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Lake Michigan Offshore Reef Bathymetric Mapping

July 1, 2017 – June 30, 2018

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INHS Technical Report 2019 (04)

Prepared for Illinois Department of Natural Resources Division of Fisheries

Issue Date: 17 January 2019

Sponsor: Division of Fisheries, Illinois Department of Natural Resources Grant/Contract No:
Federal Aid Project F-65-R-32 and F-196-R-1

Unrestricted, for immediate release

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submitted to
Division of Fisheries, Illinois Department of Natural Resources
in fulfillment of the reporting requirements of
Federal Aid Projects F-65-R-32 and F-196-R-1

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January 2019

This study is conducted under a memorandum of understanding between the Illinois Department of Natural Resources and the Board of Trustees of the University of Illinois. The actual research is performed by the Illinois Natural History Survey, Prairie Research Institute. The project is supported through Federal Aid in Sport Fish Restoration by the U.S. Fish and Wildlife Service, the Illinois Department of Natural Resources, and the Illinois Natural History Survey. The form, content, and data interpretation are the responsibility of the University of Illinois and the Illinois Natural History Survey, and not the Illinois Department of Natural Resources.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES.....	3
INTRODUCTION.....	4
RESULTS & DISCUSSION.....	5
CONCLUSIONS	7
ACKNOWLEDGEMENTS	8
REFERENCES.....	8
TABLE 1.....	9
FIGURES.....	10

LIST OF TABLES AND FIGURES

Table 1. Summary of bathymetric sampling and mean daily water levels at North, Waukegan East, Waukegan South, Lake Bluff, and Wilmette reef survey areas during 2017. *Survey line km for Lake Bluff Reef is an estimate based on preliminary data collected during the project period.....9

FIGURES

Figure 1. Location map illustrating survey coverage of North, Waukegan East, Waukegan South, and Wilmette reefs during 2017 as well as extended coverage of the Waukegan Reef Complex from surveys conducted during 2011.....10

Figure 2. Plots of predicted versus measured water depths from survey areas over a) North, b) Waukegan East, c) Waukegan South, and d) Wilmette reefs as well as e) Waukegan Reef Complex.....11

Figure 3. Display of survey tracks overlaying interpolated 1 m contour lines at a) North reef and b) Waukegan East survey areas. Gray dotted lines denote position of vessel during sampling and thin black lines denote 1 m contours.....12

Figure 4. Display of survey tracks overlaying interpolated 1 m contour lines at a) Waukegan South and b) Wilmette reefs. Gray dotted lines denote position of vessel during sampling and thin black lines denote 1 m contours.....13

Figure 5. Display of survey tracks overlaying interpolated 1 m contour lines at the Waukegan Reef Complex. Gray dotted lines denote position of vessel during 2017 sampling, light blue dotted lines denote position of vessel during 2011 sampling, and thin black lines denote 1 m contour lines.....14

Figure 6. Map of North Reef with interpolated 1 m contour lines.....15

Figure 7. Map of North Reef with 1 m contour lines and incrementing 1 m depth color scale.....16

Figure 8. A 3-dimensional bathymetric map of North Reef (1 m contours)17

Figure 9. Map of Waukegan East survey area with interpolated 1 m contour lines.....18

Figure 10. Map of Waukegan East survey area with 1 m contour lines and incrementing 1m depth color scale.....19

Figure 11. A 3-dimensional bathymetric map of Waukegan East survey area (1 m contours)...20

Figure 12. Map of Waukegan South Reef with interpolated 1 m contour lines.....21

Figure 13. Map of Waukegan South Reef with 1 m contour lines and incrementing 1 m depth color scale.....22

Figure 14. A 3-dimensional bathymetric map of Waukegan South Reef (1 m contours).....23

Figure 15. Map of the Waukegan Reef Complex with interpolated 1 m contour lines.....24

Figure 16. Map of the Waukegan Reef Complex with 1 m contour lines and incrementing 1 m depth color scale.....25

Figure 17. A 3-dimensional bathymetric map of the Waukegan Reef Complex (1 m contours).26

Figure 18. Map of Wilmette Reef with interpolated 1 m contour lines.....27

Figure 19. Map of Wilmette Reef with 1 m contour lines and incrementing 1 m depth color scale.....28

Figure 20. A 3-dimensional bathymetric map of Wilmette Reef (1 m contours)29

INTRODUCTION

The return of self-sustaining lake trout populations in Lake Michigan is a long-standing rehabilitation goal of the Illinois Department of Natural Resources (IDNR) Division of Fisheries and the Great Lakes Fishery Commission. Annual stocking of juvenile lake trout at sites lakewide since 1965 has largely resulted in minimal success until recently. Patterson et al. (2016) evaluated Illinois's fall spawning assessment data and found similar abundances of mature lake trout in recent years at unstocked Waukegan Reef compared to Julian's Reef, the only site within southern management units stocked annually. This result, along with findings of high relative catches (~50%) of unmarked 'wild' lake trout adults at both reefs in recent years has prompted the need for fall spawning assessments at additional offshore reefs in Illinois waters of Lake Michigan.

Identifying and monitoring previously unsampled lake trout spawning sites is critical for developing effective stocking and harvest regulations for this important, native sport fish. Attaining geo-referenced bathymetry data and developing accurate maps of potential spawning reefs is an essential next step facilitating the planning and implementation of lake trout spawning assessments at unsampled reefs in Illinois. Thus, the objectives of this project were to 1) document the location and extent, 2) collect bathymetry data, and 3) create contour and three-dimensional bathymetric maps of five offshore reefs in Illinois' portion of Lake Michigan. Results of this project will aid IDNR in measuring the extent of lake trout rehabilitation success and identify important potential spawning habitats that may be targeted for future protection and/or enhancement.

METHODS

Bathymetry data were collected and mapped at four offshore reefs in Illinois waters of Lake Michigan: 1) North Reef, 2) unnamed reef east of Waukegan Reef (we refer to as Waukegan East), Waukegan South Reef, and Wilmette Reef (Figure 1). Additionally, 8 survey lines ranging from 6.6 - 7.0 km in length were completed at Lake Bluff Reef on August 30, 2017. However, this bathymetric survey was not completed during the project period due to staff turnover, inclement weather, and boat engine problems. Sampling and map development for Lake Bluff Reef will continue on grant F-196 R-2.

Previous work by Collinson et al. (1979), Holm et al. (1987) and Fucciolo (1993) as well as observations from past IDNR sampling events were used to approximate the location of each reef. While the location of Waukegan South and Wilmette reefs are well established (Collinson et al. 1979; Holm et al. 1987; Redman et al., 2017), there were discrepancies in the descriptions of North, Waukegan East, and Lake Bluff reefs. During past IDNR sampling efforts, North Reef was not found in the location illustrated by Holm et al. (1987) and Fucciolo (1993), but structure was noted approximately 3 km to the west. Additionally, the location and extent of Waukegan East and Lake Bluff reefs differ in reports by Holm et al. (1987) and Fucciolo (1993). Given these inconsistencies, we conducted reconnaissance bathymetric sampling within the reported vicinity of these reefs using a set of parallel survey lines spaced 200 m apart. Once the location and extent of a given reef was determined, then additional survey lines were placed within and next to recon lines until a continuous grid of parallel survey lines spaced approximately 100 m apart was achieved. One exception was the Waukegan East survey area where data was only

collected along survey lines spaced 200 m apart in an effort to increase the chance of finding a reef structure by covering more lake bottom. Within all survey grids, data were also collected along perpendicular or intersecting survey lines to increase sample coverage as time and resources allowed. Survey lines were plotted prior to a sampling event using SonarWiz5 and Maptech Offshore Navigator software. The resulting survey grids were used for vessel navigation during data collection.

A single beam FURUNO echo sounder LS-6100 (200 kHz) with a thru-hull transducer and Standard Horizon CP180 GPS installed onboard the RV Sculpin was used to collect bathymetry data. Data points included water depth to 0.1 m and vessel position (latitude and longitude) and were generated every 2-3 seconds along a set of predetermined survey lines. Vessel speed during surveys was approximately 2.8 m/s and a data point was recorded every 5.6 - 8.4 m along each survey line. Post-sampling, data from the nearest NOAA water level gauging stations (Calumet Harbor, IL and Milwaukee, WI) were used to correct bathymetric data for changing water surface elevations (relative to chart datum; 176.0 m), because surveys were conducted on multiple dates. Using data from both gauging stations, daily average water level was calculated (<https://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels>) and used to approximate the water level during surveys on a given date (Table 1).

Point data for each reef were then imported into ESRI ArcMap and distributions of measured depth were examined to identify outliers. Extraneous data, which we refer to as that collected while approaching or leaving a survey grid area, and identified outliers were removed to limit the influence of non-representative points during geostatistical grid creation. Upon normalization, Ordinary Kriging was used to produce a continuous geostatistical layer for each reef. Predicted depths were compared to measured values to assess the accuracy of depth predictions at unmeasured locations ($R^2 > 0.99$; Figure 2). Then, using each geostatistical layer, two and three-dimensional surfaces and contour maps were produced for each reef.

Additional work completed during the project period included development of an updated, more comprehensive bathymetric map of the Waukegan Reef complex. Following the methodology previously outlined for each individual reef, point data from bathymetric surveys conducted during 2011 at Waukegan North and Waukegan South reefs (Redman et al., 2017) were combined with that collected at Waukegan East and additional portions of Waukegan South Reef during this project (2017). Total survey coverage of this area from 2011 and 2017 data collection is shown in Figures 1 and 5. Two-dimensional maps of North, Waukegan Reef complex, Julian's and Wilmette reefs along with a project narrative were also submitted for inclusion as a new "Fish Habitat" Tab on the Lake Michigan portion of IFISHILLINOIS.org, which can be viewed at <https://www.ifishillinois.org/lmich/index.php>.

RESULTS & DISCUSSION

North Reef

Reconnaissance bathymetric sampling within the North Reef survey grid revealed topographical prominences approximately 3 km west of those illustrated by Holm et al. (1987) and Fucciolo (1993), a location similar to that more recently described by IDNR (S. Robillard, personal communication). Thus, further bathymetric sampling for North Reef was constrained to this area. During July 2017, 9,607 individual data points were collected along 60.3-line km of lake bed approximately 12 km northeast of Waukegan South Harbor (Table 1; Figure 3a). After

removing 11 outliers and extraneous data, 8,301 data points were used to produce a 4.8 km² bathymetric surface ranging in water depth from 31.4 - 47.2 m.

North reef lies in approximately 37 m of water on the western side and 41 m on the eastern side with 31-32 m depths over a flat crest (-87.695093, 42.416419, midpoint of shallowest depths; Figure 6). The western side of the reef is characterized by a large area with gradually decreasing water depths to the east where the reef rises to a more prominent mound. The steepest slopes were observed along the northeastern side of this mound where a secondary peak was detected rising 3-4 meters from surrounding depths of 37-38 meters (Figures 7 and 8). Such a sharp rise in water depth is unusual in this region but was detected while sampling along a North-South oriented survey line on July 11, 2017 and then again almost 2 hours later along an East-West oriented line. Based on the raw data, these shallow depths were recorded over a distance of about 15-30 meters (-87.6905, 42.41735). More work is needed to determine whether this peak in water depth is an accurate representation of the lake bottom or if we were detecting an object or school of fish rising from the bottom. Other interesting features include a small mound with a relief of 2 m to the southeast of the main reef and an oblong depression in 37 m of water within the southwestern corner of the survey area. Further work should aim to document whether more structure exists west of the area surveyed to date.

