotic layer, thus potentially reducing productivity within the region.

4.3.1.3 Ocean Currents and Circulation

The MISTCS survey vessel, *M/V Kahana*, was not equipped with current measuring devices, therefore no information relating to current velocities and direction was gathered during this cruise. However, currents have an important influence on the characteristics of a region, necessitating their inclusion in this report. DON, 2005, provides a comprehensive review of the circulation patterns of the MISTCS study are. Below is a short discussion on surface and deepwater circulation within the North Pacific Subtropical Gyre, as gathered from a review of available literature.

The North Pacific Subtropical Gyre (NPSG) extends from 15 – 35°N and 135°E – 135°W. Documented by Karl (1999) to be the Earth's 'largest circulation pattern', it covers an area of 2 x 107 km^2. As shown in **Figure 4-11**, its northern boundary consists of the North Pacific Current, while the North Pacific Equatorial Current (NEC) creates its southern margin. The California Current forms the eastern edge of the Gyre, with the Kuroshio Current to the west. McGowan and Walker (1985) believe the present currents have bounded the NPSG since the Pliocene (107 years ago) era and 'is considered a climax community in which the climate affects the seascape, which in turn controls the community structure and dynamics' (Karl, 1999).



Adapted from DON (2005); source information: Pickard and Emery (1982) and Karl (1999).

Figure 4-11. Surface Circulation of the Pacific Ocean and Outline of the North Pacific Subtropical Gyre

The MISTCS study area is situated firmly in the southwest corner of the NPSG, subjecting the area to the well-established NEC. The NEC's trajectory is in a westward direction between 8 – 15°N as it is forced by the predominant northeast trade winds. The NEC moves at an average speed of 0.1 – 0.2 ms^{-1} (Uda, 1970; Wolanski *et al*., 2003), before it collides with the Asian landmass and diverts northwards to form the western Kuroshio Current (Pickard and Emery, 1982; Wolanski *et al*., 2003).

Karl (1999) recorded NPSG surface waters at >24°C, which is corroborated by this study. In addition, he states that these waters have 'low nutrient levels, low standing stocks of living organisms, and a persistent deepwater chlorophyll maximum' (Karl 1999). He mentions that the 'water column can be divided vertically into two distinct regions including a light-saturated nutrient-limited layer at the surface (0 to 70 m) and a light-limited nutrient-rich layer at depth (>70 m)' (Karl, 1999). Unfortunately, we were unable to confirm these statements without appropriate sampling equipment.

During July to November, the Mariana Islands are subjected to intense Pacific Ocean tropical atmospheric cyclone activity (DON, 2005; Eldredge 1983). Although not prevalent during the MISTCS study period of January to April, these intense pressure systems may influence the surface currents of the region, resulting in a deviation from normal circulation patterns. Other physical phenomenon affecting the surface currents in this region may be the Pacific El Niño (Lagerloef *et al*., 1999) and the presence of oceanic cyclonic eddies (Wolanski *et al*., 2003), which may create their own isolated physical and biological environment (Lutjeharms *et al*., 2003). To determine the effects of these phenomena, a longer term study is needed.

In most ocean regions the wind-driven circulation does not reach below the upper 1,000 m of the ocean. Currents that are driven by density differences produced by thermohaline effects achieve water renewal below that depth. The associated circulation is therefore referred to as the thermohaline circulation. Since these movements are so slow, it is unrealistic to measure them directly; they have to be deduced from the distribution of water temperature and salinity properties. During the MISTCS, only temperature was measured within the water column, and then only reliably until 200 m. To study the thermohaline properties of deep ocean waters such as these would require an intensive deepwater oceanographic survey with a well-equipped oceanographic research vessel.

However, previous studies such as Kawabe *et al*. (2003); Siedler *et al.* (2004) show that the Mariana Trough and Mariana Trench deepwaters consist of Lower Circumpolar Water (LCPW), also known as Circumpolar Deep Water (CDW) (Pickard and Emery, 1982), and North Pacific Deep Water (NPDW), superimposed by Antarctic Intermediate Water (AIW). NPDW's signature low salinity and high silicate water is formed within the northern Pacific, before translating southwards. Siedler *et al*. (2004) states that these waters are found at a depth of 2,000 – 3,500 m, extending to the western edge of the Mariana Trough. LCPW flows northwards from the South Pacific and flows into the Mariana Trough and Trench (Mantyla and Reid, 1978; Kawabe *et al*., 2003; Siedler at al., 2004). Mantyla and Reid (1978) found that Mariana seafloor ridges halt the progression of LCPW and NPDW into the Mariana Trench and that at depths of 5,585 to 10,933 m in the Trench, the water temperature ranges from 1.5° – 2.5°C, have a salinity of 34.7 ppt and 4ml/l of dissolved oxygen.

4.3.2 Biological Oceanography

4.3.2.1 Primary Productivity

Fundamentally, primary production is the rate at which a biomass of organisms is able to convert solar electromagnetic radiation and free carbon dioxide into a usable chemical energy for respiration and maintenance. Gross primary production is the total amount of energy fixed by primary producers in a given area or ecosystem. Deduct the fraction of energy needed for cell respiration and maintenance and the remainder is referred to as net primary production. Net primary production is the rate at which new biomass accrues in an ecosystem where some net primary production will be consumed and the rest will go towards growth and reproduction of primary producers.

Photosynthesis is a chemical reaction whereby light energy from the sun invigorates the photosynthetic pigments (chlorophyll *a*) in all plants to fix carbon dioxide into organic material. Photosynthetic rate is controlled by solar intensity and strength; seawater temperature and the presence of readily available nutrients (Valiela, 1995). Aquatic phytoplankton produces roughly half of the net primary production on Earth, approximately 48.5 gigatonne (Gt) of carbon per year (Field *et al*., 1998), which explains its importance to most ecosystem studies, both terrestrial and oceanic. According to Thurman (1997), daily photosynthetic carbon fixation rates may range from 0.1 mgm^{-2} to 10 mgm^{-2} as one moves from low productivity regions, such as the Western Equatorial Pacific, to high productivity areas such as the California Current.

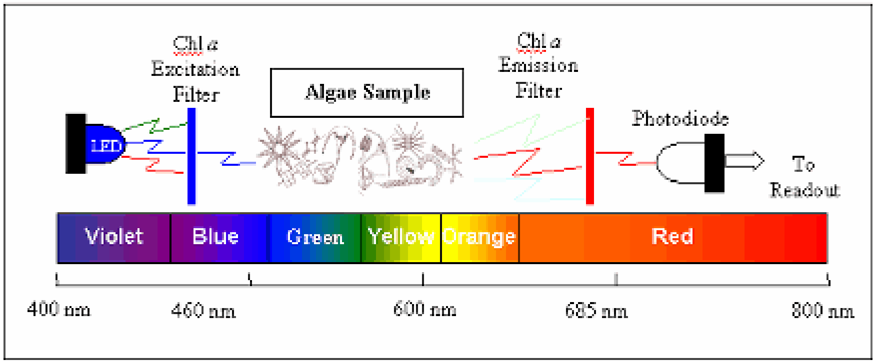
However, sunlight can only penetrate the surface layer of the ocean known as the Euphotic Zone, beyond which little photosynthesis takes place regardless of the abundance of available nutrients. Such is the unflagging determination of life on this planet that primary production is possible even without the kinetic energy of the Sun. At extreme depths, organisms, in symbiosis with bacteria, have been discovered to utilize the hydrogen sulfide from hydrothermal vents to create energy (Thurman, 1997). Hessler and Lonsdale (1991); Hashimoto *et al*. (1995); Galkin (1997) and Embley *et al*. (2004) described this chemosynthesis in greater detail, including references to the deep hydrothermal vents found within MISTCS study area. No research was conducted on any hydrothermal vents during the MISTCS cruise.

4.3.2.2 Nutrients

Rodier and LeBorgne's (1997) export flux study of the Pacific Ocean portrays the MISTCS research area as a deep, nutrient-rich layer that does not penetrate into the shallower, nutrient-depleted surface layers. In an area with such a small percentage of nutrient-producing landmass, all available nutrients must be upwelled from the deep to replenish the potentially productive surface waters. As interpreted from the MISTCS XBT drops, the persistence of the region's thermo- and therefore pycnocline may create a firm barrier between the differing nutrient layers. A stable system such as this prohibits upwelling as little mixing and overturning probably takes place. With low nutrient availability, it is logical to assume that the nutrient-dependant process of primary production will be reduced too.

4.3.2.3 Phytoplankton

Phytoplankton is the collective name for the microscopic plants that form the lowest tier of the aquatic food web. As mentioned above, these plants contain the photosynthetic pigment known as chlorophyll *a* and may be found throughout the light penetrating Euphotic Zone of the oceans. Chlorophyll *a* is a fluorescent molecule and its concentration may be measured using fluorometry, thus allowing for the calculation of primary productivity. Fluorometry is simply the measurement of the light emitted from chlorophyll molecules after excitation at a specific wavelength, as shown in **Figure 4-12**. The sensitivity of this technique is far greater than spectrophotometry, allowing for *in vivo* chlorophyll determinations and minimization of volumes filtered for extractive chlorophyll analyses (Strickland and Parsons, 1972). An understanding of the phytoplankton population and its distribution enables researchers to draw conclusions about a water body's health, composition, and ecological status.



Represents how to measure chlorophyll a concentration and therefore overall primary productivity of a region. Source: (Turner Designs, 2007)

Figure 4-12. The Principle of Fluorometry to Determine Overall Primary Productivity

The NEC, which provides the bulk of water passing the Mariana archipelago, is composed primarily of plankton-poor water. Previous studies within the MISTCS study area have shown less than 0.045 mgm^{-3} annually of chlorophyll *a* (NASA, 1998), which is slightly higher than data gathered during the MISTCS cruise. This may potentially be contributed to the winter/spring time frame of the MISTCS cruise, where solar light intensity would not represent an annual mean. DON (2005) identified two chlorophyll *a* regions peaking at $0.06mg/m^3$ off the southwest coast of Guam and surrounding Tinian and Saipan, persisting throughout the rainy and dry seasons. However, the MISTCS chlorophyll *a* picture is exactly the opposite. Data collected through the study area has returned a lower than mean chlorophyll *a* concentration southwest of Guam. DON (2005) hypothesized that the intense concentration found in these areas may be attributed to the turbulence created by the island's interruption of the mean current flow, as seen in oligotrophic waters surrounding Sicily Isles (Simpson *et al.*, 1982); the Marquesas Islands (Martinez and Maamaatuaiahutapu, 2004), and the islands of Hawaii (Gilmartin and Revelante, 1974). Wolanski *et al*. (2003) did report that an anti-cyclonic eddy was formed in the same location as the DON (2005) identified chlorophyll *a* maximum. DON (2005) suggested that the eddy retained the phytoplankton within its vortex, allowing an increase in production in that specialized location. As oceanic cyclones are known to translate in a westerly direction thought the oceans (Morrow *et al*., 2004), the circular lower concentration of chlorophyll *a* seen in the MISTCS data could possibly reflect a cyclonic eddy southwest of the island of Guam. In that case, the vortex would expel water away from its core and perhaps prohibit the detainment of chlorophyll *a*.

Low chlorophyll *a* levels generally indicate a low biomass of phytoplankton, as confirmed in a study completed by Radenac and Rodier (1996). Although not addressed during the MISTCS research, in low productivity regions the planktonic biomass is generally dominated by small nanoplankton and picoplankton (Le Bouteiller *et al*., 1992; Higgins and Mackey, 2000). Higgins and Mackey (2000) went a step further to name cyanobacteria (*Synechococcus* spp.), prochlorophytes, haptophytes, and chlorophytes; all less than one micron (μm) in size; as the phytoplanktonic species most numerous within the Western Pacific. These species are thought to account for 60% of the total chlorophyll *a* measured by Le Bouteiller *et al*. (1992).

4.3.2.4 Zooplankton

Although no attention was given to zooplankton during the MISTCS, a brief description of previous work will complete the productivity topic. Uchida (1983) provides a summary review of plankton communities and fishery resources for Guam and the Commonwealth of the Northern Mariana Islands, finding that oceanic zooplankton information of the region was scarce. Looking further, a field for zooplankton biomass estimates showed that the Pacific's lowest zooplankton concentrations of 1.35 g/m^2 were to be found within the NEC (Vinogradov and Parin, 1973). The closest station that they surveyed to the MISTCS study area was 13°31'and 139°58'E, where the zooplankton biomass was 11.7 mg/m^3 (noting the change in scale from grams to milligrams). DON (2005) report that most zooplankton studies conducted within the region have been secondary study objectives and therefore no decent time series data sets have been collected for the Mariana study area.

4.3.3 Summary

From analysis and interpretation of the MISTCS-collected data, in conjunction with a literature review, it may be determined that the Mariana Archipelago is situated within the path of the North Equatorial Current and is a region of poor primary production. The NEC is notorious for its low productivity and, with only a few islands in its path, it is not forced to vertically mix in this region. Warm sea surface temperatures, a regular tropical thermocline and consistent mixed layer create a stable vertical water column. This stability again ensures that little overturning and mixing occurs, prohibiting the surface renewal of nutrients from the deep. This is reflected in the observed low concentration of chlorophyll *a* and previous primary production reviews. A comparative analysis with marine mammal abundance and distribution data will be very useful in this area.

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APPENDIX A INFORMATION ON CETACEAN AND SEA TURTLE SPECIES SIGHTED DURING SURVEY

APPENDIX A-1. CETACEAN AND SEA TURTLE SPECIES: DISTRIBUTION AND HABITAT PREFERENCES

Endangered/Threatened Cetaceans

- **Sei Whale (*Balaenoptera borealis*)**

  Sei whales have a worldwide distribution, but are found primarily in cold temperate to subpolar latitudes, rather than in the tropics or near the poles (Horwood, 1987). Sei whales spend the summer months feeding in the subpolar higher latitudes and return to the lower latitudes to calve in winter. For the most part, the location of winter breeding areas remains a mystery (Rice, 1998; Perry *et al*., 1999).

  Sei whales are most often found in deep, oceanic waters of the cool temperate zone. Horwood (1987) noted that sei whales prefer oceanic waters and are rarely found in marginal seas; historical whaling catches were usually from deepwater, and land station catches were usually taken from along or just off the edges of the continental shelf. The sei whale appears to prefer regions of steep bathymetric relief, such as the continental shelf break, canyons, or basins situated between banks and ledges (Kenney and Winn, 1987; Schilling *et al*., 1992; Gregr and Trites, 2001; Best and Lockyer, 2002). These areas are often the location of persistent hydrographic features, which may be important factors in concentrating zooplankton, especially copepods.

  On the feeding grounds, the distribution is largely associated with oceanic frontal systems (Horwood 1987). In the North Pacific, sei whales are found feeding particularly along the cold eastern currents (Perry *et al*., 1999).

  Characteristics of preferred breeding grounds are unknown.

  Sei whales are also known for occasional irruptive occurrences in areas followed by disappearances for sometimes decades (Horwood, 1987; Schilling *et al*., 1992; Clapham *et al*., 1997; Gregr *et al*., 2005).

- **Sperm Whale (*Physeter macrocephalus*)**

  Sperm whales are found from tropical to polar waters in all oceans of the world between approximately 70°N and 70°S (Rice 1998). Females use a subset of the waters where males are regularly found. Females are normally restricted to areas with sea surface temperatures (SST) greater than approximately 15º Celsius (C), whereas males, and especially the largest males, can be found in waters as far poleward as the pack ice with temperatures close to 0ºC (Rice, 1989). The thermal limits on female distribution correspond approximately to the 50º parallels in the North Pacific (Whitehead, 2003).

  Sperm whales show a strong preference for deep waters (Rice, 1989), especially areas with high sea floor relief. Sperm whale distribution is associated with waters over the continental shelf edge, over the continental slope, and into deeper waters (Gannier, 2000; Gregr and Trites, 2001; Waring *et al*., 2001).

  In some areas, such as off New England, on the southwestern and eastern Scotian Shelf, or the northern Gulf of California, adult males are reported to quite consistently use waters with bottom depths less than 100 m and as shallow as 40 m (Whitehead *et al*., 1992; Scott and Sadove, 1997; Garrigue and Greaves, 2001). Worldwide, females rarely enter the shallow waters over the continental shelf (Whitehead, 2003).

  Sperm whale concentrations have been correlated with high secondary productivity and steep underwater topography (Jaquet and Whitehead, 1996). These main sperm whaling grounds are usually correlated with areas of increased primary productivity caused by upwelling (Jaquet *et al*., 1996). In the eastern tropical Pacific, sperm whale habitat use is significantly related to SST and depth of the thermocline (Polacheck, 1987).

- **Humpback Whale (*Megaptera novaeangliae*)**

  The winter range of the Western North Pacific stock of humpback whales extends, at least occasionally, into this region (Darling and Mori, 1993; DON, 2005). Reeves *et al*. (1999) suggested that the Marianas might be south of the normal breeding range, but clearly some whales do move into the study area in the breeding season (DON, 2005; this report). There are several recent records of humpback whales in the Marianas Islands, at Guam, Rota, and Saipan during January through March (Darling and Mori, 1993; Eldredge, 1991, 2003).

  Although Townsend (1935) indicated that many humpbacks were caught off the Marianas in earlier years, preliminary surveys of Taiwan and Saipan suggested that humpback whales were no longer common there and have not generally re-inhabited this part of the range (Darling and Mori, 1993). Darling and Mori (1993) suggested that the recent humpback whale sightings off Saipan might indicate that the range of the population is currently expanding, or alternatively, these could just be a few wayward individuals.

  February and March are the months when humpback whales are most often sighted in the Marianas (DON, 2005). The breeding season extends well into the spring; whalers took humpback whales through the month of May in the southern Marianas (Eldredge, 1991).

  The habitat requirements of wintering humpbacks appear to be determined by the conditions necessary for calving. Breeding grounds are in tropical or subtropical waters, generally with shelter created by islands or reefs. Optimal calving conditions are warm water (24° to 28°C) and relatively shallow, low-relief ocean bottom in protected areas (behind reefs) apparently to take advantage of calm seas, to minimize the possibility of predation by sharks, or to avoid harassment by males (Smultea, 1994; Craig and Herman, 2000). Females with calves occur in significantly shallower waters than other groups of whales, and breeding adults use deeper, more offshore waters (Smultea, 1994; Ersts and Rosenbaum, 2003; Gannier, 2004; Sanders *et al*., 2005). For example, humpback whale calls were detected from whales located to the northeast and east of the Puerto Rican Trench over deep water (>6,000 m) and far from any banks or islands (Swartz *et al*., 2003).

