

**MULTIBEAM SURVEY OF WHEELER NORTH REEF  
SAN CLEMENTE, CALIFORNIA**

**October 2014**



by

M. Hany S. Elwany, Ph.D.  
Tim Norall, M.Sc.  
C&C Technologies

for

Southern California Edison Company  
2244 Walnut Grove Avenue  
Rosemead, CA 91770

COASTAL ENVIRONMENTS  
2166 Avenida de la Playa, Suite E  
La Jolla, CA 92037

19 December 2014  
CE Reference No. 14-25

## TABLE OF CONTENTS

<b>1.0</b>	<b>INTRODUCTION.....</b>	<b>1</b>
<b>2.0</b>	<b>SURVEY METHODS AND INSTRUMENTATION.....</b>	<b>5</b>
<b>2.1</b>	<b>MULTIBEAM SURVEY DATE .....</b>	<b>5</b>
<b>2.2</b>	<b>SURVEY VESSEL.....</b>	<b>5</b>
<b>2.3</b>	<b>DATA ACQUISITION AND INSTRUMENTATION .....</b>	<b>5</b>
2.3.1	GPS Positioning .....	5
2.3.2	Motion Sensor and Vessel Heading .....	7
2.3.3	Sound Velocity Profiler .....	7
2.3.4	Multibeam Echo-sounder System (MBES) .....	7
<b>2.4</b>	<b>CALIBRATION AND QUALITY CONTROL OF MULTIBEAM SYSTEM .....</b>	<b>8</b>
2.4.1	Vessel Offset Survey.....	8
2.4.2	MBES Patch Test Calibration.....	8
<b>2.5</b>	<b>DATA PROCESSING .....</b>	<b>8</b>
2.5.1	Bathymetry.....	8
2.5.2	Water Column Data .....	11
2.5.3	Backscatter .....	13
<b>2.6</b>	<b>DIGITIZATION OF POLYGON AND MODULE BOUNDARIES .....</b>	<b>13</b>
<b>3.0</b>	<b>MULTIBEAM SONAR SURVEY RESULTS .....</b>	<b>19</b>
<b>4.0</b>	<b>SUMMARY AND CONCLUSIONS .....</b>	<b>26</b>
<b>5.0</b>	<b>REFERENCES.....</b>	<b>27</b>

## LIST OF APPENDICES

Appendix A.	Comparison of Module Boundaries from 2009 (Bathymetry) and October 2014 (Bathymetry) for Blocks 1-7 .....	A-1
Appendix B.	Comparison of Post-Construction (2009) and October 2014 Boundaries from Bathymetry Data for Polygons 1-17 .....	B-1
Appendix C.	Boundaries from Bathymetric Data for Module Blocks 1-7 (October 2014 Multibeam Survey) .....	C-1
Appendix D.	Boundaries from Bathymetric Data for Polygons 1-17 (October 2014 Multibeam Survey) .....	D-1
Appendix E.	Summary of Survey Data in Large-Scale Drawings (October 2014 Multibeam Survey) .....	E-1

## LIST OF FIGURES

Figure 1-1.	Location of Wheeler North Reef at San Clemente, California .....	2
Figure 1-2.	Boundaries of Wheeler North Reef, consisting of 56 modules each module is 40 x 40 m (7 blocks constructed in 1999) and 17 polygons (constructed in 2008) overlaid on multibeam bathymetric data (October 2014).....	3

Figure 1-3.	Vessel track lines for October 2014 survey .....	4
Figure 2-1.	Survey boat <i>ECO-M M/V Locator</i> , the multibeam system is mounted on the pole at the port side .....	6
Figure 2-2.	Stacked view of track line, showing kelp growing on artificial reef. Polygon edges are shown by boxes .....	12
Figure 2-3.	Integration of water column, backscatter, and bathymetry data sources over Module 28 (October 2014) .....	14
Figure 2-4.	Comparison between bathymetric and backscatter data for Modules 53, 55, and 56 (Block 7).....	15
Figure 2-5.	Survey repeatability of the southern boundary of Module 8 for three survey passes.....	16
Figure 2-6.	Survey repeatability of the eastern boundary of Module 8 for three survey passes .....	17
Figure 2-7.	Boundary digitization results for Polygon 4 based on bathymetry data, as obtained by two independent surveyors. The difference in calculating the area between the two surveyors was 0.4%.....	18
Figure 3-1.	Comparison of footprints for Polygons 1, 2, 3, 12, and 13 from multibeam surveys during September 2009 and October 2014 .....	22
Figure 3-2.	Comparison of footprints for Polygon 6 from multibeam surveys during September 2009 and October 2014.....	23
Figure 3-3.	Multibeam data for Polygon 3 from September 2009 and October 2014 surveys, showing the loss and gain of hard substrate on the inshore (east) side of the polygon.....	24
Figure 3-4.	Multibeam data for Polygon 4 from September 2009 and October 2014 surveys, showing the loss of hard substrate on the downcoast (south) side of the polygon. Note the presence of a tongue of sand in both areas of loss in the 2009 survey.....	25

**APPENDICES FIGURES**

Figure A-1.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 1 .....	A-2
Figure A-2.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 2 .....	A-3
Figure A-3.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 3 .....	A-4
Figure A-4.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 4 .....	A-5
Figure A-5.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 5 .....	A-6
Figure A-6.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 6 .....	A-7
Figure A-7.	Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 7 .....	A-8

Figure B-1.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygons 1, 2, 3, 12, and 13.....	B-2
Figure B-2.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 4.....	B-3
Figure B-3.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 5.....	B-4
Figure B-4.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 6.....	B-5
Figure B-5.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 7.....	B-6
Figure B-6.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 8.....	B-7
Figure B-7.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygons 9, 10, 11, and 14.....	B-8
Figure B-8.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 15.....	B-9
Figure B-9.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 16.....	B-10
Figure B-10.	Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 17.....	B-11
Figure C-1.	Location map for Wheeler North Reef Modules (Blocks 1-7).....	C-2
Figure C-2.	Block 1 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-3
Figure C-3.	Block 2 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-4
Figure C-4.	Block 3 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-5
Figure C-5.	Block 4 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-6
Figure C-6.	Block 5 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-7
Figure C-7.	Block 6 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-8
Figure C-8.	Block 7 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).....	C-9
Figure D-1.	Location map for Wheeler North Reef Polygons.....	D-2
Figure D-2.	Polygon 1 boundary from bathymetric data interpretation (October 2014 multibeam survey).....	D-3
Figure D-3.	Polygon 2 boundary from bathymetric data interpretation (October 2014 multibeam survey).....	D-4
Figure D-4.	Polygon 3 boundary from bathymetric data interpretation (October 2014 multibeam survey).....	D-5
Figure D-5.	Polygon 4 boundary from bathymetric data interpretation (October 2014 multibeam survey).....	D-6

Figure D-6. Polygon 5 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-7

Figure D-7. Polygon 6 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-8

Figure D-8. Polygon 7 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-9

Figure D-9. Polygon 7a boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-10

Figure D-10. Polygon 8 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-11

Figure D-11. Polygon 9 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-12

Figure D-12. Polygon 10 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-13

Figure D-13. Polygon 11 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-14

Figure D-14. Polygon 12 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-15

Figure D-15. Polygon 13 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-16

Figure D-16. Polygon 14 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-17

Figure D-17. Polygon 15 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-18

Figure D-18. Polygon 16 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-19

Figure D-19. Polygon 17 boundary from bathymetric data interpretation (October 2014 multibeam survey) ..... D-20

Figure E-1. Large scale map for Wheeler North Reef Modules (October 2014 multibeam survey).....E-2

Figure E-2. Large scale map for Wheeler North Reef Polygons (October 2014 multibeam survey).....E-3

**LIST OF TABLES**

Table 2-1. Patch test results.....9

Table 3-1. Experimental reef module areas from multibeam surveys conducted in September 2009 and October 2014.....20

Table 3-2. Polygon areas as-built (2008) and as-is (September 2009 and October 2014) from multibeam data.....21

Table 3-3. Summary of Wheeler North Reef Area for 2008, 2009, and 2014 surveys.....21

## **MULTIBEAM SURVEY OF WHEELER NORTH REEF SAN CLEMENTE, CALIFORNIA**

**October 2014**

### **1.0 INTRODUCTION**

Wheeler North Reef (WNR) was constructed by Southern California Edison (SCE) as partial mitigation for impacts to marine resources that resulted from the San Onofre Nuclear Generating Station (SONGS). The reef was constructed in two phases. Phase 1, the experimental reef, with an area of 22.4 acres, consists of seven blocks of eight modules, each of which is 40 m x 40 m (for a total of 56 modules), and was completed on 29 September 1999 (Coastal Environments, 1999). The final Phase 2 reef consists of 17 polygons with a total area of 152 acres (Coastal Environments, 2008a), and was completed on 11 September 2008.

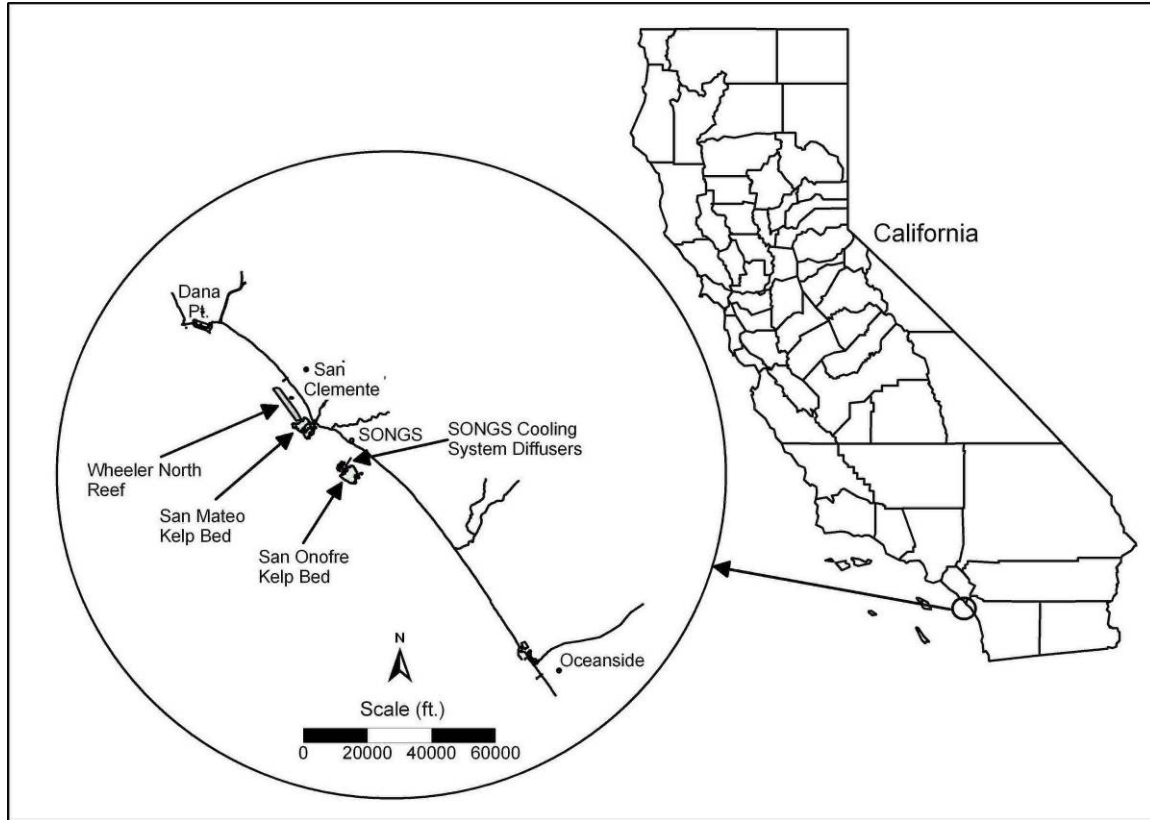
WNR is located offshore of San Clemente between the San Clemente Pier and San Mateo Point (Figure 1-1) in approximately 11 to 15 m water depth. Periodic surveys are required by the California Coastal Commission (CCC), according to Special Condition #12 of SCE's CCC construction permit (CDP #E-07-010, dated 2 February 2008), to ensure that the reef's footprint is maintaining its areal coverage.

This multibeam survey assessed the boundaries of the reef approximately five years after the most recent survey, in 2009. The survey included 100% coverage of the area occupied by the WNR, encompassing the 17 final constructed polygons as well as the 56 experimental modules (Figure 1-2). This report compares the module and polygon boundaries obtained during this survey with those obtained during the 2009 survey (Coastal Environments, 2009).

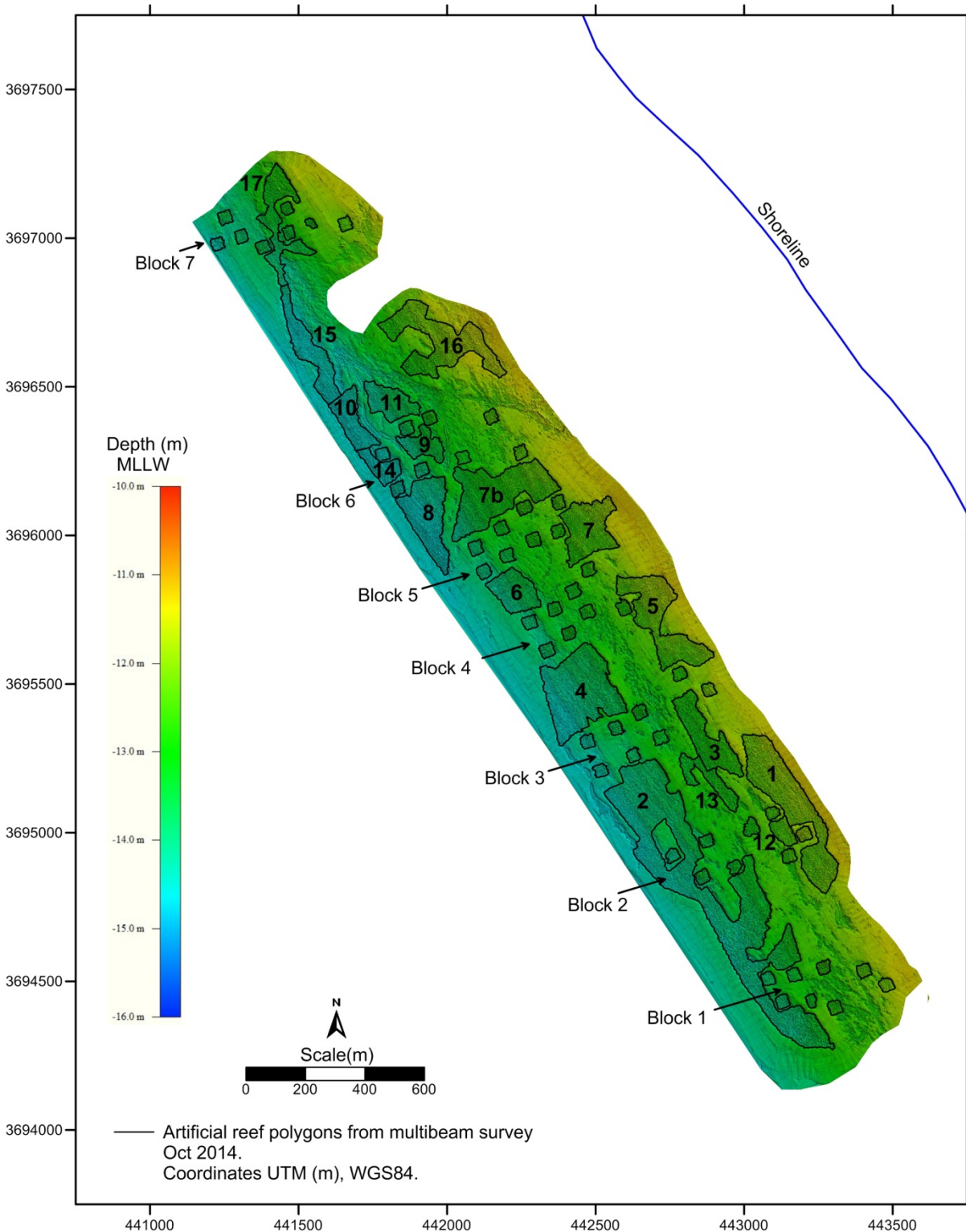
Multibeam survey operations were carried out from October 8, 2014 through October 10, 2014. Multibeam bathymetry, backscatter, and water column data were collected throughout the defined project area and were used to estimate the module and polygon boundaries. Almost all of the WNR modules/polygons were occupied by fairly dense kelp canopy, which required modifying vessel tracks and surveying the densest kelp areas during high tides. All of the data presented in this report are presented as WGS84, UTM Zone 11 (meters). Vertical sounding reference is Mean Lower Low Water (MLLW). Tide corrections are based upon actual NOAA-verified data from Station 9410230 (La Jolla). Figure 1-3 presents the vessel tracks used for this survey.

This survey found the total estimated area for Phases 1 & 2, excluding Polygons 5 and 7a, to be 152.18 acres, in comparison to 153.4 acres, as found in the September 2009 survey (Coastal Environments, 2009). Table 3-3 compares the area of WNR in the 2008, 2009 and 2014 surveys.

This report consists of four chapters and four appendices. Chapter 1 is the introduction, Chapter 2 describes the survey methods and instrumentation, Chapter 3 presents the results. The multibeam survey results are summarized in Chapter 4 and graphically in Appendices A-E.

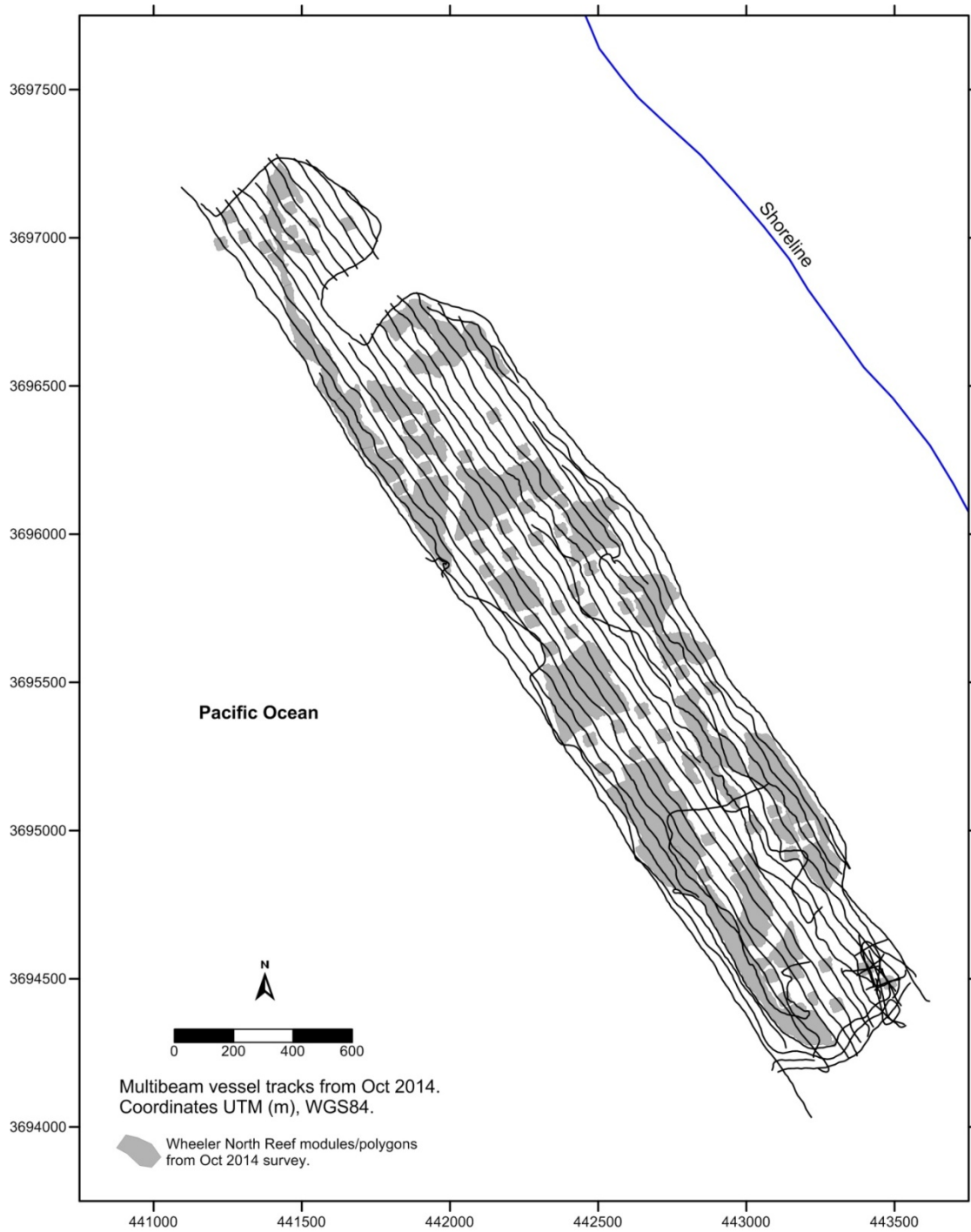


**Figure 1-1. Location of Wheeler North Reef at San Clemente, California.**



**Figure 1-2. Boundaries of Wheeler North Reef, consisting of 56 modules each module is 40 x 40 m (7 blocks constructed in 1999) and 17 polygons (constructed in 2008) overlaid on multibeam bathymetric data (October 2014).**





**Figure 1-3. Vessel track lines for October 2014 survey.**

## **2.0 SURVEY METHODS AND INSTRUMENTATION**

### **2.1 MULTIBEAM SURVEY DATE**

The fieldwork for this survey was performed from October 8, 2014 through October 10, 2014.

### **2.2 SURVEY VESSEL**

The *ECO-M M/V Locator*, a 27-foot-long Farallon boat, was used as the survey vessel for this project (Figure 2-1). The vessel was equipped with the following primary equipment for execution of the survey:

1. Kongsberg EM3002 MBES with Simrad SIS acquisition software;
2. Applanix POS MV 320v4 inertial navigation system, including topside, IMU, and antennas;
3. Odom Digibar Pro sound velocity profiler (SVP);
4. C-Nav 3050 DGNSS including antenna and cabling with C-NaviGator II QA/QC display; and
5. Hypack Hydrographic Acquisition Software 2014.

### **2.3 DATA ACQUISITION AND INSTRUMENTATION**

#### **2.3.1 GPS Positioning**

A C-Nav 3050 Differential Global Navigation Satellite System (DGNSS), coupled with the POS MV 320, provided high-accuracy positioning data during the survey. The functionality of the GPS was monitored continuously during the survey via the C-NaviGator II, PosPAC, and SIS. Positioning data were output to all sensor acquisition systems and logged.

Hypack navigation software provided real-time vessel positioning using DGNSS (C-Nav) and inertial navigation inputs (Applanix Pos MV 320). The navigation software provided paged output to the helmsman for survey-vessel tracking and data-acquisition status (including but not limited to vessel position and orientation, survey lines, background plots, charts and waypoints, line name, distance to start and end of line, distance offline, heading, course over ground, speed, data logging, and event status). The system collected, displayed, and logged a variety of DGNSS quality information and additional online quality assessment information.

The POS MV controller software (PosPAC) and C-Navigator's real-time QC displays were monitored throughout the survey to ensure the positional accuracies.



**Figure 2-1.** Survey boat *ECO-M M/V Locator*, the multibeam system is mounted on the pole at the port side.

### **2.3.2 Motion Sensor and Vessel Heading**

A POS/MV 320 motion-sensor unit measured dynamic vessel motion and orientation (heave, pitch, roll and heading). This system consists of an inertial motion unit (IMU), two GPS receivers, and a processing unit. The combined GPS of each antenna was used to estimate the orientation and heading of the vessel. The POS MV dynamic motion measurements were coupled with the MBES acquisition system (Hypack).

A GPS Azimuth Measurement Subsystem(GAMS) calibration was performed outside of the seawall at Dana Point north of the survey site. The GAMS test is for calibrating the POS/MV 320 motion-sensor for heading.

### **2.3.3 Sound Velocity Profiler**

Sound-velocity profile (SVP) data were acquired using an Odom Digibar Pro SVP probe. The SVP probe measures at a rate of ten velocity and pressure observations per second (10 Hz). For each cast, the probes were held just below the surface for one and a half minutes to reach temperature equilibrium. The probes were then manually lowered at the rate of about 0.3 meters/second to the seabed. The SVP data were used to correct the MBES data for refraction due to water column density differences.

Sound velocity profiles (SVP) of the water column were taken and applied in Simrad Seafloor Information System (SIS) at the beginning of survey operations every day. In addition, the sound velocity probe at the head of the MBES transducer continuously monitored conditions at the head, and an alarm would sound if shallow water conditions changed, requiring carrying out a new sound velocity profile survey.

### **2.3.4 Multibeam Echo-sounder System (MBES)**

A Kongsberg EM3002, a 300 kHz high-resolution multibeam echosounder, was used for the acquisition of bathymetric, backscatter, and water column data. This system can operate in nearshore water, typically to a 200-meter water depth. The system was hard mounted on the port side of the survey vessel using a C&C portable mounting bracket. The MBES was used to collect bathymetric and backscatter data from approximately 10 to 15 meter water depths during the survey. Survey speed was typically between 1.5 and 2.0 m/s in order to ensure low turbulence around the multibeam transducer pole.

Data acquired with the EM3002 were recorded and monitored in real time with the SIS for the duration of survey operations. SIS displayed a variety of real-time imagery so that sonar settings could be adjusted to improve data quality if needed.

The EM3002 was coupled with the Applanix POS MV system to account for vessel motion. All dynamic systems were tied into the C-Nav DGNSD precise-point differential packet for improved motion and heading calculation.

## **2.4 CALIBRATION AND QUALITY CONTROL OF MULTIBEAM SYSTEM**

In addition to the online QC tools and displays available for the POS MV, C-Nav, and SIS, as described in previous sections, the following calibrations and checks were conducted.

### **2.4.1 Vessel Offset Survey**

After equipment had been mobilized, offsets were measured between the sonar systems, GPS antennas, and the PosMV IMU. Once the boat was in the water, several measurements of static draft of the transducer head were taken and averaged to vertically adjust the MBES soundings from the head location to water level. Offsets were entered into either SIS or PosPAC IMU.

### **2.4.2 MBES Patch Test Calibration**

A multibeam patch test was run, so that the MBES data could be corrected for the timing, pitch, yaw, and roll errors that exist between the MBES head and the IMU unit. Data collected during the mobilization patch tests were processed using CARIS Calibration Editor. Table 2-1 presents the final patch test results. Final offsets were entered into SIS before the survey commenced.

## **2.5 DATA PROCESSING**

### **2.5.1 Bathymetry**

Multibeam bathymetry was processed using CARIS Hydrographic Information Processing System (HIPS), Version 8.1. Verified tide data from the NOAA La Jolla tide gauge were applied to the data set to reduce to the MLLW datum. The MBES data file from SIS that is imported into CARIS (the .ALL file) has the patch test corrections, vessel offsets, static draft, and SVPs already applied to the data.

After the data were corrected and cleaned, a 25-cm resolution gridded dataset, or Digital Terrain Model DTM, was exported as both a GeoTIF and an ASCII xyz file into Global Mapper for digitization. Final data products from Caris and Fledermaus were imported into AutoCAD Map 3D 2012 for chart presentation.

#### *Corrections to Bathymetry Data*

The bathymetric data had various corrections applied during different portions of the acquisition process. These corrections are listed in Table 2-1.

**Table 2-1. Patch test results.**

<b>Test</b>	<b>Patch Test (274)</b>
Navigation Timing Error	0.0 seconds
Pitch Offset	-1.65°
Azimuth Offset	-1.2°
Roll Offset	+0.18°

### *Vessel Offsets*

Offsets established prior to the survey (Section 2.4.1) were used to correct bathymetry to compensate for differences between the transducer head and the GPS antenna position. Offsets were entered into PosPAC and SIS, enabling SIS to correct the bathymetry during acquisition.

### *Sound Velocity Profiles*

Processed sound velocity profiles (SVPs) were used to correct bathymetry for sound refraction or ray bending. SVPs were applied within SIS.

### *Static Draft*

Static draft observations were measured at the MBES unit, which was attached at the side mount that is fixed on the boat. Several measurements were averaged to obtain the draft correction, which were then applied to adjust the soundings from the transducer level to the water level. The static draft value was entered into SIS.

### *Water Level Changes*

All sounding data were reduced to Mean Lower Low Water (MLLW) by CARIS using verified NOAA tides for the project area.

### *Patch Test*

A multibeam calibration (or patch test) was employed so that the data could be corrected for navigation timing, pitch, azimuth and roll offsets, which may exist between the MBES transducer and the Motion Reference Unit (MRU).

The PosMV is the master time source for all attitude and navigation data. This allows any navigation-timing error to be determined by examining and correcting the roll timing error, which is the most obvious and simplest error to calculate and correct. This is accomplished by examining the sonar swath of two lines run reciprocally over a flat bottom.

The pitch-error adjustment was performed on sets of two coincident lines run at the same velocity over sloping terrain or a conspicuous object in opposite directions. The navigation-time error was already identified. The nadir beams from each line were compared and brought into alignment by adjusting the pitch-error value.

The azimuth-error adjustment was performed on sets of two lines, run over a conspicuous topographic feature. Lines were run in opposite directions, at the same velocity with the same outer beams crossing the feature. The navigation-time error and pitch error were already identified. Data from the same outer beams for each line were compared and brought into alignment by adjusting the azimuth error value.

The roll-error adjustment was performed on sets of two coincident lines, run over flat terrain at the same velocity in opposite directions. The navigation-time error, pitch-error, and azimuth-error were already identified. Data across a swath were compared for each line and brought into agreement by adjusting the roll-error value.

Patch-test values were obtained in CARIS HIPS Calibration Editor. Calculated patch-test values were input into SIS, so the data were corrected in real time. The correction values used are given in Table 2-1.

### *Cleaning*

Swath and area-based editing techniques were employed to remove acoustic noise and data outliers. Gridded data were examined for vertical discrepancies needing localized editing, utilizing both a grazing-angle weighted grid and a standard deviation grid.

### *Removal of Kelp Artifacts*

Kelp artifacts were present in large portions of the data. This introduced these artifacts into the raw sonar data, requiring extensive cleaning to remove them from the datasets. Water column data (Section 2.5.2) were helpful in filtering the kelp and in differentiating the sea floor from the kelp.

### *DTM Generation*

After the data were cleaned in both Swath Editor and Subset Mode, a DTM grid with 0.25-cm grid cell size was created in CARIS. This grid was a grazing-angle weighted grid. Grazing-angle weighting is based on a beam's intersection angle with the seafloor, whereby a higher weight is given to beams from the inner part of a swath than to outer beams from adjacent track lines. This weighting value is important in areas with adjacent or overlapping track lines.