Waukegan East

Initial reconnaissance sampling in the Waukegan East survey area revealed no topographical prominences; thus, sampling was expanded to the east and west in an effort to locate a reef or hard bottom structure (survey lines spaced 200 m apart). During August 2017, 12,509 individual data points were collected along 90.7-line km of lake bed approximately 17 km east of Waukegan South Harbor (Table 1; Figure 3b). After removing 19 outliers and extraneous data, 12,229 data points were used to produce a 14.0 km² bathymetric surface ranging in water depth from 55.4 - 74.6 m.

In general, bathymetry was relatively gentle throughout this survey area (Figure 9). Water depth within the northern portion of the survey area gently and regularly increased from 61 m on the western side to 74 m on the eastern side. The shallowest depths (54 - 55 m) and most irregular bottom contours were recorded in the southwestern portion of the survey area (Figures 10 and 11), but no prominent reef-like features were detected. It is possible more structure exists to the south and may stretch in fragments or small structures to Waukegan South Reef. Additional sampling beyond the current survey area is needed to determine the full extent of potential habitat within this region.

Waukegan South Reef

During July and August 2017, 18,010 individual data points were collected along 110.6-line km of lake bed approximately 15 km southeast of Waukegan South Harbor (Table 1; Figure 4a). After removing 41 outliers and extraneous data, 17,129 data points were used to produce an 11.1 km² bathymetric surface ranging in water depth from 37.7 - 56.0 m.

This portion of Waukegan South Reef lies in about 41 m of water on the eastern side and 47 m of water on the western side (Figure 12). Similar to that found by Redman et al. (2017), Waukegan South Reef consisted of several small structures scattered from the northeastern to the southwestern portion of the survey area. Bounded by the 43 m contour line, the largest of these structures rose to a crest of 38 meters below the surface and encompassed an area of 0.21 km² (-87.622197, 42.312066, crest; Figures 13 and 14). Smaller features where the lakebed rose from

46 m to a minimum of 42 m below the surface were also recorded in the north central portion of the survey area. East of these features, the contour lines smoothed out as the lake bottom sloped off into depths of 50-55 m of water.

Waukegan Reef Complex

During 2011, bathymetric sampling was conducted over the entirety of Waukegan North Reef but was limited to a small area of interest at Waukegan South Reef due to budget and staff constraints (Redman et al., 2017; Figure 5). The expansion of sampling at Waukegan South Reef and addition of the Waukegan East region during the current project afforded the chance to create spatial overlap in bathymetric data from the three survey grids. As such, we added a post-proposal task to develop a continuous, comprehensive map of the Waukegan Reef complex by combining the data collected to date (Figures 5 and 15). A total of 43,366 discrete depth samples were collected in 2011 and 2017. Upon normalization and removal of outliers and extraneous data, 42,561 data points were used to produce a 33.9 km² continuous bathymetric surface ranging in water depth from 37.8 - 74.6 m.

Based on this collective work, Waukegan North Reef is the largest topographical prominence within the Waukegan Reef complex, with Waukegan South Reef consisting of smaller, lower relief structures (Figures 15, 16, and 17). The expansion of features mapped during this project likely adds to the catalog of suitable spawning habitat within the region. The presence of unclipped, “wild” lake trout, absence of stocking, and relative abundances similar to those at Julian’s Reef all suggest that the Waukegan Reef complex is a unique and valuable feature within the southern basin of Lake Michigan. Further work should aim to document the full extent of the reef by expanding mapping efforts adjacent to Waukegan North and South reefs and to quantify the amount of natural reproduction occurring within the Waukegan Reef complex.

Wilmette Reef

During September 2017, 13,726 individual data points were collected along 94.6-line km of lake bed approximately 10 km northeast of Wilmette, Illinois (Table 1; Figure 4b). After removing seven outliers and extraneous data, 13,203 data points used were to produce a 10.1 km² bathymetric surface ranging in water depth from 8.9 - 28.7 m.

The bathymetry changed dramatically within the central portion of the survey area where the crest of Wilmette Reef lies just 9 m below the surface (-87.591231, 42.136201; Figure 18). The lake bed surrounding Wilmette Reef is 18-20 m deep. Wilmette reef is oblong in shape and lies in a northeast to southwest orientation (Figure 19). The southwestern portion of the survey area proved interesting as well with a smaller feature bounded by the 16 m contour line rising to approximately 11 m below the surface (Figure 20). Further work should focus on expanding mapping efforts west of this survey area.

CONCLUSIONS

The maps developed during this project are the most recent, best-available descriptions of bottom-contours at North, the Waukegan Reef Complex and Wilmette reefs and have already aided IDNR’s efforts to evaluate lake trout spawning aggregations at additional unstocked reefs.

More specifically, bathymetry maps of North and Wilmette reefs were used to determine gill net placement during 2017 and 2018 lake trout spawning assessments and mature lake trout were caught at both reefs (per. comm. S. Robillard, IDNR). Bathymetric sampling and map development for Lake Bluff Reef will continue on grant F-196 R-2 and may also be used to further expand IDNR's lake trout spawning assessments.

Numerous reefs (e.g. Gumby Reef, R2) remain undescribed and unsampled in Illinois' waters. Given the recent catches of mature lake trout and the presence of unmarked 'wild' fish at multiple unstocked reefs (Waukegan, North, and Wilmette reefs) locating and mapping additional habitat in this region should be a priority. Future work should include bathymetric and side scan sonar surveys to allow identification and description of potential spawning habitat assess habitat quality at additional reefs.

ACKNOWLEDGEMENTS

We wish to thank the permanent and temporary staff of the Lake Michigan Biological Station who assisted with data collection. Special thanks Steve Robillard for input on reef locations and descriptions and to Scot Peterson and Charles Roswell for logistical and sampling support. We also thank J. Rimkus for her administrative support.

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Table 1. Summary of bathymetric sampling and mean daily water levels at North, Waukegan East, Waukegan South, Lake Bluff, and Wilmette reef survey areas during 2017. *Survey line km for Lake Bluff Reef is an estimate based on preliminary data collected during the project period.

Reef	Survey dates	Mean daily water level (m)	Survey line km	Interpolated area km²
North	July 6	176.99	60.3	4.8
	July 11	177.03		
Wauk. East	Aug 8	177.05	90.7	14.0
	Aug 9	177.05		
Wauk. South	July 18	177.05	110.6	11.1
	Aug 1	177.06		
	Aug 8	177.05		
Lake Bluff	Aug 30	177.03	53*	na
Wilmette	Sept 21	176.99	94.6	10.1
	Sept 26	176.96		

FIGURES

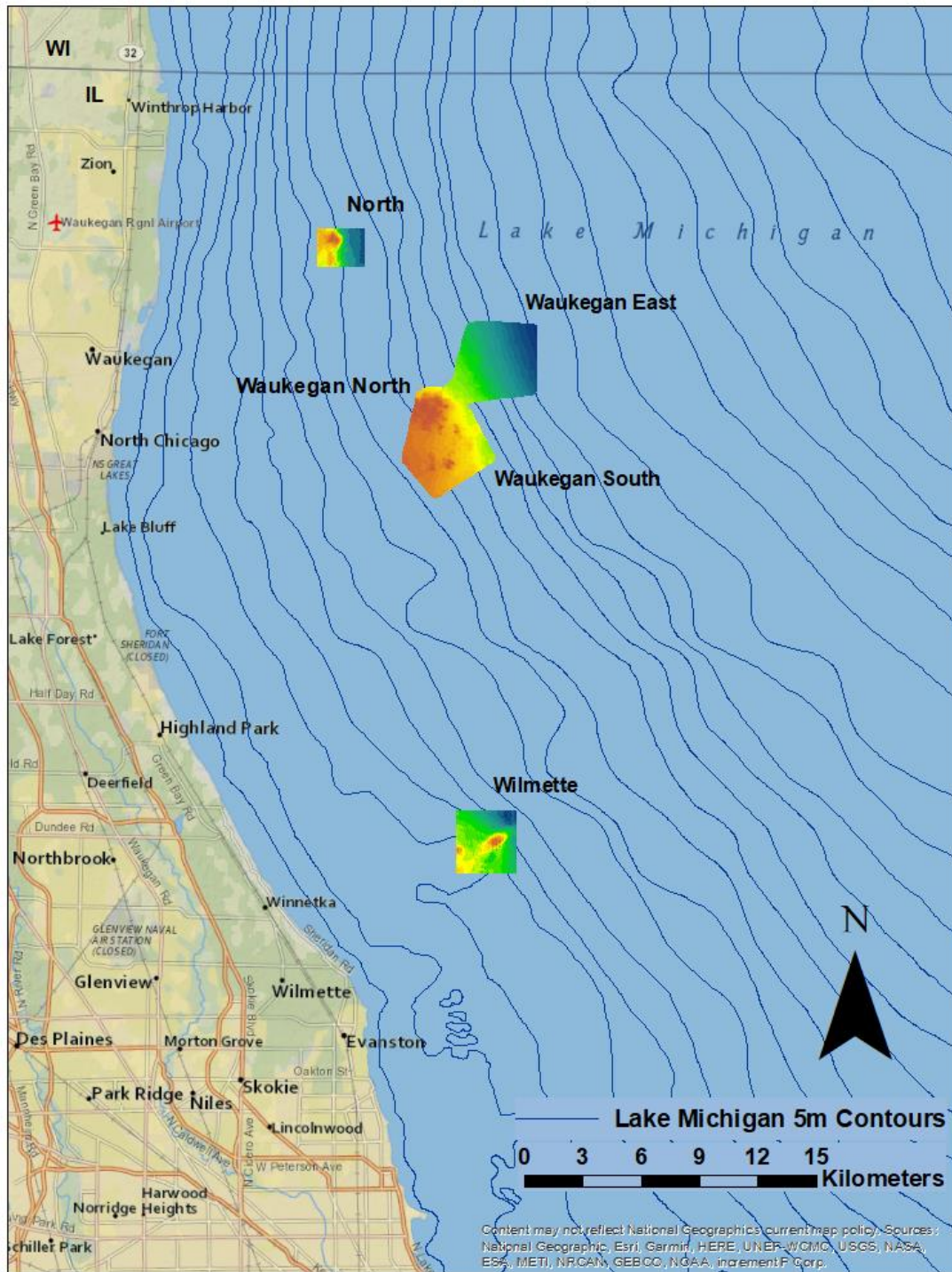


Figure 1. Location map illustrating survey coverage of North, Waukegan East, Waukegan South, and Wilmette reefs during 2017 as well as extended coverage of the Waukegan Reef Complex from surveys conducted during 2011.

