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Accuracy of bathymetric data in electronic navigational charts

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Abstract

Navigational charts are essential tools for marine navigation. But how accurate are the navigational charts that we use when going sailing? Do we really know how much faith can be placed in them? All charts, whether paper or electronic, contain data, which varies in quality due to the age and accuracy of individual surveys. In general, remote areas away from shipping routes tend to be less well surveyed, and less frequently, while areas of high commercial traffic are re-surveyed frequently to very high levels of accuracy, particularly where under-keel clearances are small. It is quite accurate to consider a chart as a jigsaw of individual surveys pieced together to form a single image. Having the necessary skills to determine how much confidence should be placed in the surveys, which combine to form a chart, should be a requirement for any sailor venturing into unfamiliar waters. When the International Hydrographic Organization (IHO) developed the S-57 standard for Electronic Navigational Charts (ENCs), this problem was recognized and it was decided that the quality of survey data used to compile ENCs had to be encoded within a composite data quality indicator 'Category of Zone of Confidence' (CATZOC) to assist seafarers in assessing hydrographic survey data and the associated level of risk of navigating in a particular area. According to IHO S-67, the accuracy of Electronic Navigational Charts is not impressive and leaves much to be desired. The author discusses these apparent shortcomings of ENCs and present erroneous approaches to this problem, so common in the seafaring community.

Introduction

Despite the best efforts of Hydrographic Offices (HOs) around the world, the Electronic Navigational Charts (ENCs) that are used today do not always depict the real world as accurately as would be desired. This situation arises because gathering detailed hydrographic data is slow and, consequently, ENCs (and paper charts as well) are compiled from multiple data sources, some modern and comprehensive, some old (even ancient) and others from all stages in between. When the International Hydrographic Organization (IHO) developed the S-57 standard, this situation was recognized and the quality of survey data used to compile ENCs had to be encoded within a composite data quality indicator 'Category of Zone of Confidence' (CATZOC) (Weintrit, 2009; Mellor, 2017).

In April 2017, the International Hydrographic Organization published the Mariners' Guide to Accuracy of Electronic Navigational Charts (ENC) (IHO S-67, 2017). That publication is intended for mariners making the transition from paper charts, SNC (Standard Navigational Charts), to ENC (Electronic Navigational Charts), those providing training for mariners making that transition, and for those simply wishing to improve their knowledge of how to determine which parts of an ENC are accurate and reliable, and which parts require caution.

Accuracy of nautical charts

All charts, whether paper or electronic, contain data, which varies in quality, due to the age, accuracy, reliability and completeness of individual surveys. A chart can be considered as a jigsaw puzzle of individual surveys pieced together to form a single image. Most charts contain a mixture of surveys of differing quality. In general, remote areas away from shipping routes tend to be less well surveyed, and less frequently, while areas of high commercial traffic are re-surveyed frequently to very high levels of accuracy and completeness, particularly where under-keel clearances are small. However, the vast majority of coastal and international shipping routes fall somewhere between these two standards, where risks and choices are less well defined. To assess these risks, mariners have traditionally relied upon familiar, but often ambiguous indicators used on paper charts, usually in a source diagram or currently in ZOC diagrams (IHO S-4, 2017). The details and interpretations often varied widely between nations, though most simply said how old a survey was, rather than how good. The variations in method, detail and interpretation render this type of quality information unsuitable for use in an electronic system, such as ECDIS, as it prevents use of automated checking routines to look along a planned route to confirm suitability. To address this, the IHO developed and published an international system to be used by all nations within their S-57 ENCs (IHO S-57, 2014). This is the "Zones of Confidence" system, often referred to as "ZOC". The degree of reliance, which can be placed in the depth information within an ENC, can be consistently determined by understanding the Zone of Confidence assessment for an area, then applying a common-sense approach.

Zones of Confidence categories

All S-57 ENC use the Zones of Confidence (ZOC) system. There may be several different ZOC areas within each individual ENC. These assessments enable mariners to consider the limitation of the hydrographic data from which the ENC was compiled, and to assess the associated level of risk to navigate in a particular area. The ZOC system only applies to the bathymetry (depths, contours, submerged rocks and reefs, etc.) – it does not apply to the accuracy of charting the high water line, wharves, navigation aids, pipelines and so on (IHO S-57, 2014; Weintrit, 2018).

