Comparison of Hydrographic Survey Data with Crowdsourced Bathymetry Data

Usporedba podataka hidrografskog premjera s podacima o dubinama mora dobivenih iz javnih izvora

Toni Radić
University of Split
Faculty of Maritime Studies
Split, Croatia
E-mail:tradic@pfst.hr

Ivica Pavić
University of Split
Faculty of Maritime Studies
Split, Croatia
E-mail: ipavic71@pfst.hr

Jakša Mišković*
University of Split
Faculty of Maritime Studies
Split, Croatia
E-mail: jmiskovi1@pfst.hr

DOI 10.17818/NM/2023/2.3
UDK 528.9:656.61
551.462
Preliminary communication / *Prethodno priopćenje*
Paper received / *Rukopis primljen:* 15. 2. 2023.
Paper accepted / *Rukopis prihvaćen:* 7. 3. 2023.

Abstract

A hydrographic survey is a standardized procedure for collecting data for the production of nautical charts and publications. It is a lengthy and costly procedure, so the survey is carried out depending on the capabilities of hydrographic organizations. It is known that relatively large parts of the world's oceans are very poorly covered by hydrographic surveys. To increase the amount of data collected, the International Hydrographic Organization (IHO) has introduced the concept of crowdsourced bathymetry (CSB). Under the CSB concept, all vessels meeting certain minimum technical requirements (carrying a global navigation satellite system and a single beam echo sounder) can participate in voluntary bathymetric data collection. The paper analyzes the method of collecting bathymetric data from CSB. The depth data collected as part of the CSB are compared with official data displayed on electronic navigational charts (ENC) in the United States of America. Four sea areas were selected in which 104 depths were compared at the same positions, and categorization was also made according to the criterion of navigational importance, i.e., the category zones of confidence (CATZOC). By comparing the official depth data from the hydrographic survey with the depth data collected from public sources for the same positions, their mutual relationships were established, from which it can be concluded that the CSB data, despite its limitations, is a very valuable supplement to the existing official data.

KEY WORDS
crowdsourced bathymetry
hydrographic survey
category zones of confidence
electronic navigational charts

Sažetak

Hidrografski premjer je standardizirani postupak prikupljanja podataka za izradu pomorskih karata i nautičkih publikacija. To je dugotrajan i skup postupak pa se premjer provodi ovisno o mogućnostima hidrografskih organizacija. Poznato je da su relativno veliki dijelovi svjetskog mora vrlo slabo pokriveni premjerom. Kako bi se povećala količina prikupljenih podataka, Međunarodna hidrografska organizacija (engl. International Hydrographic Organization – IHO) uvela je koncept prikupljanja batimetrijskih podataka iz javnih izvora (engl. Crowdsourced Bathymetry – CSB) u kojem mogu sudjelovati svi brodovi koji zadovoljavaju određene minimalne tehničke uvjete (posjedovanje satelitskog sustava za pozicioniranje i ultrazvučnog dubinomjera). U radu se analizira metoda prikupljanja batimetrijskih podataka iz javnih izvora. Uspoređuju se podaci o dubinama koji su prikupljeni iz javnih izvora sa službenim podacima prikazanima na elektroničkim navigacijskim kartama (Electronic Navigational Charts – ENC) u Sjedinjenim Američkim Državama. Odabrana su četiri morska područja u kojima se uspoređuju 104 dubine na istim pozicijama, pri čemu se koristi i kategorizacija prema kriteriju navigacijske važnosti, tj. CATZOC (Category Zones of Confidence). Usporedbom službenih i CSB podataka o vrijednostima dubina na istovjetnim pozicijama, utvrđeni su njihovi međusobni odnosi na temelju kojih se može zaključiti da CSB podaci, unatoč ograničenjima, predstavljaju vrlo vrijednu dopunu postojećim službenim podacima.

KLJUČNE RIJEČI
batimetrija iz javnih izvora
hidrografski premjer
kategorije zona pouzdanosti
elektroničke navigacijske karte

1. INTRODUCTION / *Uvod*

A hydrographic survey aims to collect data on sea depth, bottom configuration, direction and strength of sea currents, time of occurrence and range of tides, location of topographic features and objects used for surveying or navigational purposes [1]. Data obtained by hydrographic survey is recognized as official data processed by hydrographic organizations. The quality and reliability of that data have a direct impact on the safety of navigation. Therefore, the accuracy and methodology of data acquisition and processing must be of the highest level [2]. The required quality level has a significant impact on the time to perform and costs of the whole process [3]. Hydrographic

* Corresponding author

surveys are performed by national hydrographic organizations. Each hydrographic organization may establish its own standards in addition to the international standards developed by the IHO. To achieve maximum uniformity, the standards set by national organizations must be equal to or more stringent than the IHO standards [4]. Many national hydrographic organizations have limited resources for conducting hydrographic surveys, so it would be desirable to use any measurement that can contribute to the safety of maritime navigation [5]. Considering the technical requirements, technology, and methodology, hydrographic survey is an expensive and lengthy process, so only a relatively small portion of the surface of the world's seas has been adequately surveyed. According to [6], less than 20% of the world's seas have been surveyed. Because of the relatively low coverage of the world's seas by official bathymetric data, the IHO introduced the CSB concept in which all ships that have the appropriate equipment can participate during their regular activities at sea [3]. The SOLAS Convention requires merchant vessels to be equipped with a certified single beam echo sounder and a satellite navigation system [7]. Therefore, the world merchant fleet could be a great source of bathymetric data.

1.1. IHO CSB Concept / *Koncept CSB IHO-a*

The CSB concept represents the collection of bathymetric data from public sources. CSB is defined as: "the collection and exchange of data and metadata about depth measured and collected by ships that are not intended for hydrographic research and equipped with navigational instruments during their regular activities at sea" [4]. The CSB concept operates on the "trusted node" model. Depth data collected on ships are downloaded from organizations (Trusted Nodes) that serve as a link between ships and the IHO Data Center for Digital Bathymetry (IHO DCDB). To define the concept, equipment, methodology, format, and reliability of data collection, processing, and storage, and to achieve the highest possible level of data reliability, IHO has developed the publication Guidance on Crowdsourced Bathymetry (IHO B-12) [3,4]. Currently, the 3.0.0. edition of the publication is in effect and has been approved by 37 IHO member states [8]. IHO B-12 recommends that the trusted node verify the data, calculate the unreliability, and apply any data correction. After verification and processing, the data is stored on the IHO DCDB [4]. It is important to emphasize that the data collected from public sources is not official data. Such data are intended to support and supplement official data on which we cannot fully rely [3].

To accelerate the process of surveying the world's seas, the Seabed 2030 initiative was launched. This initiative was launched through the collaboration of the Japanese Nippon Foundation and GEBCO (General Bathymetric Chart of the Ocean). The Seabed 2030 initiative optimistically predicts that by 2030, the entire survey of the world's oceans will be completed, and a complete digital bathymetric map of the world's seas will be created. [6]. This initiative highlights the fact that CSB is not very effective in areas of deeper waters due to the technical limitations of standard navigational echo sounders [6].

In addition to the lower accuracy of data collected from public sources compared to data obtained through hydrographic surveys, the CSB also faces legal problems. The legal problems of this concept are related to the limitations arising from the provisions of the United Nations Convention on the Law of the Sea (UNCLOS), which relate to the exclusive right of coastal states to survey in territorial waters, archipelagic waters, and straits used for international navigation; to sovereign rights and jurisdiction with respect to marine research in the exclusive economic zone (EEZ); and to restrictions on data availability and redistribution through IHO DCDB [4, 9]. In addition to legal issues, the CSB concept may also present certain national security or political issues [10]. Since the CSB concept has a whole range of limitations, from legal to technical, a model for CSB application at the national level has been proposed, based on the concept of IHO CSB but adapted to the national level. The purpose of this model is to avoid international limitations of the concept in order to increase the national database and eventually send all or selected national CSB data to IHO DCDB according to national filters [4].

Coastal states must explicitly consent to the collection and publication of CSB data in waters under national jurisdiction. To date, 16 countries have given their consent to conduct CSB in all sea areas, 11 countries only in the EEZ, 2 countries in territorial waters and the EEZ, and one country only in waterways and during transit passage in archipelagic waters [11].