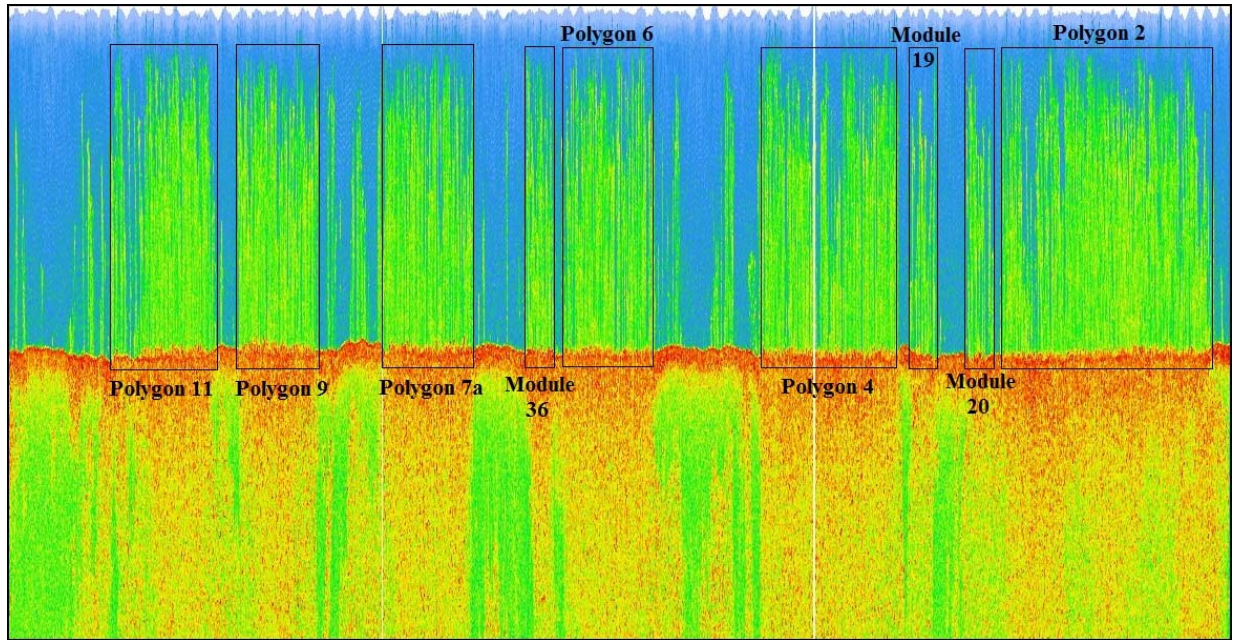
Sun-illuminated images of the grids were created within CARIS using the image manager. These images were then exported as geotiffs for use in final charting.

## **2.5.2 Water Column Data**

Multibeam water column data were processed using Fledermaus Midwater (FMmidwater). Water column data files (.WCD) were imported into geocoder along with the corresponding .ALL files, which were used as a navigational data source. All lines and navigational sources were compiled and loaded to the FMmidwater project.

Once loaded, water column data can be viewed in either fan view, which shows the along-track swath at a specific time, or in stacked view, which allows the viewing of an entire line of data as viewed from the side. The stacked view is useful in differentiating the seafloor from the kelp as shown in Figure 2-2.





**Figure 2-2.** Stacked view of track line, showing kelp growing on artificial reef. Polygon edges are shown by boxes.

### 2.5.3 Backscatter

#### *Creating Backscatter Mosaics in Geocoder*

Once the bathymetry data were cleaned, each multibeam line was exported as a .GSF file from CARIS and imported into Fledermaus Geocoder, along with its original SIS.ALL file for navigation data. Once imported, the lines were assembled and mosaicked, and a final tiff was completed. Even with the extensive cleaning of MBES data, the backscatter is not as clear as the data from 2009 (Coastal Environments, 2009), because kelp extends fully through the water column. Whenever necessary, the backscatter data are used to aid in digitization of the module and polygon boundaries.

### 2.6 DIGITIZATION OF POLYGON AND MODULE BOUNDARIES

Efforts made to filter out the presence of kelp from the multibeam bathymetry data were successful, leading to a high quality data set. The quality of the backscatter data was reduced due to presence of kelp plants in the water column, leading to increased noise in the data set. Therefore, the multibeam bathymetry data was the preferred data set for the delineation of the boundaries of the reef. A boundary is defined as the interface between the sand and the hard substrate. A boundary may change as the result of the erosion or accretion of the modules or polygons. The backscatter data and water-column data were utilized to aid in the delineation of any areas that were difficult to interpret. These areas were small and carefully delineated.

Any newly exposed hard substrate areas included within the boundary of the reef have met the following criteria: (1) the texture of the relief had to be visible; (2) kelp plants were already present in the area; and (3) the boundaries could not be expanded into areas with natural hard substrate showing in the 2009 survey.

Figure 2-3 shows an example of the integration of the collected data (bathymetry, backscatter, and water column data) in determining the boundary of Module 28. The majority of the modules and polygons had good correlation between the bathymetrically determined boundaries and the backscatter data (Figure 2-4).

The southern and eastern sides of Module 8 were surveyed three times, and each boundary line was processed independently. The boundary lines of each side were overlaid on top of each other for the southern and eastern boundaries of the module, and the results are presented in Figures 2-5 and 2-6 respectively. The results indicate that the errors which may be induced by the survey method are small.

Polygon 4 was digitized independently by two surveyors based on the criteria stated above. The results are shown in Figure 2-7. The difference in computed area from the two surveyors was very small, about 0.4%.

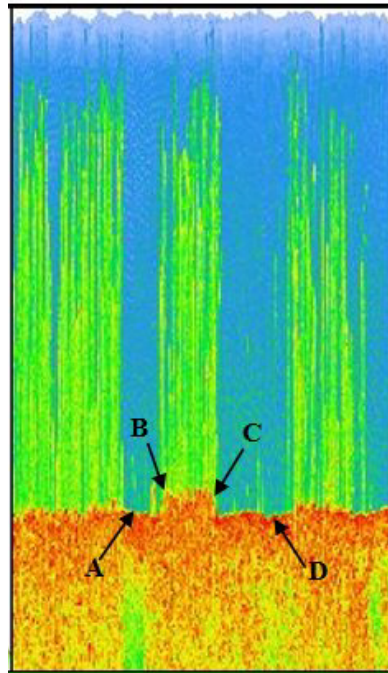


Figure A

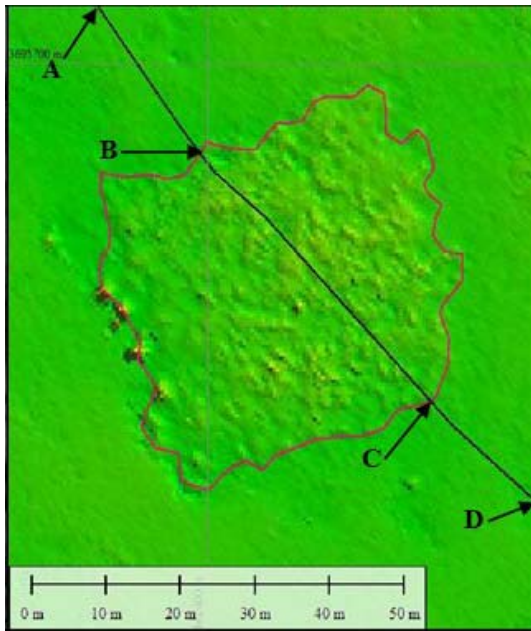


Figure B

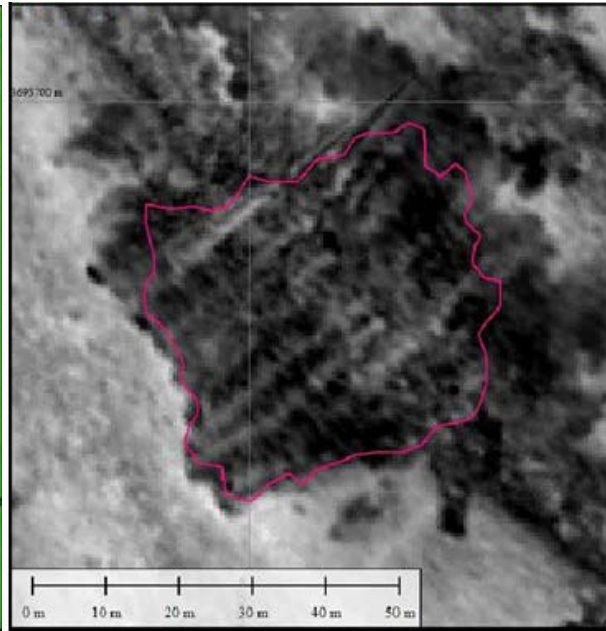
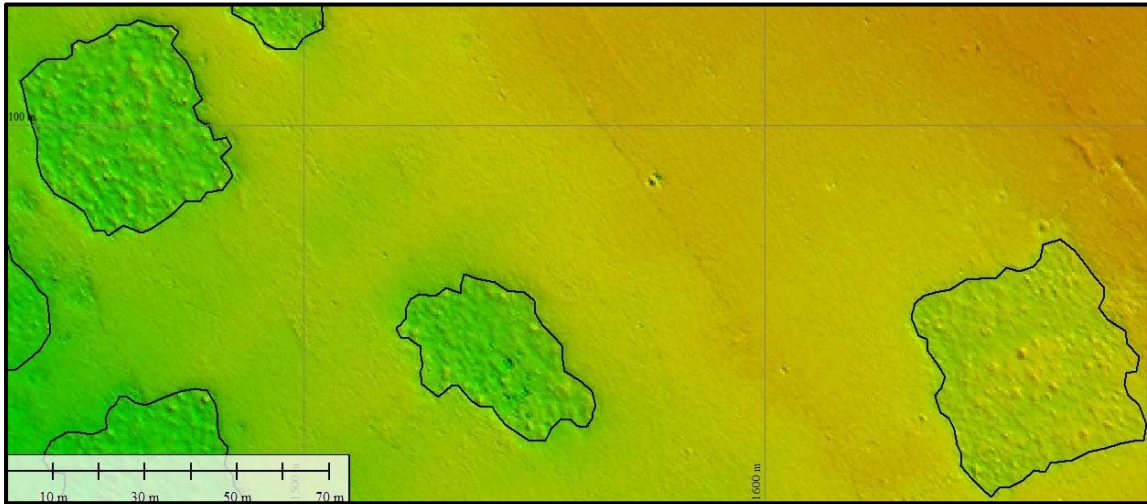
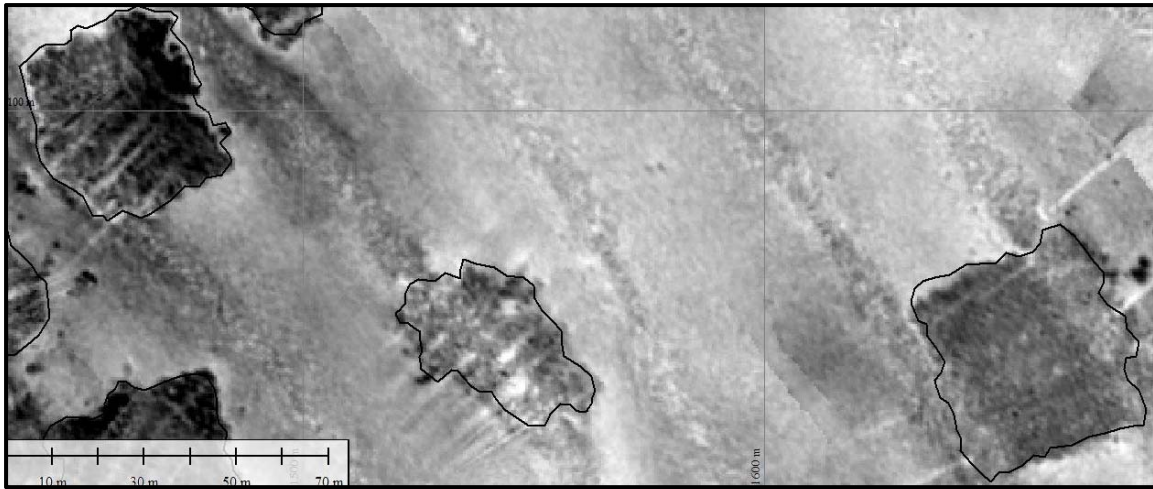


Figure C

**Figure 2-3. Integration of water column, bathymetry and backscatter data sources over Module 28 (October 2014). Figure A shows the module the water column data with the kelp plants in the water along transect A-D. Figure B shows the module boundary as estimated from bathymetry data. Figure C shows the boundary of Module 28 as estimated in Figure B overlaid on Module 28 backscatter image.**



**Figure A**



**Figure B**

**Figure 2-4. Comparison between bathymetric and backscatter data for Modules 53, 55, and 56 (Block 7). Figure A shows the boundaries of Modules 53, 55 and 56 as estimated from the bathymetric data. These boundaries were overlaid on the top of the corresponding backscatter images in Figure B.**

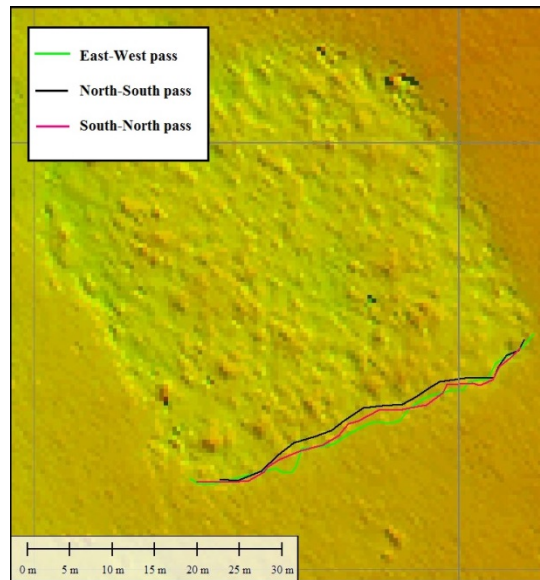


Figure A

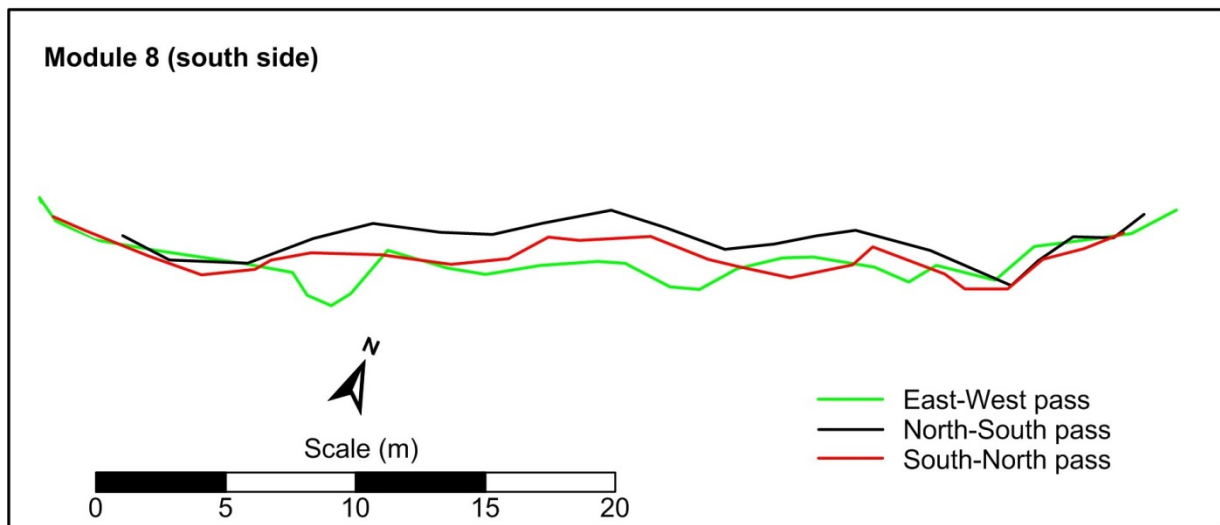


Figure B

**Figure 2-5. Survey repeatability of the southern boundary of Module 8 for three survey passes. Figure A shows the southern boundary of Module 8 as estimated from three survey passes overlaid on multibeam bathymetry. Figure B is an enlargement of the southern boundary estimates from the three passes.**

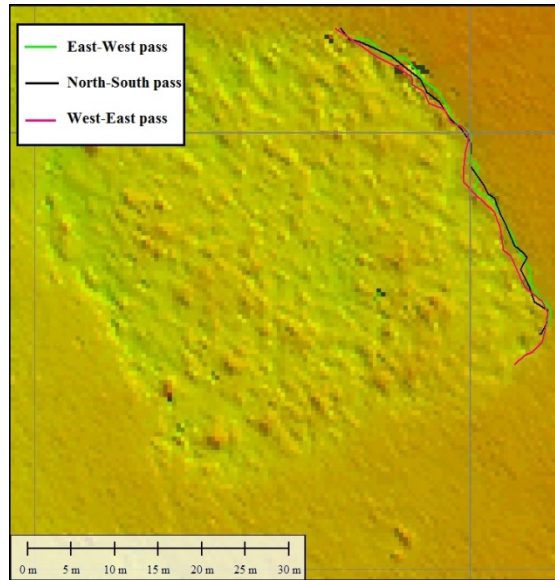


Figure A

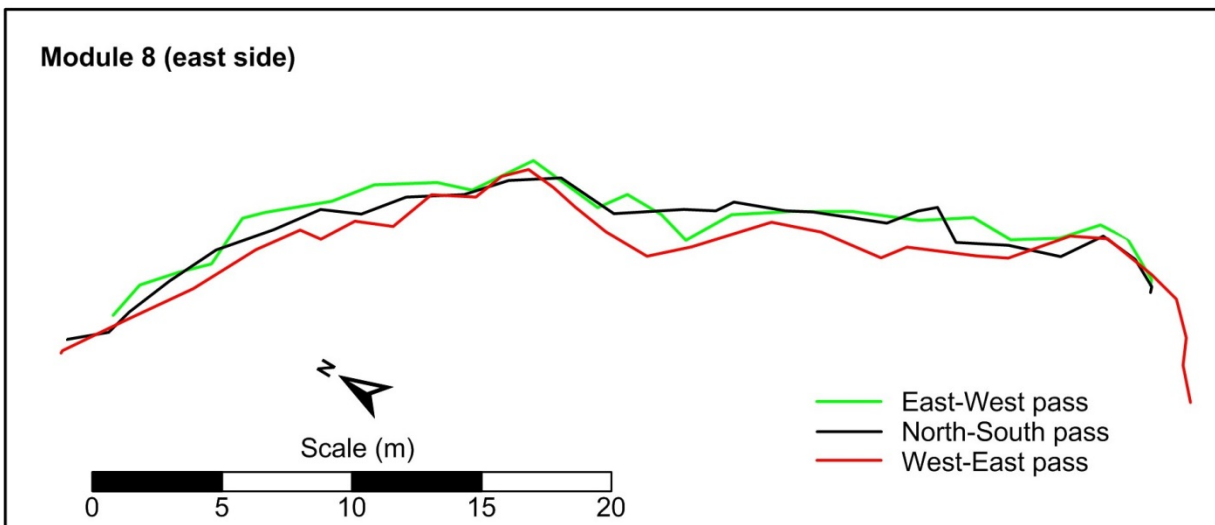
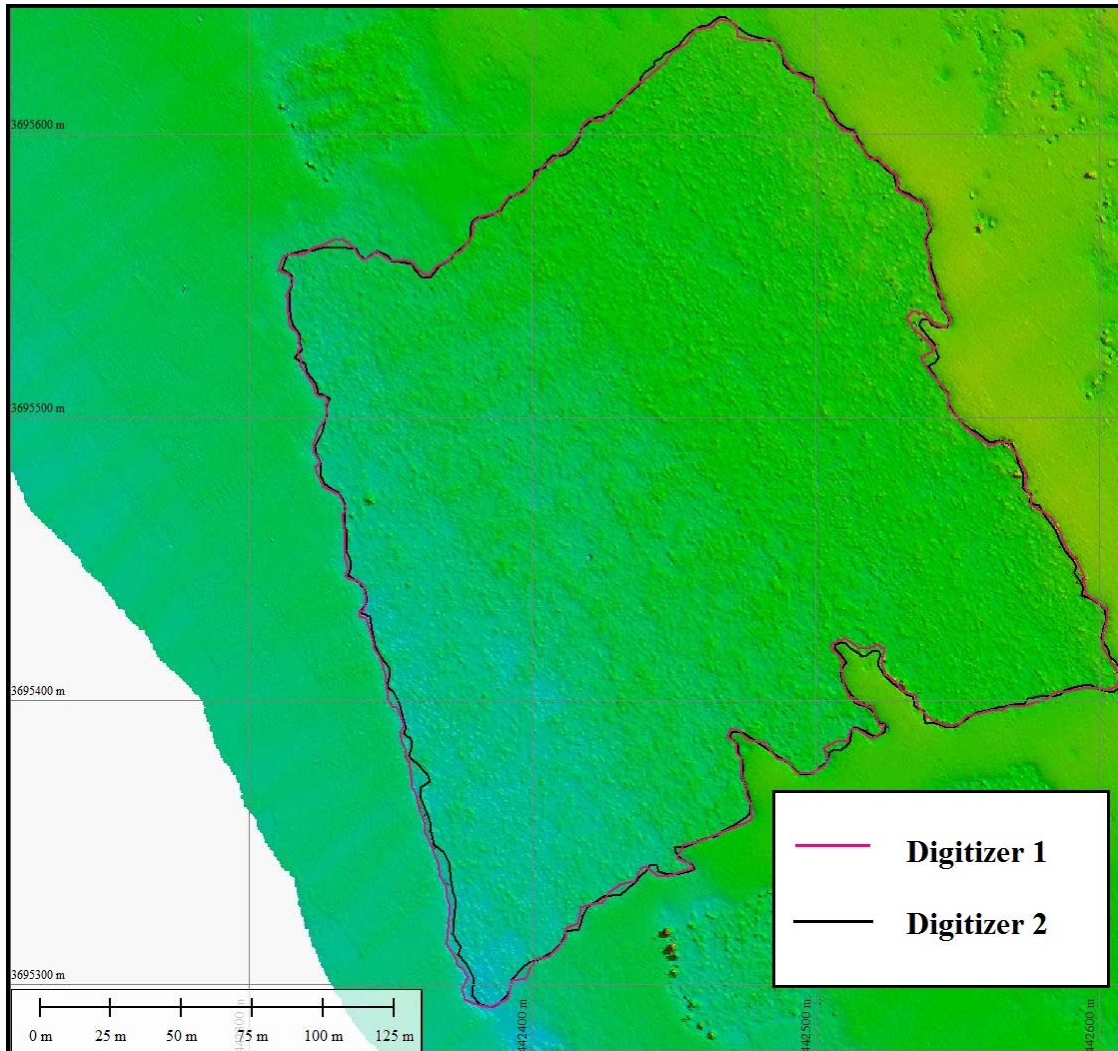


Figure B

**Figure 2-6. Survey repeatability of the eastern boundary of Module 8 for three survey passes. Figure A shows the eastern boundary of Module 8 as estimated from three survey passes overlaid on multibeam bathymetry. Figure B is an enlargement of the eastern boundary as estimated from the three passes.**



**Figure 2-7. Boundary digitization results for Polygon 4 based on bathymetry data, as obtained by two independent surveyors. The difference in calculating the area between the two surveyors was 0.4%.**

### 3.0 MULTIBEAM SONAR SURVEY RESULTS

Plots for the digitized boundaries are found in Appendices A (Modules) and B (Polygons), overlaid onto the boundary results from the September 2009 survey for comparison. The areas of the modules, based on the digitized bathymetric data, are shown in Table 3-1, while the areas of the polygons are shown in Table 3-2. Table 3-3 compares the area of WNR in the 2008, 2009 and 2014 surveys. A decrease of less than 1% in the total area of hard substrate occurred from September 2009 through October 2014. The digitized 2014 boundaries are overlaid onto the bathymetric, color-coded, sun-illuminated images for the polygons (Appendix C) and the modules (Appendix D). A summary of the survey data is presented in Appendix E in the form of large-scale drawings.

The shallow, nearshore coastal environment is a dynamic habitat with sediment transport varying over the area of the WNR. Some polygons/modules lost areas of hard substrate due to a combination of subsidence of the placed rock material and sand movement, while others gained area due to the re-exposure of areas that had previously been buried, or to the exposure of new hard substrate caused by scouring at the edges of the existing artificial reef. Even so, the footprints of the polygons/modules have remained remarkably similar to those delineated during the 2009 survey, as shown in Figure 3-1 for Polygons 1, 2, 3, 12, and 13, and Figure 3-2 for Polygon 6.

Polygons 3 and 4 (Figures 3-3 and 3-4) had the largest contiguous loss of hard substrate from the delineated boundaries of any of the polygons. The loss of area on the eastern side of Polygon 3 was partially compensated for by a gain of area on the same side. Note the loss of natural hard substrate to the east of Polygon 3. The loss of area on the south side of Polygon 4 is the result of the continuation of a tongue of sand in two locations, which was present in 2009 but at that time was not considered to be an incursion of sand on the footprint.



**Table 3-1. Experimental reef module areas from multibeam surveys conducted in September 2009 and October 2014.**

Module ID	Module area, in acres (from bathymetry)		Module ID	Module area, in acres (from bathymetry)	
	Sep 2009 <sup>a</sup>	Oct 2014		Sep 2009 <sup>a</sup>	Oct 2014
1	0.48	0.43	29	0.48	0.48
2	0.45	0.44	30	0.49	0.47
3	0.49	0.44	31	0.48	0.45
4	0.36	0.31	32	0.44	0.49
5	0.42	0.44	33	0.45	0.48
6	0.44	0.46	34	0.48	0.46
7	0.47	0.45	35	0.46	0.46
8	0.45	0.45	36	0.45	0.46
9	0.39	0.41	37	0.51	0.48
10	0.42	0.46	38	0.49	0.49
11	0.38	0.42	39	0.43	0.43
12	0.39	0.40	40	0.44	0.42
13	0.60	0.60	41	0.40	0.44
14	0.48	0.47	42	0.45	0.46
15	0.39	0.40	43	0.44	0.47
16	0.51	0.50	44	0.44	0.46
17	0.43	0.45	45	0.49	0.46
18	0.44	0.42	46	0.42	0.42
19	0.41	0.43	47	0.44	0.44
20	0.40	0.40	48	0.40	0.43
21	0.48	0.48	49	0.45	0.45
22	0.46	0.47	50	0.46	0.40
23	0.46	0.44	51	0.39	0.40
24	0.47	0.42	52	0.43	0.44
25	0.46	0.47	53	0.37	0.35
26	0.53	0.50	54	0.38	0.37
27	0.45	0.45	55	0.29	0.21
28	0.45	0.43	56	0.39	0.43
<b>Total area (Phase 1 modules)</b>				<b>24.79</b>	<b>24.67</b>

<sup>a</sup> From Coastal Environment (2009).

**Table 3-2. Polygon areas from 2008, 2009 and 2014 multibeam data.**

Sequential Polygon ID	As-built (2008 <sup>a</sup> ) area (acres)	Sep 2009 <sup>b</sup> area (acres)	Oct 2014 area (acres)
1	13.83	13.48	13.20
2	38.88	37.75	37.69
3	6.61	6.19	6.09
4	14.05	13.99	13.61
5	9.48	9.60	9.53
6	4.26	4.29	4.22
7	6.8	6.69	6.71
7a	12.2	12.24	12.09
8	7.64	7.50	7.49
9	2.52	2.62	2.58
10	3.89	3.88	3.79
11	3.48	3.69	3.69
12	1.35	1.34	1.33
13	2.85	2.92	2.89
14	2.12	2.18	2.10
15	5.54	5.47	5.55
16	11.19	11.22	11.00
17	5.32	5.41	5.56
<b>Total area (Phase 2 polygons)</b>	<b>152.02</b>	<b>150.46</b>	<b>149.13</b>

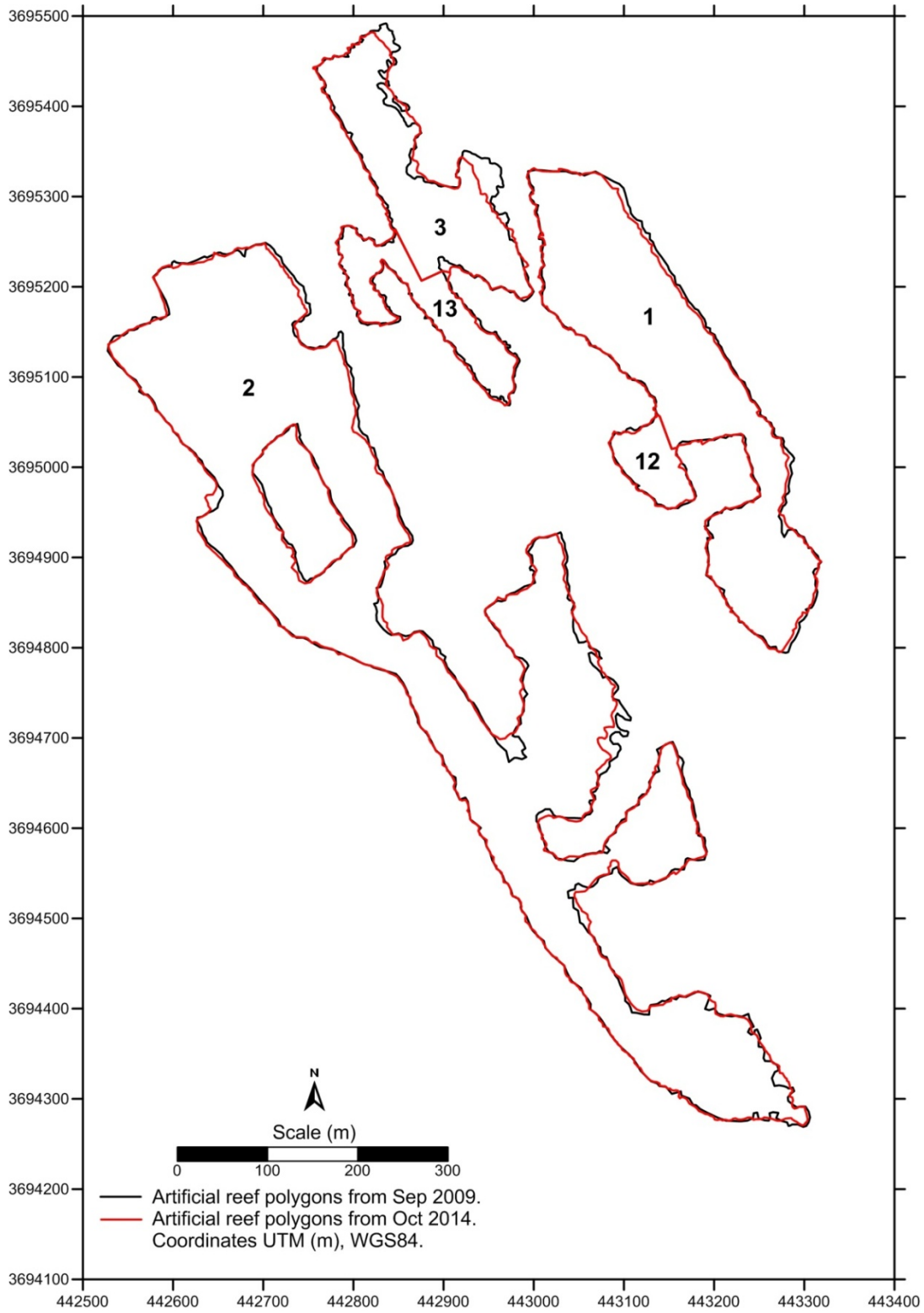
<sup>a</sup> From Coastal Environment (2008).