There are five basic levels within the ZOC system. Each differing level of quality is referred to as a 'category' within the overall ZOC system. Each category is therefore labelled, as 'CATZOC' when queried within the ENC. CATZOC is a mandatory attribute within the 'M_QUAL' quality information layer within ENC. Other optional M_QUAL attributes include the dates of a survey, the vertical or horizontal accuracy, or details of the survey technology used. Population of these optional details is generally less common (IHO S-57, 2014). The categories range from 'very high confidence' to 'unsurveyed', with an additional category for 'Unassessed' (Table 1). The impact upon mariners of the various categories is discussed in section *Impact of ZOC categories upon seafarers*.

In coastal shipping areas, the most common assessments likely to be encountered are the following (IHO S-67, 2017):

- Zone of Confidence (ZOC) B – around 30% of the world's coastal waters,
- ZOC C – around 20% of the world's coastal waters,
- ZOC D – around 20% of the world's coastal waters,
- ZOC U – around 25% of the world's coastal waters.

From these figures, it should be clear that a firm understanding of the implications of each confidence level is important for planning the safe conduct of a vessel.

Table 1. Zones of Confidence (ZOC) categories (IHO S-67, 2017)

Category	Confidence level	General description – survey characteristics
A1	Significant seafloor features detected and depths measured	High position and depth accuracy achieved using DGPS and a multi-beam, channel or mechanical sweep system
A2	Significant seafloor features detected and depths measured	Position and depth accuracy less than ZOC A1, achieved using a modern survey echo-sounder and a sonar or mechanical sweep system
B	Uncharted features, hazardous to surface navigations are not expected but may exist	Similar depth accuracy as ZOC A2 but lesser position accuracy than ZOC A2 (generally pre-dating DGPS), using a modern survey echo-sounder, but no sonar or mechanical sweep system
C	Depth anomalies may be expected	Low accuracy survey or data collected on an opportunity basis such as sounding on passage
D	Large depth anomalies may be expected	Poor quality data or unsurveyed
U	Unassessed	The quality of the bathymetric data has yet to be assessed. (Mariners should assume poor data quality until the area has been assessed)

ENC ZOC symbols

In the ENC, the different ZOC quality levels are denoted by a series of symbols containing a varying number of stars, enclosed within a triangle or ellipse (Table 2). This symbol is repeated throughout each area of equal quality. The symbols can be made visible or be hidden on the ECDIS screen depending upon the mariner's needs at any particular time. The various categories range from six stars down to two stars. There is an additional category U for areas which are 'Unassessed'.

Table 2. Position and depth accuracy in ECDIS Zones of Confidence (ZOC) (IHO S-67, 2017)

Zone of Confidence (ECDIS Symbol)	Position Accuracy	Depth Accuracy
A1	5 Meters	0.5 Meters + 1% of Depth
A2	20 Meters	1.0 Meters + 2% of Depth
B	50 Meters	1.0 Meters + 2% of Depth
C	500 Meters	2.0 Meters + 5% of Depth
D	More than 500 Meters	More Than 2.0 Meters + 5% of Depth
U (U)	Not Assessed	Not Assessed

Figure 1 shows how data quality may be represented in an ECDIS. The individual meta-features and attributes that are encoded in the ENC provide inputs into the data quality algorithm, which resides within the ECDIS system. This algorithm will produce the composite indicator. The algorithm also has the capability to accept additional optional inputs from vessel-specific parameters (entered into the ECDIS) and external information (e.g., tides). It then drives an on-demand data quality overlay that exists within the ECDIS system. The idea of one quality indicator that includes everything between the ship's keel and the bottom corresponds to the outcome of the mariner's questionnaire. It is believed this will become reality for certain regions where water-level prediction systems will become sufficiently advanced to provide the algorithm with information about the quality of the prediction. It is also believed that ship systems and mariners will be functioning at a sufficient level to provide reliable vessel-specific parameters, i.e., parameters that are time and location dependent. However, there is no certainty about the period of time that this will take before these optional parameters become available. It is the goal to provide an algorithm that is sufficiently flexible to function with or without the optional parameters, to serve mariners better in trying to plan and execute their voyages safely.

What do we mean by data quality?

