CC Range Bottom Mapping and Habitat Characterization

Final Cruise Report

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Abbreviations and Acronyms

ASCII American Standard Code for Information Interchange
AUTEC Atlantic Undersea test and Evaluation Center
BASE Bathymetry Associated with Statistical Error
BPI Bathymetric Position Index
BSURE Barking Sands Underwater Range Expansion
BTM Benthic Terrain Modeler
CC Charlie Charlie Range
C-CASS II Cable operated Camera and Sampling System II
CD compact disc
cf confirmation (taxonomic term used when an identification has not been confirmed)
cm centimeters
CO-OPS NOAA Center for Operational Oceanographic Products and Services
CORS Continually Operating Reference Station
COTS Commercial Off The Shelf
CSF Common Sensor Format (Chesapeake SonarWiz.MAP format)
CSV Comma Separated Values (text file format)
CTD Conductivity, Temperature, and Depth
CTO Contract Task Order
DB decibel
DGPS Differential Global Positioning System
EFH Essential Fish Habitat
FOL Field Operations Lead (Tetra Tech)
GAMS GPS Azimuth Measurement Subsystem
GAPS Global Acoustic Positioning System
GIS Geographic Information System
GPS Global Positioning System
HAPC Habitat Area of Particular Concern
<table>
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<th>Abbreviation</th>
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<tbody>
<tr>
<td>HCM</td>
<td>Hard Coral Mound</td>
</tr>
<tr>
<td>HIPS</td>
<td>Hydrographic Information Processing System</td>
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<tr>
<td>Hz</td>
<td>hertz</td>
</tr>
<tr>
<td>IHO</td>
<td>International Hydrographic Organization</td>
</tr>
<tr>
<td>IMU</td>
<td>Inertial Measurement Unit</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>JAX</td>
<td>Jacksonville</td>
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<tr>
<td>kHz</td>
<td>kilohertz</td>
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<td>km</td>
<td>kilometer</td>
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<td>knots</td>
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<td>LARS</td>
<td>Launch and Recovery System</td>
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<td>millisecond</td>
</tr>
<tr>
<td>MBE</td>
<td>Multibeam Echosounder</td>
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<tr>
<td>MEC</td>
<td>Munitions and Explosives of Concern</td>
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<tr>
<td>MLLW</td>
<td>mean lower low water</td>
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<tr>
<td>MPA</td>
<td>Marine Protected Area</td>
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<tr>
<td>mwd</td>
<td>meters water depth</td>
</tr>
<tr>
<td>N</td>
<td>North</td>
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<tr>
<td>NAVFAC Atlantic</td>
<td>Naval Facilities Engineering Command Atlantic</td>
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<tr>
<td>Navy</td>
<td>Department of the Navy</td>
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<tr>
<td>NE</td>
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<tr>
<td>NEXRAD</td>
<td>Next Generation Radar</td>
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<tr>
<td>NGS</td>
<td>National Geodetic Survey</td>
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<tr>
<td>NM</td>
<td>Nautical Mile</td>
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<tr>
<td>NMEA</td>
<td>National Marine Electronics Association</td>
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<tr>
<td>NNE</td>
<td>North-northeast</td>
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<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
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<tr>
<td>NOS</td>
<td>National Ocean Service</td>
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<tr>
<td>NTR</td>
<td>Navy Technical Representative</td>
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<tr>
<td>NUWC</td>
<td>Naval Undersea Warfare Center</td>
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<tr>
<td>NWUC</td>
<td>Northwest Underwater Construction</td>
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<tr>
<td>OMG</td>
<td>Ocean Mapping Group</td>
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<tr>
<td>OPAREA</td>
<td>Operating Area</td>
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<tr>
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<td>Definition</td>
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<tr>
<td>PDF</td>
<td>Portable Document Format</td>
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<tr>
<td>POM</td>
<td>Particulate Organic Matter</td>
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<tr>
<td>POS</td>
<td>Applanix POS MV 320/MV 320</td>
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<td>PPP</td>
<td>Precise Point Positioning</td>
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<td>Quality Assurance</td>
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<td>Quality Control</td>
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<tr>
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<td>Reflector 1</td>
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<tr>
<td>ROV</td>
<td>Remotely Operated Vehicle</td>
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<tr>
<td>RMS</td>
<td>Root Mean Square</td>
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<tr>
<td>RTCM</td>
<td>Radio Technical Commission for Maritime Services</td>
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<tr>
<td>R/V</td>
<td>Research Vessel</td>
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<td>SAFMC</td>
<td>South Atlantic Fishery Management Council</td>
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<td>s</td>
<td>seconds</td>
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<tr>
<td>SBE</td>
<td>Seabird Electronics</td>
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<tr>
<td>SOAR</td>
<td>Southern California Anti-Submarine Warfare Range</td>
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<tr>
<td>SS</td>
<td>Soft Substrata</td>
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<tr>
<td>SSW</td>
<td>South-Southwest</td>
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<tr>
<td>TMS</td>
<td>Tether Management System</td>
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<td>TT</td>
<td>Tetra Tech</td>
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<tr>
<td>UCTD</td>
<td>Underway CTD</td>
</tr>
<tr>
<td>USBL</td>
<td>Ultra Short Acoustic Baseline</td>
</tr>
<tr>
<td>USCG</td>
<td>United States Coast Guard</td>
</tr>
<tr>
<td>USWTR</td>
<td>Undersea Warfare Training Range</td>
</tr>
<tr>
<td>UTC</td>
<td>Coordinated Universal Time</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Transverse Mercator</td>
</tr>
<tr>
<td>VCF</td>
<td>Vessel Configuration File</td>
</tr>
<tr>
<td>VHF</td>
<td>Very High Frequency</td>
</tr>
<tr>
<td>XBT</td>
<td>Expendable Bathythermograph</td>
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<td>Expendable CDT</td>
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1.0 INTRODUCTION

The Department of the Navy (Navy) requires benthic habitat characterization in an area within the Jacksonville Operating Area (JAX OPAREA), designated the CC Range, where FIREX and GUNEX exercises have been conducted and are planned. During the FIREX exercises, non-explosive practice munitions (NEPMs) and high explosive ordnance (HE) will be used. Bathymetry and bottom habitat data will enable the Navy to assess the impact of these military exercises on the benthic environment.

Tetra Tech was awarded a task order through the Naval Facilities Engineering Command (NAVFAC) Atlantic to conduct hydrographic and ground truthing surveys and seabed characterization to facilitate the Navy’s efforts. The primary focus of the survey was to identify areas of hard bottom within the range. The information included within this final survey report addresses data collection and processing, the interpretation methods used, and presents the results of the survey.
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2.0 SYSTEM MOBILIZATION AND SETUP

The CC Range mobilization and survey efforts were conducted in two phases: (1) the hydrographic survey, comprising multibeam echosounder data acquisition, and (2) the ground-truthing survey, comprising digital still and video imagery acquisition on specified targets.

2.1 SURVEY VESSEL

Survey operations were conducted from the Research Vessel (R/V) White Holly, a high endurance, expedition vessel equipped for offshore deepwater survey operations (Figure 2.1-1). Mobilization of the survey vessel, which is 41 m in length, has a beam of 9 m and draws 3 m of water, was conducted at the Marine Group Boat Works in Chula Vista, CA and at Atlantic Marine’s Southeast Coast facility in Jacksonville, FL. Mobilization efforts in Chula Vista included modification and extension of the vessel’s stern to include an aft deck with a cutout gunnel on the stern, A-frame, hydraulics, and hydraulic rams. Communications cables were also routed through the vessel’s hull for a RESON SeaBat 7125-SV multibeam system, a Seabird 37 MicroCat conductivity and temperature sensor, and an IXSEA GAPS (GAPS) ultra short acoustic baseline (USBL) positioning system. The mobilization efforts in Chula Vista were conducted between 29 October and 06 November 2009, those in Jacksonville between 03 and 08 December 2009.

![Survey Vessel](image)

Figure 2.1-1: Survey Vessel

2.2 WEATHER MONITORING SENSORS

Weather conditions were monitored by the survey vessel captain and crew throughout the project via the National Weather Service very high frequency (VHF) broadcast and by Tetra Tech with a XM WX satellite weather system which was installed on the survey vessel during mobilization efforts in Jacksonville, FL in early December. The XM satellite weather system provided high resolution next generation radar (NEXRAD), surface wind speed and direction, satellite imagery, buoy data, sea surface temperature data, as well as forecasts for surface pressure, wave direction,
wave period, surface wind, and wave height. The XM satellite weather was displayed in real-time on Tetra Tech’s computer work stations in the survey control van.

Monitoring of weather conditions was not required as part of the project scope of work however the work plan specified that the limit for the collection of valid multibeam data was at Sea State Condition 5, (minimum wind speed of 17 knots and minimum mean wave height of 2 m). The Work Plan specified that if these conditions were encountered, the decision to suspend the survey and return to port would be made by Tetra Tech in consultation with the onboard Navy Technical Representatives (NTR) and vessel Captain (Table 2.2-1). The Work Plan also stated that if the safety of the vessel and crew were not at risk, as agreed upon by the Tetra Tech Field Operations Lead (FOL), the lead NTR and the vessel Captain, and the bathymetry were found to meet or exceed project specifications (as observed and agreed to by the Tetra Tech FOL and the lead NTR), the survey could continue under a change condition at and beyond Sea State 5.

Due to the persistence of adverse weather conditions encountered during CC Range survey operations in December, and the potential effect of these conditions on survey operations, production rates and data quality, Tetra Tech installed additional weather monitoring and recording systems to document conditions that were encountered throughout the remainder of survey and ground-truthing operations.

Two anemometers were installed above the wheelhouse on the survey vessel to provide real time and vessel specific wind speed, wind direction, and barometric pressure data (Figure 2.2-1). The RM Young Marine Wind Monitor, an accurate and reliable wind sensor specifically designed for the marine environment, measured wind speed and wind direction to an accuracy of +/- 0.3 meters per second and +/- 3 degrees, respectively. These data were displayed in the survey control van and logged. A Davis 6250 VantageVue Wireless Weather Station provided barometric pressure and temperature, as well as wind speed and wind direction updates, every 2.5 seconds (s) to a display console mounted in the survey control van. After being installed on the vessel on 25 January 2010 (RM Young Marine Wind Monitor) and 18 December 2009 (Davis 6250), these data were also logged during survey operations to document the weather conditions which were encountered.
Table 2.2-1: The Beaufort Wind Scale

<table>
<thead>
<tr>
<th>Beaufort Number</th>
<th>Knots</th>
<th>International Description</th>
<th>Effects Observed on Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Under 1</td>
<td>Calm</td>
<td>Sea like a mirror</td>
</tr>
<tr>
<td>1</td>
<td>1–3</td>
<td>Light air</td>
<td>Ripples with appearance of scales; no foam crests</td>
</tr>
<tr>
<td>2</td>
<td>4–6</td>
<td>Light breeze</td>
<td>Small wavelets; crests of glassy appearance, not breaking</td>
</tr>
<tr>
<td>3</td>
<td>7–10</td>
<td>Gentle breeze</td>
<td>Larger wavelets; crests begin to break, scattered whitecaps</td>
</tr>
<tr>
<td>4</td>
<td>11–16</td>
<td>Moderate</td>
<td>Small waves 0.5–1.25 meters high, becoming longer; numerous whitecaps</td>
</tr>
<tr>
<td>5</td>
<td>17–21</td>
<td>Fresh</td>
<td>Moderate waves of 1.25–2.5 meters high taking longer to form; many white caps; some spray</td>
</tr>
<tr>
<td>6</td>
<td>22–27</td>
<td>Strong</td>
<td>Larger waves 2.5–4 meters high forming; whitecaps everywhere; more spray</td>
</tr>
<tr>
<td>7</td>
<td>28–33</td>
<td>Near gale</td>
<td>Sea heaps up, waves 4–6 meters; white foam from breaking waves begins to blow in streaks</td>
</tr>
<tr>
<td>8</td>
<td>34–40</td>
<td>Gale</td>
<td>Moderately high (4–6 meters) waves of greater length; edge of crests begin to break into spindrift; foam is blown in well marked streaks</td>
</tr>
<tr>
<td>9</td>
<td>41–47</td>
<td>Strong gale</td>
<td>High waves (6 meters); sea begins to roll; dense streaks of foam; spray may reduce visibility</td>
</tr>
<tr>
<td>10</td>
<td>48–55</td>
<td>Storm</td>
<td>Very high waves (6–9 meters) with overhanging crests; sea takes a white appearance as foam is blown in very dense streaks; rolling is heavy and visibility is reduced</td>
</tr>
<tr>
<td>11</td>
<td>56–63</td>
<td>Violent Storm</td>
<td>Exceptionally high (9–14 meters) waves; sea covered with white foam patches; visibility still more reduced</td>
</tr>
<tr>
<td>12</td>
<td>64–71</td>
<td>Hurricane</td>
<td>Air filled with foam; waves over 14 meters; sea completely white with driving spray; visibility greatly reduced</td>
</tr>
</tbody>
</table>
2.3 HYDROGRAPHIC AND GEOPHYSICAL SURVEY SETUP

Mobilization of the vessel in Jacksonville, FL for the CC Range and USWTR hydrographic and geophysical surveys included the installation, with the exception of the RESON SeaBat 7150-F testing, and calibration of all required systems and software. This included installation and connection of the SeaBat 7125-SV and the GAPS, via divers, to the cables which were routed in Chula Vista. A diagram showing the instruments comprising the survey system is provided below in Figure 2.3-1.

Equipment mobilized for Tetra Tech hydrographic survey operations on the CC Range project are presented in Table 2.3-1; additional system performance specifications are provided in Appendix A.
### Table 2.3-1: Survey Equipment Mobilized for CC Range Survey

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Manufacturer and Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multibeam Sonar</td>
<td>RESON SeaBat 7125-SV</td>
</tr>
<tr>
<td>Multibeam Sonar</td>
<td>RESON SeaBat 7150-F</td>
</tr>
<tr>
<td>Single-Beam Echosounder</td>
<td>RESON NaviSound 640</td>
</tr>
<tr>
<td>Motion Sensor</td>
<td>Applanix POS MV 320</td>
</tr>
<tr>
<td>Heading</td>
<td>Applanix POS MV 320</td>
</tr>
<tr>
<td>Primary Position</td>
<td>Applanix POS MV 320 with U.S. Coast Guard RTCM correction input from Trimble Ag132</td>
</tr>
<tr>
<td>Auxiliary Position</td>
<td>U.S. Coast Guard beacon-corrected Trimble Ag132</td>
</tr>
<tr>
<td>USBL Positioning System</td>
<td>IXSEA GAPS</td>
</tr>
<tr>
<td>Sound Speed Profilers and Sensors</td>
<td>Oceanscience Underway CTD (UCTD), Lockheed Martin Sippican T5 XBT, RESON SVP 70, Seabird SBE 19, and Seabird MicroCAT 37</td>
</tr>
</tbody>
</table>
This page intentionally left blank
2.3.1 Multibeam Echosounder and Ancillary Sensors

The survey vessel was equipped with two multibeam echosounder (MBE) systems and a single-beam echosounder system. Both multibeam systems were configured to acquire bathymetry snippets data in addition to bathymetry data. The primary sonar systems were the SeaBat 7125-SV and SeaBat 7150-F. The secondary system was a RESON NaviSound 640 (NaviSound 640) dual frequency, single-beam echosounder (SBE).

The SeaBat 7150-F MBE array was mounted to the vessel via a steel gondola welded directly to the hull (Figure 2.3-2). The gondola acted as a protective housing and hydrodynamic fairing for the sonar. The SeaBat 7150-F was installed during mobilization and haul-out of the vessel in May 2009 for a Naval Undersea Warfare Center (NUWC) Barking Sands Underwater Range Expansion (BSURE) project. During this haul out the SeaBat 7150-F gondola, which houses the sonar’s projector and receiver arrays, was attached to the hull of the vessel.

The SeaBat 7125-SV, along with the GAPS, were mounted adjacent to the SeaBat 7150-F on the aft end of the gondola. Cables for the multibeam arrays, single beam transducer, GAPS, and sound-speed sensors were routed through the hull via dry fittings.

![Figure 2.3-2: Gondola and the RESON SeaBat 7150-F (in blue) installed on Survey Vessel](image)

The SeaBat 7125-SV is a dual-frequency 200 / 400 kHz system which ensonifies a 128-degree swath (64 degrees to starboard and 64 degree to port). For this project the SeaBat 7125-SV sonar was operated at a frequency of 400 kHz. The swath consisted of either 256 or 512 (user-selectable) individual beams that were 0.54 degree (across-track) by 1.0 degree (along-track) at nadir. The SeaBat 7125-SV, with a 400 kHz projector array, measured a swath width of up to approximately 4 times water depth, in depths up to approximately 100 meters. The maximum update rate of the system was 50 Hz (50 pulses per second). A summary of the SeaBat 7125-SV 400 kHz beam footprint within the range of water depths observed is provided in Table 2.3-2 below.
Table 2.3-2: Estimated Beam Footprint Dimensions for the SeaBat 7125-SV 400 kHz

| RESON SeaBat 7125-SV Footprint Size in Meters (Across x Along Track)1/ | Beam Width (0.5°x1°)2/ |
|---|---|---|
| Depth (m) | Nadir | ±60° |
| 25 | 0.2 x 0.4 | 1.8 x 0.9 |
| 50 | 0.4 x 0.9 | 3.5 x 1.7 |
| 75 | 0.7 x 1.3 | 5.2 x 2.6 |
| 100 | 0.9 x 1.7 | 7.0 x 3.5 |
| 200 | 1.7 x 3.5 | 14.0 x 7.0 |

Notes:
1. All calculations are based on the assumption that the bottom is flat.
2. As the distance from nadir increases, the sounding footprints change from elliptical, elongated along-track, to elliptical, elongated across-track.
3. Calculations for the 400 kHz projector array.

The gondola-mounted SeaBat 7150-F multibeam system was used in water depths beyond the optimal operating depths of the 400 kHz array on the SeaBat 7125-SV. The SeaBat 7150-F sonar is a dual frequency 12/24 kHz system that was operated at the 24 kHz setting, with a nadir beamwidth 1 degree by 1 degree at nadir for this project. At the 24-kHz frequency setting, the system is capable of survey to water depths of approximately 3,000 meters. A summary of the SeaBat 7150-F 24 kHz beam footprint within the range of water depths observed is provided in Table 2.3-3 below.

Table 2.3-3: Estimated Beam Footprint Dimensions for the SeaBat 7150-F 24 kHz

| RESON SeaBat 7150-F Footprint Size in Meters (Across x Along Track)1/ | Beam Width (1°x1°)2/ |
|---|---|---|
| Depth (m) | Nadir | ±60° |
| 50 | 0.9 x 0.9 | 3.5 x 1.7 |
| 100 | 1.8 x 1.8 | 7.0 x 3.5 |
| 200 | 3.5 x 3.5 | 14.0 x 7.0 |
| 250 | 4.4 x 4.4 | 17.5 x 8.7 |
| 500 | 8.7 x 8.7 | 34.9 x 17.5 |
| 750 | 13.1 x 13.1 | 52.4 x 26.2 |

Notes:
1. All calculations are based on the assumption that the bottom is flat.
2. As the distance from nadir increases, the sounding footprints change from circular to elliptical.
3. Calculations for the 24 kHz array.

Both MBE systems were interfaced with the motion reference unit and a sound velocity profiler for real-time beam steering and depth gate corrections. Operating parameters, such as transmit power, receive gain and ping rate, were set and monitored by the operator at the processor console to provide optimal bathymetric data quality.

An Applanix POS MV 320 (POS) position, heading, and motion sensor system and a Trimble Ag132 Differential Global Positioning System (DGPS) were utilized onboard the survey vessel
for vessel positioning and orientation. The POS integrates two dual frequency Global Positioning System (GPS) antennas and an Inertial Measurement Unit (IMU) to provide a continuous output of vessel position and orientation data. The system provides measurements of roll, pitch, and heading accurate to ±0.02 degrees and real-time heave measurements at an accuracy of 5 percent of the measured vertical displacement or ±5 centimeters (cm), whichever is greater, for swell periods of 20 seconds (s) or less (Applanix, 2009).

An auxiliary Trimble Ag132 DGPS system provided a U.S. Coast Guard Radio Technical Commission for Maritime Services (RTCM) differential correction data stream to augment the POS system. This typically enables the system to increase its positioning value to less than 2.0 m root mean square (RMS). The Ag132 received differential beacon transmittals from the nearest U.S. Coast Guard Continually Operating Reference Station.

The vessel’s motion and position data were supplied from the POS system to the acquisition system at 50 hertz (Hz) and 5 Hz, respectively. The POS also provided the 1 Hz National Marine Electronics Association’s (NMEA) time and date message (ZDA)/pulse per second message to synchronize the entire collection system to a common time reference. The POS and Ag132 antennas were positioned approximately amidships fore and aft on the survey vessel (Figure 2.3-3). The POS IMU was positioned below decks in cargo hold number two, approximately amidship, 0.6 m above the waterline and 3.1 m above the SeaBat 7150-F arrays (Figure 2.3-4).
2.3.2 C-CASS II and ROV Positioning

A GAPS acoustic positioning system was used to track the Cable operated Camera and Sampling System II (C-CASS II) and the remotely operated vehicle (ROV) used during ground-truthing operations. This system was comprised of a combined GPS aided inertial platform and hydrophone array, mounted on the gondola adjacent to the SeaBat 7125-SV, and a transponder/responder beacon that was attached to the underwater system being tracked. The system was mounted to the survey vessel’s hull in a configuration similar to that depicted in Figure 2.3-1 and shown below in Figure 2.3-5. The platform measured position, heading, roll, pitch, and heave to independently determine its position and attitude.

Figure 2.3-5: IXSEA GAPS USBL System Installed on Survey Vessel
2.3.3 Sound Speed Profiles

The following conductivity, temperature, and depth (CTD) and sound speed devices were mobilized and utilized for this project: a SeaBird Electronics SBE MicroCAT 37, a RESON SVP-70, an Oceanscience Underway CTD (UCTD), Sippican Expendable Bathythermographs (XBTs), and a SBE-19 (spare).

The SBE MicroCAT 37 was interfaced with the Seabat 7125-SV to provide sound speed measurements at the MBE transducer. The Seabat 7150-F was interfaced with two RESON SVP-70 velocimeters which are permanently mounted to the SeaBat 7150-F gondola. These sound speed measurements in real time aid in electronic beam steering during acquisition.

A combination of UCTD and XBT measurements were used to compute accurate sound velocity profiles that were applied to the data in post-processing. The UCTD was initially mounted on the vessel’s lower port aft deck and later moved to the upper deck to free up deck space and increase safety by increasing the separation between the point of deployment and recovery and the UCTD’s sheave (Figure 2.3-6); the XBT’s were typically launched just below the UCTD winch, off the stern. These devices were deployable while the ship was underway and did not typically restrict ship mobility, minimizing the time required to perform measurements. The XBT measurements were used to calculate sound speed using the conductivity/salinity data from the UCTD casts. Surface water sound speeds were monitored by the multibeam watch stander in real time. Due to the proximity of the survey area to the Gulf Stream, which could significantly affect the sound speed profile, frequent sound speed casts were performed during the survey. The sounds speed cast schedule is discussed further in Section 3.2. The data collection software was monitored by the sonar operator for significant changes in sound speed at the sonar head, which would indicate a need for an additional cast. During the survey, the obtained sound speed profiles were analyzed to try to determine areas and times where the profiles were more dynamic and additional casts were required to adequately compensate the multibeam bathymetry data. This information was used to determine the locations and frequencies for subsequent casts. Frequency of casts was adjusted, as needed, to maintain survey accuracies.
2.3.4 Interconnections

Figure 2.3-7 shows the communications setup for the devices that constituted the hydrographic and geophysical survey system used for the CC Range and USWTR surveys.
Figure 2.3-7: Equipment Mobilized for CC Range and USWTR Survey Operations
2.3.5 Systems Offsets

Device offsets were precisely defined for the multibeam sonar, attitude sensor, and GPS antennas, so that the real-time collection and post-processing systems could accurately convert the input sonar and support sensor data directly into geo-referenced XYZ coordinates.

Offsets for the SeaBat 7150-F and ancillary sensors (POS and Ag132) were determined during the survey vessel mobilization haul-out in May 2009 for a NUWC BSURE project. Upon completion of the installation of the SeaBat 7150-F and support systems installation, the sensor offsets were surveyed by Civil Consulting Group, Inc., a professional land surveyor. A total station, an instrument used in modern surveying to measure distances and angles between points using a combination of laser range finding and precise vertical and horizontal angle measurements, was used to determine the offsets between the acoustic centers of the sonars, the position of the POS IMU and IMU mount plate, all GPS antennas, and a number of other reference points on the ship. The roll and pitch of the POS MV were recorded to provide the basis for rotating the offsets into the inertial frame of the motion sensor (BSURE 2009). Verification was performed during the GPS Azimuth Measurement System (GAMS) calibration of the POS systems.

Prior to survey operations in the CC Range, the survey vessel was hauled out in Chula Vista, CA to install the A-frame and to route cables for the 400 kHz SeaBat 7125-SV multibeam sonar and the GAPS systems. During this haul out period the offsets for the SeaBat 7125-SV and GAPS were again surveyed by professional land surveyors provided by Civil Consulting Group, Inc. to determine the offsets between the acoustic centers of these sensors to the POS IMU, the established point of reference already determined on the ship. Installation offsets for the multibeam arrays and support sensors were entered in the data collection and processing software.

2.3.5.1 POS MV IMU Offsets

The POS was used as the point of reference for the survey vessel in the along-ship, across-ship, and vertical axes. The POS offsets are shown in Table 2.3-4. The POS offsets were verified using Applanix POS MV’s POSPac software, which confirmed measurements within 0.01 m. This verification process is described in detail in Section 3.1 of Appendix B2.

<table>
<thead>
<tr>
<th>Antenna</th>
<th>Across ship (stbd +) (m)</th>
<th>Along ship (fwd +) (m)</th>
<th>Vertical (down +) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary POS Zephyr GPS Antenna</td>
<td>-2.256</td>
<td>-7.137</td>
<td>-9.101</td>
</tr>
<tr>
<td>Auxiliary GPS (Trimble Ag132 Antenna)</td>
<td>-0.931</td>
<td>-7.143</td>
<td>-9.101</td>
</tr>
<tr>
<td>Secondary POS Zephyr GPS Antenna Baseline Vector (from Primary GPS Antenna)</td>
<td>2.842</td>
<td>0.037</td>
<td>-0.064</td>
</tr>
</tbody>
</table>

Note: Measured from IMU unless otherwise noted.
2.3.5.2 **HYPACK/HYSWEEP and CARIS HIPS Offsets**

Table 2.3-5 shows the offsets measured in meters, which were used for the HYPACK and HYSWEEP hardware setup and in the CARIS vessel configuration file. These offsets were measured relative to the POS.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Acrossship (stbd +) (m)</th>
<th>Alongship (fwd +) (m)</th>
<th>Vertical (down +) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESON SeaBat 7125-SV</td>
<td>-0.24</td>
<td>1.15</td>
<td>3.39</td>
</tr>
<tr>
<td>RESON SeaBat 7150-F</td>
<td>-0.083</td>
<td>5.068</td>
<td>3.116</td>
</tr>
<tr>
<td>Motion/Position Sensor</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>(Applanix POS MV)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RESON NaviSound 640</td>
<td>-0.08</td>
<td>7.59</td>
<td>3.11</td>
</tr>
<tr>
<td>transducer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IXSEA GAPS USBL</td>
<td>0.48</td>
<td>0.01</td>
<td>3.29</td>
</tr>
</tbody>
</table>

2.3.6 **Geodesy and Tide Settings**

Positional data for the project were referenced using Universal Transverse Mercator (UTM) Zone 17 North. The vertical datum was mean lower low water (MLLW) Tidal Epoch 1983–2001. Both horizontal and vertical units were measured in meters. The HYPACK acquisition software provided the real-time datum conversion from the World Geodetic System 1984 coordinates to UTM during the survey.

Preliminary tide modeling, performed while the offshore survey was on-going, was initially supplied by the National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS). Eight tide zones covering the survey area were defined for NOAA tidal zoning; these same zones were used with the global hydrodynamic model discussed below (Figure 2.3-8). Comparisons between the NOAA tides and a global hydrodynamic tidal model (FES2004) indicated that the global model provided more consistent data and resulted in less vertical separation between adjacent overlapping survey lines. As a result the global tidal model (FES2004) replaced the NOAA predictions for the remainder of the offshore survey. This model was also used to develop draft charts and data provided in the Draft version of this Cruise Report.

The global hydrodynamic tidal model was used to construct a predicted tide series for each of the tidal zones. The model is entitled FES2004 and incorporates tidal amplitude and phase predictions for 15 tidal constituents over a 1/8° grid, which covers the entire world's oceans (Lyard *et al.*, 2006). WebTide Global Data are available from Fisheries and Oceans Canada.

A predicted tidal time series was constructed for the duration of the survey within each of the tidal zones. The amplitude and phase for each of nine tidal constituents included with the model within each zone was interpolated from the mesh. To convert the predicted tidal time series to a predicted water level, barometric pressure data from the Davis anemometer on the survey vessel, when available, was converted to a change in water level using the inverse barometer effect.
(Wunsch and Stammer, 1997). A comparison between NOAA and global hydrodynamic tidal models is provided in Appendix B-1.

To further improve and refine the tidal data for the project Tetra Tech recommended and the Navy approved use of Precise Point Positioning (PPP) navigation post-processing technique. This method, which is described in detail in Section 3.3.4 and in Appendix B-2, was used to produce the Final charts for the project.

![Figure 2.3-8: Tidal Zones Used in the NOAA and Global Hydrodynamic Tide Models](image)

2.4 **GROUND TRUTHING MOBILIZATION AND SETUP**

Equipment required for ground-truthing operations in the CC Range, including a remotely operated vehicle (ROV) and a C-CASS II seabed imaging system, were mobilized between 30 April and 05 May 2010 upon completion of multibeam survey activities. A formal review of acquired multibeam data and the selection of the proposed ground truthing locations were conducted by Tetra Tech and Navy representatives on 20 and 21 April 2010, at the Tetra Tech office in Bothell, WA.

Equipment mobilized for seabed imaging operations in the CC Range project area are presented in Table 2.4-1 and discussed below. Equipment specification sheets are presented in Appendix A of this report.
Table 2.4-1: Ground Truthing Equipment

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Manufacturer and Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Still / Digital Video Cameras</td>
<td>C-CASS II</td>
</tr>
<tr>
<td>ROV Digital Still / Digital Video Cameras</td>
<td>Sub-Atlantic Mohican Inspection Class ROV</td>
</tr>
</tbody>
</table>

2.4.1 C-CASS II

The C-CASS II seabed imaging platform was deployed for the CC Range ground-truthing survey using the survey vessel’s A-Frame, high speed winch and coaxial cable which had previously been utilized for sub-bottom profiler towfish operations during the geophysical survey in USWTR. The C-CASS II was equipped with a color digital still camera and a color digital video camera (Figure 2.4-1). The petite ponar grabs samplers installed on the C-CASS II were not used in the CC Range due to safety concerns associated with the possibility of encountering munitions and explosives of concern (MEC). Positioning for the C-CASS II was provided by the GAPS system mobilized previously for USWTR geophysical survey operations.

Figure 2.4-1: C-CASS II Mobilized on the Aft Deck of the Survey Vessel
2.4.2 ROV Installation and Setup

The Inspection Class Mohican ROV system, provided by Northwest Underwater Construction, was deployed for ground-truthing operations. The ROV system, including operations container, and launch and recovery system (LARS; comprised of the A-Frame and winch) was installed amidships on the survey vessel during the ground-truthing mobilization. The control components for the ROV were located in an International Organization for Standardization (ISO) control container installed on the fore deck of the survey vessel. The cage tether management system (TMS), including the ROV, was deployed off the ship’s starboard side and was operated in “live boating mode” in order to maneuver in the high current environment of the Gulf Stream. Figure 2.4-2 shows the components of the ROV system.

The ROV was equipped with a color digital video camera for continuous recording throughout the dive and a color digital still camera that was triggered on command by the surface operators for documenting particular features of interest. An additional down-looking black and white video camera and a color video feed from the still camera were also recorded. A Tritech altimeter and Mk2 scaling laser were also installed on the ROV. Inclusion of a scaling laser was not required by the Navy scope of work or the project Work Plans, however Tetra Tech provided the laser and had Northwest Underwater Construction install it onto the ROV with the objective of providing measurement capabilities within the video and still photographs; the distance between the laser points was 10 cm. Addition of supplementary lights to the ROV made the laser more difficult to see and, depending on range to target, water clarity and target material, the laser was not always visible.

Positioning and tracking of the ROV was conducted using the GAPS and a transponder beacon installed on the ROV.
Figure 2.4-2: ROV LARS (left) and TMS (right)
3.0 CC RANGE SURVEY DATA ACQUISITION AND PROCESSING

The CC Range survey mapped approximately 754 square kilometers (km$^2$) of seabed across the shelf break in water depths ranging from 40 to 679 m. The survey area, situated on the continental shelf and upper Florida-Hatteras Slope was located approximately 64 kilometers (km) east of Mayport, FL (Figure 3.0-1).