<sup>b</sup> From Coastal Environment (2009).

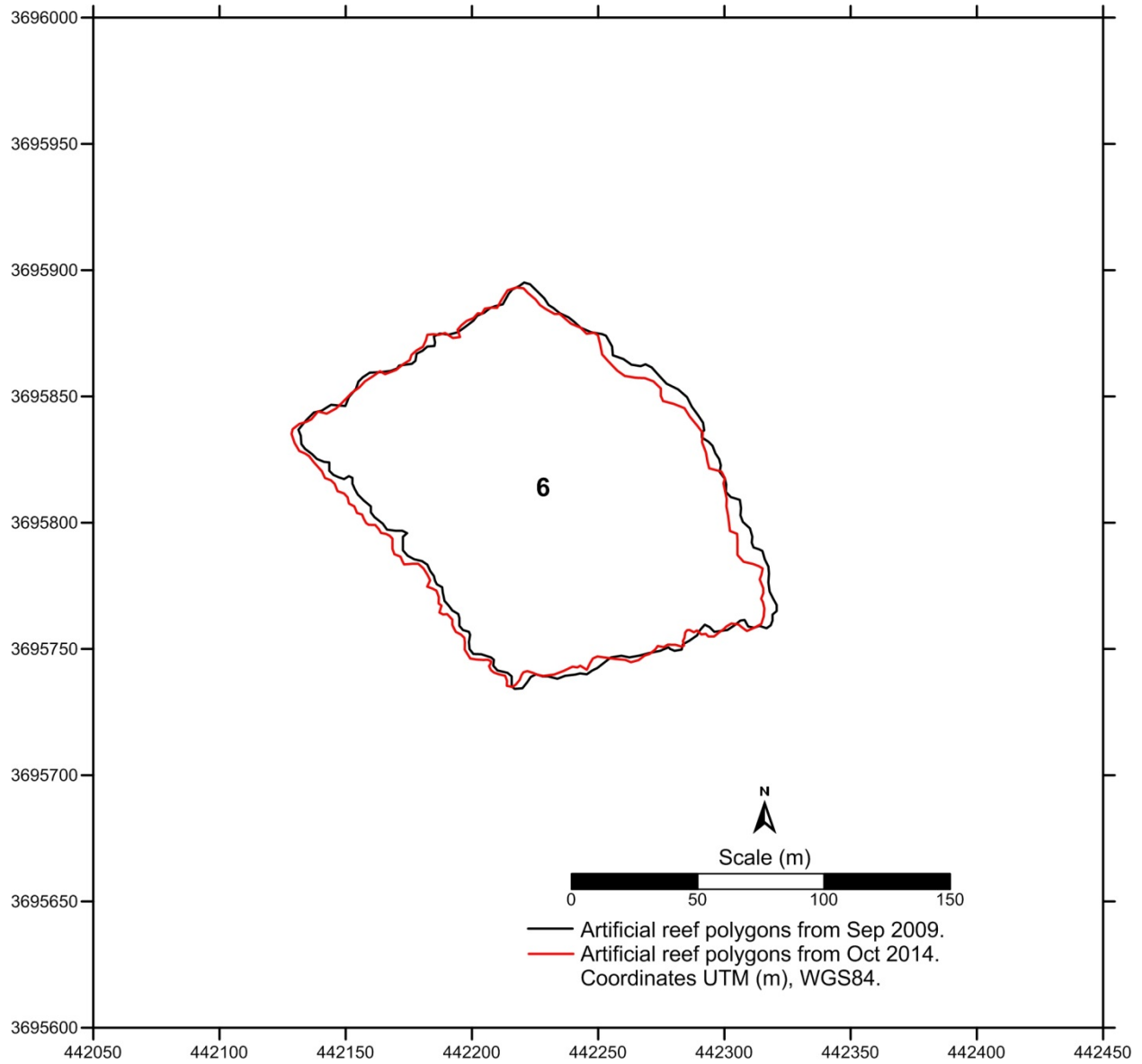
**Table 3-3. Summary of Wheeler North Reef Area for 2008, 2009 and 2014 surveys**

Wheeler North Reef	As-built (2008) area (acres)	Sep 2009 area (acres)	Oct 2014 area (acres)
<b>As-Built</b>			
Phase 1 Modules	24.79 <sup>a</sup>	24.79	24.67
Phase 2 Polygons	152.02	150.46	149.13
<b>Total (Acres)</b>	<b>176.81</b>	<b>175.25</b>	<b>173.80</b>
<b>Modules plus Polygons except # 5 and 7a</b>			
Phase 1 Modules	24.79	24.79	24.67
Phase 2 Polygons	130.26	128.62	127.51
<b>Total (Acres)</b>	<b>155.05</b>	<b>153.41</b>	<b>152.18</b>

<sup>a</sup> As estimated from multibeam bathymetry data in 2009 (CE, 2009).

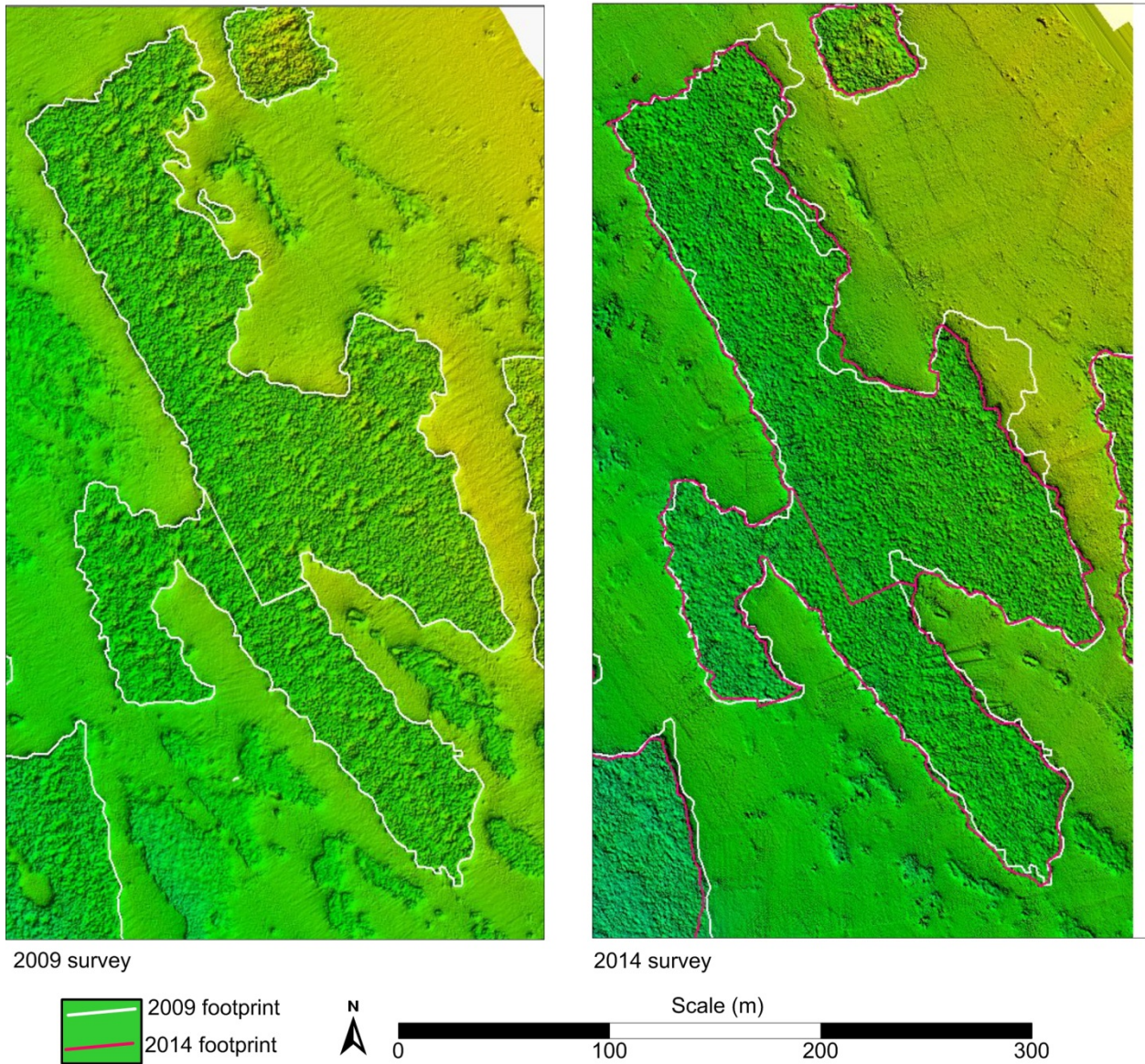


**Figure 3-1. Comparison of footprints for Polygons 1, 2, 3, 12, and 13 from multibeam surveys during September 2009 and October 2014.**



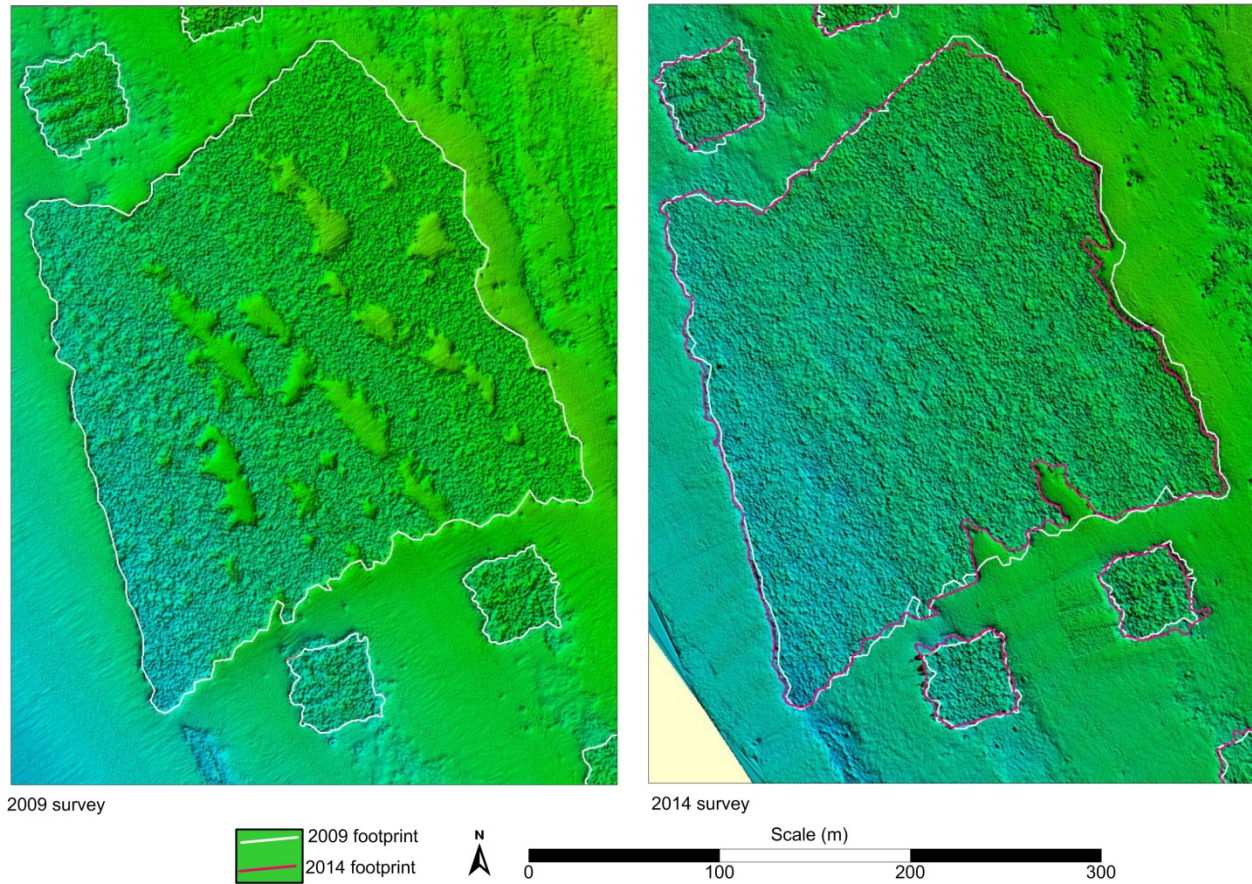
**Figure 3-2. Comparison of footprints for Polygon 6 from multibeam surveys during September 2009 and October 2014.**

Polygon 3



**Figure 3-3. Multibeam data for Polygon 3 from September 2009 and October 2014 surveys, showing the loss and gain of hard substrate on the inshore (east) side of the polygon.**

Polygon 4



**Figure 3-4. Multibeam data for Polygon 4 from September 2009 and October 2014 surveys, showing the loss of hard substrate on the downcoast (south) side of the polygon. Note the presence of a tongue of sand in both areas of loss in the 2009 survey.**

#### 4.0 SUMMARY AND CONCLUSIONS

A multibeam survey was carried out from October 8, 2014 through October 10, 2014 to determine the area of hard substrate of WNR. The reef consists of 56 (40 x 40 m) modules and 17 polygons, ranging in size from 1.35 to 38.88 acres. The survey covered 100% of the reef areas (Figures 1-2 and 1-3).

The survey performed during October 2014 to assess the hard substrate coverage of the WNR obtained high-quality multibeam data, in spite of the presence of high-density kelp. The survey was carried out during high tides as the water overtopped the kelp canopy to minimize kelp entanglement in the MBES.

The bathymetric data was the primary data source in delineating the boundaries of the modules and polygons. Backscatter and water column data were utilized to aid in delineation of the areas that were difficult to interpret based on bathymetric data alone (Figures 2-3 and 2-4).

The repeatability of the survey was tested with two methods. The first method involved surveying the southern and eastern edge of Module 8 three times from different directions (Figures 2-5 and 2-6). The second method consisted of digitizing the edges of the polygon using two independent surveyors (Figure 2-7). The results show that the survey accuracy and digitizing deviation is within 1-2 m, and that the deviation from one point to another fluctuates, such that the survey error in estimating the total area is likely to be 1% or less.

Figures 3-3 and 3-4 show the multibeam data for Polygons 3 and 4, respectively, and their nearby areas, based on the September 2009 and October 2014 surveys. From these figures, we can see that some of the natural reef features inshore of WNR have become buried by sand movement, a phenomenon that has also been observed on the easternmost boundary of WNR. However, although some small, inshore areas have become buried, the reef's boundaries have remained remarkably similar to those seen in the 2009 survey. The results of the survey are presented graphically in Appendices A-E.

The changes in area among all modules between September 2009 and October 2014 were small. The results of the 2009 and 2014 surveys show that the total area of the modules was 24.79 acres in 2009 and 24.67 acres in 2014 (Table 3-1). This equates to a 0.5 percent change in total module area.

The October 2014 survey (Table 3-2) showed a total WNR area (excluding Polygons 5 and 7a) of 152.17 acres, vs. the September 2009 survey, which showed a total area 153.41 acres, accounting for a loss of 0.8%.

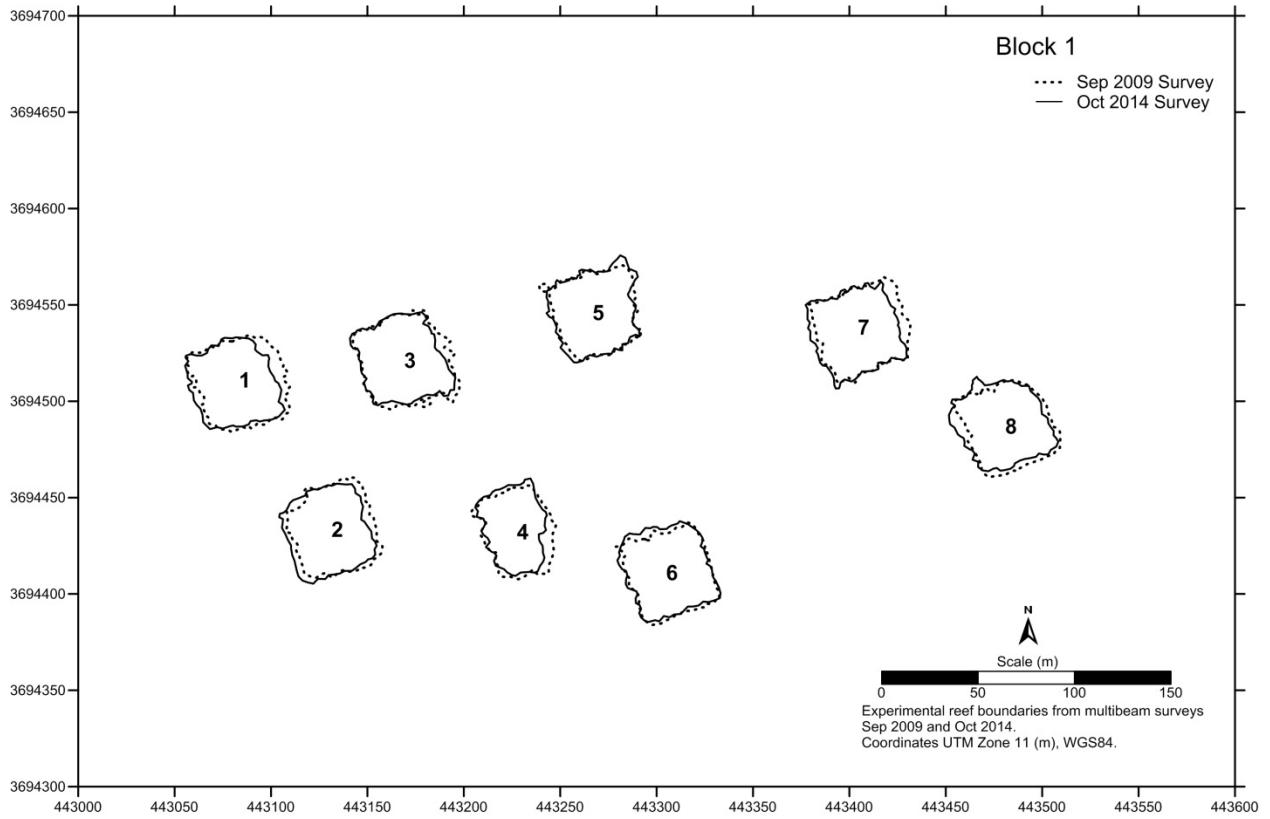
## 5.0 REFERENCES

- California Coastal Commission (CCC), 2008. Coastal Development Permit #E-07-010 (Southern California Edison Company). Adopted on 2 February 2008, California Coastal Commission, 45 Fremont Street, Suite 2009, San Francisco, CA 94105-2219, 35 pp.
- Coastal Environments, 1999. Construction of Southern California Edison Experimental Artificial Kelp Reef, San Clemente, California, Volume I. Report submitted to Southern California Edison, 2244 Walnut Grove Avenue, Rosemead, CA 91770, 24 November 1999, CE Ref. No. 99-14, 35 pp. and 4 appendices.
- Coastal Environments, 2008a. Final Construction Report for Wheeler North Reef at San Clemente, California (SONGS Artificial Reef Mitigation Project, Phase 2 Mitigation Reef), Volume I. Report submitted to Southern California Edison Company, Rosemead, CA 91770, CE Reference No. 08-33, 4 November 2008, 43 pp. and 4 appendices.
- Coastal Environments, 2008b. Final Construction Report for Wheeler North Reef at San Clemente, California (formerly the SONGS Artificial Reef Mitigation Project, Phase 2 Mitigation Reef), Volume II: Data Report. Prepared for Southern California Edison, CE Reference No. 08-34, 5 November 2008 (revised 12 December 2008), 8 pp. and 7 appendices.
- Coastal Environments, 2009. Multibeam Survey of Wheeler North Reef, San Clemente, California. Prepared for Southern California Edison, CE Reference No. 09-23, 9 November 2009, 21 pp. and 9 appendices.
- Coastal Environments, Fugro Pelagos, Inc., and EcoSystems Management Associates, Inc., 2006a. Sea Floor Characterization for SONGS Artificial Reef Mitigation Project at San Clemente, California, Volume I. Report submitted to Southern California Edison, 2244 Walnut Grove Avenue, Rosemead, CA 91770, 16 March 2006, CE Ref. No. 06-01, 54 pp. and 3 appendices.
- Coastal Environments, Fugro Pelagos, Inc., and EcoSystems Management Associates, Inc. 2006b. Sea Floor Characterization for SONGS Artificial Reef Mitigation Project at San Clemente, California, Volume II. Report submitted to Southern California Edison, 2244 Walnut Grove Avenue, Rosemead, CA 91770, 16 March 2006, CE Ref. No. 06-02.

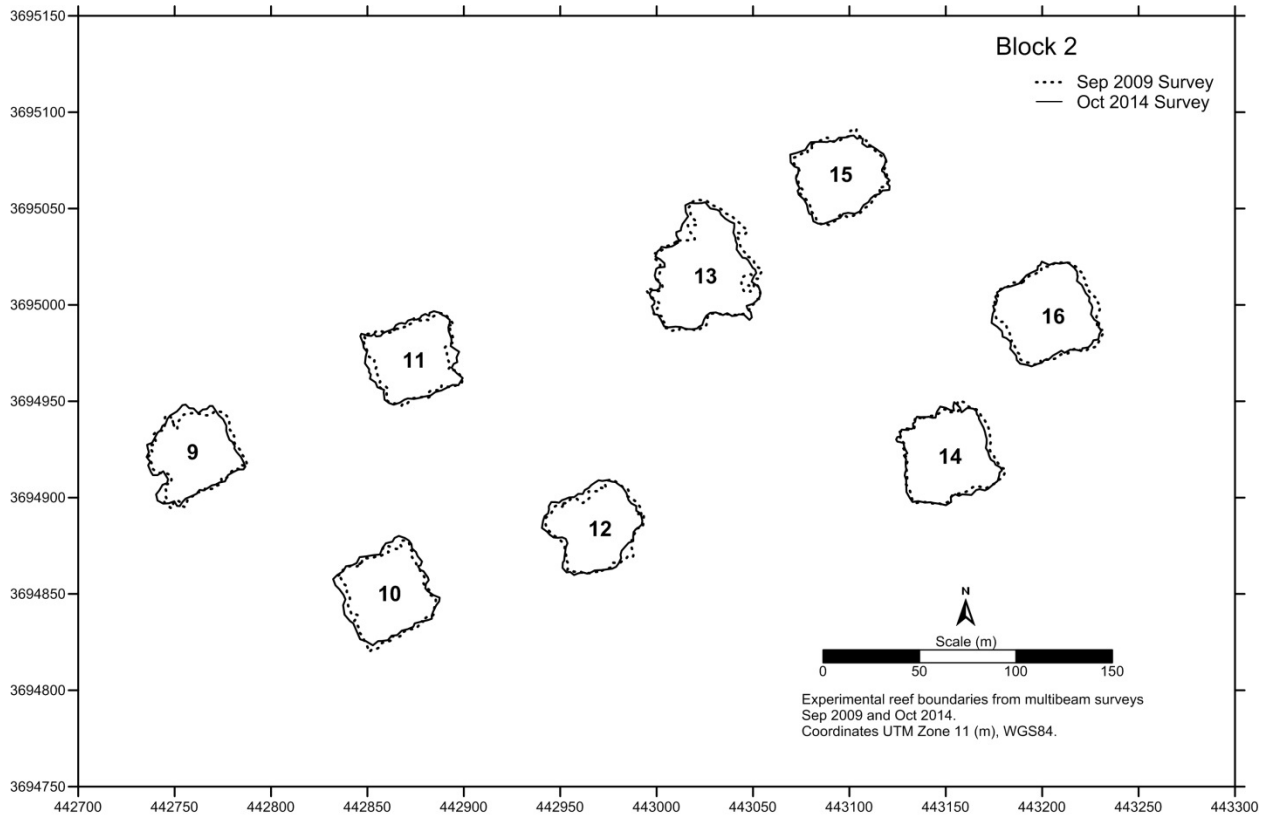


**APPENDIX A**

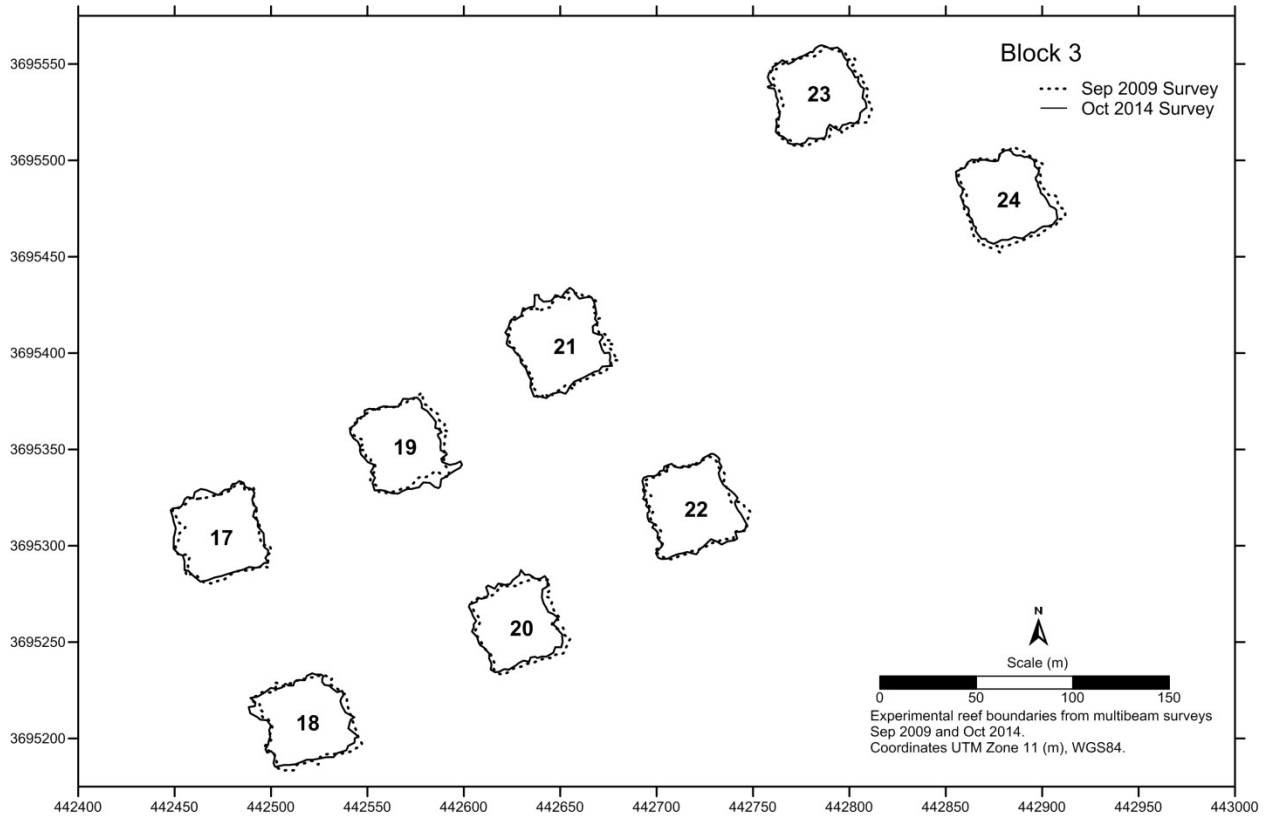
**COMPARISON OF MODULE BOUNDARIES FROM 2009 (BATHYMETRY) AND  
OCTOBER 2014 (BATHYMETRY) FOR BLOCKS 1-7**



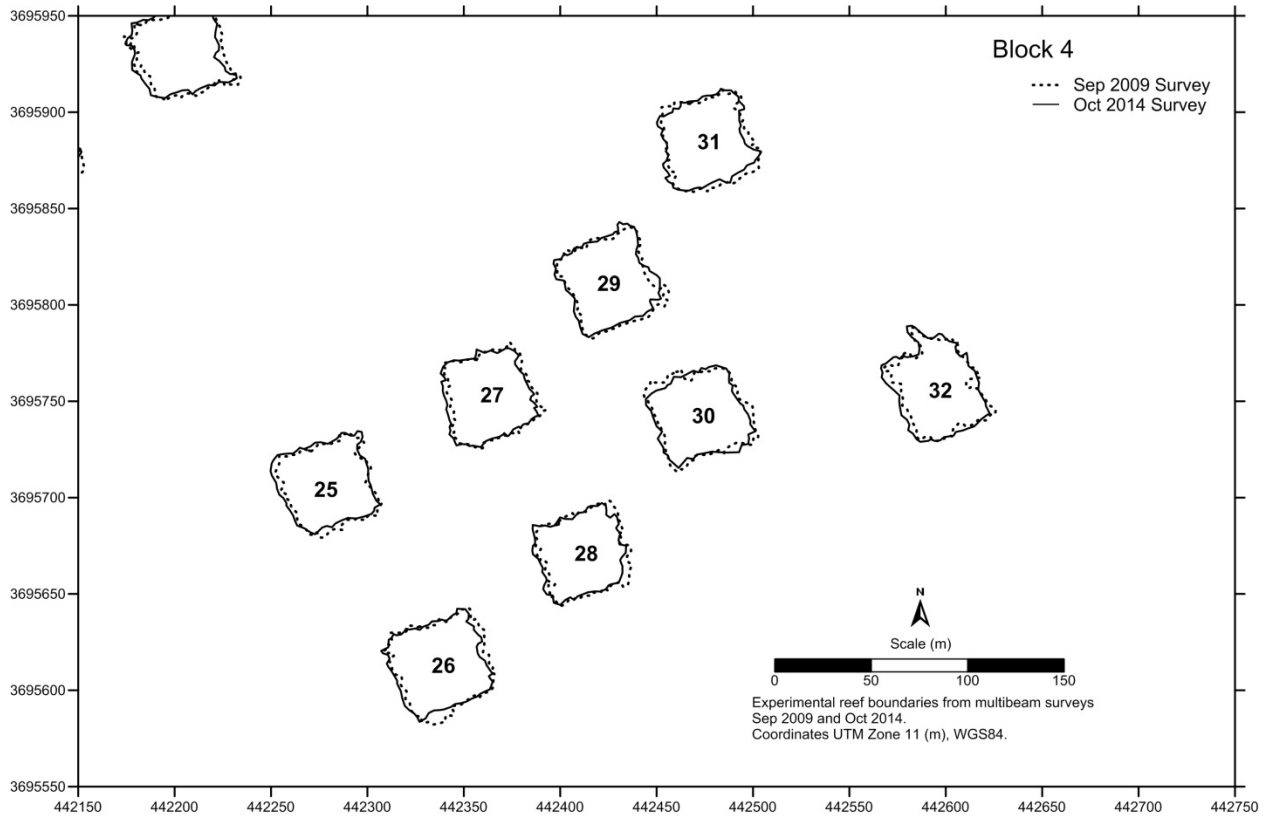
**Figure A-1. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 1.**