Non-Endangered/Non-Threatened Cetaceans

- **Bryde's Whale (*Balaenoptera edeni/brydei*)**

  Bryde's whales are seen year-round throughout tropical and subtropical waters (Kato, 2002). Long migrations are not typical of Bryde's whales, though limited shifts in distribution toward and away from the equator, in winter and summer, respectively, have been observed (Cummings, 1985). The Bryde's whales' large wintering grounds may extend from the western North Pacific to the central North Pacific, with 20°N perhaps being the northernmost boundary (Ohizumi *et al*., 2002). In summer, the distribution of Bryde's whales in the western North Pacific extends as far north as 40°N, but many individuals remain in lower latitudes, as far south as about 5°N. Data also suggest that winter and summer grounds partially overlap in the central North Pacific (Kishiro, 1996; Ohizumi *et al*., 2002). Some whales remain in higher latitudes (around 25°N) in both winter and summer (Kishiro, 1996).

  Bryde's whales are found both offshore and near the coasts in many regions. Off eastern Venezuela, Bryde's whales are often sighted in the shallow waters between Isla Margarita and Peninsula de Araya, as well as into waters where there is a steep slope, such as the Cariaco Trench (Notarbartolo di Sciara, 1982). Along the Brazilian coast, distribution and seasonal movements of the Bryde's whale appear to be influenced by the behavior, distribution, and abundance of Brazilian sardine (*Sardinella brasiliensis*) schools that approach the coast to spawn in shallow waters (Zerbini *et al*., 1997). In the Gulf of Mexico, all Bryde's whale sightings have been near the shelf break in DeSoto Canyon (Davis *et al*., 2002). Bryde's whales are sometimes seen very close to shore and even inside enclosed bays (Best *et al*., 1984).

Whaling catches also have shown that the Bryde's whale is not always a coastal species (Ohsumi, 1977).

The Bryde's whale appears to have a preference for water temperatures between approximately 15° and 20°C (Yoshida and Kato, 1999).

- **Rough-toothed Dolphin (*Steno bredanensis*)**

  Rough-toothed dolphins are typically found in tropical to warm-temperate waters globally (Miyazaki and Perrin, 1994).

  The rough-toothed dolphin is often regarded as an offshore species that prefers deep waters; however, it can occur in waters with variable bottom depths (e.g., Gannier and West, 2005; Kuczaj et al., 2007). It rarely occurs close to land, except around islands with steep drop-offs nearshore (Mignucci-Giannoni, 1998; Gannier, 2000; Reeves *et al*., 2002; Ritter, 2002; Gannier and West, 2005; Webster *et al.,* 2005; Kuczaj *et al*., 2007).

  This species has been observed in relatively shallow coastal waters in some locales (Flores and Ximenez, 1997; Lodi and Hetzel, 1999), including those locales (e.g., Canary Islands) where it is typically found in deeper waters (e.g., Ritter, 2002).

- **Bottlenose Dolphin (*Tursiops truncatus*)**

  The overall range of *Tursiops* is worldwide in tropical to temperate waters. Tursiops live in coastal areas of all continents (except Antarctica), around many oceanic islands and atolls, and over shallow offshore banks and shoals.

  In the eastern tropical Pacific and elsewhere there are pelagic populations that range far from land (Scott and Chivers, 1990; Reeves *et al*., 2002).

  Bottlenose dolphins found in nearshore waters around the main Hawaiian Islands are island-associated, with all sightings occurring in relatively nearshore and shallow waters (<200 m), and no apparent movement between the islands (Baird *et al*., 2002, 2003). Baird *et al*. (2003) noted the possibility of a second population of bottlenose dolphins in the Hawaiian Islands, based on sighting data, with a preference for deeper (bottom depth of 400 to 900 m) waters.

- **Pantropical Spotted Dolphin (*Stenella attenuata*)**

  The pantropical spotted dolphin is distributed in tropical and subtropical waters worldwide (Perrin and Hohn, 1994), primarily in oceanic waters (Jefferson *et al*., 1993).

  Sightings near islands can be close to shore where deep water is nearby (e.g., Gannier, 2002; Mignucci-Giannoni *et al*., 2003).

  Sightings have been reported in coastal waters of Guam by Trianni and Kessler (2002) and coastal populations of pantropical spotted dolphins are known in some tropical locations, such as off Central America and Hawaii (Perrin and Hohn, 1994). Peddemors (1999) reported rare sightings in shallow waters (app. 30 m in bottom depth) off southern Africa.

  In the eastern Pacific, the pantropical spotted dolphin is an inhabitant of the tropical, equatorial, and southern subtropical water masses, characterized by a sharp thermocline at less than 50 m depth, surface temperatures greater than 25ºC and salinities less than 34 parts per thousand (Au and Perryman, 1985).

  The coastal spotted dolphin (*Stenella attenuata graffmani*) is considered to be a subspecies of the pantropical spotted dolphin (e.g., Escorza-Treviño et al. 2005) and is managed as a separate stock by National Marine Fisheries Service (NMFS).

- **Spinner Dolphin (*Stenella longirostris*)**

  The spinner dolphin is found in tropical and subtropical waters worldwide. Most sightings of this species have been associated with inshore waters, islands, or banks such as Hawaii, the Mariana Islands, the South Pacific, the Caribbean, and Fernando de Noronha Island off Brazil (Perrin and Gilpatrick. 1994), Spinner dolphins occur in both oceanic and coastal environments.

Oceanic populations, such as those in the eastern tropical Pacific, often are found in waters with a shallow thermocline (Au and Perryman, 1985; Reilly, 1990). The thermocline concentrates pelagic organisms in and above it, upon which the dolphins feed. Spinner dolphins are associated with tropical surface water typified by extensive stable thermocline ridging and relatively little annual variation in surface temperature (Reeves *et al*., 1999).

Coastal populations usually are found in island archipelagos, where they are tied to trophic and habitat resources associated with the coast (Norris and Dohl, 1980; Poole, 1995). Norris *et al*. (1994) suggested that the availability of prey and resting habitats are the primary limiting factors influencing the occurrence of spinner dolphins in Hawaii. Spinner dolphins at islands and atolls rest during daytime hours in shallow, wind-sheltered nearshore waters and forage over deep waters at night (Norris *et al*., 1994; Östman, 1994; Poole, 1995; Gannier 2000, 2002; Lammers, 2004; Östman-Lind *et al*., 2004). Suitable habitat for resting includes bay complexes around islands (Poole, 1995), or shallow waters near the coast (Lammers, 2004). Preferred resting habitat is usually more sheltered from prevailing tradewinds than adjacent areas and the bottom substrate is generally dominated by large stretches of white sand bottom rather than the prevailing reef and rock bottom along most other parts of the coast (Norris *et al*., 1994; Lammers, 2004). These clear, calm waters and light bottom substrates provide a less cryptic backdrop for predators like tiger sharks (Norris *et al*., 1994; Lammers, 2004). Spinner dolphins often rest in lagoons (Gannier, 2000; Trianni and Kessler, 2002).

- **Striped Dolphin (*Stenella coeruleoalba*)**

The striped dolphin has a worldwide distribution in cool-temperate to tropical waters and is considered to be an oceanic species (Hubbs *et al*., 1973; Archer and Perrin, 1999).

Striped dolphins are usually found beyond the continental shelf, typically over the continental slope out to oceanic waters, often associated with convergence zones and waters influenced by upwelling (Miyazaki *et al*., 1974; Au and Perryman, 1985; Reilly, 1990). At islands, the species appears to prefer open oceanic habitat (e.g., Anderson *et al*., 2005).

This species appears to avoid waters with sea temperatures of less than 20ºC (Van Waerebeek *et al*., 1998).

Neretic waters are rarely (but occasionally) entered by this species (e.g., Hubbs *et al*., 1973; Van Waerebeek *et al*., 1998; Mobley *et al*., 2000).

- **Melon-headed Whale (*Peponocephala electra*)**

Melon-headed whales are found worldwide in tropical and subtropical waters, most often in offshore, deep waters (Jefferson and Barros, 1997).

Nearshore sightings are generally from areas where deep, oceanic waters are found near the coast, for example, at islands (Leatherwood *et al*., 1992; Gannier, 2000; Gannier, 2002; Perryman, 2002; MacLeod *et al*., 2004; Huggins *et al*., 2005; Dolar *et al*., 2006).

Shallow water sightings (less than 100 m in bottom depth) have been recorded in Hawaii and the Marianas (e.g., Jefferson *et al*., 2006; Southall *et al*., 2006).

In the eastern tropical Pacific, this species is primarily found in upwelling modified and equatorial waters (Au and Perryman, 1985; Perryman *et al*., 1994).

In the Hawaiian Islands, Huggins *et al*. (2005) suggested that interchange among the islands might occur based on photo-identification results.

- **Pygmy Killer Whale (*Feresa attenuata*)**

The pygmy killer whale has a worldwide distribution in deep tropical and subtropical oceans and is considered to be an oceanic species (Ross and Leatherwood 1994).

Near continents, it is found primarily in deeper waters offshore of the continental shelf (Caldwell and Caldwell 1971; Davis et al. 2002). The species does approach close to shore at oceanic islands, since deep waters are very close in such areas (Nishiwaki *et al*., 1965; Leatherwood *et al*., 1992; Rudolph *et al*., 1997; Gannier, 2002).

- **False Killer Whale (*Pseudorca crassidens*)**

  The false killer whale is found in tropical and temperate waters, primarily in oceanic and offshore areas (Baird 2002). The species does approach close to shore at oceanic islands, since deep waters are very close in such areas (Rudolph *et al*., 1997; Gannier, 2002).

  Inshore and seasonal movements are occasionally associated with movements of prey and shoreward flooding of warm ocean currents (Stacey *et al*., 1994; Odell and McClune, 1999).

  In the Hawaiian Islands, Baird *et al*. (2005) noted considerable inter-island movements of individuals.

- **Short-finned Pilot Whale (*Globicephala macrorhynchus*)**

  The short-finned pilot whale is found in tropical to warm-temperate seas, generally in deep offshore areas. Pilot whales are found over the continental shelf break, in slope waters, and in areas of high topographic relief (Olson and Reilly, 2002).

  While pilot whales are typically distributed along the continental shelf break, they are often found close to shore at oceanic islands, where the shelf is narrow and deeper waters are nearby (Montero and Arechavaleta, 1997; Mignucci-Giannoni, 1998; Gannier, 2000; Anderson *et al*., 2005).

  A number of studies in different regions suggest that the distribution and seasonal inshore/offshore movements of pilot whales coincide closely with the abundance of cephalopods, their preferred prey (Hui, 1985; Payne and Heinemann, 1993; Mignucci-Giannoni, 1998; Bernard and Reilly, 1999).

- **Beaked Whales (Family Ziphiidae)**

  Five beaked whale species have possible occurrence in the waters off Guam and CNMI – the Cuvier's beaked whale (*Ziphius cavirostris*), three species of *Mesoplodon* (Blainville's [M. *densirostris*], Ginkgo-toothed [*M. ginkgodens*, and Hubbs' [*carlhubbsi*]), and Longman's beaked whale (*Indopacetus pacificus*) (DON, 2005; MacLeod *et al*., 2006). Actual identification to species is inferred only and not confirmed for any beaked whale species in waters off Guam and CNMI.

  World-wide, beaked whales normally inhabit continental slope and deep oceanic waters (>200 m) (Waring *et al*., 2001; Pitman, 2002; MacLeod *et al*., 2004; Ferguson *et al*., 2006; MacLeod and Mitchell, 2006). Beaked whales are only occasionally reported in more shallow waters (Pitman 2002), particularly around islands with steep drop-offs and deep water close to shore.

  As noted by MacLeod and D'Amico (2006), in many locales, occurrence patterns have been linked to physical features, in particular, the continental slope, canyons, escarpments, and oceanic islands.

  At oceanic islands, Cuvier's beaked whales are found in deeper waters than Blainville's beaked whales (MacLeod *et al*., 2004; Baird *et al*., 2006; Claridge, 2006).

  In the eastern tropical Pacific, beaked whales are found in waters over the continental slope to the abyssal plain, ranging from well-mixed to highly-stratified (Ferguson *et al*., 2006).

  Site fidelity by some Cuvier's and Blainville's beaked whales to specific areas has been demonstrated by several long-term studies in various locales including off the west coast of Hawaii (McSweeney *et al*., 2007), the Bahamas (Claridge, 2006), and Genoa Canyon (Ligurian Sea) (Ballardini *et al*., 2006). However, as noted by MacLeod and D'Amico (2006), there are too few studies conducted to make any general conclusions on residency and habitat use.

Sea Turtles

The only turtle sighting during the MISTCS survey was identified to species as a hawksbill turtle.

- **Hawksbill Turtle (*Eretmochelys imbricata*)**

  Hawksbill turtles are circumtropical in distribution, generally occurring from 30°N to 30°S latitude within the Atlantic, Pacific, and Indian Ocean basins (NMFS and USFWS, 1998b). Although they exhibit similar habitat and water temperature preferences, hawksbills are generally less common than green turtles (*Chelonia mydas*) around insular habitats of the North Pacific Ocean, with the exception of the waters surrounding Palau (NMFS 1998).

  There are only a few recent hawksbill occurrence records in the study area, indicating a likely presence of this species in the coastal waters surrounding the islands of the southern Marianas arc (i.e., from FDM south to Guam) (Kolinski, 2001; Kolinski *et al*., 2001; DON, 2005).

  In the Pacific Ocean, the oceanic whereabouts of this early life stage is unknown (NMFS and USFWS, 1998b). In the Atlantic Ocean and Caribbean Sea, early juveniles are known to inhabit oceanic waters, where they are sometimes associated with drift lines and floating patches of Sargassum (Parker, 1995; Witherington and Hirama, 2006). However, it is likely that Pacific individuals would occur in similar areas of advection where flotsam accumulates.

  Late juvenile and adult hawksbill turtles forage around coral reefs, mangroves, and other hard-bottom habitats in open bays and coastal zones throughout the tropical Pacific Ocean.

  Pritchard (1995) indicates that hawksbills nest sporadically in Guam and rarely, if ever, in the CNMI (Pritchard, 1995; DON, 2005).

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APPENDIX A-2. CETACEAN AND SEA TURTLE SIGHTING INFORMATION

See Microsoft Excel Worksheet.

APPENDIX B PASSIVE ACOUSTIC MONITORING INFORMATION

APPENDIX B-1. ACOUSTIC DETECTION LOG

This contains all acoustic detections for the Mariana Island Sea Turtle and Cetacean Survey (MISTCS). All detections were reviewed, in some cases from the acoustic recordings. Additions to the original list are labeled with an ‘A’ or ‘B’ after the Detection # (see column 3). Night-time survey detections are labeled with an ‘N’ after the detection #. Latitude (Lat) and Longitude (Long) are based on the position on the trackline when the animal was first detected and does not necessarily represent the animal’s or group’s location. ‘Sighting #’ (last column) refers to the visual sighting number, if one was made.

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
1	1/16/07	0A	UNID	Unid Delphinid	17:26	18:02	12.86	143.82	yes	2	no	
1	1/16/07	0B	*Physeteridae*	*P. macrocephalus*	17:27	18:02	12.88	143.83	yes	3	no	
1	1/18/07	1	UNID	Unid Delphinid	11:39	11:43	11.413	142.571	no	0	no	1
1	1/18/07	2	*Physeteridae*	*P. macrocephalus*	12:16	12:21	11.393	142.641	no	0	no	
1	1/18/07	3	UNID	Unid Delphinid	13:25	13:33	11.352	142.768	yes	2	no	
1	1/19/07	5	*Physeteridae*	*P. macrocephalus*	13:08	13:35	10.95	145.23	yes	14	no	
1	1/19/07	6	*Physeteridae*	*P. macrocephalus*	14:28	14:57	10.942	145.313	yes	11	no	
1	1/20/07	7	UNID	Unid Delphinid	9:58	10:33	10.685	146.956	yes	5	no	
1	1/20/07	8	*Balaenoptera*	*B. borealis*	10:54	11:13	10.685	147.014	no	0	no	3
1	1/20/07	9	*Physeteridae*	*P. macrocephalus*	17:12	17:13	10.547	147.672	yes	0	no	
1	1/21/07	10	*Balaenoptera*	*B. borealis*	9:33	10:23	10.469	147.493	no	0	no	5
1	1/21/07	12	*Physeteridae*	*P. macrocephalus*	12:31	14:08	10.173	147.115	yes	12	yes	6
1	1/21/07	13	*Physeteridae*	*P. macrocephalus*	14:08	14:13	10.046	147.003	yes	1	no	7
1	1/22/07	14	UNID	Unid Delphinid	17:47	18:00	11.017	144.667	no	0	no	
1	1/23/07	15	UNID	Unid Delphinid	9:10	9:15	11.269	144.309	no	0	no	
1	1/23/07	16	*Delphinidae*	*S. attenuata*	15:35	15:47	11.75	143.424	no	0	no	9
1	1/23/07	17	UNID	Unid Delphinid	16:55	18:24	11.795	143.294	yes	21	no	10
1	1/24/07	18	*Delphinidae*	Mixed Group	11:41	12:16	12.222	142.538	yes	4	no	11
1	1/24/07	19	UNID	Unid Delphinid	14:56	15:00	12.439	142.123	yes	3	no	
1	1/25/07	20	UNID	Unid Delphinid	9:35	9:39	12.671	143.996	no	0	no	
1	1/25/07	21	*Balaenoptera*	*B. acutorostrata*	10:31		12.673	144.119	no	0	no	
1	1/25/07	22	*Physeteridae*	*P. macrocephalus*	10:45	10:54	12.684	144.162	yes	5	no	
1	1/25/07	24	*Balaenoptera*	*B. acutorostrata*	15:14	20:45	12.753	145.147	yes	9	no	13
1	1/26/07	25	UNID	Unid Delphinid	6:58		12.777	145.173	yes	2	no	