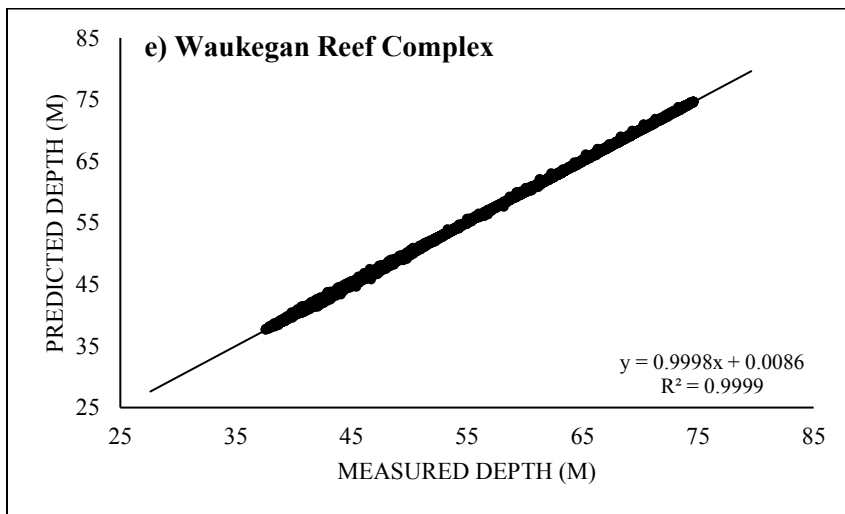
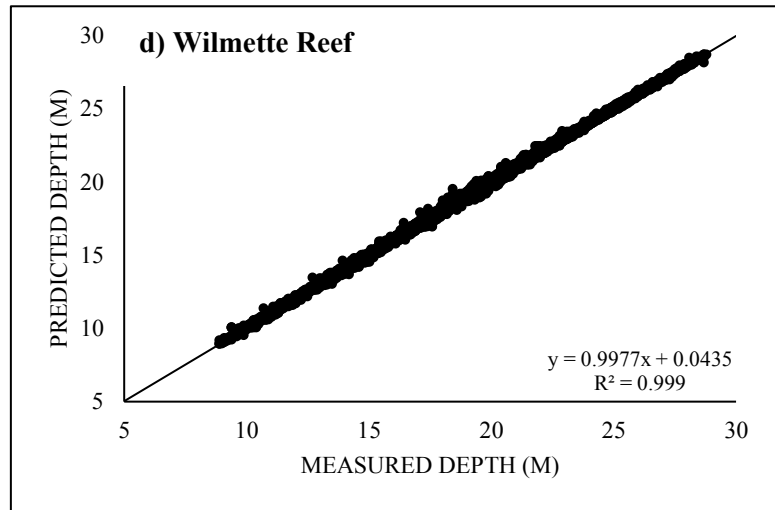
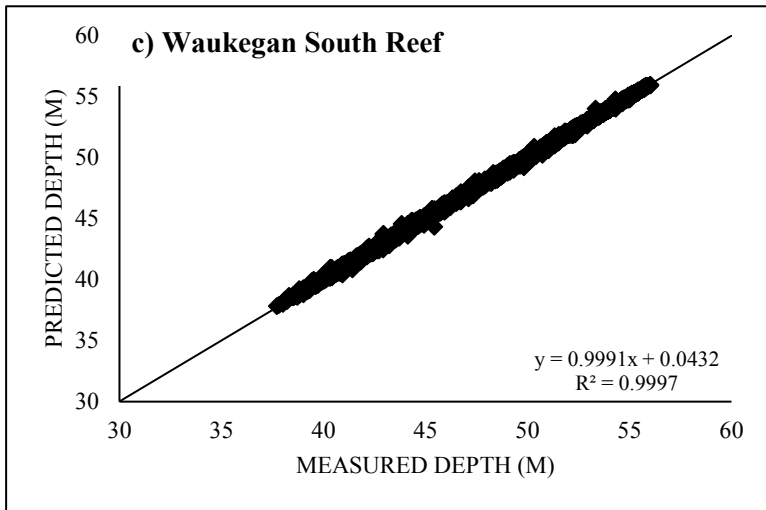
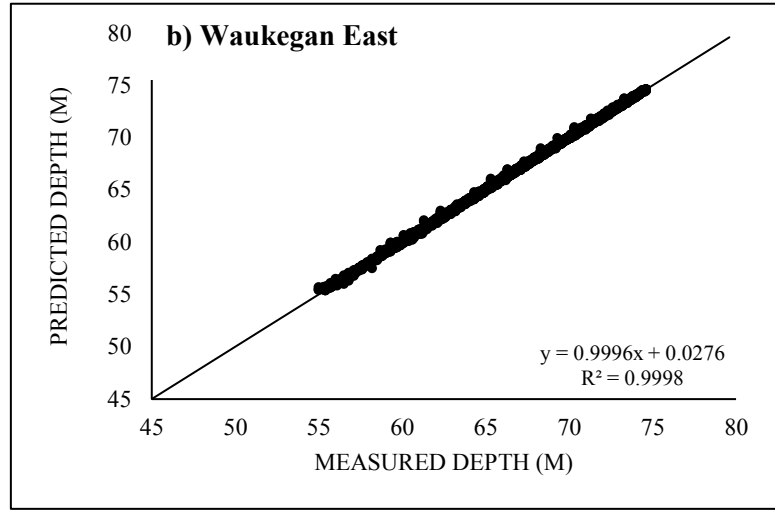
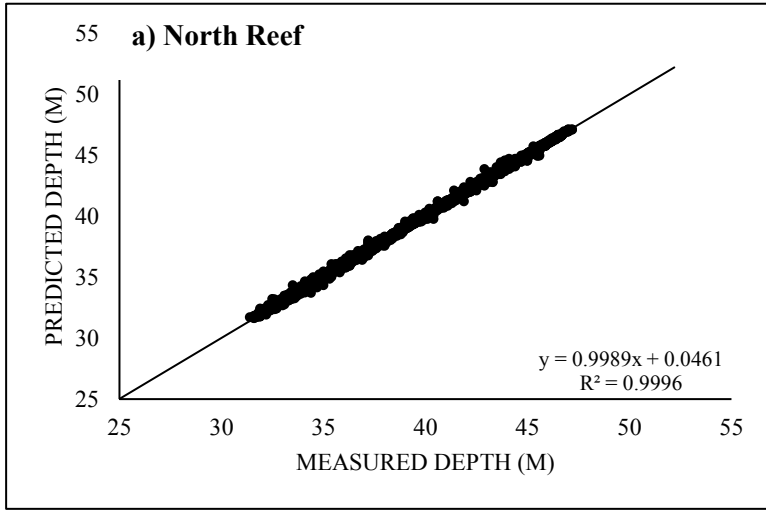


Figure 2. Plots of predicted versus measured water depths from survey areas over a) North, b) Waukegan East, c) Waukegan South, and d) Wilmette reefs as well as e) Waukegan Reef Complex.

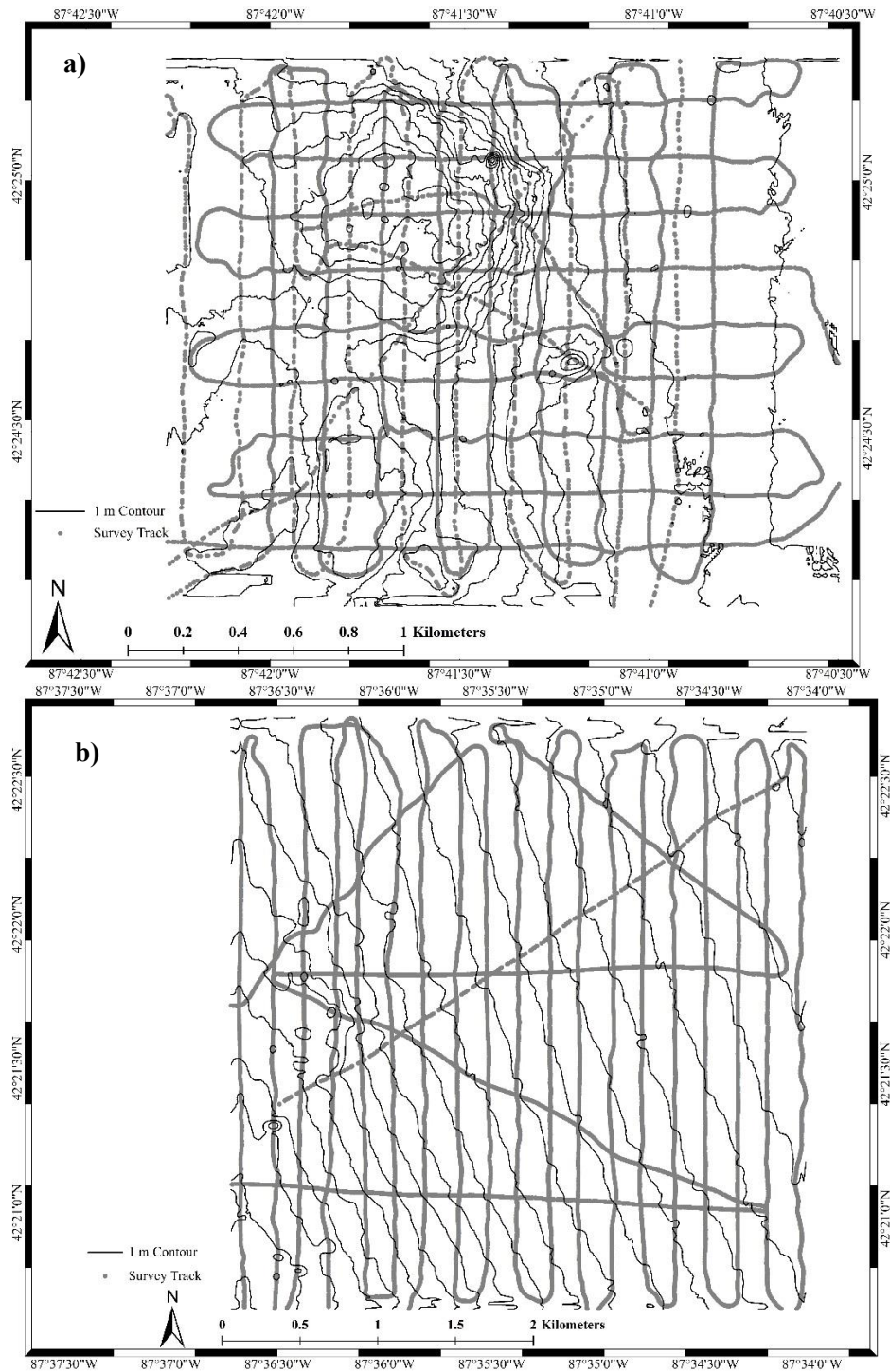


Figure 3. Display of survey tracks overlaying interpolated 1 m contour lines at a) North reef and b) Waukegan East survey areas. Gray dotted lines denote position of vessel during sampling and thin black lines denote 1 m contours.