Generally, data quality is a perception or an assessment of the fitness of data to serve its purpose in a given context. Aspects of data quality include: accuracy, completeness, update status, relevance, consistency across data sources, reliability, appropriate presentation and accessibility. Chart data quality

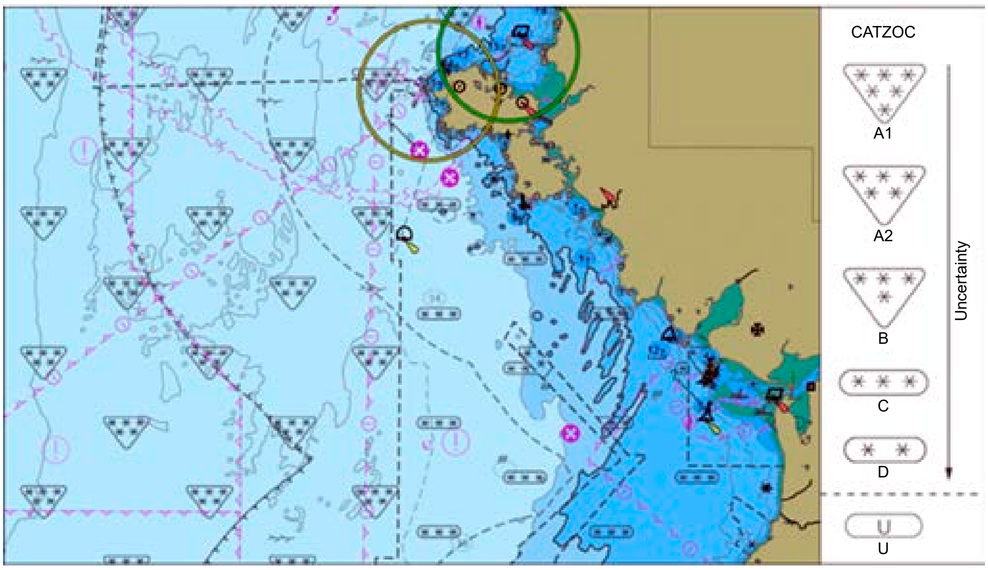

Figure 1. Visualisation of CATZOC symbols on an ENC (Gladisch, Ruth & Jonas, 2017)

comprises the following: source of data, accuracy of data and up-to-dateness of data. Data quality is considered to be meta information. As such, it can be encoded at three different levels. Data quality information is considered to be application specific. Therefore, rules for encoding data quality must be defined by the relevant product specification. In the context of ENC, data quality indicates how well the chart agrees with reality. This is achieved by meta information attached to either the entire dataset, a specific area or individual features. The meta information includes: measurement uncertainty (e.g., the variation between similar measurements at the same location), completeness (e.g., seafloor coverage), and currency (e.g., temporal degradation). Measurement uncertainty can relate to position (2D), vertical (1D), horizontal distance (1D) and orientation (1D) information, at a 95% confidence level. This measurement uncertainty should include all relevant variations due to the measurement procedure, processing errors and visualisation. Uncertainties due to completeness and currency do not lend themselves to such statistical definitions and are therefore handled separately.

Data quality information in current ENCs

S-57 allows the quality of survey data to be recorded in several so-called metadata attributes. However, most cannot be visualised. They can be discovered if the mariner uses functions in the ECDIS to interrogate the data but this severely limits their usefulness. The only data quality information that can be visualised is CATZOC and this is mandatory. This is a single composite indicator for bathymetry: it takes vertical and horizontal uncertainty along with an assessment of the completeness of the survey, and combines these via a simple algorithm to place the bathymetry in one of 5 categories.

Providing all the individual indicators meet the required standards, the area of the ENC can be allocated the relevant ZOC. Once a ZOC category has been assigned, this can be displayed in the ECDIS as a series of stars overlaid on the ENC – the greater number of stars the better the survey (Figure 1). Unfortunately, replies to a comprehensive questionnaire issued to mariners by the DQWG (IHO Data Quality Working Group) made it clear that CATZOC is not adequate, since mariners do not like the visualisation (i.e. the stars), or understand; it nor can they make adequate decisions based upon it. In addition, CATZOC cannot indicate temporal degradation. The start and end dates of the survey can be encoded, but these cannot be visualised. Such a definition does not help the mariner but there is hope of improving on this with the newly developed standard of IHO S-100 (Powell, 2011; Gladisch, Ruth & Jonas, 2017).

Credibility of sources

Establishing the credibility of sources is a matter for professional judgement and experience. All incoming data must be checked for possible errors and inconsistencies. It is essential that the quality of all positional and depth data is established before use. Where there are conflicting or inconsistent sources of information, or there are doubts about the accuracy or validity of the information, clarification should be sought from the appropriate authority. If no answer is forthcoming, a judgement must be made. In such instances, it is important to record the reasons for the decisions, for use when considering later information or for future research. The following guidelines may provide assistance regarding source data types which are commonly received by hydrographic offices. They apply to source material for primary charting areas and for areas largely derived from the publications of other hydrographic offices (IHO S-4, 2017).