Bathymetry data were collected using a Seabat 7125-SV in water depths ranging from approximately 40 to 100 m and a SeaBat 7150-F between approximately 100 and 679 mwd (Appendix C, Chart 1). Multibeam bathymetry data were collected along 119 main lines and 5 crosslines (Appendix C, Chart 2).

Figure 3.0-1: Task Order 0029 Project Area (in blue)
3.1 PROJECT SCHEDULE

Mobilization of the survey vessel for bottom mapping and habitat characterization survey operations in the CC Range was conducted between 03 and 08 December 2009 (see Section 2 for details). Offshore survey operations for the CC Range bottom mapping and habitat characterization survey were conducted between 08 and 16 December 2009. Data holidays were filled on 08 and 09 April 2010 following the completion of USWTR bottom mapping efforts.

Ground truthing activities were performed at discrete locations within the project area following the completion of bathymetry acquisition. The ROV dive and C-CASS II deployment sites were selected and approved by representatives from the Navy and Tetra Tech during a meeting held at the Tetra Tech Bothell, WA office on 20 and 21 April 2010, during which the post-survey data were reviewed. Ground-truthing operations, including ROV dives and deployments with the C-CASS II camera system, were conducted between 05 and 24 May 2010.

A detailed project and survey schedule summary is provided in Table 3.1-1.
### Table 3.1-1: Summary of Task Order 0029 Operations

<table>
<thead>
<tr>
<th>Task</th>
<th>Start Date</th>
<th>End Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task A</td>
<td>1/1/2011</td>
<td>1/31/2011</td>
<td>Activity 1</td>
</tr>
<tr>
<td>Task D</td>
<td>4/1/2011</td>
<td>4/30/2011</td>
<td>Activity 4</td>
</tr>
</tbody>
</table>

**Notes:**
- Task A was completed ahead of schedule.
- Task B encountered unexpected delays.
- All tasks were completed within the originally planned duration.

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January 14, 2011
3.2 Data Quality Assurance/Quality Control Methodology

To ensure that the data collected met the survey requirements, several quality assurance (QA) and quality control (QC) measures were implemented, including system confidence checks prior to the start of survey operations. These included position checks, lead lines, and comparisons between multiple systems and to preexisting data. The velocity of sound through the water column was derived from conductivity, temperature, and depth measurements (UCTD casts) and XBT casts. Sound velocity casts were conducted every 12 hours at a minimum, but frequency was increased, as necessary, at Tetra Tech’s discretion, to maintain survey accuracy requirements. Due to the proximity of the survey area to the Gulf Stream, which could significantly affect the sound speed profile, sound speed frequently exceeded several casts in a 12 hr period. A total of 71 UCTD and 96 XBT casts were conducted across the CC Range survey area and were applied to the multibeam data for sound speed corrections (Figure 3.2-1). Cast details are provided in Appendix D of this report. Spatial variability was taken into account as well as temporal variability when determining cast locations. These locations were recorded, and each cast was compared to the previous cast to identify any significant changes in the water column. Turns were limited and vessel speed was adjusted to ensure adequate seafloor ensonification. Tetra Tech performed cross lines totaling approximately 5 percent of the main scheme across the survey area to ensure the data met International Hydrographic Organization (IHO) standards.

![Sound Speed Profile](image)

**Figure 3.2-1: Speed of Sound Casts Collected In CC Range**
3.3  **Multibeam Echosounder Bathymetric Data Acquisition and Processing**

Multibeam echosounder bathymetry data acquisition operations were performed between 08 and 16 December 2009 and 08 and 09 April 2010. During these periods of time, survey operations were generally conducted 24 hours per day and 7 days per week, weather conditions allowing. Processing of the bathymetry data was performed in near real-time as the survey data collection was performed.

The approved Final Work Plan specified the sea state limitation for the collection of valid multibeam data at a Sea State Condition of 5 (minimum wind speed of 17 kts, minimum mean wave height of 2m). Due to the unusually adverse weather experienced in the winter of 2009-2010, these sea state conditions were encountered or exceeded more than 50% of the time that MBE surveys were conducted in December and April. As a result of these weather conditions, the quality of multibeam bathymetry and snippets imagery data were adversely affected. Although multibeam sonar data met or exceeded IHO Order 1a, raw bathymetry data and digital terrain models contained artifacts caused by excessive vessel motion that would not be present in data collected under lower sea state conditions. Additionally, elevated sea state conditions produced artifacts and increased “noise” in the snippets data (refer to Appendix E for additional details). Data acquired during inclement weather also required additional processing time to minimize the effects.

### 3.3.1 Acquisition System

HYPACK hydrographic software utilizing the HYSWEEP multibeam module was the multibeam/snippets acquisition system for the survey (Figure 3.3-1a and Figure 3.3-1b). The system provided precise time tagging of the sensors and data displays for QC by the multibeam operator as well as real-time vessel navigation information to the helmsman. The survey line plan and vessel tracks were displayed with the multibeam swath coverage during survey operations. These displays enabled the hydrographers to monitor vessel motion, data quality and MBE swath coverage in real time, throughout the survey.
Figure 3.3-1: HYPACK/HYSWEEP Acquisition Display: a) Left Screen b) Right Screen
3.3.2 Acquisition Procedure

A GAMS calibration and a MBE patch test were conducted on 08 December 2009 while the survey vessel transited to the CC Range project site prior to the start of MBE survey operations. These calibration efforts were applied to survey operations conducted in the CC Range. To minimize delays from vessel traffic, a local notice to mariners was issued through the U.S. Coast Guard to advise vessels of the survey operations. Vessel traffic was informed of the operations prior to leaving the dock.

The multibeam bathymetric and snippets data were logged in the HYPACK/HYSWEEP acquisition program. Hydrographers continuously monitored position and vessel orientation accuracies to ensure they remained within project specifications during acquisition. The sonar was adjusted to maximize signal return and coverage by adjusting the range, power, gain, and pulse width settings. Vessel speeds were adjusted to maintain a high signal-to-noise ratio and to meet IHO Order 1a standards.

During line turns and when the file size reached 100 MB, the data were transferred to the CARIS processing stations where the data were used to create preliminary sun-illuminated Bathymetry Associated with Statistical Error (BASE) surfaces for QA/QC analysis. A sun illuminated display models bright reflections and shadows in a digital terrain model based on slopes and a defined light source. This type of display tends to bring out much more detail in a displayed terrain model and highlights both terrain features and any data artifacts that may be present in the data.

3.3.3 Bathymetric Data Processing

Post-processing of the multibeam data was conducted utilizing CARIS hydrographic information processing system (HIPS) multibeam analysis and presentation software (Figure 3.3-2). Patch test data were analyzed and any alignment corrections were applied. Preliminary zoned water-level data were applied to adjust all measurements to MLLW. Sound velocity profiles were generated from UCTD/XBT measurements and used to correct slant range measurements and compensate for ray path bending.

Data processing consisted of navigation editing, attitude editing, swath editing, and subset editing. Navigation edits included reviewing the data for time jumps and removing abrupt vessel turns. Attitude data were reviewed for gaps and consistency. Depth filtering was used to eliminate large outliers in the water column; minimum and maximum values varied by survey area. If there was adequate coverage from neighboring swaths, across-track filters were also used to limit the swath’s outer beams.

Processing with the swath edit mode was used to remove the remaining fliers as well as unreliable soundings from down-sloping beams. Sounding data were reviewed and edited for data fliers from bottom multiples and noise due to aeration in the water column. These data points were flagged as rejected and were not used in the final data set. Sounding data were not eliminated and could be re-accepted during the subset editing process. Rejected data could also be re-accepted, if needed, to fill data gaps if they met accuracy standards based on comparisons to adjacent data.
The HIPS subset editor and BASE surface creation was the final phase of editing. Subset editing enables the hydrographer to evaluate each swath against its neighboring swath while identifying potential tidal and motion artifacts. The verification of feature alignment from adjacent swaths was used to confirm sensor offsets. BASE surfaces were created to identify systematic errors or artifacts within the data set and were used to create line plans in HYPACK to fill any data holidays (i.e., gaps). The BASE surfaces were analyzed with multiple resolutions, sun angles, sun azimuths, and vertical exaggerations to confirm data quality. The BASE surface routine produced images representing depth, shoal-biased depth, deep-biased depth, mean depth, standard deviation, sounding density, and depth uncertainty. During acquisition in the field, editing steps were expedited to create BASE surfaces to confirm adequate multibeam coverage for each survey area and to assess data quality. Comparative analysis included cross plan line depth comparisons with the newly collected data.

Final exported data from the BASE surfaces included ASCII XYZ text files and an ArcASCII Grid. A final analysis was performed on the depth surfaces with the HIPS QC Report and/or Fledermaus Pro software.

![Figure 3.3-2: CARIS Subset Editor](image)

### 3.3.4 Precise Point Positioning Bathymetric Data Processing

Precise Point Positioning is part of the POSPac post-processing software offered by Applanix, the provider of the POS MV position, heading, and attitude sensor used for the survey. Inertial sensor and GPS data collected during the survey are combined and processed with precise ephemerid data for the GPS satellites available from the National Geodetic Survey (NGS)
approximately two weeks after the original survey. A satellite's ephemeris is the position of the satellite with respect to time (i.e. a description of its orbit). Precise ephemerides are corrected orbits for the GPS satellites. These data provide more accurate positions for the GPS satellites than what is available in real time and as a result the data are processed to provide horizontal position accuracies of approximately 1 decimeter and vertical positions of 1 to 2 decimeters. These data were used to replace the tide model data discussed in Section 2.3.6 and Appendix B1 to improve the line to line elevation measurements and final charts. Since PPP derived vessel elevations are actual measurements, rather than a model, they can better account for local variations in water surface elevation induced by winds or the effects of currents and bottom topography. A detailed discussion of the PPP data processing method is included in Appendix B2.

3.4 **Benthic Terrain Classification**

The Benthic Terrain Modeler (BTM, version 1.0; Wright et al. 2005), a collection of ESRI ArcGIS-based tools for benthic analysis developed by the Department of Geosciences at Oregon State University and NOAA Coastal Services Center, was used to characterize the seabed bathymetry and classify the benthic terrain within the CC Range survey area. These analyses compared positions of grid points in the bathymetry digital terrain model to adjacent points, to determine areas of different terrain structures (Figure 3.4-1). This process created Bathymetric Position Index (BPI) data sets at fine and broad scales which were combined with slope data to generate a classification dictionary. Slope, or measure of steepness first-order derivative, was derived using the ArcGIS Spatial Analyst extension for surface analysis (Appendix C, Chart 3). BPI was calculated following the methodology presented by Lundblad et al. (2006) and summarized below.

BPI is a second-order derivative of bathymetry, as it is calculated from the slope. BPI is a measure of where a reference location is located relative to surrounding locations. BPI data sets were created through a neighborhood analysis function incorporated in the BTM. Positive BPI values indicate features and regions that are higher than the surrounding area. Therefore, areas of positive BPI values generally characterize ridges and other associated features within the benthic terrain. Negative BPI values denote features and regions that are lower than the surrounding area, such as valleys and other similar features. BPI values near zero are either flat areas (where the slope is near zero) or areas of constant slope (where the slope of the point is significantly greater than zero).
The BTM applies the algorithm presented below that utilizes a neighborhood function to produce BPI data sets from input bathymetric datasets and user-defined annulus radii:

\[
\text{BPI (scalefactor)} = \text{int}(\text{bathy} - \text{focalmean(bathy, annulus, irad, orad)}) + 0.5,
\]

where:

- \text{scalefactor} = \text{outer radius in map units multiplied by bathymetric data resolution},
- \text{bathy} = \text{bathymetric grid},
- \text{annulus} = \text{shape of the area used to calculate the focal mean},
- \text{irad} = \text{inner radius of annulus in cells}, and
- \text{orad} = \text{outer radius of annulus in cells},

Input values for the CC Range BPI calculations are presented in Table 3.4-1 below. Scale factors were calculated by the BTM based on user input values for grid cell size and annulus outer radius.
Two different BPI datasets, with two different scale factors, were produced during the benthic terrain classification process. Broad scale BPI data sets have larger analysis neighborhoods and thus a larger scale factor and are used to identify larger features (Appendix C, Chart 4). Fine scale BPI data sets have smaller analysis neighborhoods and thus a smaller scale factor and are used for identifying smaller features (Appendix C, Chart 5). Because of the variability of terrain within the CC Range survey area, along with a relative lack of features on the continental shelf compared with the upper slope, different annulus outer radii, and thus different scale factors, were used in the broad scale calculations.

| Table 3.4-1: Parameters Used To Calculate Broad and Fine Scale BPI Grids |
|------------------------|---------------------|----------------|---------------------|---------------------|----------------|
| Scale                  | Depth Range (m)     | Bathy Grid Cell Size (m) | Inner Annulus Radius (units) | Outer Annulus Radius (units) | Scale Factor |
| Broad                  | 0-100               | 5                       | 1                       | 20                   | 100           |
|                       | 100-250             | 20                      | 1                       | 10                   | 200           |
|                       | >250                | 25                      | 1                       | 10                   | 250           |
| Fine                   | 0-100               | 5                       | 1                       | 3                    | 15            |
|                       | 100-250             | 20                      | 1                       | 3                    | 60            |
|                       | >250                | 25                      | 1                       | 3                    | 75            |

Once BPI data sets have been created at both fine and broad scales, the BTM utilizes the following algorithm to create standardized the BPI data sets:

$$BPI(scale\ factor)_{std} = \text{int}(((BPI(scale\ factor) - mean) / std\ dev) \times 100) + 0.05$$

where:

- $scale\ factor = outer\ radius\ in\ map\ units \times input\ bathymetric\ data\ set\ resolution(cell\ size)$
- $mean = \text{mean cell value across BPI data set}$
- $std\ dev = \text{standard deviation of cell values across BPI data set}$

Standardization is conducted because bathymetric data tends to be spatially autocorrelated. In other words locations that are closer together are more related than locations that are farther apart and therefore, the range of BPI values increases with scale. Standardization of the raw BPI values allows for the classification of BPI data sets at almost any scale (Benthic Terrain Modeler Version 1.0 Help Documentation).

The BTM is complemented by a rugosity analysis, which compares surface areas of regions within the survey data set to the corresponding planar areas. Rugosity data describe topographic roughness and provide further information on the structure of the terrain. Rugosity values near one indicate flat, smooth areas; higher values indicate areas of high relief. Rugosity calculated using this technique is highly correlated with slope. The highest rugosity values show a relationship with the high slope and lower rugosity with low slope. The rugosity derivation
utilized a focal analysis of a 3 grid cell by 3 grid cell neighborhood. Chart 6 in Appendix C provides the rugosity results for the CC Range bathymetry survey.

Appendix C, Chart 7, provides the results of the BTM Zone Classifications and Appendix C, Chart 8 provides the result of the BTM Terrain Classifications for the CC Range bathymetry data set. These classifications were generated using a bathymetry grid size of 5 m in water depths of approximately 40 to 100m, a grid size of 20 m from approximately 100 to 250m and a grid size of 25 m greater than 250m. The BTM used a classification dictionary that was written by Lundblad for the main Hawaiian Islands (Lundblad, 2008) as a starting point, and then modified some of the definitions to be more applicable to the north Florida continental shelf and slope. A comparison between the two classification tables is presented in Table 3.4-2 and is described below. The Hawaiian Islands classification dictionary was comprised of 15 terrains: Narrow Depression, Depression on Flat, Midslope Depression, Depression on Crest, Open Depression, Broad Flat, Shelf, Escarpment, Crest in Depression, Crest on Flat, Midslope Depression, Narrow Crest, Near Vertical Wall, Broad Crest and Deep Shelf. Tetra Tech modified the bounding depth parameters of the Shelf class from a lower limit of -100 to -58, and the upper limit for Deep Shelf from -100 to -58, and then renamed the terrain “Deep Shelf” to “Upper Slope” to better describe the USWTR survey area. Two of the terrains in the Hawaiian Islands dictionary, Broad Flat and Near Vertical Wall, were not present in the USWTR area and thus were removed from the dictionary. Using this modified classification dictionary in the BTM, the USWTR area was classified into 4 benthic zones and 13 benthic terrains.

<table>
<thead>
<tr>
<th>Hawaiian Islands Classification Dictionary (Lundblad, 2008)</th>
<th>North Florida (CC Range) Classification Dictionary</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Narrow Depression</td>
<td>1 Narrow Depression</td>
<td></td>
</tr>
<tr>
<td>2 Depression on Flat</td>
<td>2 Depression on Flat</td>
<td></td>
</tr>
<tr>
<td>3 Midslope Depression</td>
<td>3 Midslope Depression</td>
<td></td>
</tr>
<tr>
<td>4 Depression on Crest</td>
<td>4 Depression on Crest</td>
<td></td>
</tr>
<tr>
<td>5 Open Depression</td>
<td>5 Open Depression</td>
<td></td>
</tr>
<tr>
<td>6 Broad Flat</td>
<td>*</td>
<td>Not present in CC Range</td>
</tr>
<tr>
<td>7 Shelf</td>
<td>6 Shelf</td>
<td>Depth parameters modified (refer to Table 3.4-3 and 3.3-4)</td>
</tr>
<tr>
<td>8 Escarpment</td>
<td>7 Escarpment</td>
<td></td>
</tr>
<tr>
<td>9 Crest In Depression</td>
<td>8 Crest In Depression</td>
<td></td>
</tr>
<tr>
<td>10 Crest on Flat</td>
<td>9 Crest on Flat</td>
<td></td>
</tr>
<tr>
<td>11 Midslope Crest</td>
<td>10 Midslope Crest</td>
<td></td>
</tr>
<tr>
<td>12 Narrow Crest</td>
<td>11 Narrow Crest</td>
<td></td>
</tr>
<tr>
<td>13 Near Vertical Wall</td>
<td>*</td>
<td>Not present in CC Range</td>
</tr>
<tr>
<td>14 Broad Crest</td>
<td>12 Broad Crest</td>
<td></td>
</tr>
<tr>
<td>15 Deep Shelf</td>
<td>13 Upper Slope</td>
<td>Name and depth parameters modified (refer to Table 3.4-3 and 3.3-4)</td>
</tr>
</tbody>
</table>

The modified classifications present within the CC Range were defined as follows and are presented in Table 3.4-3 and Table 3.4-4.
Benthic Zone Classification Definitions:

**Crests**: High points in the terrain where there are positive bathymetric position values. Index values greater than one standard deviation from the mean in the positive direction

**Depressions**: Low points in the terrain where there are negative bathymetric position values. Index values greater than one standard deviation from the mean in the negative direction

**Flats**: Flat points in the terrain where there are near zero bathymetric position index values. Values that are within one standard deviation of the mean

Flats have a slope that is less than or equal to 5°

**Slopes**: Sloping points in the terrain where there are near zero bathymetric position index values that are within one standard deviation of the mean.

Slopes have a slope that is greater than 5°

Slopes are otherwise called escarpments in the NOAA/NOS classification scheme.

<table>
<thead>
<tr>
<th>Table 3.4-3: Benthic Zone Classifications and Bounding Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Classification</strong></td>
</tr>
<tr>
<td><strong>Class</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Benthic Terrain Classification Definitions:

**Narrow Depression**: A depression where both fine and broad features within the terrain are lower than their surroundings.

**Depression on Flat**: A fine scale depression within a broader flat terrain.

**Midslope Depression**: A fine scale depression that laterally incises a slope of greater than 5°.

**Depression on Crest**: A fine scale depression within a crested terrain.

**Open Depression**: A broad scale depression with a U-shape where any nested, fine scale features are flat or have constant slope.
Shelf: A broad flat area where the terrain contains few, nested, fine scale features. A shelf is shallower than 58 m depth (this depth value was decided based on 3D visualization and the presence of a ridge along the shelf break). The slope is less than 5°.

Escarpment: A constant slope where the slope values are between 5° and 70° and there are few, nested, fine scale features within the broader terrain.

Crest in Depression: A fine scale crest within a broader depressed terrain.

Crest on Flat: A fine scale crest within a broader flat terrain. Slope value is less than 5°.

Midslope Crest: A fine scale crest that laterally divides a slope. This often looks like a ledge in the middle of a slope.

Narrow Crest: A crest where fine features within the terrain are higher than their surroundings.

Broad Crest: A crest where broad features within the terrain are higher than their surroundings.

Upper Slope: A broad flat area where the terrain contains few, nested, fine scale features. An upper slope is deeper than 58 m depth (this depth value was decided based on 3D visualization and the presence of a ridge along the shelf break). The slope is less than 5°.

Table 3.4-4: Benthic Terrain Classifications and Bounding Parameters

<table>
<thead>
<tr>
<th>Classification</th>
<th>Broad Scale BPI Parameters</th>
<th>Fine Scale BPI Parameters</th>
<th>Slope</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Zone</td>
<td>Lower Bounds</td>
<td>Upper Bounds</td>
<td>Lower Bounds</td>
</tr>
<tr>
<td>1 Narrow Depression</td>
<td></td>
<td>-100</td>
<td>-100</td>
<td></td>
</tr>
<tr>
<td>2 Depression on Flat</td>
<td>-100</td>
<td>100</td>
<td>-100</td>
<td>5</td>
</tr>
<tr>
<td>3 Midslope Depression</td>
<td>-100</td>
<td>100</td>
<td>-100</td>
<td>5</td>
</tr>
<tr>
<td>4 Depression on Crest</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Open Depression</td>
<td>-100</td>
<td>-100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>6 Shelf</td>
<td>-100</td>
<td>100</td>
<td>-100</td>
<td>100</td>
</tr>
<tr>
<td>7 Escarpment</td>
<td>-100</td>
<td>100</td>
<td>-100</td>
<td>100</td>
</tr>
<tr>
<td>8 Crest In Depression</td>
<td>-100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Crest on Flat</td>
<td>-100</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>10 Midslope Crest</td>
<td>-100</td>
<td>100</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>11 Narrow Crest</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Broad Crest</td>
<td>100</td>
<td>-100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>13 Upper Slope</td>
<td>-100</td>
<td>100</td>
<td>-100</td>
<td>100</td>
</tr>
</tbody>
</table>
3.5 MULTIBEAM SNIPPETS DATA PROCESSING

Seabed acoustic imagery data were acquired simultaneously with the multibeam data using a SeaBat 7125-SV (400 kHz) and a SeaBat 7150-F (24 kHz) echosounder. Processing of imagery data acquired from multibeam sonar can provide an additional aid to classifying seafloor sediment types and locating sensitive habitats.

A review of existing processing tools for the raw snippets data showed that many of the software publishers were still in development and that there was no commercial off the shelf (COTS) solution that could assure success in processing these data within the project schedule constraints. To ensure that project goals could be met, Tetra Tech contracted with Dr. Jonathan Beaudoin, who has previously developed algorithms for this type of processing and published the results in several peer-reviewed articles, to modify his algorithms and software to work with these data (please refer to Appendix E). The resulting processing tools were run in parallel with tests of updates to the COTS tools as they became available.

Processing these data included correction of the imagery data for variable sonar settings and geometric effects. Navigation, orientation, heading, and multibeam bathymetry and sidescan imagery information were recorded in the HYPACK HSX file, while the .7K files provided snippets data. Vessel configuration information and sound speed profiles were obtained from CARIS HIPS project files and a list of rejected soundings, the result of bathymetric cleaning efforts, were also exported from the CARIS HIPS data files. All of these data were converted to Ocean Mapping Group (OMG) format, which is compatible with Dr. Beaudoin’s software, for processing.

The data were then radiometrically corrected on a ping-by-ping basis (sample by sample) for sonar system variables such as transmitter source level, receiver gain, pulse length, and beam patterns and for variations between the two sonar systems.

For a detailed description of acoustic imagery data processing refer to Appendix E.

Features, including relatively subtle changes in sediment type, were quite distinct in the mosaic resulting from these processing efforts and the mosaic as a whole showed very good contrast (Appendix C Chart 9; Figure 3.5.1). Bright areas of higher reflectivity (light) were clearly distinct from areas of lower reflectivity (dark). The snippets mosaic was the primary tool used in the geological interpretation to define sediment types and areas of hard and soft bottom (discussed in detail in Section 3.7).
However, line to line variability in the intensity made it difficult to utilize automated classification methods. Class breaks occurred between adjacent tracks that had slightly different intensity levels in the mosaic but were clearly part of the same geologic area when viewed with the human eye. Extensive efforts were made to develop a method that resolved the track to track variability. Some investigation was conducted into normalization across-track, as track-parallel class breaks can occur when sonar data have not been corrected for beam pattern effects or have not been normalized for the seafloor’s varying response with incidence angle. These investigations are discussed in detail in Appendix E, however the conclusion reached was that the variability was occurring primarily between tracks rather than across-track.

In summary, while mosaics produced using OMG processing methods showed clearly defined features and full dynamic range suitable for interpretation and classification methods, efforts to generate mosaics suitable for automated classification methods yielded limited results. Therefore, a significant effort was then made towards developing an automated classification method that could compensate for track to track variability; these efforts are described in Section 3.8.

3.6 GROUND-TRUTH: C-CASS II AND ROV OPERATIONS

The locations for the C-CASS II and ROV dive operations were determined upon review of the multibeam and geophysical survey data at the Navy and Tetra Tech post-survey meeting held in Seattle in April 2010. The proposed dive locations were overlaid on charts containing the bathymetry data and provided to the Navy for final review, approval, and prioritization prior to the ground truth mobilization efforts. ROV and C-CASS operations were conducted in the CC Range between 05 and 24 May 2010.

3.6.1 C-CASS Operations

The Navy made the decision to focus the limited amount of time available to conduct ground truthing within the CC Range (5 days) with ROV deployments rather than C-CASS deployments because the greater mobility of the ROV provided multiple sample points of data rather than the single point sample that the C-CASS provided. As a result, only two sites were investigated with the C-CASS II in the CC Range (Appendix C, Chart 1 and Chart 10). Digital still images and
digital video were collected during the C-CASS II deployments that were used to aid in seabed classification. No sediment grab samples were conducted in the CC Range.

Details on the C-CASS II deployments, including sediment descriptions, are included in Appendix F of this report.

### 3.6.2 ROV Operations

Twelve sites were investigated with the ROV in the CC Range (Figure 3.6-1 and Appendix C, Chart 1, Chart 10 and Chart 11). Due to the prevailing south to north current, all ROV dives were conducted from south to north. Appendix G contains information on the ROV operations, including the date and time for all attempted and successful dives.

Observations from the ROV video and digital still images were used to ground truth the bottom type classifications derived from the snippets data and to verify the characteristics of significant bottom features, such as reefs, rocks, and extensive biological communities that were identified as having a potentially significant impact on the Navy’s planned construction activities. As a result of John Reed of Harbor Branch (who was specified in the Final Work Plans) being unavailable, Tetra Tech subcontracted Andrea Quattrini with the NTR’s approval as an expert on benthic habitat to support the ground-truthing survey. Ms. Quattrini is a Ph.D. candidate at Temple University and a biologist with extensive knowledge of southeastern United States benthic biological communities and she has a specialty in deepwater coral. During ground-truthing operations she observed and cataloged biological organisms and habitat characteristics encountered during the ROV dives and the C-CASS II deployments.

![Figure 3.6-1: ROV Dive Sites in CC Range](image)

Habitat classifications of the ROV dive areas in the CC Range were carried out using primarily the ROV video data. The dominant primary and secondary habitat types (Table 3.6-1 and Table 3.6-2) along each ROV track were recorded in a Microsoft Access database during each ROV deployment. This database is included with the final digital deliverables for this report. Each time that the dominant primary or secondary habitat changed along the dive track, habitat data were recorded. After the dives, video data were reviewed to finalize habitat classifications. Although video data were the primary source of habitat classification and should be used for
general descriptions and ground-truthing of the target areas, the digital still photographs and video captures provided additional information on substrate type. Digital stills supplemented the video data particularly when the video was not useful (e.g. too bright/dark or the ROV was too high off bottom). Habitat and associated fauna captured in each photograph were recorded in Microsoft Excel spreadsheets. The photo log is included with the final digital deliverables for this report. Digital still file names were also incorporated into the Microsoft Access database as appropriate.

The habitat types chosen for these ground-truthing efforts were modified from Wentworth (1922), Partyka et al. (2007), and Zitello et al. (2009) and approved by the NTR. Primary and secondary habitat types are listed in Table 3.6-1 and Table 3.6-2, with corresponding definitions. Photos showing examples of the different habitat types and significant features observed are provided in Section 4.3. Abbreviations for each primary habitat class were used for data entry. Because it can be difficult to classify sediment types without samples, general sediment sizes (fine, medium or coarse) that could be successfully and consistently classified by visual observation were used. Live coral presence was noted for habitat forming corals only (listed in Table 3.6-2). Hard coral types excluded cup corals and stylasterids as these corals are inconspicuous and not easily observable in video. Of note, the primary habitat type “hard coral mounds” are commonly known as coral carbonate mounds, which are defined as “topographic seafloor structures that have accumulated through successive periods of reef development, sedimentation, and (bio)erosion” (Roberts et al. 2009). In several instances, particularly in the CC Range, the ROV transited over what appeared to be coral carbonate mounds in a certain stage of formation. The topographic features were covered with varying amounts of coral rubble; at times small, live *Lophelia pertusa* colonies and other lithified materials were present. If it could be distinguished on video that the ROV was transiting on this type of feature, the video was coded as a “hard coral mound”. In some cases multibeam survey data were used post-dive to determine whether the ROV transited along a feature that was considered a hard coral mound. by determining whether the dive track crossed a mound identified in the multibeam bathymetry. These data were not used to determine the presence or absence of live coral.

During ground truthing operations the vessel experienced surface currents which occasionally exceeded 5 knots, creating difficulties for both the vessel and ROV in holding relative positions during ROV deployments. The side deployment of the ROV compounded these difficulties and contributed to the poor positional control that resulted from use of a non dynamic positioned (DP) vessel and the strong dynamic currents of the Atlantic Gulf Stream. Given the space constraints on the survey vessel, a stern deployment was not an option. However, both the survey vessel captain and ROV contractor agreed that a side deployment was viable and the preferred option. Surface vessel positional instability translated down the cable to the ROV, often making it difficult for the ROV pilot to maneuver and occasionally “jerking” the ROV when its own thrusters were unable to compensate for the heavy currents and vessel forces. During one deployment in heavy current the ROV and its tether management system (TMS) were dragged along the bottom for some distance. The velocity of the Gulf Stream in relation to the survey vessel heading and the starboard side deployment of the ROV also caused considerable strain to be put upon the ROV umbilical during deployment. This strain on the umbilical may have contributed to a short in the umbilical as well as other intermittent electrical
issues. In addition these Gulf Stream related positional challenges resulted in blurred video and still images of the seafloor during the initial ROV dives.

To address these challenges, Tetra Tech and Northwest Underwater Construction came up with the following solutions:

- The standard ROV incandescent headlights were augmented with a much brighter high intensity discharge light. This addition significantly improved quality of digital still images collected on dives conducted after 10 May 2010. Prior to addition of supplementary lights the still images were often blurry however the video was deemed suitable for classification by the on-board NTR.
- A large diameter sheave was added to the LARS to aid in relieving some of the strain put upon the ROV umbilical and to allow for additional vessel maneuverability during deployments.
- These upgrades, along with the increased experience of both the vessel and ROV pilots, resulted in significant improvements in both the positional challenges and image quality for the remainder of the ROV dives.

Despite these improvements, strong Gulf Stream currents continued to play a major factor during all stages of the ROV operations. Operational parameters had to be implemented to ensure equipment and personal safety. Each dive presented its own set of challenges as the Gulf Stream is a highly dynamic environment. These forces over time could have resulted in some of the electrical and mechanical failures experienced during the operations.