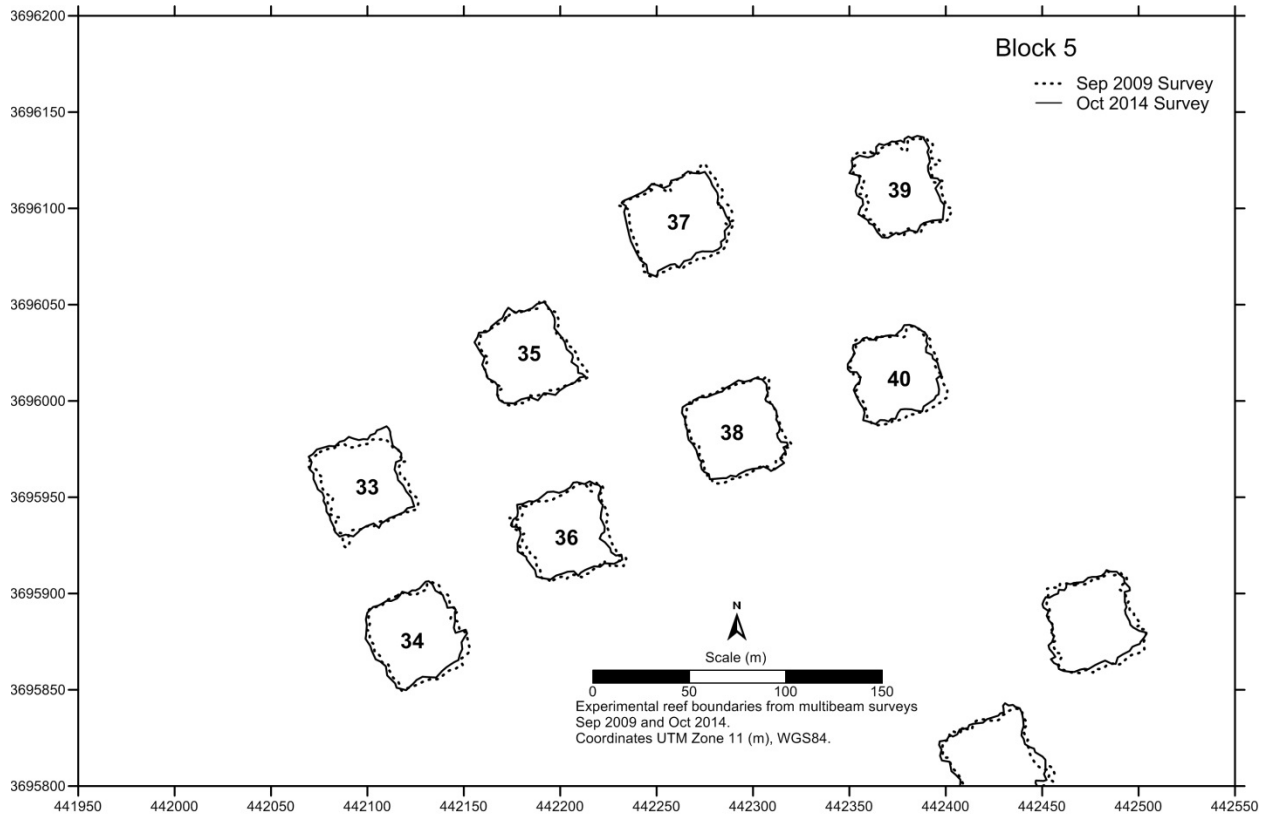
**Figure A-2. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 2.**



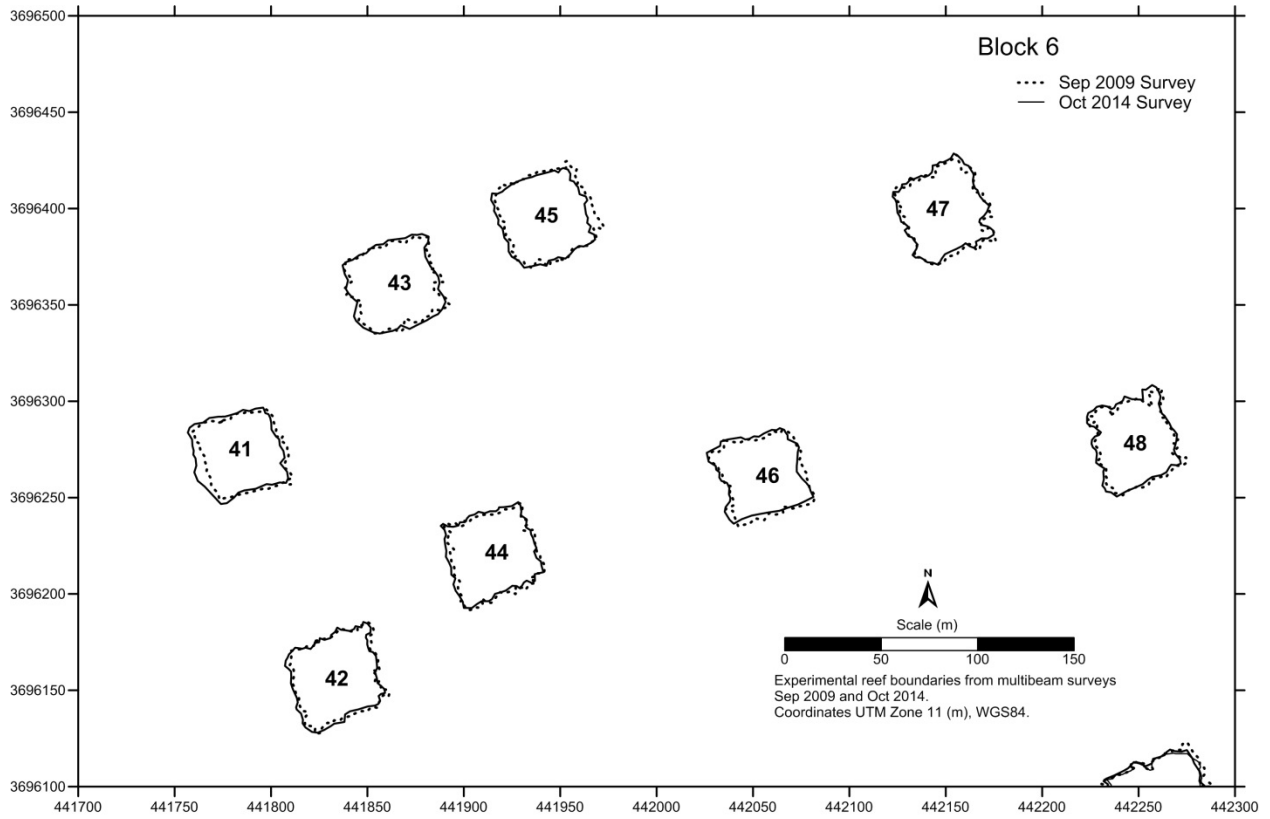
**Figure A-3. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 3.**



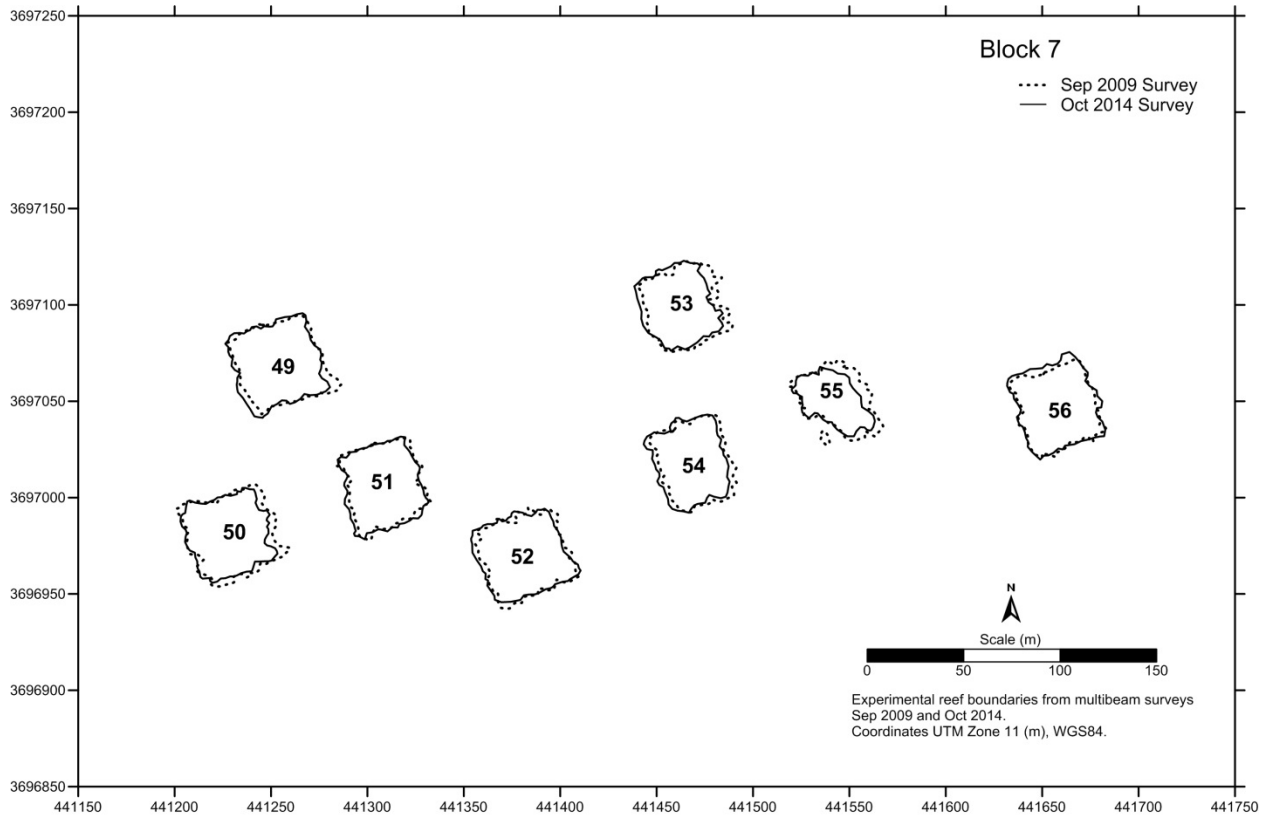
**Figure A-4. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 4.**



**Figure A-5. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 5.**



**Figure A-6. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 6.**

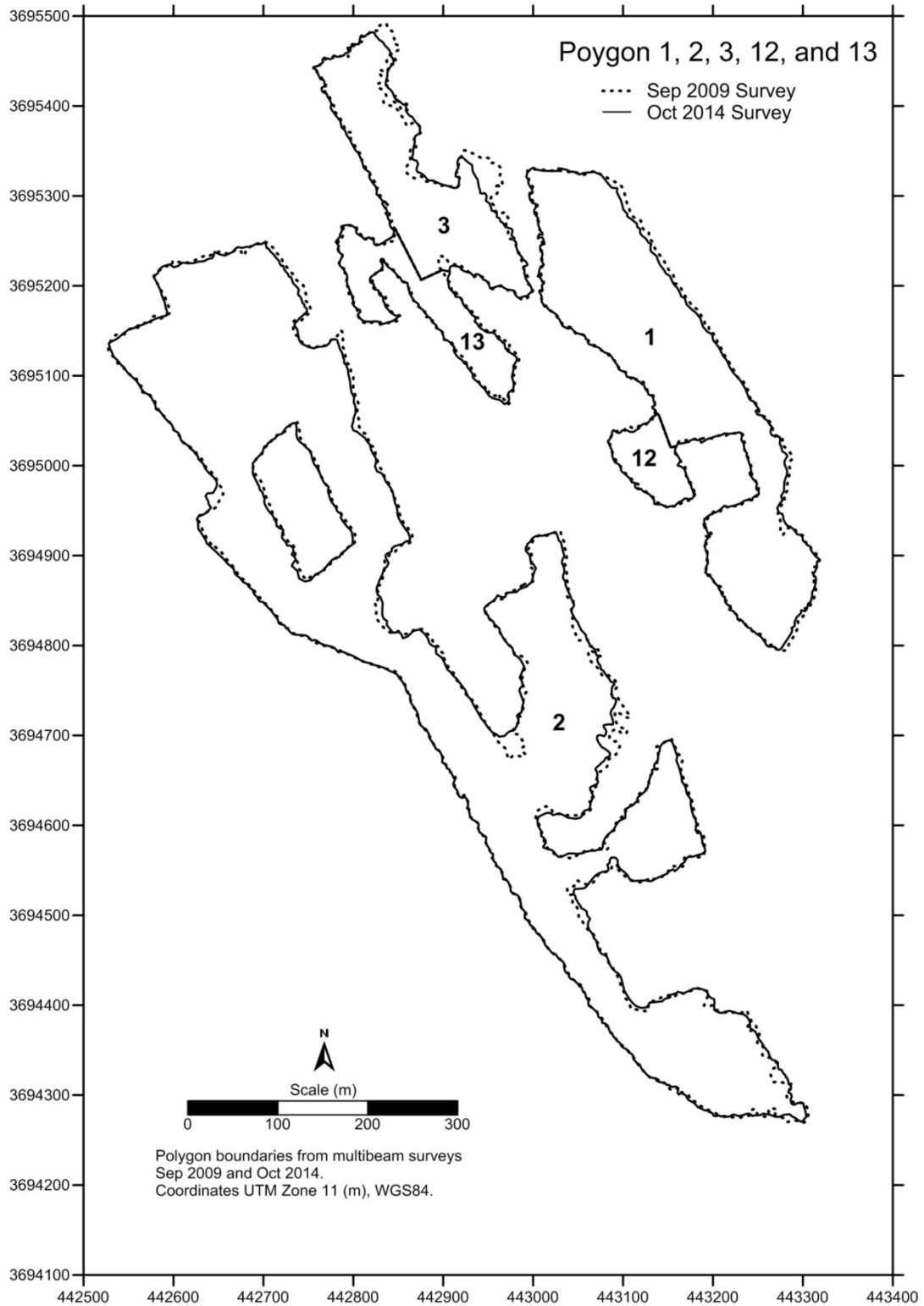


**Figure A-7. Comparison of module boundaries from 2009 (bathymetry) and October 2014 (bathymetry) for Block 7.**

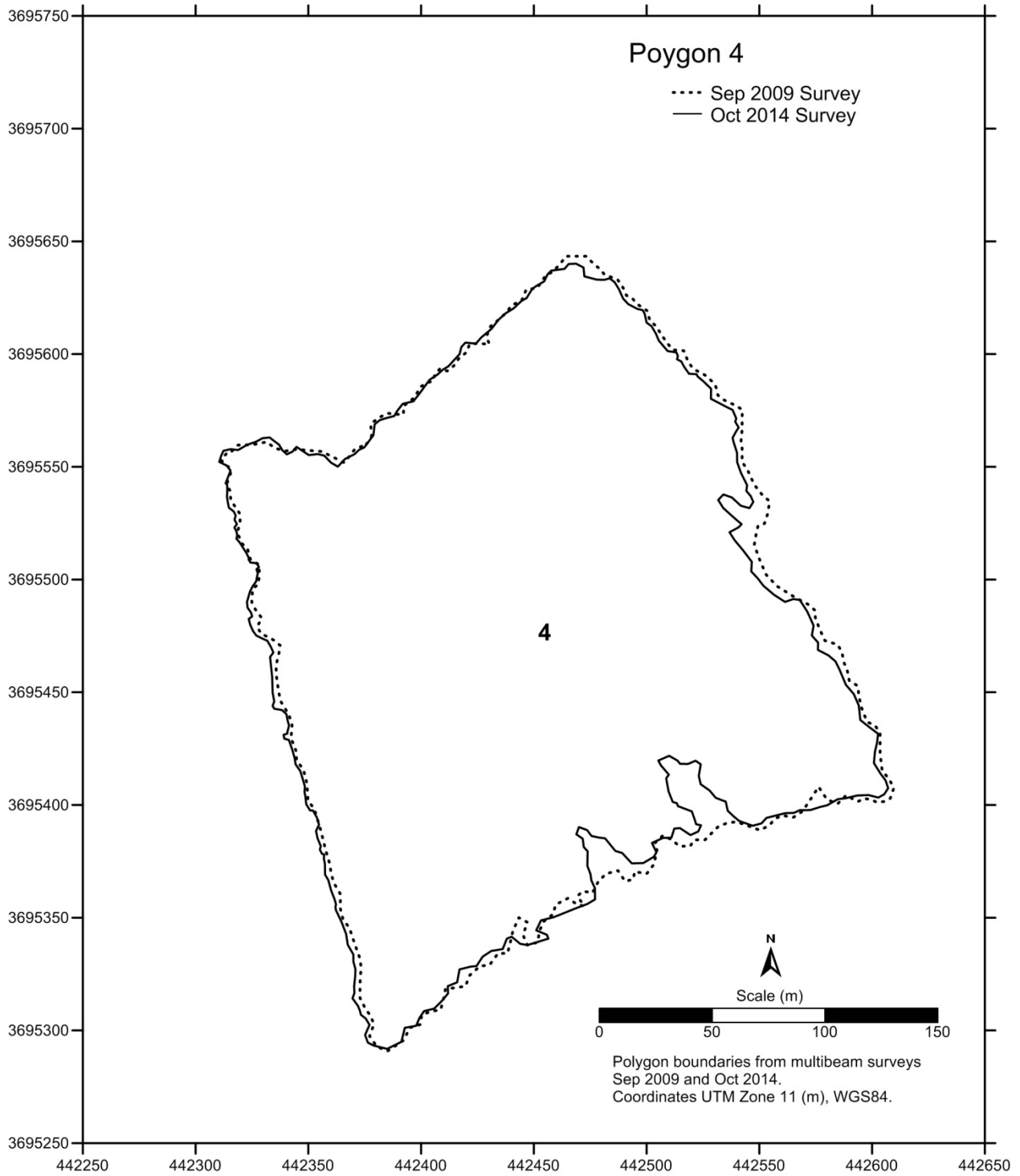


## **APPENDIX B**

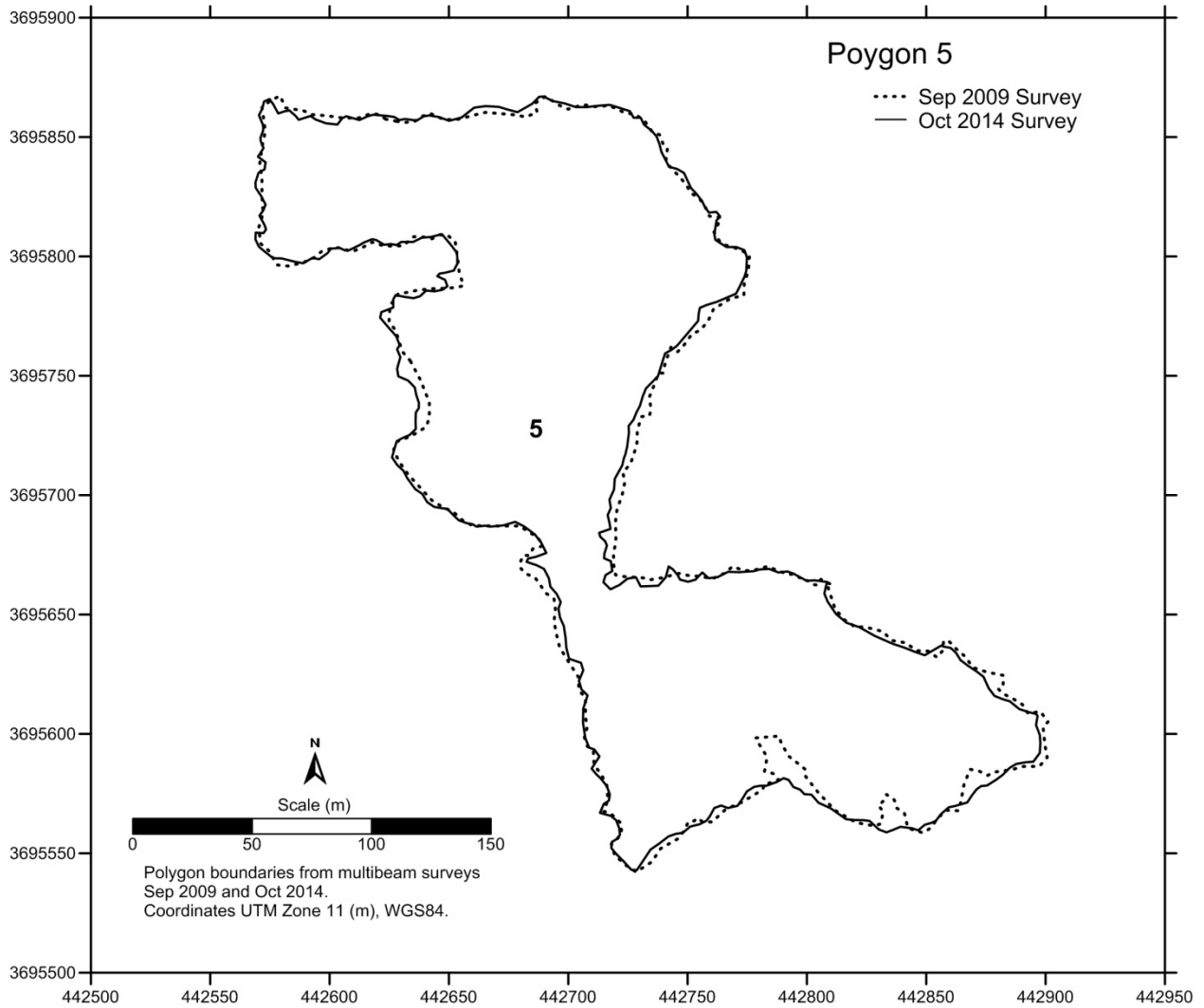
### **COMPARISON OF POST-CONSTRUCTION (2009) AND OCTOBER 2014 BOUNDARIES FROM BATHYMETRY DATA FOR POLYGONS 1-17**



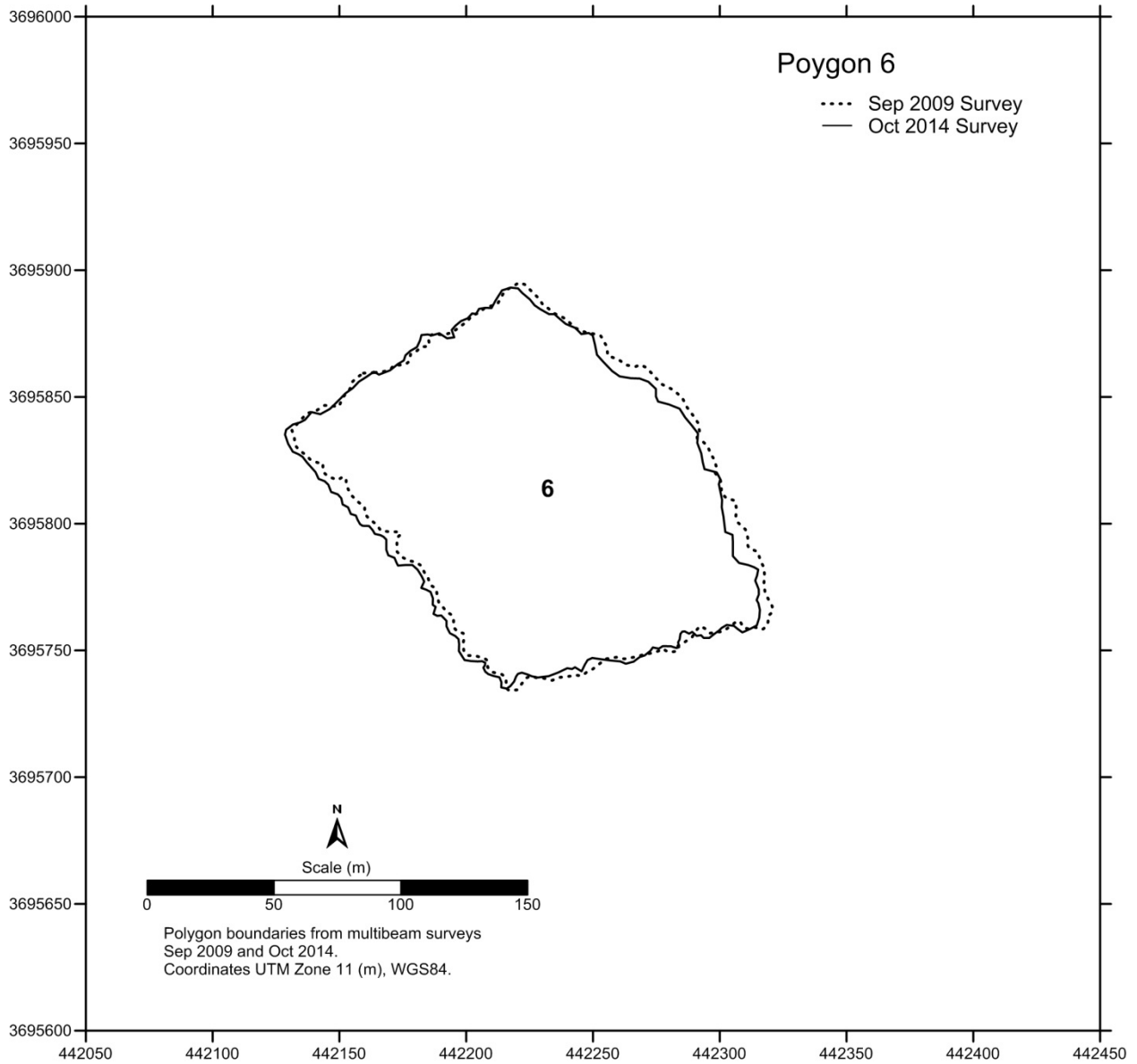
**Figure B-1. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygons 1, 2, 3, 12, and 13.**



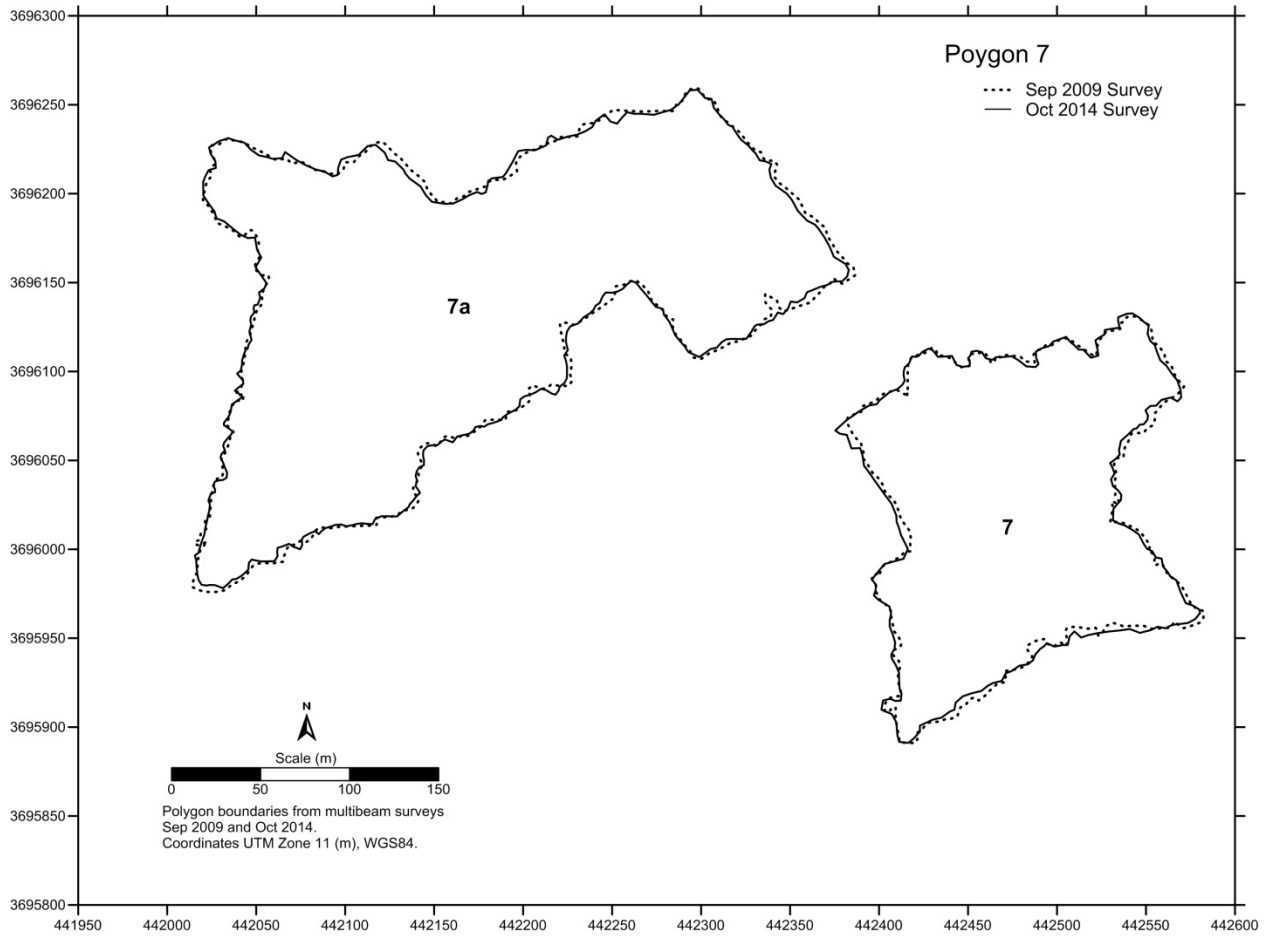
**Figure B-2. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 4.**