A very important role in collecting data from public sources is played by companies that produce navigation equipment, such as Navionics, Nobletec, Navico, Furuno, and Raymarine, which have created platforms that allow users to collect, publish, and read measurements recorded by them or other users of the platform [12]. Not only are these platforms publicly available, but they also allow private individuals to contribute bathymetric data to the databases used to create unofficial charts [5]. Private organizations also produce electronic charts based on their own and other sources. Although these charts are not official ENC, Weintrit emphasizes the importance of data collection and chart production by private organizations and/or companies [13].

Some of these companies have developed systems for their own display of the data collected from the users of their equipment. For example, the Norwegian company Olex has developed its own data display, which it claims [14] is for use in fishing, aquaculture, port work, and subsea piping. Depth data collected by GPS and sonar are continuously calculated and added to previous measurements. Using this data, Olex creates a realistic 3D representation of the seabed while listing software upgrade options to integrate the system with relevant hardware such as AIS, multibeam echo sounders and trawl/ROV positioning.

Analysis of IHO DCDB in the U.S. East Coast area shows that Rose Point stands out as one of the leading CSB data providers. In addition to data collection, Rose Point also provides route planning services using ECS software. Due to the cooperation between Rose Point and NOAA, this software can use official ENCs from the NOAA database [15]. NOAA is the national nautical chart producer for the United States. NOAA is responsible for upgrading charts, surveying the seafloor, responding to maritime emergencies, and searching for underwater obstructions that pose a danger to navigation. On the organization's official website, a display of data from ENC cells is also be viewed in the form of a web map service (NOAA ENC viewer) [16]. In this way, NOAA provides end users with a pictorial representation of ENC on its own web pages. This allows users to familiarize themselves with their products, i.e., to get an insight of the appearance and content of the ENCs, which are presented with all the latest official updates to the ENCs.

The only private company that has a publicly available version of the depth data display is Navionics. This platform displays data from official hydrographic sources, public and private surveys, and contributions from boaters [17]. The data are updated daily and are visible in the Navionics Chart viewer [18]. When listing private companies involved in the display of depth data, the C-Map service must also be mentioned. C-Map provides up-to-date vector charts with details derived from official information provided by the hydrographic offices. In addition to vector charts, this platform also offers options such as depth shading, routing, tides and current projections, and detailed marina port plans [19].

1.2. ENC and depth accuracy assessment / *ENC i procjena točnosti dubine*

ENC is an official digital vector chart that complies with the relevant IMO requirements and IHO standards [7, 20]. ENCs are issued by the hydrographic offices, which are also responsible for their updating in the same way as for paper navigational charts. ENC contains all cartographic data essential for the safety of navigation, and unlike paper charts, they have the possibility to include additional information (i.e., information contained in Pilot, List of Lights and Fog Signals) [21], where the amount of information can be varied and scaled [22]. Thus, these are charts that contain only official chart data from hydrographic surveys and other official navigational information. ENCs are the main type of charts on which an ECDIS relies. IMO Resolution MSC.232(82) prescribes in paragraph 1.7 that ECDIS should have at least the same reliability and availability of presentation as paper charts published by government-authorized hydrographic offices [23]. For a whole range of reasons, the reliability of the data is not equal, so Zones of Confidence have been introduced. Considering that the surveys were conducted in different parts of the seas in different time periods and with different means, variations in the quality of the data are to be expected. Possible errors can be recorded in the form of data on depths and their positions at the time of survey through depth data accuracy assesment. In this regard, a CATZOC (Category Zone of Confidence) is a deviation that helps to ensure which of these variables are accurate and to what extent errors are to be expected. Considering the possible errors in depth and position, the data are divided into 6 confidence zones (CATZOC): A1, A2, B, C, D, and U. This allows the navigator to assess the confidence that charting authorities have in the underlying depth information in different sea areas [24]. Hydrographic offices display on their own ENCs the corresponding CATZOCs. CATZOC, in fact, reflects charting standards and not just the standard of hydrographic surveys [25]. Considering that, according to the provisions of the SOLAS Convention, certain types of ships must have an ECDIS and ENCs and considering all the advantages that the new digital technology brings, it is important not to forget the potential limitations and possible shortcomings [26].

In this paper, the bathymetric data from the CSB are compared to the official data from the National Oceanic and Atmospheric Administration (NOAA) ENCs. A methodology for the depth comparison in terms of navigational accuracy through the CATZOC categorization was developed. Depths at the same positions in a total of four areas available in the IHO DCDB database and in the NOAA ENC database were compared, leading to conclusions regarding the feasibility of using the CSB data.

The paper consists of five sections. Section one presents the basic characteristics and comparison between the hydrographic survey and the CSB concept in the context of the presentation and use of the official and unofficial chart data. Section two reviews the literature on bathymetric data collection and presentation. Section three describes the methodology of comparing CSB data with official data presented at ENC in four selected areas. Section four presents results based on the comparison of CSB and ENC data in the selected areas where the discrepancies in these data are observed in the context of CATZOCs. Section five presents conclusions.

2. LITERATURE REVIEW / *Pregled literature*

The IHO began developing the CSB concept to encourage and enable mariners and professionally manned vessels to collect bathymetric data. The primary goal of this initiative was to supplement data collected through hydrographic surveys. To enable further development and implementation of the CSB concept, IHO Crowdsourced Bathymetry Working Group (IHO CSBWG) was established. The IHO CSBWG developed the IHO B-12 publication. This publication defines the CSB concept, the method of data collection, processing and storage, and the requirements for the equipment used to perform these actions [27]. After verification and data processing by a trusted node system, the data are stored in the database IHO DCDB, where anyone can access the data for commercial, scientific, or personal purposes [28].

The IHO's DCDB was established in 1990 with the goal of storing bathymetric data collected worldwide. IHO DCDB provides an overview of the various bathymetric data, including data collected using the CSB concept. CSB is integrated with DCDB through various partner organizations, companies, and non-profit groups that allow users to store data on depths collected by their own vessels. A very important role in the inclusion of CSB data in IHO DCDB has been played by Rose Point Navigational Systems. This private company allows users of its software to record their position, time, and depth. Users of this platform have the option of complete anonymity, i.e., they can provide additional information if they are willing (name of the vessel, model and characteristics of the instruments used to record the measurement) [29, 30]. In particular, [29] highlights the potential of using CSB data in coastal shallow waters that are difficult for traditional survey vessels to access, as well as in areas where old technical means were used for surveying (especially surveys conducted before the second half of the 20th century). Crowdsourced reports play a very important role in drawing attention to critical areas. Such data can be used by cartographers to decide on a possible resurvey of certain areas and thus make improvements to nautical charts [30]. Port areas, where even the smallest changes in the configuration of the seabed can affect the safety of navigation, are found to be critical areas. To detect potential seabed configuration changes in port areas, Doctech has developed a model to collect soundings from service vessels (tugs and pilot boats) operating in the port on a daily basis. Docktech uses this data to periodically produce harbour charts and provide the harbormaster with up- to-date information on the need for dredging, relocation of marker buoys, etc. [31]. Recently, numerous opportunities have opened up for the application of crowdsourcing in the applied sciences, especially given the breadth of its use and the possibilities of using smartphones. In [32], authors explore the possibility of using a mobile application to involve users in water level measurements.