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
1	1/26/07	26	*Balaenoptera*	*B. acutorostrata*	7:02	11:55	12.8	145.427	yes	19	yes	
1	1/26/07	27	UNID	Unid Delphinid	10:11	10:31	12.812	145.631	yes	4	no	
1	1/26/07	28	*Physeteridae*	*P. macrocephalus*	10:23	12:58	12.825	145.865	yes	25	yes	
1	1/26/07	30	*Physeteridae*	*P. macrocephalus*	13:35	15:59	12.841	146.074	yes	17	no	14
1	1/26/07	31	*Balaenoptera*	*B. acutorostrata*	13:45	16:43	12.8602	146.3387	yes	12	no	
1	1/27/07	33	*Balaenoptera*	*B. acutorostrata*	7:36	9:17	12.6915	147.6647	yes	11	no	
1	1/27/07	34	*Balaenoptera*	*B. acutorostrata*	8:59	12:58	12.5189	147.4798	yes	37	yes	
1	1/27/07	35	*Physeteridae*	*P. macrocephalus*	12:49	12:58	12.2769	147.257	yes	1	no	
1	1/27/07	36	UNID	Unid Delphinid	12:47	13:50	12.2688	147.2497	yes	1	no	
1	1/27/07	37	UNID	Unid Delphinid	14:17		12.1008	147.0974	yes	1	no	
1	1/27/07	38	*Balaenoptera*	*B. acutorostrata*	14:42	16:59	11.8298	146.8255	yes	7	no	
1	1/27/07	39	*Balaenoptera*	*B. acutorostrata*	17:20	17:51	11.7504	146.7431	yes	4	yes	
1	1/27/07	40	*Balaenoptera*	*B. acutorostrata*	17:45		11.6993	146.6916	yes	1	no	
1	1/27/07	41	*Delphinidae*	*S. attenuata*	17:43		11.667	146.683	no	0	no	15
1	1/28/07	42	UNID	Unid Delphinid	9:07	10:07	11.427	146.437	no	0	no	17
1	1/28/07	43	UNID	Unid Delphinid	18:05		10.447	145.449	no	0	no	
1	1/29/07	44	UNID	Unid Delphinid	7:15	7:43	10.0257	144.9117	yes	9	yes	
1	1/29/07	46	*Delphinidae*	*S. attenuata*	13:54	14:29	10.5016	143.6691	yes	4	no	19
1	1/29/07	47	UNID	Unid Delphinid	15:22	16:36	10.371	143.644	yes		no	21
1	1/29/07	47A	UNID	Unid Delphinid	17:08	17:42	10.562	143.351	no	0	no	22
1	1/30/07	48	*Delphinidae*	*S. attenuata*	11:13	12:30	10.7221	142.7714	yes	20	yes	25
1	1/30/07	49	UNID	Unid Delphinid	14:39	15:50	10.8962	142.3428	yes	14	yes	26
1	1/31/07	50	UNID	Unid odontocete	8:05	9:49	11.6931	143.6274	yes	1	yes	
1	1/31/07	51	UNID	Unid Delphinid	8:34	9:49	11.7197	143.5415	yes	8	yes	
1	1/31/07	52	UNID	Unid Delphinid	10:18	11:33	11.8276	143.2407	yes	9	yes	
1	1/31/07	54	*Physeteridae*	*P. macrocephalus*	13:57	14:58	12.0919	142.6291	yes	26	yes	27
1	1/31/07	55A	UNID	Unid Delphinid	14:48	14:51	12.104	142.596	no		no	28
1	1/31/07	55	*Physeteridae*	*P. macrocephalus*	17:15	17:50	12.2667	142.1443	yes	1	no	
1	2/1/07	56	UNID	Unid Cetacean	7:08	7:28	12.3257	143.7754	yes	4	yes	
1	2/1/07	57	*Physeteridae*	*P. macrocephalus*	8:43	10:45	12.34	144.1191	yes	10	yes	
1	2/1/07	57A	*Balaenoptera*	*B. borealis*	12:46		12.342	144.478	no	0	no	29
1	2/1/07	58	*Balaenoptera*	*B. acutorostrata*	16:17		144.971	145.06	yes	7	no	

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
1	2/1/07	59	UNID	Unid Delphinid	18:03	18:05	12.3278	145.0784	yes		no	
1	2/2/07	60	UNID	Unid Delphinid	11:59	13:38	12.7293	145.7519	yes	14	no	
1	2/2/07	63	*Physeteridae*	*P. macrocephalus*	13:55		12.8491	145.3985	yes	16	yes	20
1	2/2/07	63A	*Balaenoptera*	*B. acutorostrata*	14:43		12.854	145.383	no	0	no	
2	2/6/07	64	*Physeteridae*	*P. macrocephalus*	15:55	16:23	13.8876	144.903	yes	1	no	
2	2/6/07	65	UNID	Unid Delphinid	16:28	17:29	13.992	144.9824	yes	12	yes	
2	2/6/07	66	*Physeteridae*	*P. macrocephalus*	17:56	18:01	14.1212	145.0618	yes	2	no	
2	2/7/07	67	*Balaenoptera*	*M. novaeangliae*	7:16	14:24	15.5097	146.2418	yes	7	no	
2	2/8/07	75	*Physeteridae*	*P. macrocephalus*	12:58	14:11	17.4406	147.2145	yes	7	no	34
2	2/8/07	76	*Physeteridae*	*P. macrocephalus*	15:22	16:33	17.0768	147.0389	yes	5	yes	
2	2/8/07	77	*Physeteridae*	*P. macrocephalus*	17:34	17:57	16.9002	146.8229	yes	1	no	
2	2/8/07	68	*Physeteridae*	*P. macrocephalus*	8:07	8:48	18.0165	147.9231	yes	17	yes	32
2	2/8/07	71	*Physeteridae*	*P. macrocephalus*	9:11	9:45	17.9102	147.7947	yes	15	yes	
2	2/9/07	78	*Delphinidae*	*S. bredanensis*	13:01	14:39	17.4355	145.6631	yes	4	no	35
2	2/9/07	79	*Physeteridae*	*P. macrocephalus*	13:37	15:31	17.448	145.6384	yes	13	yes	36
2	2/9/07	81	*Physeteridae*	*P. macrocephalus*	17:23		17.646	145.322	no	0	no	
2	2/10/07	82A	UNID	Unid Cetacean	7:52	7:56	17.777	144.892	no	0	no	
2	2/11/07	82	UNID	Unid Delphinid	8:25	8:56	16.6679	143.2756	yes	1	no	38
2	2/11/07	83	*Delphinidae*	*S. attenuata*	10:32	10:43	16.84	143.077	no	0	no	40
2	2/11/07	84	*Delphinidae*	*G. macrorhynchus*	12:25	13:25	17.067	142.899	no	0	no	41
2	2/11/07	85	UNID	Unid delphinid	16:29	17:28	17.5082	142.3754	yes	8	no	42
2	2/12/07	86	UNID	Unid Delphinid	7:02	7:11	17.2552	144.1834	yes	2	no	
2	2/12/07	87	*Physeteridae*	*P. macrocephalus*	13:39	14:00	17.0451	145.1509	yes	9	yes	43
2	2/12/07	88	*Physeteridae*	*P. macrocephalus*	14:08	14:59	17.0284	145.24	yes	13	yes	44
2	2/12/07	90	*Balaenoptera*	*M. novaeangliae*	15:16	16:57	17.002	145.365	no	0	no	
2	2/13/07	91	*Delphinidae*	*Tursiops truncatus*	14:36	14:59	15.448	147.077	no	0	no	45
2	2/13/07	92	UNID	Unid Cetacean	15:39	15:51	15.318	146.991	no	0	no	
2	2/14/07	93	*Delphinidae*	Mixed Group	9:19	9:43	15.258	146.173	no		no	46
2	2/14/07	94	*Physeteridae*	*P. macrocephalus*	9:47	10:55	15.321	146.1049	yes	26	yes	
2	2/14/07	97	*Balaenoptera*	*M. novaeangliae*	9:20	15:54	15.4159	145.9862	yes	5	yes	
2	2/14/07	98	*Delphinidae*	*S. coeruloealba*	16:39	16:46	15.191	146.686	no		no	47
2	2/15/07	99	UNID	Unid Delphinid	8:42	9:08	16.2891	144.7617	yes	2	no	

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
2	2/15/07	100	UNID	Unid Delphinid	14:11	16:34	15.6585	144.152	yes	12	no	
2	2/15/07	100A	*Physeteridae*	*P. macrocephalus*	20:57		15.199	143.658	no	0	no	
2	2/15/07	100B	UNID	Unid Cetacean	22:10		15.203	143.647	no	0	no	
2	2/16/07	101	UNID	Unid Delphinid	7:23	7:34	15.0714	143.4207	yes	4	yes	
2	2/16/07	102	UNID	Unid Delphinid	9:47	10:54	15.4096	143.0707	yes	11	yes	
2	2/16/07	103	*Delphinidae*	*S. coeruloealba*	15:36	16:08	15.968	142.5423	yes	1	no	49
2	2/16/07	104	UNID	Unid Delphinid	17:14	17:35	16.0827	142.3961	yes	5	no	51
2	2/16/07	105	*Delphinidae*	*P. crassidens*	17:47	19:02	16.122	142.37	no	0	no	52
2	2/17/07	106	*Physeteridae*	*P. macrocephalus*	7:04	10:25	15.5893	144.6302	yes	6	yes	
2	2/17/07	106A	UNID	Unid Delphinid	7:08	7:22	15.653	144.383	no	0	no	53
2	2/17/07	107	*Physeteridae*	*P. macrocephalus*	11:54	12:14	15.4661	145.0832	yes	9	yes	
2	2/17/07	108	UNID	Unid odontocete	12:47	12:56	15.437	145.224	no	0	no	
2	2/17/07	109	*Physeteridae*	*P. macrocephalus*	14:34	15:56	15.3283	145.595	yes	9	no	55
2	2/17/07	110	*Balaenoptera*	*M. novaeangliae*	16:30		15.3129	145.7863	yes	9	yes	
2	2/17/07	111	*Delphinidae*	*S. longirostris*	17:06	17:18	15.31	145.831	no	0	no	56
2	2/17/07	1N	*Balaenoptera*	*M. novaeangliae*	19:45	22:49	15.2846	145.702	yes	1	no	
2	2/17/07	2N	*Balaenoptera*	*M. novaeangliae*	11:43	13:55	15.489	145.049	no	0	no	54
2	2/18/07	3N	*Balaenoptera*	*M. novaeangliae*	22:49	0:07	15.301	145.778	no	O	no	
2	2/18/07	4N	*Physeteridae*	*P. macrocephalus*	0:50	3:49	15.098	145.5312	yes	4	yes	
2	2/18/07	5N	*Balaenoptera*	*M. novaeangliae*	2:43		15.205	145.567	no		no	
2	2/18/07	6N	*Balaenoptera*	*M. novaeangliae*	3:55	6:40	15.4089	145.8246	yes	15	yes	
2	2/18/07	7N	UNID	Unid Delphinid	5:53		15.44	145.92	no		no	
2	2/19/07	112	UNID	Unid Delphinid	7:14	8:21	14.9625	147.3228	yes	1	no	
2	2/19/07	113	*Balaenoptera*	*M. novaeangliae*	7:53		14.9708	147.4454	yes	1	no	
2	2/19/07	114	*Balaenoptera*	*B. acutorostrata*	7:56	12:22	14.9965	147.6232	yes	8	no	
2	2/19/07	115	*Delphinidae*	*S. coeruloealba*	12:34	13:48	14.6661	147.4965	yes	5	no	62
2	2/19/07	116	*Balaenoptera*	*B. borealis*	13:54	14:17	14.621	147.563	no		no	64
2	2/19/07	118	*Delphinidae*	*P. crassidens*	13:43	16:06	14.5578	147.4654	yes	2	no	66
2	2/20/07	119	*Delphinidae*	*P. crassidens*	14:05	15:08	13.7283	146.2787	yes	4	yes	68
2	2/20/07	120	*Delphinidae*	*S. coeruloealba*	16:48	21:22	13.885	146.081	no	0	no	70
2	2/21/07	121	*Physeteridae*	*P. macrocephalus*	8:08	8:59	14.2318	145.7991	yes	4	yes	
2	2/21/07	122	*Physeteridae*	*P. macrocephalus*	10:52	12:26	14.598	145.3663	yes	5	no	

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
2	2/21/07	123	*Physeteridae*	*P. macrocephalus*	12:04	14:26	14.865	145.1388	yes	13	no	
2	2/21/07	124	*Physeteridae*	*P. macrocephalus*	13:18	14:26	14.8619	145.1416	yes	8	no	71
2	2/21/07	125	*Physeteridae*	*P. macrocephalus*	14:28	15:20	14.9207	145.0016	yes	3	no	72
2	2/21/07	126	UNID	Unid odontocete	15:52	16:36	14.839	144.877	no		no	
2	2/21/07	127	UNID	Unid odontocete	17:00	18:10	14.769	144.777	yes		no	74
2	2/21/07	128	*Physeteridae*	*P. macrocephalus*	17:10	17:11	14.75	144.7574	yes		no	
2	2/22/07	129	UNID	Unid odontocete	7:41		14.476	144.503	no		no	
2	2/22/07	130	*Delphinidae*	*S. coeruloealba*	16:46	16:53	13.544	143.559	no		no	78
2	2/24/07	131	*Delphinidae*	*S. attenuata*	10:13		14.668	143.123	no		no	80
2	2/24/07	132	*Delphinidae*	*S. attenuata*	11:54		14.509	142.954	no		no	81
2	2/24/07	133	*Delphinidae*	*S. attenuata*	13:48		14.307	142.789	no		no	83
2	2/24/07	134	*Delphinidae*	*S. coeruloealba*	15:22		14.186	142.701	no		no	85
2	2/25/07	136	UNID	Unid Delphinid	9:40		13.494	144.329	no		no	89
2	2/25/07	137	*Physeteridae*	*P. macrocephalus*	9:47	10:25	13.4802	144.4267	yes	3	no	
2	2/25/07	138	*Delphinidae*	*P. crassidens*	10:20	10:28	13.4809	144.4226	yes	3	no	90
3	3/1/07	138A	UNID	Unid Delphinid	17:15		13.696	145.46	no	0	no	
3	3/8/07	139	*Physeteridae*	*P. macrocephalus*	10:36	10:53	13.5575	144.7083	yes	3	no	92
3	3/8/07	139A	UNID	Unid Delphinid	17:43		13.653	145.727	no	0	no	
3	3/9/07	140	*Balaenoptera*	*B. acutorostrata*	6:51	9:08	13.517	147.761	no	0	no	
3	3/9/07	141	*Delphinidae*	*S. coeruloealba*	7:30	8:52	13.3257	147.7117	yes	3	no	94
3	3/9/07	142	*Delphinidae*	*S. coeruloealba*	9:46	10:08	13.1933	147.6471	yes	2	no	95
3	3/9/07	143	*Physeteridae*	*P. macrocephalus*	12:23	14:23	12.7385	147.233	yes	10	no	
3	3/9/07	144	*Physeteridae*	*P. macrocephalus*	14:33	15:13	12.6234	147.1184	yes	13	yes	
3	3/11/07	145	*Delphinidae*	*Peponocephala electra*	8:51	9:20	13.1048	144.3224	yes	4	no	97
3	3/11/07	146	*Balaenoptera*	*B. acutorostrata*	16:08	18:26	12.0276	143.5265	yes	9	no	
3	3/12/07		*Balaenoptera*	*B. acutorostrata*	7:32	9:32	11.924	145.094	no	0	no	
3	3/12/07	147	*Balaenoptera*	*B. acutorostrata*	11:54	13:58	11.965	145.673	no	0	no	
3	3/12/07	149	UNID	Unid Delphinid	15:53	15:59	11.977	146.224	no	0	no	
3	3/13/07	150	*Delphinidae*	*P. crassidens*	7:48	9:39	11.6362	147.6165	yes	12	yes	98
3	3/13/07	151	*Delphinidae*	*P. crassidens*	10:01	10:31	11.5799	147.5576	yes	3	no	99
3	3/13/07	154	*Delphinidae*	*P. crassidens*	11:16	11:22	11.5002	147.5204	yes	4	no	100

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
3	3/13/07	155	*Delphinidae*	*P. crassidens*	12:11	13:50	11.4121	147.4092	yes	7	no	101
3	3/14/07	158	*Delphinidae*	*S. attenuata*	10:03		10.539	146.438	no		no	106
3	3/14/07	159	*Delphinidae*	*P. crassidens*	17:05	17:59	10.4826	146.0795	yes	9	no	109
3	3/15/07	160	UNID	Unid cetacean	11:24		11.4544	145.5461	yes	1	no	
3	3/15/07	161	*Balaenoptera*	*B. acutorostrata*	12:41	16:33	11.0372	144.981	yes	15	yes	
3	3/16/07	162	*Delphinidae*	Mixed Group	11:37		10.172	144.1244	yes	2	no	111
3	3/16/07	163	*Physeteridae*	*P. macrocephalus*	14:46	15:20	10.3983	143.7836	yes	4	no	
3	3/16/07	164	UNID	Unid Delphinid	15:20	16:05	10.5538	143.6653	yes	14	no	
3	3/17/07	165	*Physeteridae*	*P. macrocephalus*	6:43	7:37	12.0683	143.9781	yes	6	no	
3	3/17/07	166	*Balaenoptera*	*B. acutorostrata*	6:56	7:26	12.0055	143.9191	yes	1	no	
3	3/17/07	167	*Delphinidae*	*P. crassidens*	8:00	9:55	11.7178	143.711	yes	15	no	112
3	3/17/07	168	UNID	Unid Delphinid	11:10	11:13	11.574	143.5573	yes	1	no	
3	3/17/07	169	UNID	Unid Delphinid	14:16	14:17	11.1919	143.2118	yes	1	no	
3	3/17/07	170	*Physeteridae*	*P. macrocephalus*	17:15	17:36	10.9507	142.7252	yes	10	yes	113
3	3/17/07	171	*Physeteridae*	*P. macrocephalus*	17:45	18:00	10.9068	142.6917	yes	4	no	113
3	3/18/07	172	*Physeteridae*	*P. macrocephalus*	8:09	11:20	10.5427	142.4113	yes	22	no	115
3	3/18/07	173	*Delphinidae*	*S. attenuata*	9:13	9:15	10.5455	142.4202	yes	1	no	116
3	3/18/07	174	*Physeteridae*	*P. macrocephalus*	9:35	11:44	10.4573	142.3505	yes	1	no	117
3	3/18/07	175	*Delphinidae*	*S. attenuata*	10:07		10.446	142.342	no	0	no	118
3	3/18/07	177	*Physeteridae*	*P. macrocephalus*	12:07	12:47	10.2288	142.1547	yes	11	yes	120
3	3/18/07	178	*Delphinidae*	*S. attenuata*	12:55	13:12	10.1705	142.1003	yes	3	no	121
3	3/18/07	179	*Physeteridae*	*P. macrocephalus*	14:34		10.1586	142.0175	yes	1	no	122
3	3/18/07	180	UNID	Unid odontocete	14:54	16:05	10.2947	142.0248	yes	4	no	126
3	3/18/07	181	*Physeteridae*	*P. macrocephalus*	15:40	18:12	10.3348	142.0647	yes	20	yes	125
3	3/19/07	183	*Balaenoptera*	*B. acutorostrata*	11:18	13:34	12.8128	143.1862	yes	3	no	
3	3/20/07	184	*Balaenoptera*	*B. acutorostrata*	7:28	11:04	13.3254	144.9174	yes	19	no	
3	3/20/07	185	*Balaenoptera*	*B. acutorostrata*	10:29	11:31	13.3416	144.9254	yes		no	
3	3/20/07	186	*Balaenoptera*	*B. acutorostrata*	16:27	17:26	12.4881	144.399	yes		no	
4	3/24/07	187	UNID	Unid Cetacean	17:21	17:30	14.29	145.4715	yes	4	no	
4	3/25/07	188	*Balaenoptera*	*B. acutorostrata*	7:07	9:47	15.5828	146.9789	yes	9	no	
4	3/25/07	189	*Balaenoptera*	*B. acutorostrata*	13:12	14:47	16.1849	147.6464	yes	9	no	
4	3/25/07	190	*Physeteridae*	*P. macrocephalus*	15:09		16.366	147.852	no	0	no	