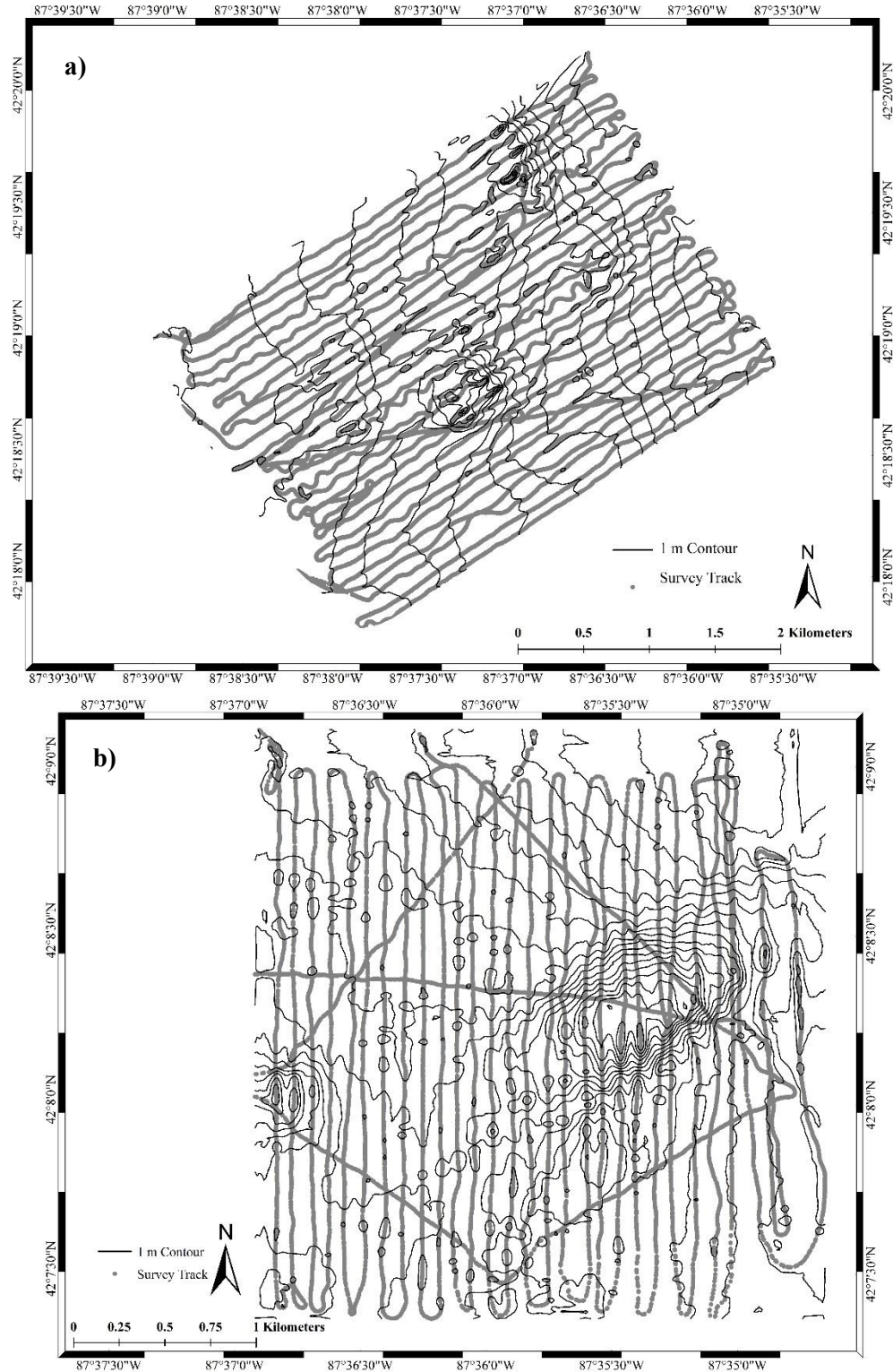


Figure 4. Display of survey tracks overlaying interpolated 1 m contour lines at a) Waukegan South and b) Wilmette reefs. Gray dotted lines denote position of vessel during sampling and thin black lines denote 1 m contours.

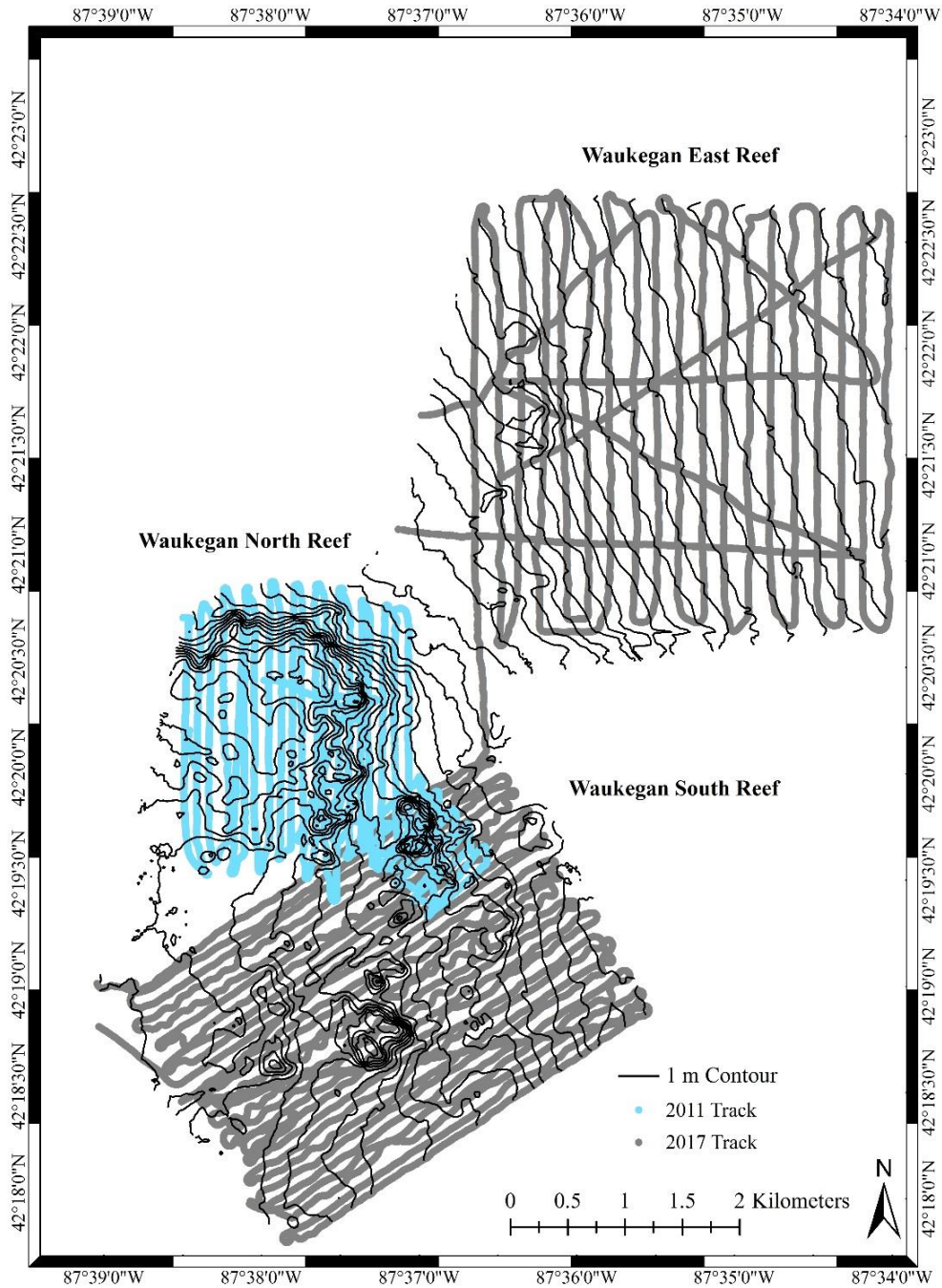


Figure 5. Display of survey tracks overlaying interpolated 1 m contour lines at the Waukegan Reef Complex. Gray dotted lines denote position of vessel during 2017 sampling, light blue dotted lines denote position of vessel during 2011 sampling, and thin black lines denote 1 m contour lines.

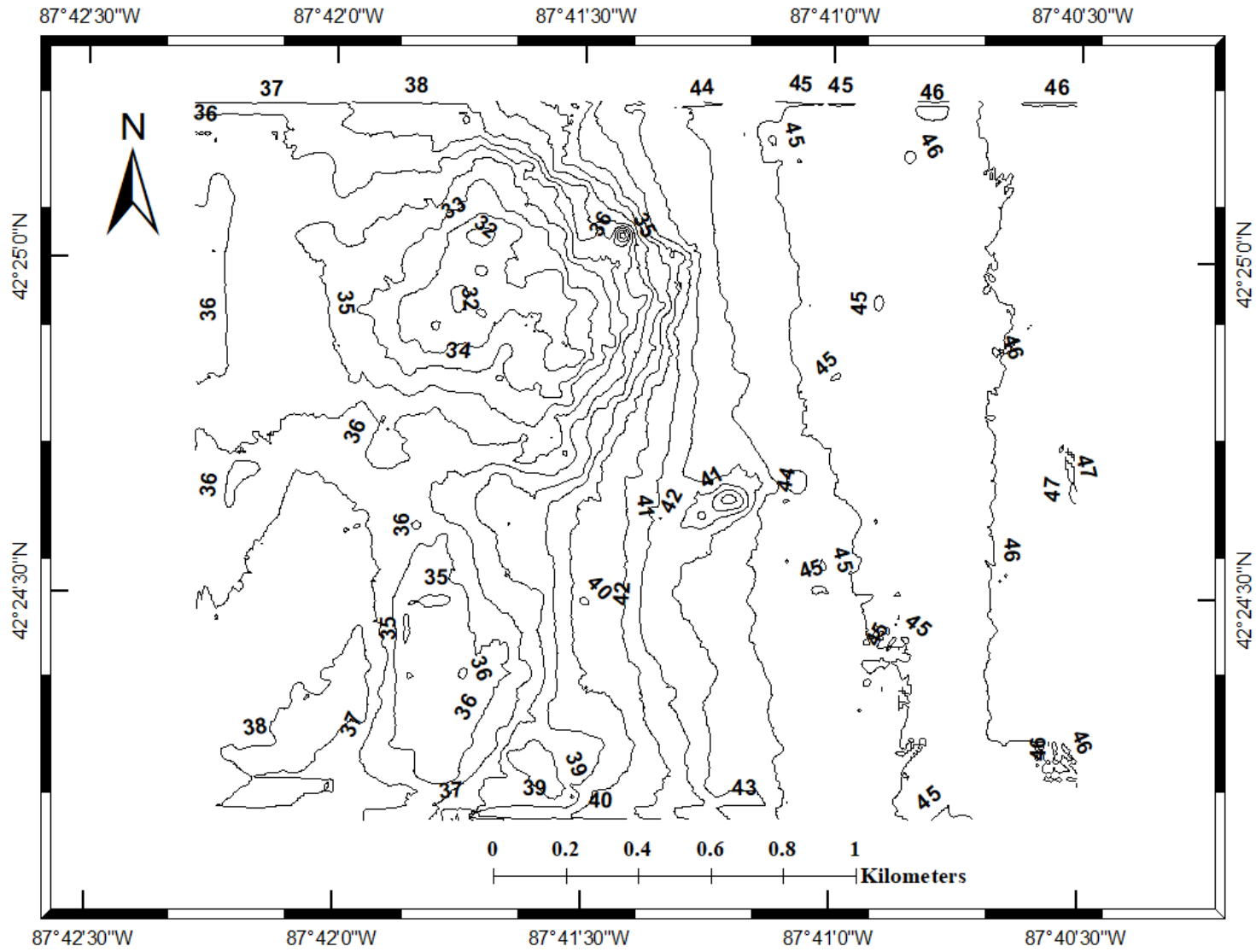


Figure 6. Map of North Reef with interpolated 1 m contour lines.