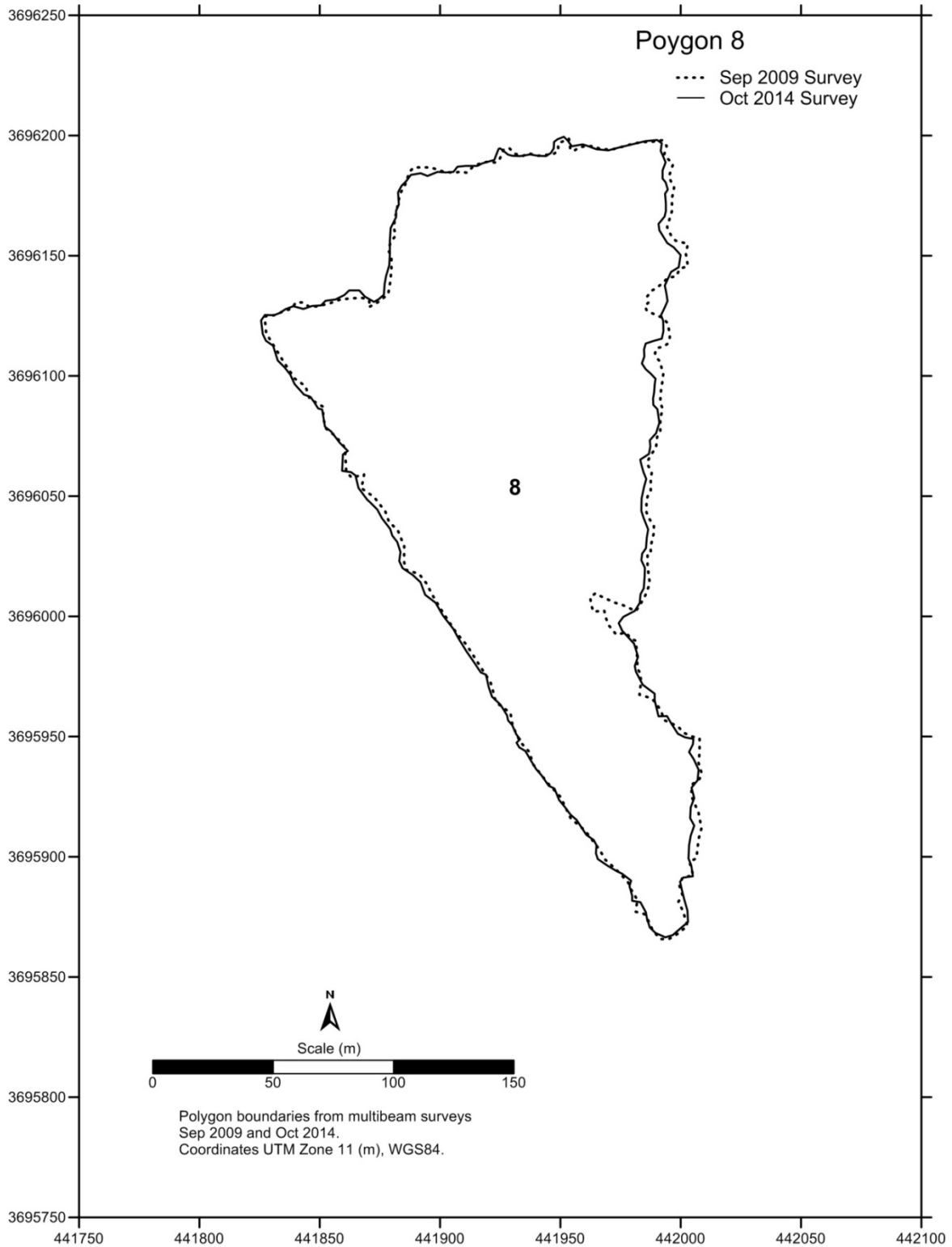
**Figure B-3. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 5.**



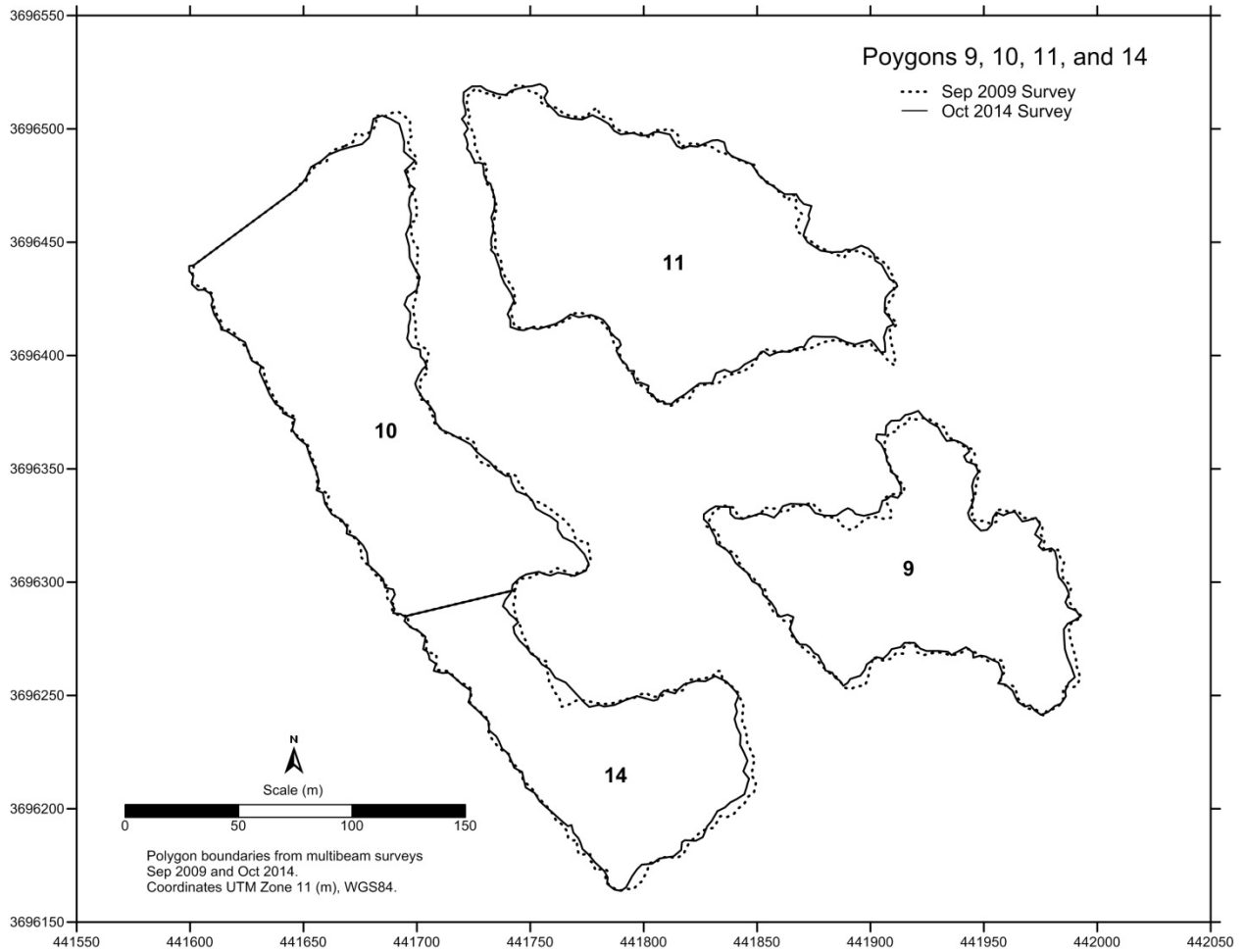
**Figure B-4. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 6.**



**Figure B-5. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 7.**

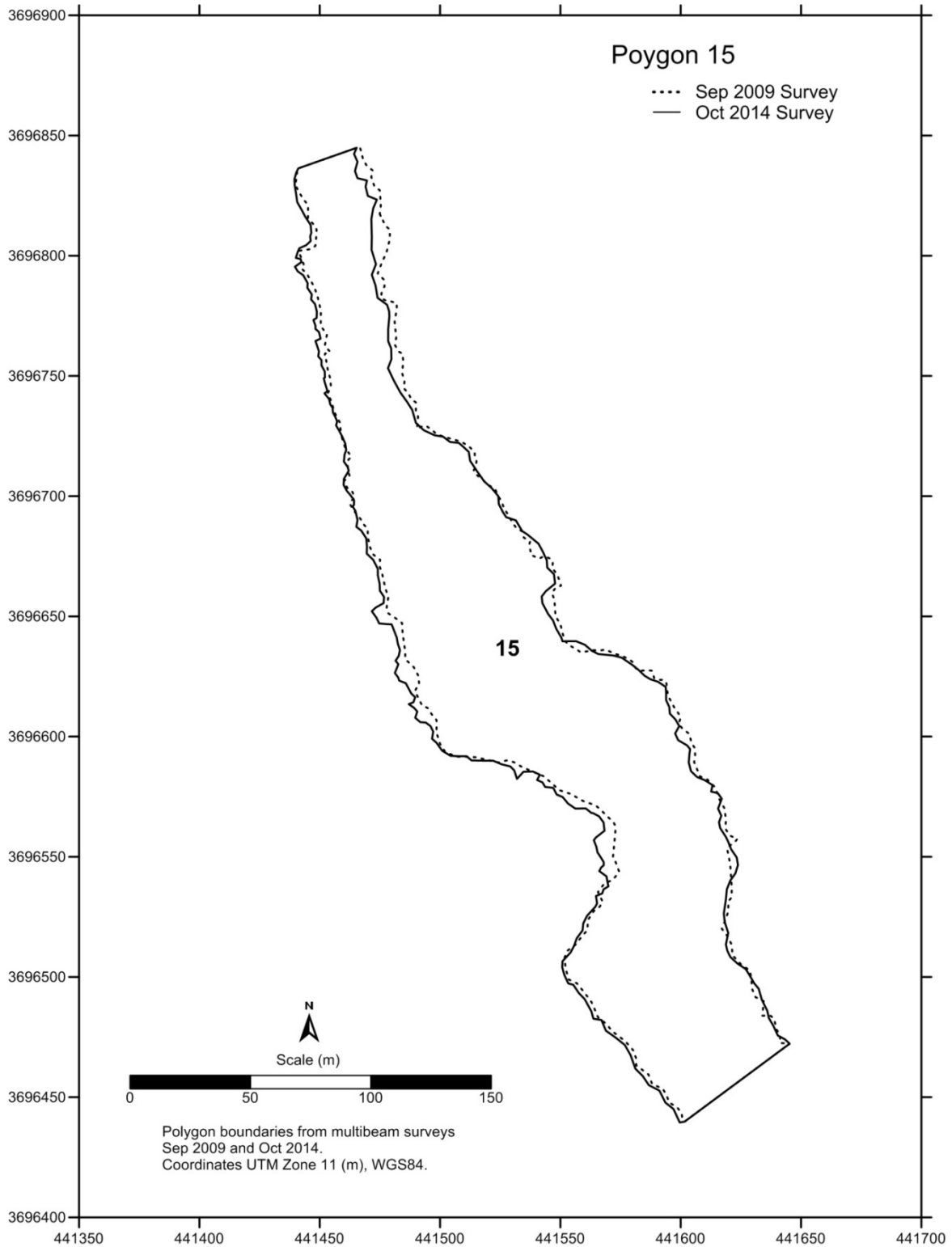


**Figure B-6. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 8.**

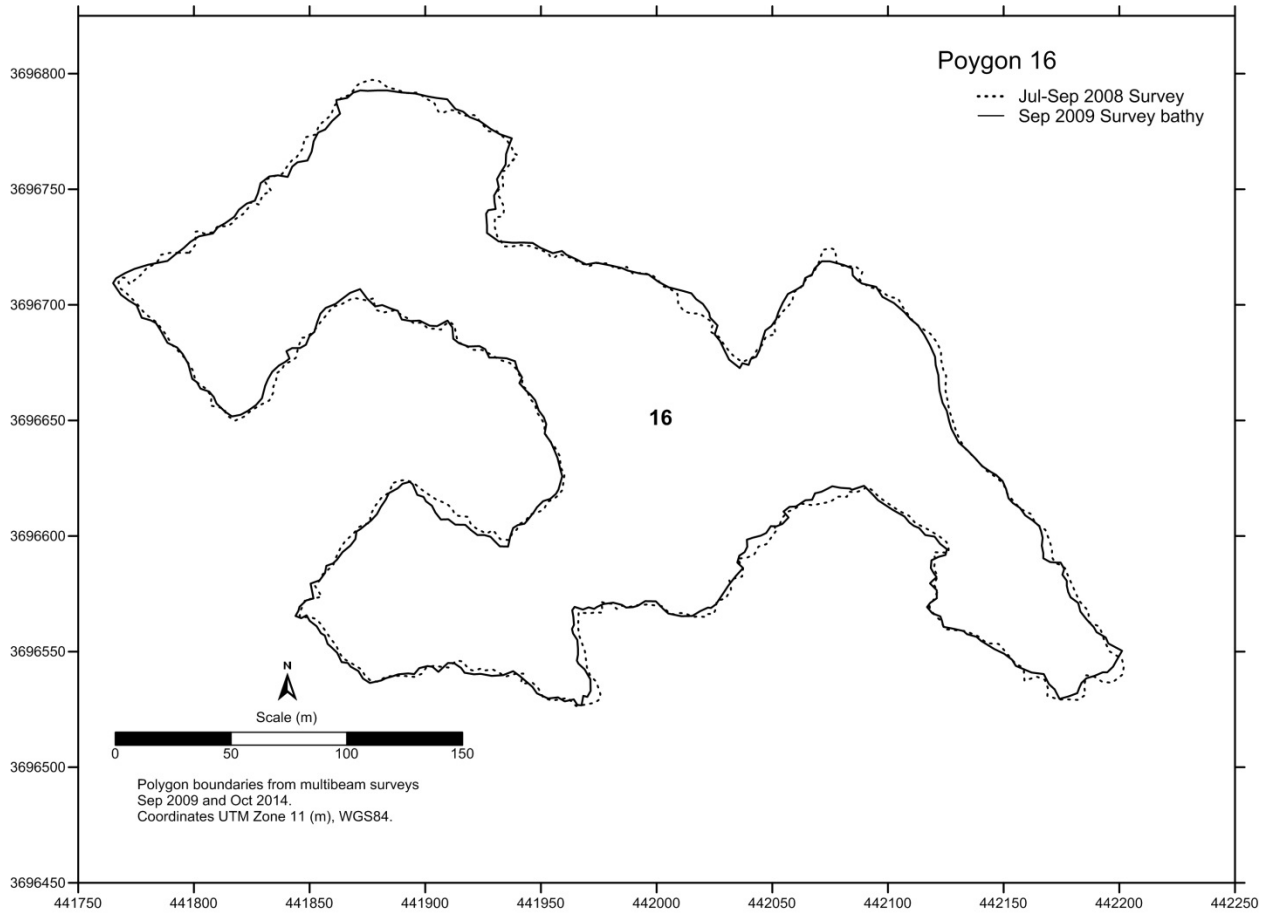


**Figure B-7. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygons 9, 10, 11, and 14.**

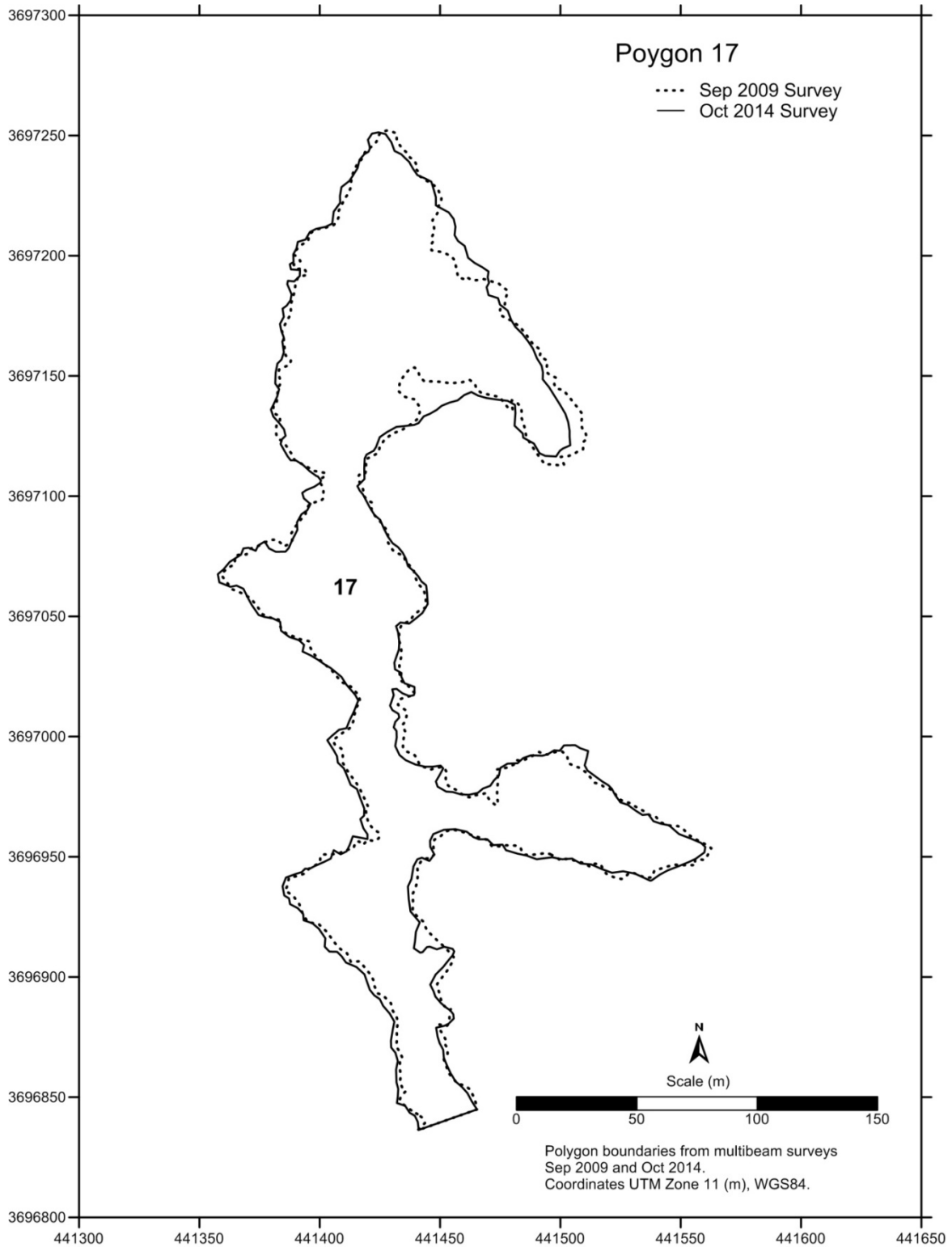




**Figure B-8. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 15.**



**Figure B-9. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 16.**



**Figure B-10. Comparison of post-construction (2009) and October 2014 boundaries from bathymetry data for Polygon 17.**

**APPENDIX C**

**BOUNDARIES FROM BATHYMETRIC DATA FOR MODULE BLOCKS 1-7  
(OCTOBER 2014 MULTIBEAM SURVEY)**

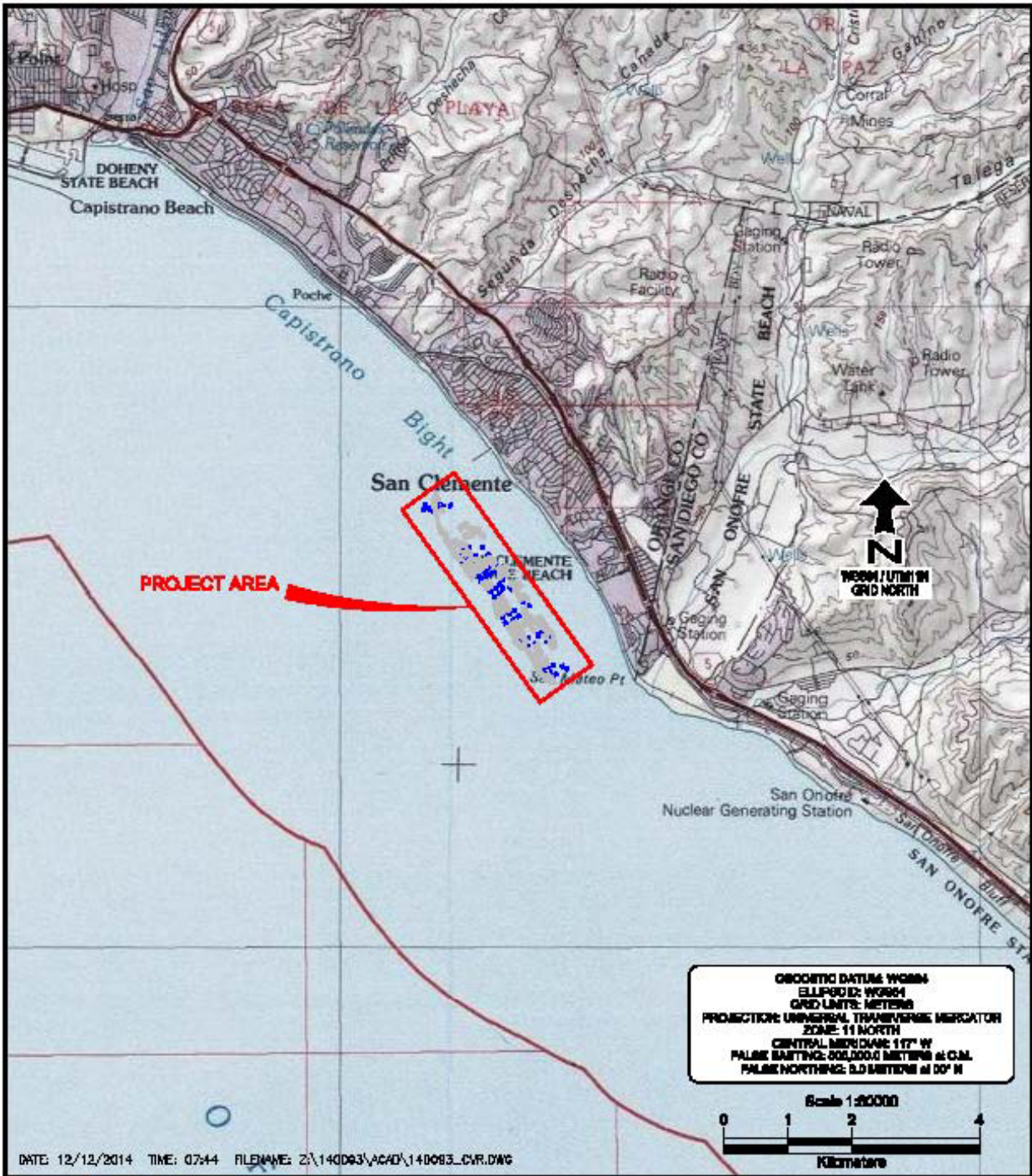


Figure C-1. Location map for Wheeler North Reef Modules (Blocks 1-7).

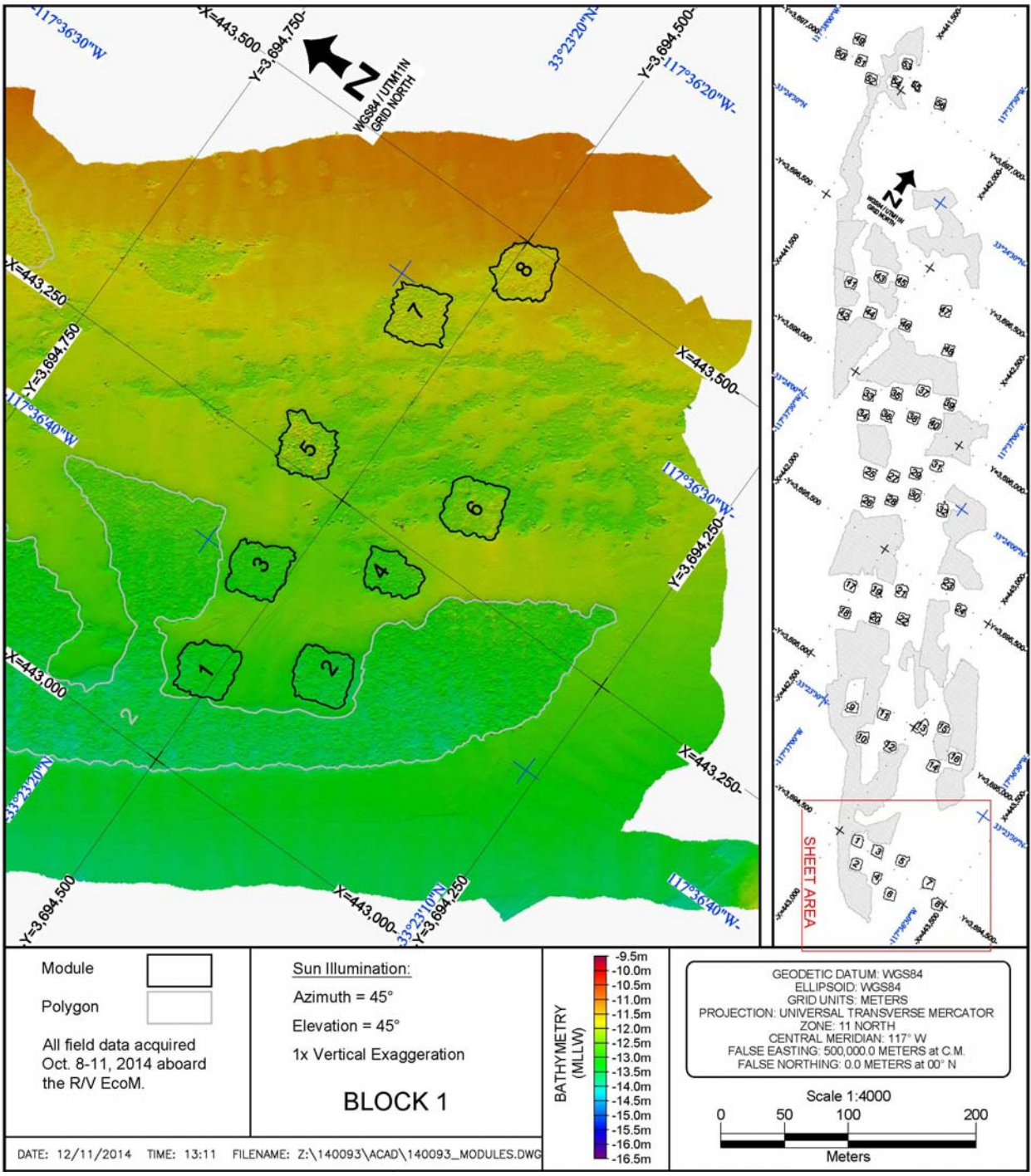


Figure C-2. Block 1 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).

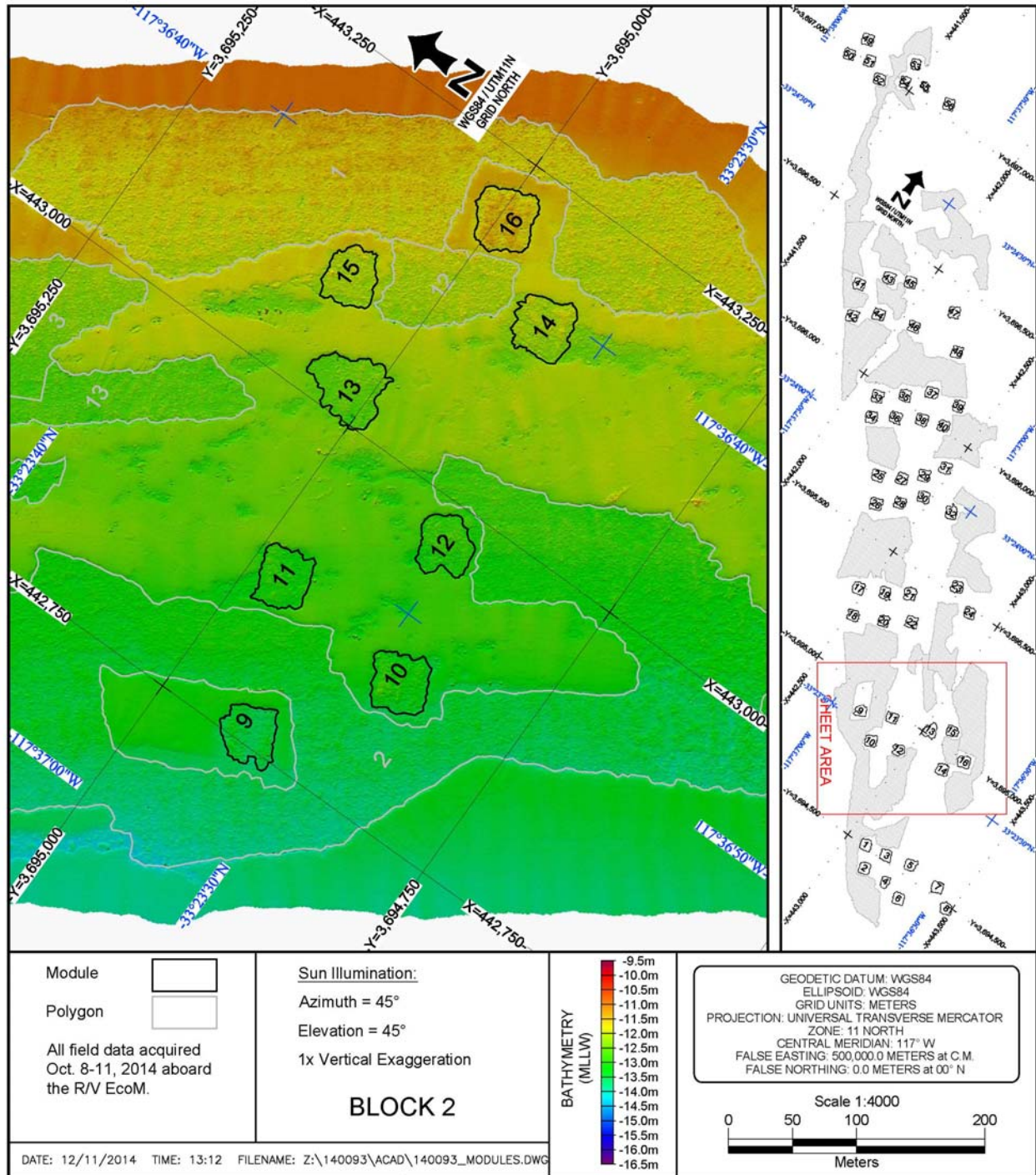


Figure C-3. Block 2 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).