The quality and accuracy of CSB data depends on environmental factors. In [33], factors such as tidal range, wind, and waves and their effects on data quality are analyzed. Baxter highlights the CSB concept as one of the solutions to compensate for the decline in global government survey capacity. In his paper, he compares bathymetric data obtained from acquired through CSB datasets and multibeam echosounder surveys in Plymouth Sound [34]. In [35], Sedaghat et al. analyze CSB data for the Baltimore Harbor area and find that the anomaly presented in the depth data may indicate the presence of submerged debris. Calder describes the design of an end-to-end system for managed volunteer bathymetric collection consisting of an inexpensive wireless data logger for NMEA0183 and NMEA2000 data, associated firmware to manage the collection, a mobile application for data transfer to the cloud and further data transfer to international data repository. Doing so would strongly support many data collection events that would otherwise be ignored for reasons of complexity. In turn, this would provide more and better data to projects such as Seabed 2030, with the goal of fully mapping world oceans [36]. In [37], crowdsourced data from the Olex AS database for the regions of Newfoundland, Labrador and Eastern Canada are used. The data used were mostly collected from fishing vessels. Olex AS enables its own users to record and share collected bathymetric data with each other. Due to the density of fishing activities in the observed area, a larger number of crowdsourced data is available than the official data provided by the Department of Fisheries and Oceans Canada. The aim of the paper is to show the potential contribution of CSB data to a better understanding of certain regions through the identification and classification of attributes of underwater terrain [37]. The authors in [38] developed software architecture for collecting dataset for environmental model simulations. Distributed leisure Yachts sensor Network for Atmosphere and Marine Observations (DYNAMO) as the Internet of Floating Things (IoFT) framework for coastal marine data crowdsourcing used for collecting a continuously updated dataset for environmental model simulations, such as the application for marine pollution simulation by using crowdsourced seafloor depth data. The authors in [39] describe a framework for using sensors on boats to construct new bathymetric datasets. The data was collected through the IoFT ecosystem called DYNAMO . FACE-IT Galaxy workflow engine was used to manage collected data, and CUDA-accelerated algorithms were used to process a large amount of data [39]. Although the IHO CSB data application is not analyzed in [38] and [39], the application of bathymetric data collected from pleasure boats in coastal navigation is analyzed for environmental simulations, which shows additional possibilities of applying CSB data even in that additional fields.

In general, there are a number of problems associated with bathymetric data. One of them is the uneven distribution. On the one hand, we have a relatively small number of these data, and on the other hand, data congestion may occur in some sea areas. Therefore, Kamolov and Park refer to excessive data congestion as one of the main problems of the CSB concept. In order to reduce the data congestion, i.e., to eliminate unnecessary and incorrect data, the use of the fuzzy C-means clustering method (FCM) was proposed in [40]. With the help of this method, the data processing time is significantly reduced. The performance of the FCM algorithm depends on the selection of the initial cluster center. If the initial center of the cluster is selected near the final center of the cluster, the FCM algorithm converges the data faster and the processing time is drastically reduced [42]. In [43], a newer algorithm for more efficient clustering (psFCM) is proposed that significantly reduces the calculation time required to distribute the data among the clusters.

From the literature review, it is obvious that the CSB concept has not been fully researched, especially in the segment of the navigational importance of these data.

3. METHODOLOGY / *Metodologija*

The methodology is based on the comparison of unofficial bathymetric data (CSB) with official data (ENC) depth values. A comparison is based on the analysis of the depth's values from the two sources at the same geographical position. Depth data from IHO DCDB are used as the data source for CSB, while depth data from official ENCs are downloaded from the official websites of hydrographic organizations such as NOAA, whose data are analyzed in this paper. Indeed, through the cooperation between IHO DCDB and NOAA, it is possible to display the data in the DCDB database in such a way that the data collected under the CSB concept can be displayed through the display used in the NOAA ENC web map service. Therefore, in this paper, the depth values in the considered areas displayed on the NOAA ENC Web Map Service were compared with the same depth values in the database IHO DCDB. By integrating these two systems, it is possible to compare the same positions recorded in two different databases. All compared data are presented in the same horizontal datum (WGS 84), and positions are given in decimal degrees. When comparing depth data at the same positions, categorization was also performed according to the criterion of navigational reliability of the data, i.e., CATZOC (category zones of confidence). According to IHO standard S-67 (Mariners' Guide to Accuracy of Depth Information in Electronic Navigational Charts), depth accuracies are determined (Table 1).

Table 1 CATZOC marks and limitations
Tablica 1. CATZOC oznake i ograničenja

ZOC	POSITION ACCURACY	DEPTH ACCURACY
A1	± 5 m + 5% depth	0,5 m + 1% depth
A2	± 20 m	1,00 m + 2% depth
B	± 50 m	1,00 m + 2% depth
C	± 500 m	2,00 m + 5% depth
D	Worse than ZOC C	Worse than ZOC C
U	Unassessed-The quality of the depth is yet to be answered	

Source: [44]

For each CATZOC IHO predicts a different degree of accuracy of the depth level values. The positional accuracy of analyzing

Table 2 Methodology for comparison of ENC and DCDB depths

Tablica 2. Metodologija usporedbe dubina s ENC i DCDB

ENC CHART DEPTH (d)	CSB depth (d_c)	X (CAT ZOC)*	d'	Δd
d_1	d_{c1}	X_1(ZOC A1)=1%d_1+0,5m	$d_1'=d_1 \pm X_1$	$\Delta d_1=d_{c1}-d_1'$
d_2	d_{c2}	X_2(ZOC A2)=2%d_2+1m	$d_2'=d_2 \pm X_2$	$\Delta d_2=d_{c2}-d_2'$
d_3	d_{c3}	X_3(ZOC B)=2%d_3+1m	$d_3'=d_3 \pm X_3$	$\Delta d_3=d_{c3}-d_3'$
d_4	d_{c4}	X_4(ZOC C) =5%d_4+1m	$d_4'=d_4 \pm X_4$	$\Delta d_4=d_{c4}-d_4'$
…	…	…	…	…
d_n	d_{cn}	X_n(ZOC A1-C)**=p%d_n+y	$d_n'=d_n \pm X_n$	$\Delta d_n=d_{cn}-d_n'$
* according to S-67, CAT ZOC depth accuracy (Table 1)				
** for ZOC D and U depth accuraccy according to S-67 is currently not exactly defined or assessed.				

data was not specifically considered in this paper because only depth data in the same overlapping positions of two layers (IHO DCDB database and NOAA ENC database) were considered.

To compare the mutual relationships between the values of the analyzed data the methodology presented in Table 2 was developed in this paper. In the first step, the depth values in the database NOAA ENC and in the database IHO DCDB are determined and recorded. In the second step, CAT ZOC is downloaded with ENC for four analyzed areas. Based on the provisions of S-67 depth accuracy, for each of CATZOC and depth, value X_n is expressed. In the third step corrected ENC depth (including the possible variation of the depth value expressed as maximum and minimum depth) is calculated and expressed as *d'*. In the fourth step, the mutual relationships between the depth from ENC and the depth from IHO DCDB are determined and expressed as *Δd*.

The terms listed in Table 2 denote:

- (d) - stands for the depth values in meters of the analyzed positions displayed on the ENC.
- (d_c) - represents the depth values in meters of the identical analyzed positions shown in IHO DCDB.
- (X) - represents the depth accuracy as per Table 1 for each ZOC
- (y) - a variable whose value is determined in accordance with IHO S-67 and displayed in Table 1
- (d') - represents the possible variation of the depth value expressed as maximum and minimum depth in accordance with S-67
- (Δd) - represents the differences between the depth values from the IHO DCDB and the analyzed depth values of the same position from ENC.

By analyzing the data presented in Table 2, it is also possible to calculate and display the overall average of the difference in analyzed depth data from identical positions from the IHO DCDB and ENC according to the following expression:

$$\overline{D} = \frac{\Delta d_1 + \Delta d_2 + \cdots \Delta d_n}{n} \quad (3.1.)$$

Where:

- $\overline{D}$ - represents the total average value of the difference in depth data, expressed as an arithmetic mean.
- Δd_1-Δd_n are the differences of the compared depths, and
- n - is the total number of analyzed and compared identical positions from the database IHO DCDB or ENC.

The aim of this value is only to show the relative overall differences of the compared data values in a particular area.

Each analyzed area is described by one figure (that represent the part of the ENC cell) and one graph for each selected area. The figures show the official depth values with the overlap of purple lines. These purple lines indicate IHO DCDB data collected from ships participating in the CSB concept. The intersections of IHO DCDB and NOAA ENC data are presented on the graphs. Only for clarity, the positions of the compared depths are connected by lines in the graphs. Thus, these lines do not show the bathymetry of the seafloor. The lines merely connect two adjacent points to facilitate monitoring and analysis of the depth data presented in the graph.

Data on CATZOC areas were downloaded from the NOAA ENC web map service and were used to approximate the level of acceptability or criticality of CSB data compared to ENC data. Graphs show the results of the depth data synthesis for a limited number of available intersection data. In this way, the determined and listed variation of the depth value from ENC (*d'*) and depth value from IHO DCDB (d_c), are displayed and compared on a graph with the aim to visualize the relationship among them. The conclusion was made based on comparison of mutual relationship of depth values from two sources at the same positions.