Table 3.6-1: Habitat Classifications Distinguished in ROV Dive Operations

<table>
<thead>
<tr>
<th>Geomorphological Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft Substrata (SS) Unconsolidated Sediment</td>
<td></td>
</tr>
<tr>
<td>Mud/Clay M</td>
<td>Mud/Clay silt with fine grain size</td>
</tr>
<tr>
<td>Sand/Shell Hash S</td>
<td>Fine to Coarse sand sediment includes varying amounts of shell hash</td>
</tr>
<tr>
<td>SS with Rock Rubble SRR</td>
<td>Abundant soft substrate with sparsely scattered low relief rock or rock rubble (see below)</td>
</tr>
<tr>
<td>SS with Coral Rubble SCR</td>
<td>Abundant soft substrate with sparsely scattered coral rubble (see below)</td>
</tr>
<tr>
<td>Scattered Rock/Coral SCRR</td>
<td>Mixture of scattered rock and coral rubble</td>
</tr>
<tr>
<td>Hardbottom</td>
<td></td>
</tr>
<tr>
<td>Rock Rubble RR</td>
<td>Broken up pieces of low relief, unattached rock across the seafloor (&lt; 0.25 m diameter, pebble/cobble/gravel)</td>
</tr>
<tr>
<td>Coral Rubble CR</td>
<td>Broken up pieces of low relief, unattached, dead, coral rubble; generally found in flats or small topographic features (not part of a coral carbonate mound-see below)</td>
</tr>
<tr>
<td>Rock Outcrop RO-HR</td>
<td>Exposed rock substrate of varying shapes and sizes protruding from the seafloor; high relief (&gt; 1 m)</td>
</tr>
<tr>
<td>Rock Outcrop/Low relief Hardbottom RO-LR</td>
<td>Exposed rock substrate of varying shapes and sizes protruding from the seafloor; generally not loose as in rubble; low relief (&lt;1 m); unlike pavement in that many rock faces are exposed, not a continuous flattened sheet of hardbottom</td>
</tr>
<tr>
<td>Geomorphological</td>
<td>Abbreviation</td>
</tr>
<tr>
<td>-------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Rock Ledge</td>
<td>RL</td>
</tr>
<tr>
<td>Pavement</td>
<td>P</td>
</tr>
<tr>
<td>Pavement with Sand</td>
<td>PS</td>
</tr>
<tr>
<td>Channels</td>
<td></td>
</tr>
<tr>
<td>Artificial Substrate</td>
<td>A</td>
</tr>
<tr>
<td>Unknown</td>
<td>U</td>
</tr>
</tbody>
</table>

**Table 3.6-2: 2° Habitat Classifications**

<table>
<thead>
<tr>
<th>2° Habitat Classifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sand Size</strong></td>
</tr>
<tr>
<td>Fine</td>
</tr>
<tr>
<td>Medium</td>
</tr>
<tr>
<td>Coarse</td>
</tr>
<tr>
<td><strong>Attached Fauna Abundance</strong></td>
</tr>
<tr>
<td>Sparse</td>
</tr>
<tr>
<td>Moderate</td>
</tr>
<tr>
<td>Abundant</td>
</tr>
<tr>
<td><strong>Attached Fauna Type</strong></td>
</tr>
<tr>
<td>Order Antipatharia</td>
</tr>
<tr>
<td>Order Gorgonacea</td>
</tr>
<tr>
<td>Mixed (various fauna-corals, encrusting, hydroids, glass sponges)</td>
</tr>
<tr>
<td>Other Soft Corals</td>
</tr>
<tr>
<td>Hard Coral (see below)</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

**Live Coral Presence**  
(Includes Gorgonians [sea fans], Antipatharians [black corals], and Scleractinians [hard corals] noted below)  
Yes or No

<table>
<thead>
<tr>
<th>Hard Coral Type</th>
<th>Hard Coral (Live/Dead)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lophelia pertusa</td>
<td>Dead</td>
</tr>
<tr>
<td>Oculina sp.</td>
<td>Live</td>
</tr>
<tr>
<td>Enallopsammia profunda</td>
<td>Mixed</td>
</tr>
</tbody>
</table>

**3.7 GEOLOGICAL INTERPRETATION AND SEDIMENT CLASSIFICATION**

While much industry-wide effort is currently focused on the development of automated habitat classification methods, as far as Tetra Tech is aware, no standardized methodology has yet been established for use within the range of water depths and bottom types present within the CC Range. Tetra Tech has been testing various industry software (see Section 3.8 below for a
discussion of automated classification methods) and working towards development of methods for automated classification throughout this and other projects but has had limited success due to the challenges associated with processing of snippets data (these challenges are discussed in detail in Appendix E).

The benthic habitat classification map (Appendix C, Chart 10) was compiled by a geologist experienced in geological interpretation of marine survey data. The method utilized an updated version of traditional marine geological interpretation methods that use overlays of seabed imagery (often a sidescan mosaic), bathymetry and sediment sampling results. This process involved evaluation of all of the data collected during the marine survey, including examination of the bathymetry and snippets data, as well as still images and video from the C-CASS II and ROV and the observations recorded by the project biologist. Each data set was prepared in a manner appropriate for that data type, discussed further below, prior to import into an ArcGIS project. Although the results are qualitative and subjective, they are based on the geologist’s experience with these types of data.

Datasets imported into the GIS project for display and analysis included:

- Multibeam Products
  - Bathymetry – grids created at 5 m (less than 100 mwd), 20 m (100-250 mwd) and 25 m (greater than 250 mwd), Appendix C Chart 1
  - Bathymetric contours and shaded relief – created from the bathymetric grids using ArcGIS Spatial Analyst
  - Slope - created from the bathymetric grids using ArcGIS Spatial Analyst (Appendix C, Chart 3)
  - Multibeam derivatives produced by the Benthic Terrain Model, including rugosity, benthic zones and benthic terrains (procedure discussed in Section 3.4 and presented in Appendix C Charts 4 through 6)
  - Snippets – geo-referenced tif images of seabed acoustic imagery produced using the procedure discussed in Section 3.5 and Appendix E, and presented in Appendix C, Chart 9

- Ground-truthing Products
- C-CASS II deployment locations (shapefiles)
- ROV dive tracks (shapefiles)
- ROV observations (shapefile of observations recorded in the Microsoft Access database)
- Background Information
- Nautical charts
- CC Range survey boundary
- Deepwater Coral HAPC boundary
Videos and still images collected during the C-CASS II and ROV operations were not imported into the GIS project but were reviewed throughout the interpretation.

The primary dataset used for delineation of sediment types was the snippets dataset, in the same way that a sidescan sonar mosaic often serves as a basemap for geological interpretation. The high resolution multibeam bathymetry datasets and shaded relief showed variations in texture and fine-scale features that were incorporated into the interpretation. Polygons defining sediment variations were digitized in an ArcGIS project using these data (Figure 3.7-1).

![Figure 3.7-1: Interpretation Workflow: Sediment Type Boundaries Defined Using Snippets (left) and Shaded Relief (right)](image)

Due to the complexity of the geology in the deeper water, features from the Benthic Zone Classifications (BZC; Appendix C, Chart 7) were used to help define changes in sediment types associated with those features.

The BZC crests were divided into two groups, elongated and circular features, using a length to area calculation, and overlaid on the snippets imagery. The elongated crests were located primarily on the continental shelf along the shelf break and defining the furrows in water depths between 180 and 240 m. The circular crests were found to correspond very well with areas of low reflectivity in the snippets data (Figure 3.7-2).

The BZC depressions primarily corresponded to the essentially flat floors of the furrows between 180 and 240 mwd and to areas that encircled many of the mounds. The BZC depressions did not cleanly delineate the furrows and so these features were digitized using the snippets, as they corresponded with areas of lower reflectivity snippets data (Figure 3.7-3). The BZC depressions between mounds sometimes correlated with moats around the larger mounds but also were
present where the seabed appeared flat between the mounds. While the majority of these depressions corresponded with low reflectivity snippets data they were not used in the interpretation.

Figure 3.7-2: BZC Circular Crests (on Shaded Relief at Left) Correlate with Low-Reflectivity Snippets (right)

This method of classification did not identify every furrow and mound that can be distinguished by eye in the datasets but did highlight the major features and the results corresponded very well with sediment types interpreted from the snippets and ground-truthing observations.

Bathymetric data, including shaded relief images and contours, were used to distinguish subtle features such as areas of pavement, which may be covered by a thin layer of sand. For example, towards the outer shelf, the emergence of hardened features was more apparent in the bathymetric data than in the snippets data (Figure 3.7-4).
The mounds detected along the eastern side of the CC Range were very distinct in the bathymetry and the snippets data. The surficial sediment type polygons were drawn by overlaying the different datasets in the GIS project and observing how features were related spatially. Once these polygons were defined, ground truth data, including C-CASS II and ROV observations were used to define the classifications.
The continental shelf was classified primarily as sand, with areas of coarse sand and shells corresponding with brighter snippets data. Areas of pavement and the ridge crest were defined as described above and classified based on the snippets reflectivity and the one C-CASS II observation at site C-CASS 03, as well as proximity to the USWTR area where additional samples were collected and ROV dives were conducted.

The transition from medium sand to silt/clay fine sand on the upper slope was very difficult to determine from the snippets data and should be considered a gradual transition. Sediment samples and sub-bottom profiler data from USWTR showed that very fine sediment was present in a similar depth range. The transition from low reflectivity sediments to a very bright seabed was very distinct in the snippets data. One C-CASS II deployment (C-CASS 07) and two ROV dives (ROV 01 and ROV 02) were conducted in this highly reflective area between approximately 180 and 240 mwd where distinct linear to sinuous shaped, SSW-trending furrows are present in the bathymetry and snippets data, and revealed that the seabed was covered primarily by sand with scattered rock rubble. Unlike the observation in USWTR, where ROV dives investigating these features revealed that the edges of the furrows are primarily rocky, the furrows crossed during ROV 01 and ROV 02 showed a very subtle change in sediment from sand with rock rubble to sand with less rock rubble. For this reason, the elongated crests defined by the BTM were not used to define rock outcrops along these furrows as they were in USWTR. The floors of the furrows did have lower reflectivity in the snippets data than the surrounding seabed of sand with rubble and therefore were classified as sand.

Between approximately 250 and 400 mwd ROV dives ROV 03, 04, 05 and 06 showed that the lower reflectivity sediments were primarily sand. The sand in these areas was comprised of dense black sand and finer tan sand that was rippled in areas to produce distinct patterns on the seabed. East of the rippled black and white sand the seabed was covered by numerous mounds. In areas where mound density was very high the seabed between the mounds had low reflectivity and where the mounds had greater separation the surrounding seabed was very reflective. The mounds themselves consistently corresponded with low reflectivity snippets data. ROV dives on the mounds showed that they were covered primarily by coral rubble and therefore the mounds, defined by the BZC circular crests, have been classified as coral rubble. All of the mounds investigated with the ROV (all dives except ROV 01 and ROV 02) were found to contain dead *Lophelia pertusa* and live *Lophelia pertusa* was found on six of these dives (ROV 6, 7, 10 and 13 through 15). Some mounds were classified as hard coral mounds based on ROV observations but, while this classification is mentioned in the ROV summaries for each dive, there is no distinction between coral rubble and hard coral mounds in the seabed classification. ROV observations in areas surrounding the mounds indicated that the highly reflective seabed was composed primarily of rubble and some low-relief rock outcrops, whereas the lower reflectivity sediments were composed primarily of a combination of sand and coral rubble with some rock rubble.

The interpretation process was qualitative and was derived from all of the datasets acquired during the survey. In addition, knowledge gained about the area in general from the USWTR survey area, located southwest of the CC Range that included geophysical data from a sub-bottom profiler, sediment grab and core samples, as well as ROV observations, was considered during the classification (Appendix C, Chart 10).
3.8 AUTOMATED SEABED CLASSIFICATION SCHEMES

The following summarizes the methods and results for efforts to implement a fully automated seabed classification model.

Snippet Data Preparation and Processing

Snippet data processed as described in Appendix E were adjusted for image segmentation and classification in the following manner, using ArcGIS 9.3.1 /ArcInfo Software: Missing data values or “holidays” (comprising less than 0.5% (0.29) of the total surveyed data) were filled using a 10 by 10 cell block statistic mean value with a 23% random factor added to mask the influence of the more uniform block statistic value in the image segmentation process. Data were re-sampled from 3m to 9m cells as a first smoothing. A moving window mean function was then applied to the grid using a variety of window sizes from 3m to 30m by 60m in order to minimize the effect of bubble wash and other noise. Increasing levels of smoothing/generalization were effective in eliminating the bubble wash tracks, however, generalization sufficient to eliminate the noise component also resulted in unacceptable degradation in the “signal” component of the data as well.

Data Preparation and Image Segmentation in ENVI 4.7 / ENVI Zoom 4.7

ENVI layer stacked images were masked for nonzero no data values in ENVI 4.7 and analyzed using the Feature Extraction workflow utility in ENVI Zoom 4.7. Iterative adjustments to the scale factor and merge level in this process were first made to yield bounding polygons or image objects that corresponded in scale to features identified by expert interpretation (refer to Section 3.7), and to yield polygons that represented a finer scale that would enable more polygons containing a single class of “ground-truth” observation from the ROV database (refer to Section 4.3) for the creation of supervised classification training areas. These adjustments did not yield results at any combination of scale level and merge factor that corresponded sufficiently to features identified by expert interpretation to warrant use in supervised classification.

Initial image segmentation efforts were carried out on snippet data only, segmentation was also performed on snippet and bathymetry derived data (Benthic Terrain Classifications (BTC), refer to Section 3.4). Using snippet data that were generalized using 30 by 60 and 15 by 30 moving window mean analysis in combination with BTC in a 2-band stacked image, segmentation resulted in a slightly degraded, vectorized representation of the BCT dataset. Using no, or minimal generalization of the snippet data and no other inputs, segmentation resulted in polygons almost entirely based on the survey tracks and bubble wash noise. Optimal segmentation results were achieved using snippet data only, smoothed using a 15 by 30 cell moving window mean and segmented in ENVI Zoom using a scale factor of 60 and a merge level of 80. However, even with these results, segment breaks did not correspond sufficiently to expert interpretation to allow supervised classification of the CC Range.
4.0 SURVEY RESULTS AND INTERPRETATION

4.1 GEOMORPHOLOGICAL AND DATA OVERVIEW

The CC Range survey area was located approximately 64 NM off the coast from Jacksonville, Florida. The survey area extended from the outer continental shelf, across the shelf break, and onto the upper Florida-Hatteras Slope (Figure 4.1-1). Further to the east the Blake Plateau, a distinct, broad platform scoured and shaped by the Gulf Stream, separates the Bahama Banks calcium carbonate province to the south from the shelf and coastal plain terrigenous province to the north (Pratt and Heezen, 1964). The seabed in the CC Range deeper than approximately 385 mwd is encompassed by a Deepwater Coral Habitat Area of Particular Concern (Coral HAPC). This designation, effective 22 July 2010, protects what is thought to be the largest distribution of pristine deepwater coral ecosystems in the world (SAFMC, 2009, 2010). This area is described further in Section 4.1.3 below.

![Figure 4.1-1: Regional Overview](image)

Figure 4.1-1: Regional Overview
Seabed slope terminology used in the following text is defined as follows:

<table>
<thead>
<tr>
<th>Gradient</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1°</td>
<td>Essentially Flat</td>
</tr>
<tr>
<td>1°</td>
<td>Very Gentle</td>
</tr>
<tr>
<td>1.1°-5°</td>
<td>Gentle</td>
</tr>
<tr>
<td>5.1°-10°</td>
<td>Moderate</td>
</tr>
<tr>
<td>10.1°-20°</td>
<td>Steep</td>
</tr>
<tr>
<td>Greater than 20°</td>
<td>Very Steep</td>
</tr>
</tbody>
</table>

The western edge of the survey area was situated on the continental shelf, which deepens very gently towards the east from a water depth of 40 m to the shelf break at approximately 58 m water depth. The seabed on the shelf undulates very gently in a northeast-trending orientation as a series of low dunes. Along the outer shelf, a series of linear ridges trend NNE through the range, parallel to the shelf break. The ridges rise 1 to 4 m above the surrounding seabed before dropping steeply on the seaward side to the upper slope. Slopes on the ridges primarily range between 1° up to 5°, with isolated steep steps up to 20°. This ridge system is discussed further in Section 4.1.1. Once past the shelf break the essentially featureless upper slope deepens gently towards the east. Between 180 and 240 m water depth SSW-trending, linear scour marks, referred to in this document as “furrows” in reference to their shape, some more than 20 kilometers in length and 300 meters wide dominate the slope. At approximately 330 m water depth, the seabed becomes rougher and is covered with numerous locally steep (5° to 20°) mounds. These features are discussed further in Section 4.1.2.

Results from the BTM clearly show the major features observed. The Benthic Zones mapped were primarily flats, with crests and depressions associated with the shelf break ridges, furrows, and the mound areas in deeper water (Appendix C, Chart 7). The Benthic Terrain Classifications map highlights the same areas. Most of the CC Range survey area was comprised of shelf (13.8%) and upper slope (68.5%) terrain. The ridge crest and mound areas were mapped as crests and depressions (Appendix C, Chart 8). Both of these charts show that the primary habitat areas will be associated with these distinct areas. Tables 4.1-1 and Table 4.1-2 provide the area in km² of each BTM classification and percentages within the CC Range area.

<table>
<thead>
<tr>
<th>Classification</th>
<th>CC Range Area (km²)</th>
<th>Percent of Total CC Range Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Zone</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Crest</td>
<td>59</td>
</tr>
<tr>
<td>2</td>
<td>Depression</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Flat</td>
<td>650</td>
</tr>
<tr>
<td>4</td>
<td>Slope</td>
<td>22</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>756</td>
</tr>
</tbody>
</table>
Another product of the Benthic Terrain Model was the rugosity chart (Appendix C, Chart 6). In general this product showed features associated with variations in seafloor roughness.

### 4.1.1 Shelf Break Ridge

Physiographic features at the shelf break are characteristic along the southeastern coast of the United States. The shelf break in the CC Range survey area is relatively indistinct compared with regions to the north and south. The ridge in the CC Range is a continuation of the algal limestone and calcareous sandstone linear ridges identified along the shelf break in the USWTR area and like them, also were probably constructed on low-lying ridges formed during low level stands of sea level mainly during the Holocene transgression (MacIntyre and Milliman, 1970). The ridge observed in the CC Range was about two to three hundred meters in width, with steep slopes up to 20° in isolated areas. The ridge rises 1 to 4 meters above the surrounding seabed before dropping to the upper slope to seaward (Figure 4.1-2). Ridge morphology is fairly consistent throughout the range with no distinct breaks in the ridgeline (Figure 4.1-3). Exposed rock surfaces along the ridge provide habitat opportunities for biological communities that likely inhabit the ridge. Low-relief and high-relief outcrops and areas of pavement inhabited by abundant attached and mobile fauna are expected based on observations from five ROV dives conducted along this ridge system in USWTR (three conducted by Tetra Tech and two by NOAA). Based on observations from these dives, attached organisms may include fields of whip corals, gorgonians, acelonaceans, large sponges, and patches of *Oculina* sp. Expected fishes include vermillion snapper, porgies, hogfish, scamp, spotted moray, amberjack, lionfish, reef butterflyfish, and squirrelfish. It should be noted that the three dives conducted by Tetra Tech in USWTR were conducted at night and therefore the species observed there and expected here may not be representative of all species that inhabit the ridge.
Figure 4.1-2: Profile Along the Ridge
No vertical exaggeration on the plan view image, VE = 10 on profile; colorbars show water depth in meters.

Figure 4.1-3: Profiles across the Ridge
Note profiles show considerable vertical exaggeration
4.1.2 Upper Florida Hatteras Slope

East of the shelf break at approximately 58 mwd, the seabed of the upper Florida Hatteras Slope deepens gently towards the east. Between the shelf break and approximately 180 m water depth the seabed was smooth and featureless and covered by a relatively low reflectivity sediment layer likely comprised of fine sand and silt. At about 180 m water depth the slope decreased slightly but distinctly and the seabed became essentially flat or had a very gentle slope (1° or less). At this point seabed reflectivity increased and the seabed was marked by numerous SSW-trending, linear furrows that resembled scour marks. Some more than 20 kilometers in length and 300 meters wide, these furrows are up to several meters deep. Snippet data indicate relatively low-reflectivity material has collected on the floors of these furrows while the surrounding material is relatively reflective. Dives ROV 01 and 02 traversed these furrows; refer to Section 4.3 for details from these dives. Figure 4.1-4 below shows several of these features and includes a profile across two of these features that were explored during dive ROV 02. The wider trough (left) is 300 m wide and about 4 m deep while the trough on the right is about 100 m wide and less than 1 m deep. Observations from the ROV showed that the seabed in the area was covered with sand and scattered rock rubble, while the trough floors were primarily sand.

Figure 4.1-4: Linear to Sinuous Furrows On Upper Slope

These linear to sinuous furrows may have been formed by iceberg scour, a suggestion supported by a 2008 publication documenting similar features mapped in similar water depths off of South Carolina (Hill, J.C. et al., 2008). The furrows mapped off of South Carolina were typically 10 to 100 m wide and less than 10 m deep and their lengths were greater than 10 km, while some of the larger furrows were 400 m wide and 20 m deep. The 2008 study suggested that these furrows were evidence of an iceberg rafting event associated with the retreating ice margin during the last glaciation. At the time of publication their discovery was the southernmost record...
of iceberg transport. Iceberg transport is largely controlled by ocean surface currents and records (such as Heinrich layers) have suggested that most icebergs released during Quaternary glaciations were restricted to polar and mid-latitudes. However, the 2008 paper suggested that there may have been an additional southerly component of transport along the western Atlantic margin. The data presented by Hill et al., suggested that, based on the location and orientation of keel marks mapped off South Carolina, icebergs were entrained in a southwestward-flowing coastal current. In addition, Hill et al. reported that bottom contour currents appeared to have eroded and reworked the sediments associated with the furrows, enhancing the width and depth of troughs. The furrows mapped in the CC Range may represent evidence for iceberg transport south of the Charleston Bump.

Deeper than about 250 m water depth the seabed was covered by a relatively low reflectivity material and was relatively featureless until about 310 m water depth when mound features became more prevalent. Observations from dive ROV 03, which was conducted in this area, indicated the seabed in this area is primarily covered by sand.

Deeper than approximately 310 m water depth the area was dominated by mounds, up to several hundred meters in diameter and less than 5 to over 30 m in height, with the tallest mound mapped approaching 50 m in height (Appendix C, Chart 1). Some of these mounds have coalesced to form linear ridges up to 10 km in length and approximately one kilometer wide (Figure 4.1-5). The mounds themselves have relatively low reflectivity, presumably due to entrained fine material such as silt and sand as well as unconsolidated coral rubble that comprise the mounds (Appendix C, Chart 9).

Figure 4.1-5: Abundant Mounds (left) Coalescing to Form Chains (right)

Numerous high-relief mounds have been mapped further offshore Jacksonville in water depths below 440 m and up to 800 m depth. These structures, termed lithoherms, were rocky pinnacles capped by coral debris and live coral thickets of the deep water coral *Lophelia pertusa* as well as large populations of massive sponges and gorgonians and smaller macroinvertebrates (Paull et al., 2000; Reed et al., 2006, SAFMC, 2010). Additionally, mounds of unconsolidated sediment and coral debris, termed bioherms, capped with thickets of live coral (including *Lophelia pertusa*
and *Oculina* sp.) have been described. These deep water coral reefs are usually found in regions of fairly strong currents or upwelling, where coral structures capture suspended sediment and build mounds to heights of a few meters to over 50 m (Reed and Ross, 2005). To minimize confusion and in accordance with current terminology we refer to mounds observed in the CC Range as hard coral mounds, or HCMs, in various stages of formation (Roberts et al, 2009).

The seabed surrounding these mounds is fairly reflective in some areas however in others a relatively low reflectivity material blankets the seabed (Appendix C, Chart 9). ROV observations indicated the higher reflectivity material was primarily coral and rock rubble while the lower reflectivity material was primarily silt and sand.

Biological organisms that included clusters of deep water coral, *Lophelia pertusa*, were observed on six of the nine dives conducted on the mounds (Figure 4.1.5). ROV dives 04 through 07, 09, 10, and 13 through 15, investigated various mounds; refer to Section 4.3 for detailed observations.

### 4.1.3 Deepwater Coral Habitat Area of Particular Concern

NOAA Fisheries Service and the Secretary of Commerce recently approved (July 2010) the designation of five areas in the South Atlantic as Coral HAPCs (Figure 4.1-6). The largest of these areas, the Stetson–Miami Terrace CHAPC encompasses the eastern side of the CC Range in water depths deeper than approximately 385 m (Appendix C, Chart 11). Abundant mounds were mapped in the HAPC area. The seabed surrounding the mounds had relatively high snippets reflectivity, whereas the mounds themselves had relatively low reflectivity. Six sites were investigated with the ROV in the HAPC area; ROV 07, 09, 10 and 13 through 15. Observations from the ROV determined that the seabed was comprised primarily of sand with varying amounts of rock and coral rubble. The proportion of coral rubble increased on the mounds in comparison to the surrounding seabed. ROV 10 and 13 through 15 crossed features designated as hard coral mounds and live *Lophelia pertusa* patches were observed at all sites except ROV 09. Dead *Lophelia pertusa* was observed at all sites.
4.2 **C-CASS Video and Digital Still Camera Observations**

At the Navy’s direction only two C-CASS II deployments were conducted in the CC Range. Digital video and still images recorded with the C-CASS provided valuable bottom type information in areas not investigated with the ROV. Results of the deployments and brief descriptions of the casts are provided in Appendix F.

4.3 **ROV Dive Summaries and Classifications**

Eleven dives were investigated with the ROV (Appendix C, Chart 12). Biological and habitat observations were cataloged in real time during the ROV dive operations. Video from the dives was also reviewed post-survey for additional classification. The result was a searchable Microsoft Access database compiled for all ROV dives that included dive number, date, and time, as well as observations regarding geomorphological setting, seabed substrate composition, observed biological organisms, and references to relevant digital still images. This database is included with the digital deliverables associated with this report.

All dives are summarized below. The inset maps show the target bathymetry and significant features indicated by the symbology presented below, including sites of live *Lophelia pertusa*, and hard coral mounds. The start point for each ROV dive is marked by a green circle.

ROV Dive Site 01 – 06 May 2010

The target for ROV 01 was rough terrain at approximately 200 mwd where southwest-trending furrows incise the slope (Figure 4.3-1). The ROV launched at 1959 and reached the bottom at 2014 at a water depth of approximately 193 m. The current was fairly strong on the bottom (up to 1.5 knots); therefore, the ROV was moving fast over the bottom. The dive started over low relief, fine sand and silt, and within a few minutes, some scattered rock rubble was prevalent. This soft substrate with scattered rock rubble was the dominant habitat observed throughout the dive. Attached fauna was sparse to abundant at this site and at times included yellow and white gorgonian (Plexauridae) corals that formed habitat (Figure 4.3-2). Colonies ranged in size from 10 to 30 cm tall and
wide. Brittle stars were perched on several colonies, and scorpionfish, *Laemonema* hakes, and phycid hakes (mostly *Urophycis* sp.) were often observed lying next to the colonies. Also of note, a horseshoe crab was observed quickly followed by a rajid skate. *Rochinia* spider crabs were the most abundant mobile mega invertebrate observed. Other alcyonaceans (soft corals) were abundantly attached to the rock rubble, and at times, the attached corals were mixed 50/50 with gorgonians and alcyonaceans. Few colonial, white anemones were observed at times, which appeared like hard coral colonies from a distance (Figure 4.3-3). Digital still images were poor quality for this dive, so stills were clipped from video.

![Gorgonians on Sand](image1.jpg)

**Figure 4.3-2: Gorgonians on Sand**

![White Anemones on Sand and Scattered Rock](image2.jpg)

**Figure 4.3-3: White Anemones on Sand and Scattered Rock**
ROV Dive Site 02 – 06 May 2010

Target ROV 02 was a SW-oriented furrow in water depths ranging from 195 to 205 m (Figure 4.3-4). After a first dive attempt, the ROV had to re-surface because the ship was out of position. The ROV was then launched for a second time at 1108. The ROV reached the bottom at 1140 at approximately 195 mwd. The soft substrate was fine sand with low-relief, scattered, rock rubble. The seabed was mostly homogeneous throughout the dive, with a few patches of soft substrate lacking carbonate. The ROV reached a maximum depth of 205 m as it crossed the furrow. In addition, there were patches of scattered rock with attached fauna; however, fauna was mostly sparse to absent (Figure 4.3-5). Attached fauna that was present included a few gorgonians, sponges, hydroids, and other alcyonaceans. Few fishes were present, including scorpionfish (Family Scorpaenidae), Laemonema hakes, phycid hakes, and a chain catshark (Scyliorhinus retifer). Megainvertebrates included spider crabs (Rochinia crassa) (Figure 4.3-6), squat lobsters (Eumunida picta), Cidaris sea urchins, and sea biscuits. Digital still images were of poor quality due to the speed of the ROV over bottom, so still images were clipped from video every two minutes for this dive. ROV left bottom at 1223.

Figure 4.3-4: ROV 02 Dive Track

Figure 4.3-5: Scattered Rock and Sand

Figure 4.3-6: Megainvertebrates Included

Rochinia
ROV Dive Site 03

The target for dive ROV 03 was an 8 m high mound at a water depth of about 290 m. The first attempt, ROV 03-1, ended up west of the target; ROV 03-2 crossed the target feature (Figure 4.3-7).

ROV 03-1 – 19 May 2010

The ROV reached the bottom at 1356 at approximately 293 m depth. The ROV transited NNE towards the target mound over soft substrate that was scattered with coarse material (shell hash, pebbles) over medium sand. This substrate was annotated on the video tape incorrectly as scattered coral rubble (digital still evaluation helped refine). There was also a mixture of black and tan colored sediments here as well (Figure 4.3-8). The ROV transited west of the mound, and then moved over the northwest extent of the mound. Scattered coral rubble was observed on the mound. Coral rubble pieces were small fragments, and included dead *Lophelia pertusa* fragments and what appeared to be cup corals (Figure 4.3-9). The mound was not coded as a “hard coral mound” because of the overall lack of coral rubble and lithified material, although the feature may be in a certain stage of coral mound formation. On the flank of the mound at 284 mwd, there were sparse, attached alcyonaceans. Megafauna were few, and dominated by skates (*Fenestraja plutonia*). Overall, the video quality was fair, as the bright lights washed out much of the footage.

Figure 4.3-7: ROV 03 Dive Track

Figure 4.3-8: Spotted Hake (*Urophycis regia*) on Black and Tan Sand

Figure 4.3-9: Scattered Coral Rubble on Black and Tan Sand
**ROV 03-2 – 19 May 2010**

This was the second dive at site ROV 03. The ROV landed on bottom at approximately 293 m to the southwest of the mound at a water depth of approximately 288m. The ROV transited over a substrate of medium sand with coarser material on top (annotated as fine sand on video tape; digital stills aided in classification). Black colored sand occurred throughout the area as well (Figure 4.3-10). The ROV crossed over a mug with “Grace Line”, a passenger steamship company, inscribed on the bottom (Grace Line) (Figure 4.3-11). The habitat was consistent as the ROV moved over the feature from the southwest, reaching a minimum depth of 282 m atop the mound. A few white branches of *Lophelia pertusa* were observed. Although this was annotated on the videotape as live *Lophelia pertusa*, post-processing of the video revealed this to be dead coral rubble (Figure 4.3-12). The mound was not coded as a “hard coral mound” because of the overall lack of coral rubble and lithified material, although the feature may be in a certain stage of coral mound formation. The coral rubble that was observed included *Lophelia pertusa* and possibly cup corals. On the top of the mound, at approximately 292 mwd, alcyonaceans (soft corals) were sparsely attached. Notably, the entire area was fairly barren; only a few species that were few in number were observed, including skates (*Fenestraja plutonia*), shortbeard codling (*Laemonema barbatulum*) and spotted hake (*Urophycis regia*) (Figure 4.3-13). Overall, the video quality was fair, as the bright lights washed out much of the footage.

![Figure 4.3-10: Black and Tan Medium Sand and Scattered Rubble (S and SCR)](image1)

![Figure 4.3-11: Grace Line Ceramic Mug](image2)
ROV Dive Site 04 – 19 May 2010

Dive ROV 04 crossed the western extent of a westerly-trending linear ridge comprised of coalesced mounds (Figure 4.3-14). The ROV began its dive to the southwest of the feature at 340 mwd; however, the ROV had difficulty staying near bottom in the beginning of the dive. The habitat in the area was medium grained sand (black in color) with coarse shell hash (Figure 4.3-15). Sparsely scattered coral rubble may have been present as well, but this was difficult to tell in the video and was not seen in the digital stills. At approximately 1843, scattered coral rubble was observed as the ROV began transiting up slope. At 1845 the ROV reached the top of the feature at approximately 335 mwd where medium grained sand (black in color) was again the dominant habitat, forming sand ripples with lighter colored sand (Figure 4.3-16). Patches of scattered coral rubble (Lophelia and possibly cup corals) with sparsely attached fauna were also apparent on top of the mound (Figure 4.3-17). Scattered coral rubble continued down the northeast slope of the feature. This feature could be in a stage of coral mound formation; however, scattered rubble was sparse and no live coral or carbonate outcrops were observed. Thus, this mound was not coded as a “hard coral mound”. The soft sediment in
the entire area appeared to be fairly compacted as it did not stir up too much when bumped with the ROV. Fauna were not common in the area, but of the fauna observed, pancake urchins were dominant followed by shortbeard codling (*Laemonema barbatulum*). Other fauna observed in the area included golden crabs (*Chaceon fenneri*), greeneys (*Chlorophthalmus agassizi*), rajid skates, scorpionfish (*Trachyscorpia cristulata*) and blackbelly rosefish (*Helicolemus dactylopterus*). Brittle stars were very abundant and were observed with their arms in the water column. They were so abundant that they resembled attached fauna (Figure 4.3-18). Off the feature to the north, patches of scattered coral rubble and the black rippled sand were common (Figure 4.3-19).