Leg	Date	Detection #	Family	Species	Detection Start	Detection End	Lat	Long	Bearings	# Bearings	Acoustic Localization	Sighting #
4	3/25/07	191	*Physeteridae*	*P. macrocephalus*	18:09		16.7277	147.7351	yes	1	no	
4	3/26/07	192	*Physeteridae*	*P. macrocephalus*	6:59	7:43	16.8925	147.6419	yes	8	yes	130
4	3/26/07	193	UNID	Unid odontocete	8:06		16.98	147.551	no	0	no	
4	3/26/07	194	UNID	Unid Delphinid	15:22	16:02	17.8833	146.6199	yes	1	no	
4	3/27/07	194A	*Balaenoptera*	*B. acutorostrata*	6:48		17.771	146.271	no	0	no	
4	3/29/07	195	*Delphinidae*	*G. macrorhynchus*	8:29	9:02	17.7254	143.2291	yes	1	no	134
4	3/29/07	196	UNID	*Unid odontocete*	9:19	9:43	17.6503	143.156	yes	3	no	
4	3/29/07	197	*Physeteridae*	*P. macrocephalus*	11:44	12:33	17.3103	142.8103	yes	2	no	
4	3/29/07	198	*Physeteridae*	*P. macrocephalus*	18:21		16.59	142.095	no		no	
4	3/30/07	199	*Physeteridae*	*P. macrocephalus*	9:25	9:59	16.3335	142.4146	yes	15	yes	
4	3/31/07	200	*Physeteridae*	*P. macrocephalus*	12:55	14:16	15.6362	146.0937	yes	21	no	137
4	4/2/07	201	*Balaenoptera*	*M. novaeangliae*	6:57	11:46	16.0963	146.2467	yes	27	no	
4	4/2/07	202	*Physeteridae*	*P. macrocephalus*	13:01	13:43	15.6813	145.6659	yes	14	yes	
4	4/4/07	203	UNID	Unid odontocete	13:57	14:54	15.0241	144.9791	yes	2	no	
4	4/5/07	204	UNID	Unid odontocete	9:01	9:16	15.6704	144.3609	yes	5	yes	
4	4/7/07	205	UNID	Unid Delphinid	7:28	8:18	14.914	142.3289	yes	19	yes	
4	4/8/07	206	*Balaenoptera*	*B. acutorostrata*	7:10	9:28	14.0981	145.7858	yes	2	no	
4	4/8/07	207	*Balaenoptera*	*B. acutorostrata*	10:35	14:09	13.9105	146.3049	yes	11	no	
4	4/9/07	208	*Balaenoptera*	*B. acutorostrata*	14:18		14.387	147.068	no	0	no	
4	4/9/07	208A	*Physeteridae*	*P. macrocephalus*	14:53		14.385	147.058	no	0	no	
4	4/10/07	209	*Balaenoptera*	*B. acutorostrata*	7:04	9:25	14.7277	146.2035	yes	7	yes	
4	4/10/07	210	*Delphinidae*	Mixed Group	11:30		14.3838	145.8583	yes	1	no	145
4	4/10/07	211	*Physeteridae*	*P. macrocephalus*	11:36		14.3855	145.8471	yes	1	no	144
4	4/11/07	212	UNID	Unid Delphinid	6:28	7:01	13.6056	145.0443	yes	11	yes	

APPENDIX B-2. NARRATIVE OF SELECTED SONOBUOY RECORDINGS BASED ON NOTES AND COMMENTS MADE DURING REAL-TIME MONITORING

25 Jan 07: During this day station, minke whale 'boings' were recorded.

15 Feb 07: This was the first evening station conducted. Sperm whale clicks and unidentified dolphin whistles were recorded. It is of interest to note, there were no visual or acoustic detections with the towed array of sperm whales on the 15th or 16th.

18 Feb 07: Sonobuoys were deployed on singing humpbacks to provide additional resolution on the lower frequency components of the song. This supplemented the recordings made from the array.

****19 Feb 07**: Though brief in duration, a recording of at least one call was made in the vicinity of identified sei whales.

20 Feb 07: During this night station, unidentified dolphin whistles were recorded. Striped dolphins were detected visually and acoustically approximately 3 hours previously, but no confirmation of species ID made at the time for this recording. We recommend processing these whistles through the program ROCCA (Oswald *et al*., 2007) for possible species identification.

****17 Mar 07**: During this night station, sperm whale clicks and unidentified large whale calls in the range of 400-500 Hertz (Hz) were recorded. (Sperm whales were detected both visually and acoustically earlier in the day as well as on the following day).

18 Mar 07: This buoy was deployed in the vicinity of Bryde's whales, sperm whales, and bottlenose dolphins. Excellent recordings were made of clicks, codas, and creaks from the sperm whales as well as whistles from the dolphins. This buoy was recorded in synchrony with the towed array. Some sperm whales not detected on the array were clearly detected on the buoy and vice versa. Sei whale vocalizations were not detected, but further review of recordings is needed to confirm.

25 Mar 07: During this night station, sperm whale clicks were detected. Sperm whales were detected earlier in the day and the following day acoustically. No visual detections were made.

****26 Mar 07**: During this night station, minke whale boing's and an unidentified 40-35 Hz signal were detected. No visual or acoustic detections of Minke whales were made on the 26th or 27th. The source of the low frequency signal could not be determined. It cannot be ruled out that the ship is the source of this apparent call. Unidentified baleen whales were visually detected on the 26th and 27th.

28 Mar and 5 Apr 07: During these night stations, the unidentified 40-35 Hz signal was once again detected. There were no visual or acoustic detections of baleen whales made those days or the days directly after.

*****5 Apr 07**: During this night station, the unidentified 40-35 Hz signal was again detected. In addition, an unidentified 500-600 Hz signal was recorded twice. No whales were detected on the 5th or the 6th either visually or acoustically.

7 and 8 Apr 07: During this night station, three buoys were deployed as we neared and crossed the north side of the island of Rota. Unidentified dolphin whistles (possible blackfish type) and minke whale boings were detected. Minke whale boings were not detected on the 7th, but were detected on the 8th with the array. Spotted dolphins were visually detected on the 8th.

8 Apr 07: During this day, drop on sei/Bryde's sighting #142, boings, unidentified whistles, and possible 40-35 Hz signals were detected. Minke whales and dolphins were detected earlier in the day.

9 Apr 07: During this day, drop on sei/Bryde's sighting #143, boings, Sperm whale clicks and the unidentified 40-35 Hz signals were detected. Sperm whales were not detected visually the 8th, 9th or 10th.

10 Apr 07: During this night station, the 40-35 Hz signal was once again detected briefly. There were no confirmed baleen whales visually detected this day.

APPENDIX B-3. ACOUSTICS - RECOMMENDATIONS, CONSIDERATIONS, AND FUTURE RESEARCH

Based on the 2007 field effort and results, there are several recommendations that we believe would improve the quantity and quality of acoustic data obtained in future efforts. These recommendations are intended for improving the effectiveness of acoustic monitoring and do not take into consideration visual survey constraints and needs. A compromise between the two approaches is necessary to optimize the effectiveness of both of them combined. The degree to which each method is compromised will depend on the relative importance for acoustic or visual methods for the goals of the research.

1. Consider passive acoustic monitoring needs during selection of a research vessel.
   a. The more quiet the vessel is, the more effective the acoustic monitoring is.
   b. Clean power is essential for the acoustic system. Preferably, an isolated power source can be dedicated just for the acoustics system.
   c. Lab space must be adequate and dry
2. Sampling design and protocol recommendations:
   a. Sample design should include acoustic monitoring considerations.
      i. Vessel survey speed should be as low as possible.
      ii. Monitoring stations (especially if survey speed is > 7 knots).
      iii. Time should be allocated to investigate unidentified acoustic detections (in the same manner unidentified visual sightings are).
      iv. Nighttime surveys and/or monitoring should be considered.
3. The following improvements to localization techniques are recommended:
   a. Real-time localization techniques (*i.e.,* crosspair triangulation) should be incorporated into acoustic system.
   b. Dual array system should be developed and incorporated into the design.
   c. Depth and heading sensors should be integrated into the array. This will provide more precise information on the array position which will allow:
      i. More accurate bearings and localizations.
      ii. Dive profiles to be determined for individual animals.
4. A sonobuoy system should be included in the research plan (this was not an original component of this project).
   a. System should be installed and tested prior to cruise
      i. Antenna placement is critical – should be tested in port.
      ii. Yagi and omni antennas should be used.
      iii. Antenna pre-amps should be installed.
      iv. Multiple receivers (at least two) should be used.
5. Data analysis should include a more thorough review of recordings (analysis time is cheap relative to ship time).

Passive acoustic monitoring and surveying methods have different requirement and constraints than visual based survey methods. For example, platform height and stability is an important consideration for visual methods but are of no importance to acoustic methods. Perhaps the most important consideration for towing a hydrophone array is minimizing noise. Therefore, the noise characteristics of the survey vessel should be considered as should the speed at which the array will be towed. All motorized survey vessels produce some noise, both from propulsion and from ancillary machinery (e.g. generators). Some vessels are inherently quieter than others. Flow noise (i.e. noise created by turbulence of water flowing past the hydrophone) and cable strum are two other sources of noise that are directly related to vessel speed.

In general, newer vessels tend to be quieter. Some vessels are specially designed for acoustic work (e.g. geo-seismic survey and Navy submarine hunter vessels). These vessels typically use diesel-electric propulsion systems and have noise isolating mechanisms for mounting the engines and generators. All these features can greatly reduce noise transmission from the survey vessel to the ocean. Other possibilities include motor-sailing vessels (excellent for acoustic surveys but usually not as a visual platform), and small (10-25 ft) inflatable vessels (deployed from a mother vessel to more closely approach animal groups to obtain recordings). Noise reduction is not only beneficial for acoustic monitoring, but it also helps minimize the effects of the vessel noise on the behavior of the animals being surveyed. One of the primary assumptions of line-transect surveys is that animals are neither attracted nor repelled from the survey vessel, a condition which is usually not met due to reactions of animals to the noise produced by the research vessel.

Flow noise and cable strum occur at the hydrophone array. These are two sources of noise that can significantly reduce detection of low frequency (<100 Hz) sounds. Ship noise can be excessive at frequencies under 1 kHz especially at the speeds which line-transect surveys are conducted (usually 8-10 knots). The simplest way to reduce all these sources of noise is to reduce the speed of the survey vessel. However, if this is not possible, a "listening station" protocol can be used as a compromise between the methods. A listening station consists of a brief period in which the survey vessel slows down to allow lower noise conditions and subsequently, more effective mid-to-low-frequency monitoring than possible when surveying at full survey speed. For example, listening stations were used in a recent acoustic-visual survey for killer whales from NOAA's R*/V McArthur* ((Norris *et al*., 2006). The listening stations were conducted every ~30 min and at the end of each transect, before and after the ship turned. Before the start of the listening station, the ship's speed was reduced to ~2-3 knots, just enough to maintain steerage. The array was monitored for a period of 5-10 min after which the ship resumed normal survey speed. In deep waters, the reduction in speed allows the hydrophone array to sink, further increasing the probability of detection of some signals, such as low frequency signals produced by baleen whales and mid-frequency signals produced by sperm whales.

Clean power is another important consideration for acoustic work. Electrical noise present in the power systems of most ships can greatly reduce the ability to process weak signals from the hydrophone. Radio-Frequency (RF) noise and high-voltage electrical lines can also introduce noise into the acoustic system, especially when these sources are located near the deck cable or entry point of the hydrophone array from sea to the deck. These are important considerations when choosing a research vessel, and when deciding the location and setup of the acoustic system.

Sampling design is a critical component for the planning of any survey. Sampling design for visual line-transect surveys is well established with detailed guidelines available (Buckland *et al*., 2004). Sampling design for acoustic surveys are nit well established but similar considerations and assumptions must be met (See Discussion Topic IV and Appendix A. in Mellinger and Barlow, 2003). In order to properly design a survey the specific goals and methods should be clearly defined. If acoustic surveys are to be included in the design of a line-transect survey, they should be integrated with visual methods according to the goals. For example, if acoustics are being used as an independent platform to assess the bias of the line-transect the detection function at distance = 0 (i.e. *g(0)*), then there should be no information exchanged between visual observers and bio-acoustic monitors until the animals have completely passed the beam.

Another alternative is to use data from both visual and acoustic data in the distance sampling formula. For example, average group size estimates can be obtained from visual methods, and acoustic data can be used to estimate the detection function, g(x), (Barlow and Taylor, 1999). This requires less stringent protocols with regards to independent platforms, but still requires that acoustic information not be used by visual observers to cue them.

There are other, more practical considerations when using acoustic surveys. For example:

- How many hydrophone elements to use and in what configuration in the towed array? Should more than one towed array be deployed?
- What should the frequency response of the system be?
- Should night-time surveys or night-time listening stations be conducted?
- Should the acoustics team be allowed to direct the ship to a localization event in order to confirm the species identity and group size (if not detected visually)?

These are all questions that can only be answered if the goals of the study are clearly defined. Doing so, will help to optimize the effectiveness of the acoustic data collected, and insure that it can be used to provide information to address the study goals.

Real-time localization of bio-acoustic signals is an area of research experiencing recent progress in the field of underwater acoustics. Real-time localization allows nearly instantaneous estimation of an animal's position, sometime in three-dimensions. For example, algorithms have been developed to allow underwater positions and even tracks of sperm whales to be determined using data from a towed, 4 element array (Thode, 2004, 2005). These algorithms are currently being incorporated into open source software being developed for use in detecting and tracking marine mammal from their sounds (http://www.pamguard.org/home.shtml). Two-dimensional localization is already possible in real-time and has been used to identify the source of minke whale boing (Rankin and Barlow, 2005). The approach they used consisted of "target-motion analysis" in which a sound source is located through the intersection of successive bearing fixes (Lewis *et al*., 2007). This requires turning the vessel slightly, so that the left-right ambiguity inherent in line-arrays can be resolved. Another approach is to use a pair of widely spaced (>200m) of hydrophones to allow the animals location to be determined instantaneously from the intersection of bearings between the two hydrophone pairs. Adding a second array, with the hydrophone element lined-up perpendicular to the one of the hydrophones in the first array, allows the left-right ambiguity to be resolved instantaneously. This approach is useful when animal locations need to be determined quickly or tracking of animals is necessary (Norris *et al*., 2006).

Sonobuoys are an effective tool for detecting and recording marine mammal sounds. During the MISTCS cruise, a sonobuoy system was set-up and used opportunistically, but time, personnel and funding constraints limited its use and especially analysis of the data collected. Sonobuoys are particularly useful for detecting low-frequency sounds or if the research vessel is unable to slow or turn to investigate encounters. Maximizing signal reception and obtaining low-failure rate sonobuoys (i.e. either unexpired or recently expired ones), is an important consideration for planning sonobuoy operations in the future. We recommend use of a sonobuoy system in the future. Adequate planning and funding of this field component would allow it to be effectively incorporated into the research plan.

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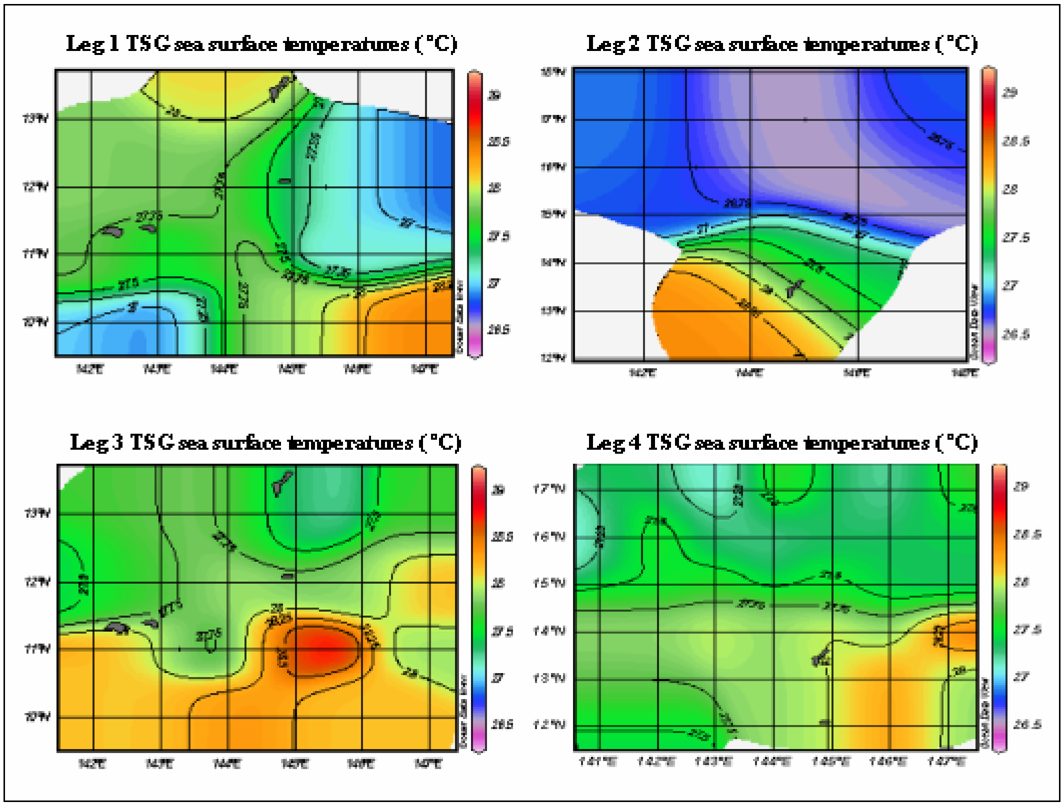
Thode, A. 2005. Three-dimensional passive acoustic tracking of sperm whales (*Physeter macrocephalus*) in ray-refracting environments. *Journal of the Acoustical Society of America* 118:3575-3584.