It is important to mention that the limitations of the study are the uneven distribution of data in the DCDB, the relatively small number of data that can be compared, and the impossibility of comparing data in all CATZOCs.

4. RESULTS / *Rezultati*

Analysis of the data from IHO DCDB shows that most of the measurements were made on the coasts of the United States. Since there is cooperation between IHO DCDB and NOAA, it is possible to compare bathymetric data from these sources. The overlay option of US NOAA allows the display of CSB data over ENC cells. Four areas were selected for comparison where there is a sufficient amount of data from these two sources at the same positions and with the same horizontal datum (WGS-84). The comparison areas are referred to as Areas 1 through 4.

Data from the ENC cell US4NY1AM ("Approaches to New York Fire Island Light to Sea Girt") were used as the source for the official depth data [45]. Area 1 (0.46 square miles) is located in the harbor area of New York, USA, and is defined by coordinates A(40.650˚N74.054˚W), B(40.650˚N74.036˚W), C(40.643˚N74.036˚W), D(40.643˚N74.054˚W), and is shown in Figure 1.

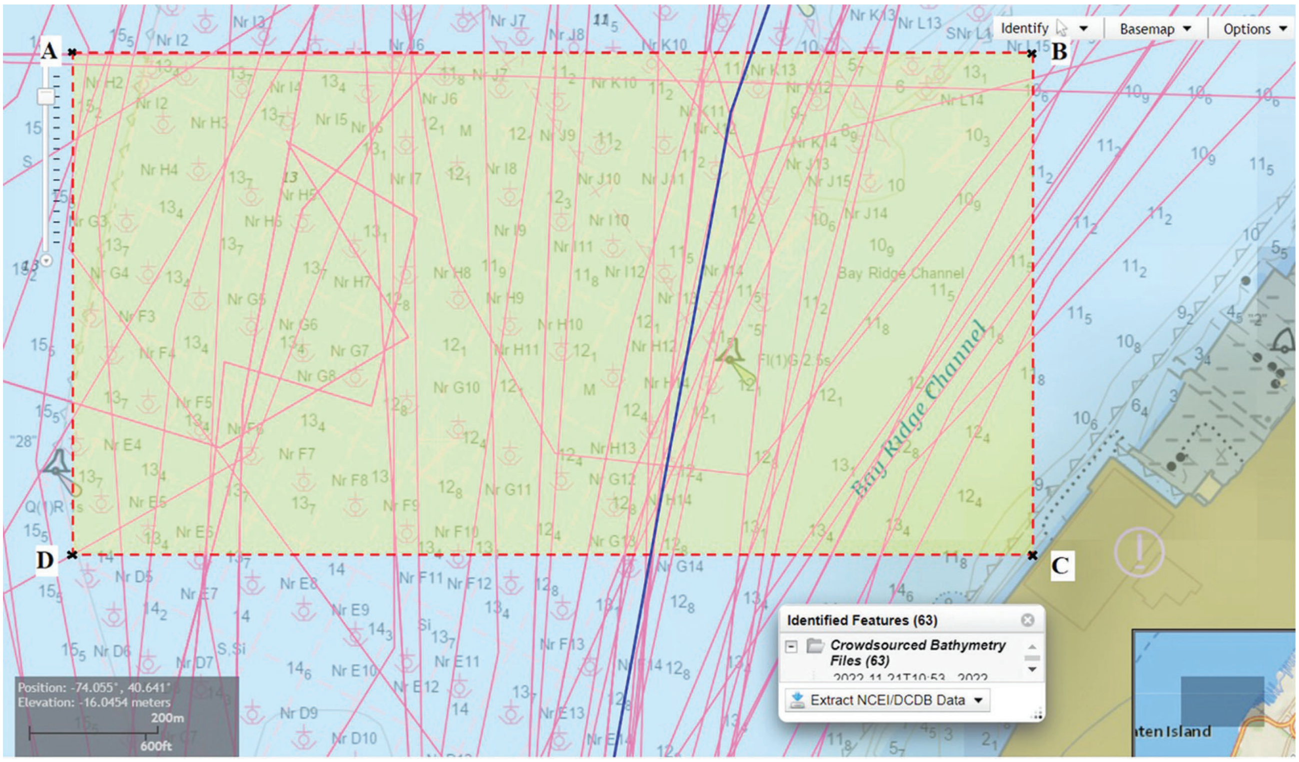

Figure 1 Boundaries of Area 1 overlayed with IHO DCDB data

Slika 1. Granice Područja 1 preklopljene podacima IHO DCDB

Source: [46]

Figure 1 shows an integrated view of the data from IHO DCDB (purple lines) and ENC in Area 1. The figure shows that the depth data from the two databases do not overlap to any great extent. For this reason, it was not possible to compare all the data in Area 1. The analysis showed that the positions in Area 1 overlap by 36 depths. A comparison of these depths is shown in Figure 2.

From Figure 2, it can be seen that the depths of IHO DCDB largely follow the upper positive limit of CATZOC. The analysis also shows that the largest individual deviation of the data from IHO DCDB from the upper positive CATZOC boundary is 1.0403 m in position 40.646˚N and 74.040˚W. The overall mean between the data from IHO DCDB and the upper positive depth from ENC, expressed as an arithmetic mean according to 3.1, is 0.048 m.

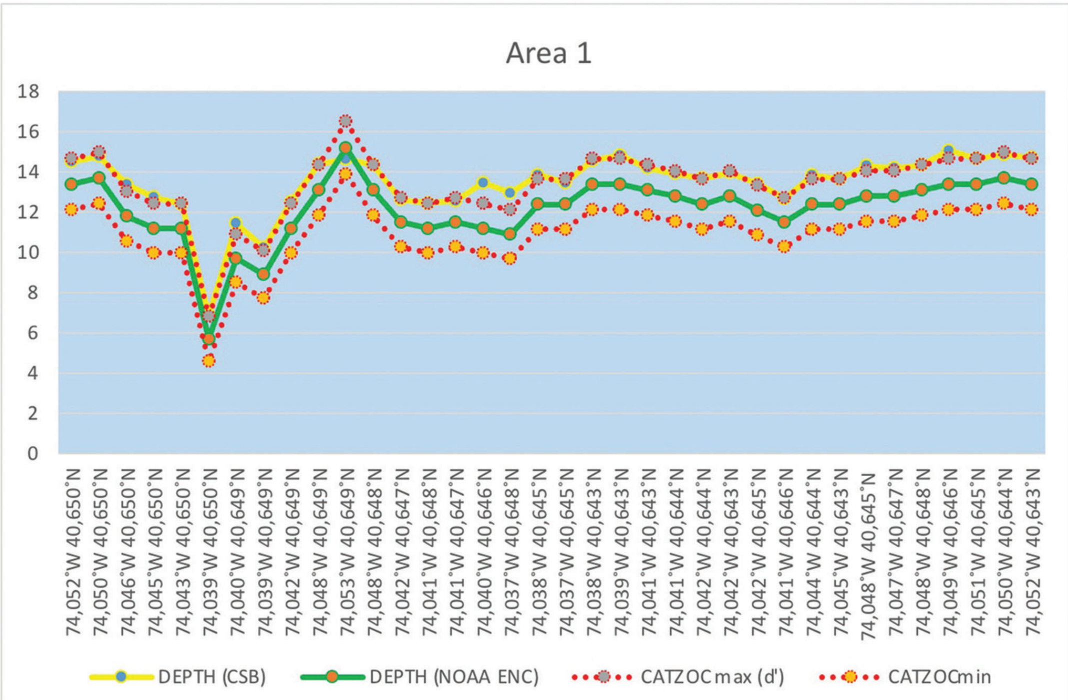

Figure 2 A comparison of overlapped depts in the Area 1

Slika 2. Usporedba dubina koje se preklapaju u Području 1

Sources: [16, 46]