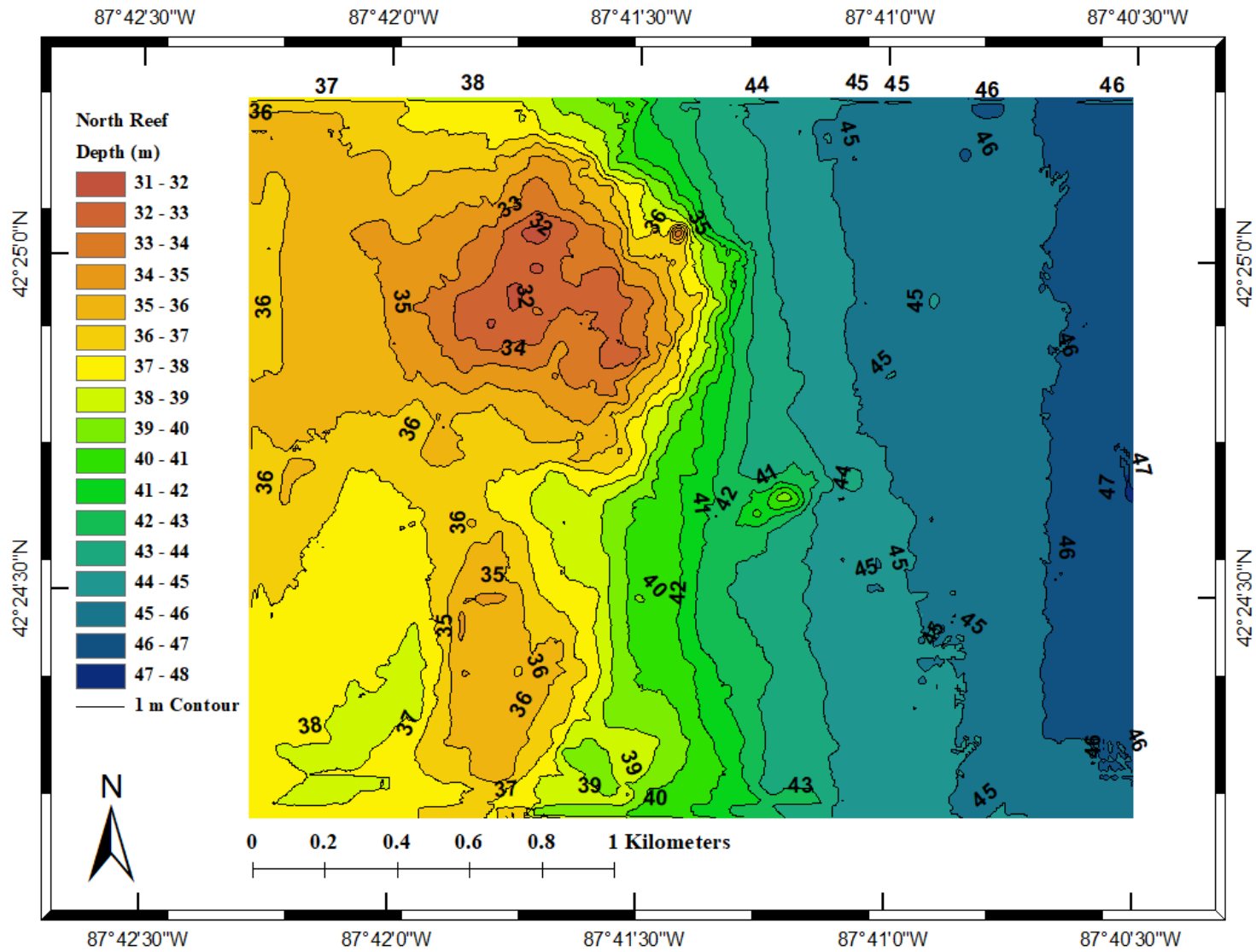


Figure 7. Map of North Reef with 1 m contour lines and incrementing 1 m depth color scale.

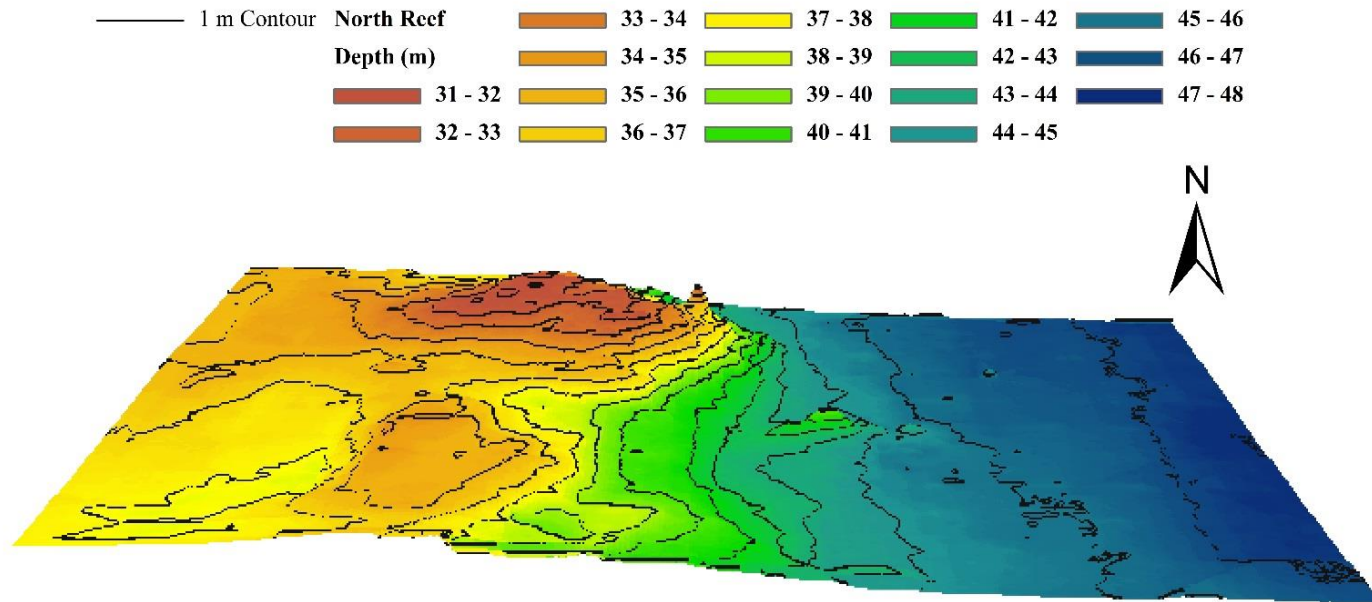


Figure 8. A 3-dimensional bathymetric map of North Reef (1 m contours).

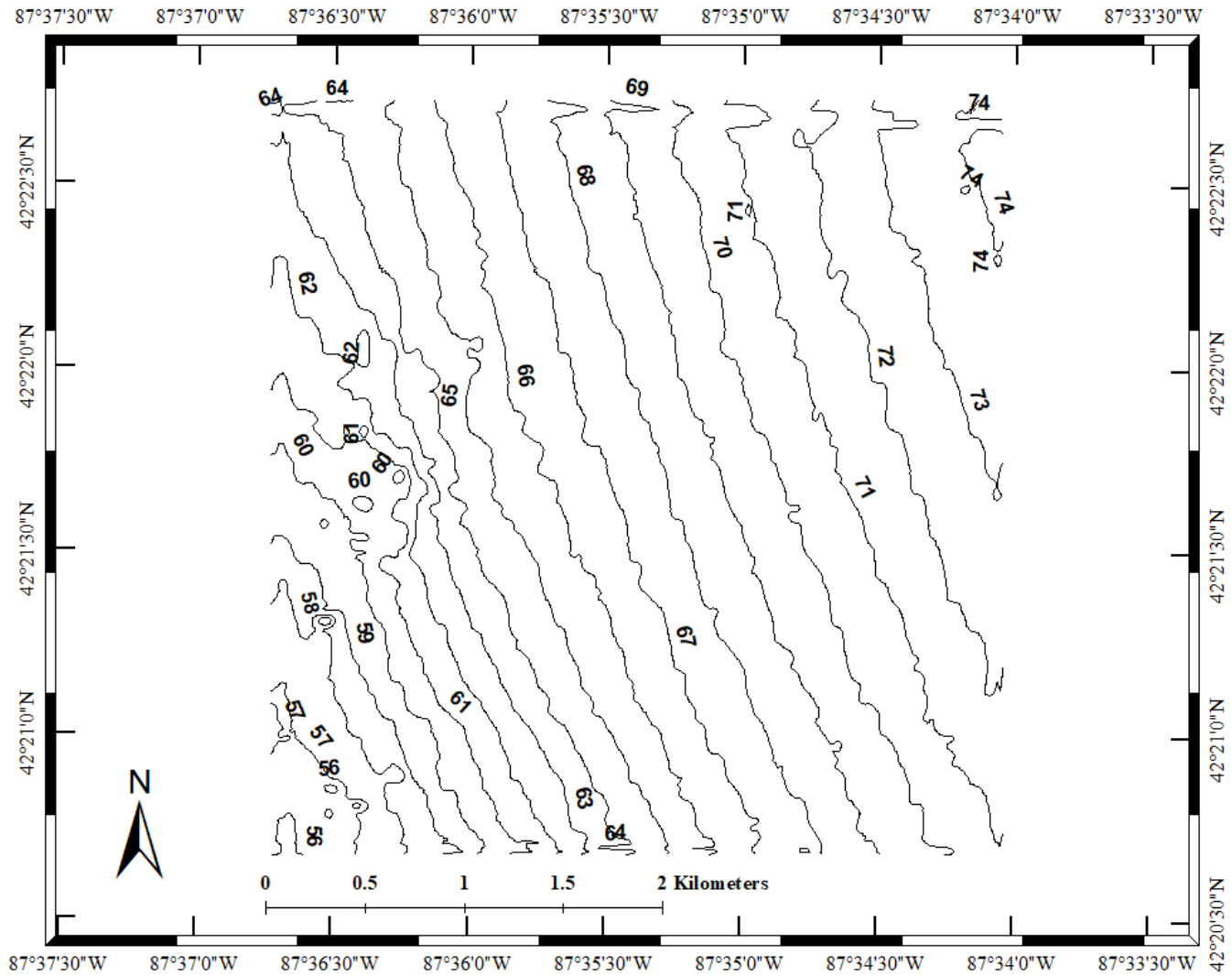


Figure 9. Map of Waukegan East survey area with interpolated 1 m contour lines.