APPENDIX C OCEANOGRAPHIC INFORMATION PER LEG



Leg 1 TSG sea surface temperatures (°C)

Leg 2 TSG sea surface temperatures (°C)

Leg 3 TSG sea surface temperatures (°C)

Leg 4 TSG sea surface temperatures (°C)

Figure C-1. Geographical Temperature Distribution per Leg

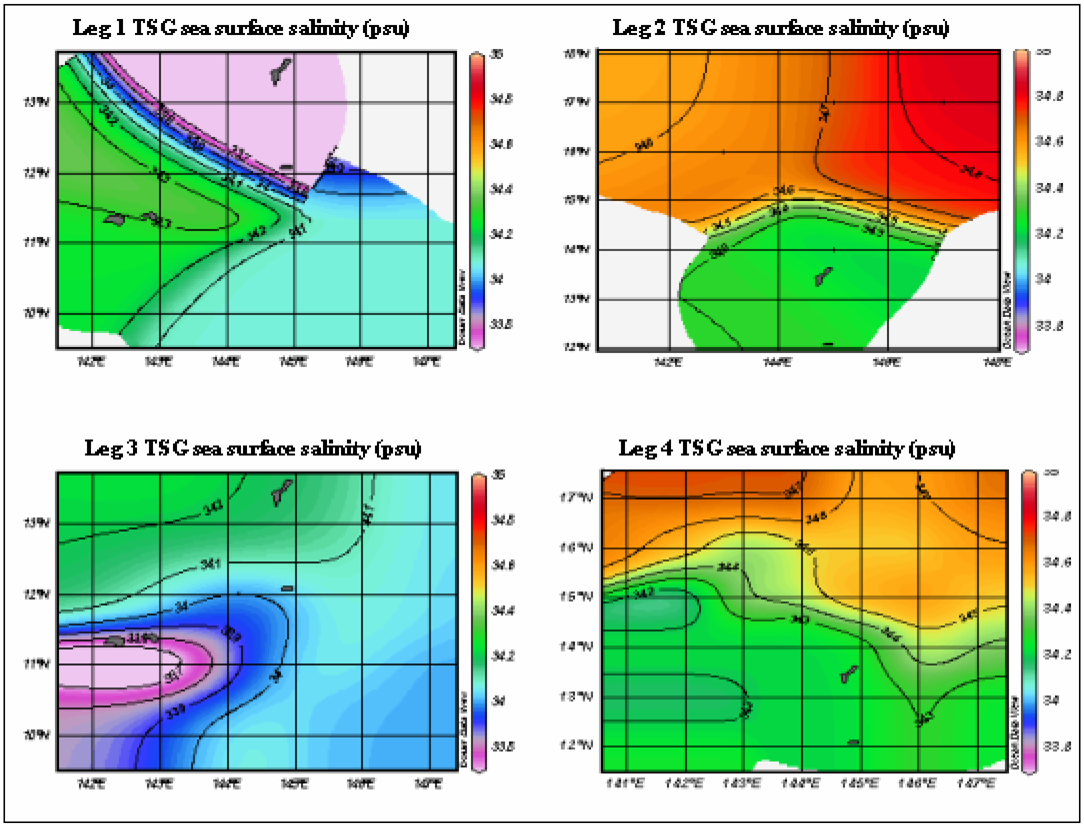
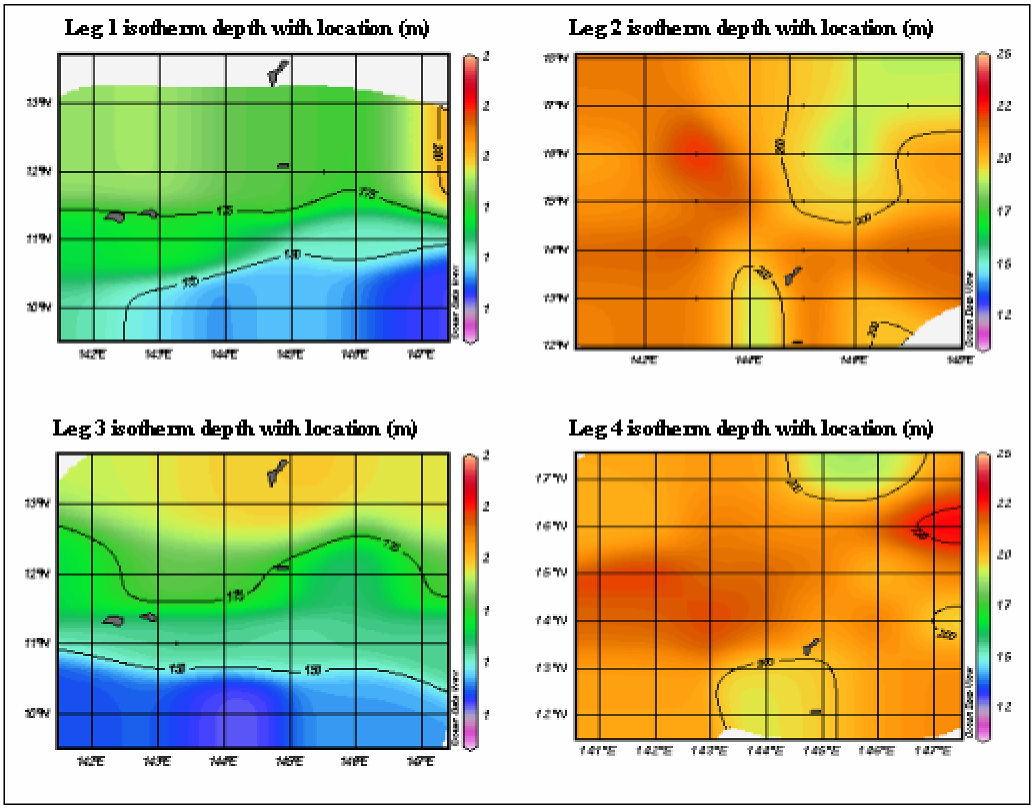


Figure C-2. Geographical Salinity Distribution per Leg



Leg 1 isotherm depth with location (m)

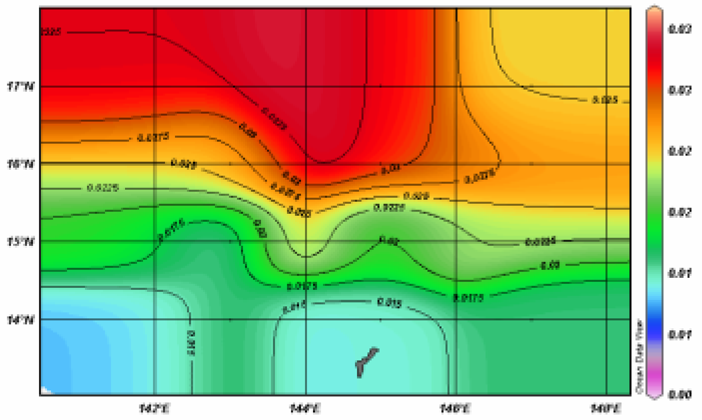
Leg 2 isotherm depth with location (m)

Leg 3 isotherm depth with location (m)

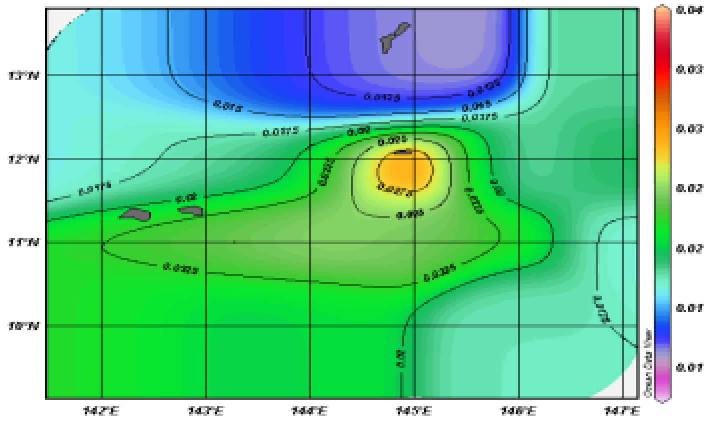
Leg 4 isotherm depth with location (m)