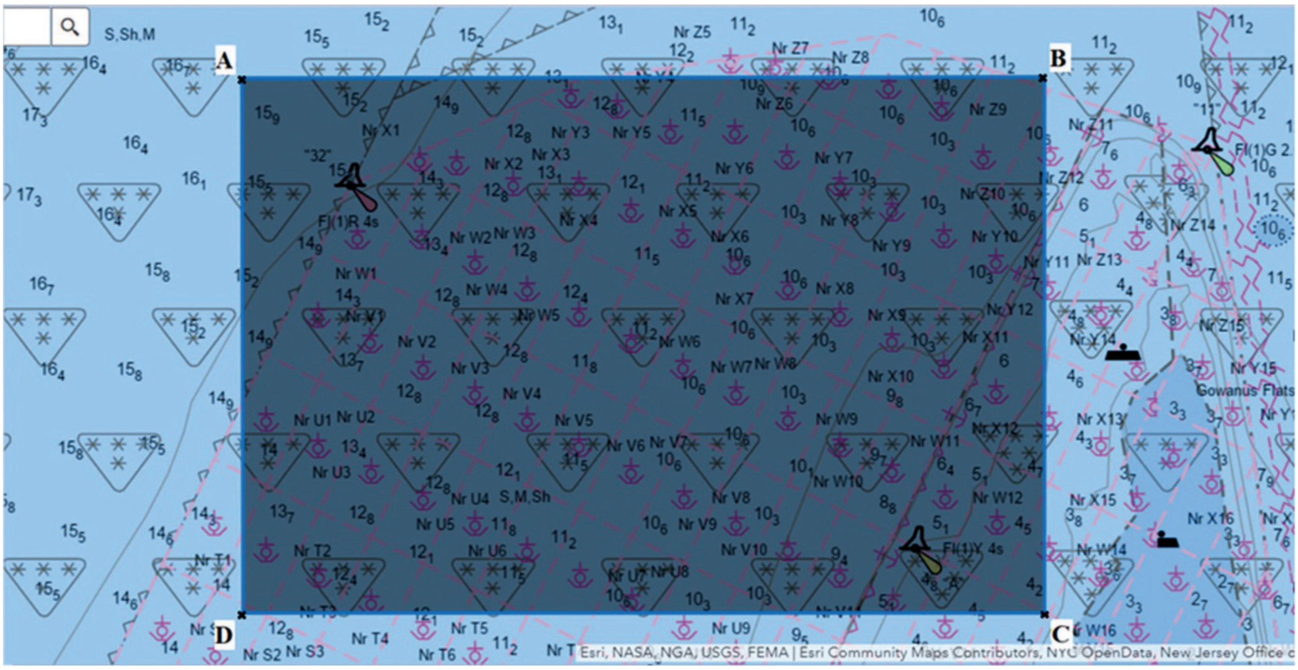

Figure 3 Boundaries of Area 2 with NOAA ENC WMS CATZOC data

Slika 3. Granice Područja 2 s NOAA ENC WMS CATZOC podacima

Source: [16]

The second comparison area, Area 2 (0.47 square miles), is also located in the New York Harbour area, USA, and is bounded by the following coordinates: A(40.673˚N74.042˚W), B(40.673˚N74.027˚W), C(40.666˚N74.027˚W), and D(40.666˚N74.042˚W), and is shown in Figure 3.

Figure 3 shows a section of ENC cell US4NY1AM (approaching New York Fire Island Light to Sea Girt) with official depth data. Two levels of CATZOC (ZOC A1 and ZOC B) can also be seen. The analysis showed that the positions in Area 2 overlapped by 29 depths. The first three depths are in ZOC A1, while the other 26 depths are in ZOC B. A comparison of these depths is shown in Figure 4.

From Figure 4, it can be seen that the depths of IHO DCDB largely follow the upper positive bound of CATZOC. The analysis shows that the largest individual deviation of the data from IHO DCDB from the upper positive CATZOC boundary is 1.2317 m in position 40.672˚N and 74.033˚W. The overall mean between the data from IHO DCDB and the upper positive depth of ENC, expressed as an arithmetic mean according to 3.1, is 0.121 m.

The third comparison area, Area 3 (0.44 square miles) is bounded by the coordinates: A(40.715˚N74.031˚W), B(40.715˚N74.020˚W), C(40.704˚N74.020˚W), and D(40.704˚N74.031˚W), and is shown in Figure 5. Data from cell US3NY01M ("Approaches to New York Nantucket Shoals to Five Fathom Bay") were used as the source for the analysis of the official depth data in this area.

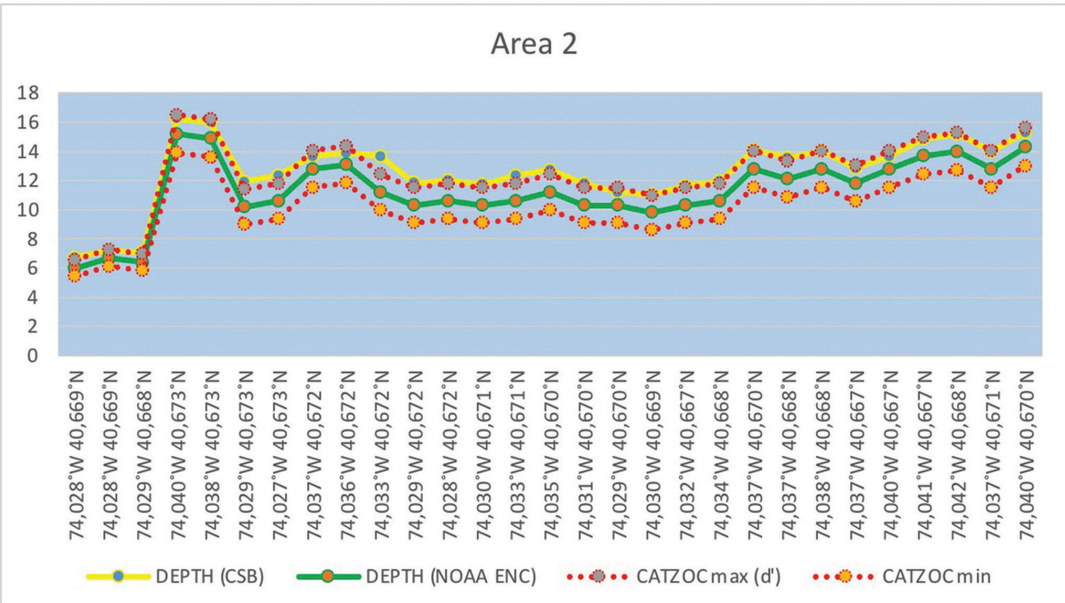

Figure 4 A comparison of overlapped depts in the Area 2

Slika 4. Usporedba dubina koje se preklapaju u Području 2

Sources: [16, 46]