![Figure 4.3-15: Pancake Urchin on Compacted Black Sand.](image)

![Figure 4.3-16: Rippled Black and Tan Sand on Top of Mound](image)

![Figure 4.3-17: Scattered Rubble (SCR) with Sparse Fauna, including a glass sponge, on Top of Mound](image)

![Figure 4.3-18: Octopus, Sponge and Abundant Brittle Stars on Top of Mound](image)

![Figure 4.3-19: Rippled Black and Tan Sand North of the Mound](image)
ROV Dive Site 05 – 19 May 2010

Dive ROV 05 crossed a west-trending line of coalesced mounds (Figure 4.3-20). The ROV moved northwest across a soft substrate comprised of compacted, rippled black and tan, fine to medium grain sand with scattered coarse material (Figure 4.3-21). The tan colored sand appeared to be finer, and looser than the dense, black sand. The ripple areas rose and fell like small rolling hills, with tan colored sand forming channels between the areas (Figure 4.3-22). The transitions between the light and dark sediment types were abrupt. At approximately 2046 the ROV began moving up the coalesced mounds, where scattered coral rubble (*Lophelia pertusa* and possibly cup corals) covered the seabed. Sponges and glass sponges were sparsely attached. These habitat types were seen throughout the dive: patches of scattered coral rubble intermixed with larger areas of rippled black/tan sand (Figures 4.4-23 and 4.4-24). Although some coral rubble was seen on the feature, this did not appear to be a “hard coral mound”. The rippled sand continued north of the mound, but became infrequent and less extensive toward the end of the dive (approximately 2110). Overall, fauna was depauperate in the area, but a few crabs, pancake urchins, blackbelly rosefish (*Helicolenus dactylopterus*), scorpionfish (*Trachyscorpi cristulata*), shortbeard codling (*Laemonema barbatulum*), silver hake (*Merluccius albidus*), unidentified ophidiiform, and sharks (*Scyliorhinus retifer* and *Squalus cubensis*) were observed. Brittle stars were abundant in the coral rubble areas and could be seen with their arms stretched out into the water column.
Figure 4.3-21: Rippled Sand (S)

Figure 4.3-22: Rippled Sand (S)

Figure 4.4-23: Coral Rubble and Abundant Brittle Stars on Mound

Figure 4.3-24: Chain Cat Shark (Scyliorhinus retifer) on Scattered Coral Rubble
Dive ROV 06 crossed a NNW-trending chain of coalesced mounds, the tallest of which was approximately 38 m (Figure 4.3-25). The ROV reached the bottom south of the feature at a water depth of approximately 385 m and headed NNE. The area south of the mound was comprised primarily of medium grain sand with scattered rock rubble and coarse shell fragments (Figure 4.3-26). The rock rubble had sparsely attached sponges and cup corals. An admixture of two sand types (black and tan color) was prevalent in the area. This admixture formed ripples on the bottom, and the sediment seemed fairly compacted (Figure 4.3-27). Small patches of Lophelia pertusa were observed on the scattered rocks south of the mound (Figure 4.3-28). Other fauna in this area included: greeneyes (Chlorophthalmus agassizi), skates (Breviraja claramaculata), and shortbeard codling (Laemonema barbatulum). Figure 4.3-29 shows a 76 mm cartridge that was identified on the seabed as a MK201 Blind Loaded and Plugged. The 76 mm cartridge ammunition is designed for US Navy Frigate usage. The ammunition is issued in the form of a fixed, completely assembled round, referred to as a cartridge. The 76 mm cartridge consists of a steel cartridge case that contains a primer assembly and a propelling charge. The cartridge case is then crimped around an explosive loaded projectile body and a fuse is assembled to the cartridge. The cartridge case, primer, propelling charge and projectile body is common to all the cartridges. The particular 76 mm cartridge shown in Figure 4.3-29 is a MK201 Blind Loaded and Plugged (BL-P). The standard projectile body is filled with inert material to bring it within the weight tolerance of the service projectile. The nose is fitted with an inert (dummy) fuse. These cartridges are used for target practice, ranging, and proving ground tests (identification and information provided by the Navy).
A thin layer of coral rubble occurred up slope, and low-relief carbonate rock outcrops occurred in patches (Figure 4.3-30). Although small and few live *Lophelia pertusa* thickets were observed, this feature is typical of a coral carbonate mound dominated by coral rubble at some stage of formation (Figure 4.3-31). At the top of the feature, at a water depth of approximately 340 m, a dense cover of soft corals (alcyanaceans) was apparent as well as a few glass sponges. As the ROV went down slope on the northern side of the mound, scattered coral patches occurred. In the flat area to the north of the feature, sand was prevalent.
The ROV landed on a 22 m high feature at approximately 395 mwd that appeared to be a coral carbonate mound in a certain stage of formation; however, due to the movement of the ship and ROV it was not possible to determine the extent of live *Lophelia pertusa* or lithified material on the mound (Figure 4.3-32). Thus, this mound was not coded as a “hard coral mound”. The sediment between mounds, at approximately 430 mwd, was comprised of fine sand with coarser material on top, including some scattered coral rubble and shell fragments (Figure 4.3-33). These sediment types were patchy between the two features. As the ROV moved northward over another, smaller mound (approximately 15 m in height), a thicker layer of coral rubble was observed. One live *Lophelia pertusa* colony observed was approximately 10 cm in diameter (Figure 4.3-34). In addition, a few rock outcrops were evident near the top of the mound at approximately 405 mwd (Figure 4.3-35). Attached fauna included soft corals and gorgonians, including *Plumarella* sp. and possibly bamboo corals. The second half of the dive consisted of the ROV moving northward down slope, and then along a fine sediment bottom with sand waves oriented in a south-north direction. Rattails (*Nezumia* spp.),
coral hake (*Laemonema melanurum*), blackbelly rosefish (*Helicolenus dactylopterus*), codling, and a blind torpedo ray (*Benthobatis marcida*) were observed as well as several pencil urchins and two golden (*Chaceon fenneri*) crabs.

**Figure 4.3-33: Blind Torpedo Ray (*Benthobatis marcida*) on Scattered Coral Rubble and Sand**

**Figure 4.3-34: Live *Lophelia pertusa* on Coral Rubble**

**Figure 4.3-35: Rock Outcrops on Scattered Coral and Rock Rubble**

**ROV Dive Site 08**

Dive ROV 08 was cancelled due to high current activity. Please refer to Appendix G for details.

**ROV Dive Site 09 – 20 May 2010**

Dive ROV 09 was conducted south of ROV 08 across several smaller (4 to 22 m high) mound structures (Figure 4.3-36). The habitat in the beginning of the dive was fine soft sediment with scattered coral rubble at a depth of approximately 475 m (Figure 4.3-37). At 1554, the ROV began transiting along the southeastern slope of a feature that was covered with a thicker layer of coral rubble with attached mixed fauna (alcyonaceans, gorgonians, sponges). This was the tallest feature crossed on this dive at approximately 22 m in height. The ROV did not cross over the tallest point but reached a minimum depth of approximately 452 m. At 1557, the ROV moved down the northern slope of the feature, where coral rubble with attached fauna continued. The ROV then moved along a scattered coral rubble
habitat with attached gorgonians and glass sponges (Figure 4.3-38), reaching a maximum depth of approximately 478 m before crossing over another small mound (4 m in height). On the video, it was annotated that this area was between two major features.

Habitats were fairly patchy throughout the dive, with varying amounts of coral rubble overlaying fine sand with varying amounts of attached fauna (sparse to abundant). In the areas between the major features, dunes of sand and scattered coral rubble were separated by areas of white, rippled sand (Figure 4.3-39). These sand ripples did not contain the black colored sand as seen in other areas. At 1621, the ROV moved across the northern slope of an 8 m high mound that was covered with coral rubble. At 1633 the ROV moved up the slope of another mound (9 m in height) that was covered with coral rubble. Overall, no live coral, lithified material, or large thickets/bushes of dead coral were observed on the features, but these features should be considered as “hard coral mounds” because of the extent of coral rubble.

This was not coded as such in the database and digital photo log because it was difficult to tell from the video when the ROV moved across a feature. Black sand appeared towards the end of the dive amidst the coral rubble, though white sand was prevalent throughout the dive. Pancake urchins, an octopus, shortbeard codling (*Laemonema barbatulum*), skate (*Fenestraja plutonia*), a deepwater shark (*Etmopterus* sp.), greeneyes (*Chlorophthalmus agassizi*), blackbelly rosefish (*Helicolenus dactylopterus*), and rattails (*Nezumia* spp.) were observed.
ROV Dive Site 10 – 20 May 2010

Site ROV 10 was located east of ROV 07 in an area of dense mounds (Figure 4.3-40). The ROV reached the bottom at a water depth of approximately 507 m, over a fine sand and silt sediment with coarse material on top, including coarse shell hash and dead coral rubble. This was the dominant habitat in the flat areas between the features (Figure 4.3-41). The features, approximately 14 to 16 m in height, were covered with coral rubble and coarse shell fragments and were coded as hard coral mounds because of the prevalence of coral rubble and lithified carbonates (Figure 4.3-42); one colony of live *Lophelia pertusa* was observed (approximately 12 cm diameter) (Figure 4.3-43). Attached fauna were sparse to moderate, and included a variety of glass sponges and gorgonians, including bamboo coral (Isididae), *Plumarella* sp. and the common white gorgonian (Plexauridae).
At times, gorgonians dominated the attached fauna. In addition, a black coral, *Bathypathes* sp., was observed at 0605 (Figure 4.3-44, left). Of note, a shark species (*Etmopterus* sp.) that we had not yet observed (Figure 4.3-44, right) was seen as well as a blind torpedo ray (*Benthobatis marcida*) and a goosefish (*Lophiodes reticulatus*).
ROV Dive Site 11
Dive ROV 08 was cancelled due to an elevated sea state. Please refer to Appendix G for details.

ROV Dive Site 12
Dive ROV 12 was cancelled due to high currents and mechanical problems. Please refer to Appendix G for details.
ROV Dive Site 13 – 20 May 2010

The target for dive ROV 13 was a mound located very near the southern limit of the survey area that was approximately 37 m in height (Figure 4.3-45). The ROV landed on the bottom at 1859 to the south of the feature and outside of the survey area at approximately 580 mwd. The sediment was fairly compacted and appeared to consist of medium grain sand. The bottom was covered with scattered coral rubble and attached gorgonians (including Plumarella sp.), sponges, and glass sponges (Figure 4.3-46). The ROV moved north to the feature up a gradual slope where this habitat continued with patches of sparse to abundant attached fauna and thicker layers of coral rubble. At 1913, a small (approximately 10 cm) live Lophelia pertusa colony was observed. At 1914, a large (approximately 70 cm) bamboo coral colony (Isididae) on what appeared to be the top of a small ridge was observed (Figure 4.3-47).

At 1915, the sediment consisted primarily of scattered coral rubble with abundantly attached mixed fauna. In general, the area south of the feature was depauperate of mobile fauna. However, blind torpedo rays (Benthobatis marcida) and deepwater sharks (Etmopterus sp.) were observed. Of note, a swimming crinoid was observed at 1904 and a coral hake (Laemonema melanurum) was seen in association with the bamboo coral. The ROV began moving up the southern slope of the feature at approximately 1923. The feature was a coral carbonate mound, with the slopes covered with thick coral rubble and dead, compacted coral that formed thickets. Attached fauna (sponges, gorgonians) were abundant. At times, live coral colonies or thickets of dead coral tipped with live branches were observed. Live and dead coral colonies included both Lophelia pertusa and Enallopsammia profunda (Figure 4.3-48). At 1926, a large Enallopsammia profunda thicket was observed, and this was near the top of one of the peaks at 541 mwd in the southwestern area of the feature. Large (approximately 50 to 100 cm) bamboo coral colonies were observed scattered throughout the area. At 1930, the ROV was in the center of the feature and this area appeared to have an extensive coverage of coral thickets (both live and dead). Both live and dead Enallopsammia profunda appeared to be more abundant than Lophelia pertusa. At approximately 1937 the ROV crossed over the shallowest peak of the mound at about 535 mwd before moving down the northern slope of the mound. The slope was covered with thickets of dead coral and coral rubble. At times, live coral branches were seen. Plumarella sp. were abundantly attached to the coral rubble on the slope and at the base of the feature. The area to the north of the feature was covered with scattered coral rubble and patches of dead coral thickets with sparse to abundant attached fauna (mostly Plumarella sp. and glass sponges). Mobile fauna
were noticeably depauperate on the feature, with the exception of an occasional coral hake (*Laemonema melanurum*) and a rattail (*Nezumia* spp.).

![Image](image1.png)  
Figure 4.3-46: Sand and Scattered Coral Rubble (SCR) with Moderate Mixed Fauna.  

![Image](image2.png)  
Figure 4.3-47: Bamboo Coral on Coral Rubble.  

![Image](image3.png)  
Figure 4.3-48: Hard Coral Mound (HCM) with Abundant Fauna, Including Mixed Live and Dead *Lophelia pertusa* and *Enallopsammia profunda*
ROV Dive Site 14

The target for dive ROV 14 was a cluster of mounds approximately 10 to 18 m in height, in the southeastern corner of the survey area (Figure 4.3-49). ROV technical problems cut short the first dive, and so two dives were conducted in the area. Dashed sections of ROV 14-2 show where ROV positions were interpolated due to acoustic positioning drop-outs.

ROV 14-1 – 20 May 2010

The ROV landed at about 610 mwd and crossed over a small (approximately 5 m in height) mound, reaching a minimum water depth of approximately 587 m. *Lophelia pertusa* rubble was apparent on the slope, as well as a few carbonate rock outcrops. Although few live coral colonies were observed, this mound appeared to be a coral carbonate mound dominated by coral rubble. Bottlebrush corals (Family Chrysogorgiidae) were common, as well as several species of glass sponges, white fan sponges, and the commonly observed alcyonacean in this area was abundant. One bamboo coral colony (ca. 40cm height) was observed. This dive was cut short due to complications with the ROV communications.

ROV 14-2 – 21 May 2010

The ROV arrived on bottom at 1914 at approximately 610 mwd and transited northward to a target feature over a rock rubble bottom with underlying sands of medium grain size (Figure 4.3-50). At approximately 1932, the ROV started heading up the slope of a feature that rose approximately 12 m from base. At the base of the slope, the substrate consisted of finer sands mixed with scattered, rock rubble and then scattered dead coral rubble. As the ROV transited up the slope on the western side of the feature, a thicker layer of coral rubble was observed and it appeared this was a coral-built carbonate mound, although only branches of live *Lophelia pertusa* were present (Figure 4.3-51). No large colonies, thickets, or bushes were seen, although a few scattered low-relief carbonate blocks were observed (Figure 4.3-52). In the area to the north of the mound, scattered coral rubble was the dominant substrate. At times, a thicker layer of coral rubble was present or scattered coral rubble was mixed with rock rubble. The ROV continued transiting NNE along this type of habitat to a second feature, which consisted of two mounds together with a narrow channel between them at the northern end. At the base of these features, more patches of fine sands were seen with varying amounts of coral rubble. The ROV split the two mounds through the channel, so the ship moved to the western mound and the ROV
transited along the northeastern flank where coral rubble was the dominant substrate (Figure 4.3-53). Attached fauna were sparse to abundant and included predominantly the gorgonian *Plumarella* sp., a few species of glass sponge, a bottlebrush coral (Family Chrysogorgiidae), and small white gorgonians (Plexauridae). The amount of attached fauna (sparse to abundant) varied throughout the area. Few fishes and invertebrates were seen, including several species of sharks, a duckbill eel (Nettastomatidae), rattails (*Nezumia* spp.), and codling (*Laemonema barbatulum*). The ROV experienced some positioning drop-outs during this dive, resulting in the need for interpolation between several sections of the trackline. These sections have been plotted as “inferred ROV Track” on the charts.

Figure 4.3-50: Rock Rubble (RR) with Sparse Gorgonacea.

Figure 4.3-51: Hard Coral Mound (HCM) with Moderate Fauna
**ROV Dive Site 15 – 07 May 2010**

Dive ROV 15 was conducted along a ridge in the northeastern corner of the survey area (Figure 4.3-54). The ridge rises approximately 68 m from the surrounding seabed before dropping steeply east of the ridge. The ROV began the dive at the southwestern end of the ridge at a water depth of approximately 580 m. Strong current activity hindered the progress of the ROV, however observations made during this short dive indicated that this ridge was a coral carbonate mound. The western slope was steep and covered with dead *Lophelia pertusa* rubble mixed with fine sediment. Attached fauna was generally sparse to absent and included few soft corals and hexactinellid (glass) sponges. A few low-relief, lithified carbonate blocks (less than 1m in diameter) were seen on the slope near the base of the ridge.

![Figure 4.3-52: Low Relief Rock Outcrops](image)

![Figure 4.3-53: Mixed Fauna on a Hard Coral Mound](image)

![Figure 4.3-54: ROV 15 Dive Track](image)
(Figure 4.3-55). As the ROV transited up slope, larger branches and thickets of dead *Lophelia pertusa* were observed as well as a few (approximately 5) low relief, live *Lophelia pertusa* colonies. These were approximately 0.5 m in diameter (Figure 4.3-56). Of note, a characteristic deep reef fish species that is often seen in primary, deep coral reef habitat was observed, *Laemonema melanurum*, otherwise known as the coral hake. The shallowest point on the ridge reached by the ROV was approximately 545 mwd on the western slope. Digital still images were poor quality for this dive, so stills were clipped from video.
5.0 SURVEY INSTALLATION AND QUALITY PROCEDURES

The objective of the CC Range survey was to collect a multibeam bathymetry dataset that encompassed a full search of the seafloor and met IHO Order 1a accuracy standards (Figure 5.0-1). For IHO Order 1a, feature detection is a 2 m cube for water depths of up to 40 m and 10 percent of depth for water depths beyond that depth. The CC Range survey depth range was approximately 40 to 679 meters; therefore, a 2 m cube and a 68 m cube were the specified bounds for the feature detection for this project. The resolution of the SeaBat 7125-SV and the SeaBat 7150-F allowed the detection of significantly smaller features than this specification. The strategies developed for the survey area took into account minimum depths, general bathymetry, and time allotment. After the equipment was installed, a series of checks were performed to ensure that the data met or exceeded the IHO standards specified for this project.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Order</th>
<th>Special</th>
<th>1a</th>
<th>1b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 1</td>
<td>Description of areas.</td>
<td>Areas where under-keel clearance is critical</td>
<td>Areas shallower than 100 metres where under-keel clearance is less critical but features of concern to surface shipping may exist.</td>
<td>Areas shallower than 100 metres where under-keel clearance is less critical but features of concern to surface shipping may exist.</td>
</tr>
<tr>
<td>Chapter 2</td>
<td>Maximum allowable THU 95% confidence level</td>
<td>2 metres</td>
<td>5 metres + 5% of depth</td>
<td>5 metres + 5% of depth</td>
</tr>
<tr>
<td>Para 3.2 and note 1</td>
<td>Maximum allowable EUV 95% confidence level</td>
<td>a = 0.25 metre, b = 0.0075</td>
<td>a = 0.5 metre, b = 0.013</td>
<td>a = 0.5 metre, b = 0.013</td>
</tr>
<tr>
<td>Glossary and note 2</td>
<td>Full sea floor search</td>
<td>Required</td>
<td>Required</td>
<td>Not required</td>
</tr>
<tr>
<td>Para 3.4</td>
<td>Feature Detection</td>
<td>Cubic features &gt; 1 metre</td>
<td>Cubic features &gt; 2 metres, in depths up to 40 metres, 10% of depth beyond 40 metres</td>
<td>Not required</td>
</tr>
<tr>
<td>Para 3.5 and note 3</td>
<td>Recommended maximum line spacing</td>
<td>Not defined as full sea floor search</td>
<td>Not defined as full sea floor search</td>
<td>3 x average depth or 25 metres, whichever is greater</td>
</tr>
<tr>
<td>Chapter 2 and note 5</td>
<td>Positioning of fixed aids to navigation and topography significant to navigation (95% confidence level)</td>
<td>2 metres</td>
<td>2 metres</td>
<td>2 metres</td>
</tr>
<tr>
<td>Chapter 2 and note 5</td>
<td>Positioning of the coastline and topography less significant to navigation (95% confidence level)</td>
<td>10 metres</td>
<td>20 metres</td>
<td>20 metres</td>
</tr>
<tr>
<td>Chapter 2 and note 5</td>
<td>Mean position of floating aids to navigation (95% confidence level)</td>
<td>10 metres</td>
<td>10 metres</td>
<td>10 metres</td>
</tr>
</tbody>
</table>

To calculate the error limits for depth accuracy the corresponding values of a and b listed in Table 1 have to be introduced into the formula

$$\pm \sqrt{a^2 + (b \cdot d)^2}$$

with

- a constant depth error, i.e. the sum of all constant errors
- b*d depth dependent error, i.e. the sum of all depth dependent errors
- b factor of depth dependent error
- d depth

**Figure 5.0-1: IHO Fifth Edition Summary of Minimum Standards for Hydrographic Surveys**
Tetra Tech performed installation calibrations of the POS MV and both the SeaBat 7125-SV and SeaBat 7150-F at the start of the survey operations. Quality checks on the sonar and support sensor data to verify installation calibrations, comparing overlapping parallel and cross lines, were performed on an ongoing basis, throughout the survey data collection period, and verified in subsequent post-processing.

### 5.1 **Installation QC**

While a bar check can be performed fairly easily if a MBE or SBE are installed on a side-mount or bow-mount pole, it was not practical to do so with the NaviSound 640 SBE, SeaBat 7125-SV, or SeaBat 7150-F multibeam sonars that were mounted near the centerline of the large survey vessel used for this project. Instead, the multibeam depths were compared to those from the single-beam system and analytic software tools were used to determine and report the correlation between the MBE data sets (refer to Section 5.3.1).

### 5.2 **Position QC/Validation**

Prior to departing the Jacksonville area, a spare Trimble Ag132 DGPS (Ag132) was set up on a National Ocean Survey (NOS) bench mark and data were logged. This QC check of the Ag132 was performed to verify the positional (X and Y) accuracy of the unit based on received U.S. Coast Guard differential corrections.

NOS benchmark 0220, a brass cap embedded in concrete and encased in a 4-inch polyvinyl chloride (PVC) pipe, was used for this position quality check. The GPS antenna was set directly over the control point. The Ag132 interfaced with HYPACK navigation software was used to log a static position file for approximately 5 minutes. Resulting values from the check are summarized in Table 5.2-1.

<table>
<thead>
<tr>
<th>NOS 0220 Reported Coordinates</th>
<th>X: 458563.7326</th>
<th>Y: 3362443.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT Recorded Average Values</td>
<td>X: 458563.61</td>
<td>Y: 3362443.60</td>
</tr>
<tr>
<td>Horizontal Difference</td>
<td>0.12 m</td>
<td>-0.29 m</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>X = 0.16 m</td>
<td>Y = 0.08 m</td>
</tr>
<tr>
<td>Geodesy: UTM Zone 17, Units: Meters</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.2-1 shows the instrumentation used for the test as well as the NOS bench mark. These data confirmed that the positioning systems utilized on the vessel for the USWTR survey were capable of achieving horizontal accuracy of two meters and that the U.S. Coast Guard correction was being received and properly applied.

Figure 5.2-2 shows the scatter plot of the positions reported by the rover QC Ag132 GPS during the data collection over the control point. The rover QC Ag132 was then placed directly adjacent to the Ag132 installed on the survey vessel and data were logged separately from the rover Ag132 and the POS MV. The Ag132 antenna position was calculated by applying the vessel heading and the offsets from the POS MV IMU to the antenna. This position was then compared to the positions reported by the rover. This allowed Tetra Tech to tie the position
accuracy of the ships survey navigation system back to the benchmark. Figure 5.2-3 shows the scatter plot of the positions reported by the rover QC Ag132 compared to the positions reported by the POS MV 320 for the Ag132 antenna installed on the vessel.

Figure 5.2-1: Trimble Ag132 Logging Confirmation Data on NOS Benchmark 022

Figure 5.2-2: Rover QC AG vs. NOS Benchmark 0220 Comparison Scatter Plot
5.3 SYSTEM CALIBRATION AND CONFIDENCE CHECKS

5.3.1 Multibeam and Single Beam Comparison

In an effort to evaluate the accuracy of the SeaBat 7125-SV multibeam and the NaviSound 640 single beam sonar systems installed on the survey vessel, surface to surface and point to surface comparisons were conducted during the patch test. These tests took place 08 December 2009 offshore of Jacksonville, FL.

Using CARIS and HYPACK, the multibeam and single beam data were cleaned for navigational, attitude, and noise errors. Relevant tide (station 8720218 in Mayport, FL) and sound velocity corrections were also applied in CARIS and HYPACK and the data were merged. A one meter grid was then created in Fledermaus from the edited multibeam data. Using the Fledermaus Cross-Check application, a point to surface comparison was then conducted between the multibeam and single beam data. Single beam and multibeam data were collected simultaneously. Single beam tracklines are displayed over the multibeam one meter grid surface in Figure 5.3-1. The mean and median difference between these measurements was -0.14 m and -0.125 m, respectively.
Pass/fail criteria in the Cross-Check application are based on the shallowest depths in the comparisons. When there is a large range of depths in the input data, as there was in this comparison, this provides a worst-case, excessively stringent result, since tolerances for the comparisons should increase with the depths of the measurements. While this caused the Special Order level comparison to be rejected, passing the Order 1a test indicates there was a very good correlation between the single beam and multibeam data.

![Figure 5.3-1: Fledermaus Cross-Check Application (Single Beam Data vs. Multibeam Data)](image)

### 5.3.2 Static Draft Correction

The static draft is the draft of the vessel at rest, fully loaded, and outfitted for surveying. The value is affected by the amount of equipment, fuel, personnel, and other gear loaded onto the vessel, and is also a function of the density of the water in which the vessel is operating. Draft measurements were performed several times throughout the survey by observing the draft marks on the hull and were found to be very consistent. In May 2009, a vertical offset measurement between the draft marks and the transducer was determined (BSURE). This allowed the survey team to observe the draft marks on the hull and calculate the sonar’s static draft while the vessel was in the water. These values were entered into the CARIS vessel configuration file (VCF) to reflect the change in draft during the survey (Table 5.3-1).
## Table 5.3-1: Survey Vessel Draft Measurements

<table>
<thead>
<tr>
<th>Date</th>
<th>Starboard IMU Draft (m)</th>
<th>Port IMU Draft (m)</th>
<th>Average IMU Draft (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/08/09</td>
<td>0.3</td>
<td>0.5</td>
<td>0.4</td>
<td>Static draft measurement taken at Atlantic Marine, Jacksonville, Florida, prior to leaving dock for survey</td>
</tr>
<tr>
<td>12/21/09</td>
<td>0.35</td>
<td>0.55</td>
<td>0.45</td>
<td>Static draft measurement taken at Atlantic Marine, Jacksonville, Florida, after partial completion of survey</td>
</tr>
<tr>
<td>3/26/10</td>
<td>0.35</td>
<td>0.45</td>
<td>0.43</td>
<td>Static draft measurement taken at St. John’s Boat Company, Jacksonville, Florida, towards completion of survey</td>
</tr>
</tbody>
</table>

### 5.3.3 POS MV GAMS Calibration

A successful POS GAMS calibration was performed offshore on 08 December 2009, prior to conducting the multibeam patch test and survey operations. The GAMS is used to aid the POS in determining precise heading, and a calibration is necessary after system installation. The GAMS test required the vessel to perform a series of dynamic maneuvers that allowed the POS to identify a solution for the current installation (Table 5.3-2).

### Table 5.3-2: POS MV GAMS Calibration

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GAMS Values (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>POS GPS Antenna Separation (meters)</td>
<td>2.841</td>
</tr>
<tr>
<td>Heading Calibration Threshold (degrees)</td>
<td>0.500</td>
</tr>
<tr>
<td>Heading Correction (degrees)</td>
<td>0.000</td>
</tr>
</tbody>
</table>

### 5.3.4 Sound Speed Profilers

Variations in sound speed through the water column cause the sonar beams to refract and the path length to increase or decrease with the changes in sound speed. These effects increase with beam angle from nadir (vertical) and with water depth. To compensate for these effects, the survey system must collect sound speed profiles through the water column and create a mathematical model that determines the true ranges and angles to the bottom for each beam for each sounding.

As specified within the project Work Plan, UCTD and XBT sensors were used throughout the CC Range survey to monitor sound speed through the water column. The UCTD sensors collect conductivity, temperature, and pressure information, providing the full data set required to calculate the sound speed versus depth. The XBT collects temperature data only, requiring the input of an average salinity to calculate sound speed, and determines depth as a function of time from launch.

UCTD and XBT casts were deployed while the ship was underway and traveling at a speed of up to 8 kts. For increased accuracy, the survey used UCTD sensors as the primary sound speed profile collection system. To confirm the accuracy of the sound speed profiles collected, Tetra Tech periodically compared the results of the three separate systems: XBT, XCTD and UCTD
(Figure 5.3-2, Figure 5.3-3, Figure 5.3-4). An average salinity value extracted from the UCTD data was used in the XBT software to calculate the sound speeds from the temperature profile.

Figure 5.3-2: XCTD/XBT Comparison

Figure 5.3-3: UCTD/XCTD Comparison
5.3.5 Multibeam Patch Test

During the Sea-Trials of the survey vessel and sonar systems off the east coast of Florida on 08 December 2009, Tetra Tech conducted a multibeam “calibration” or “patch” test to determine the installation angles of the SeaBat 7125-SV 400 kHz and the SeaBat 7150-F 24 kHz multibeam sonar systems.

This test was conducted approximately 67 NM east of Jacksonville, over a line of rock ridges running parallel to the coast. The test was conducted in approximately 50 to 60 m of water using DGPS aided Applanix POS MV to maximize positioning and heading accuracies. A parallel set of rock ridges, possible former shorelines, running roughly north-south along the coast, were selected for the calibration. The ridge structure provided well defined slopes in excess of 10% and some small discrete features (Figure 5.3-5).

Multiple collections were performed over 3 survey lines laid out over the features. Cross sections perpendicular to the vessel track, in flat areas away from the rock ridges, were used to determine roll offsets. Cross sections parallel to the vessel track were used to determine latency, pitch, and yaw offsets.
The data were collected and processed using HYPACK/HYSWEEP and then imported into Caris HIPS software. Calibration values were determined both in HYPACK MBMax and in Caris and compared as a further validity check.

The derived installation offsets from the MBMax processing are listed in Table 5.3-3.

### Table 5.3-3: RESON SeaBat 7125-SV 400 kHz and 7150-F 24 kHz Patch Test Results

<table>
<thead>
<tr>
<th></th>
<th>RESON SeaBat 7125-SV 400 kHz</th>
<th>RESON SeaBat 7150-F 24 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>-0.34</td>
<td>-0.42</td>
</tr>
<tr>
<td>Pitch</td>
<td>-0.20</td>
<td>-0.50</td>
</tr>
<tr>
<td>Yaw</td>
<td>-0.60</td>
<td>-1.00</td>
</tr>
<tr>
<td>Latency</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The patch test analysis of the SeaBat 7125-SV 400 kHz was subsequently performed using the Caris patch test tool in an effort to improve the results. While these differences were small, they did result in a slight improvement of the correlations between data from overlapping survey lines.

The SeaBat 7150-F offsets were compared to those derived and validated during a previous deep water survey conducted in August of 2009 off of San Diego, CA in approximately 1700 m of water. The roll offset was the same; however, there were small differences in the yaw and pitch offsets. Since the patch test for the earlier project had been conducted in much deeper water,
which provides more accurate results for those offsets, the pitch and yaw offset values from the previous calibration were used.

The updated patch test results are shown in Table 5.3-4. These values were used for all processing.

### Table 5.3-4: Reprocessed Multibeam Sonar Patch Test Results

<table>
<thead>
<tr>
<th></th>
<th>RESON SeaBat 7125-SV 400 kHz</th>
<th>RESON SeaBat 7150-F 24 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll</td>
<td>-0.36</td>
<td>-0.42</td>
</tr>
<tr>
<td>Pitch</td>
<td>-0.53</td>
<td>-0.10</td>
</tr>
<tr>
<td>Yaw</td>
<td>-0.60</td>
<td>-0.80</td>
</tr>
<tr>
<td>Latency</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

#### 5.3.6 Tie Line Comparisons

Multiple tie lines, lines approximately perpendicular to the survey data collection lines, were collected as a further QC check and to confirm IHO Order 1a was being achieved. The Fledermaus CrossCheck utility, which conducts a point-to-surface comparison, was used to compare the data collected from the survey main scheme lines and the survey tie lines.