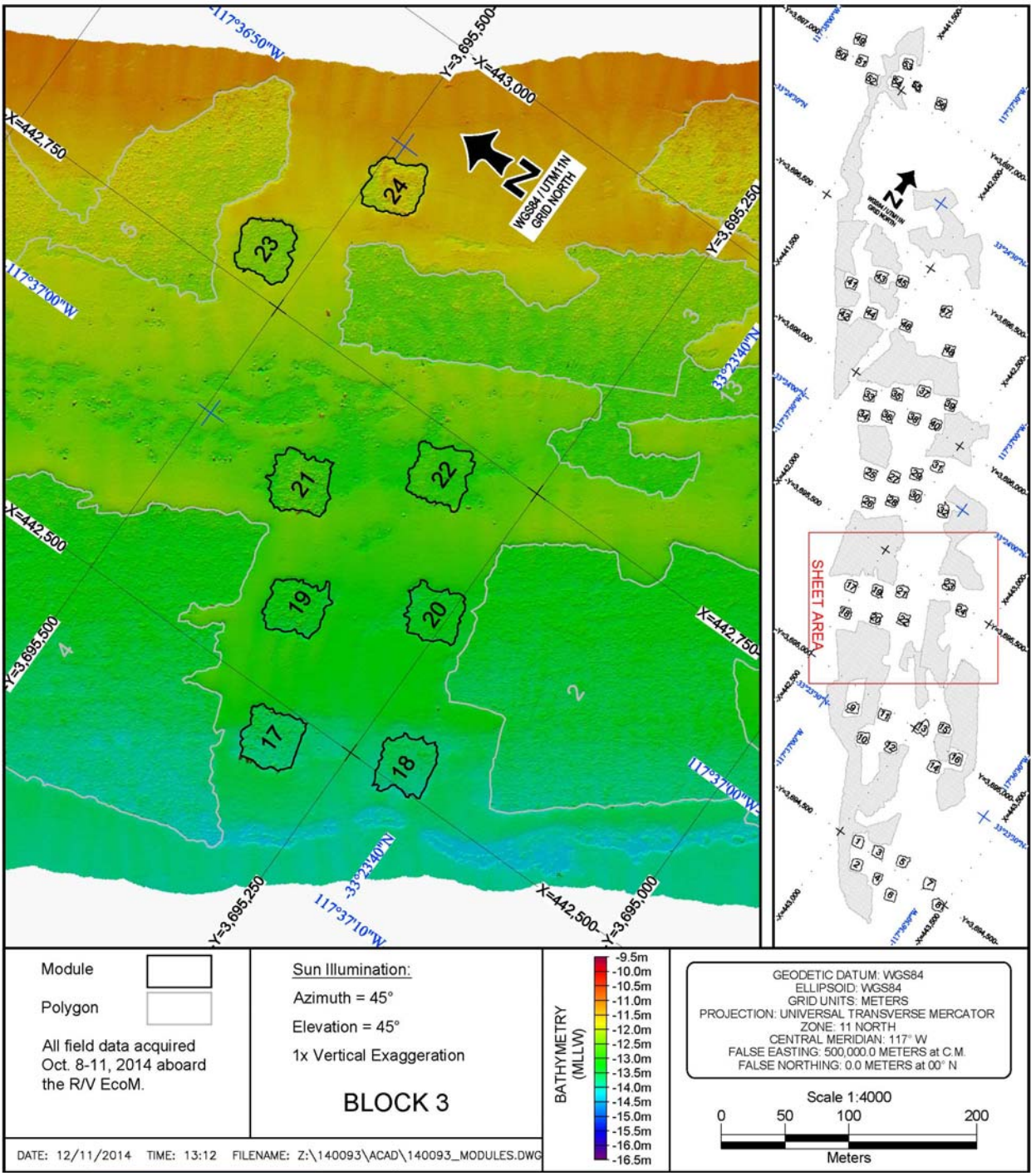


Figure C-4. Block 3 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).



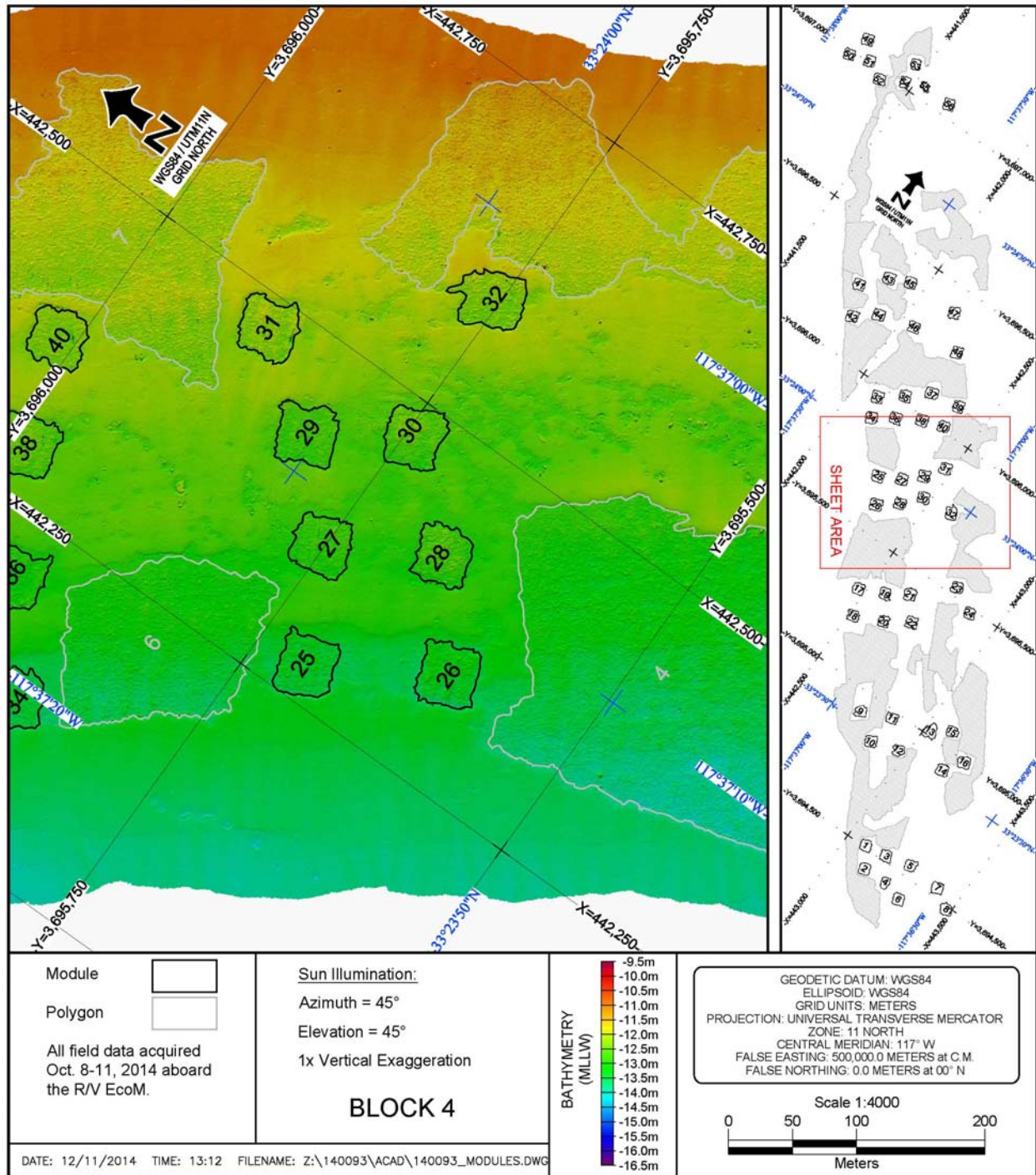


Figure C-5. Block 4 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).

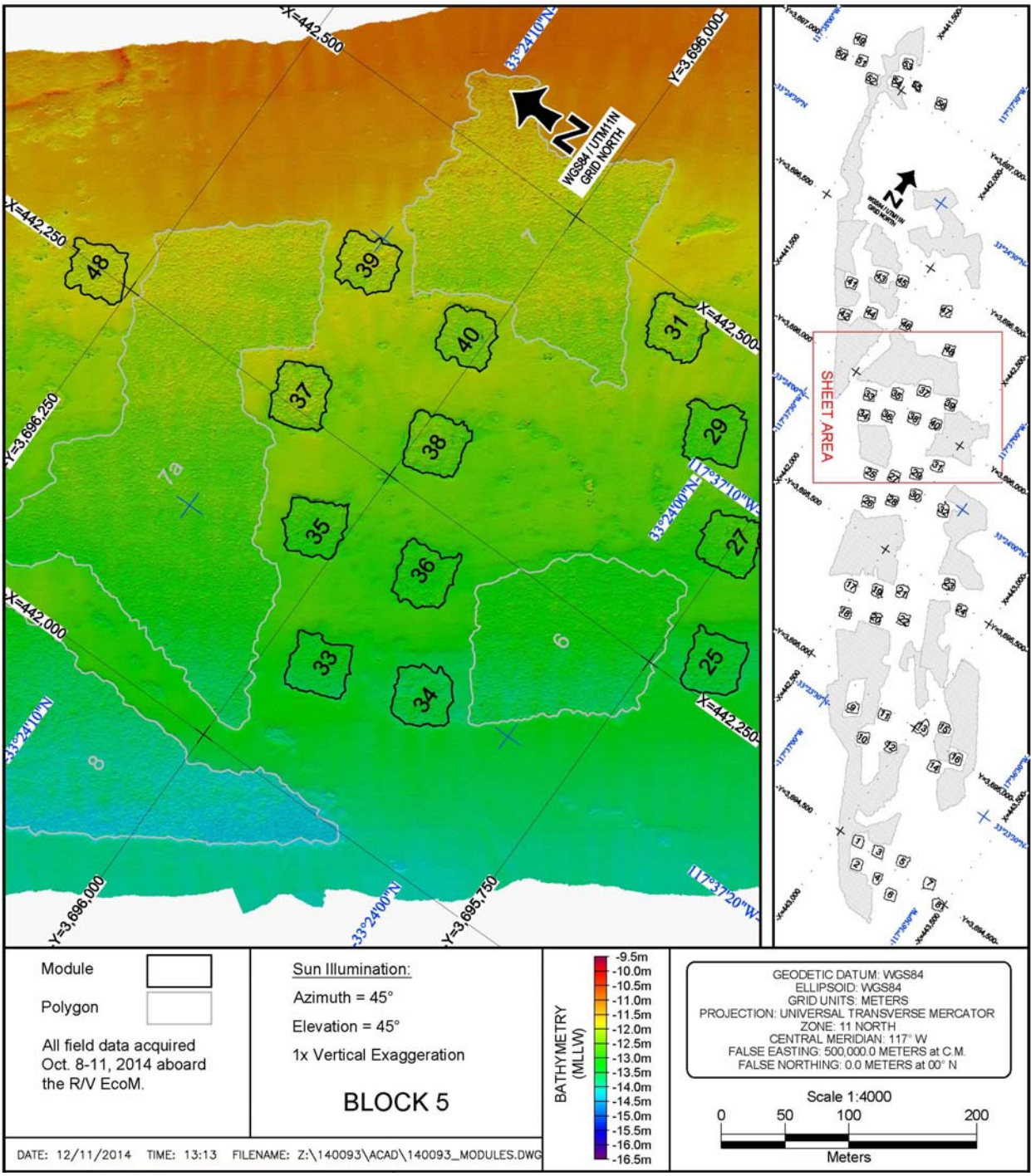


Figure C-6. Block 5 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).

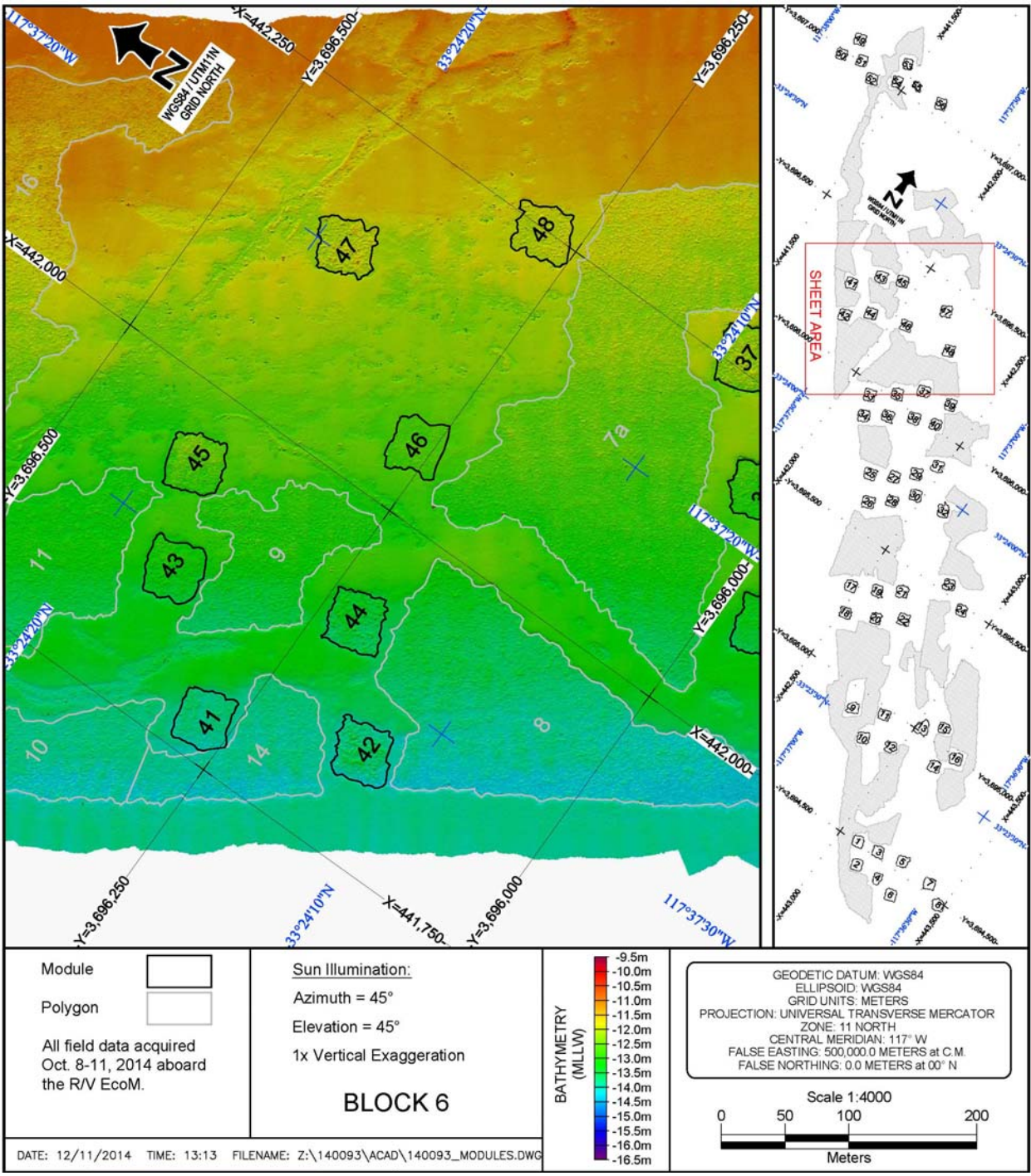


Figure C-7. Block 6 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).

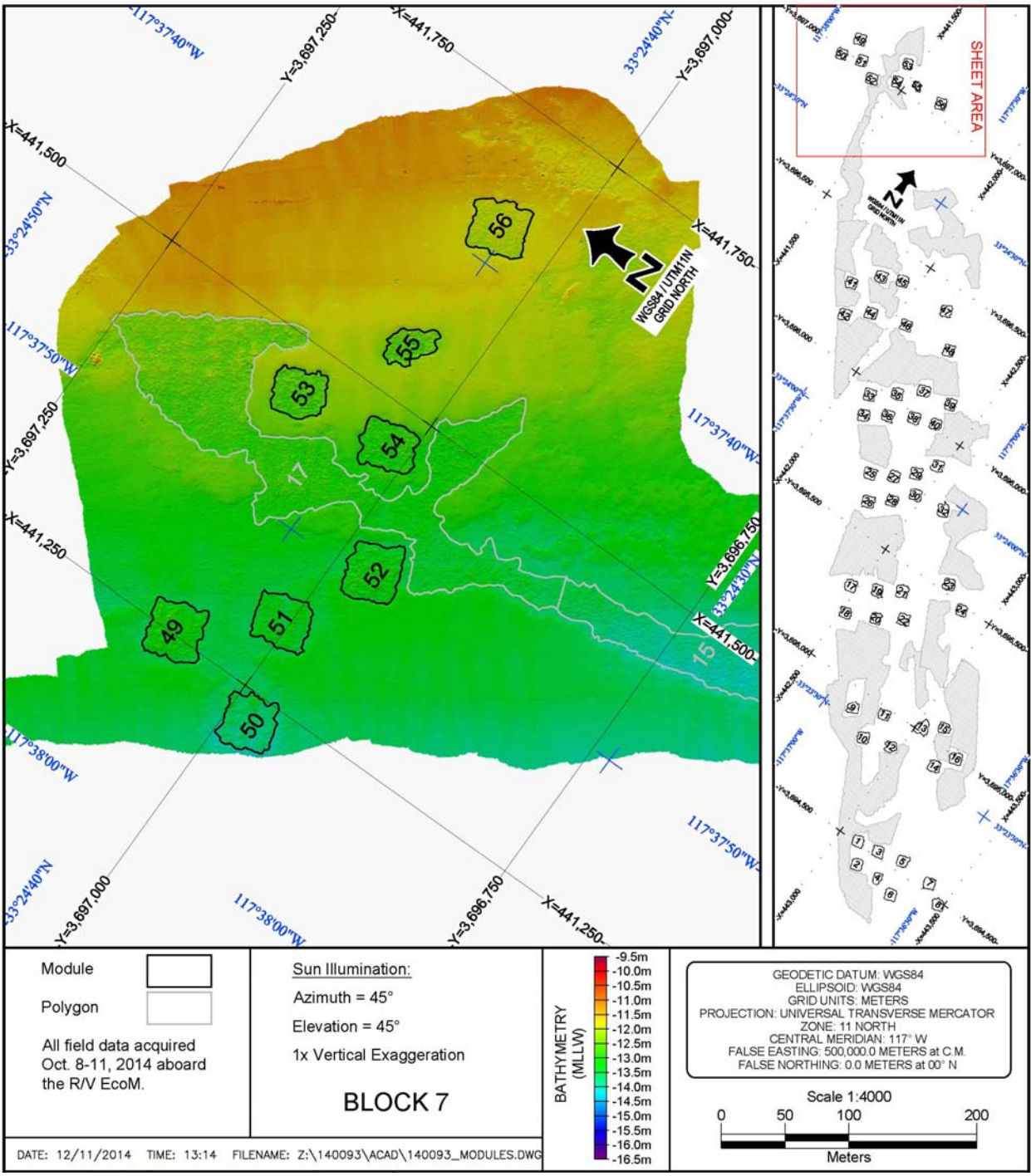


Figure C-8. Block 7 module boundaries from bathymetric data interpretation (October 2014 multibeam survey).

**APPENDIX D**

**BOUNDARIES FROM BATHYMETRIC DATA FOR POLYGONS 1-17  
(OCTOBER 2014 MULTIBEAM SURVEY)**

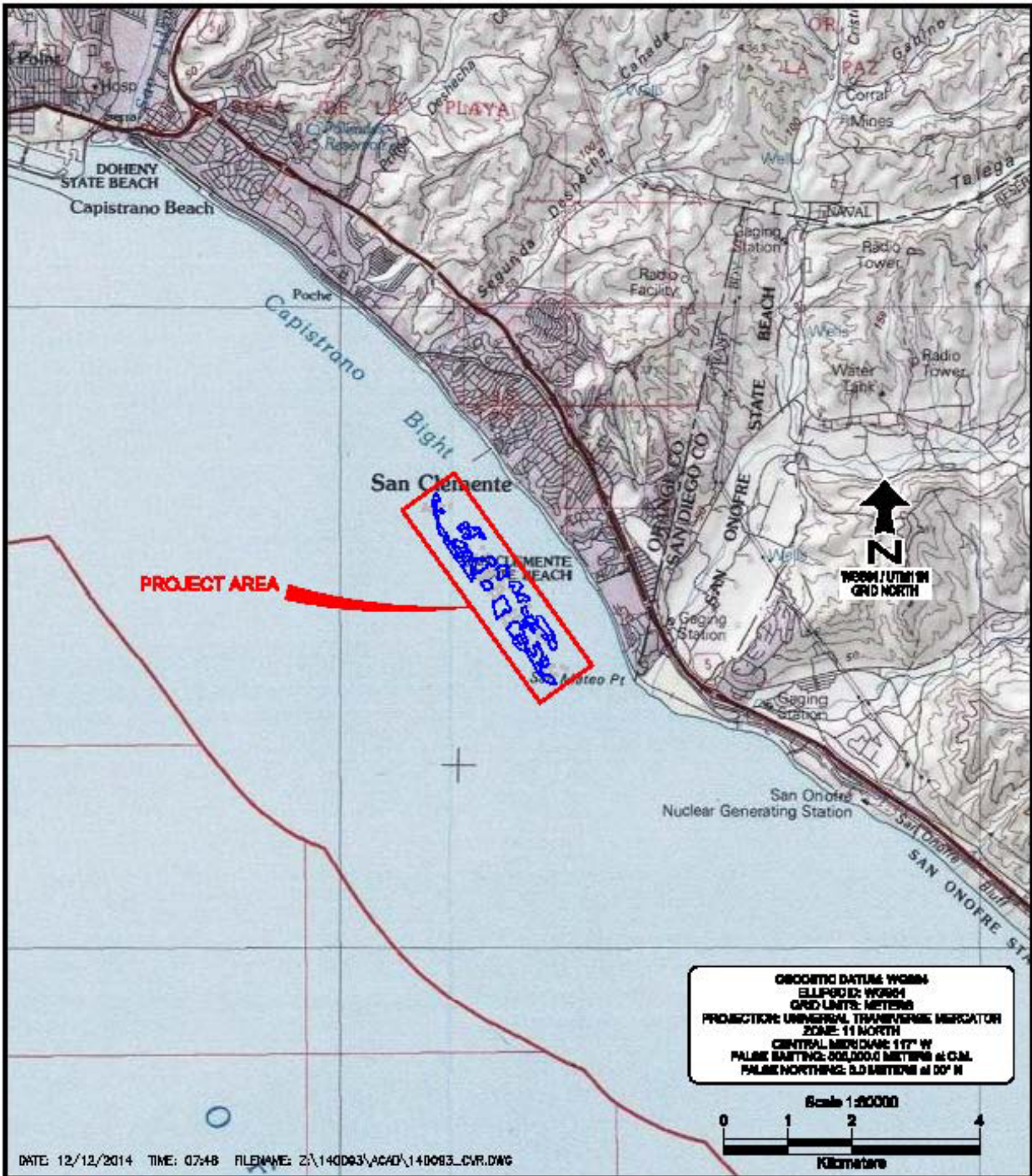


Figure D-1. Location map for Wheeler North Reef Polygons.

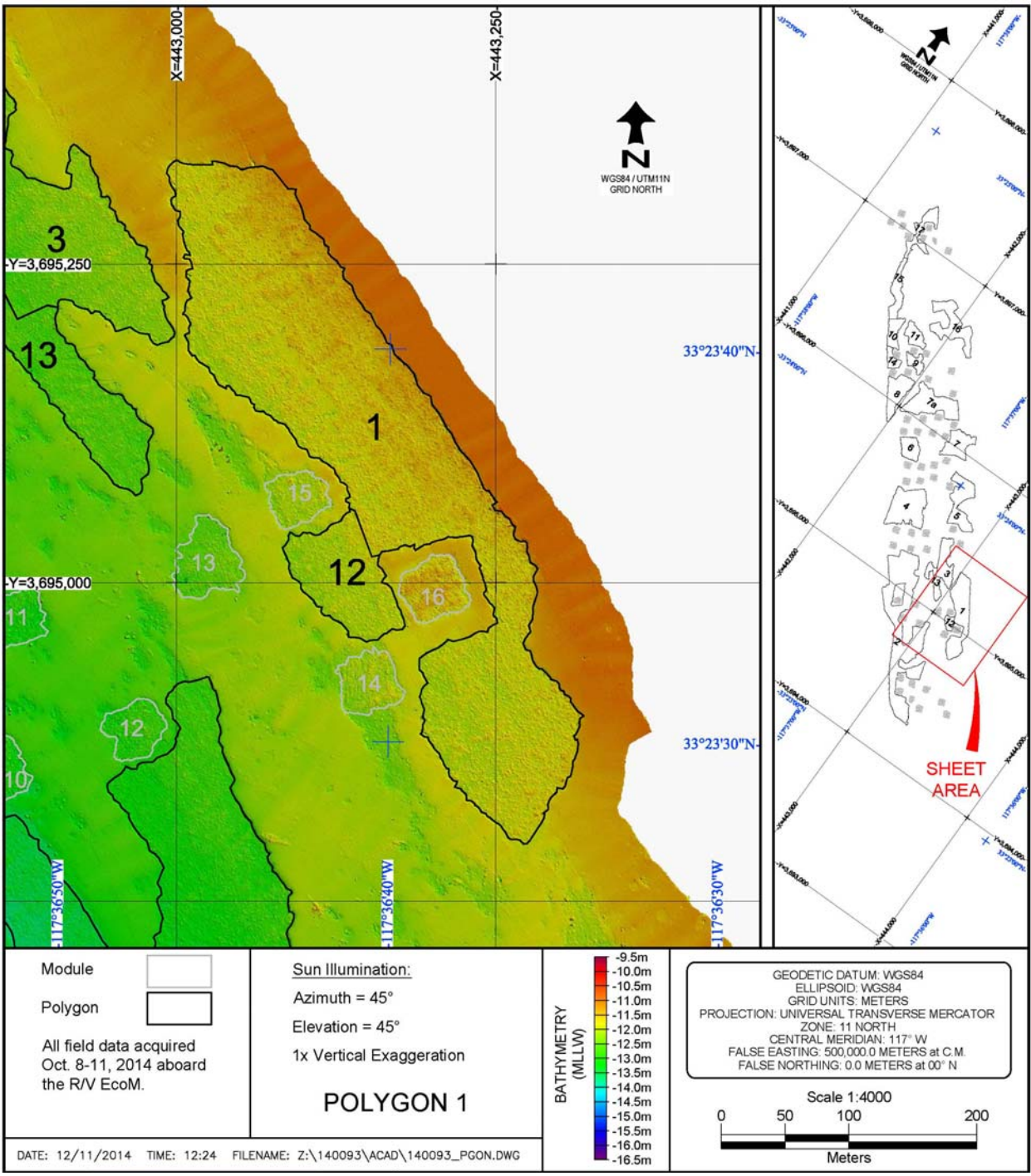


Figure D-2. Polygon 1 boundary from bathymetric data interpretation (October 2014 multibeam survey).

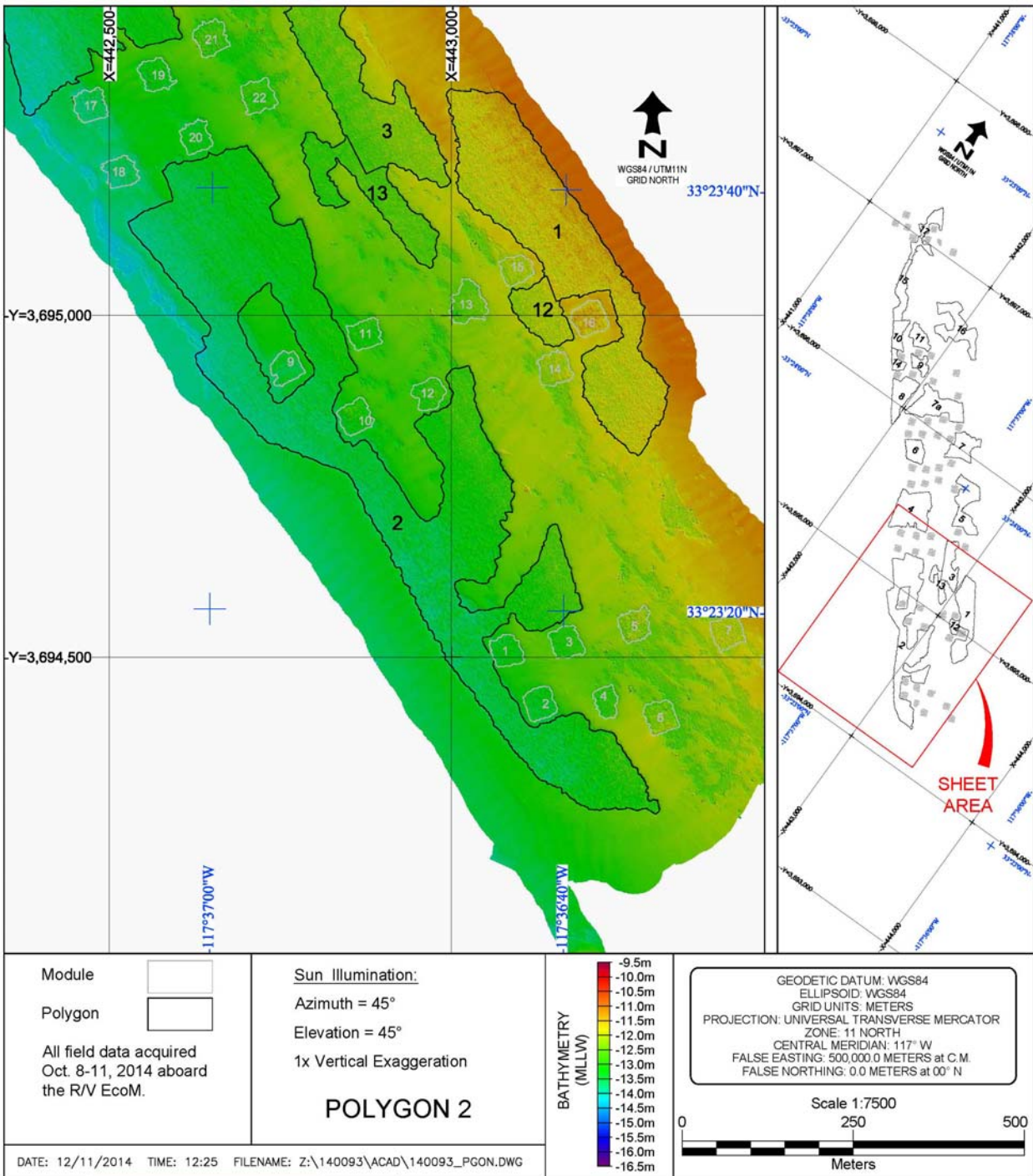


Figure D-3. Polygon 2 boundary from bathymetric data interpretation (October 2014 multibeam survey).