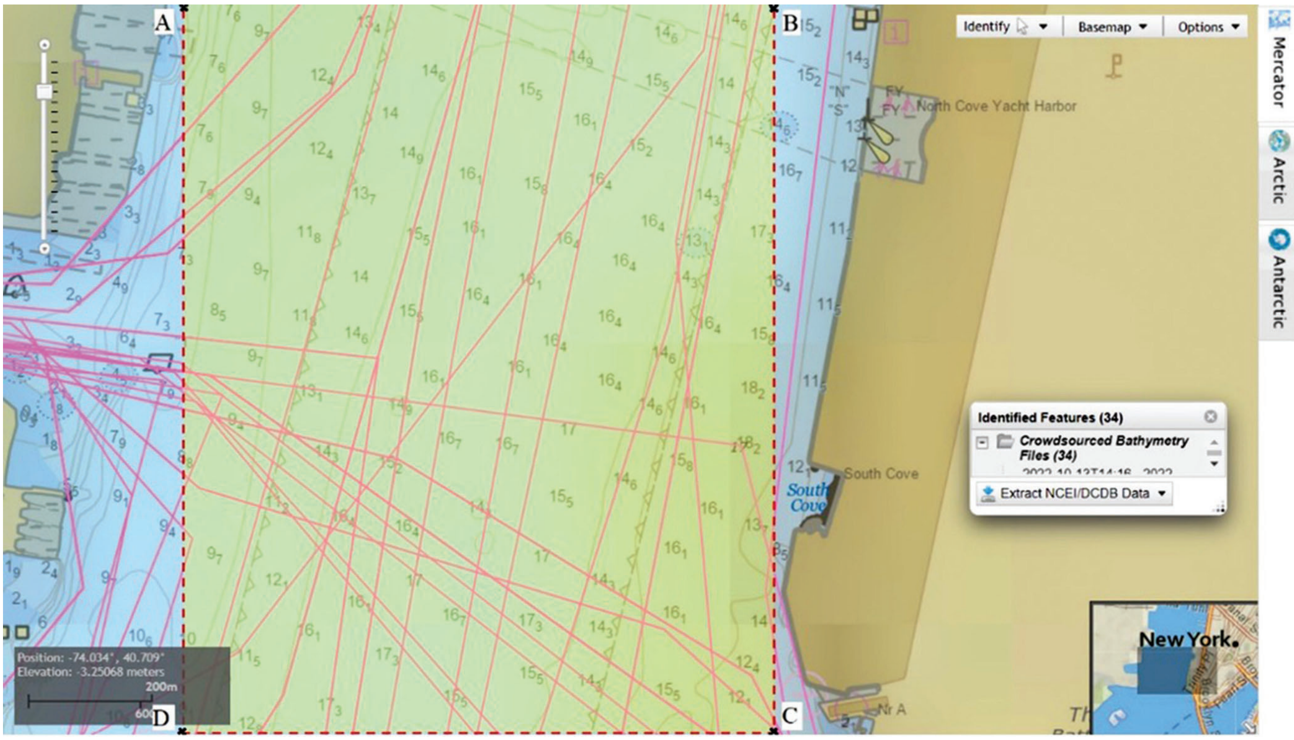

Figure 5 Boundaries of Area 3 overlayed with IHO DCDB data

Slika 5. Granice Područja 3 preklopljene podacima IHO DCDB

Source: [46]

Figure 5 shows an integrated view of the data from IHO DCDB (purple lines) and ENC in Area 3. The figure shows that the depth data from the two databases do not overlap to any great extent. The analysis showed that the positions in Area 3 overlap by 21 depths. A comparison of these depths is shown in Figure 6.

All depths shown in figure 6 are in ZOC B. Figure 6 shows that the depths of IHO DCDB largely follow the upper positive boundary of CATZOC. The analysis also shows that the largest individual deviation of the data from IHO DCDB from the upper positive CATZOC boundary is 1.937 m in position 40.707˚N and 74.025˚W. The overall mean between the data from IHO DCDB and the upper positive depth from ENC, expressed as an arithmetic mean according to 3.1, is 0.207 m.

The fourth comparison area, Area 4, is located in the Gulf of Mexico at the entrance to Tampa Harbour. Data from ENC cell US3GC06M ("Tampa Bay to Cape San Blas") were used as the source for the analysis of the official depth data in this area. The area is bounded by the following coordinates: A(27.624˚N83.059˚W), B(27.624˚N82.894˚W), C(27.579˚N82.894˚W), and D(27.579˚N83.059˚W), and is shown in Figure 7.

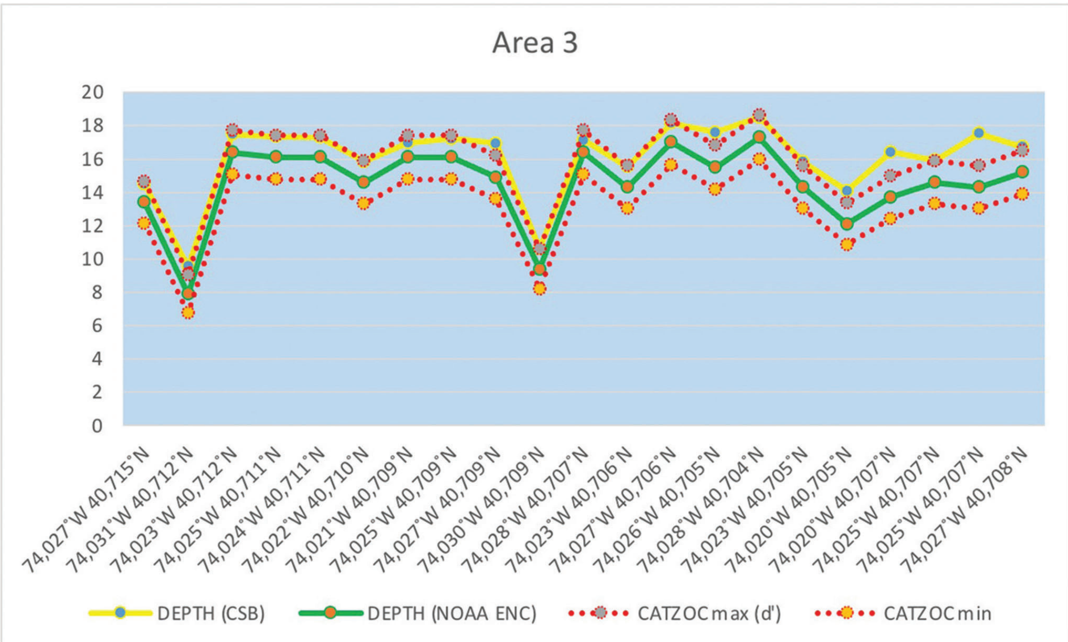

Figure 6 A comparison of overlapped depts in the Area 3

Slika 6. Usporedba dubina koje se preklapaju u Području 3

Sources: [16, 46]

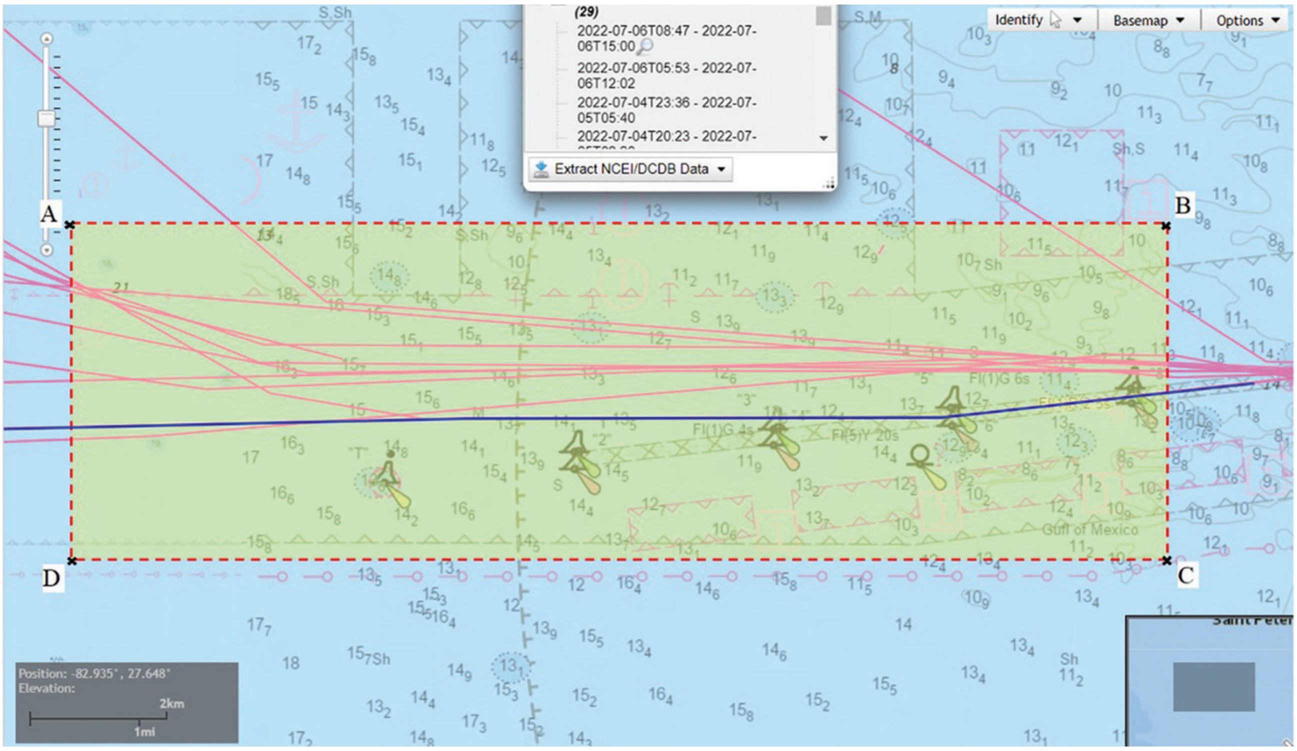

Figure 7 Boundaries of Area 4 overlayed with IHO DCDB data
Slika 7. Granice Područja 4 preklopljene podacima IHO DCDB

Source: [46]

All depths shown in Figure 7 are located in ZOC A1. The analysis showed that the positions in Area 4 overlap by 18 depths. A comparison of these depths is shown in Figure 8.