Table 5.3-5 shows the comparison results between the survey gridded surface and tie line XYZ point data. Appendix H contains screen captures from these point-to-surface comparisons. All comparisons showed a high level of repeatability throughout the survey operations period and compliance with IHO Order 1a.
Table 5.3-5: Representative Tie Line Comparison Results

<table>
<thead>
<tr>
<th>Test Line</th>
<th>Data Range (m)</th>
<th>Data Mean (m)</th>
<th>Median Diff (m)</th>
<th>Mean Diff (m)</th>
<th>Std Dev (m)</th>
<th>Mean Depth + 1.96 * SD</th>
<th>IHO Order 1a Error Limit (m)</th>
<th>Met Order 1a Spec?</th>
</tr>
</thead>
<tbody>
<tr>
<td>118_Shallow</td>
<td>42 - 105</td>
<td>51</td>
<td>-0.18</td>
<td>-0.18</td>
<td>0.10</td>
<td>0.02</td>
<td>0.83</td>
<td>Yes</td>
</tr>
<tr>
<td>119_Shallow</td>
<td>43 - 89</td>
<td>52</td>
<td>-0.17</td>
<td>-0.18</td>
<td>0.10</td>
<td>0.02</td>
<td>0.84</td>
<td>Yes</td>
</tr>
<tr>
<td>120_Shallow</td>
<td>38 - 105</td>
<td>53</td>
<td>-0.18</td>
<td>-0.19</td>
<td>0.12</td>
<td>0.05</td>
<td>0.85</td>
<td>Yes</td>
</tr>
<tr>
<td>121_Shallow</td>
<td>43 - 105</td>
<td>57</td>
<td>-0.22</td>
<td>-0.22</td>
<td>0.15</td>
<td>0.07</td>
<td>0.89</td>
<td>Yes</td>
</tr>
<tr>
<td>123_Shallow</td>
<td>44 - 105</td>
<td>53</td>
<td>-0.19</td>
<td>-0.20</td>
<td>0.12</td>
<td>0.04</td>
<td>0.85</td>
<td>Yes</td>
</tr>
<tr>
<td>124_Shallow</td>
<td>41 - 100</td>
<td>50</td>
<td>0.01</td>
<td>0.01</td>
<td>0.10</td>
<td>0.21</td>
<td>0.82</td>
<td>Yes</td>
</tr>
<tr>
<td>All_Shallow</td>
<td>38 - 105</td>
<td>52</td>
<td>-0.15</td>
<td>-0.15</td>
<td>0.14</td>
<td>0.12</td>
<td>0.84</td>
<td>Yes</td>
</tr>
<tr>
<td>118_Mid</td>
<td>94 - 258</td>
<td>196</td>
<td>0.15</td>
<td>0.11</td>
<td>0.74</td>
<td>1.56</td>
<td>2.60</td>
<td>Yes</td>
</tr>
<tr>
<td>119_Mid</td>
<td>94 - 257</td>
<td>197</td>
<td>-0.02</td>
<td>-0.05</td>
<td>0.54</td>
<td>1.01</td>
<td>2.61</td>
<td>Yes</td>
</tr>
<tr>
<td>120_Mid</td>
<td>100 - 257</td>
<td>194</td>
<td>-0.04</td>
<td>-0.04</td>
<td>0.64</td>
<td>1.21</td>
<td>2.57</td>
<td>Yes</td>
</tr>
<tr>
<td>121_Mid</td>
<td>100 - 257</td>
<td>191</td>
<td>-0.17</td>
<td>-0.11</td>
<td>0.73</td>
<td>1.31</td>
<td>2.53</td>
<td>Yes</td>
</tr>
<tr>
<td>123_Mid</td>
<td>99 - 257</td>
<td>193</td>
<td>-0.17</td>
<td>-0.16</td>
<td>0.54</td>
<td>0.90</td>
<td>2.56</td>
<td>Yes</td>
</tr>
<tr>
<td>124_Mid</td>
<td>93 - 258</td>
<td>190</td>
<td>0.14</td>
<td>0.14</td>
<td>0.75</td>
<td>1.61</td>
<td>2.52</td>
<td>Yes</td>
</tr>
<tr>
<td>All_Mid</td>
<td>93 - 258</td>
<td>194</td>
<td>-0.03</td>
<td>-0.02</td>
<td>0.66</td>
<td>1.26</td>
<td>2.57</td>
<td>Yes</td>
</tr>
<tr>
<td>118_Deep</td>
<td>244 - 623</td>
<td>406</td>
<td>-0.01</td>
<td>0.02</td>
<td>1.58</td>
<td>3.11</td>
<td>5.30</td>
<td>Yes</td>
</tr>
<tr>
<td>119_Deep</td>
<td>244 - 625</td>
<td>453</td>
<td>-0.17</td>
<td>-0.25</td>
<td>1.74</td>
<td>3.17</td>
<td>5.91</td>
<td>Yes</td>
</tr>
<tr>
<td>120_Deep</td>
<td>244 - 624</td>
<td>416</td>
<td>-0.15</td>
<td>-0.14</td>
<td>1.78</td>
<td>3.35</td>
<td>5.43</td>
<td>Yes</td>
</tr>
<tr>
<td>121_Deep</td>
<td>243 - 634</td>
<td>430</td>
<td>0.03</td>
<td>-0.02</td>
<td>2.07</td>
<td>4.04</td>
<td>5.61</td>
<td>Yes</td>
</tr>
<tr>
<td>123_Deep</td>
<td>243 - 654</td>
<td>403</td>
<td>-0.04</td>
<td>-0.09</td>
<td>1.71</td>
<td>3.26</td>
<td>5.26</td>
<td>Yes</td>
</tr>
<tr>
<td>124_Deep</td>
<td>243 - 590</td>
<td>396</td>
<td>-0.07</td>
<td>-0.07</td>
<td>1.62</td>
<td>3.11</td>
<td>5.17</td>
<td>Yes</td>
</tr>
<tr>
<td>All_Deep</td>
<td>243 - 654</td>
<td>419</td>
<td>-0.07</td>
<td>-0.10</td>
<td>1.78</td>
<td>3.39</td>
<td>5.47</td>
<td>Yes</td>
</tr>
</tbody>
</table>

5.3.7 ROV System Navigation Check

A system navigation check for the ROV platform to verify the accuracy of the IXSEA GAPS USBL system during the ground truthing consisted of driving the ROV over a distinct pinnacle feature and then comparing the horizontal and vertical ROV beacon position to the high resolution multibeam bathymetry data. This check confirmed the GAPS system was accurately tracking the position of the ROV system. In addition, vertical position was continually monitored and compared to the MBES data on every dive. Based on this information, the system was found to provide accurate data.

ROV tracklines were edited to remove fliers and navigation gaps less than two minutes in length were interpolated for continuity.
6.0 DELIVERABLES

To make the most use of the at-sea time, preliminary processing of all collected data was conducted while at sea. Editing of the bathymetry data occurred during and immediately following acquisition with an approximate half-day delay between data collection and preliminarily processed bathymetry. All of the preliminary bathymetry editing was completed prior to the departure of the survey vessel and crew from the project site to verify that the survey objectives had been met prior to demobilization of the multibeam equipment. Preliminary processing and software development for the multibeam snippets data were performed offshore; final processing of snippets imagery data was completed post-survey.

Seabed classifications from the snippets imagery and other data sets were conducted using ArcGIS tools to determine the boundaries of various bottom types within the survey area, and to help locate any discrete features, such as reefs, that may represent either protected habitat or are relevant to the planning of subsequent construction activities.

A copy of all bathymetric shipboard processed preliminary data was delivered to the client at the completion of the survey operations.

ROV and C-CASS II video and preliminary biological observation and classification log were provided to the NTR upon completion of the ground-truthing operations.

Refer to Table 6-1 for all project-specific deliverables required to complete this offshore survey and benthic habitat characterization effort and to Table 6-2 for a summary of project delivery dates.

### Table 6-1: Summary of Data Deliverables

<table>
<thead>
<tr>
<th>Delivery</th>
<th>Product</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipboard</td>
<td>Preliminary Bathymetry</td>
<td>ASCII XYZ&lt;br&gt;Arc ASCII Grid</td>
</tr>
<tr>
<td></td>
<td>Preliminary Seabed</td>
<td>SeaBat 7125-SV and 7150–F snippet data in HSX format (Delivered with raw bathymetry data)</td>
</tr>
<tr>
<td></td>
<td>Classification</td>
<td>SeaBat 7125-SV and 7150–F snippet data in HSX format (Delivered with raw bathymetry data)</td>
</tr>
<tr>
<td></td>
<td>C-CASS II digital still images</td>
<td>JPG</td>
</tr>
<tr>
<td></td>
<td>C-CASS II digital video</td>
<td>AVI</td>
</tr>
<tr>
<td></td>
<td>ROV digital still images</td>
<td>JPG</td>
</tr>
<tr>
<td></td>
<td>ROV video</td>
<td>MPEG</td>
</tr>
<tr>
<td>Draft</td>
<td>Draft Report</td>
<td>Electronic (.pdf)</td>
</tr>
<tr>
<td>Final</td>
<td>Final Report</td>
<td>Electronic (.pdf)&lt;br&gt;Paper</td>
</tr>
<tr>
<td></td>
<td>Final Bathymetry</td>
<td>Raw data (Hypack and CARIS Project files)&lt;br&gt;ASCII XYZ&lt;br&gt;Arc ASCII Grid</td>
</tr>
</tbody>
</table>
Table 6-1: Summary of Data Deliverables (continued)

<table>
<thead>
<tr>
<th>Delivery</th>
<th>Product</th>
<th>Format</th>
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<tbody>
<tr>
<td>Final</td>
<td>Final Seabed Classification</td>
<td>Raw data (Delivered with raw Hypack project files, C-CASS II, and ROV data) Shapefile polygons of sediment classification</td>
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<tr>
<td>(cont.)</td>
<td>C-CASS II digital still images</td>
<td>JPG</td>
</tr>
<tr>
<td></td>
<td>C-CASS II digital video</td>
<td>AVI</td>
</tr>
<tr>
<td></td>
<td>ROV digital still images</td>
<td>JPG</td>
</tr>
<tr>
<td></td>
<td>ROV observations</td>
<td>Microsoft Access Database</td>
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<tr>
<td></td>
<td>ROV video</td>
<td>MPEG</td>
</tr>
<tr>
<td></td>
<td>PPP Data</td>
<td>Raw and processed POSPac, GPS precise ephemeris, and PPP GPS data</td>
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Table 6-2: Data Set and Report Deliverable Submission Criteria

<table>
<thead>
<tr>
<th>Submission</th>
<th>Number of Hard Copies/Electronic</th>
<th>Due Date (Calendar Days or Date)</th>
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<tr>
<td>Preliminary Data Set</td>
<td>0/1</td>
<td>At completion of at-sea survey</td>
</tr>
<tr>
<td>Draft Cruise Report</td>
<td>0/1</td>
<td>30 July 2010</td>
</tr>
<tr>
<td>Pre-Final Cruise Report</td>
<td>0/1</td>
<td>12 November 2010</td>
</tr>
<tr>
<td>Final Cruise Report</td>
<td>10/10</td>
<td>14 January 2011</td>
</tr>
<tr>
<td>Raw &amp; Processed Hydrographic Survey Data</td>
<td>0/2</td>
<td>with Final Cruise Report by 14 January 2011</td>
</tr>
<tr>
<td>ROV Video Footage</td>
<td>0/2</td>
<td>with Final Cruise Report by 14 January 2011</td>
</tr>
</tbody>
</table>

Data Delivery and CD-ROM Requirements

- Tetra Tech will provide draft and final versions of the cruise report summarizing data collected and problems encountered during the hydrographic and ground-truthing surveys of the CC Range. Draft version electronic only, final version as both an electronic and hardcopy (10 copies) version.
- Both the raw and processed hydrographic survey data for the CC Range will be provided with the final report.
- All ROV video footage collected during the survey (2 copies) will be provided on external hard drives with the final report.
- Portable Document Format (PDF) files of final documents shall be provided in the following formats:
  - The entire document shall be provided as a single PDF file.
  - The PDF file shall have bookmarks for each item identified in the document's table of contents. The bookmark shall use the same description as provided in the table of contents. If the bookmark is lengthy, it shall be abbreviated as needed. Bookmarks shall be to the second level (e.g., 1.1, 1.2, 1.3, etc.). The signature page, list of acronyms, individual tables, photos, or figures shall not be bookmarked.
The compact disc (CD) jewel case cover (outside front) and CD label shall use the current approved layout and include the NAVFAC Atlantic Logo, Contract Number, Contract Task Order (CTO) Number, Report Title, Site, Location, and Date Report Finalized. Standard CD jewel cases shall be used. The jewel case spine shall identify the report title, site, and location.
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7.0  WORKPLAN AND CONTRACT REVISIONS

The following Navy approved technical changes were made to the CC Range survey and ground truthing work plan and contract after the initial award of the task order in September 2009.

- Grab sampling for ground truthing within the CC FIREX-GUNEX was removed from the Work Plan at Navy’s request on 30 November 2009. This was done due to safety concerns associated with the possibility of encountering munitions and explosives of concern (MEC) within the range. Acquisition of video and still camera images were added to the C-CASS system as an alternative and replacement for sediment grab sampling in the CC Range.

- The Navy awarded Modification 01 to TO 0028 on 01 March 2010. This modification added still photo acquisition to the remotely operated vehicle (ROV) ground truthing tasks of TO 0028 and TO 0029. During ground truthing C-CASS deployments were limited to two deployments, at the Navy’s direction, in favor of focusing efforts on ROV operations.

- Historically adverse weather conditions well in excess of those anticipated negatively impacted the task order survey and deliverable schedules. The contract and approved Final Work Plan specified the sea state limitation for the collection of valid multibeam was at Sea State Condition 5 (minimum wind speed of 17 kts, minimum mean wave height of 2m). Offshore conditions exceeded those limitations more than 50% of the time that the MBE survey was conducted in December 2009 and April 2010. When encountered, these inclement weather conditions adversely impacted the quality of multibeam sonar data, including backscatter and snippets data. Although multibeam sonar data meet or exceed IHO Order 1a, raw bathymetry data and digital terrain models contain artifacts that would not be present in data collected under more favorable sea state conditions. Additionally, elevated sea state conditions produced artifacts and increased “noise” in the backscatter/snippets data.

- An analysis of multibeam sonar data collected with the RESON SeaBat 7125-SV determined that 95% of the data from the outer beams (60 to 64 degrees from nadir, port and starboard sides) were within Order 1a acceptance criteria. Since Order 1a requires compliance with a 95% confidence level Tetra Tech requested and the Navy approved use of 128 rather than 120 degrees of the SeaBat 7125-SV sonar swath as stated in the Final Work Plan. This acceptance criteria revision was made to increase survey efficiency and minimize the impact of delays associated with adverse weather.

- The period of performance for the task order was extended from 30 June 2010 to 30 September 2010 through Modification 01 of the Task Order. As a result of this, the schedule for delivery of the Draft and Final Cruise Reports and all data (both raw and processed) were revised to 30 July 2010 and 30 September 2010, respectively.

- The period of performance for the task order was extended from 30 September 2010 to 23 December 2010 through Modification 02 of the Task Order. As a result of this, the schedule for delivery of Final Cruise Report and all data (both raw and processed) was revised to 23 December 2010.
The period of performance for the task order was extended from 23 December 2010 to 14 January 2011 through Modification 03 of the Task Order. As a result of this, the schedule for delivery of Final Cruise Report and all data (both raw and processed) was revised to 14 January 2011.
8.0 LITERATURE CITED


APPENDIX A

EQUIPMENT DATA SHEETS

The following are copies of the equipment data sheets provided by the manufacturers of the primary systems used during the CC Range offshore survey and ground-truthing effort.
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WhiteHolly Expeditions

AVAILABLE FOR CHARTER
- HULL MOUNTED SEABAT 7150-F - full ocean depths!

- General hydrographic surveying
- Oil & Mineral exploration
- EEZ mapping projects
- Cable route & pipeline surveys
- Scientific research
- Diving and ROV operations
- Competitive prices and flexibility to meet client requirements.

Multi Beam Sonar Particulars

| Depth Range | 200 meters - 8000 meters |
| Swath Width | up to 4 times water depth |
| Dual Frequency | 12 kHz and 20 kHz |
| Multi beam accessories | Reson Single beam dual freq, TO 2112 Reson EVP 70 sound velocity sensor |

Associated Equipment available:
- Applanix POS MV/V 320
- Ocean Science Underway CTD
- Seabotix XBT/XTBT Acquisition System
- Reson Seabat 7150-F

Vessel Particulars

| Flag | United States |
| Built by | US Navy |
| Dimensions | 113' x 39' x 12' |
| Cruise Speed | 9.0 knots |
| Engines | 2 x 353 hp Caterpillar |
| Range | 8000 nautical miles |
| Endurance | up to 40 days |
| Accommodation | Passengers = 10 - 3 double cabins, 1x 4 cabin + 1 double with head |
| Other Facilities | Metes, Salon office, administrative office, Large dining salon |
| Deck capacity | 1200 sq ft main deck for consists of 400 sq ft + 800 sq ft aft deck + 900 sq ft lower deck |
| Deck Crane | 10 ton lift, reach 20 ft either side of vessel |

Click here >> http://WWW.WHITEHOLLY.ORG for further particulars or charter rates. Or call Captain Vincent Backen on: 0011 1 (707) 552 6053

www.whiteholly.org 1001 Bridgeway, #551, Sausalito, CA. 94965 USA

January 14, 2011
SYSTEM CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>7125 SV</th>
<th>7125 ROV</th>
<th>7125 AUV</th>
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</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>200 or 400 kHz (dual freq. available)</td>
<td>200 or 400 kHz (dual freq. available)</td>
<td>200 or 400 kHz (dual freq. available)</td>
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<tr>
<td>Along-track transmit beamwidth</td>
<td>2.2° (± 0.5°) at 200 kHz / 1° (± 0.2°) at 400 kHz</td>
<td>2.2° (± 0.5°) at 200 kHz / 1° (± 0.2°) at 400 kHz</td>
<td>2.2° (± 0.5°) at 200 kHz / 1° (± 0.2°) at 400 kHz</td>
</tr>
<tr>
<td>Across-track receive beamwidth</td>
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<td>1.1° (± 0.05°) at 200 kHz / 0.5° (± 0.03°) at 400 kHz</td>
<td>1.1° (± 0.05°) at 200 kHz / 0.5° (± 0.03°) at 400 kHz</td>
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<td>Max ping rate</td>
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<td>50 Hz (± 1 Hz)</td>
<td>50 Hz (± 1 Hz)</td>
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<td>Puls length</td>
<td>10 to 300 µsec</td>
<td>10 to 300 µsec</td>
<td>10 to 300 µsec</td>
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<td>256E/A, 256ED, 512E/A, 512ED at 200kHz</td>
<td>256E/A, 256ED, 512E/A, 512ED at 200kHz</td>
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<td>Max Swath angle</td>
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<td>120°</td>
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<td>Depth resolution</td>
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<td>6 nm</td>
<td>6 nm</td>
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<td>Data output</td>
<td>Bathymetry, sidescan &amp; snippets</td>
<td>Bathymetry, sidescan &amp; snippets</td>
<td>Bathymetry, sidescan &amp; snippets</td>
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<td>110/220 VAC, 50/60 Hz</td>
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<td>500W average</td>
<td>500W average</td>
<td>500W average</td>
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<td>48V DC (±10%)</td>
<td>48V DC (±10%)</td>
<td>48V DC (±10%)</td>
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<td></td>
<td>110W max</td>
<td>110W max</td>
<td>110W max</td>
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<td></td>
<td>200W max</td>
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<td></td>
<td>6m optional</td>
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<td>5m pigtail</td>
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<td>System depth rating</td>
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COMPONENT

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<th>7125 AUV</th>
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<td>EM 2200 Receiver</td>
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<td>7-L Link Control Unit</td>
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<td>✓</td>
<td>x</td>
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<td>7-P sonar Processor Unit with monitor, Keyboard and Pointer Device</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
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<td>SV Transceiver with monitor, Keyboard and Pointer Device</td>
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<td>✓</td>
<td>x</td>
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<tr>
<td>7-L Integrated Control &amp; Processor Unit</td>
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<td>Standard Cable Set</td>
<td>✓</td>
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<td>Shipping cases, manuals &amp; accessories</td>
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WEIGHT & DIMENSIONS

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<thead>
<tr>
<th>Component</th>
<th>TC2160 400 kHz projector</th>
<th>TC2163 200 kHz projector</th>
<th>EM2200 200/400 kHz receiver</th>
<th>Surface transceiver</th>
<th>LCU bottle</th>
<th>ICPU frame</th>
<th>7-P processor</th>
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<tbody>
<tr>
<td>Height (mm)</td>
<td>77</td>
<td>115</td>
<td>102</td>
<td>5U</td>
<td>530</td>
<td>172</td>
<td>5U</td>
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<tr>
<td>Width (mm)</td>
<td>62</td>
<td>100</td>
<td>495</td>
<td>19°</td>
<td>6174</td>
<td>166</td>
<td>19°</td>
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<td>Depth (mm)</td>
<td>295</td>
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<td>131</td>
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<td>Weight/kgwater</td>
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</table>
SeaBat 7150

- State-of-the-Art Modular Design
- Ultra High Resolution to Full Ocean Depth
- Single and Dual Frequency Operation (12 and 24kHz)
- 880 Beams (mode dependent) to Cover a Total Receive Sector of 150°
- Focused Beamwidths of 1° x 1° (24kHz), 2° x 2° (12kHz) (7150-F)
- Multi-ping Technology for Yaw Compensation & 100% Coverage at High Vessel Speeds

Featuring a true integrated modular dual frequency design, the SeaBat 7150 system provides the user the ultimate in resolution, performance and system expandability.

The system can be configured for either 12kHz and/or 24kHz operation, providing a choice of both ultra high resolution in shallow water and extended range in deeper waters. The modular design allows the user to increase system resolution to job or budget, simply by adding individual array modules.

Unparalleled technological advancements have been made in the SeaBat 7150. Standard features include increased receive beams for greater sounding density, automatic mode operation, transmit and receive beamfocusing, equidistant and equiangular beam spacing and pitch, roll and yaw compensation using multiping.

The SeaBat 7150 is controlled by the 7-P, a high performance sonar processor that manages data flow and signal processing using state-of-the-art FPGA architecture. The 7-P provides a Windows®-based GUI user interface, allowing system configuration, control, data output, storage and built-in-test environment (BITE) displays to assist the operator.

www.reson.com
# SeaBat 7150

**Full Ocean Depth Multibeam Echosounder**

## SYSTEM PERFORMANCE
- **Operating Frequency:** 12kHz or 24kHz (nominal with dual frequency option)
- **Number of Beams:** Up to 512 Receiver Beams Across Swath (mode dependent)
- **Beamstepping:** Equi-distant and Equi-angle
- **Swath Coverage:** 150°
- **Transmit and Receive Beams:** Various, dependent on the selected configuration
- **Update Rate:** Range Dependent, 1kHz Maximum
- **Motion Compensation:** Pitch: ±1°
  - Roll: ±15°
  - Yaw: ±3° (using multiping)

## SIX SYSTEM CONFIGURATIONS
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Single Frequency 12kHz</th>
<th>Single Frequency 24kHz</th>
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</thead>
<tbody>
<tr>
<td>7150-B</td>
<td>2° x 2° beams</td>
<td>2° x 2° beams</td>
</tr>
<tr>
<td>7150-C</td>
<td>1° x 1° beams</td>
<td>2° x 2° beams</td>
</tr>
<tr>
<td>7150-D</td>
<td>1° x 1° beams</td>
<td>1° x 1° beams</td>
</tr>
<tr>
<td>7150-F</td>
<td>1° x 1° beams</td>
<td>2° x 2° beams at 12kHz</td>
</tr>
<tr>
<td>7150-H</td>
<td>1° x 1° beams</td>
<td>2° x 2° beams</td>
</tr>
<tr>
<td>7150-I</td>
<td>1° x 1° beams</td>
<td>1° x 1° beams</td>
</tr>
</tbody>
</table>

## OPTIONS
- 19" Marine Grade Monitor
- 1TB External RAID Drive
- 7150 Mounting Frames
- 7150 Base Unit
- 5VP-70 Sound Velocity Profiler with 25m Cable
- Service & Maintenance Agreement
- 50m Transceiver to 7P Cable
- 100m Transceiver to 7P Cable

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Image courtesy of Ocean.
NaviSound 600 Series
Advanced Hydrographic Singlebeam Echosounders

- High ping rate, up to 20Hz
- High performance. Resolution 1cm
- Frequency range from 15 – 600kHz
- Up to four independent frequencies in simultaneous operation mode
- Support depths up to 1200m
- Rollback of recorded echogram even whilst recording
- Sound Velocity profile compensation with built-in editor software

NaviSound 600

RESON’s NaviSound 600 Series is a new range of Advanced Hydrographic Survey Echosounder designed to meet the needs of Hydrographic surveyors working on medium to large survey vessels. Best choice for surveying in shallow water, harbors, waterways, off-shore and for dredging applications.

Supports dual, triple or quad channel sounding operation. Convenient four-channel Multi Channel System (MCS). Continuous internal data storage with playback capability, and unique RESON developed tamper resistant data set encryption, - offering a verifiable back-up alternative to paper recorder.

NaviSound 600 Series provide reliable depth measurement and convenient, easy-to-operate capabilities. Premium features include 19” Panel PC for desk, roof or 15” rack mount. Marine approved by: ClassNK, GL, DNV, BV, ABS and LRS. NaviSound 600 Series is delivered with NaviSound Control Center software (NCC). The NaviSound 600 data output is supported by all Hydrographic survey software packages.

The control and display software has the ability to graphically display, record and playback the depth profiles and print-out on a standard Windows Printer as well. The NaviSound 600 Series is separated in two parts for installation of the transceiver part close to the transducer and the Panel PC in the sonar room. Data transfer via Ethernet/USB/COM/LPT connection.

Individual NaviSound 600 models are as follows:

- NS 620: Standard Hydrographic Echosounder supports dual channel simultaneous operation
- NS 630: Enhanced Hydrographic Echosounder supports triple channel simultaneous operation
- NS 640: Improved Hydrographic Echosounder supports quad channel simultaneous operation

www.reson.com
POS MV 320 - Providing robust, reliable, and repeatable position and orientation marine solutions

POS MV maintains positioning and orientation accuracy under the most demanding conditions regardless of vessel dynamics. POS MV provides high update rate (up to 200 Hz) georeferencing and motion compensation for vessel mounted remote sensing systems.

THE POS MV ADVANTAGE

- High quality state of the art Inertial Measurement Units (IMUs) developed by the world’s leading supplier of inertial technology
- IMUs with high quality accelerometers and gyro integrated into a strap down navigation solution proven to produce the best results for resolving individual multibeam pointing angles
- Robust heading aiding from GPS Azimuth Measurement Subsystem (GAMS)
- Proprietary tightly coupled Inertially Aided GPS technology providing robust positioning with industry leading immunity to GPS outages and almost instantaneous reacquisition of RTK following a GPS outage
- Industry leading real time Heave estimation
- TrueHeave™ implemented for maximum immunity to filter transients and phase lag error
- The only positioning and orientation system with full raw data logging capabilities suitable for use in the Apllanix POSPac post processing package.
- The only Inertially Aided Post Processed Kinematic (IAPPK) Solution in the Marine Hydrographic industry providing the most accurate positioning and orientation results possible
- Proven reliability with over 400 systems in service, the Apllanix POS MV is the proven industry standard for Marine Hydrographic Surveying

* For detailed upgrade information please call your Apllanix Marine office.

* POS MV 320 comes with a 2 year warranty.

To find out more about the POS MV™ System go to www.applanix.com
CC Range Bottom Mapping and Habitat Characterization
Final Cruise Report
N62470-08-D-1008, TO 0029

POS MV™ 320
SPECIFICATIONS

Accuracy

POS MV 320 Main Specifications (with Differential Corrections)
Roll Pitch: 0.02° (1 sigma with CGS or DGPS)
Heave Accuracy: 5 cm or 5% (whichever is greater) for periods of 600 seconds or less
Heading Accuracy: 0.02° (1 sigma) with 2 m antennae and 0.01° (1 sigma) with 4 m antennae
Position Accuracy: 65 - 2 m (1 sigma) depending on quality of differential corrections
Velocity Accuracy: 0.05 m/s horizontal

POS MV 320 during GPS Outage
Roll Pitch: 0.02° (1 sigma)
Heave Accuracy: 5 cm or 5% (whichever is greater) for wave periods of 600 seconds or less
Heading Accuracy: 0.02° (1 sigma) with 2 m antennae and 0.01° (1 sigma) with 4 m antennae
Position Accuracy: 65 cm (1 sigma) for 30 minutes, 46 cm (1 sigma) for 60 minutes

Interfaces

Ethernet (100 base-T): Parameters, True, Status, position, attitude, heave, velocity, track, speed, dynamics, performance metrics, raw IMU data, raw GPS data.
Serial RS232 I/O: User selectable to NMEA output (0-5), up to 2000Hz, Attitude output (0-5), Auxillary GPS input (0-5), Base GPS correction input (0-2).
High Rate Attitude Output: User selectable binary messages
Auxiliary GPS Input: NMEA Standard ASCII messages
Base GPS Correction Input: RTCM 1, 7, 10, 15, CMR, and CMR input formats accepted

Environmental

Temperature Range (Operating): -40°C to +60°C
IMU: 0°C to +45°C
Processor: -50°C to +70°C
GPS Antenna: -40°C to +70°C

Temperature Range (Storage): -40°C to +60°C
IMU: 0°C to +45°C
Processor: -25°C to +45°C
GPS Antenna: -50°C to +70°C
Humidity:
IMU: 10% - 95% RH, ingress protection of IP65
Processor: 10% - 90% RH, non-condensing
GPS Antenna: 0% - 90% RH

Shock & Vibration (TMU):
Operating: 90 g, 6 ms terminal load peak
Non-Operating: 220 g, 5 ms half-sine

Physical Characteristics

Size:
IMU: 204 mm X 204 mm X 168 mm
PSC: 322 mm X 199 mm X 256 mm
IMU: 2.0 U 19 mm radius mount
GPS Antenna (3D): 117 mm X 53 mm

Weight:
IMU: 35 kg
Processor: 5 kg
GPS Antenna: <0.5 kg

Power:
Processor: 110V/230Vac, 50/60 Hz, auto-switching 80Watt
IMU: Power provided by PSC
GPS Antenna: Power provided by PSC

Applanix Corporation
65 Lakeview Circle
Richmond Hill, Ontario
Canada L4B 1G3
Tel: +1 905-768-4800
Fax: +1 905-768-8077

Applanix LLC
17451 Village Grove Drive
Houston, TX
USA 77089
Tel: +1 713-806-9900
Fax: +1 713-806-9909

Applanix United Kingdom
Ramsden House,
Old Knavesmoor, Chirbury
SY11 3PW, UK
Tel:+44 1995 85959
Fax:+44 1995 85959

January 14, 2011
AgGPS 132

Combination DGPS receiver with The Choice technology

**Standard Features**

- 12-channel DGPS receiver
- L-band reliable, differential correction receiver
- Dual-channel digital medium frequency beacon receiver
- Sub-meter differential accuracy
- 2 line, 16-character backlit liquid crystal display
- 4 button keyboard
- Combined L1/L2 GPS, Satellite transponder and beacon receiver
- Two programmable T/R-295 metal pore
- INREACH output/ISP-250A input
- TSP 1/0
- Operation manual
- 8 meter coaxial transponder cables
- GPS receiver to PC cable
- Magnetic mount transducer

**Physical Characteristics**

- **AgGPS 132 Housing**
  - Size: 145mm(W) x 63mm(H) x 156mm(D)
  - Weight: 0.78kg (16.8 lb)
  - Power: 7W (max), 10 to 12 VDC
  - Operating temp: -30°C to +65°C
  - Storage temp: -30°C to +85°C
  - Humidity: 100% condensation, until fully sealed
  - Sealing: Dust proof, waterproof, shock resistant
  - Ground/Antenna
    - Size: 35.5mm(D) x 14mm(H)
    - Weight: 29g (1.2 oz)
    - Operating temp: -30°C to +85°C
    - Storage temp: -40°C to +85°C
    - Humidity: 100% condensation, until fully sealed
    - Sealing: Dust proof, waterproof, shock resistant

**Ordering Information**

- AgGPS 132: Part Number 45000.00
- Add 10 Hz capability: Part Number 45170.10
- Add 9600 baud capability: Part Number 45170.50
- Add AgGPS Base Station: Part Number 45190.90
- Add BaseFlex Multi-Path Reduction: Part Number 45190.10
- AgField Pack 100Vdc: Part Number 45200.00
- AgField Pack 240Vdc: Part Number 45200.10
- Ag Leader/Leader extension cable: Part Number 40000

**Performance Characteristics**

- 12-channel, parallel tracking, L1, C/A, code and carrier phase decoded measurement and multi-beacon capability
- Update rate: 1 Hz standard, 10Hz optional
- Differential mode accuracy:
  - 0.1 m/√(0.01 KPH)²
- Differential performance:
  - Less than 1 meter horizontal RMS²
  - Less than 3 meters (95% confidence)
  - Autopilot and ACC4 standard format broad cast from Trimble 10000s or equivalent reference station
- Timing error:
  - ≤10 milliseconds, typical
- NMEA output: AINX, GGA*, GLL, GSA, GSV, VTC*, HME, ZDA
- Differential correction broadcast via NMEA output
- Frequency range: 283.5 kHz to 286.0 kHz
- Gain setting: 100 dB
- Data rate: 50, 100, 200 bits per second
- Code strength: 10 μW minimum margin @ 1000bps
- Dynamic range: 100 dB
- Gain setting: 70 dB ±600 Hz offset
- Frequency offset: ±7 ppm precision
- Interface format: ±5 cm® RS-232 (max 9600 bps)
- Beacon installation: ±5 seconds, typical
- Operating modes: Auto power down, data guard, and manual modes
- Uses Satellite Differential correction on the receiver