Official (and officially sponsored) surveys prepared specifically for nautical charting should be validated by competent surveyors. It must be ensured, as far as possible, that any errors and uncertainties arising from the method of surveying are understood and that the survey remains acceptable for use (IHO S-44, 2008). Unofficial surveys are undertaken for oil companies, cable-laying companies or other contractors and are not specifically designed for charting purposes. Such surveys are often supplied to hydrographic offices but should be treated with caution. Although they can be a source of soundings, they must not be used for disproving critical soundings because of the following limitations:

Surveys are often provided to hydrographic offices with little or no supporting information, making it impossible to know how the survey was conducted, e.g. the method of depth selection applied. However, if there is sufficient metadata, such surveys should be validated by a competent surveyor.

Such surveys (including swathe surveys with apparently very dense datasets) are designed to meet the specification of the survey sponsor, which is unlikely to be in direct support of nautical charting. For example, a survey may have been processed to select the mean depth in any given area, rather than the shoal-biased depth, which would be selected in a hydrographic survey. Mean depth may give a much better 'image' of the sea floor, but filter out pinnacles.

The components of an assessment

Assessments are made based upon four criteria, following which a single ZOC rating is derived for each area of differing quality. The lowest rating for any individual component within that area determines which ZOC category is assigned. Individual assessment criteria are: typical survey characteristics; seafloor coverage (this relates to the possibility that something may have been missed and is therefore not on the chart); position accuracy, and depth accuracy (this relates only to what has been detected and is therefore charted, not what might remain undetected). Of these, the most important factor for mariners is seafloor coverage. For over 95% of the world's coastal waters, this determines the sensible clearance that should be maintained between a ship's keel and the seabed and where any additional precautions may be needed. In the majority of coastal waters, and many oceanic areas, the potential size of an undetected seabed 'surprise' may be equal to or larger than any uncertainty about how good the charted depths may be; it is what may not be charted that really matters. The next most important factor is position accuracy. As there will always be shoals and other features either too shallow or too risky to steam over, the sensible approach is to avoid them. The position accuracy for each category gives some idea of how far away from a hazard a ship should remain (IHO S-67, 2017).

The least important factor is depth accuracy, simply because it is the controlling factor in only a small proportion of the world's coastal waters. It only assumes greater relevance where full seabed coverage has been achieved, such as within or near ports, or in certain channels. In areas where full seabed coverage has not been achieved, the safety margin allowing for the possibility of an uncharted 'surprise' is much larger than the allowance for the accuracy of charted depths. Mariners should not require a detailed understanding of survey characteristics, as long as they understand the implications for shipping explained within each different ZOC category. These three major contributing factors are discussed further in the following paragraphs, with the implications for shipping in each ZOC area discussed in the section *Impact of ZOC categories upon seafarers*.

One limitation of the ZOC system is that it provides little information about when a survey was conducted, or whether the seabed is stable. While the date can be provided in an additional data field within an ENC, this is rarely done, doesn't form part of the chart 'image', and may be difficult to find. In areas where the seabed is subject to change, national hydrographic offices should be downgrading the assigned ZOC category, restoring it only once a replacement survey is incorporated. However, this isn't always done, so it's wise to note areas of sandwaves, dates within dredged channels, and any other notes advising that channels may have changed.

Seafloor coverage

This is the most important factor in assessing and categorizing a survey. Did the surveyor miss anything? Was it potentially small or very large? Are there likely to be any nasty, undetected 'surprises'? The question of whether there are still any nasty surprises in an area affects the majority of the world's coastal and oceanic waters – it is only once there is confidence that nothing has been missed (and therefore nothing left off the chart) that the question of how close a ship can pass to the charted seabed becomes relevant. Yes, charting a dynamic seafloor is not easy (Dorts, 2014). The possibility of dangers being missed typically arises from older surveys, which simply were not as effective as using modern systems. It is only in ZOC areas A1 and A2 where full seafloor coverage has been achieved. It is therefore only in these areas that the accuracy of the charted depths directly defines where a ship can go, and how deep the draft of that ship can be. Even then, according to the ZOC system, there is a very small possibility that small features may remain undetected (less than a maximum size of 2 cubic metres for depths less than 40 metres).