Figure C-3. Geographical Thermocline Isotherm Depth per Leg

a. Leg 2 chlorophyll a



b. Leg 3 chlorophyll a



c. Leg 4 chlorophyll a

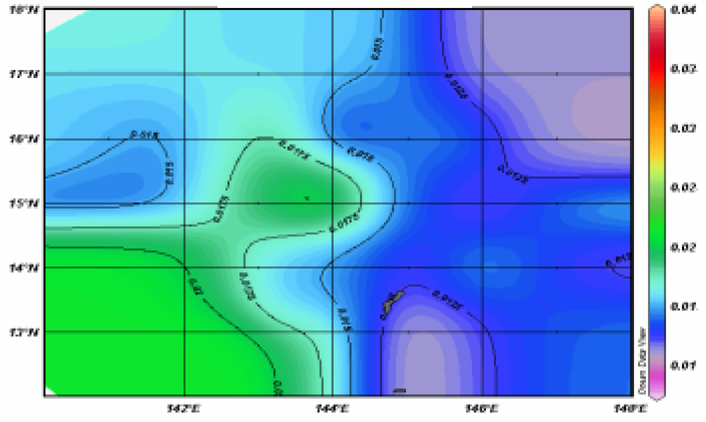


Figure C-4. Geographical Chlorophyll a Distribution per Leg

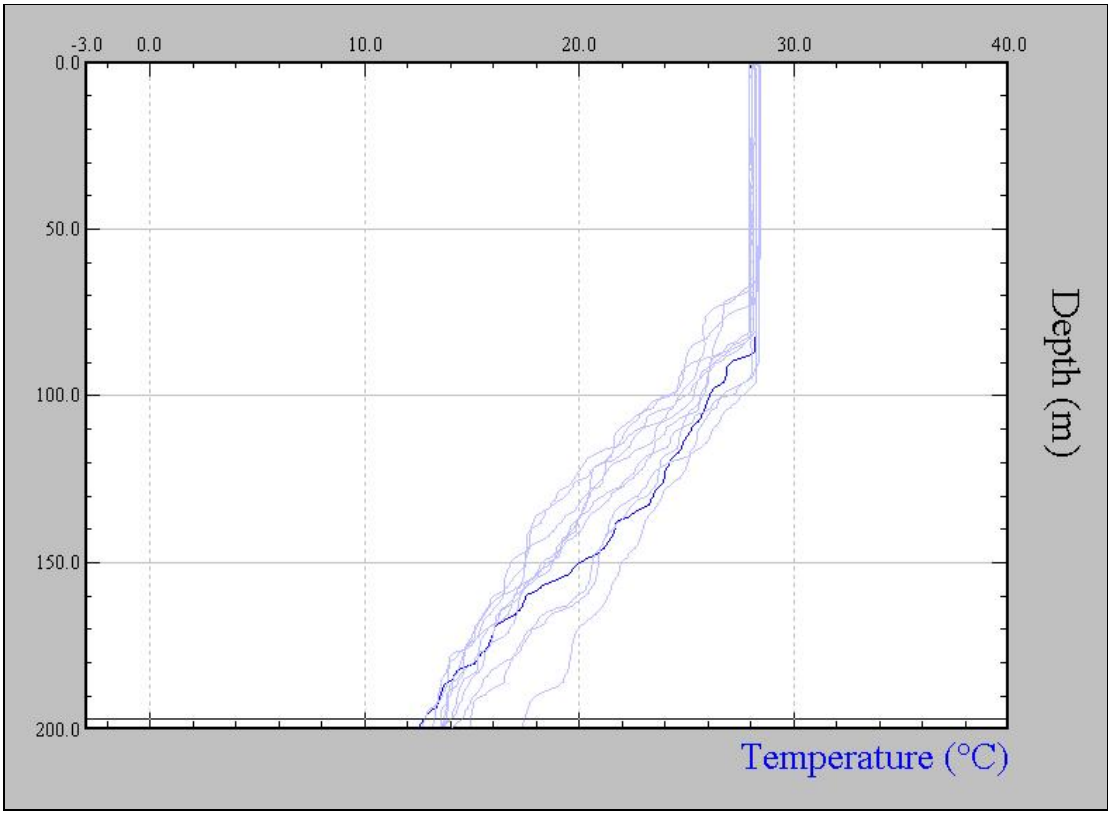


Figure C-5. Leg One XBT Drops 013 – 023

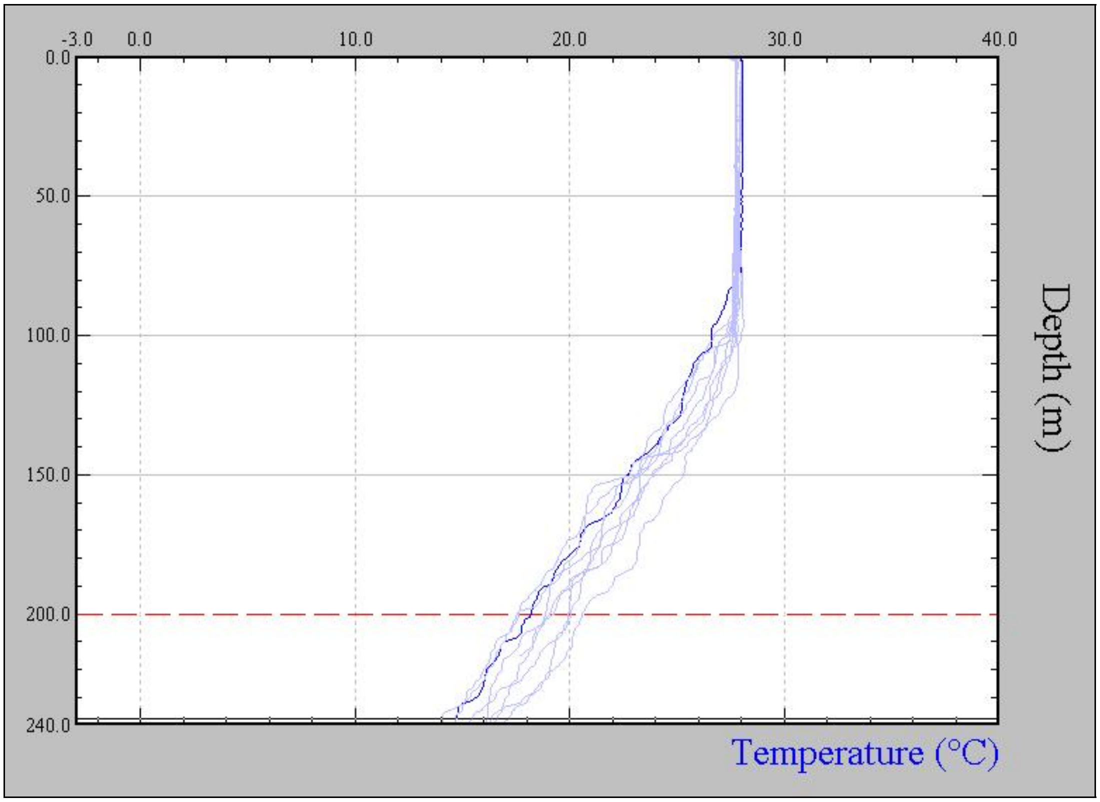


Figure C-6. Leg One XBT Drops 024 – 035

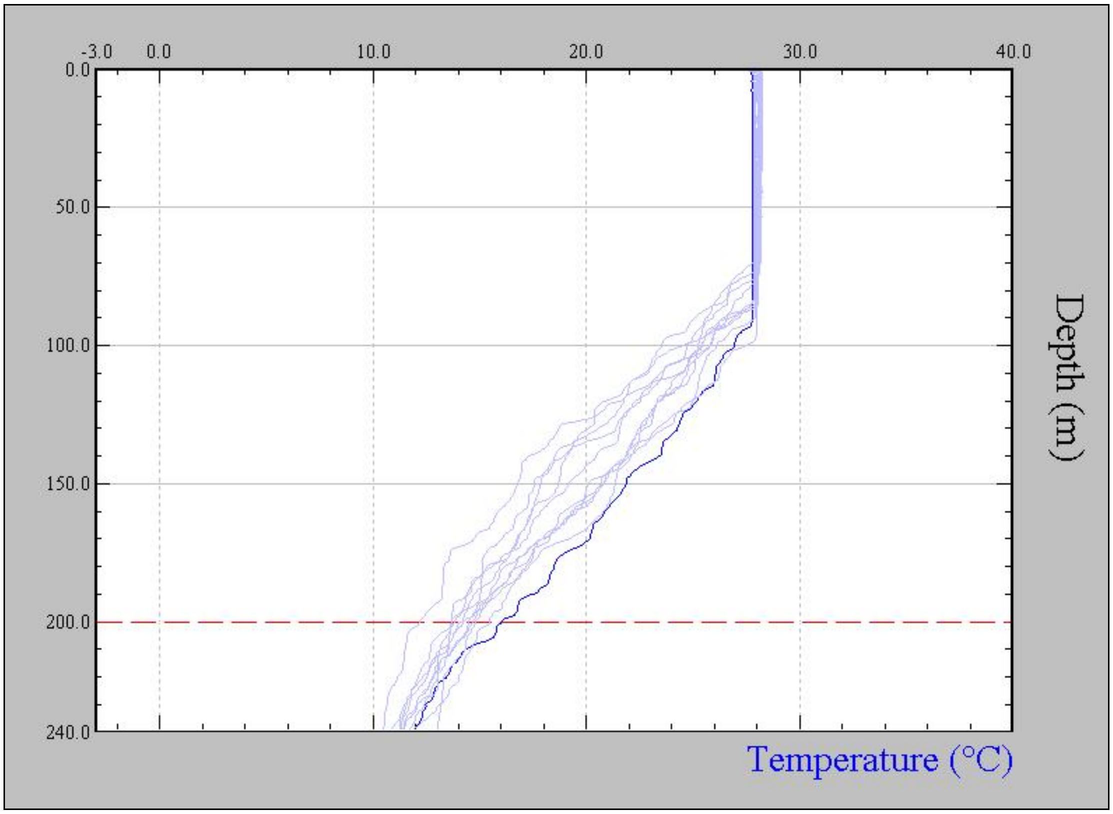


Figure C-7. Leg One XBT Drops 036 – 046

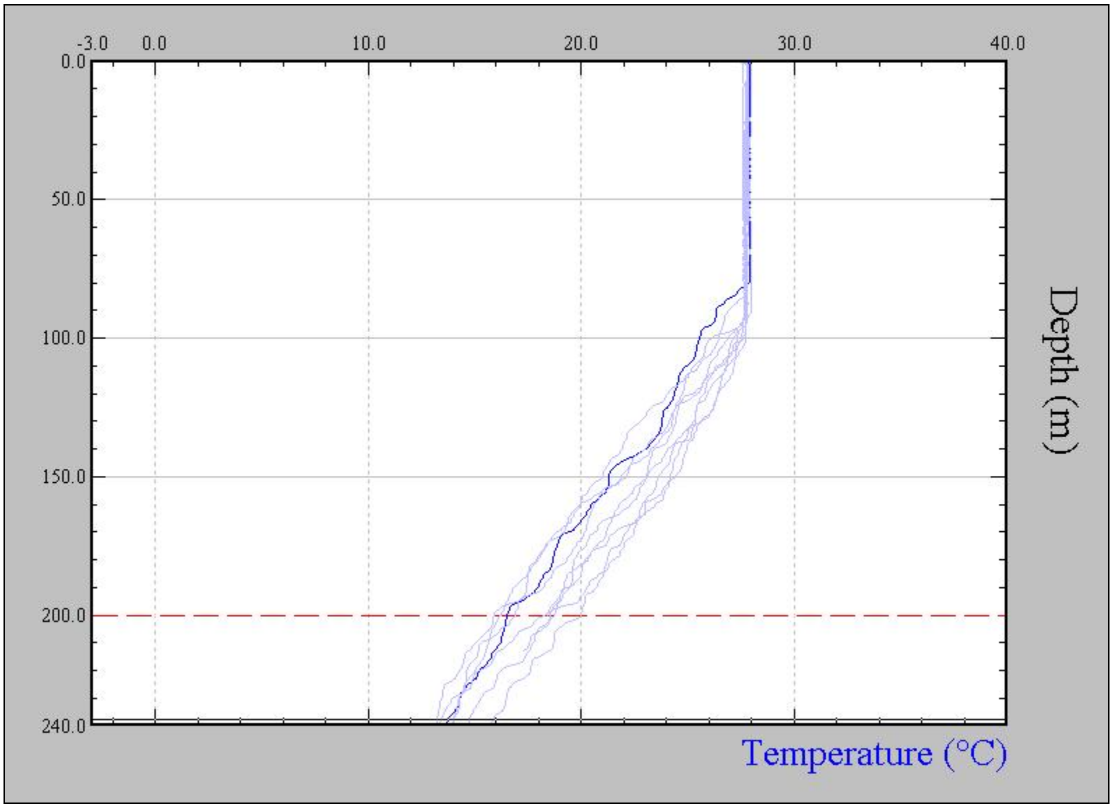


Figure C-8. Leg One XBT Drops 047 – 055

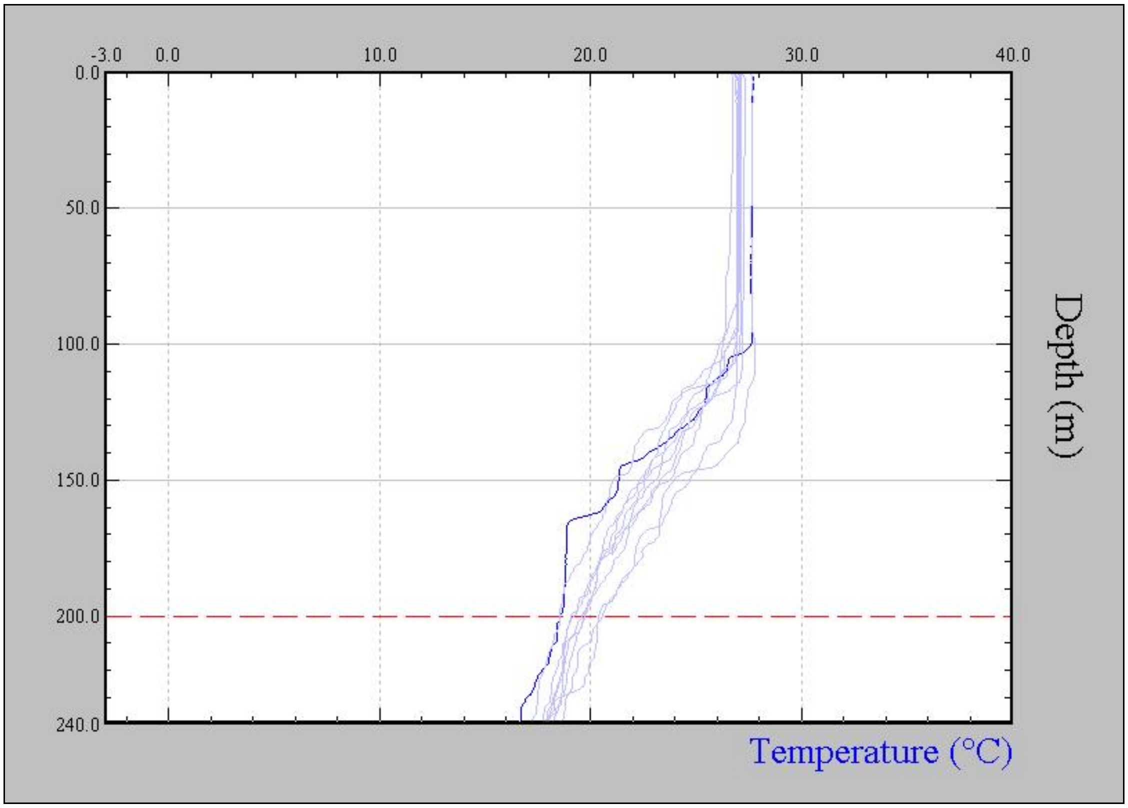


Figure C-9. Leg Two XBT Drops 056 – 066

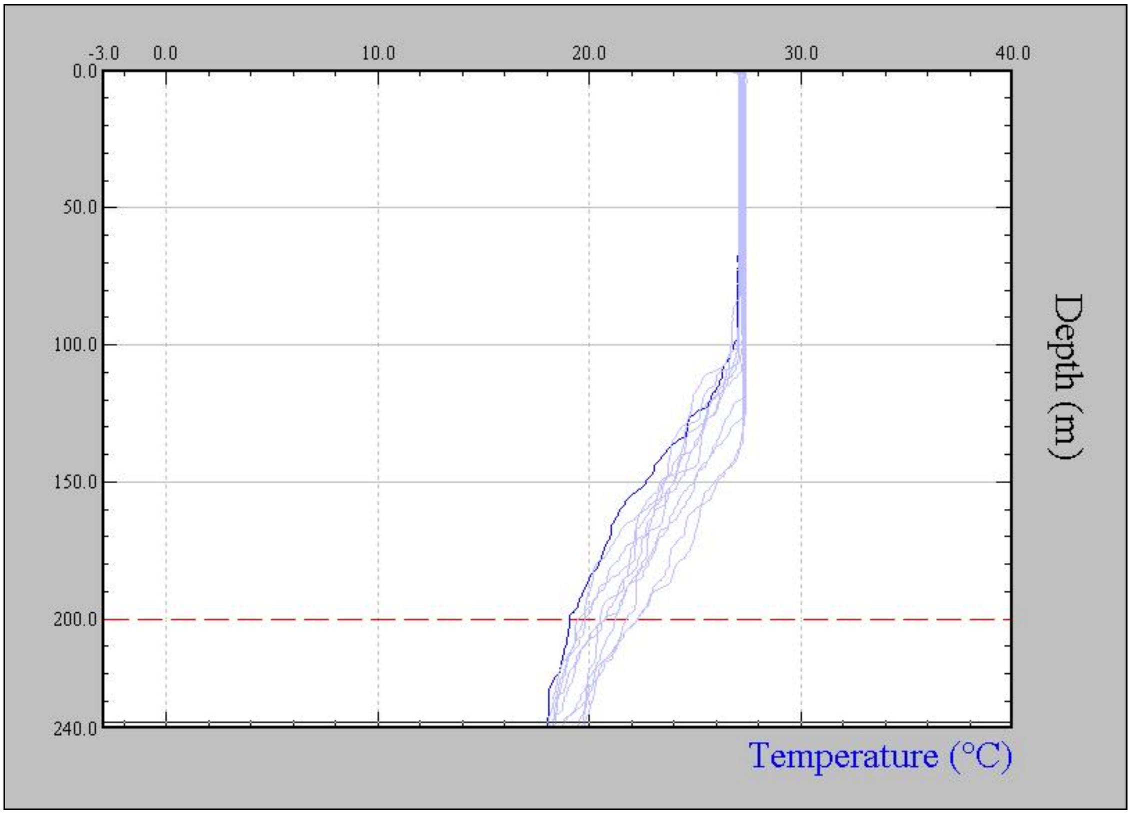


Figure C-10. Leg Two XBT Drops 067 – 077

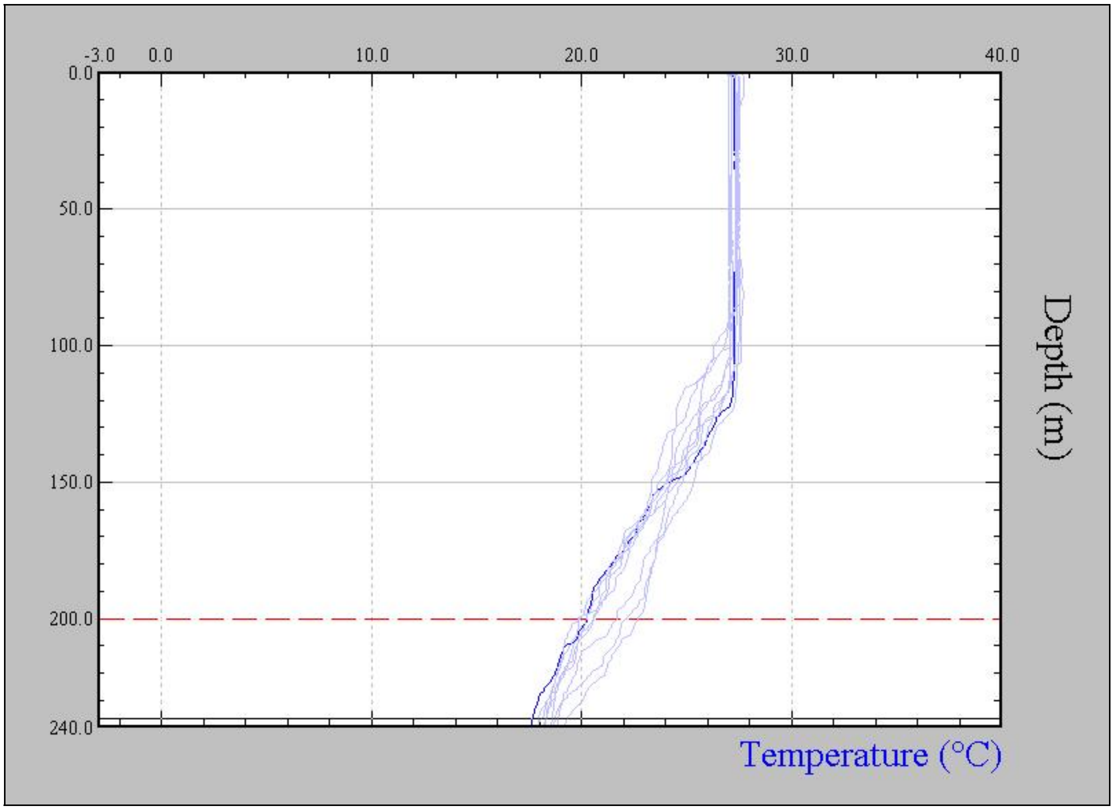