**Methode/Converter Support**

- Bit Error Rate: 10⁻⁷ for Eb/N0 of ≥9.5 dB
- Acquisition and reacquisition time:
  - ≤2 seconds, typical
- Frequency: 1561.090 MHz
- Channel spacing: 50 kHz

**Trimble**

Trimble Navigation Limited
Corporate Office
100 Blue Hill Road
South Natick, MA 01760
Telephone: 1-508-821-1900
Fax: 1-508-821-7344
Email:Trimble@trimble.com

Trimble Navigation Limited
Eurasia Office
9th Floor, Building I
Citibank Business Park
145 Cuffe Parade
Mumbai 400021
India
Telephone: +91-22-2249-1000
Fax: +91-22-2249-1005
Email: info@trimble.com

Trimble Navigation Limited
Nederland Office
Kloosterberg 313
2312 ZZ Leiderdorp
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Telephone: +31-79-340-6400
Fax: +31-79-340-8100
Email: info@trimble.com

Trimble Navigation Limited
Australian Office
Level 10/ 1033 Pitt St
Sydney NSW 2000
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Telephone: +61-2-8255-2200
Fax: +61-2-8255-2299
Email: info@trimble.com

Page A-9 of 36
January 14, 2011
### Accuracy (rms) with real-time/RTK

<table>
<thead>
<tr>
<th>ATX1230 GG / ATX1230 / GX1230 GG / GX1230</th>
<th>GX1220</th>
<th>GX1210</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RTK capability</strong></td>
<td>Yes, standard</td>
<td>No</td>
</tr>
<tr>
<td><strong>Rapid static (phase)</strong></td>
<td>Hori: 5mm + 0.5ppm</td>
<td>Hori: 5mm + 0.5ppm</td>
</tr>
<tr>
<td>Static mode after initialization</td>
<td>Vert: 10mm + 0.2ppm</td>
<td>Vert: 10mm + 0.2ppm</td>
</tr>
<tr>
<td><strong>Kinematic (phase)</strong></td>
<td>Hori: 1mm + 0.1ppm</td>
<td>Hori: 1mm + 0.1ppm</td>
</tr>
<tr>
<td>moving mode after initialization</td>
<td>Vert: 20mm + 1ppm</td>
<td>Vert: 20mm + 1ppm</td>
</tr>
<tr>
<td><strong>Code only</strong></td>
<td>Typically 25cm</td>
<td>Typically 25cm</td>
</tr>
</tbody>
</table>

### Accuracy (rms) with DGPS/RTCM

<table>
<thead>
<tr>
<th>ATX1230 GG / ATX1230 / GX1230 GG / GX1230</th>
<th>GX1220</th>
<th>GX1210</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DGPS/RTCM standard</strong></td>
<td>DGPS/RTCM optional</td>
<td>DGPS/RTCM optional</td>
</tr>
<tr>
<td><strong>DGPS/RTCM</strong></td>
<td>Typically 25cm (rms)</td>
<td>Typically 25cm (rms)</td>
</tr>
</tbody>
</table>

### Accuracy (rms) in single receiver navigation mode

<table>
<thead>
<tr>
<th>ATX1230 GG / ATX1230 / GX1230 GG / GX1230</th>
<th>GX1220</th>
<th>GX1210</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Navigation accuracy</strong></td>
<td>5–10m rms for each coordinate</td>
<td>5–10m rms for each coordinate</td>
</tr>
<tr>
<td><strong>Degradation effect</strong></td>
<td>Degradation possible due to SA</td>
<td>Degradation possible due to SA</td>
</tr>
</tbody>
</table>

### On-the-Fly (OTF) initialisation

<table>
<thead>
<tr>
<th>ATX1230 GG / ATX1230 / GX1230 GG / GX1230</th>
<th>GX1220</th>
<th>GX1210</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OTF Capability</strong></td>
<td>Real time and post processing</td>
<td>Post processing only</td>
</tr>
<tr>
<td><strong>Reliability of OTF initialisation</strong></td>
<td>Better than 99.99%</td>
<td>Not applicable</td>
</tr>
<tr>
<td><strong>Time for OTF initialisation</strong></td>
<td>Typically 8secs, with 5 or more satellites on L1 and L2</td>
<td>Not applicable</td>
</tr>
<tr>
<td><em><em>OTF Range</em>#</em>*</td>
<td>Typically up to 30km in normal conditions</td>
<td>Not applicable</td>
</tr>
<tr>
<td>*Assuming reliable data link is available in RTK case</td>
<td>Up to 40km in favorable conditions</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

### Position update and latency

<table>
<thead>
<tr>
<th>ATX1230 GG / ATX1230 / GX1230 GG / GX1230</th>
<th>GX1220</th>
<th>GX1210</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position update rate</strong></td>
<td>Selectable: 0.05 sec (20Hz) to 60 secs</td>
<td>Selectable: 0.05 sec (20Hz) to 60 secs</td>
</tr>
<tr>
<td><strong>Position latency</strong></td>
<td>0.03 sec or less</td>
<td>0.03 sec or less</td>
</tr>
</tbody>
</table>
GAPS
PORTABLE, CALIBRATION FREE USBL

The calibration free Global Acoustic Positioning System (GAPS) combines USBL, INS and GPS technologies. The most accurate USBL in its category, it works in deep or extremely shallow water and difficult environments where other systems have failed.

FEATURES
- Calibration-free
- 4,000 m range, accuracy 0.2% of the slant range*, 200 deg coverage
- All-in-one system, simple to use
- Provides absolute position as well as surface GPS-robust position

BENEFITS
- No mobilization/demobilization: fully operational in less than 1 hour
- Adapted to all applications: shallow and deep water, and noisy environments
- Easily transferrable from one vessel to another
- Robust to acoustic and GPS hazards

*Performance depends on environment/sea conditions

APPLICATIONS
- Towfish tracking
- AUV, ROV and any subsea vehicle
- Diver tracking
### GAPS Technical Specifications

#### Performance

<table>
<thead>
<tr>
<th>Subsea Positioning (1)</th>
<th>0.2% of slant range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning Accuracy</td>
<td>4,000 m</td>
</tr>
<tr>
<td>Operating Range</td>
<td>200 deg below acoustic array</td>
</tr>
<tr>
<td>Operating Frequency</td>
<td>20 to 30 kHz</td>
</tr>
</tbody>
</table>

#### Surface Positioning and Attitude

<table>
<thead>
<tr>
<th>Heading / Roll / Pitch</th>
<th>0.01 deg (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>2 to 5 cm (external RTK receiver)</td>
</tr>
<tr>
<td></td>
<td>0.5 to 3 m (supplied DGPS or accurate GPS receiver)</td>
</tr>
<tr>
<td></td>
<td>2 m / 2 minutes</td>
</tr>
</tbody>
</table>

#### Operating / Environment

<table>
<thead>
<tr>
<th>Power Supply / Consumption</th>
<th>20 VDC / 60 W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Temperature</td>
<td>-5 °C to 35 °C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-20 °C to +70 °C</td>
</tr>
</tbody>
</table>

#### Physical Characteristics

<table>
<thead>
<tr>
<th>Housing Material</th>
<th>Carbon Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight in Air / Water</td>
<td>15 kg / -7 kg (positive buoyancy)</td>
</tr>
<tr>
<td>Housing Dimensions (Ø x H)</td>
<td>295 mm x 638 mm</td>
</tr>
<tr>
<td>Array Depth Rating</td>
<td>50 m</td>
</tr>
</tbody>
</table>

#### Interfaces

<table>
<thead>
<tr>
<th>Protocols</th>
<th>Industry standards (Native compatibility with IKSEA sensors PHINS, RAMSES,...)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully Compatible</td>
<td>Any external GPS, DGPS and RTK receivers</td>
</tr>
</tbody>
</table>

Automatic sound velocity corrections (ray bending & velocity error)

- 10 Hz output rate for subsea positioning data (irrespective of depth)
- 100 Hz output rate for surface positioning data

---

(1) Performance depends on environment / noise conditions
(2) Heading, Roll, Pitch figures are RMS values

Specifications subject to change without notice

IXSEA: • EMEA : +33 (0)1 30 08 98 88 • USA : +1 (781) 937 8800 • ASIA : +85 6747 4912 • www.ixsea.com
SPECIFICATIONS

MODEL DT3030EHLW ELECTRO-HYDRAULIC WINCH
DIMENSIONS:

WIDTH 76 INCHES
LENGTH 58 INCHES (INCLUDES LEVEL-WIND)
HEIGHT 66 INCHES (INCLUDES LEVEL-WIND)
DRUM DIAMETER 20 INCHES
FLANGE DIAMETER 46 INCHES
DRUM WIDTH 36 INCHES

CAPACITY:

4,500 METERS OF 45° DIA. CABLE (LEAVES 2” CLEAR FLANGE)

CONSTRUCTION:

ALL WELDED STEEL WITH STAINLESS STEEL HARDWARE

COATING:

SYSTEM IS BLASTED TO NEAR WHITE METAL AND PAINTED WITH
THREE-COAT EPOXY SYSTEM, ZINC PRIMER, TIECOAT, TOP COAT
EPOXY

BEARINGS:

SEALED, SELF-ALIGNING BALL BEARINGS

ELECTRIC MOTOR:

36 HP 230/440/460V 60HZ, THREE-PHASE, TOTALLY
ENCLOSED FAN COOLED; SOFT START INCLUDED.

PUMP:

CLOSED LOOP AXIAL PISTON SUNDSTRAND.

HYDRAULIC MOTOR:

AXIAL PISTON SUNDSTRAND

LINE PULL & SPEED:

5,000 LBS BARE DRUM @ 0-150FPM

SYSTEM:

CLOSED LOOP, MOTOR COUPLED TO DRUM VIA PLANETARY
GEAR REDUCER AND FAILSAFE BRAKE PROVIDED. MULTIPLE
DISC FAILSAFE BRAKE BETWEEN MOTOR AND GEARBOX.

RESERVOIR:

INCORPORATED INTO BASE OF THE WINCH
CONTROLS:

SELF-CENTERING SINGLE LEVER JOY STICK PROVIDES LINEAR VARIABLE SPEED OPERATION. PRESSURE GUAGE, POWER ON/OFF SWITCHES AND NEMA 4X MOTOR STARTER ENCLOSURE ARE ALL SAFELY MOUNTED FOR EASY OPERATION.

BRAKE SYSTEM:

FAIL-SAFE BRAKE IS ACTUATED FROM CENTER POSITION OF "JOY STICK". LOSS OF HYDRAULIC PRESSURE OR LOSS OF ELECTRIC POWER, SYSTEM INCLUDES MANUALLY OPERATED 3" STAINLESS STEEL BAND BRAKE AS A STANDARD SAFETY FEATURE.

LEVEL-WIND SYSTEM:

HYDROACTIVE CABLE GUIDE SYSTEM, FRONT MOUNTED BALL SCREW TYPE, AUTOMATIC BI-DIRECTIONAL ANGLE SENSING SYSTEM WITH MANUALLY OPERATED OVERRIDE FEATURE.

WEIGHT:

APPROXIMATELY 4200 LBS

HANDLING:

LOAD TESTED 4 POINT LIFT EYES/FORK LIFT TUBES

DT MARINE PROVIDES:

WINCH ENGINEERING SERVICES, ALUMINUM OR STEEL CONSTRUCTION, EXPLOSION PROOF MODELS, LEVEL-WINDS, CABLE SHEAVES, CABLES, SLIP-RINGS, REMOTE CONTROL OPERATIONS AND COMPLETE CUSTOMER SERVICE AFTER THE SALE. FOR PRODUCTS AND SERVICES CONTACT: DARRELL TROVILLE @ (713)460-1400

MOUNTING BOLT PATTERN:

REFER TO THE FOLLOWING DIAGRAM.
SPECIFICATIONS

MODEL DT305EM ELECTRO-MECHANICAL WINCH

DIMENSIONS:

- WIDTH: 34 INCHES
- DEPTH: 34 INCHES
- HEIGHT: 38 INCHES
- DRUM DIAMETER: 20 INCHES
- FLANGE DIAMETER: 30 INCHES
DRUM WIDTH  10 INCHES

CAPACITY:  
300 FEET (91 METERS) OF .75 DIA. CABLE (LEAVES 2” CLEAR FLANGE)
892-FT (271 METERS) OF .45 DIA. CABLE (LEAVES 2” CLEAR FLANGE)

CONSTRUCTION:  
ALL WELDED ALUMINUM WITH STAINLESS STEEL HARDWARE

COATING:  
SYSTEM IS BLASTED TO NEAR WHITE METAL AND PAINTED WITH THREE-COAT EPOXY SYSTEM, ZINC PRIMER, TIECOAT, TOP COAT OF EPOXY.

BEARINGS:  
SEALED, SELF-ALIGNING BALL BEARINGS

ELECTRIC MOTOR:  
5HP, TOTALLY ENCLOSED FAN COOLED BRAKE MOTOR DRIVING A RIGHT ANGLE GEARBOX CONNECTED TO THE DRUM THROUGH SPROCKETS AND CHAIN. WILL NEED TO PROVIDE 230VAC OR 460VAC THREE PHASE POWER (INTERCHANGEABLE). 230VAC@15.2A 460VAC@7.6A.

LINE PULL & SPEED:  
1,200 LBS BARE DRUM RATING @ 0-95 FPM.

CONTROLS:  
A JOYSTICK CONTROLLER IS USED FOR VARIABLE SPEED OPERATION.

BRAKE SYSTEM:  
AN ELECTRIC FAILSAFE BRAKE IS INSTALLED BETWEEN THE ELECTRIC MOTOR AND THE RIGHT ANGLE GEAR BOX.

LEVEL-WIND SYSTEM:  NONE

WEIGHT:  APPROXIMATE WEIGHT IS 400LBS

HANDLING:  LOAD TESTED 4 POINT LIFT EYES.

MOUNTING BOLT PATTERN:  
REFER TO THE FOLLOWING DIAGRAM.
DT MARINE PROVIDES:
WINCH ENGINEERING SERVICES, ALUMINUM OR STEEL CONSTRUCTION, EXPLOSION PROOF MODELS, LEVEL-WINDS, CABLE SHEAVES, CABLES, SLIP-KINGS, REMOTE CONTROL OPERATIONS AND COMPLETE CUSTOMER SERVICE AFTER THE SALE. FOR PRODUCTS AND SERVICES CONTACT: DARRELL TROVILLE @ (719) 460-1400
Benefits

Cost-Effective
Cost per profile decreases with increasing use of the probe

Superior Data Quality
Uses high-resolution Sea-Bird sensors and internal recording

High Resolution
Depth measured directly with submeter accuracy via a pressure sensor

Minimal Post-Processing
No need for salinity offset corrections or adjustments to the drop-rate equation using CTD profile data

Quick Set-Up
Ready in a few hours. No permanent wiring or desktop installation required

Portable
Minimal demands for deck space and no need for probe storage

Continuous Profiling
No need to alter ship speed

Free-Cast
Probe fully decoupled from ship

Environment Friendly
No pollution with waste materials and is used in ecologically sensitive areas

24/7
Designed for continuous operation

Bluetooth Capability
Wireless data download via Bluetooth

The OceanScience Underway CTD™ provides research-quality CTD profiles from moving vessels. The system is extremely portable, cost-effective, and environment-friendly.

The UCTD consists of a custom low-drag, high-accuracy, retrievable Sea-Bird CTD, high-speed winch with levelwind, line rewinder unit and davit. The instrument yields high-quality CTD measurements to over 400 meters depth. It can be operated at ship speeds up to 20 knots.

The UCTD is ideal for both research applications and hydrographic surveys. The complete system weighs less than 50 kg and requires minimal deck space. Deployments are easy to perform and do not interfere with other ship activities. Data download uses state-of-the-art wireless technology for quick turnaround. The UCTD system combines the convenience of expendables without the recurring cost and negative environmental impact.
Underway CTD Components

Probe System
The probe consists of a high accuracy Sea-Bird CTD instrument with embedded data acquisition system and Bluetooth wireless communication interface. The sensor is contained within a streamlined pressure case with an integrated line spool.

Winch
The winch features a large-capacity reel with a custom high-torque DC drive unit and motorized leveling. Adjustable clutch and motor control allow for fast and safe probe retrieval. The 10-400 UCTD reel holds 1400 meters of Spectra line for profiles to over 1000 meters depth at 10 knots.

Rewinder
The microprocessor controlled, dual motor tail rewriter precisely loads the tail spool with Spectra line. The unit may be programmed for different profile depths and is fully automated for quick turnaround.

Power Supply
A 1500 W power supply with 110/220 VAC, 50/60 Hz input supplies power to all system components.

Davit
A universal Davit is available to mount on a rail or tugger stand via a 4” x 4” hole pattern with an adjustable boom.

CTD Sensor Specifications

<table>
<thead>
<tr>
<th></th>
<th>Conductivity (S/m)</th>
<th>Temperature (°C)</th>
<th>Depth (dbar)</th>
<th>Salinity (psu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>0.0005</td>
<td>0.002</td>
<td>0.5</td>
<td>0.003</td>
</tr>
<tr>
<td>Data Accuracy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw</td>
<td>0.03</td>
<td>0.01 to 0.02</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Processed</td>
<td>0.002 to 0.005</td>
<td>0.004</td>
<td></td>
<td>0.02 to 0.05</td>
</tr>
<tr>
<td>Range</td>
<td>0 to 9</td>
<td>-5 to 43</td>
<td>0 to 2000</td>
<td>0 to 42</td>
</tr>
</tbody>
</table>

Contact Information
The Oceaneering Group
4120 Avenida de la Plata
Oceanside, CA 92056
Phone (760) 754-2100
Fax (760) 754-2165
info@oceaneering.com

www.oceaneering.com
Expendable Conductivity/Temperature/Depth Profiling System (XCTD)
An Accurate and Cost-Effective Means to Collect Salinity Profiles While Underway
Expendable Bathythermograph
Expendable Sound Velocimeter
(XBT/XSV)

A standard XBT/XSV system consists of an expendable probe, a data processing/recording system, and a launcher. An electrical connection between the probe and the processor/recorder is made when the canister containing the probe is placed within the launcher and the launcher breach door is closed. Following launch, wire descends from the probe as it descends vertically through the water. Simultaneously, wire descends from a spool within the probe canister, compensating for any movement of the ship and allowing the probe to freefall from the sea surface unaffected by ship motion or sea state.

The XBT/XSV system uses a sea water spool. As soon as an electrode within the nose of the expendable probe makes contact with the water, the circuit is complete and temperature or sound velocity data can be telemetered to the shipboard data processing equipment. Data are recorded and displayed in real time as the probe falls. The nose of each expendable probe is precision weighted and the unit spun-stabilized to assure a predictable rate of descent. From this rate of descent, probe depth is determined to an accuracy of ±2%.

When the probe reaches its rated depth (a function of ship speed and the quantity of wire contained within the shipboard spool) the profile is completed and the system is ready for another launch.

**XBT and XSV are available in air-launched and sub-launched configurations.**

**Expendable Bathythermograph (XBT)**
Temperature profiles and computed sound velocity data obtained by the XBTs are used by ASW operators to identify the impact of temperature on sonar propagation and acoustic range prediction. The XBT also provides a quick and inexpensive means of collecting temperature data for oceanographic and geophysical studies.

The XBT contains a precision thermometer located in the nose of the probe. Changes in water temperature are recorded by changes in the resistance of the thermistor as the XBT falls through the water. The XBT is capable of temperature accuracies of ±0.1°C.

The XBT has proved to be reliable in over 30 years of use. During this time, Lockheed Martin has developed several variations of the standard probe to meet the requirements of a wide range of applications.

---

**Lockheed Martin expendable profiling systems offer antisubmarine warfare (ASW) specialists and oceanographers a fast, accurate, cost-effective means of collecting environmental data without restricting ship operation.**
Expendable Sound Velocimeter (XSV)

Lockheed Martin also offers an XSV for the direct measurement of sound velocity. The XSV obtains accurate sound velocity profiles for the support of ASW operations, mine countermeasure operations and oceanographic research. The XSV measures the speed of sound in water using a transducer sound velocity sensor. The XSV obtains real-time sound velocity data accurate to ±0.25 meters/second at depths up to 2000 meters.

The XSV can significantly increase the accuracy of sound propagation and acoustic range predictions, improving the accuracy of acoustic positioning systems and provide data for the study of acoustic propagation in the world's oceans. The XSV is most useful in such areas as Arctic, Mediterranean and coastal waters, where high salinity variability may cause computed sound velocity data, based upon temperature profiles and assumed salinity data, to be inaccurate.

XBT provides a quick and inexpensive means of collecting temperature data...

XSV obtains accurate sound velocity profiles...

<table>
<thead>
<tr>
<th>Applications</th>
<th>Maximum Depth</th>
<th>Rated Ship Speed</th>
<th>Vertical Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-1</td>
<td>Standard probe used by the U.S. Navy for ASW missions. 460 m</td>
<td>1500 ft</td>
<td>30 knots</td>
</tr>
<tr>
<td>T-5</td>
<td>Drop from a ship or submarine. 1830 m</td>
<td>6000 ft</td>
<td>6 knots</td>
</tr>
<tr>
<td>Fast Deep™</td>
<td>Provides maximum depth capabilities at the highest possible ship speed of any XBT. 1000 m</td>
<td>3280 ft</td>
<td>25 knots</td>
</tr>
<tr>
<td>T-6</td>
<td>Oceanographic applications. 460 m</td>
<td>1500 ft</td>
<td>15 knots</td>
</tr>
<tr>
<td>T-7</td>
<td>Increased depth for improved sound propagation in ASW and other military applications. 760 m</td>
<td>2500 ft</td>
<td>15 knots</td>
</tr>
<tr>
<td>Deep Blue</td>
<td>Increased launch speed for oceanographic and naval applications. 760 m</td>
<td>2500 ft</td>
<td>20 knots</td>
</tr>
<tr>
<td>T-10</td>
<td>Commercial fisheries applications. 850 m</td>
<td>2700 ft</td>
<td>10 knots</td>
</tr>
<tr>
<td>T-11</td>
<td>High resolution for U.S. Navy mine counter-measures and physical oceanographic applications. 460 m</td>
<td>1500 ft</td>
<td>6 knots</td>
</tr>
</tbody>
</table>

Expendable Sound Velocimeter (XSV)

<table>
<thead>
<tr>
<th>Applications</th>
<th>Maximum Depth</th>
<th>Rated Ship Speed</th>
<th>Vertical Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>XSV-01</td>
<td>ASW application where salinity varies, with greater than 30 km of sound path. 850 m</td>
<td>2700 ft</td>
<td>15 knots</td>
</tr>
<tr>
<td>XSV-02</td>
<td>Increased depth for improved ASW and oceanographic applications. 2000 m</td>
<td>6500 ft</td>
<td>8 knots</td>
</tr>
<tr>
<td>XSV-03</td>
<td>High resolution for improved mine counter-measures and ASW applications in shallow water, physical oceanographic surveys, commercial oil industry support. 850 m</td>
<td>2700 ft</td>
<td>5 knots</td>
</tr>
</tbody>
</table>

System Depth Accuracy: ±4 meters or 2% of depth, whichever is larger (for XSV).

* All probes may be used at speeds above rated maximum, however there will be a proportional reduction in depth capability. All probes are shipped 12 in a case which is constructed of weather resistant, unbreakable material. Shipping weight varies from 20 lbs. to 41 lbs., depending on probe type. Dimensions of the case vary from 17" x 14" x 10" (2.3 cu. ft.) to 17" x 14" x 9" (2.1 cu. ft.).

The XBT is capable of temperature accuracies of ±0.1°C.

The XSV obtains real-time sound velocity data accurate to ±0.25 meters/second at depths up to 2000 meters.
Expendable Conductivity/Temperature/Depth Profiling System (XCTD)

An accurate and cost-effective means to collect salinity profiles while underway.

The Expendable Conductivity/Temperature/Depth (XCTD) Profiling System is an accurate and cost-effective means to collect salinity profiles while underway. The system consists of the Digital XCTD probe, developed by the Tsunami Seiki (TSDK) Co. Ltd. of Yokohama, Japan and Lockheed Martin’s representative and licensed manufacturer of XCTDs in Japan. These models of XCTDs are available for different depths and ship speeds.

Models
- XCTD-1
  - 1000 m at 12 knots
- XCTD-2
  - 1830 m at 3.5 knots
- XCTD-3
  - 1000 m at 20 knots

The Digital XCTD is calibrated at three temperatures and three conductivities during the manufacturing process.

Specifications

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Conductivity</th>
<th>Temperature</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>5 to 50 mS/cm</td>
<td>-2 to 35°C</td>
<td>1600 m</td>
</tr>
<tr>
<td>Resolution</td>
<td>.017 mS/cm</td>
<td>.01°C</td>
<td>17 cm</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±.05 mS/cm</td>
<td>±.02°C</td>
<td>2%</td>
</tr>
<tr>
<td>Response Time</td>
<td>40 mSec</td>
<td>100 mSec</td>
<td>—</td>
</tr>
</tbody>
</table>

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Lockheed Martin
Maritime Systems & Sensors
Seven Bannons Road
Marion, MA 02738
An ISO9001 2000 Company

Sea-Air Systems
1(208)748-1169 (x183)
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January 14, 2011
MK21 Oceanographic Data Acquisition System
Versatile and Low Cost Capability to Collect, Display and Store Data
MK21 Oceanographic Data Acquisition System

**Description**
The MK21 Oceanographic Data Acquisition System is available in two configurations — ISA and USB. The MK21 ISA is a 5/8 size PC card which is installed in an ISA slot in a PC. The MK21 USB system is compatible with most laptop and desktop PC computers operating in Windows 2000, Windows XP or higher. The MK21 USB is delivered in a 19-inch rack mountable enclosure. The MK21 ISA card can be upgraded to USB with the addition of the MK21 USB Upgrade Kit. Data collection is controlled by the MK21 and the buffered I/O stores all the data until it can be read in by the operating system. Every data point is time stamped by an independent clock on the MK21 to ensure no data is lost or skipped. The MK21 also has flash memory for in system programming capability to give users the flexibility to add newly developed probe capability and firmware upgrades. The MK21 is compatible with all Lockheed Martin expendable probes and launchers.

Software developed for use with Lockheed Martin expendable probes provides a variety of data processing capabilities. Profiles of ocean characteristics may be displayed real-time in graphic form and the data permanently stored. The user may retrieve this information for further analysis in several formats to aid in a detailed understanding of the ocean environment.

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Maritime Systems & Sensors
Seven Barnabas Road
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An ISO9001:2000 Company

Sea-Air Systems
1(508)748-1160 (x183)
e-mail: james.m.hannon@lmco.com

**Operation**
The operator uses the computer keyboard and display to select the type of probe to be launched and other parameters to be stored with the data such as date, time and latitude-longitude. The computer performs system diagnostics and prelaunch tests and then indicates the probe is ready for launch. It then receives probe data during the probe descent and displays and stores the information.

Data is easily translated to an ASCII test format so the user can readily generate the measured profiles using spread sheet applications or transfer data to any path or range prediction program.

The MK21 Software has automatic GPS input capability (NMEA 0813), selectable IGSS and original drop rates, a new, easier-to-use display and improved post-processing options.

**Features:**
- A highly visual, user-friendly display that utilizes the capabilities of Windows.
- Improved post-processing options.
- User-selectable features include drop rate, probe terminal depth, auto postprocessing, noise reduction, data averaging, and calculated salinity, density, and sound velocity profiles.

**Kit Contents:**
- MK21 processor card.
- MK21 application software.
- MK21 to launcher interface box.
- Operator’s manual.

**System Specifications**

<table>
<thead>
<tr>
<th>Probe Type</th>
<th>XBT</th>
<th>XSV</th>
<th>XCTD</th>
<th>XCTD-1</th>
<th>AXSV**</th>
<th>AXCTD**</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sampling Rate</strong></td>
<td>10Hz</td>
<td>10Hz</td>
<td>4Hz</td>
<td>25Hz</td>
<td>10Hz</td>
<td>4Hz</td>
</tr>
<tr>
<td><strong>Vertical Resolution</strong></td>
<td>0.1°C</td>
<td>0.25°F</td>
<td>0.05°C</td>
<td>0.05°F</td>
<td>0.05°C</td>
<td>0.05°F</td>
</tr>
<tr>
<td><strong>Temperature Resolution</strong></td>
<td>0.05°C</td>
<td>0.00°F</td>
<td>0.05°C</td>
<td>0.00°F</td>
<td>0.05°C</td>
<td>0.00°F</td>
</tr>
<tr>
<td><strong>Temperature Range</strong></td>
<td>-2 to 35°C</td>
<td>-2.2 to 35°C</td>
<td>-2.2 to 35°C</td>
<td>-2.2 to 36°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sound Velocity Resolution</strong></td>
<td>0.1°</td>
<td>0.05°F</td>
<td>0.05°</td>
<td>0.05°F</td>
<td>0.05°</td>
<td>0.05°F</td>
</tr>
<tr>
<td><strong>Sound Velocity Range</strong></td>
<td>1000-1500 m/s</td>
<td>1000-1500 m/s</td>
<td>1500-1500 m/s</td>
<td>1500-1500 m/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Conductivity Resolution</strong></td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Conductivity Range</strong></td>
<td>0-30</td>
<td>0-30</td>
<td>0-30</td>
<td>0-30</td>
<td>0-30</td>
<td>0-30</td>
</tr>
</tbody>
</table>

System Depth Accuracy: 0.4 meters or 2% of depth, whichever is greater.
* Nominal accuracy characterization based on XCTD horizontal profiles against a calibrated transfer CTD (both comparison used the smoothing). 95% of total data was within ±0.05° and m/s/cm of the transfer CTD.
** External RF demodulator required.
SBE 19 SEACAT Profiler CTD

SVP 70

- Accurate & reliable sound velocity measurement in seawater
- Compact housing in titanium for corrosion immunity and high strength
- Mechanical design for easy cleaning, optimal flow and flexible integration
- Galvanically isolated multiple communication interfaces as standard
- Direct path ultrasonic echosounding with 2MHz transducer element
- Instant electronic temperature and pressure compensation via internal sensors
- Integrated electronics and up to 6000m depth rating

The RESON SVP 70 sound velocity probe is developed for fixed-mount installation on surface ships, outboard rigs, submarines, AUVs, ROVs and other self-propelled platforms. The SVP 70 uses the latest electronic technology combined with an innovative mechanical design to yield a compact, robust, yet very flexible product.

The SVP 70 uses a direct path echosounding technique that instantly compensates for temperature and pressure with internal sensors.

The SVP 70 comes in a water resistant case including brackets for mounting, a 3m accessory cable, bolts, and a user manual with system description. Additional adaptor kits and fairing accessories are available.

www.reson.com
SVP 70
A new generation of fixed-mount sound velocity probes

PRODUCT SPECIFICATION

Sound velocity
Range: 1350 - 1800m/s
Resolution: 0.01 m/s
Accuracy: (0-50m ±0.05m/s) (50-500m ±0.2%)
Sampling Rate: 20Hz and lower programable
Sampling Mode: On request, continuous

I/O Interfaces
Connector: Bims MCI891M1** (Titanium)
Output: M/I891M, True RS-232 and True RS-422
Baud Rate: 2400-115200
Cable Length: 10m
Output Options: Direct, filtered, variable
Output Formats: Universal Programmable ASCII, Vaisport, ARIL, SVP24, NMEA, and others

Electrical
Supply: 8-55VDC
Current: 150mA @ 12V

Physical
Diameter: 44mm (maximum)
Length: 165mm (excl. connector)
End-Cap Height: 68mm (maximum)
Connector (MCI891M): 52.3mm x Ø22mm
Weight: approximately 1.0kg (excl. cable)

Environmental
Pressure: 0 - 6000bar
Temperature: -20 to +85°C

Sales Package
900-63-6000-00 - SVP 7V
904-63-6800-00 - Accessories Kit (5 pcs. DIN912 M6*10, 3 pcs. DIN931 M8*10, 4 x Mounting O-rings, 2.5m length cable, 1 unit connector, 1 unit cable holder)
701-6001 - 3M Mounting Bracket with wall mount option
904-63-6801-00 - Plastic Transport Case
904-63-6802-00 - Operatino Manual
904-63-6803-00 - Quick Reference Manual
904-63-6804-00 - Test Cable, 5.5m long terminated with R232 and R232 D-sub connections
904-63-6808-00 - 25m Wet Cable with connector
904-63-6809-00 - MCA Mini Tube Locking Sleeve
Optical Cables, 25m wet cable, 1 unit connector, 1 unit cable holder
904-63-6806-00 - 1.5m + 904-6406-0900-00 + Test + 904-6406-0901-00 - 3.5m +
904-63-6808-00 - 25m + 904-63-6806-00 - 60m

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January 14, 2011
MicroCAT C-T Sensor (Serial Interface)

The SBE 37-SI MicroCAT is a high-accuracy conductivity and temperature (pressure optional) sensor with Serial Interface, which includes a non-volatile FLASH memory. Externally powered, it is useful as a stand-alone monitoring device, and is easily integrated with current meters, ROVs, AUVs, towed sonars, and other instrumentation platforms. Constructed of titanium and other non-corroding materials to ensure long life with minimum maintenance, the MicroCAT’s depth capability is 7000 meters; it is also available with an optional 250-meter plastic ShallowCAT housing.