From Figure 8, it can be seen that the depths of IHO DCDB largely follow the upper positive limit of CATZOC. The analysis also shows that the largest individual deviation of the data from IHO DCDB from the upper positive CATZOC boundary is 0.808 m in position 27.603˚N and 83.036˚W. The overall mean between the data from IHO DCDB and the upper positive depth from ENC, expressed as an arithmetic mean according to 3.1, is 0.219 m.

The analysis showed that the CSB data values were within the upper positive limits in all 4 comparison areas. From a navigation perspective, this may be a potential problem since the CSB depths are greater than those indicated on ENC.

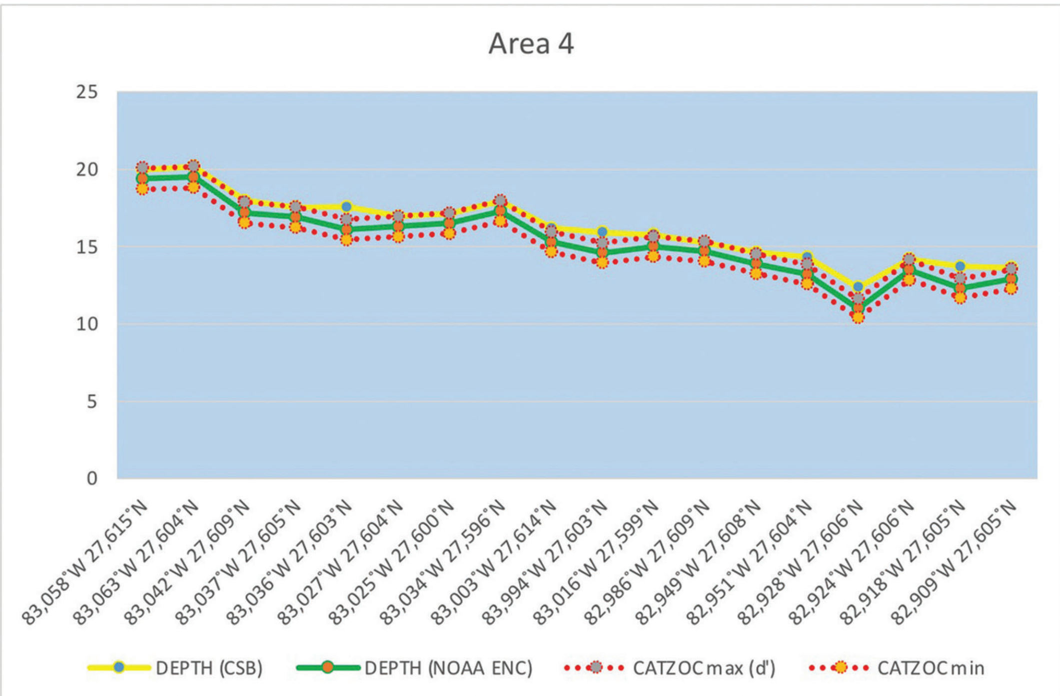

Figure 8 A comparison of overlapped depts in the Area 4
Slika 8. Usporedba dubina koje se preklapaju u Području 4

Sources: [16, 46]

It should be emphasized, that this is unofficial data and is not used for navigation. Notwithstanding this shortcoming, it can be said that it is very valuable data that meets the reliability requirements defined by CATZOC. At this stage, it is not possible to determine the reasons for these discrepancies. For a complete analysis, a larger number of overlapping depths and the existence of complete metadata on the CSB data are needed. This could be the subject of future research.

5.CONCLUSION / *Zaključak*

In this paper the analysis and comparison of depth data from the official ENCs and CSB data was performed. For the analysis, the official depth data were retrieved from the NOAA website, while the CSB data were retrieved from the IHO DCDB website.

The amount of CSB data, and proportionally the amount or density of official data, decreases as one moves further from the coast, i.e., it correlates with the scale of ENC. Indeed, the density of displayed data at ENC can be expected to be higher at a larger scale than the density of depth data at ENC at a smaller scale. Therefore, the possibility of a large amount of depth data overlapping at the same positions from ENC with smaller scale is lower. For this reason, harbor areas and port approaches were primarily chosen as comparison areas in this work.

By analyzing depth data at identical positions in four selected areas on the east coast of the U.S., depth data were compared for a total of 104 positions, of which 22 are in the CATZOC category A1 area and 82 positions are in the CATZOC category B area. The results show that all analyzed depth data collected with the CSB were within the range of CATZOC upper positive depth values.

Although only 104 positions in four areas were analyzed, the proposed method is applicable to all CSB data because comparison with data from ENC can further verify the reliability of the CSB data. This relatively simple method will be applicable worldwide.

Currently, CSB concept is not universally accepted worldwide (only 16 countries have fully accepted it). From the data available in the IHO DCDB database, it appears that only a very small number of vessels participate in the CSB concept. For example, in Area 4, which is 31.3 square miles, data were collected from only two vessels (Genesis Patriot and La Force). Considering that Area 4 is located near the Port of Tampa, there is a distinct possibility that by including a greater number of vessels in the CSB concept, better analysis of depth data may be possible.

Increasing the number of vessels participating in the CSB concept and improving depth data analysis would open the possibility of broader use of CSB data.

Author Contributions: Conceptualization, I. P. and J. M.; Methodology, J. M. Validation, T. R., I. P. and J. M.; Formal Analysis, T. R., I. P. and J. M.; Investigation, T. R.; Resources, T. R.; Data Curation, T. R., I. P. and J. M.; Writing – Original Draft Preparation, T. R., I. P. and J. M.; Writing – Review & Editing, I. P. and J. M.; Visualization, T. R.; Supervision, I. P.

Funding: The research presented in the manuscript did not receive any external funding.

Conflict of interest: None.

REFERENCES / *Literatura*

[1] IHO. (2019). *IHO S-32, Hydrographic Dictionary*. Monaco. Retrieved from http://iho-ohi.net/S32/engView.php?page=4

[2] National Ocean Service. *What is Hydrography?*. Retrieved from https://oceanservice.noaa.gov/facts/hydrography.html.

[3] IHO. (2022). *IHO B-12, Guidance to Crowdsourced Bathymetry, Edition 3.0.0.* Monaco. Retrieved from https://iho.int/uploads/user/pubs/bathy/B_12_CSB-Guidance_Document-Edition_3.0.0_Final.pdf.

[4] Pavić, I. Kasum. J., Mišković. J. & Alujević. D (2020). Analysis of Crowdsourced Bathymetry Concept and It's Potential Implications on Safety of Navigation. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation,* 14(3), 681-686. Retreived from http://dx.doi.org/10.12716/1001.14.03.21

[5] Calder, B. R., Dijkstra, S. J., Hoy, S., Himschoot, K. & Schofield, A. (2020). A Design for a Trusted Community Bathymetry System. *Marine geodesy,* 43(4), 327-358. Retreived from https://doi.org/10.1080/01490419.2020.1718255

[6] Jakobsson, M. (Ed.) (2020). *The Nippon Foundation – GEBCO – Seabed 2030, Roadmap for Future Ocean Floor Mapping.* Retreived from https://seabed2030.org/sites/default/files/documents/seabed_2030_roadmap_v11_2020.pdf

[7] IMO. (2020). *International Convention for the Safety of Life at Sea (SOLAS), 1974, Consolidated Edition, 1st January 2020.* IMO Publishing, London, United Kingdom.

[8] IHO. (2022). *IHO File No. S3/8151 & S3/7198 & S3/0104 Circular Letter N° 41 Adoption of Edition 6.1.0 of S-44 – IHO standards for hydrographic surveys and Edition 3.0.0 of B-12 – Guidance for crowdsourced bathymetry*. Retrieved from https://iho.int/uploads/user/circular_letters/eng_2022/CL41_2022_EN_v1.pdf

[9] UN. United Nations Convention on the Law of the Sea. Retrieved from: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

[10] Luma-Ang, C. S. (2017). Crowdsourced Bathymetry: Supporting Progress or Threatening Security. *The Maritime Review*, 17-5, 23-25. Retrieved from: https://maritimereview.ph//past-issues/mr-2017-09-10.pdf

[11] IHO. (2020). *Acceptance of Crowdsourced Bathymetry Activities and provision of resultant dataset in National Waters of Jurisdiction.* Retrieved from: https://iho.int/uploads/user/Inter-Regional%20Coordination/CSBWG/MISC/B-12_2020_EN_Acceptance_of_CSB_Data_in_NWJ_v3.0.pdf

[12] Brett, J. in Cruising world. (2015 July 24). *Eliminating the unknown*. Retrieved from https://www.cruisingworld.com/eliminating-unknown/

[13] Weintrit, A. (2009). *The electronic chart display and information system (ECDIS) An operational handbook*. Taylor & Francis Group, London, UK.