Figure C-11. Leg two XBT Drops 078 – 088

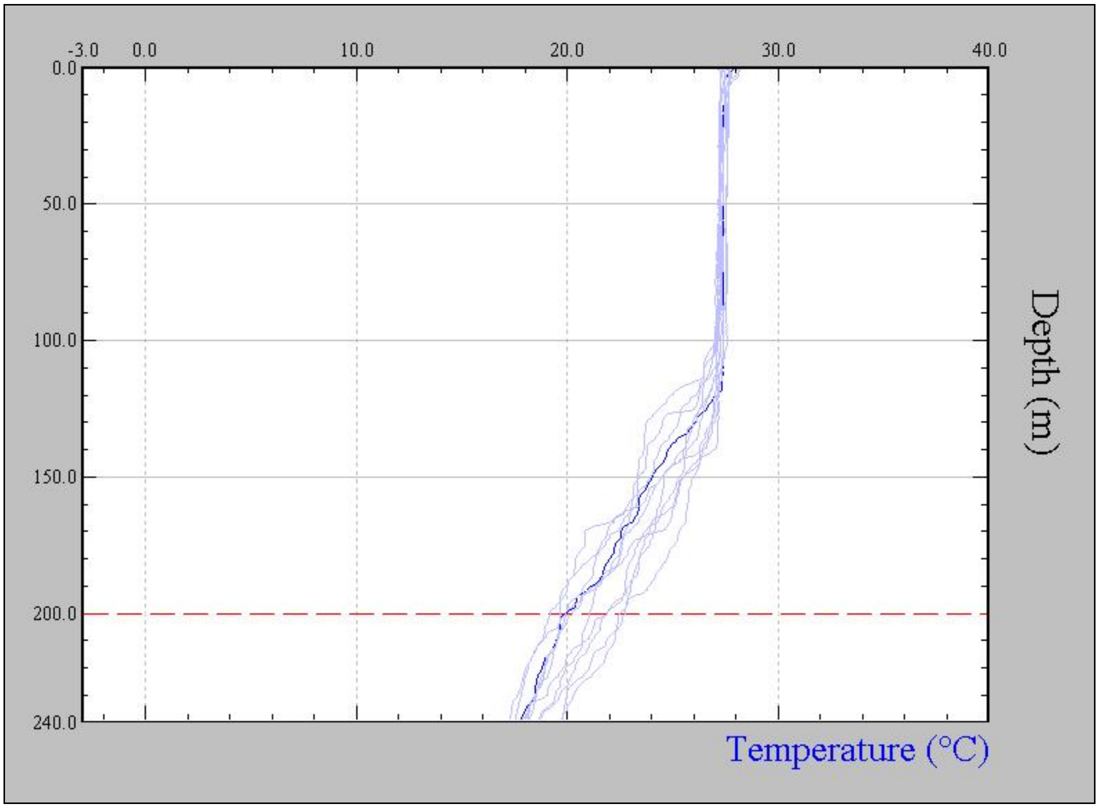


Figure C-12. Leg Two XBT Drops 089 – 099

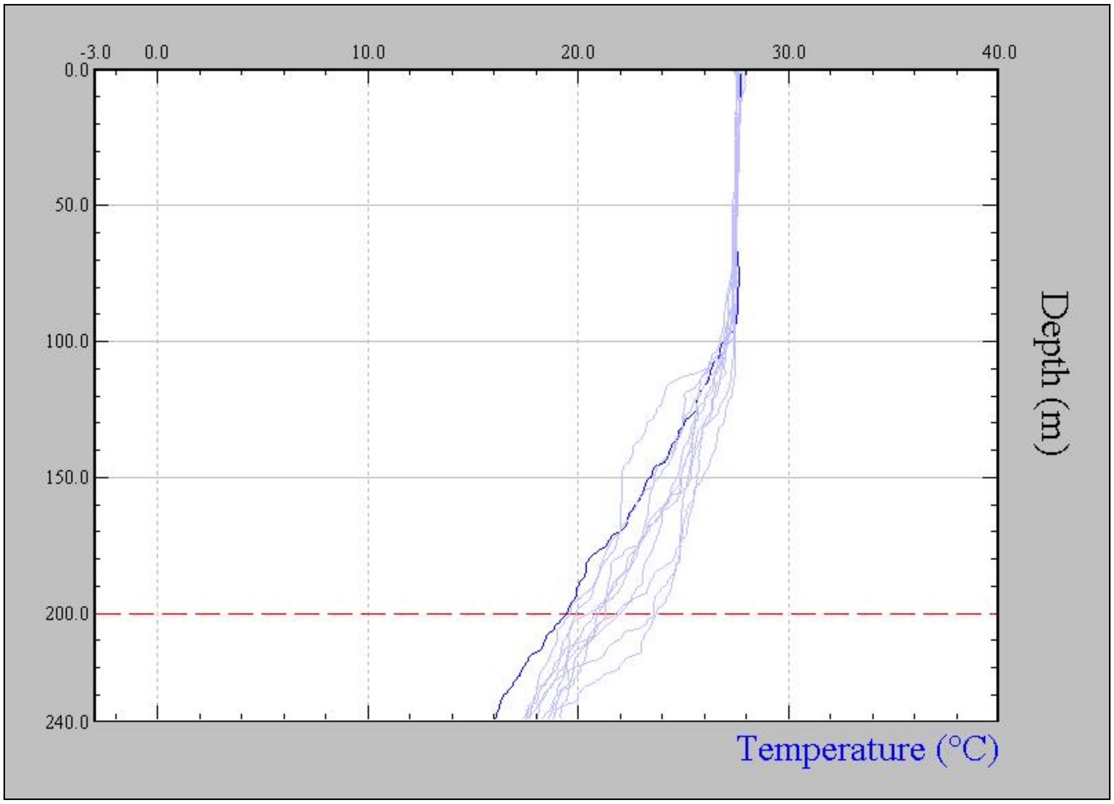


Figure C-13. Leg Two XBT Drops 100 – 110

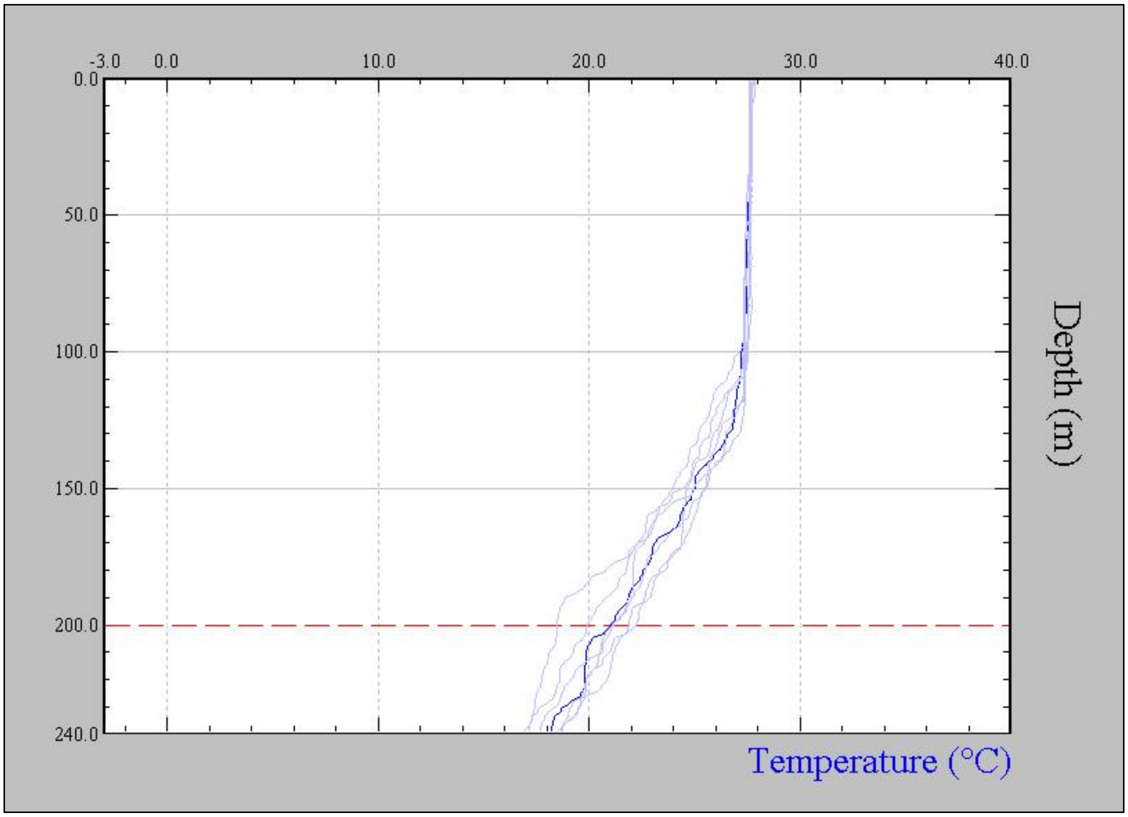


Figure C-14. Leg Two XBT Drops 111 – 117

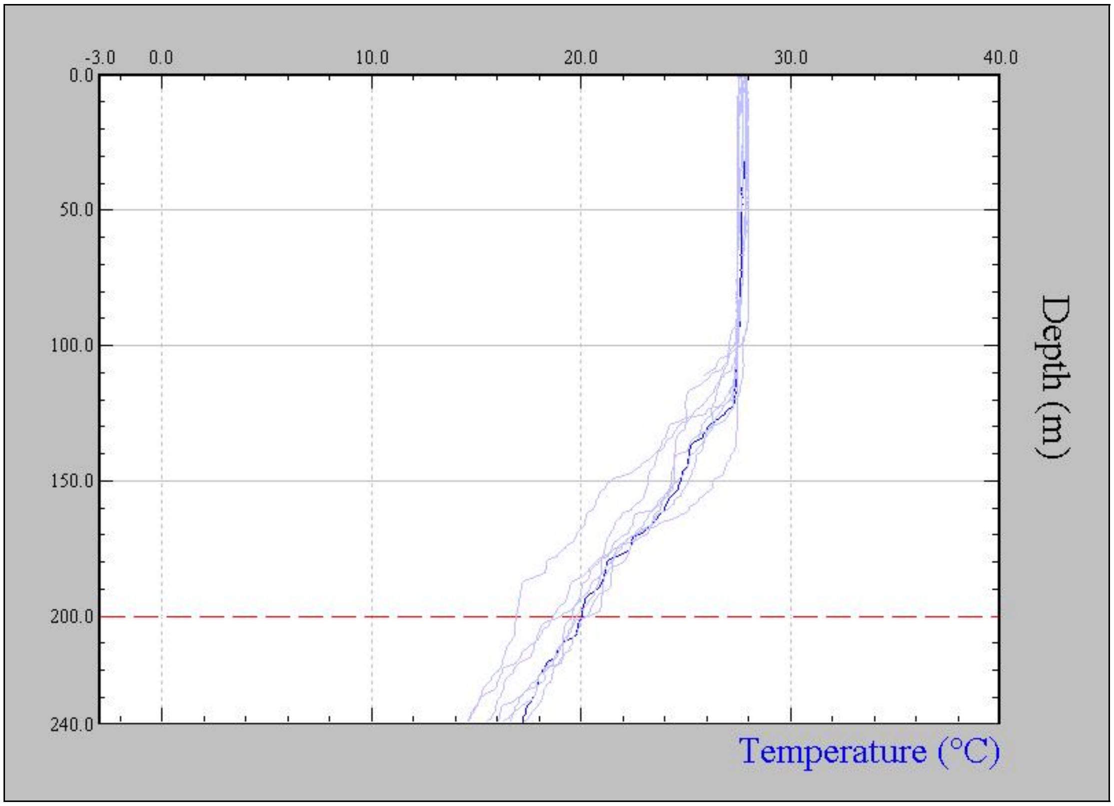


Figure C-15. Leg Three XBT Drops 119 – 129

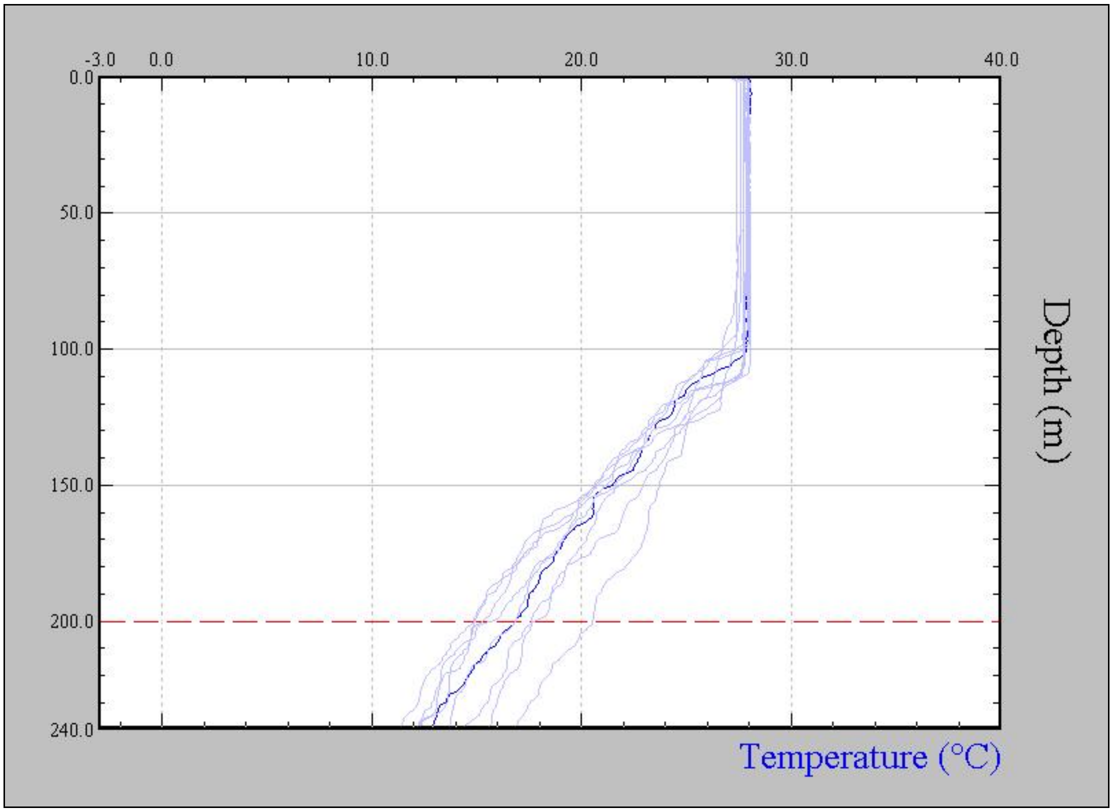


Figure C-16. Leg Three XBT Drops 131 – 142

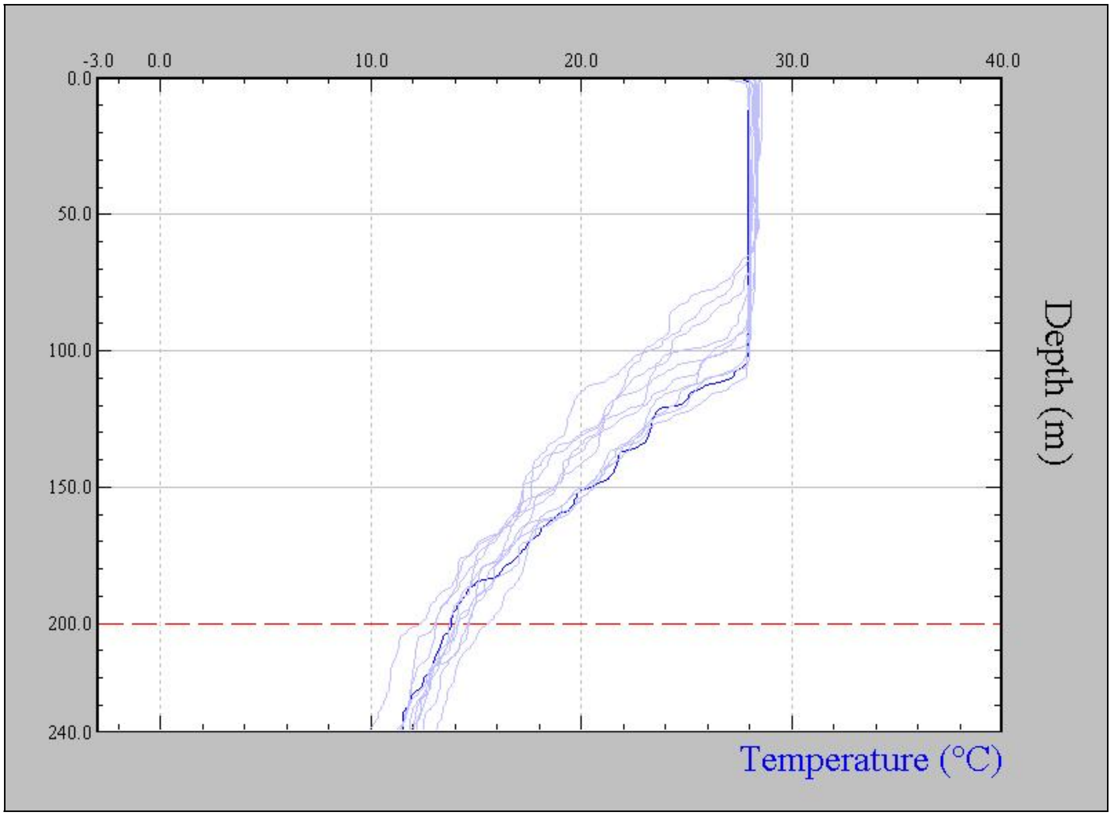


Figure C-17. Leg Three XBT Drops 143 – 153

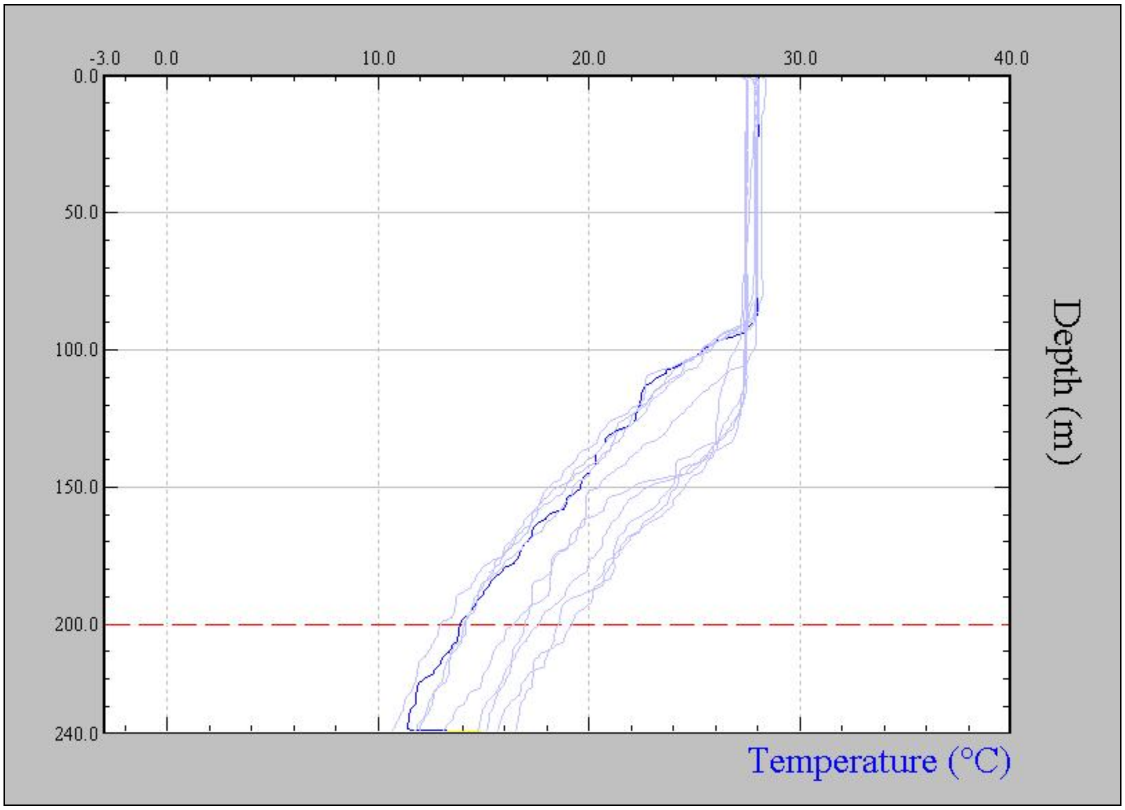


Figure C-18. Leg Three XBT Drops 154 – 164

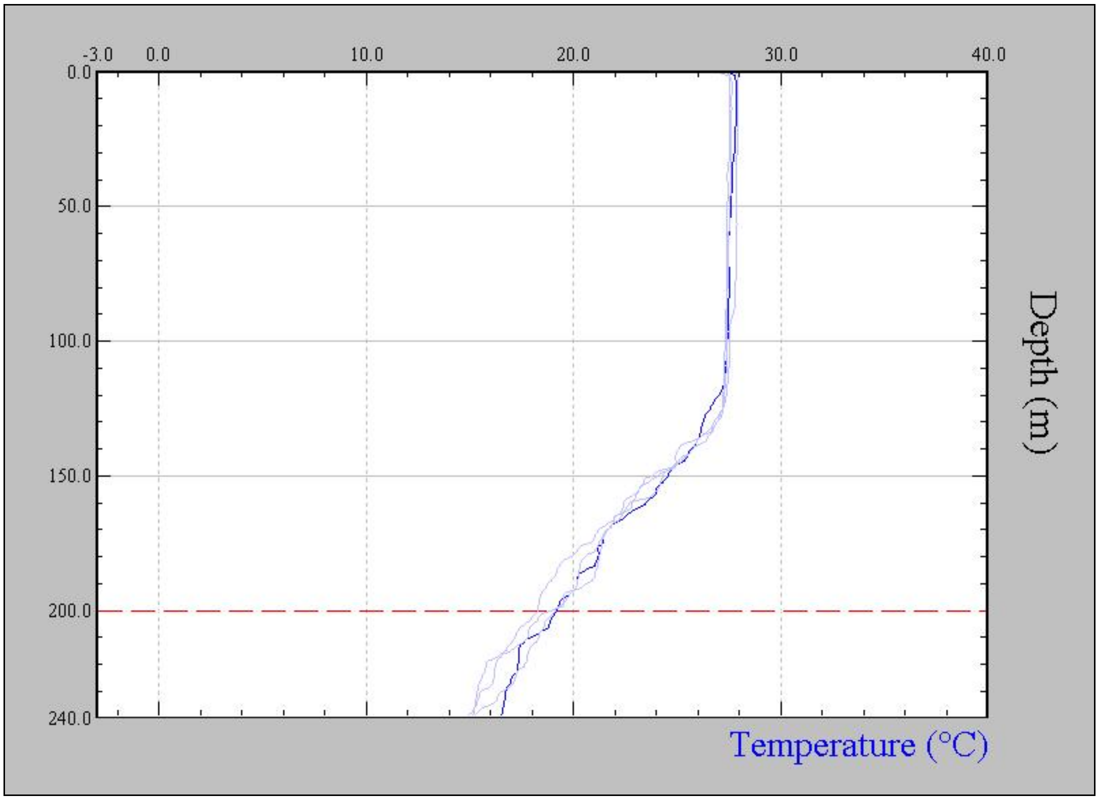


Figure C-19. Leg Three XBT Drops 165 – 168