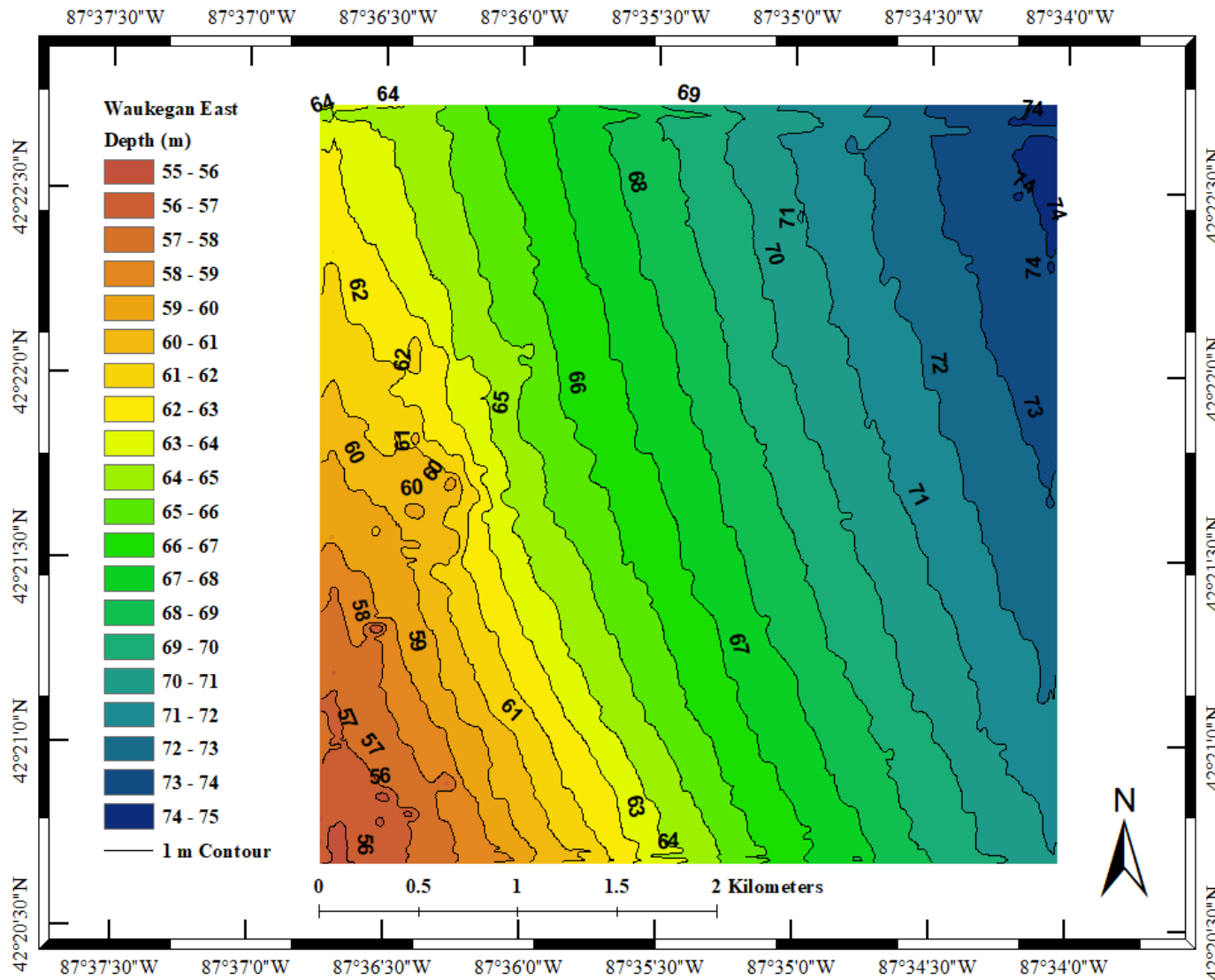


Figure 10. Map of Waukegan East survey area with 1 m contour lines and incrementing 1 m depth color scale.

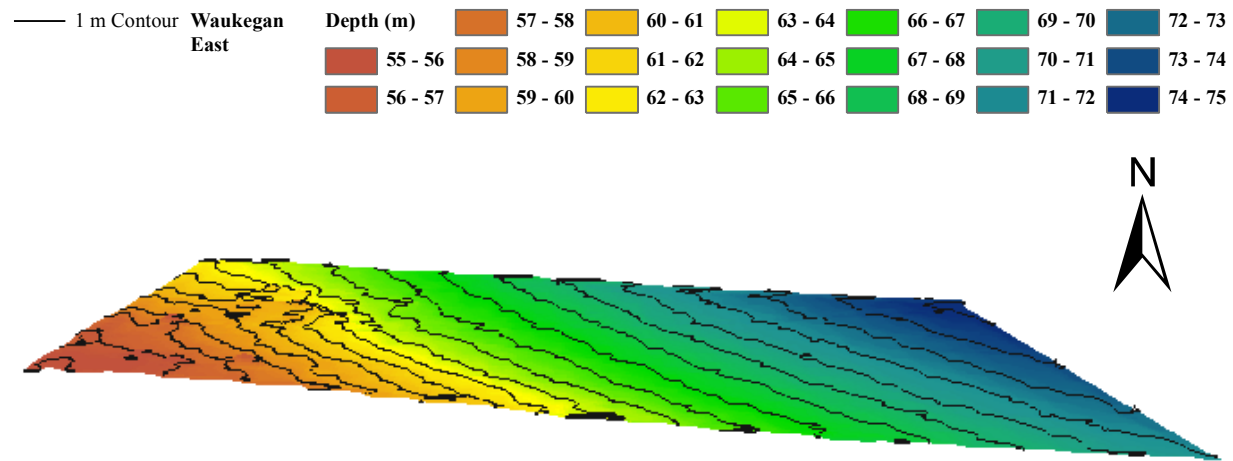


Figure 11. A 3-dimensional bathymetric map of Waukegan East survey area (1 m contours).

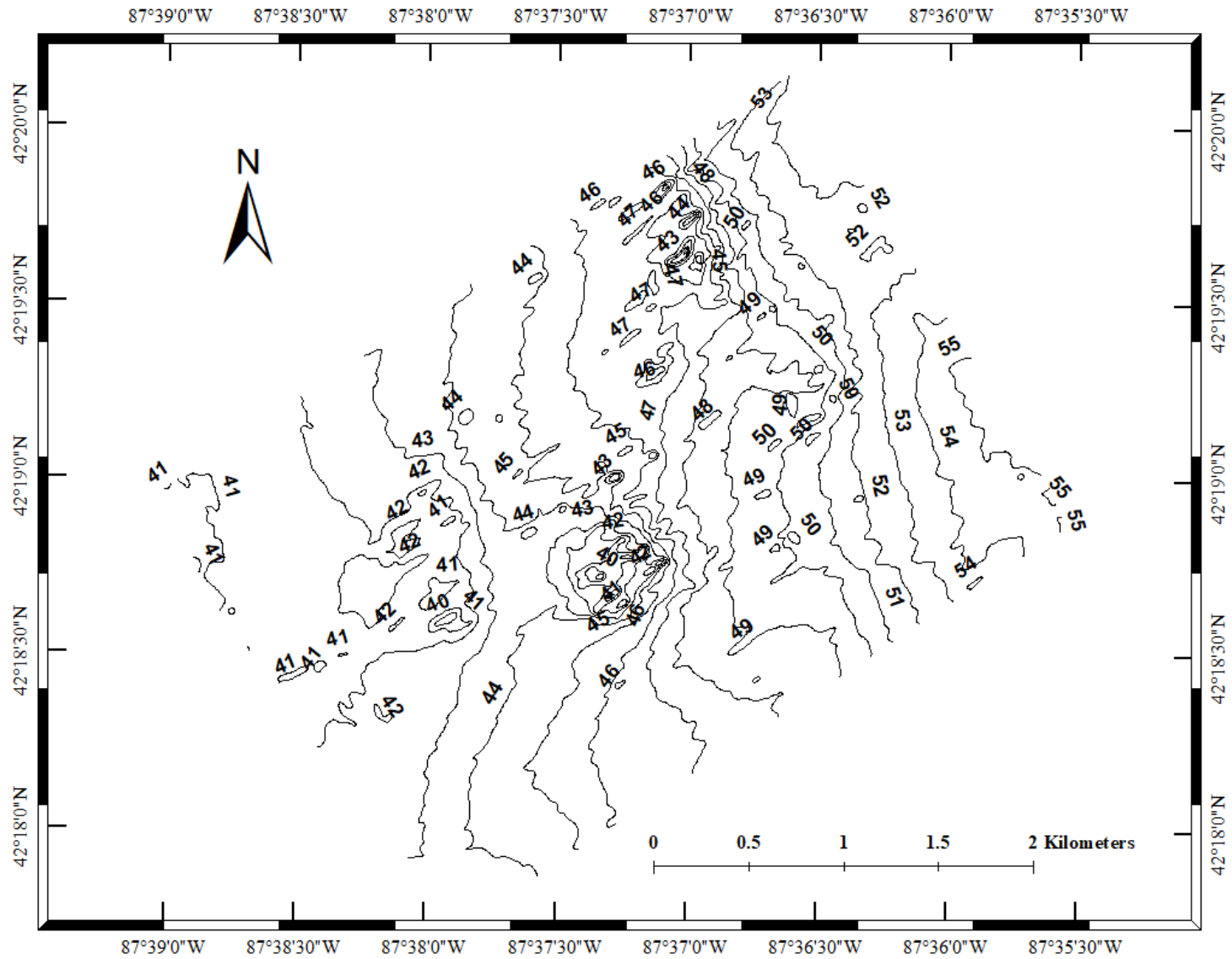


Figure 12. Map of Waukegan South Reef with interpolated 1 m contour lines.

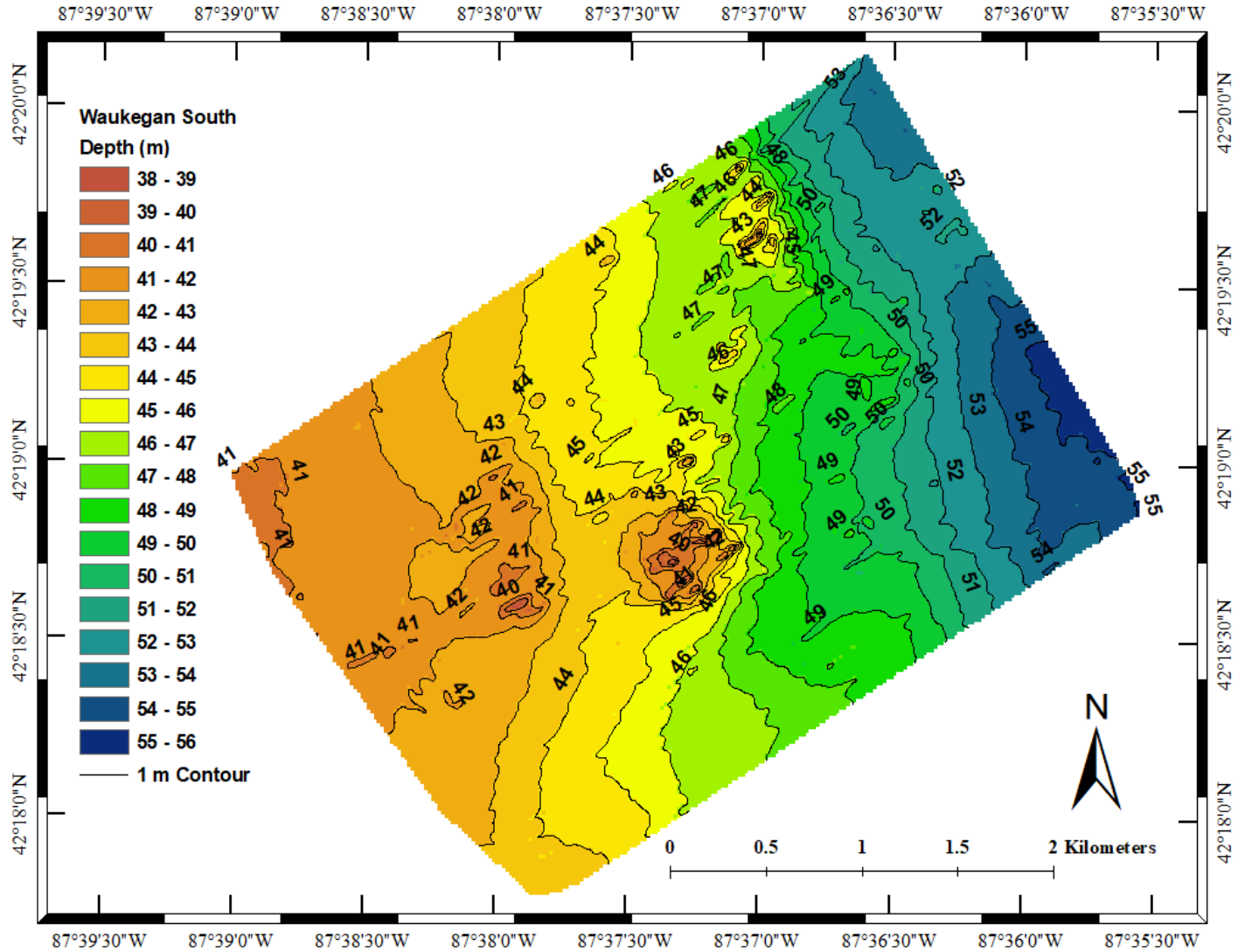


Figure 13. Map of Waukegan South Reef with 1 m contour lines and incrementing 1 m depth color scale.