ZOC B, C and D areas result from surveys that were progressively less detailed. In these areas, there is an increasing possibility of undetected features absent from the chart (ranging from a small rock or shoal through to a submerged reef). In a ZOC B area, there is unlikely to be anything undetected affecting surface navigation, though it remains possible. The hydrographic office responsible for the chart will have (or should have) made their assessment based upon the quality of the survey, the depth of water and the size of vessels using the area. In a ZOC C area, there is a strong possibility of undetected features (or charted features significantly out of position). These areas can be considered inadequately surveyed. In a ZOC D area there is a very strong likelihood of large undetected features absent from the chart (or charted features even further out of position). As these areas either have no systematic survey, or are completely unsurveyed, these features may well be as large as an entire submerged reef rising to just below the surface. If contemplating entering a ZOC D area, extensive precautions should be taken, in order to ensure there is sufficient time to react to dangers as they are revealed.

Position accuracy

The next most important factor in most circumstances is accuracy of position of the bathymetry. This includes depth contours, charted depths, reef edges or other charted seabed features. Positioning accuracy is typically determined by the positioning systems used during the hydrographic survey, as well as any loss of accuracy transferring older data from the survey to the chart, or between older data standards and WGS-84. Most ships using modern satellite-based navigation systems can be navigated with much greater accuracy than most of the surveys still used in charts. While some parts of a chart will be based upon modern surveys, away from the most critical areas most charts still rely upon surveys done with progressively older survey systems. While they were cutting-edge for their time, few of these systems were as good as GNSS today. It is only since the 1990s that satellite-based navigation systems have been widely available to survey ships. These give a positioning accuracy of seabed features somewhere in the range of 2 to 20 metres. Determining the position of a feature on the seabed can be much harder than just positioning the survey ship itself.

From the late 1940s to the 1990s, survey ships depended upon shore-based electronic positioning systems, transmitting their signal over short or medium ranges, giving accuracy of around 20 to 100 metres. In coastal areas, this means that anything the ship found could be up to 100 metres from where it was thought to be. Much of this depended upon how accurately the transmitter ashore was positioned, as well as the accuracy of the transmitted ranges to generate the 'fix'. Prior to this, survey ships used sextants to measure angles between a system of prominent marks, or flag poles built on towers established ashore, with surveyors 'angling' for hours at a time. A second row of towers could be built in shallow water or on reefs to extend the network further offshore, but with a further reduction in accuracy. Depending upon how accurately the towers were placed, accuracy of 50 to 500 metres was possible for the survey ship. So again, when something was found, particularly offshore, the true position could quite easily be up to 500 metres from where it was surveyed to be.

Further offshore, where information was collected by ships relying entirely upon celestial navigation, positions could be considerably less accurate, typically no better than 1 to 2 Nm, and frequently worse.

While modern satellite imagery can be used to correct the position of many isolated visible offshore features, such as islands, reefs or perhaps shoals breaking in rough weather, anything more than a few metres below the surface is likely to remain unseen, and therefore possibly well out of its true position.

However, the quoted positional accuracy of charted features is only part of assessing how far to stay clear of a potential danger. Using the example of a rock surveyed to a 20-metre positional accuracy in the approaches to a port, the Master also needs to consider the size of the vessel, the accuracy of the ship's navigation system, and possibly other vessel parameters. The more correct safe distance in this example is likely to be over 50 metres (IHO S-67, 2017):

20 m	positional accuracy of charted seabed feature,	plus
15 m	half ship's beam,	plus
15 m	GNSS accuracy,	plus
5 m	ship orientation / motion	
55 m	total safe distance to clear hazard	

Depth accuracy

Depth accuracy refers to how well the depth of a known feature has been measured below chart datum – it clearly does not refer to the accuracy of something which remains undetected. The margin allowed by a ship's Master for the possibility that something remains undetected within a survey is a separate concern influenced by the seafloor coverage. The three biggest factors affecting depth accuracy in relatively shallow coastal waters are the accuracy of the tidal observations, the motion of the survey ship and the setup of the echo sounder. Old leadline surveys actually contain very accurately measured depths; however, they have a high risk of not detecting shoaler depths nearby. In contrast, a modern multibeam echo sounder misses very little, but requires careful setup and use to deliver accurate results.

Impact of ZOC categories upon seafarers

Put in simple terms, mariners should be able to navigate with confidence in areas with ZOC A1 and A2 classifications. It is also unlikely that an uncharted danger affecting surface navigation exists in ZOC B areas. In ZOC C areas mariners should exercise caution since hazardous uncharted features may be expected, particularly in or near reef and rocky areas. A very high degree of caution is required for areas assessed as ZOC D, as these contain either very sparse data or may not have been surveyed at all. Finally, it is good practice to treat ZOC U areas with the same degree of caution as ZOC D areas. To put this in perspective, the Table 3 is an overall analysis of over 14 million square kilometres of coastal ENC from 32 nations (IHO S-67, 2017). The analysis did not include ports and harbours.