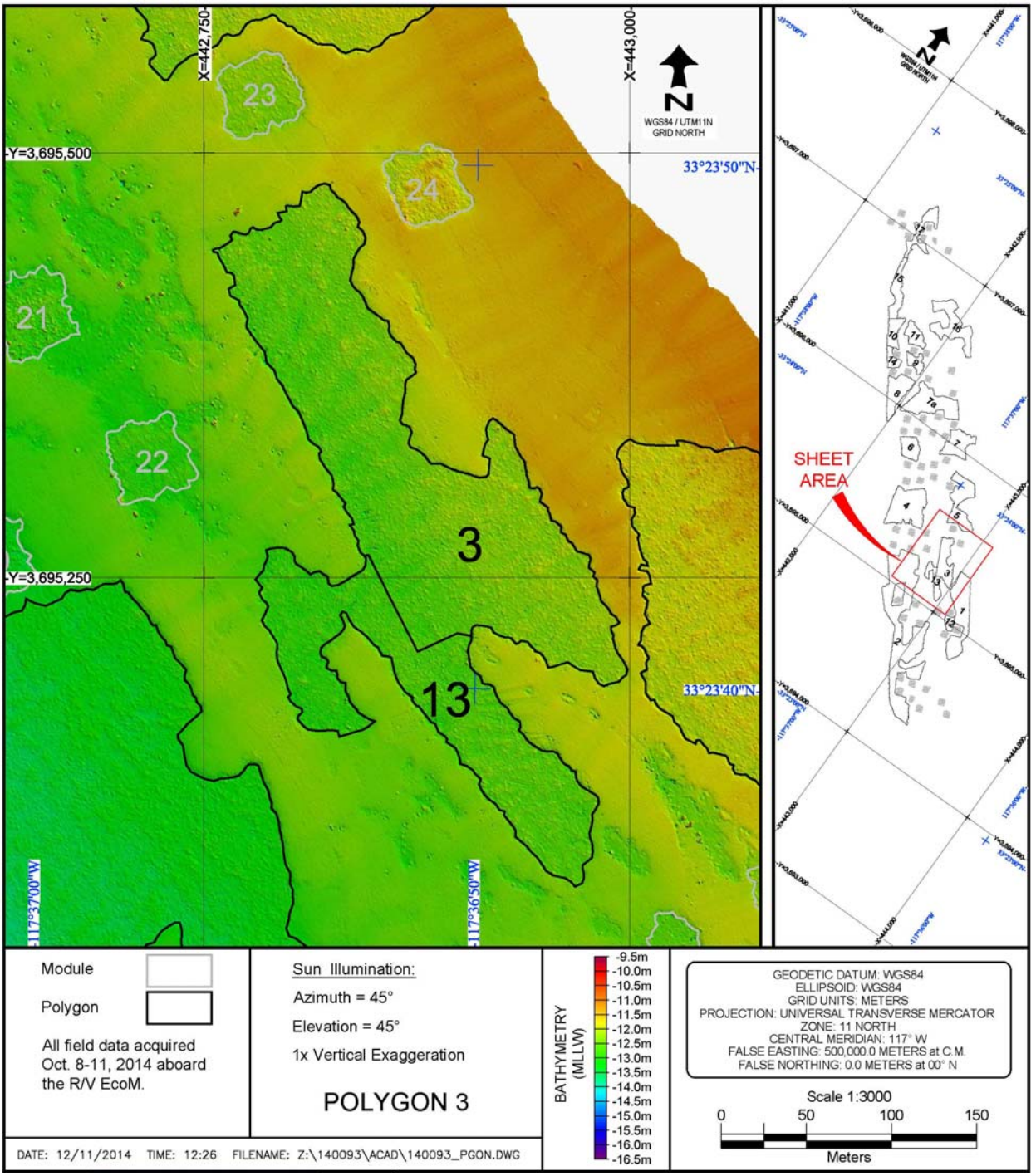


Figure D-4. Polygon 3 boundary from bathymetric data interpretation (October 2014 multibeam survey).

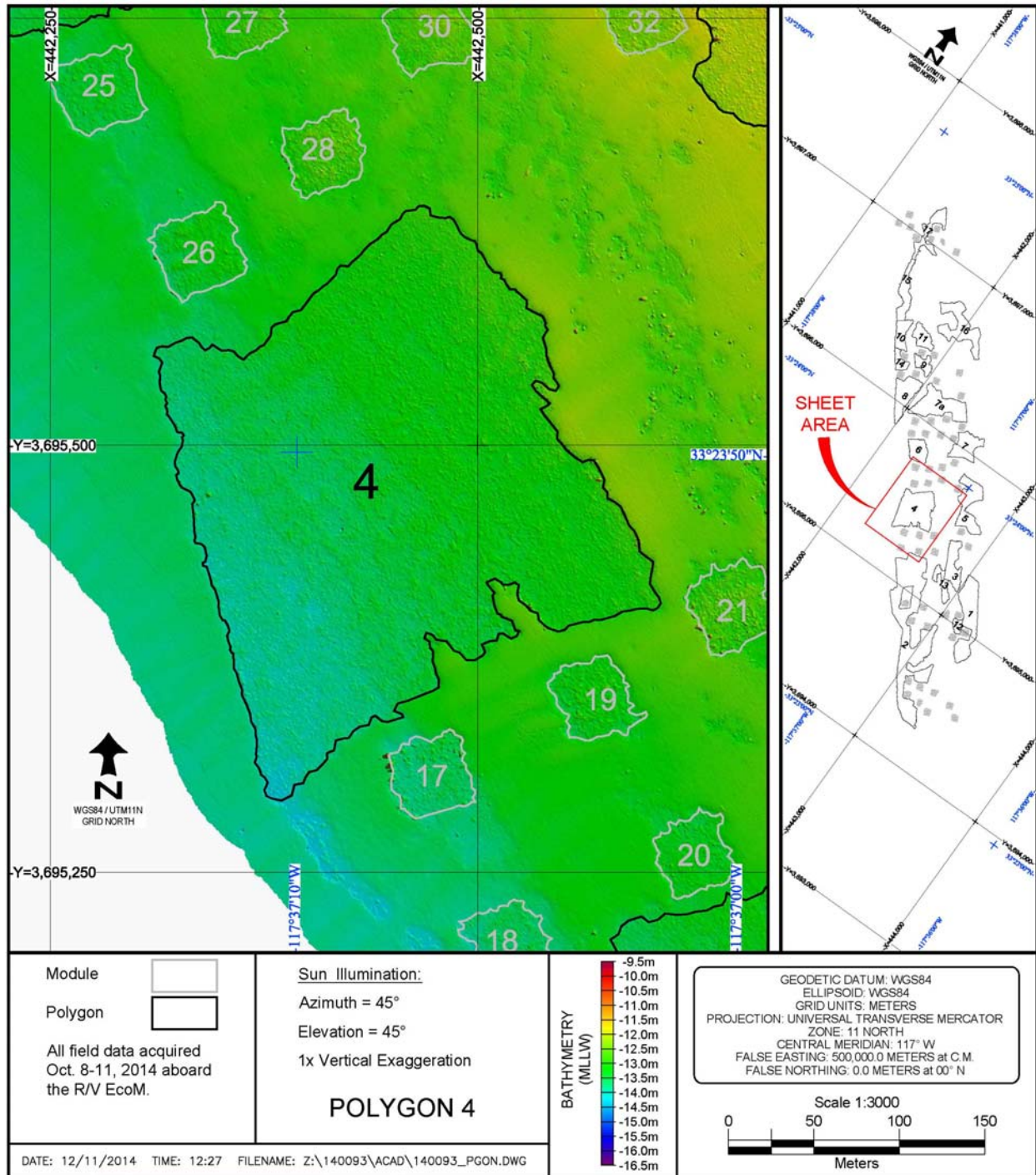


Figure D-5. Polygon 4 boundary from bathymetric data interpretation (October 2014 multibeam survey).

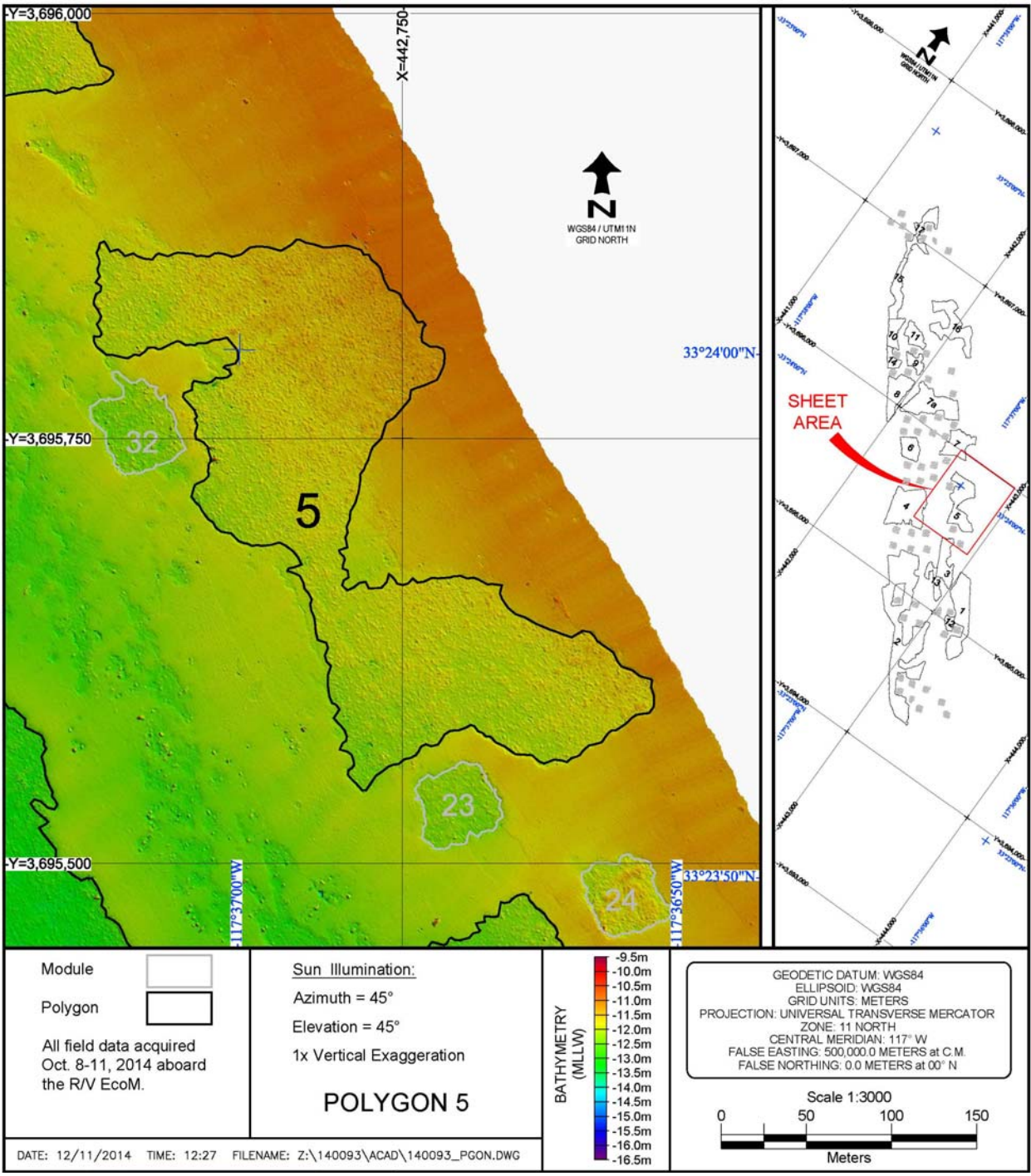


Figure D-6. Polygon 5 boundary from bathymetric data interpretation (October 2014 multibeam survey).

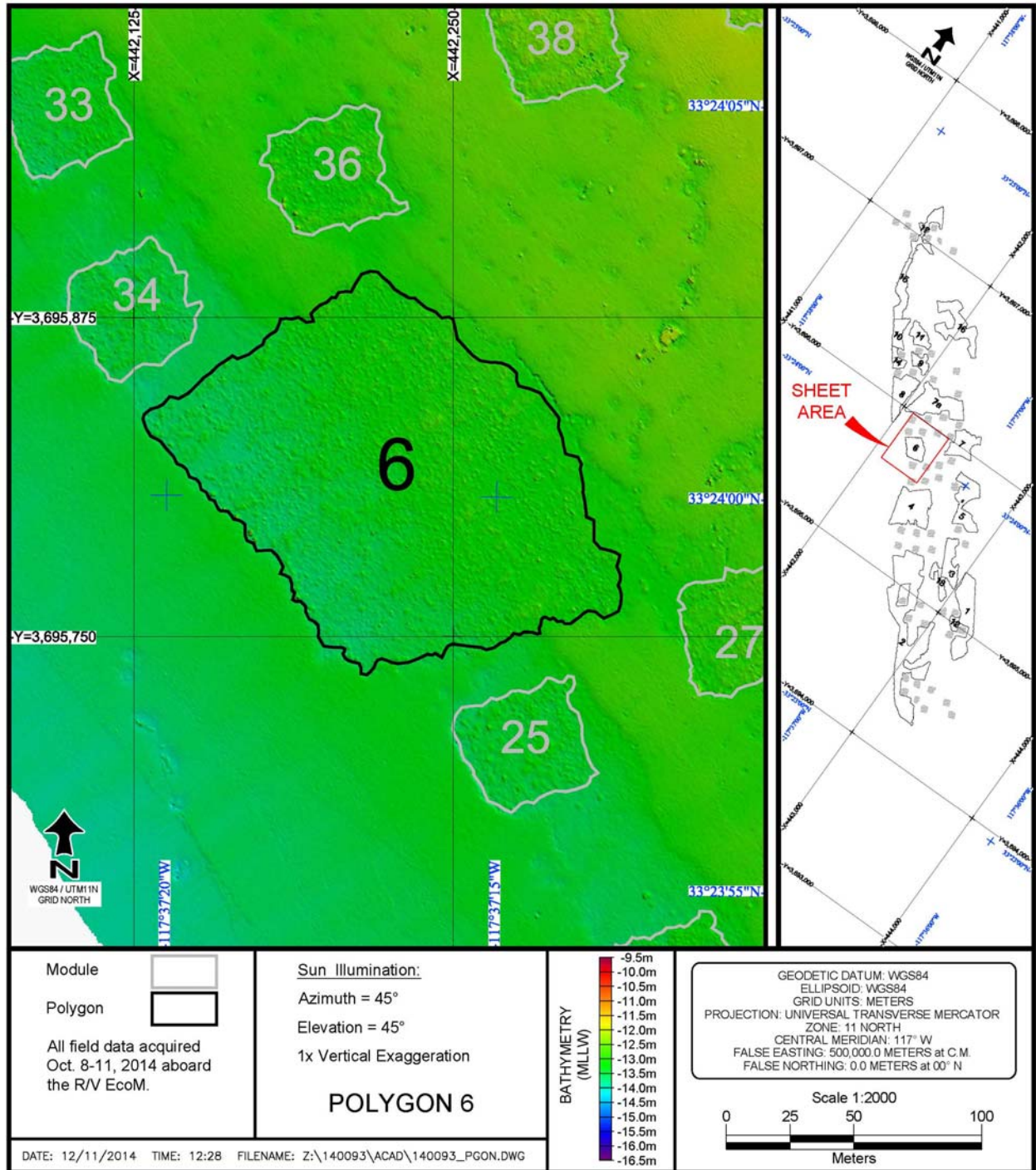


Figure D-7. Polygon 6 boundary from bathymetric data interpretation (October 2014 multibeam survey).

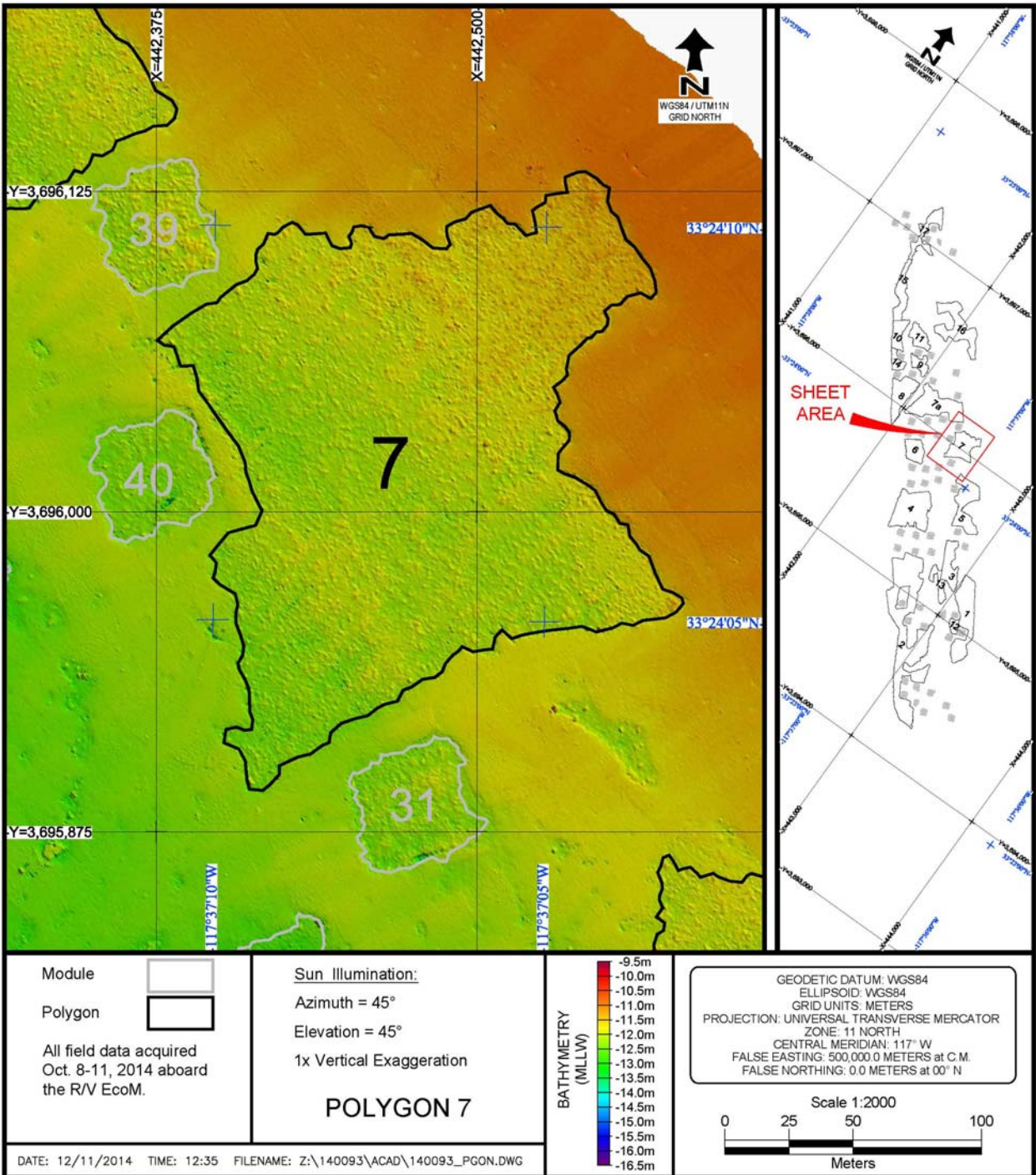


Figure D-8. Polygon 7 boundary from bathymetric data interpretation (October 2014 multibeam survey).

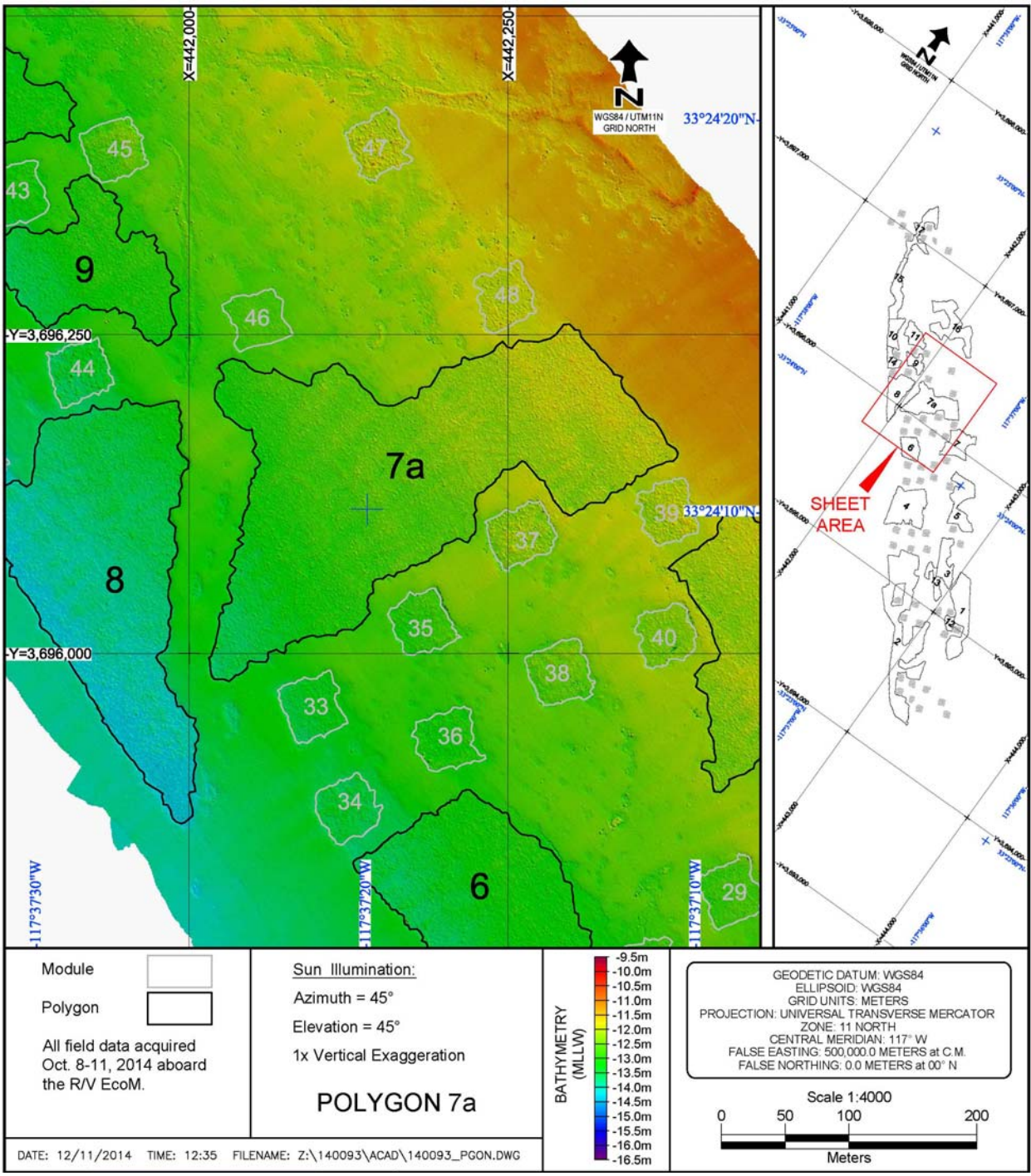


Figure D-9. Polygon 7a boundary from bathymetric data interpretation (October 2014 multibeam survey).

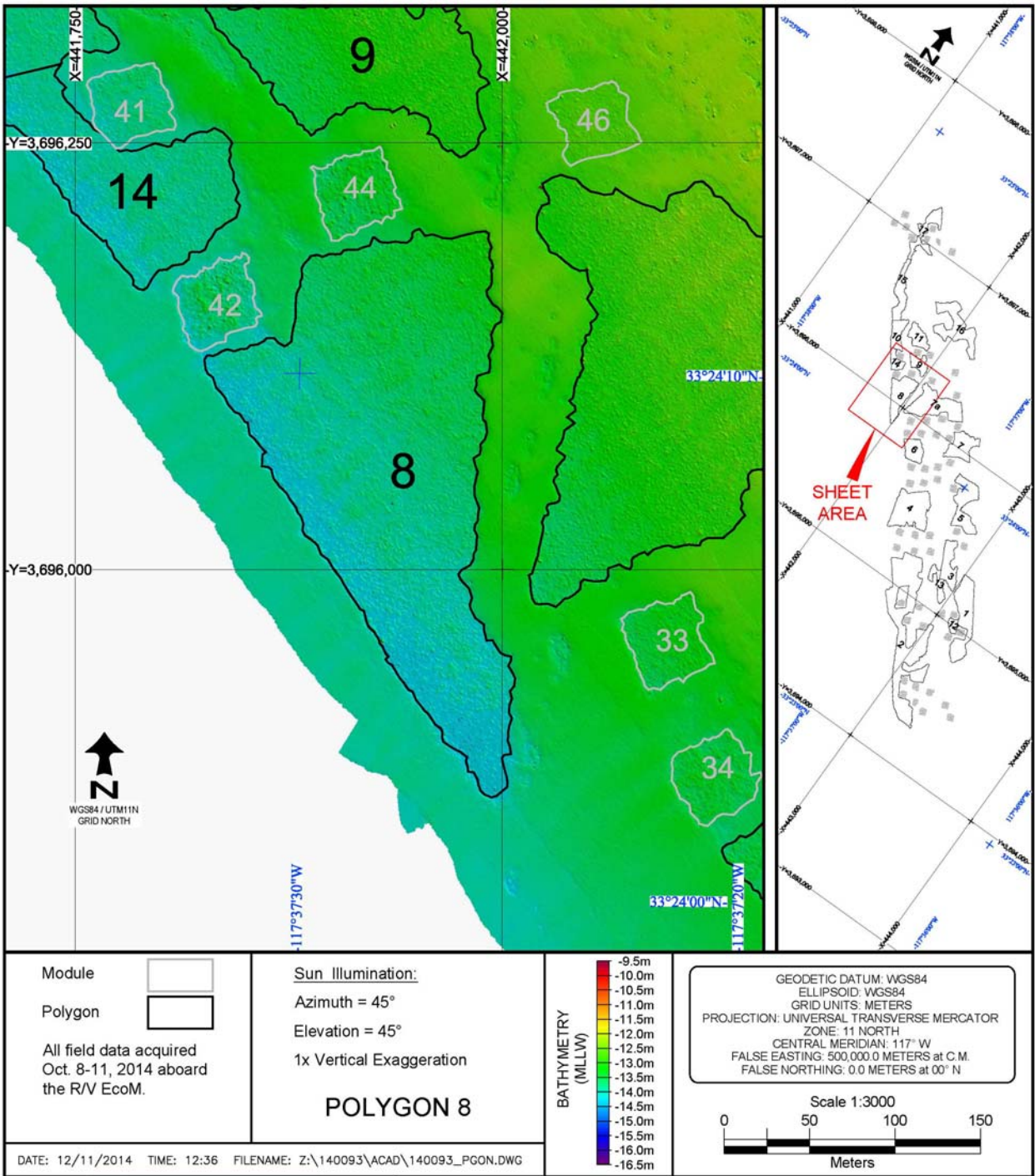


Figure D-10. Polygon 8 boundary from bathymetric data interpretation (October 2014 multibeam survey).

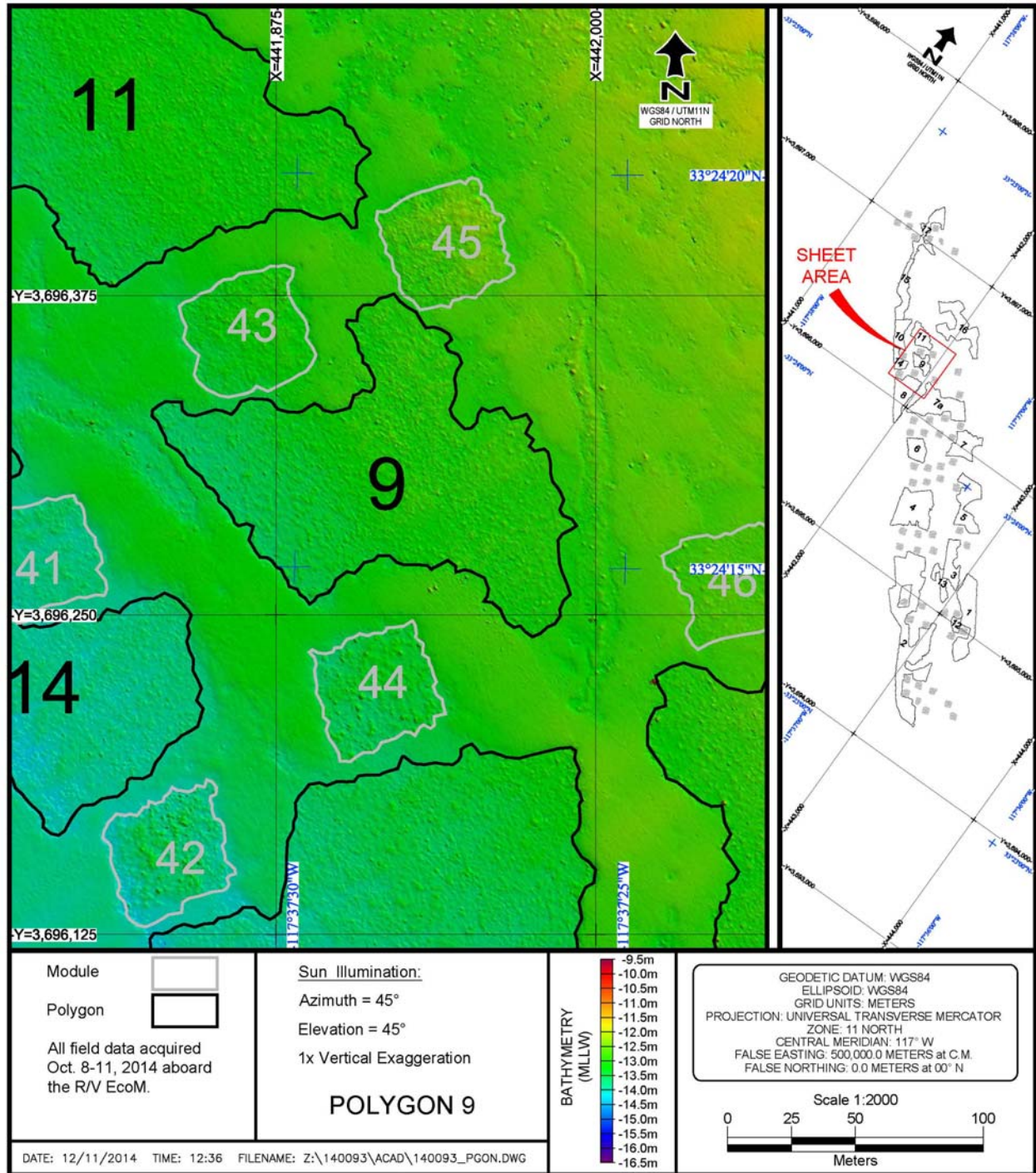


Figure D-11. Polygon 9 boundary from bathymetric data interpretation (October 2014 multibeam survey).