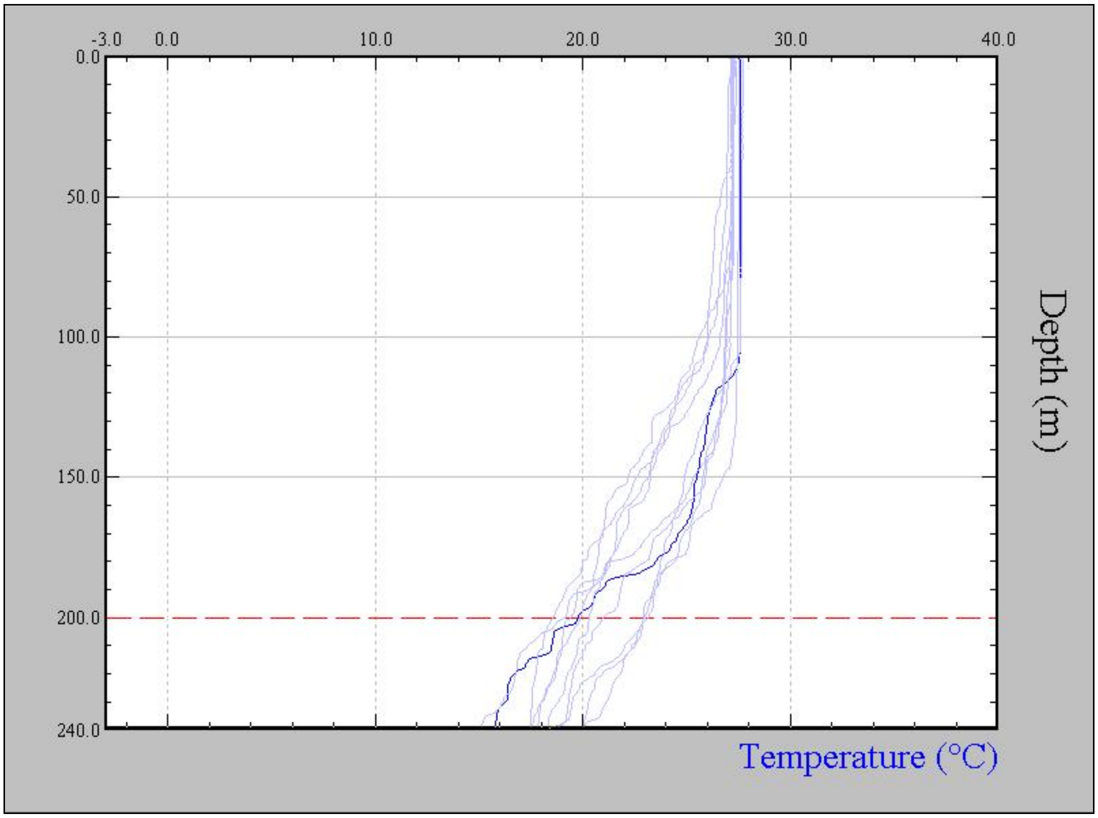
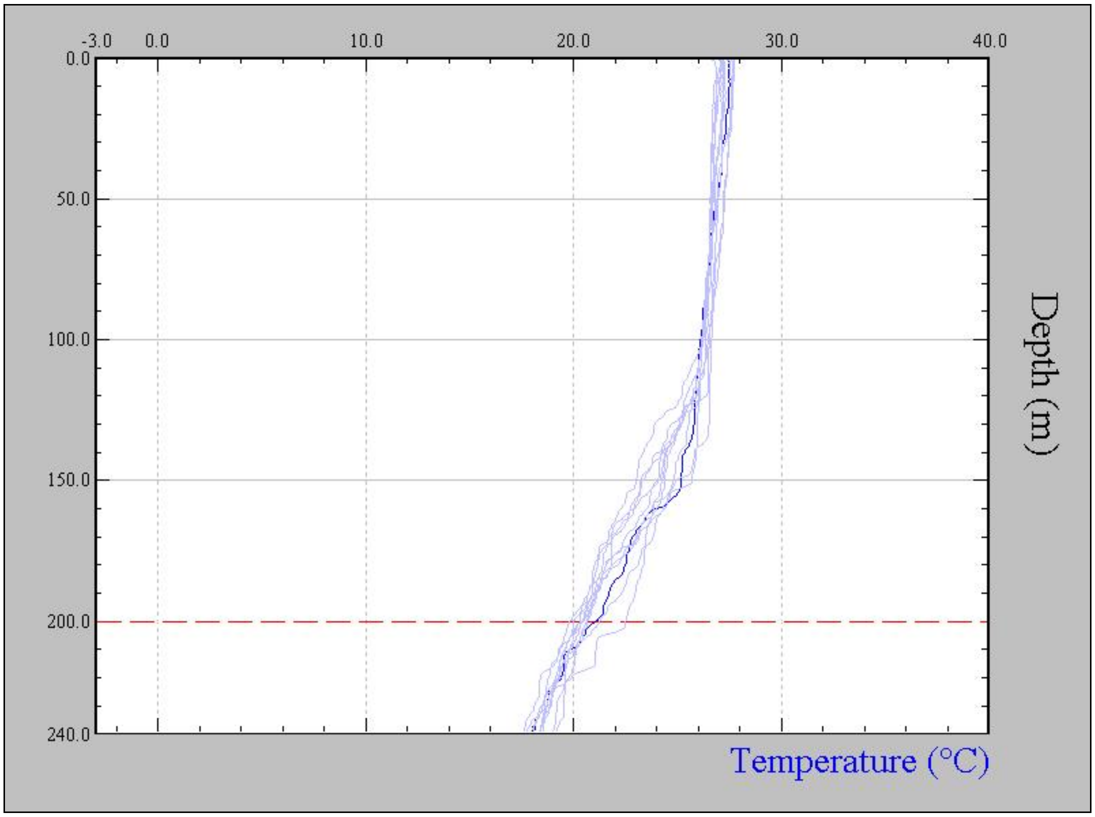


Figure C-20. Leg Four XBT Drops 169 – 180



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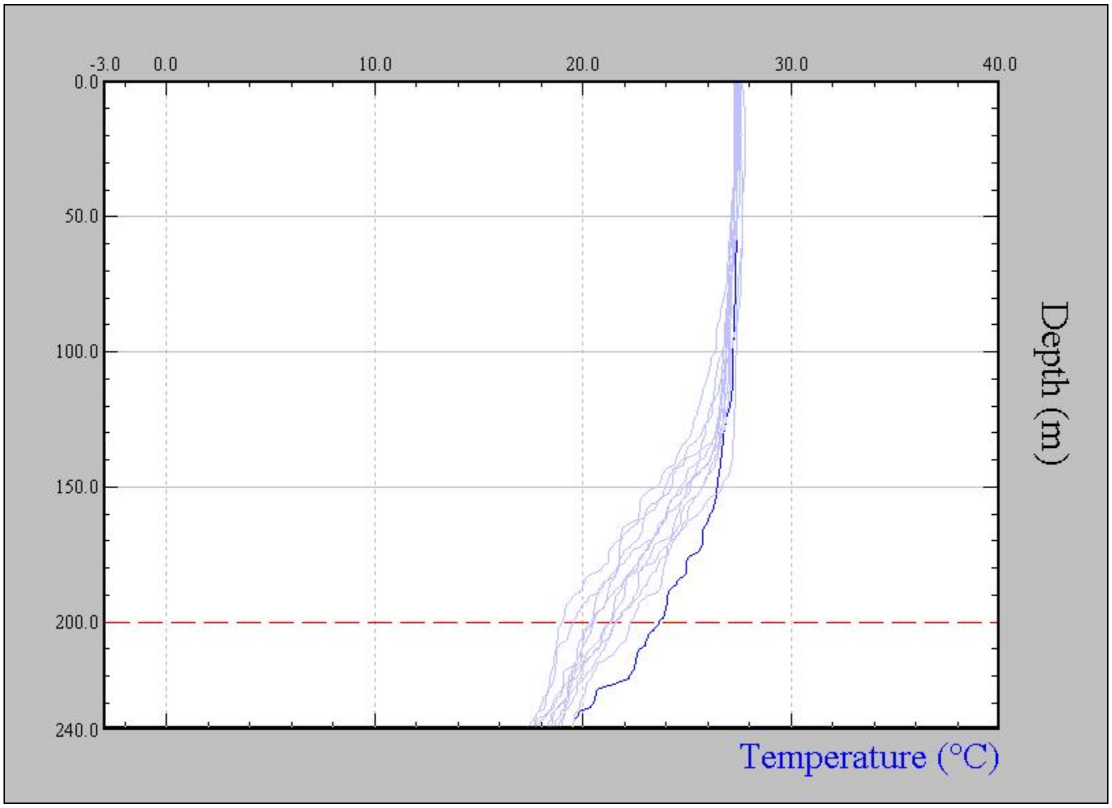

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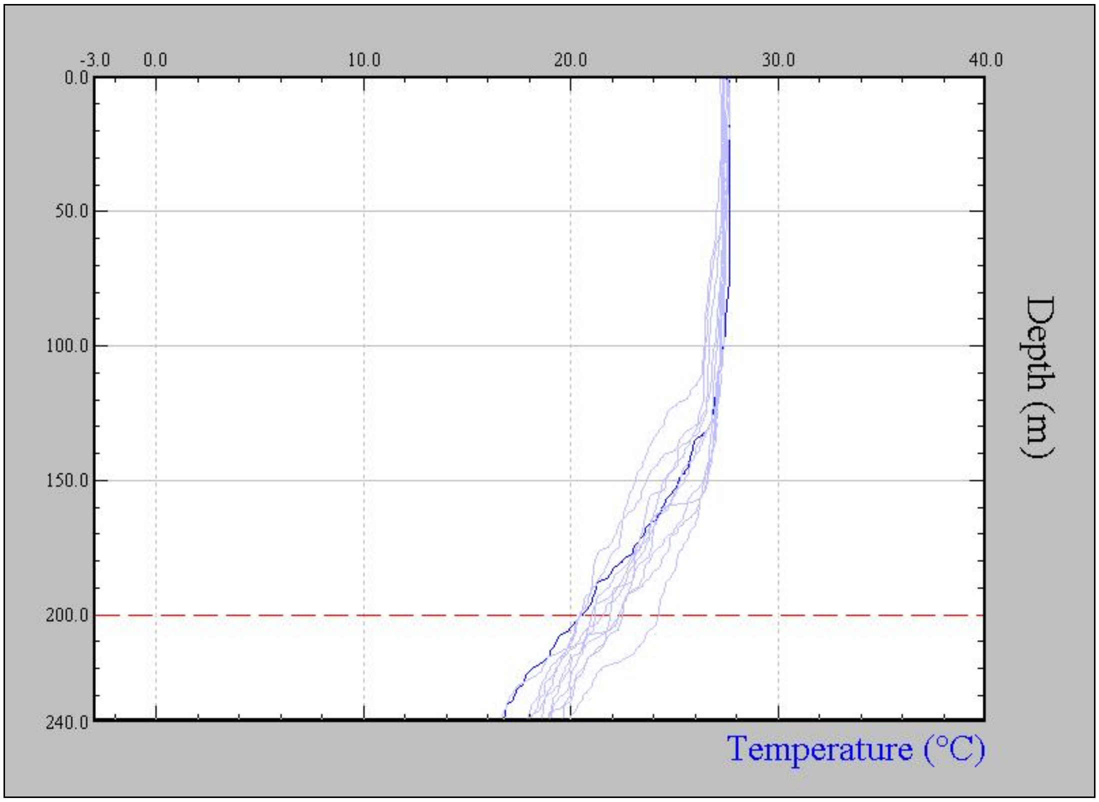

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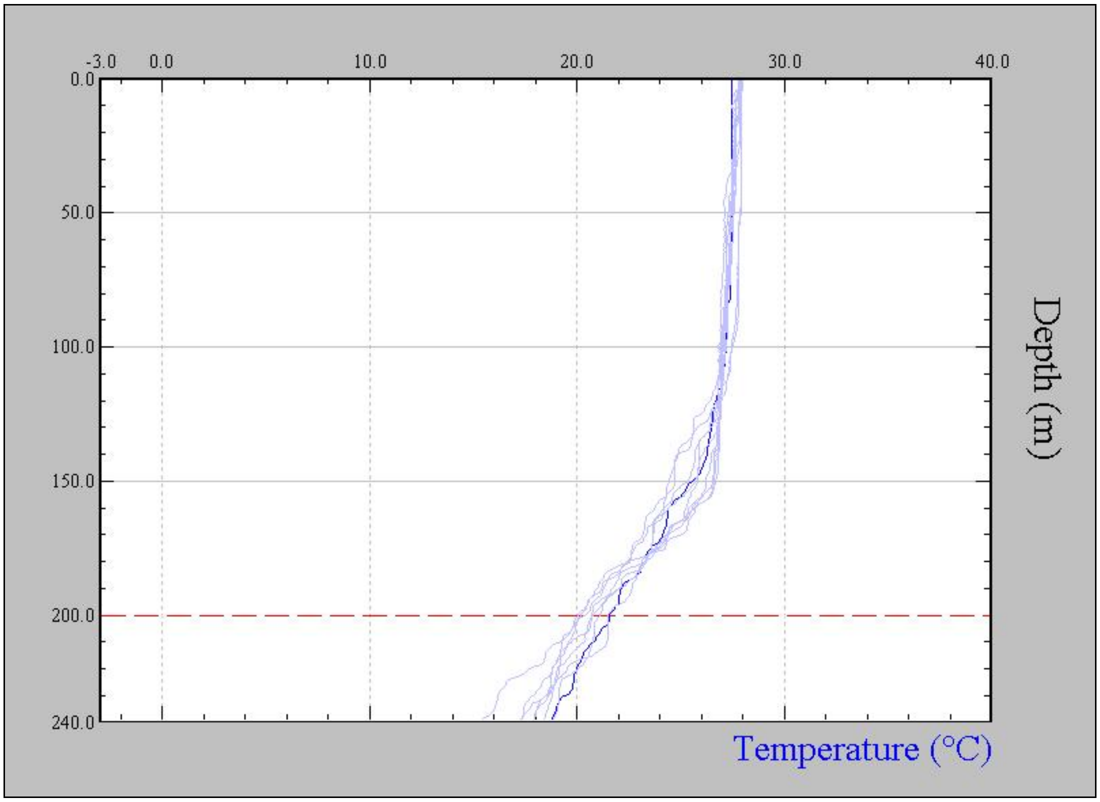

Figure C-24. Leg Four XBT drops 218 – 230

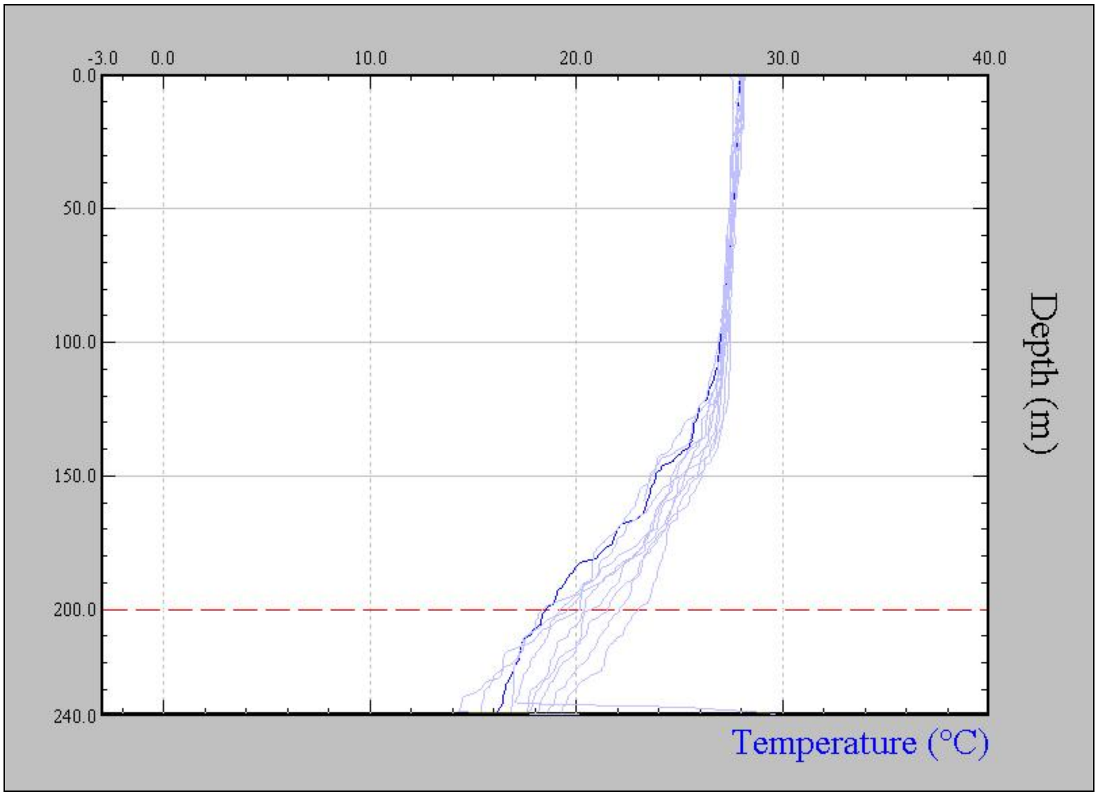

Figure C-25. Leg Four XBT Drops 231 – 241

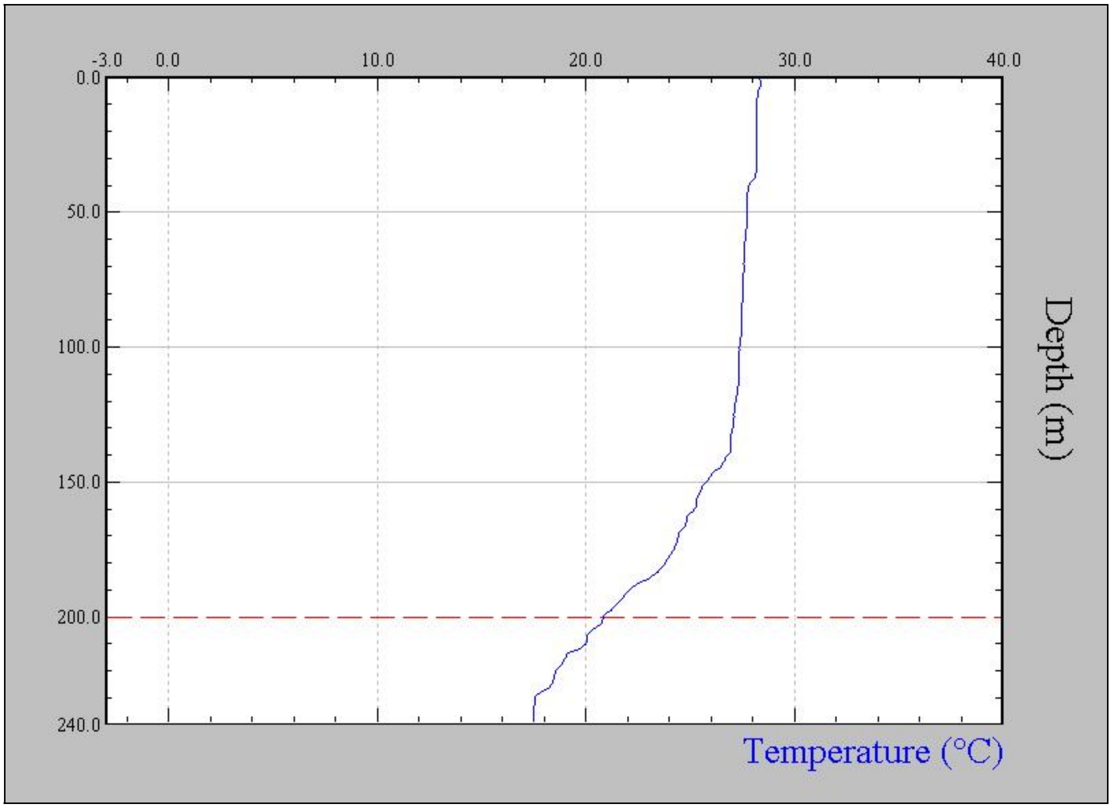

Figure C-26. Leg Four XBT Drops 242

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APPENDIX D FINAL CRUISE REPORT

See following document.

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