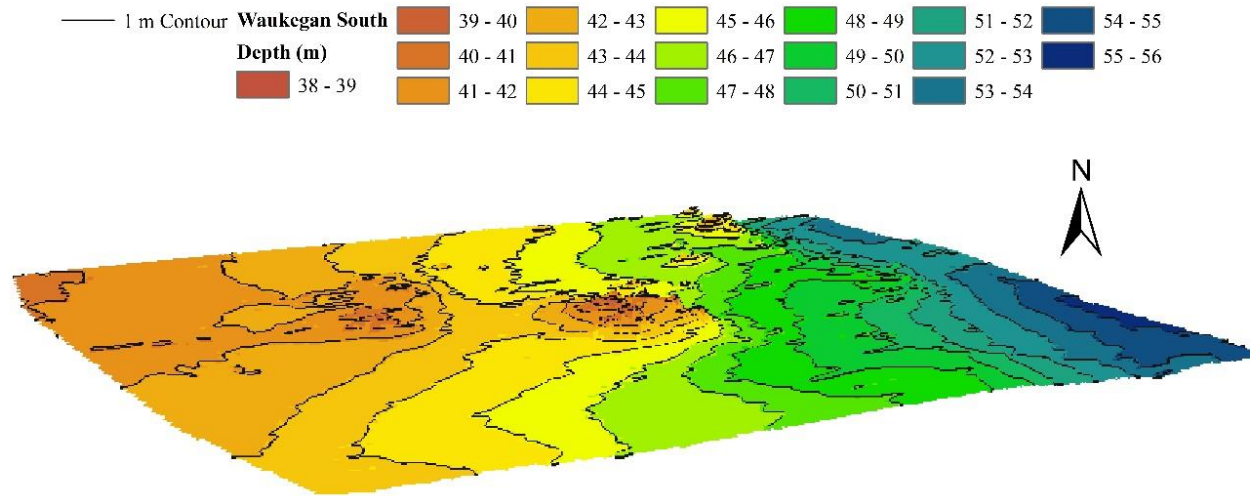


Figure 14. A 3-dimensional bathymetric map of Waukegan South Reef (1 m contours).

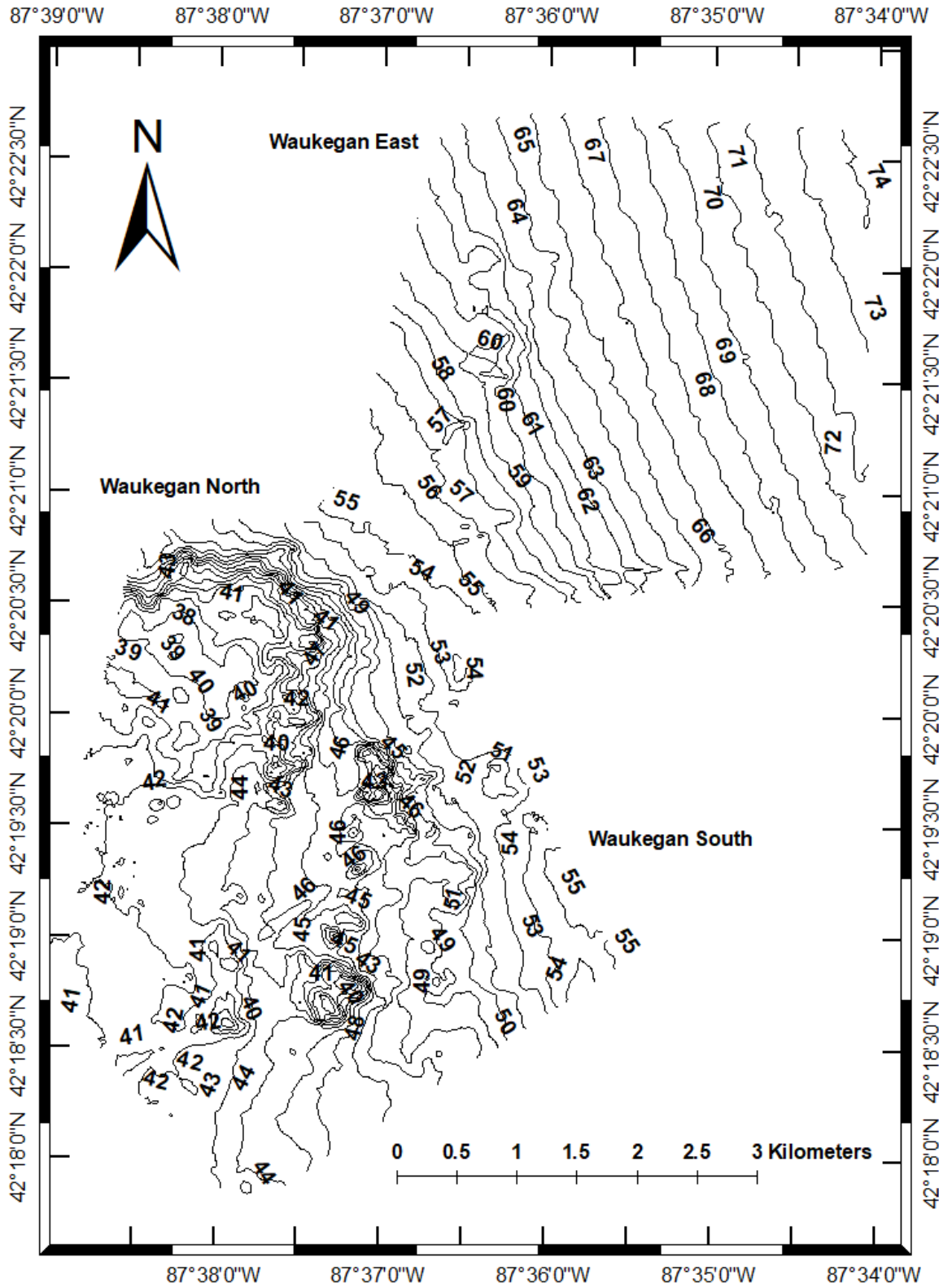


Figure 15. Map of the Waukegan Reef Complex with interpolated 1 m contour lines.

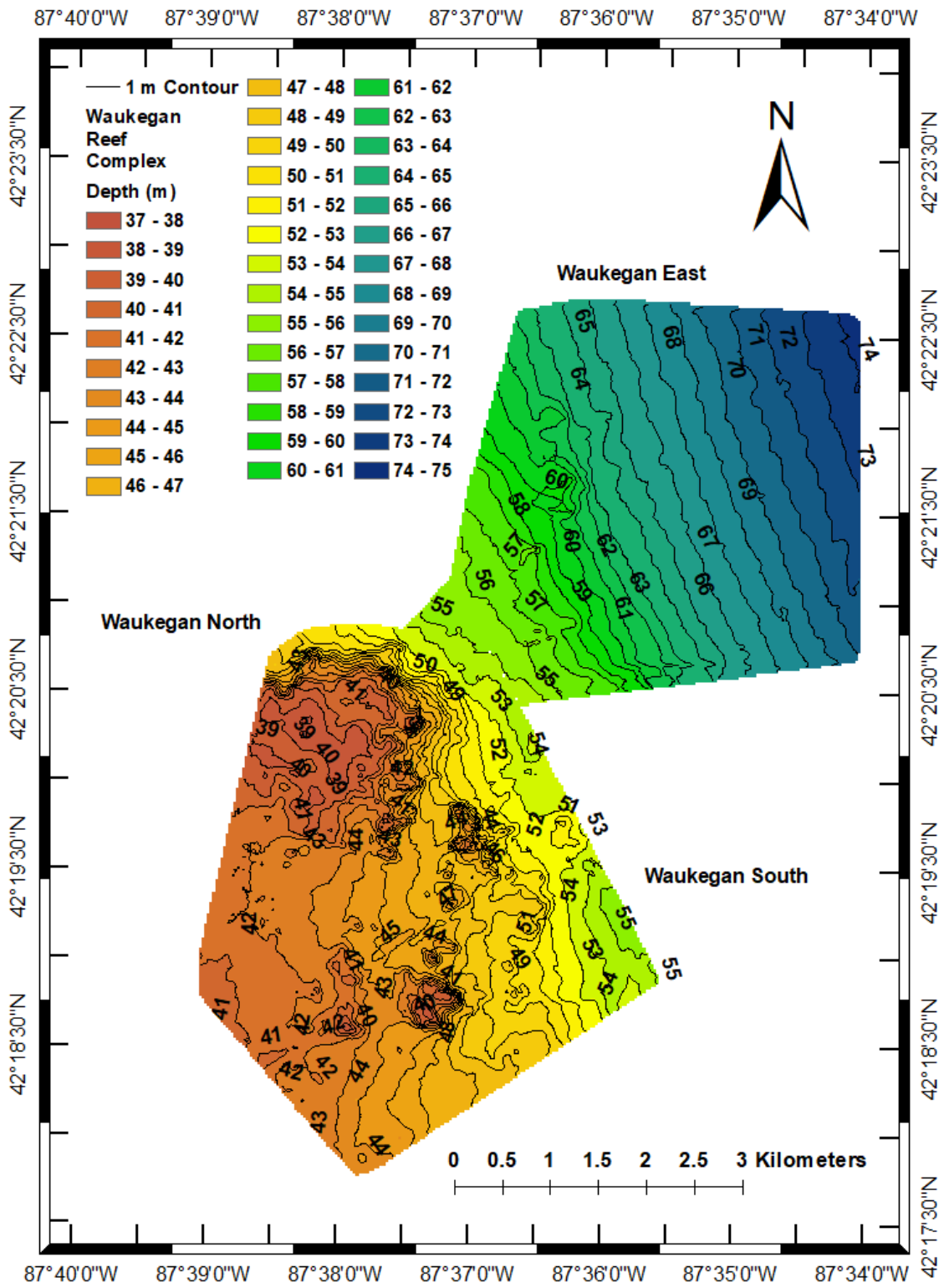


Figure 16. Map of the Waukegan Reef Complex with 1 m contour lines and incrementing 1 m depth color scale.