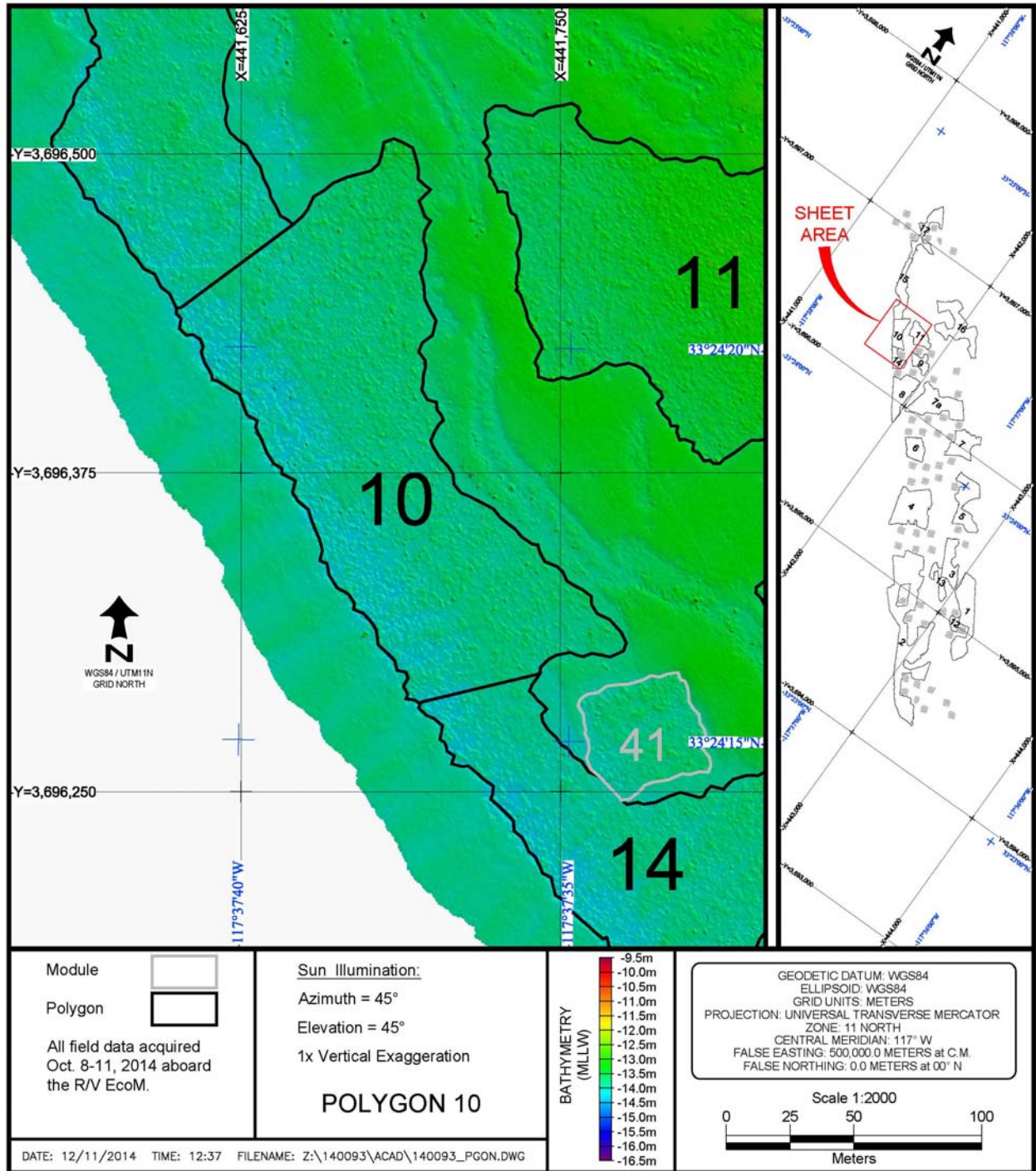


Figure D-12. Polygon 10 boundary from bathymetric data interpretation (October 2014 multibeam survey).

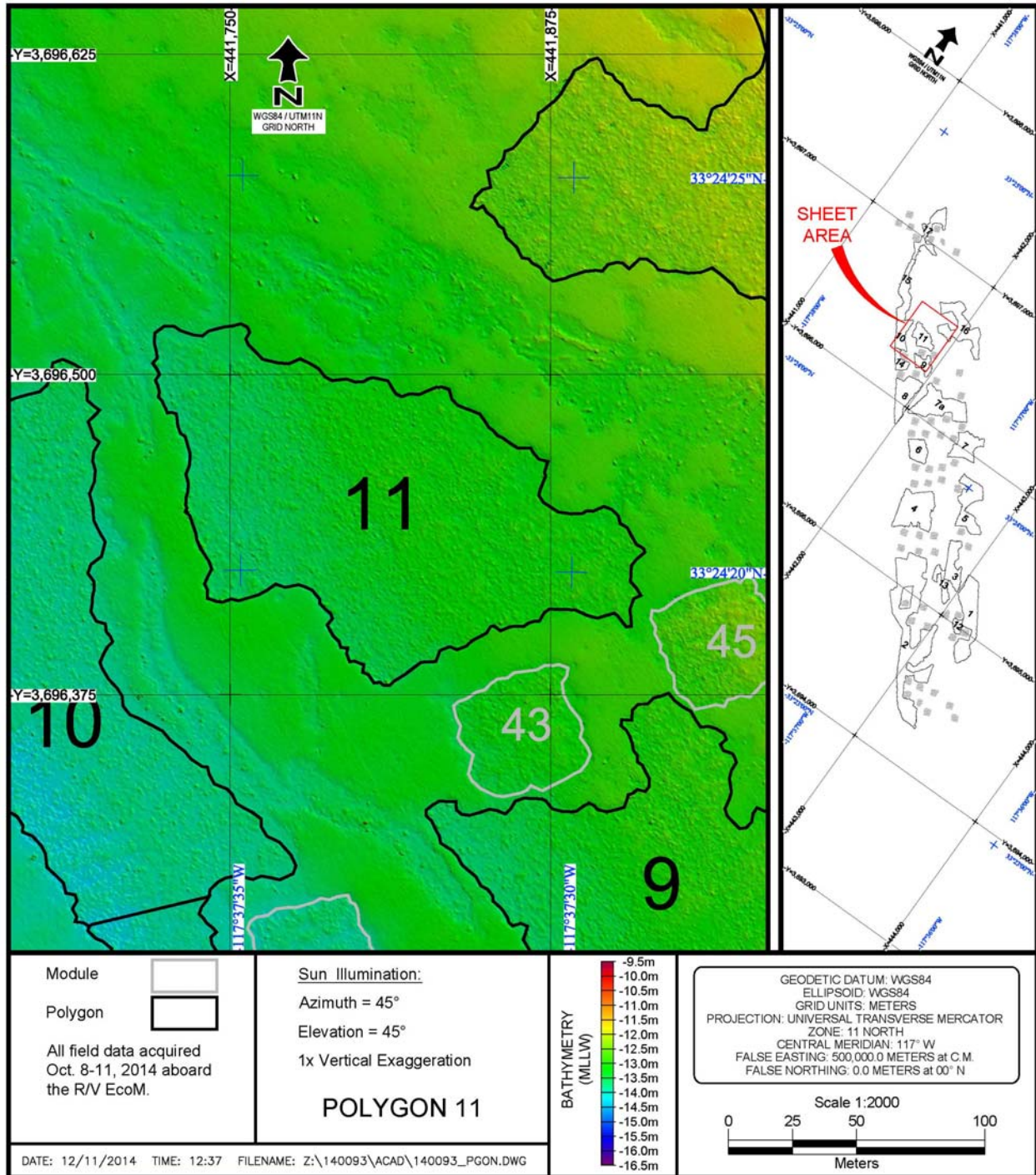


Figure D-13. Polygon 11 boundary from bathymetric data interpretation (October 2014 multibeam survey).

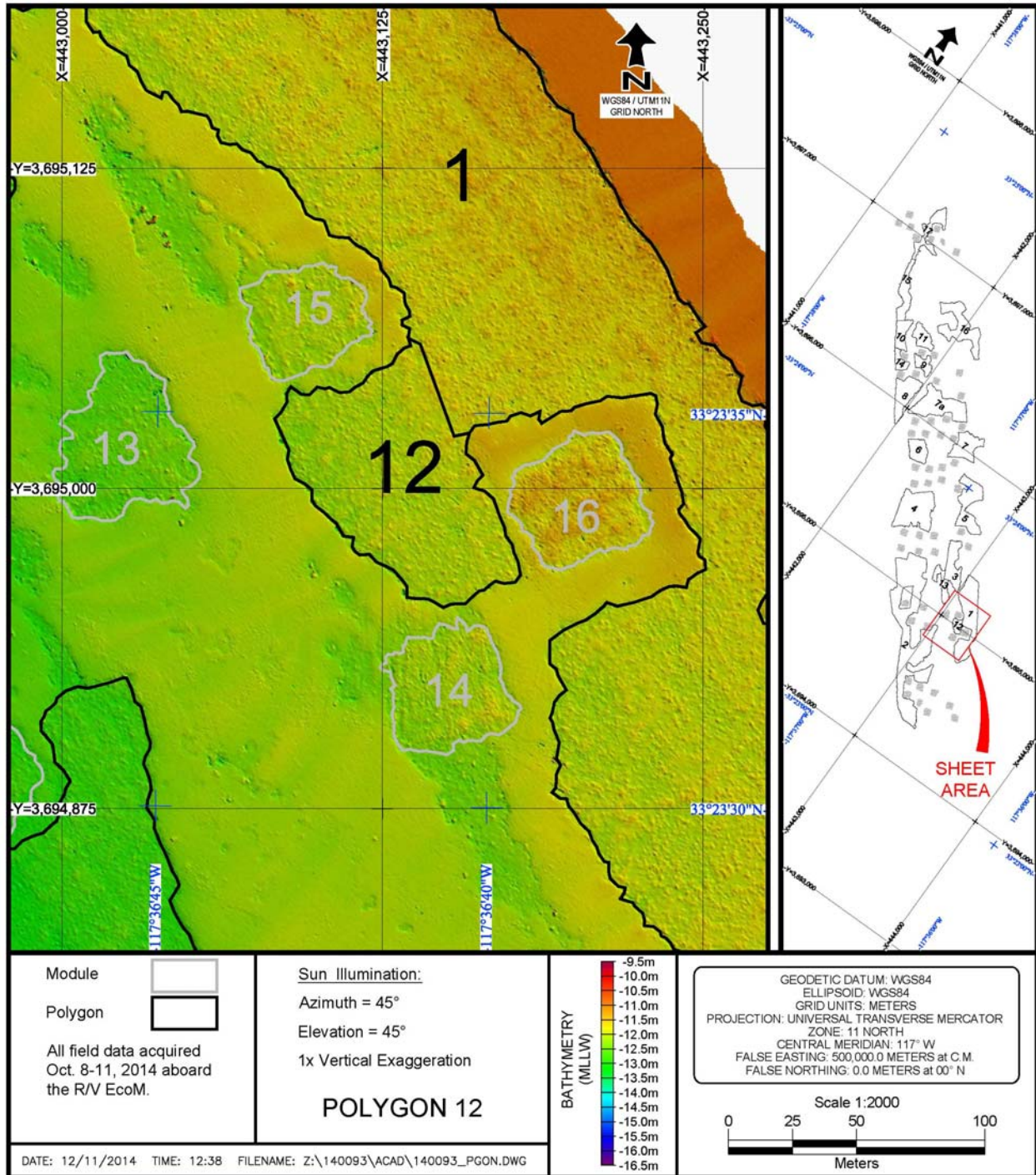


Figure D-14. Polygon 12 boundary from bathymetric data interpretation (October 2014 multibeam survey).

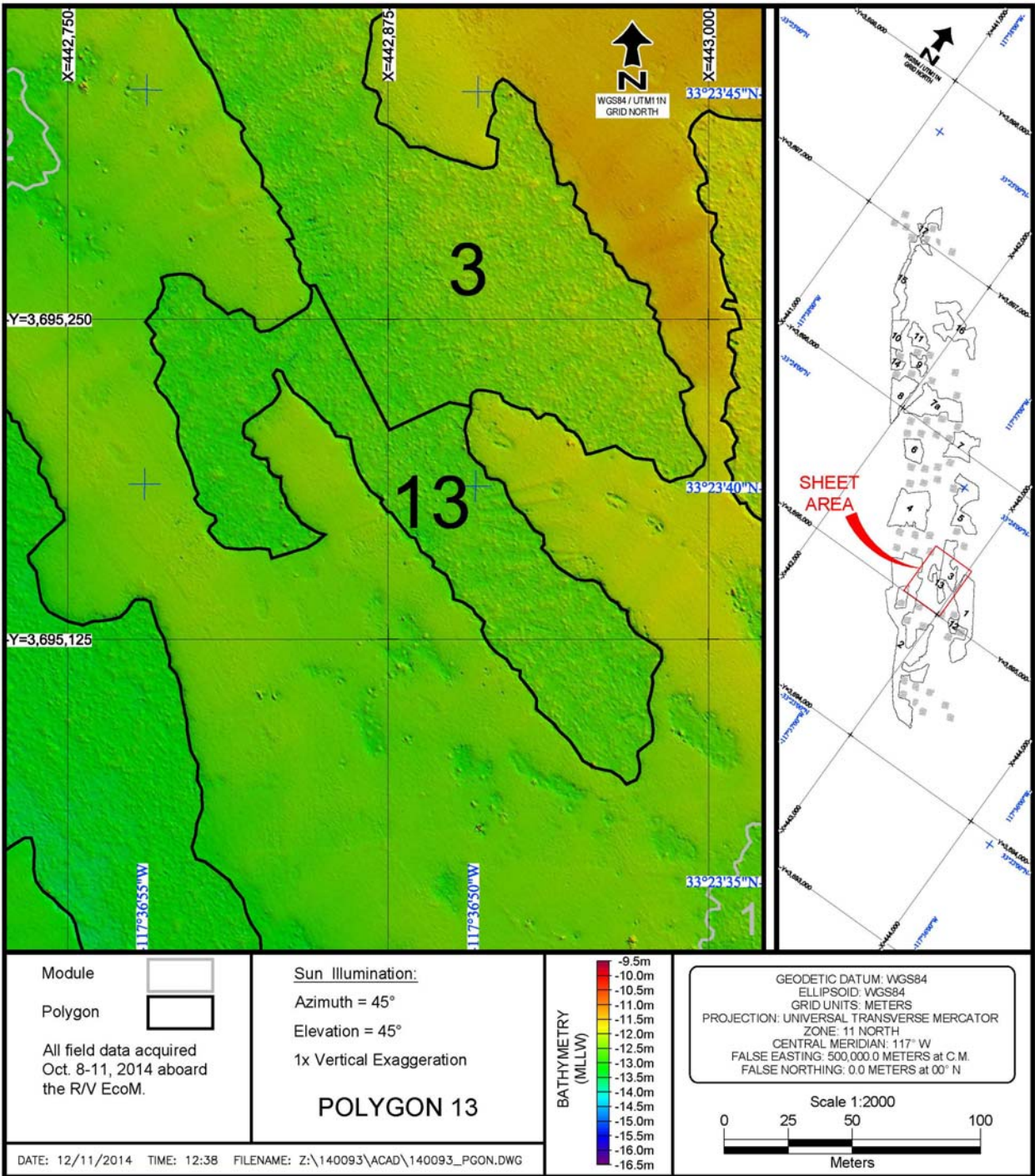


Figure D-15. Polygon 13 boundary from bathymetric data interpretation (October 2014 multibeam survey).

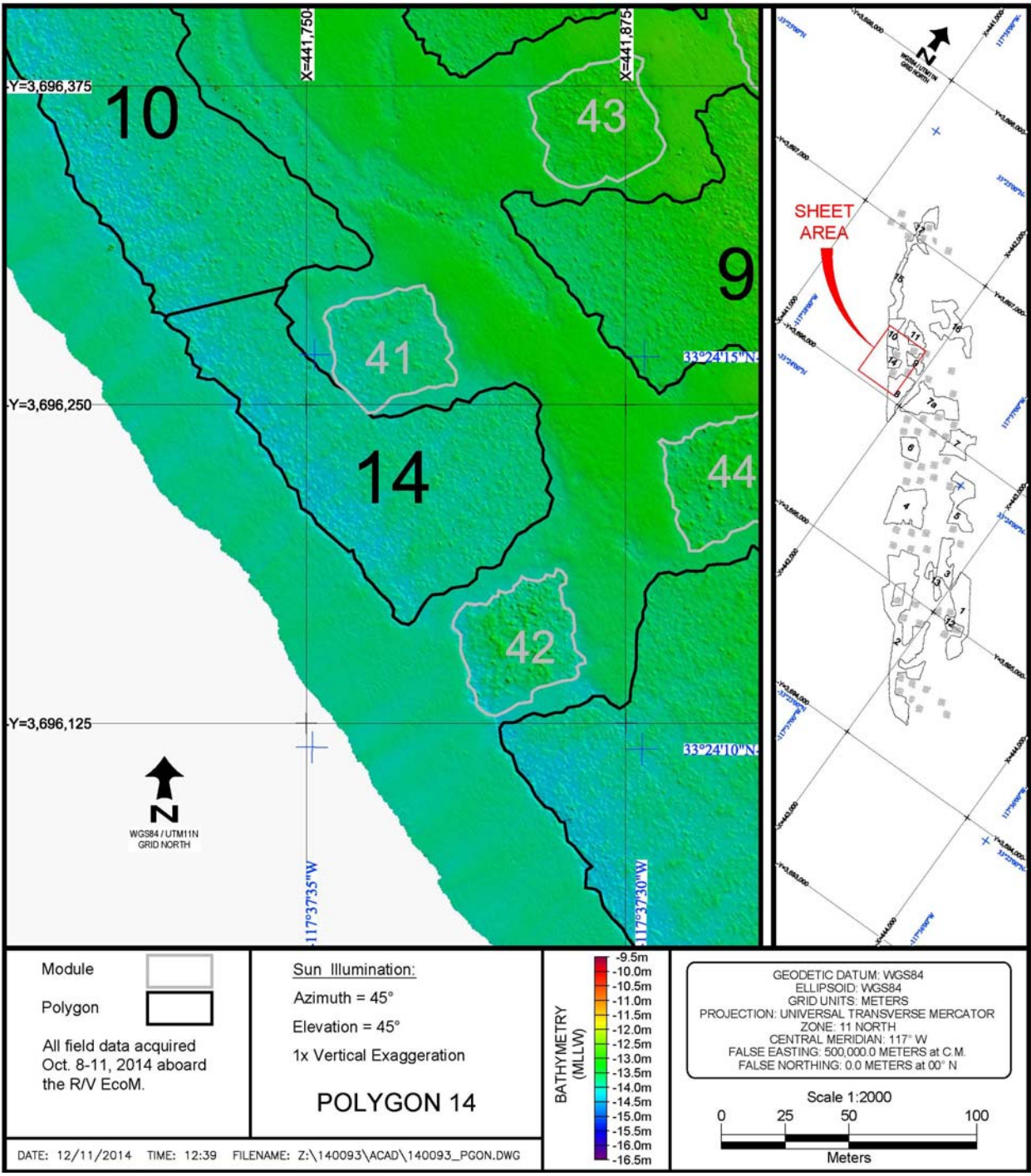


Figure D-16. Polygon 14 boundary from bathymetric data interpretation (October 2014 multibeam survey).

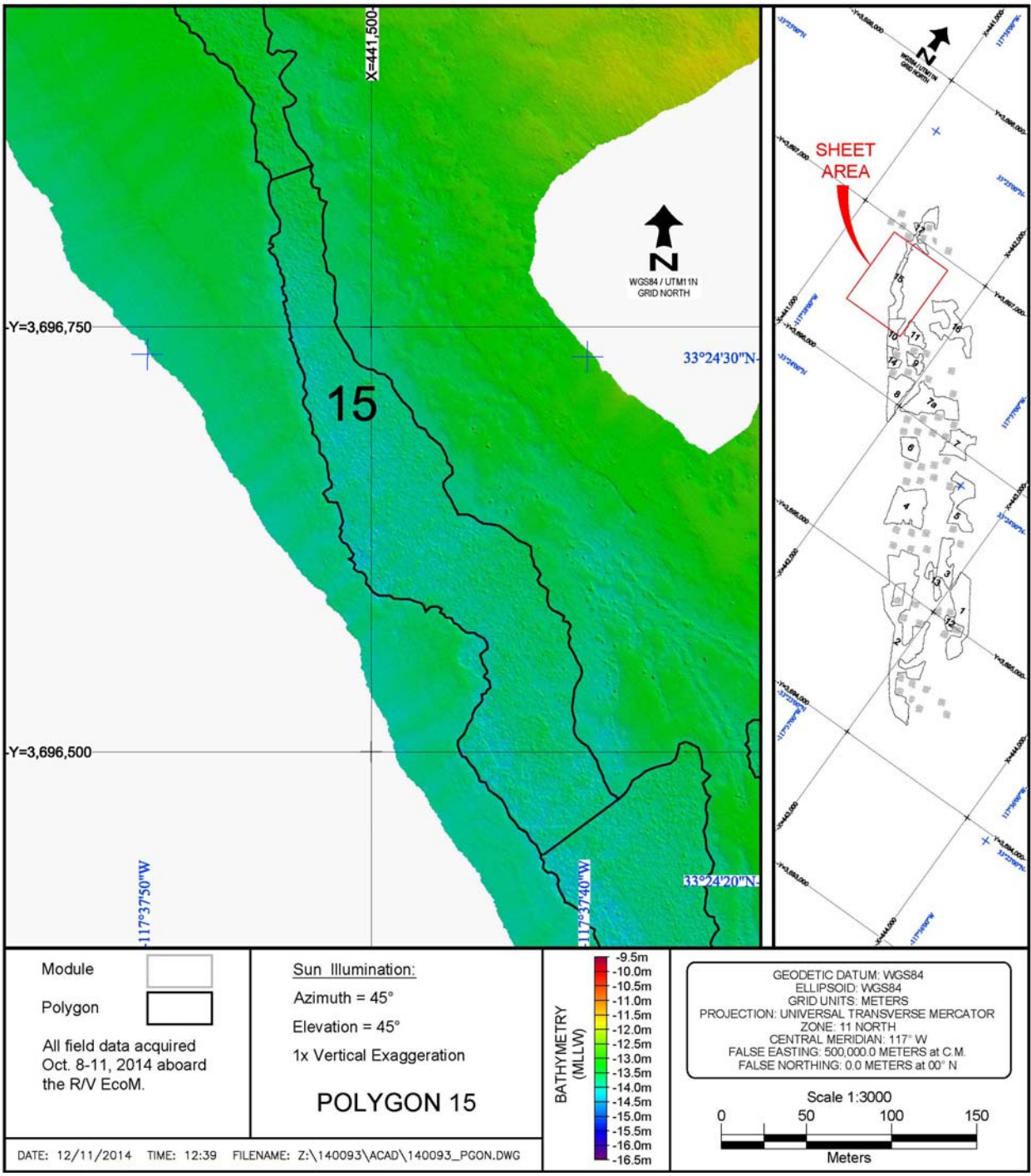


Figure D-17. Polygon 15 boundary from bathymetric data interpretation (October 2014 multibeam survey).

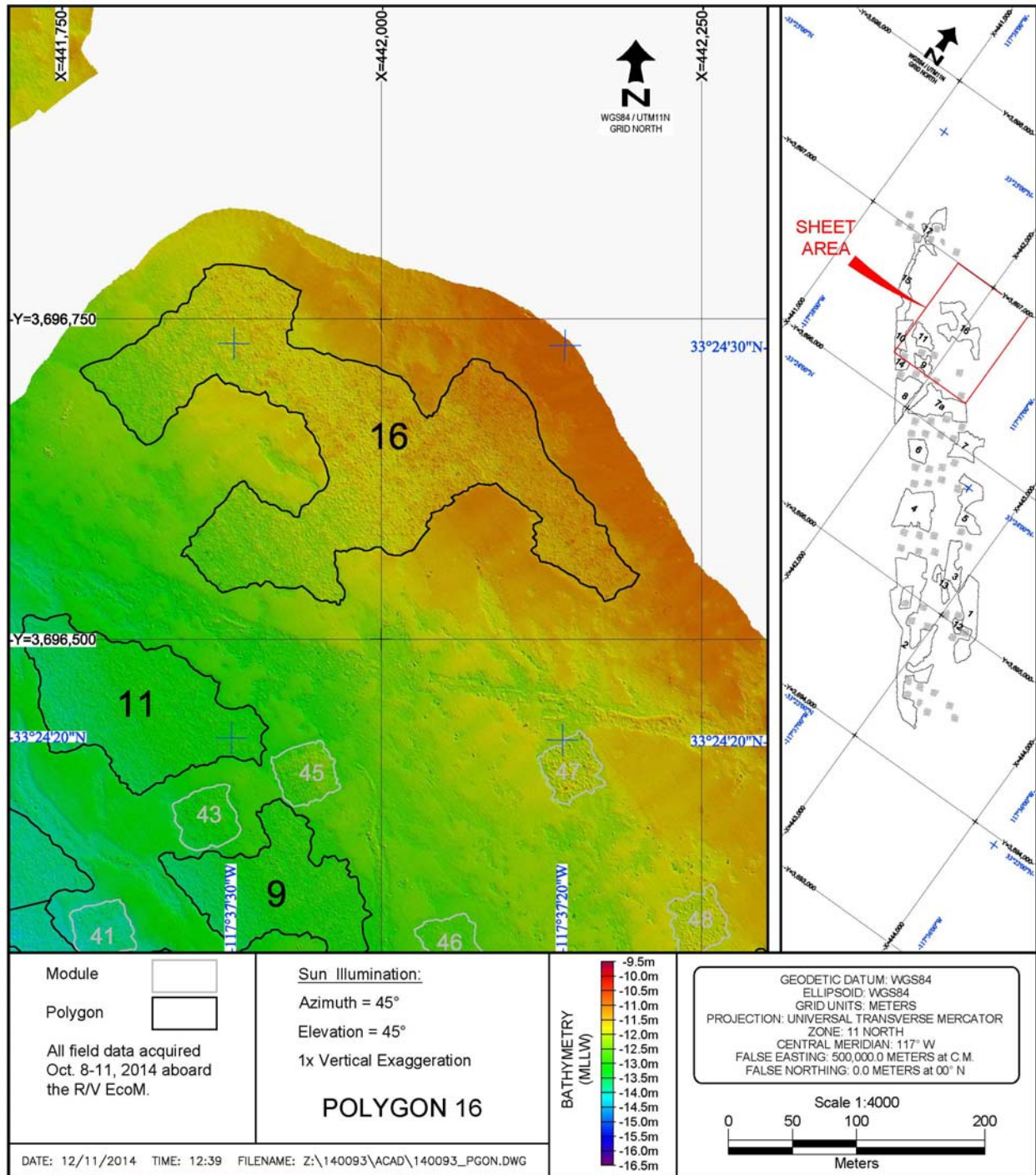


Figure D-18. Polygon 16 boundary from bathymetric data interpretation (October 2014 multibeam survey).

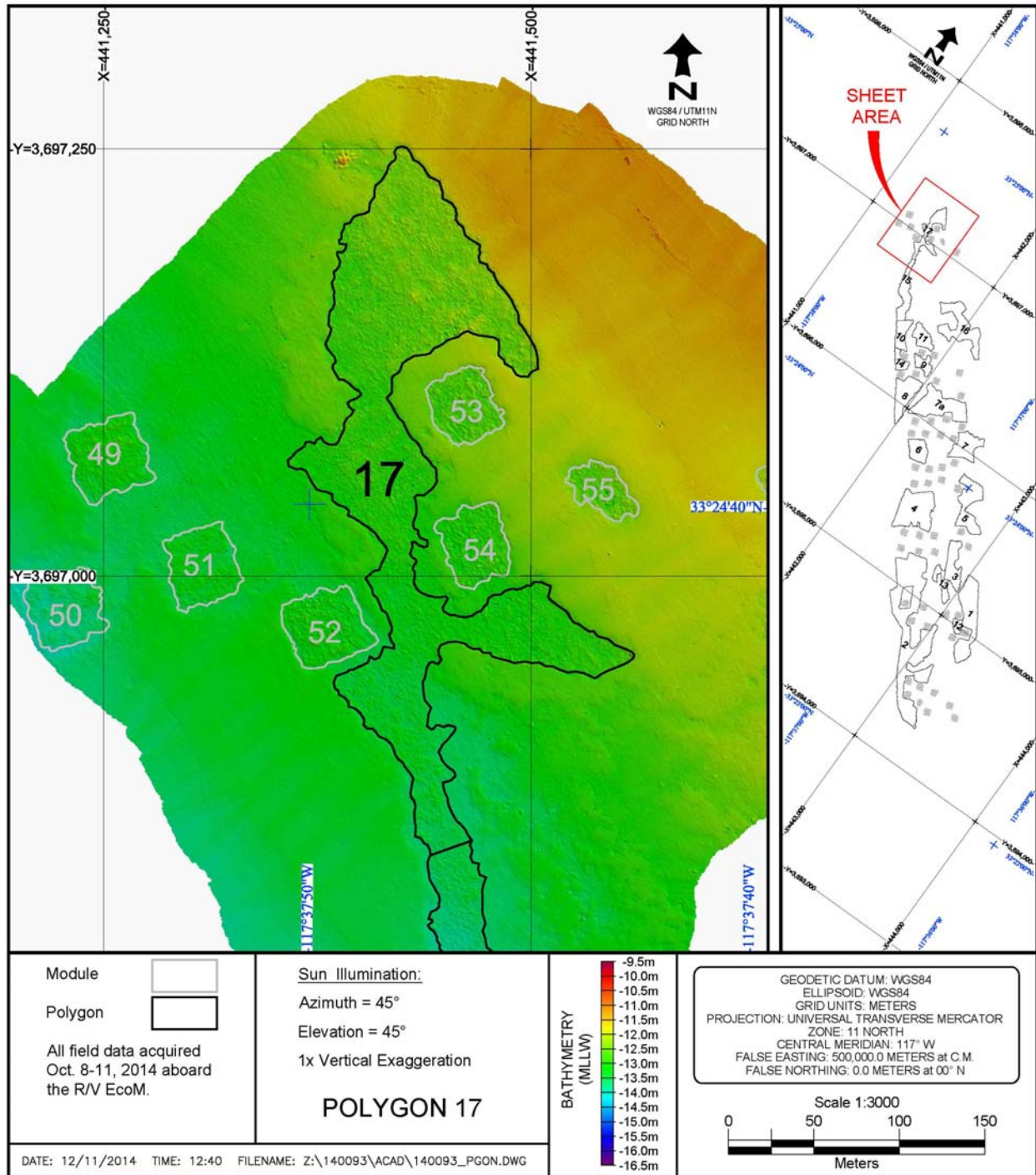


Figure D-19. Polygon 17 boundary from bathymetric data interpretation (October 2014 multibeam survey).



**APPENDIX E**

**SUMMARY OF SURVEY DATA IN LARGE-SCALE DRAWINGS**  
**(OCTOBER 2014 MULTIBEAM SURVEY)**