Calibration coefficients are stored in EEPROM, allowing the MicroCAT to output data in ASCII engineering units (decimal or XML format); raw output is also available. The data always includes Conductivity, Temperature, and Pressure (if optional sensor installed); users can choose to add any combination of time, sound velocity (Chen-Miller), salinity, depth, and density.

The MicroCAT retains the temperature and conductivity sensors used in our time-proven SEACAT and SEACAT plus products. Electrical isolation of the conductivity electronics eliminates any possibility of ground-loop noise. The MicroCAT’s unique internal-field conductivity cell permits the use of expendable anti-fouling devices. Its aged and pressure-protected thermistor has a long history of exceptional accuracy and stability.

The optional Druck pressure sensor has a superior design that is entirely different from conventional ‘silicon’ types in which the deflection of a metallic diaphragm is detected by epoxy-bonded silicon strain gauges. The Druck sensor employs a micro-machined silicon diaphragm into which the strain elements are implanted using semiconductor fabrication techniques. Unlike metal diaphragms, silicon’s crystal structure is perfectly elastic, so the sensor is essentially free of pressure hysteresis. Compensation of the temperature influence on pressure offset and scale is performed by the MicroCAT’s CPU.

SENSOR INTERFACE ELECTRONICS

Temperature is acquired by applying an AC excitation to a hermetically sealed Vishay reference resistor and an ultra-stable aged thermistor (drift rate typically less than 0.002 °C per year). The ratio of the thermistor resistance to reference resistance is determined by a 24-bit A/D converter; this A/D also processes the pressure sensor signal. Conductivity is acquired using an ultra-precision Wien-Bridge oscillator.

COMMUNICATIONS AND INTERFACING

The MicroCAT communicates directly with a computer via a standard RS-232 serial interface. Real-time data can be transmitted up to 1600 meters (5200 feet) at 600 baud (power considerations may limit the distance), simultaneous with recording. Data can be uploaded at up to 115.2 K baud. Firmware upgrades can be downloaded through the communications port by the user, without opening the instrument. An optional RS-485 interface allows multiple MicroCATs to share a common 4-wire cable (power, common, data +, data -), minimizing cable complexity for C-T chains.

User-selectable operating modes include:

- **Autonomous Sampling** — The MicroCAT is pre-programmed to sample, store data in FLASH memory, and transmit data. There are two types of autonomous sampling:
  - **Continuous sampling** at the fastest rate possible (1.0 second minimum without pressure)
  - **Interval sampling** at intervals of 9 seconds to 8 hours.
- **Pooled Sampling** — On command from a computer or satellite, radio, or wire telemetry equipment, the MicroCAT takes a sample and transmits data.
- **Serial Line Sync** — In response to a pulse on the serial line, the MicroCAT wakes up, samples, stores data in FLASH memory, transmits data, and goes to sleep.

SOFTWARE

The MicroCAT is supplied with a powerful Windows 2000/XP software package, SEASOFT®-Win32, which includes:

- **SeatekV2®** — Command program for easy communication and data retrieval.
- **SBE Data Processing®** — Programs for calculation, display, and plotting of conductivity, temperature, pressure (optional), and derived variables such as salinity and sound velocity.

Sea-Bird Electronics, Inc.
1808 136th Place NE, Bellevue, Washington 98005 USA
Website: http://www.seabird.com

E-mail: seabird@seabird.com
Telephone: (425) 643-0868
Fax: (425) 643-9954
**MicroCAT C-T Sensor (Serial Interface)**

**SBE 37-S1**

**SPECIFICATIONS**

**Measurement Range**
- Conductivity: 0 - 7 S/m (0 - 70 mS/cm)
- Temperature: -5 to 35 °C
- Optional Pressure: 20/1000/3500/6000/10000/2000/3500/7000 (meters of deployment depth capability)

**Initial Accuracy**
- Conductivity: 0.0003 S/m (0.003 mS/cm)
- Temperature: 0.002 °C
- Optional Pressure: 0.1% of full scale range

**Typical Stability**
- Conductivity: 0.0003 S/m (0.003 mS/cm) per month
- Temperature: 0.0002 °C per month
- Optional Pressure: 0.05% of full scale range per year

**Resolution**
- Conductivity: 0.00001 S/m (0.0001 mS/cm)
- Temperature: 0.0001 °C
- Optional Pressure: 0.002% of full scale range

**Clock Stability**
- 5 seconds/month

**Memory**
- 8 Mbyte; capacity in excess of 530,000 samples

**Input Power**
- 0.5 Amps at 8.5 - 24 VDC

**Quiescent Current**
- 30 microAmps

**Communication Current**
- 4.3 milliAmps

**Acquisition Current**
- 15 milliAmps

**Acquisition Time**
- 1.0 - 2.6 seconds/sample, dependent on sampling mode and inclusion of pressure sensor

**Housing, Depth Rating, & Weight**
- Standard: Titanium, 7000 m (23,000 ft)
- Weight in air: 2.9 kg (6.5 lbs)
- Weight in water: 1.9 kg (4.3 lbs)
- Optional ShallowCAT: Plastic, 250 m (820 ft)
- Weight in air: 2.2 kg (4.9 lbs)
- Weight in water: 1.2 kg (2.7 lbs)

---

* Power consumption values are for standard RS-232 interface; for optional RS-485 interface, see RS-485 manual.

---

**SBE**

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1808 136th Place NE, Bellevue, Washington 98005 USA
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E-mail: seabird@seabird.com
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Fax: (425) 643-9954

Page A-32 of 36
January 14, 2011
MOHICAN Inspection ROV System

Our Mohican Inspection Class ROV system incorporates an enhanced propulsion system allowing it to continue working in high current conditions when other systems have to return to surface, providing a customer benefit of reduced vessel time and costs.

- Ultra-High Thrust Greater Than 100 kgf / 220 lbf Both Axial and Lateral
- Six Brushless DC Thrusters with Sub-Atlantic’s Statoshield™ Technology and Dynamic Vectoring
- 3000 Volt, 400 Hz Power System
- Long, Small Diameter, Low Drag Tether
- 2,000 Metre / 6,500 Feet Standard Rating
- 35 kg / 77 lbs Standard Payload (Options)
- Auto-Functions
- Multiple Video Channels
- Deep Live Boat, Tunnel or TMS Operation
- Manipulator Options
- Integral High Pressure Cleaning System Option
- Various Skid Options

The Mohican ROV features a small diameter tether and high output brushless DC thrusters operating on Sub-Atlantic’s Dynamic Vectoring™ system. The Mohican comes with three or six simultaneous video channels transmitted through a fibre-optic telemetry system for sharp, high quality video inspections. The ROV is also equipped with additional power sources for attachment of manipulator and tools such as our high pressure jetting and cleaning skid used in platform inspections.

Mohican uses a 3000 Volt, 400 Hz power transmission system from surface to ROV resulting in a small tether, main lift cable and launch & recovery system. This transmission system makes Mohican particularly suited for long tunnel inspections and deep live-boating operations.
Live Boat or TMS Operation

The Mohican can be free-flown in "live boating" mode or with our captive type TMS systems (see TMS detachable). We also offer a range of Launch and Recovery Systems (LARS).

Compact Control

Surface equipment consists of three basic units:
- Surface Control Unit (SCU) in an 8U x 19" rack mount configuration.
- Transformer Power Unit (TPU) incorporating transformer in a floor mounted cabinet.
- Hand Control Unit (HCU) which is lightweight and portable.

The components are generally installed in ISO control cabinets supplied by customer or Sub-Atlantic.

The HCU (top), SCU (left), and TPU (right) are compact for operation in small control spaces. The three units are linked by interconnecting cables with plugs and sockets.

As an alternative, the HCU and SCU can be supplied mounted in a 19" rack mount flight case complete with two 17" colour monitors. An additional spare slot can accommodate a video recorder. The rear case panel forms the base during operation to locate the HCU.

Mohican System Specification

ROV General Specification

Depth Rating: 2000 msw (6560 ftsw) standard (deeper options)
Payload: 35 kg (77 lb) lead ballast
Height: 800 mm (25.5 in)
Length: 150 mm (4.3 in)
Width: 770 mm (30.3 in)
Wass in Air: 296 kg (654 lb)
Max Thrust: 110 kgf (242 lb)
Reverse: 110 kgf (242 lb)
Lateral: 110 kgf (242 lb)
Vertical: 75 kgf (165 lb)
Max Velocity (Operational Current): 1.75 m/s (3.5 K)
Turning Rate: 180 Degrees Per Second (approx)

Surface Equipment General Specification

SCU

Height: 460 mm (18.1 in)
Width: 460 mm (18.1 in)
Depth: 460 mm (18.1 in)
Mass: 2 kg (4.5 lb)
SCU Power Requirements: 220/240 Vac 50/60 Hz 2 kW

TPU

Height: 650 mm (25.6 in)
Width: 630 mm (24.8 in)
Depth: 505 mm (19.9 in)
Mass: 280 kg (618 lb)

HCU

Height: 160 mm (6.3 in)
Width: 400 mm (15.8 in)
Depth: 230 mm (9.1 in)
Mass: 1.5 kg (3 lb)

Flight Case Option with 2 x 9" monitors & 8U control module

Height (operation): 980 mm (38.6 in)
Height (transport): 800 mm (31.5 in)
Width: 520 mm (20.5 in)
Depth (operation): 720 mm (28.3 in)
Depth (transport): 550 mm (21.7 in)
Mass: 66 kg (145 lb)
SCU Power Requirements: 220/240 Vac 50/60 Hz 2 kW

Tether and Main Lift Cable Dimensions

Tether (standard): 16.5 mm / 0.65 in, diameter
Main Lift Umbilical (upto 4000 msw): 25.5 mm / 1.0 in, diameter
Tether Management System
Sub-Atlantic's cage type TMS is renowned in the industry for ruggedness, reliability and simplicity.
- Size I suitable for Mohican
- 350 metres capacity of 16.5 mm diameter tether
- Stainless steel telescopic frame allowing underslung tool skids on ROV
- Fully electric single drive motor
- Refer to TMS data sheet.

Launch & Recovery Systems
Launch and recovery systems can be supplied to different depth requirements and formats such as A-frame or jib crane.

Control Cabins
- Various sizes and configurations available
- A-60 and Zomed specifications
- Workshop options

Mohican ROV Dimensions

Size I TMS Dimensions

The specification details are illustrative for marketing purposes only. Actual equipment may be different as a result of product improvement or other reasons. Specific interface and performance information should be referenced at time of order placement.

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Tel: +1 2241 998660  Fax: +1 2241 998661  E: sales@sub-atlantic.co.uk

Sub-Atlantic Inc, 10642 Village Little York, Suite 100, Houston, TX 77041-4014-USA
Tel: +1 713 329 6330  Fax: +1 713 329 6399  E: sales@sub-atlantic.com

Mohican (22 Feb 2008)
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APPENDIX B

B1. COMPARISON OF NOAA TIDE ZONING AND FES2004 TIDAL MODEL ZONING

B2. PRECISE POINT POSITIONING (PPP) TIDAL CORRECTIONS
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APPENDIX B1

COMPARISON OF NOAA TIDE ZONING AND FES2004 TIDAL MODEL ZONING
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1.1 **Comparison of NOAA Tide Zoning and FES2004 Tidal Model Zoning**

While it is difficult to quantify the quality of two models that predict tidal solutions without having actual local tide gauge data, overlapping multibeam echosounder (MBE) survey lines can be analyzed for relative differences. Assuming that there are no contributing errors in the multibeam data, other than inaccuracies in the tidal solution, the vertical separation between adjacent and overlapping lines can indicate the errors in a tidal prediction(s).

The NOAA tide zoning for the USWTR survey area is based on a gauge which is located at Mayport (Bar Pilots Dock), FL (Station ID: 8720218). This gauge is situated at the mouth of the St. Johns River and is therefore affected by the river discharge and by the shallow water modifications to the tidal wave. From examining the harmonic constituents of the station, it can be observed that approximately 10 cm of tidal amplitude at the station is from shallow water constituents, which would not be observed at the survey site.

As shown in Figure B1-1, three random areas were chosen for comparison of tidal modeling results, one to the north of the survey area and two to the south. In Area 1 a vertical offset between MBE survey lines can be observed on the order of 0.2 meters with the zoned NOAA tide applied. This difference decreases to less than 0.05 meters when the FES2004 modeled tides are applied to the same MBE survey lines (Figure B1-2). Similar results were observed in Areas 2 and 3 (Figure B1-3 and B1-4).

![Figure B-1 – Three Comparison Areas in Relation to Jacksonville, FL and the Reference Gauge 8720218](image-url)
Figure B1-2. CARIS profiles from Area 1 with zoned predicted NOAA tides on top and zoned FES2004 model tides on the bottom. Each line represents an individual multibeam survey line; colors are selected randomly by CARIS. Vertical exaggeration is 300x.
Figure B1-3. CARIS profiles from Area 2 with zoned predicted NOAA tides on top and zoned FES2004 model tides on the bottom. Each line represents an individual multibeam survey line; colors are selected randomly by CARIS. Vertical exaggeration is 300x.
Figure B1-4. CARIS profiles from Area 3 with zoned predicted NOAA tides on top and zoned FES2004 model tides on the bottom. Each line represents an individual multibeam survey line; colors are selected randomly by CARIS. Vertical exaggeration is 300x.

The zoned NOAA and FES2004 world model tides were plotted in Microsoft Excel in order to graphically compare the two solutions (Figure B1-5). Although their periods are very similar, the amplitude of the zoned NOAA tide solution is approximately 0.2 meters greater than the FES2004 model solution at times. This may account for the discrepancies observed in the three sample areas shown above.
Figure B1-5. A plot comparing the FES2004 model (blue curve) with the NOAA tide (red curve). The straight line in the center of the plot (at about 12:00 PM) on Jan 1, 2010 represents a period when no bathymetric data was collected.

1.2 SPECIAL ORDER TIE-LINE COMPARISON

In some locations the FES2004 model tides do not reduce the separation between overlapping survey lines as compared to the zoned NOAA tides. For lines using each of these tidal solutions, a tie-line analysis Quality Control (QC) report was output from CARIS highlighting the percentage of soundings which meet the International Hydrographic Organization (IHO) Special Order accuracy specifications. Four areas within the survey domain were chosen at random for analysis (Figure B1-6). The associated QC graphs (Percentage of Soundings Passed vs. Beam Angle) are shown in Figures B1-7 through B1-10. Note the change in scale on the Y-Axis on the figures below.
Figure B1-6. Four areas, chosen at random from near the center (both horizontally and vertically) of the survey area. Vertical lines are the main survey lines and the horizontal lines are tie-lines.
Figure B1-7. Graph displaying the percentage of soundings that meet IHO Special Order specifications for both the FES2004 model (blue curve) and NOAA tides (red curve) in Area 1. The y-axis is percentage, while the x-axis is the beam angle (degrees) of the sounding.

Figure B1-8. Graph displaying the percentage of soundings that meet IHO Special Order specifications for both the FES2004 model (blue curve) and NOAA tides (red curve) in Area 2. The y-axis is percentage, while the x-axis is the beam angle (degrees) of the sounding. Note the change in the y-axis scale from the previous figure.
Figure B1-9. Graph displaying the percentage of soundings that meet IHO Special Order specifications for both the FES2004 model (blue curve) and NOAA tides (red curve) in Area 3. The y-axis is percentage, while the x-axis is the beam angle (degrees) of the sounding. Note the change in the y-axis scale from the previous figure.

Figure B1-10. Graph displaying the percentage of soundings that meet IHO Special Order specifications for both the FES2004 model (blue curve) and NOAA tides (red curve) in Area 4. The y-axis is percentage, while the x-axis is the beam angle (degrees) of the sounding. Note the change in the y-axis scale from the previous figure.
1.3 CONCLUSIONS

The CARIS tie-line QC reports show a similar percentage of soundings from each tide model solution passing IHO Special Order accuracy specifications. When compared to the NOAA tide solution, the FES2004 model shows greater vertical agreement between the individual survey lines, as well as estimates tidal amplitudes without the bias from shallow water constituents. This data indicates that FES2004 model and the NOAA tidal model provide similar results.
APPENDIX B2

PRECISE POINT POSITIONING (PPP) TIDAL CORRECTIONS
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1.0 INTRODUCTION

As specified in the project work plans, the bathymetry data were processed using tidal models. While the NOAA and FES2004 world hydrodynamic models, which are described in the Appendix B, Section 1, provide fairly accurate tidal corrections, local wind, current and weather conditions at the site can cause deviations from the model. These deviations can create anomalies in the bathymetry surface calculation, which uses the water surface heights derived from the tide model as a vertical reference for the sonar data. The bathymetry data processed with the tide models show mismatches between adjacent lines, which in a survey this size are collected hours or even days apart. These mismatches are frequently on the order of 0.2 to 0.6 meters or larger, a significant part of the error budget when surveying in depths less than 100 meters.

PosView software was used to collect raw GPS and inertial data from the primary positioning system, an Applanix POS MV, utilized during the 2009/2010 CC Range and USWTR bathymetry surveys. The files were imported into the POSPac Marine Mapping Suite post processing software and a precise point positioning (PPP) solution was calculated using measured satellite clock and orbit corrections. PPP uses precise ephemeris data, provided by the National Geodetic Survey (NGS) within approximately 14 days of the end of a GPS week, to improve both the horizontal and vertical GPS solution to sub-decimeter accuracy.

Tetra Tech collected the POSPac data in both survey areas; however it was not a requirement of the contract or work plan to do so. At several points during the survey, the POSPac collection failed or the data did not produce valid outputs when processed. Since these data were collected as a value added item, rather than a requirement, those sections of the survey were not re-collected. The tide model data that best matched the surrounding valid PPP processing results were used to provide water surface elevations in these areas.

2.0 DETERMINING SEPARATION

Two types of comparisons were performed with the PPP processed data from the POS MV: water level checks against verified tides when the vessel was positioned near a NOAA tide station and a comparison of bathymetry data processed with the tide model and PPP elevations.

2.1 TIDAL STATION COMPARISON

In order to validate PPP heights, comparisons were made to verified NOAA tides. Two POSPac data sets were processed using the PPP software and exported as ASCII times and elevations, referenced to the WGS-84 ellipsoid. The first one was collected on March 16, 2010 at St. John’s Boat Yard, across the St. John’s River from the Mayport tidal station (Station ID: 8720218), and the second, on April 10, 2010, while in the St. John’s River at the Mayport tidal station.

The POSPac data from the same area was also processed using another Applanix post-processing software tool to derive a post-processed kinematic (PPK) solution. The software uses data from Continually Operating Reference Stations (CORS) available from NGS to apply corrections to the POSPac data collected in real time. This technique allows for centimeter level positioning.
accuracies. The PPK derived heights correlated to the PPP derived heights with differences on the order of 1 decimeter, approximately the published accuracy of the PPP processing.

As shown in Table B2-1 and B2-2, the ellipsoid heights were then converted to the North American Vertical Datum of 1988 (NAVD 88) using the GEOID03 model separation values at the location of the data. As the PPP data are relative to the reference point of the vessel, the height of the reference point relative to the waterline was subtracted from the data to reference it to the water level. This average measurement of 0.4 m was recorded at various times throughout the survey. The NOAA documentation for the Mayport tide station shows the datum separation between NAVD 88 and local MLLW datum is 0.912 meters. This value was added to the PPP data. Figure B2-1 shows these values, while Figure B2-2 illustrates the spatial relationship between MLLW and NAVD 88.

A check was also performed using the NGS GEOID 09 model; however the differences between the GEOID03 and GEOID09 models were only 1.7 cm at the primary tide station benchmark and as a result were not considered significant.

The calculated PPP heights were then compared to the verified NOAA tide data at the Mayport tidal station. The results showed the PPP tide data were consistently biased 1.5 meters below the NOAA tide data.
Table B2-1: Tide Station comparison on March 16, 2010, during the time frame of the USWTR survey (Refer to the USWTR Cruise Report [Section 3.1]).

<table>
<thead>
<tr>
<th>Time (GMT)</th>
<th>Mayport Tide Station MLLW (m)</th>
<th>GPS Water Level (Ellipsoid) (m)</th>
<th>Geoid 2003 Separation (m)</th>
<th>CPS NAVD88 Heights (m)</th>
<th>Vessel Waterline (m)</th>
<th>NAVD to MLLW Difference (m)</th>
<th>PPP MLLW Heights Difference Between NOAA MLLW PPP MLLW</th>
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Standard Dev. 0.17 0.19 0.00 0.19 0.00 0.00 0.19 0.03
Table B2-2: Tide Station Comparison on April 10, 2010

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<th>Geoid 2003 Separation (m)</th>
<th>GPS NAVD88 Heights (m)</th>
<th>Vessel Waterline (m)</th>
<th>NAVD to MLLW Difference (m)</th>
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Minimum: 0.95 -29.54 -28.51 -1.03 0.40 0.91 -0.51 1.46
Maximum: 1.17 -29.32 -28.51 -0.81 0.40 0.91 -0.30 1.52
Stand. Dev.: 0.08 0.08 0.00 0.08 0.00 0.00 0.08 0.02

Figure B2-1. Elevation on Station Datum sheet from NOAA’s Tide & Currents website (http://tidesandcurrents.noaa.go) for Mayport tidal station.
2.2 Sounding Comparison

The second method employed to confirm the validity of the PPP heights was to apply the PPP tide solution to various survey lines throughout the survey area, while applying NOAA zoned tide to adjacent lines. This was done by outputting a smoothed best estimate trajectory (SBET) file from POSPac and then applying it in CARIS HIPS and SIPS 6.1. To convert from the ellipsoid to NAVD 88, the GEOID03 model was downloaded from the National Geodetic Survey’s website (http://www.ngs.noaa.gov) and applied in CARIS along with the local 0.912 meter datum shift to MLLW. The NOAA zoned tide was applied to adjacent lines. Multiple profiles from across the survey area were then examined to measure the difference between the soundings with the PPP tide and soundings with the NOAA zoned tide (Figure B2-3). The profiles showed the PPP tide data consistently 1.5 meters below the NOAA data.
Figure B2-3. Soundings with NOAA zoned tide applied (the three upper lines) vs. soundings with PPP tide applied (the two lower lines). The vertical exaggeration is 200x.

3.0 ACCURACY CHECK

The offsets between all sensors and a number of control points on the R/V White Holly were surveyed with a laser total station, under the direction of a licensed, professional land surveyor, during vessel mobilization. These offsets were subsequently checked using a combination of calibration software within the POS MV and tape measure by members of the field survey crew. No significant differences from the values provided by the professional land surveyor were found.

3.1 POSPac Reference to GPS Lever Arm Calibration

A POSPac reference to GPS lever arm calibration was run on data collected during the survey to confirm the lever arm values measured between the survey vessel’s reference point and the POS antennas. Figure B2-4 shows that, after a calibration period, the values are within a centimeter of the measured value of -9.101 m. This calibration also provides a POSPac merit value which quantifies the confidence in the calibration. As Figure B2-5 shows, after the initial calibration period, the merit value of the calibration is 100, the highest value possible.
Figure B2-4. POSPac Reference to GPS Lever Arm Calibration Results

Figure B2-5. POSPac Reference to GPS Lever Arm Figure of Merit
4.0 PPP TIDE FILE CREATION

Smoothed best estimate trajectory (SBET) files were applied to the remaining survey lines in CARIS HIPS and SIPS 6.1 and PPP tide was calculated using the GEOID03 model and the 0.912 meter shift to MLLW. The data was then smoothed using a box car, 60 second moving average and exported into ASCII files containing date, time and orthometric height. The heights were then shifted a positive 1.5 meters to account for the measured bias.

The resulting solution was plotted in Golden Software’s Grapher 8 program, along with the FES2004 world model and NOAA zoned tide solutions (Attachment B2-1). The average reverse draft value of 0.4 meters was added to the world model and NOAA zoned tides in order to make them relative to the survey vessel’s reference point. During times where the PPP data was not viable due to corrupted position data or GPS error, a best fit solution was taken from the world model or NOAA zoned tides and was inserted into the PPP tide file.

The edited PPP tide file was brought into CARIS and applied to the soundings.

5.0 ANALYSIS

5.1 RESULTS

As shown in Attachment B2-1, the PPP solution does seem to represent a tidal signature. There appear to be no areas of increased noise, systematic biases, or blunders. Gaps in the curves are times when no bathymetric data was collected during CC Range survey operations. At various times throughout the survey, the PPP solution seems to match the world model tide very closely, while matching the NOAA zoned tide at other times. During many periods, the PPP solution appears to be the median between the other two. Table B2-3 compares the world model and NOAA zoned tides with the PPP solution.

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<th>NOAA - PPP (m)</th>
<th>Model - PPP (m)</th>
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</thead>
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<td>Median</td>
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Figures B2-6 through B2-8 show CARIS profiles taken of the data with the world model tide (as provided in the Draft version of this cruise report) and with the PPP tide. Note that the locations of the profiles are primarily in shallow water depths (<100m). This is because of the lack of noticeable offsets in the deeper water (>100m). The maximum vertical separation measured between these lines was 0.15 meters with the PPP tide, and 0.35 meters with the world model tide. The average vertical separation measured between lines was 0.1 meters with the PPP tide and 0.25 meters with the world model tide.
Figure B2-6. Profile 1 with world model tide on top, PPP tide on the bottom. Vertical exaggeration is 300x. Inset shows the location of the profile.
Figure B2-7. Profile 2 with world model tide on top, PPP tide on the bottom. Vertical exaggeration is 300x. Inset shows the location of the profile.
Figure B2-8. Profile 3 with world model tide on top, PPP tide on the bottom. Vertical exaggeration is 300x. Inset shows the location of the profile.
Three uncertainty surfaces were created in CARIS with the PPP tide: a 25 meter grid (depths >250m), 20 meter grid (depths 100-250m) and 5 meter grid (depths <100m). These were imported into IVS3D Fledermaus and compared to matching surfaces created with the world model tide. The results are displayed in Figures B2-10 through B2-12. For depths greater than 250 meters, the average separation between the two surfaces is 0.44 meters and the standard deviation is 0.37 meters. 100-250 meter water depths showed an average separation of 0.18 meters and a standard deviation of 0.16 meters. Depths less than 250 meters had an average separation of 0.13 meters and a standard deviation of 0.19 meters.

![Surface Statistics](image)

Figure B2-10. Surface comparison: PPP vs. world model tide (Depths > 250 meters).
5.2 CONCLUSIONS

The PPP tidal solution does a very good job of representing the change in water level over the survey region. Vertical separations between survey lines generally decreased between 0.1 and 0.2 meters with the PPP tidal solution. This greatly improved vertical alignment between survey lines and, in many cases, removed the separation. Areas where a vertical separation still exists...
can be explained by potential inaccurate sound velocity corrections and the accuracy tolerances of the PPP processing.

During times when PPP solution was not found to be valid and world model or NOAA zoned tide were used, the results were mixed. In some areas, no tidal separations are evident, however in others, up to a 0.25 meter vertical separation still exists, due to the local variations that a broad area model can not predict.

The use of PPP water level measurements appears to offer significant improvement over broad area models when compensating for local water level variations induced by wind and currents. It provides a bathymetry surface with far fewer and smaller line to line artifacts, which greatly enhances the accuracy and usefulness of analyses such as the Benthic Terrain Modeler developed by NOAA and Oregon State University.
Attachment B2-1 Final Tidal Comparisons

1. All heights are relative to survey vessel reference point, which is, on average, 0.42m above MLLW, Epoch 1983-2001.
2. Final edited PPP tidal solution utilizes GPS PPP tidal data combined with a best fit solution during GPS data outages.
1. All heights are relative to survey vessel reference point, which is, on average, 0.42m above MLLW, Epoch 1983-2001.
2. Final edited PPP tidal solution utilizes GPS PPP tidal data combined with a best fit solution during GPS data outages.
CC Range Bathymetric Position Index (BPI) Broad Scale Survey Equipment

- Multibeam Sonar
- Positioning System
- Heading Sensor
- Motion Sensor

Geodetic Settings

- Horizontal Datum: WGS-84
- Projection: UTM Zone 17 North
- Horizontal Units: Meters
- Vertical Datum: MLLW (Epoch 1983-2001)
- Vertical Units: Meters

Survey Area Boundary

- Deepwater Coral Habitat
- Area of Particular Concern (HAPC)

Bathymetric Position Index (BPI) Broad Scale

- (0-100m: 20m radius, 100m-250m: 200m radius, >250m: 250m radius)
- (0-100m: 5m, 100m-250m: 20m, >250m: 25m)

CARIS Uncertainty

- 0.25

Survey Area Boundary

- CC Range Boundary
- Deepwater Coral Habitat
- Area of Particular Concern (HAPC)

Scale = 1:50,000

Surveyed:

- December 2009, April-May 2010

Crew Chief:

- C. Graves, B. Johnston, R. Funk
- MJ Watson

Prepared by:

- B. Bridge, J. Hobson, R. Feldpausch

TetraTech

19600 North Creek Parkway
Bothell, WA 98011
1 (425) 482-7600

NAVFAC Atlantic

CC Range Bathymetric Position Index (BPI) Broad Scale

- RESON 7125-SV/7150-F
- Applanix POS MV 320

- Sound Speed Profilers
- Oceanscience UCTD/Sippican XBT

- Vertical Control
- USCG DGPS Corrections

- Horizontal Control
- NOAA Tide Model

- Horizontal Datum
- Projection
- Horizontal Units
- Vertical Datum
- Vertical Units

- Survey Area Boundary
- CC Range Boundary
- Deepwater Coral Habitat
- Area of Particular Concern (HAPC)

- Bathymetric Position Index (BPI) Broad Scale

- (0-100m: 20m radius, 100m-250m: 200m radius, >250m: 250m radius)

- (0-100m: 5m, 100m-250m: 20m, >250m: 25m)

- CARIS Uncertainty

- 0.25
HAPC

580000

590000

600000

610000

620000

3380000

3390000

3400000

19803 North Creek Parkway
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TetraTech
NAVFAC Atlantic

CC Range Bathymetric Position Index (BPI) Fine Scale
Survey Equipment

- Multibeam Sonar
- Positioning System
- Heading Sensor
- Motion Sensor

- Geodetic Settings
  - Horizontal Datum: WGS-84
  - Projection: UTM Zone 17 North
  - Horizontal Units: Meters
  - Vertical Units: Meters
  - Geodetic Settings
  - Horizontal Datum: WGS-84
  - Projection: UTM Zone 17 North
  - Horizontal Units: Meters
  - Vertical Units: Meters

- Sound Speed Profilers
- Oceanscience UCTD/Sippican XBT

- Vertical Control
  - Vertical Datum: NOAA Tide Model
  - Vertical Control: Vertical Datum

- Survey Area Boundary
- CC Range Boundary
- Deepwater Coral Habitat Area of Particular Concern (HAPC)

- Bathymetric Position Index (BPI) Fine Scale
  - 0-100m: 15m radius
  - 100m-250m: 60m radius
  - >250m: 75m radius

- Bathymetry
  - Elevation in Meters
  - Scale = 1 km

- Slope
  - Degree Slope
  - <0
  - >0

- Surveyed Dates
  - December 2009, April-May 2010

Crew Chief: C. Graves, B. Johnston, R. Funk
Surveyed by: C. Graves, B. Johnston, R. Funk

Checked by: MJ Watson

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1 of 12

Plate 1

Sheet 5 of 12
Benthic Zone Classifications

1. Crests - High points in the terrain where there is a positive bathymetric position index value one standard deviation above the mean. These are generally elevated areas.
2. Depressions - Low points in the terrain where there is a negative bathymetric position index value one standard deviation below the mean. These are generally submerged areas.
3. Flats - Flat points in the terrain where there is near zero bathymetric position index values that are within one standard deviation of the mean. Flats have a slope that is less than or equal to 5°.
4. Slopes - Sloping points in the terrain where there are near zero bathymetric position index values that are within one standard deviation of the mean. Slopes have a slope that is greater than 5°.

Horizontal Datum: WGS-84
Projection: UTM Zone 17 North
Geodetic Settings:
- Horizontal Datum: WGS-84
- Projection: UTM Zone 17 North
- Geodetic System: WGS-84
- Vertical Datum: MLLW (Epoch 1983-2001)
- Cell Size/Grid Method: [Cell Size/Grid Method]
- Bathymetric Position Index (BPI) Parameters:
  - Fine Scale: (0-100m: 15m radius, 100m-250m: 60m radius, >250m: 75m radius)
  - Broad Scale: (0-100m: 100m radius, 100m-250m: 200m radius, >250m: 250m radius)
- Bathymetric Position Index (BPI) Descriptions:
  - Crests: High points in the terrain where there is a positive index value one standard deviation above the mean.
  - Depressions: Low points in the terrain where there is a negative index value one standard deviation below the mean.
  - Flats: Flat points in the terrain where there is near zero index values that are within one standard deviation of the mean. Flats have a slope that is less than or equal to 5°.
  - Slopes: Sloping points in the terrain where there are near zero index values that are within one standard deviation of the mean. Slopes have a slope that is greater than 5°.