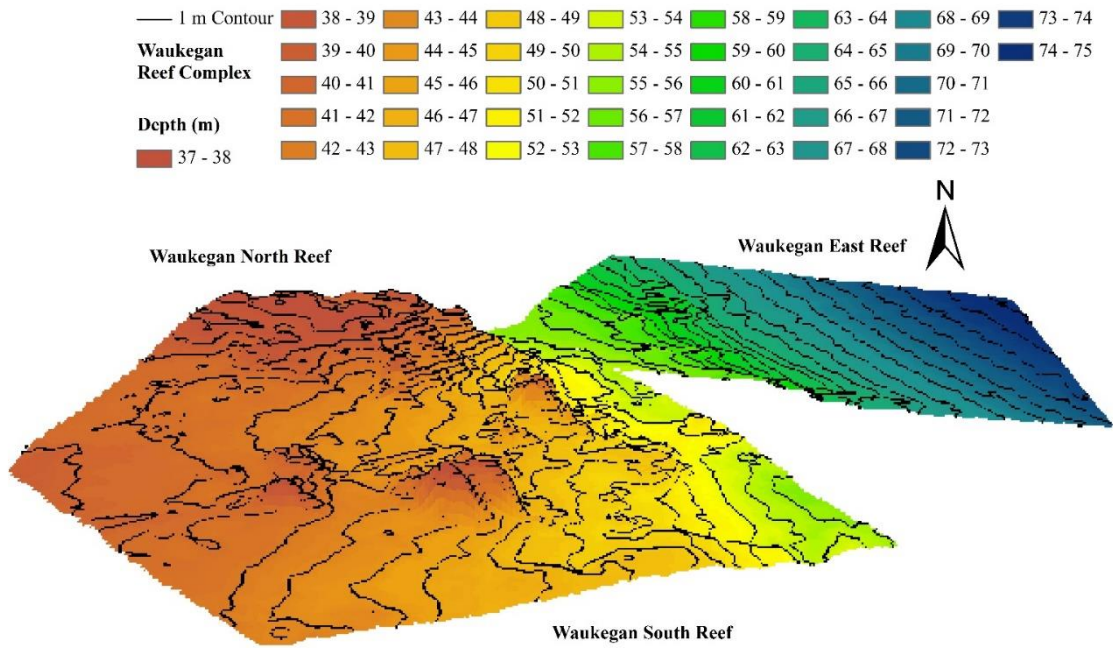


Figure 17. A 3-dimensional bathymetric map of the Waukegan Reef Complex (1 m contours).

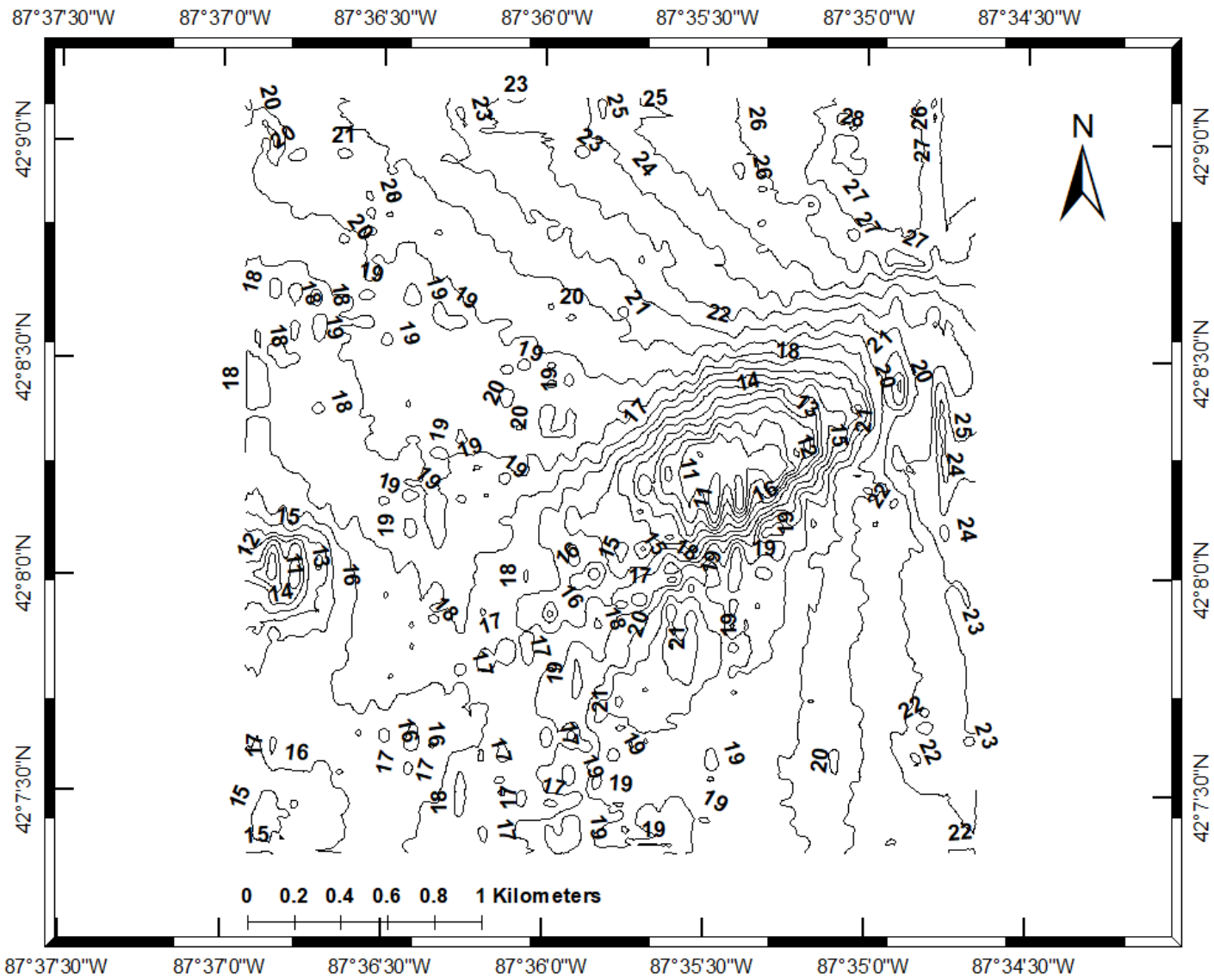


Figure 18. Map of Wilmette Reef with interpolated 1 m contour lines.

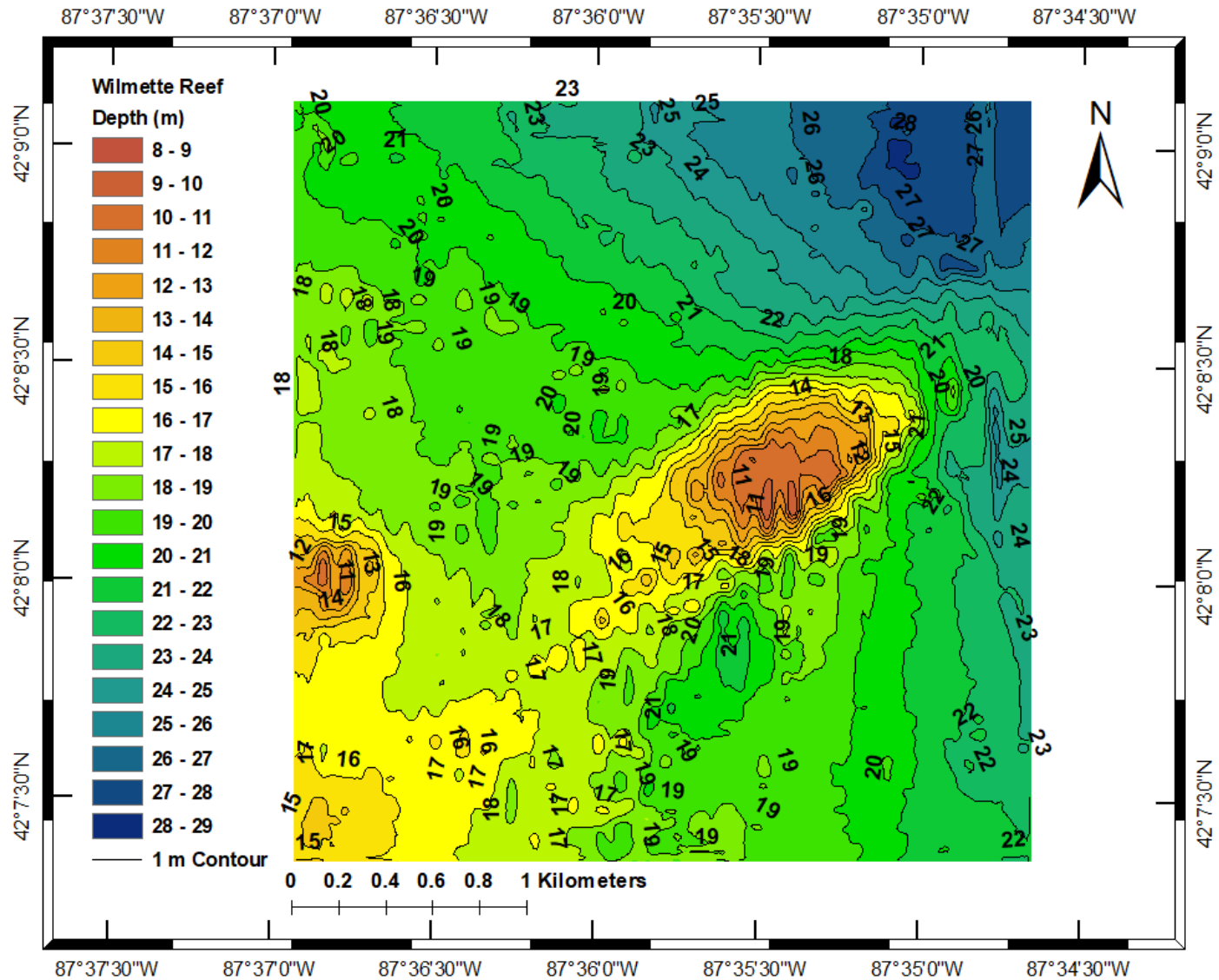


Figure 19. Map of Wilmette Reef with 1 m contour lines and incrementing 1 m depth color scale.

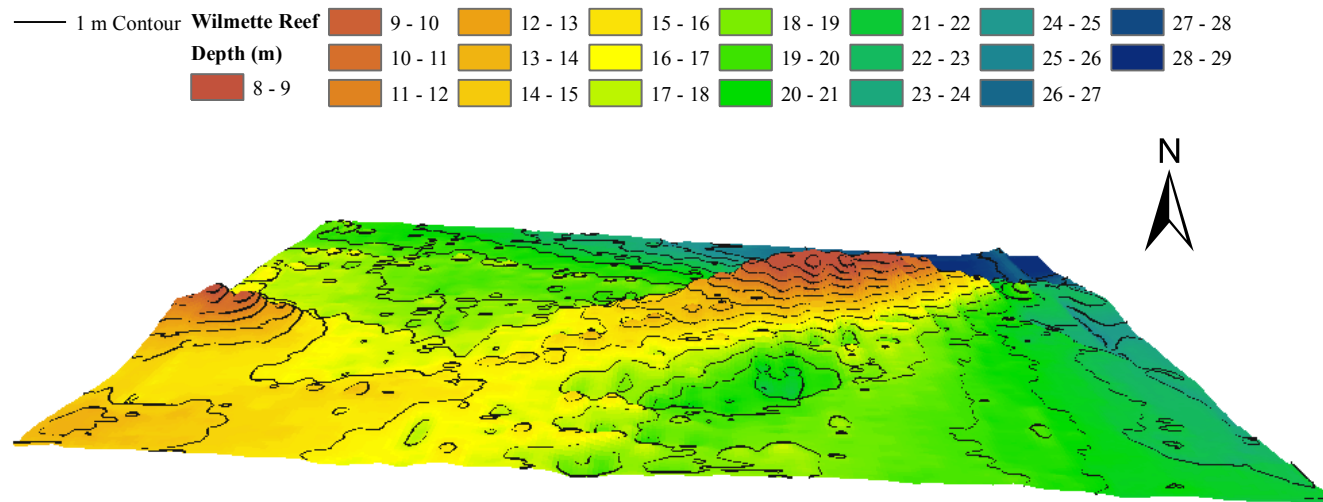


Figure 20. A 3-dimensional bathymetric map of Wilmette Reef (1 m contours).