[14] Olex. *Charting and navigation*. Retrieved from https://olex.no/index_en.html.

[15] Rose point. *The New Rose Point ECS.* Retrieved from https://www.rosepoint.com/rose-point-ecs /

[16] NOAA. *NOAA ENC Viewer.* Retrieved from https://nauticalcharts.noaa.gov/enconline/enconline.html.

[17] Navionics. *Chartplotter charts.* Retrieved from https://www.navionics.com/fin/charts/features/navionics.

[18] Navionics. *Navionics viewer.* Retrieved from https://webapp.navionics.com/?lang=en#boating@ 6&key=qpxeG%7BnneB

[19] C-map. *C-map All charts*. Retrieved from https://www.c-map.com/all-charts/

[20] IHO. (2018). *IHO S-66, Facts about electronic charts and carriage requirements, Edition 1.1.0.* Monaco. Retrieved from https://iho.int/uploads/user/pubs/standards/s-66/S-66%20Edition%201.1.0_Final_Clean.pdf

[21] Hecht, H., Berking, B., Büttgenbach, G., Jonas, M. & Alexander, L. (2002). *The electronic chart: functions, potential and limitations of a new marine navigation system.* GITC bv, Lemmer, Netherlands.

[22] Kjerstad, N. (2016). *Electronic and Acoustic Navigationsystems for Maritime Studies, First Edition*. NTNU, Ålesund, Norway.

[23] IMO. (2006, December, 5). *IMO Resolution MSC.232(82), Adoption of the revised performance standards for electronic chart display and information systems (ECDIS).* Available at https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMO Resolutions/MSCResolutions/MSC.232(82).pdf

[24] Hecht, H., Berking, B., Jonas, M. & Woster, M. (2017). *The electronic chart fundamentals, functions, data and other essentials, a textbook for ECDIS use and training (fourth edition)*. GITC bv, Lemmer, Netherlands.

[25] IHO. (June, 2014.). *IHO S-57, IHO transfer standard for digital hydrographic data supplementary Information for the encoding of S-57 Edition 3.1, (Edition 3.1.3).* Monaco, Available at https://iho.int/uploads/user/pubs/standards/s-57/S-57_e3.1_Supp3_Jun14_EN.pdf

[26] Thornton, P. (2016). *The ECDIS manual.* Whiterby publishing group ltd, Edinburgh, Scotland, UK.

[27] Wölfl, A.-C. et. al. (2019). Seafloor Mapping – The Challenge of a Truly Global Ocean Bathymetry. *Froniters in Marine Science,* 6(2019). Retrieved from: https://www.frontiersin.org/articles/10.3389/fmars.2019.00283/full

[28] Jencks, J. & Chappell, A. (2018). Working Together to Map the Gaps. *Hydro International.* Retrived from: https://www.hydro-international.com/content/article/working-together-to-map-the-gaps

[29] Simoniello, C. et. al. (2019). Citizen-Science for the Future: Advisory Case Studies From Around the Globe. *Froniters in Marine Science*, 6(2019). Retrieved from: https://www.frontiersin.org/articles/10.3389/fmars.2019.00225/full

[30] NOAACOASTSURVEY. (14. June 2016). *Beta test of crowdsourced bathymetry holds promise for improving U.S. nautical charts.* Retrieved from: https://nauticalcharts.noaa.gov/updates/beta-test-csb/

[31] Ginker, B., Solomon, S., & Hassin, A. (2022). Evaluation of a crowd sourced bathymetric approach. *The International Hydrographic Review*, 28, Retrieved from: https://ihr.iho.int/articles/evaluation-of-a-crowd-sourced-bathymetric-approach/

[32] Elias, M., & Maas, H. G. (2022). Measuring water levels by handheld smartphones – A contribution to exploit crowdsourcing in the spatio temporal

densification of water gauging networks. *International Hydrographic Review,* 27:9-22. Retrieved from: http://dx.doi.org/10.58440/ihr-27-a01

[33] Jia, S., Liang, Z., Zhang, L. & Yuan, H. (2022). Uncertainty Modeling of Crowdsourced Bathymetry Data Influenced by Marine Environment. *2022 3rd International Conference on Geology, Mapping and Remote Sensing (ICGMRS), Zhoushan, IEEE*, 846-852. Retrieved from: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9849245

[34] Baxter, C. Crowdsourced Bathymetry Utilising the Crowd to obtain high quality depth data. Retrieved from: https://www.ths.org.uk/documents/ths.org.uk/ downloads/1._chris_baxter.pdf

[35] Sedaghat, L., Hersey, J., & McGuire, M. P. (2013). Detecting spatio-temporal outliers in crowdsourced bathymetry data. *Geocrowd '13. Proceedings of second ACM Sigspatial international workshop on crowdsourced and volunteered geographic information,* 55-62. Retrived from: https://dl.acm.org/doi/abs/10.1145/2534732.2534739

[36] Calder, B. (2023). Design of a Wireless, Inexpensive Ocean of Things System for Volunteer Bathymetry. *IEEE*. Retrieved from: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=10007655

[37] Novaczek, E., Devillers, R. & Edinger, E. (2019). Generating higher resolution regional seafloor maps from crowd-sourced bathymetry. *Plos one,* 14(6). Retrieved from: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0216792

[38] Di Luccio, D., Riccio, A., Galletti, A., Laccetti, G., Lapegna, M., Marcellino, L., Kosta, S. & Montella, R. (2020). Coastal Marine Data Crowdsourcing Using the Internet of Floating Things: Improving the Results of a Water Quality Model. *IEEE Access*, 8, 101209-101223, Retrieved from: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9098885

[39] Montella, R. et. al. (2019). Workflow-based automatic processing for Internet of Floating Things crowdsourced data. *Future generation computer systems,* 94, 103-119. Retrieved from: https://doi.org/10.1016/j.future.2018.11.025

[40] Kamolov, A. A. & Park, S. (2021). Prediction of Depth of Seawater Using Fuzzy C-Means Clustering Algorithm of Crowdsourced SONAR Data. *Sustainability,* 13(11), 5823. Retrieved from: https://doi.org/10.3390/su13115823

[41] IHO. (2020). *IHO S-67, Mariners' Guide to Accuracy of Depth Information inElectronic Navigational Charts (ENC), Edition 1.0.0.* Monaco. Retrieved from https://iho.int/uploads/user/pubs/standards/S-67/S-67%20Ed%201.0.0%20Mariners%20Guide%20to%20Accuracy%20of%20Depth%20Information%20in%20an%20ENC_EN.pdf

[42] Sharma, R. (2022 July 27). *What is Clustering and Different Types of Clustering Methods.* Retrieved from: https://www.upgrad.com/blog/clustering-and-types-of-clustering-methods/

[43] Hung M-C. & Yang D-L. (2001). An Efficient Fuzzy C-Means Clustering Algorithm. *Proceedings 2001 IEEE International Conference on Data Mining*, 225-232. Retrieved from: https://doi.org/10.1109/ICDM.2001.989523

[44] IHO. (2020). *IHO S-67, Mariners' Guide to Accuracy of Depth Information inElectronic NavigationalCharts (ENC), Edition 1.0.0. Monaco*. Retrieved from https://iho.int/uploads/user/pubs/standards/S-67/S-67%20Ed%201.0.0%20Mariners%20Guide%20to%20Accuracy%20of%20Depth%20Information%20in%20an%20ENC_EN.pdf

[45] Primar. *Primar portal, Primar chart catalogue*. Retrieved from: https://primar.ecc.no/primar/portal/cc/mapClient.jsf.

[46] *IHO Data Centre for Digital Bathymetry Viewer.* Retrieved from: https://www.ncei.noaa.gov/maps/iho_dcdb/