Survey Equipment:
- Multibeam Sonar: RESON 7125-SV/7150-F
- Positioning System: Applanix POS MV 320
- Heading Sensor: Applanix POS MV 320
- Motion Sensor: Applanix POS MV 320
- Sound Speed Profilers: Oceanscience UCTD/Sippican XBT
- GPS Precise Point Positioning/USCG DGPS Corrections
- NOAA Tide Model
- Vertical Datum: MLLW (Epoch 1983-2001)

Reviewed by: [Reviewed by]

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T: 1 (425) 482-7600

CC Range Benthic Zone Classifications and Bathymetric Derivatives

Sheet: 7 of 12
Plate: 1
### Benthic Terrain Classifications

**Bathymetry**

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<th>Broad Scale BPI Parameters</th>
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**Geodetic Settings**

- **Horizontal Datum**: WGS-84
- **Projection**: UTM Zone 17 North
- **Positioning System**: Apollo POS MV 320
- **Sound Speed Profiler**: Oceanscience UCTD/Sippican XBT
- **GPS Precise Point Positioning**: NOAA Tide Model

**Survey Equipment**

- **Multibeam Sonar**: Reson 7125-SV/7150-F
- **Heading Sensor**: Applanix POS MV 320
- **Motion Sensor**: Applanix POS MV 320
- **Cell Size/Grid Method**: C. Graves, B. Johnston, R. Funk
- **Reviewed by**: MJ Watson

**Survey Area**

- **CC Range Boundary**
- **Survey Area Boundary**
- **Deepwater Coral Habitat Area of Particular Concern (HAPC)**

**Benthic Terrain Classification Descriptions**

1. **Narrow Depression** - A depression where both fine and broad features are lower than their surroundings.
2. **Depression on Flat** - A fine-scale depression within a flat terrain.
3. **Midslope Depression** - A fine-scale depression that laterally incises a slope greater than 5°.
4. **Depression on Crest** - A fine-scale depression within a crested terrain.
5. **Open Depression** - A broad-scale depression with a U-shape where any nested, fine-scale features are flat or have constant slope.
6. **Shelf** - A broad flat area where the terrain contains few, nested, fine-scale features and has a slope less than 5°.
7. **Escarpment** - A constant slope where the slope values are between 5° and 70° and have few, nested, fine-scale features within the broader terrain.
8. **Crest in Depression** - A fine-scale crest within a broader depressed terrain.
9. **Crest on Flat** - A fine-scale crest within a broader flat terrain with a slope less than 5°.
10. **Midslope Crest** - A fine-scale crest that laterally divides a slope. This often looks like a ledge in the middle of a slope.
11. **Narrow Crest** - A crest where both fine and broad features are higher than their surroundings.
12. **Broad Crest** - A crest where both fine and broad features are higher than their surroundings.
13. **Upper Slope** - A broad flat area where the terrain contains few, nested, fine-scale features and has a slope less than 5°.

**Bathymetric Position Index (BPI)**

- **Fine Scale**: (0-100m: 15m radius, 100m-250m: 60m radius, >250m: 75m radius)
- **Broad Scale**: (0-100m: 100m radius, 100m-250m: 200m radius, >250m: 250m radius)

**Notes**

1. **Derived using the Benthic Terrain Modeler (BTM), version 1.0, released April 2005**


3. **BTM functions as an interactive toolbar within ArcMap, and relies on a methodology developed by former graduate students Emily Lundblad, Emily Larkin, and Ron Rinehart under the direction of Dr. D.J. Wright.**

4. **Uncertainty calculations are grid based and may vary for the same region when analyzed at different grid resolutions.**

5. **rorreek**
APPENDIX D

SOUND VELOCITY CAST LOG
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<th>Lat</th>
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ACRONYMS AND ABBREVIATIONS

dB          decibel
HIPS        Hydrographic Information Processing System
kHz         kilohertz
OMG         Ocean Mapping Group
TtEC        Tetra Tech EC, Inc.
TVG          time varying gain
1.0 INTRODUCTION

Multibeam bathymetry provides a detailed definition of the topography of the seafloor and significant information on the geological structures, terrain, and likely sediment makeup of many areas within the survey area. Processing of imagery data acquired from multibeam sonars can provide another dimension that can aid in classifying sediment types, locating sensitive habitats, and defining those areas and conditions that will have an effect on planned construction work.

The sonars that were used to conduct bathymetric surveys of the CC Firex/Gunex Range located within the Jacksonville (JAX) Operating Area (OPAREA) from December 2009 to April 2010 can produce two types of imagery. These include multibeam sidescan, which effectively generates a single amplitude time series on either side of the track line, like conventional sidescan sonar and snippets (sometimes referred to as backscatter), which extract a segment of imagery from each beam, centered about the bottom detection. The latter is much easier to accurately geo-reference in survey areas with a lot of vertical relief due to the inherent correlation between the imagery and the bathymetric soundings and is the preferred type of imagery for bottom classification in many cases.

A review of existing processing tools for the raw snippets data showed that many of the software publishers were still in development and that there was no commercial off-the-shelf (COTS) solution that could ensure success in processing these data within the project schedule constraints. To ensure that project goals could be met, Tetra Tech (Tt) contracted with Dr. Jonathan Beaudoin, a Research Scientist at the Center for Coastal and Ocean Mapping at the University of New Hampshire. Dr. Beaudoin has extensive experience in processing backscatter data from RESON multibeam systems (Beaudoin et al., 2002; Gardner and Beaudoin, 2005; Intelmann et al., 2006; Intelmann et al., 2007). Dr. Beaudoin modified his algorithms and software to work with these data; the resulting processing tools were run in parallel with tests of updates to the COTS tools as they became available.

The following is a description of the processing used to generate mosaics suitable for subsequent analysis and processing to extract the imagery data needs for the project.

2.0 SEABED IMAGERY PROCESSING

Seabed bathymetry and acoustic imagery data were acquired in the Jacksonville (JAX) Operating Area (OPAREA) from December 2009 to April 2010. Two multibeam echosounder systems were used to acquire the data: a RESON SeaBat 7150 (24 kHz) and a SeaBat 7125 (400 kHz) for the survey effort. Bathymetric data were of primary interest; however, the return signal strength was of interest for seafloor characterization. The aim of this memorandum is to document the post-processing efforts undertaken by Dr. Beaudoin to correct the seabed imagery data for variable sonar settings and geometric effects.

Some data from other projects were used to support development efforts to provide a broader range of conditions and help make the processing more robust.
3.0 BATHYMETRIC DATA REDUCTION

Data were converted into Ocean Mapping Group (OMG) format from raw HYPACK data files. The HYPACK files provided navigation, orientation, and heading information whereas the .7K files provided bathymetry, multibeam sidescan imagery (single amplitude time series for each side), and snippets (backscatter – a time series sample from each beam, centered around bottom detect) data. The vessel configuration information and sound speed profiles were obtained from CARIS Hydrographic Information Processing System (HIPS) project files, both of which were converted into OMG format. To avoid the need to re-clean the bathymetric data, a list of rejected soundings was also exported from the CARIS HIPS data files to allow the information to be used to flag soundings in the OMG format files. Small inconsistencies between timing conventions between CARIS and OMG format resulted in a small number of visual inspection of soundings and removal of remaining outliers.

4.0 RADIOMETRIC DATA REDUCTION

A common byproduct of multibeam bathymetric surveys is an estimate of the backscattered acoustic intensity from the seafloor. These data are of interest to geoscientists because maps of the acoustic backscattering strength can be used to infer physical properties of the sea bottom. Before such maps can be created, the return signal intensities must be reduced to as close a measure of the acoustic backscattering strength of the seafloor as possible by radiometrically correcting the data on a ping-by-ping (and sample-by-sample) basis for sonar system variables such as transmitter source level, receiver gain, pulse length, and beam patterns.

Normalization and correction procedures vary between sonar systems; some manufacturers go to great lengths to provide normalized backscatter imagery in real time whereas others provide the data in a raw state. Each approach has advantages and disadvantages. The advantage of the first approach is that the imagery data are immediately ready for map production. The disadvantage, however, is that this method is susceptible to real-time corruption of the normalization algorithms. In this case, the user is faced with reversing the real-time corrections and normalization (which is not necessarily trivial) and re-applying their own correction scheme.

The disadvantage of the first approach is avoided altogether by using the second method because it typically eliminates the need to reverse engineer what was done to the data in order to remove artifacts from real-time correction and normalization procedures. The disadvantage of the second approach is that the user must always apply their own correction and normalization procedures.

The RESON 7125 and 7150 follow the second approach—providing seabed imagery in a raw state (though it should be noted that the 7150 can be upgraded to provide calibrated output imagery). Corrections that must be performed for these two systems include:

- Source level
- Static receiver gain
- Time-varying gain (TVG)
- Pulse length
- Transmitter beam pattern
These system parameters can be varied by the operator during acquisition (with the exception of the transmitter beam pattern); the settings chosen during acquisition are logged in the data stream output by the system, as described in the SeaBat 7125 and 7150 operator’s manuals (RESON 2006, 2008).

4.1 **RESON 7150**

The imagery data from the RESON 7150 were corrected using the following model:

\[
BS_{\text{rel}} = 20\log_{10}(DN) + DB_{\text{SHIFT}} - SL - G - 10\log_{10}(A) \tag{4.2}
\]

where:

- \( BS_{\text{rel}} \) = the seafloor’s relative acoustic backscattering strength
- \( DN \) = the 16-bit digital number output by the 7K processor, assumed directly proportional to units of linear pressure (hence \( 20\log_{10}(DN) \)) instead of \( 10\log_{10}(DN) \)
- \( DB_{\text{shift}} \) = an additive constant used to shift data into the expected range of seafloor backscatter values, this is the largest source of uncertainty in this process
- \( SL \) = source level of the transmitter in dB re 1 microPascal at 1 m
- \( G \) = receiver gain in dB (time-invariant over the reception cycle, not to be confused with time varying gain (TVG))
- \( A \) = the ensonified area, calculated as \( A = W \times L \), where
- \( W \) = the width of the footprint in the along-track direction, given as \( W = \theta_{tx} \times R \), with \( R \) representing the range in meters
- \( L \) = the beamwidth limited length of the footprint in the across-track direction, given as the minimum of \( L = \min \{ c/t/(2\cos(grz)) , R \times \theta_{rx} / \sin(grz) \} \)

where:

- \( \theta_{tx} \) = the -3dB beamwidth of the transmitter in the along-track direction
- \( c \) = the speed of sound
- \( t \) = the pulse length
- \( grz \) = the grazing angle, estimated by fitting a least-squares plane to a set of 8 soundings surrounding the sounding and then calculating the angle between the beam ensonification vector and the normal to the plane
- \( \theta_{rx} \) = the -3dB beamwidth of the receiver in the across-track direction (note that the receiver beamwidth grows with beam angle off normal for a flat array sonar)
It was not necessary to adjust the real-time TVG parameters to optimize bottom tracking and maximize swath coverage during acquisition for the CC range area. No radiometric corrections were made for real-time TVG applied in the sonar however, as the real-time TVG (Figure E-1) appears to differ from the equations documented in the RESON 7150/7125 operator’s manuals in two aspects:

1. A maximum gain value occurs at a certain range where the amplifiers are at their maximum gain (e.g., range of approximately 170 m in Figure E-2). This suggests that seabed imagery acquired beyond this range may require additional gain in post-processing to overcome the effects of spherical spreading and attenuation.

![Figure E-1. RESON 7150 TVG Curve (absorption coefficient=10, spreading coefficient=30, static gain = 0)](image)

2. The logarithmic portion of the TVG curve is inconsistent with the equation documented in the operator’s manual (Figure E-2). First, there appears to be a large offset between the applied TVG and that prescribed by the operator’s manual for the same TVG settings. Second, the dynamic range of the applied TVG is roughly half of that expected based on the equation from the operator’s manual (a gain increase of approximately 27 dB from 10 to 150 m, compared to an expected gain increase of approximately 48 dB). This would indicate that most seabed imagery acquired would require additional gain corrections to augment that applied by the real-time TVG.
Given these discrepancies, it is difficult to ascertain 1) how much gain has been applied and/or 2) when the maximum gain has been exceeded. The former situation proves difficult in shallower areas (where the maximum gain has not been exceeded) because one cannot determine the amount of gain applied (thus, the remaining amount required to overcome the total anticipated transmission loss cannot be known). The latter situation proves difficult because the crossover range cannot be determined and it is not possible to rigorously determine the exact range at which to begin applying additional gain corrections. Both of these difficulties are compounded by the wide range of TVG settings used during acquisition. Since RESON was not able to supply an accurate model of the TVG applied during data collection, it was not possible to fully compensate the imagery data for transmission losses through the water column. This has the unfortunate side effect of leaving the backscatter imagery contaminated with the effects of the varying TVG settings. These have been partially removed through manual adjustment of along-track signal levels within the same survey line (by Dr. Beaudoin).
4.2 RESON 7125

The correction of the RESON 7125 data followed a similar approach as that of the 7150 however an additional TVG correction was applied since the depth range in the shallower areas did not saturate the real-time TVG. The correction model for the RESON 7125 was

\[
BS_{\text{rel}} = 20 \log_{10}(DN) + DB_{\text{SHIFT}} - SL - G - 10 \log_{10}(A) \\
+ 2 \times (\alpha_{\text{new}} - \alpha_{\text{applied}}) \times \frac{R}{1000} \\
+ (40 - \text{spreading}_{\text{applied}}) \times \log_{10}(R)
\]

where:

- \(\alpha_{\text{new}}\) = an appropriate absorption coefficient applied in post-processing, in dB/km
- \(\alpha_{\text{applied}}\) = the absorption coefficient applied in real-time, in dB/km
- \(R\) = the range in meters
- \(\text{spreading}_{\text{applied}}\) = the scaling constant for the logarithmic portion of the sonar’s real-time TVG

Equation 4.3

After correction of the RESON 7125 data, small residual signal strength discrepancies persisted, these were usually associated with pulse length variations. Data were manually adjusted to remove the remaining artifacts.

4.3 SIGNAL NORMALIZATION AND GEO-REGISTRATION

After correcting for as many system parameters as possible, the data from the RESON 7150 and 7125 were then normalized for across-track signal variation due to the varying seafloor response with incidence angle. Normalization curves were compiled by averaging return signal strength as a function of beam grazing angle as described in Intelmann et al. (2006). Normalizing by grazing angle (as opposed to sonar relative incidence angle) gives a truer measure of the seafloor’s backscattering strength but has the drawback of reducing image contrast in areas where seafloor topography plays a strong part in modulating the return signal strength. For seafloor characterization purposes, having topographic effects removed is desirable because the remaining signal strength variations are due to seafloor backscattering properties and not imaging geometry. In this work, the data were normalized across the swath by tabulating a mean angular response (indexed by grazing angle in 1-degree bins) and computing an angle-varying correction based on the mean response between grazing angles of 30° and 70°. This was applied to swaths by computing a rolling mean angular response with a window size of 500 swaths to accommodate changes in seabed acoustic type scattering properties over the course of a survey line.

Geometric registration follows the method described in Beaudoin et al. (2002). Briefly, the bathymetry associated with the imagery data is used to register the imagery data at the correct position on the seafloor. This avoids the positioning uncertainties associated with traditional methods of image registration, such as the flat seafloor assumption. It should be noted that the
seafloor imagery, though potentially of higher resolution, has no greater positional accuracy than the bathymetric data.

Minor cosmetic corrections were then applied to fill small gaps in the backscatter time-series data and to remove swaths with invalid data (i.e., no valid soundings contributing) and those with invalid navigation. The data from all survey lines were then mosaicked using an auto-seaming method in which the transition between survey lines is made at the midpoint between survey lines.

4.4 **Bubble Wash-down Clipping**

When surveying in moderate to high sea states, the combination of waves and vessel motion can result in clouds of bubbles being pushed down through the water column and passing below the sonar head. Bubbles in water make almost perfect reflectors for sound, so a cloud of bubbles will block some or all of the sound energy from/to the sonar depending on the density of the cloud and the size relative to that of the sonar array. Under the weather and sea state conditions that occurred during the survey, both the RESON 7150 and 7125 have been affected by bubble wash-down to varying degrees.

Figure E-3 shows a conceptual representation of the time series signal returns observed in the sonar imagery during bubble wash-down events. When a cloud of bubbles passes below the sonar, the sound energy from the projector and returned from the bottom are scattered, yielding a very low signal level at the receivers. As the bubble cloud dissipates, the received signal levels come back up but take a number of pings to return to normal levels.

![Bubble Wash-Down Effects and Clipping](image)

**Figure E-3. Bubble Wash-Down Effects and Clipping**
In the processing, a clip threshold is set to remove the invalid data resulting from too much of the sound energy being scattered. There is a trade-off in setting the threshold for the clipping. If it is set to a very low level, fewer pings will be rejected, and some with reduced signal levels will be accepted. If the threshold is set higher, more of the reduced signal level pings will be rejected and there may be data gaps along track, depending on the vessel speed, ping rate, and required along-track data interval.

The depth and recovery time from a large number of bubble wash-down events were reviewed by Dr. Beaudoin as part of the imagery processing. It was determined that there was too much variability in the slopes and recovery times to reliably derive accurate signal levels to use to replace the induced gaps in the data. In the CC Range, mosaic processing was implemented to replace the gaps with a boundary average summed with a low level of synthesized noise. The noise was added to reduce the visual impact of the fill and to more closely match the surrounding area to reduce the probability of creating spurious responses in the automated classification process. This approach did eliminate most of the spurious responses in the classification analysis of the mosaic, but full recovery of information for these areas was not possible.

5.0 RESULTS

Mosaics of the raw and near-calibrated imagery are provided for the RESON 7125 and 7150 data sets in Figure E-4. These data were corrected for source level and pulse length variations but not for TVG and transmission loss beyond that done real-time in the sonars. As indicated earlier, accurate compensation for transmission losses was precluded by the inaccuracy of the TVG model available from RESON. Supplemental processing, based on analysis of the imagery, was implemented to minimize the induced variations between collections with the same settings, however this did not result in significant improvements in the classification processing.

Raw imagery and calibrated imagery represent the signal after a logarithmic compression. Grayscale is directly proportional to echo level (raw imagery) and backscattering strength (corrected imagery), i.e., strong reflectors appear bright and weak reflectors appear dark.

The correction and normalization procedures were previously tested and refined using a variety of data, including RESON 7125 and 7150 snippet data acquired during various other projects. The projects included periods of inclement weather during which there was significant vessel roll and/or pitch that affected data quality. A full description is provided in the USWTR Final Survey Report. Some data showed significant low signal strength artifacts that persisted over several swaths of data. These are likely associated with bubble wash-down events in which a portion of the transmit and/or receive arrays are masked by air bubbles in higher sea states with the appearance of the artifact being heading-dependent (e.g., steaming with the seas versus against). Cosmetic filters have been implemented to remove these effects; however, they are experimental in nature and require much fine tuning.
Note: The imagery is still contaminated with source level– and TVG-related artifacts.

Figure E-4. Raw (Top) and Corrected (Bottom) Seabed Imagery Data from CC Range

6.0 ADDITIONAL POST-PROCESSING EFFORTS AND SEABED CLASSIFICATION

6.1 INVESTIGATING TVG AND STATIC GAIN CORRECTIONS

Backscatter data were acquired to aid in the process of seafloor characterization, however, class breaks were observed during the characterization procedures, significantly hindering the automated characterization process (Figure E-5). The automated process detects boundaries between areas of differing intensities and/or textures in the imagery and uses these data in conjunction with other data sources to help locate and classify the bottom types within the survey boundaries.
The class breaks were aligned parallel to the survey line direction, these types of breaks can occur when sonar data have not been corrected for beam pattern effects or have not been normalized for the seafloor’s varying response with incidence angle.

Upon further examination of the results from the 7150 data classification, it was observed that the class breaks in the 7150 data were associated with inter-line signal offsets and thus cannot be due to incorrect angular response normalization. The inter-line signal offsets were instead attributed to the inability to properly compensate the signals for TVG due to the difference between the documented 7150 TVG algorithms and what is actually applied within the sonar. There may also be temporal differences in water conditions which can affect the amount of sound energy lost to absorption, and temperature induced variations in amplifier gains in the sonars.

As described in the USWTR survey report, the RESON provided MatLab routines and instructions to calculate the TVG curve for 7125 and 7150 systems did not correlate to the the real-time TVG curves available from the 7150 sonar. The 7125 does not provide the TVG diagnostic display, so its real-time response could not be compared to the RESON documentation.
7.0 REFERENCES


Tetra Tech, 2009, USWTR Final Survey Report. Bothell, WA

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APPENDIX F
C-CASS II OPERATIONS

F1. C-CASS II DIVE AND SAMPLE LOGS

F2. C-CASS II SEAFLOOR PHOTOS
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The dive log for the C-CASS II is presented below in Table F1-1. Descriptions of the seabed from the C-CASS II digital still and video images from each site are presented in Table F1-2. Digital still images from both sites are presented in Figures F2-1 and F2-2.

### F1. C-CASS II DIVE AND SAMPLE LOGS

#### Table F1-1: CC Range C-CASS II Dive Log

<table>
<thead>
<tr>
<th>Dive Site</th>
<th>Attempt</th>
<th>Status</th>
<th>Dive Number</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Target Depth (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCASS 3</td>
<td>1 of 1</td>
<td>Complete</td>
<td>US_050610_0729_GT3_C-CASS_3</td>
<td>05/06/10</td>
<td>07:29</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>CCASS 7</td>
<td>1 of 1</td>
<td>Complete</td>
<td>US_050610_1503_GT3_C-CASS_7</td>
<td>05/06/10</td>
<td>15:03</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>CCASS 9</td>
<td>1 of 1</td>
<td>Scrubbed</td>
<td>US_050610_XXXX_GT3_C-CASS_9</td>
<td>05/06/10</td>
<td>N/A</td>
<td>N/A</td>
<td>Technical Problem</td>
</tr>
</tbody>
</table>

#### Table F1-2: CC Range C-CASS II Seabed Photo Log

<table>
<thead>
<tr>
<th>Station</th>
<th>Date Time (UTC)</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
<th>Latitude (°N)</th>
<th>Longitude (°W)</th>
<th>Water Depth (m)</th>
<th>Material Description</th>
<th>Sample Comment</th>
<th>Geo-Acoustic Classification</th>
<th>Litho / Composition / Comments:</th>
<th>Seabed Photo</th>
<th>Video</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5/9/10 07:29</td>
<td>581050</td>
<td>3387382</td>
<td>30.51527817</td>
<td>-80.15435867</td>
<td>54</td>
<td>medium SAND / RO-LR</td>
<td>No Sample (as per project specifications)</td>
<td>SAND / RO-LR</td>
<td>Low relief hard bottom was evident; possibly broken pavement. Attached fauna was present, but sparse.</td>
<td>CC_050610_0729_GT3_C-CASS_3</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5/9/10 15:02</td>
<td>595099</td>
<td>3396775</td>
<td>30.70011517</td>
<td>-80.22526950</td>
<td>204</td>
<td>medium SAND</td>
<td>No Sample (as per project specifications)</td>
<td>SAND</td>
<td>Sandy seabed</td>
<td>CC_050610_1503_GT3_C-CASS_7_100.jpg</td>
<td>No video</td>
</tr>
</tbody>
</table>
F2. C-CASS II SEAFLOOR PHOTOS

**C-CASS Camera Still**

**CC_050610_0729_GT3_C-CASS_3_(2)**

**Description:** The first deployment of the CCASS was over target 3. The vehicle moved very quickly across the seafloor, although low relief hardbottom was evident; possibly broken pavement. Attached fauna was present, but sparse.

<table>
<thead>
<tr>
<th>WGS 84 Spheroid and Datum</th>
<th>30.61627617° N</th>
<th>80.15438567° W</th>
<th>Water Depth 52m</th>
</tr>
</thead>
</table>

*Figure F2-1: Bottom Photo C-CASS II Site 3*
**Description:** The C-CASS II landed on a sandy seabed with medium grain size.

| WGS 84 Spheroid and Datum | 30.70011517° N | 80.0235695° W | Water Depth 202m |

**Figure F2-1: Bottom Photo C-CASS II Site 7**
APPENDIX G

ROV DIVE LOG
Dive log for ROV dives conducted in the CC Range presented below in Table G-1.

### Table G-1: ROV Dive Log

<table>
<thead>
<tr>
<th>Dive Site</th>
<th>Attempt</th>
<th>Status</th>
<th>Dive Number</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Target Depth (m)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROV 01</td>
<td>1 of 3</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/06/10</td>
<td>N/A</td>
<td>195</td>
<td>ROV mechanical problem</td>
</tr>
<tr>
<td>ROV 01</td>
<td>2 of 3</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/06/10</td>
<td>N/A</td>
<td>195</td>
<td>ROV mechanical problem</td>
</tr>
<tr>
<td>ROV 01</td>
<td>3 of 3</td>
<td>Complete</td>
<td>US_050610_2014_GT3_ROV_1</td>
<td>5/06/10</td>
<td>20:14</td>
<td>195</td>
<td></td>
</tr>
<tr>
<td>ROV 02</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/06/10</td>
<td>N/A</td>
<td>200</td>
<td>Vessel out of position</td>
</tr>
<tr>
<td>ROV 02</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_050610_1137_GT3_ROV_2</td>
<td>5/06/10</td>
<td>11:37</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>ROV 03</td>
<td>1 of 2</td>
<td>Partial</td>
<td>US_051910_1356_GT3_ROV_03</td>
<td>5/19/10</td>
<td>13:56</td>
<td>290</td>
<td>ROV off targeted feature</td>
</tr>
<tr>
<td>ROV 03</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_051910_1531_GT3_ROV_03</td>
<td>5/19/10</td>
<td>15:31</td>
<td>290</td>
<td>Rerun to cross target feature</td>
</tr>
<tr>
<td>ROV 04</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/19/10</td>
<td>N/A</td>
<td>335</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>ROV 04</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_051910_1833_GT3_ROV_04</td>
<td>5/19/10</td>
<td>18:33</td>
<td>335</td>
<td></td>
</tr>
<tr>
<td>ROV 05</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/19/10</td>
<td>N/A</td>
<td>375</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>ROV 05</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_051910_2040_GT3_ROV_05</td>
<td>5/19/10</td>
<td>20:40</td>
<td>375</td>
<td></td>
</tr>
<tr>
<td>ROV 06</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/19/10</td>
<td>N/A</td>
<td>350</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>ROV 06</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_052010_1233_GT3_ROV_06</td>
<td>5/20/10</td>
<td>12:33</td>
<td>350</td>
<td></td>
</tr>
<tr>
<td>ROV 07</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/19/10</td>
<td>N/A</td>
<td>410</td>
<td>ROV off targeted feature</td>
</tr>
<tr>
<td>ROV 07</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_051910_0015_GT3_ROV_07</td>
<td>5/19/10</td>
<td>00:15</td>
<td>410</td>
<td></td>
</tr>
<tr>
<td>ROV 08</td>
<td>1 of 1</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/20/10</td>
<td>N/A</td>
<td>410</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>ROV 09</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/20/10</td>
<td>N/A</td>
<td>475</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>ROV 09</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_052010_1550_GT3_ROV_09</td>
<td>5/20/10</td>
<td>15:50</td>
<td>475</td>
<td></td>
</tr>
<tr>
<td>ROV 10</td>
<td>1 of 1</td>
<td>Complete</td>
<td>US_052010_0533_GT3_ROV_10</td>
<td>5/20/10</td>
<td>05:33</td>
<td>495</td>
<td></td>
</tr>
<tr>
<td>ROV 11</td>
<td>1 of 1</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/20/10</td>
<td>N/A</td>
<td>495</td>
<td>Dive cancelled due to high sea state</td>
</tr>
<tr>
<td>ROV 12</td>
<td>1 of 3</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/7/10</td>
<td>N/A</td>
<td>495</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>ROV 12</td>
<td>2 of 3</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/19/10</td>
<td>N/A</td>
<td>495</td>
<td>Dive cancelled due to high currents</td>
</tr>
<tr>
<td>Dive Site</td>
<td>Attempt</td>
<td>Status</td>
<td>Dive Number</td>
<td>Date</td>
<td>Time (UTC)</td>
<td>Target Depth (m)</td>
<td>Comments</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
<td>---------</td>
<td>------------------------------</td>
<td>--------</td>
<td>------------</td>
<td>------------------</td>
<td>---------------------------------------</td>
</tr>
<tr>
<td>ROV 12</td>
<td>3 of 3</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/21/10</td>
<td>N/A</td>
<td>N/A</td>
<td>ROV mechanical problem</td>
</tr>
<tr>
<td>ROV 13</td>
<td>1 of 1</td>
<td>Complete</td>
<td>US_052010_1857_GT3_ROV_13</td>
<td>5/20/10</td>
<td>18:57</td>
<td>540</td>
<td></td>
</tr>
<tr>
<td>ROV 14</td>
<td>1 of 2</td>
<td>Partial</td>
<td>US_052110_0036_GT3_ROV_14</td>
<td>5/20/10</td>
<td>00:36</td>
<td>600</td>
<td>ROV dragged off target by vessel</td>
</tr>
<tr>
<td>ROV 14</td>
<td>2 of 2</td>
<td>Complete</td>
<td>US_052110_1914_GT3_ROV_14</td>
<td>5/21/10</td>
<td>19:14</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>ROV 15</td>
<td>1 of 2</td>
<td>Scrubbed</td>
<td>N/A</td>
<td>5/6/10</td>
<td>N/A</td>
<td>575</td>
<td></td>
</tr>
<tr>
<td>ROV 15</td>
<td>2 of 2</td>
<td>Partial</td>
<td>US_050710_0113_GT3_ROV_15</td>
<td>5/7/10</td>
<td>01:13</td>
<td>575</td>
<td>Currents push ROV off target</td>
</tr>
</tbody>
</table>
APPENDIX H
MULTIBEAM CROSS-LINE DATA STATISTICS
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1.0 TIE LINE COMPARISONS

To confirm that IHO Order 1a specifications were achieved throughout the CC Range bathymetry survey, as well as to provide a further quality check (QC), six tie lines were surveyed, running approximately perpendicular to the main survey lines. These lines were divided into 3 sections (0-100 meter, 100-250 meter and 250+ meter depths) and exported from CARIS HIPS and SIPS as XYZ point data. These data were compared to the gridded CC Range multibeam bathymetric surfaces using Fledermaus’ CrossCheck utility. This analysis, as summarized in the main body of the CC Range Cruise Report (Section 5.3.6) confirmed that the bathymetry data met Order 1a specifications.

Following the comparison conducted for each tie line the individual lines were grouped together in CrossCheck and compared to the CC Range gridded surface. This comparison also confirmed that the data met IHO Order 1a specifications.

Figures H-1 through H-6 provide screen grabs of the Fledermaus CrossCheck results in depths greater than 250 meters, while Figures H-8 through H-13 provide screen grabs from 100 – 250 meter depths. Figures H-15 through H-20 show the results from the 0 to 100 meter depths. Figures H-7, H-14, and H-21 are the comprehensive comparisons for the 250+ meter, 100-250 meter and 0-100 meter depth ranges, respectively.
Figure H-1. Tie Line 118 vs. Main Lines (250+ m Depths)
Figure H-3. Tie Line 120 vs. Main Lines (250+ m Depths)
Figure H-4. Tie Line 121 vs. Main Lines (250+ m Depths)
Figure H-6. Tie Line 124 vs. Main Lines (250+ m Depths)
Figure H-7. All Tie Lines vs. Main Lines (250+ m Depths)
Figure H-8. Tie Line 118 vs. Main Lines (100-250 m Depths)
Figure H-9. Tie Line 119 vs. Main Lines (100-250 m Depths)
Figure H-10. Tie Line 120 vs. Main Lines (100-250 m Depths)
Figure H-11. Tie Line 121 vs. Main Lines (100-250 m Depths)
Figure H-13. Tie Line 124 vs. Main Lines (100-250 m Depths)
Figure H-15. Tie Line 118 vs. Main Lines (0-100 m Depths)
Figure H-16. Tie Line 119 vs. Main Lines (0-100 m Depths)
Figure H-17. Tie Line 120 vs. Main Lines (0-100 m Depths)
Figure H-18. Tie Line 121 vs. Main Lines (0-100 m Depths)
Figure H-19. Tie Line 123 vs. Main Lines (0-100 m Depths)
Figure H-20. Tie Line 124 vs. Main Lines (0-100 m Depths)
Figure H-21. All Tie Lines vs. Main Lines (0-100 m Depths)
APPENDIX I

DIGITAL REPORT
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