As we can see the situation in the busiest maritime water areas looks not so bad, but it is very far from perfect; the B category dominates, while areas covered by categories A1 and A2, unfortunately, do not impress. But what about the rest of the world? For example, until autumn 2013, mainly categories B and C were used for Norwegian coastal waters, based on the following classifications: ENCs with source data from older surveys (before 1960) are given ZOC value C, while ENCs with source data from surveys younger than ca. 1960 are given ZOC value B. From 1st of January 2014, areas measured with multibeam sonar and which otherwise met the requirements were given the categories A1 or A2: delimitation of the different zones is added to the ENCs to always show which zone you are in. Navigators must show great care when using (D)GPS and electronic charts in areas with older surveys, as the accuracy and completeness of the depth indicators are not in accordance with modern standards. Additionally, navigators should ensure that navigation is conducted at all times with good safety margins and in accordance with proper navigational practices (Kartverket, 2017).

An alternative way to understand ZOC (using the star symbols)

An alternative way to understand the basic concept of confidence levels might be to think about the number of stars symbolizing each area. Even if the specifics are not considered, most people (mariners are people) understand that if something is given more stars in an assessment than another, the one with more stars is considered to be ‘better’. A good example that works similarly to ZOCs might be choosing a hotel from listings on a website. Everyone knows that a six-star hotel is much better than a three star hotel, and will try very hard to stay away from a two-star hotel. Equally, when a listed hotel hasn’t been assessed, most people are unsure, so tend to assume it isn’t very good. Zones of Confidence work exactly the same way. Wherever possible, ships should be kept in those areas rated with a higher number of stars (preferably four or more, and three stars only with caution). Those areas with only two star, or unassessed, should be considered very carefully and avoided if circumstances permit.

ZOC A1 (6 stars)

Surveys within this category have met the requirements for full seabed search. ZOC A1 is only achievable with recent technology, and is usually subject to a program of regular re-survey. ZOC A1 surveys generally only cover those areas of minimal under-keel clearance in harbours and shallow channels. The likelihood of any remaining undetected features is extremely low, and is most likely to be the result of undetected silting, or a channel which moves as a result of storms or seasonal changes. A very high degree of confidence can be had that there are no uncharted features between the charted depths or other features already shown on the chart. The positions of charted seabed features should be better than 5 metres. In practical terms,

Table 3. Sample areas covered by the ENC with information on the ZOC category (IHO S-67, 2017)

Category	% area of English Channel	% area of Singapore & Malacca Straits	% area of world’s coastal ENC (32 nations)	Confidence
A1 (6 stars)	3.6%	1.4%	0.7%	Very Good
A2 (5 stars)	9.4%	0.2%	1.0%	Very Good
B (4 stars)	62.9%	2.5%	30.5%	Good
C (3 stars)	21.3%	76.2%	21.8%	Fair
D (2 stars)	2.8%	1.1%	20.5%	Low
Unassessed (U)	0.0%	18.5%	25.4%	Low

mariners should only require a relatively small allowance for an under-keel clearance in a ZOC A1 area. For a 10–20 metres draft ship, this would be an allowance of at least 0.6 to 0.8 m for the accuracy of charted depths, plus allowances for squat, settlement, ship motion and the accuracy of tidal predictions (if real-time tides are unavailable). If the Master considers that there is the possibility of undetected features, such as in an area where depths may have recently changed, it may be wise to allow another 2 m safety margin. Conversely, the Harbour Master or pilot may advise that a smaller under-keel margin is possible. This will be the result of what is known as a 'Special Order' survey. While still within the overall ZOC A1 category, these surveys have achieved vertical accuracy better than ±0.25 m. Under-keel margins this small should only be considered on the specific advice of the Harbour Master or Pilot, supported by real-time tidal observations, or with the benefit of excellent, and very recent, local knowledge. Without this knowledge or advice, under-keel margins as small as these should not be considered.

ZOC A2 (5 stars)

Surveys within this category have also met the requirements for full seabed search. They have the same level of confidence as ZOC A1 that there are no uncharted features lying between the charted depths or other features already shown on the chart. However, the safety margins the Master should allow in a ZOC A2 area are larger than those in a ZOC A1 area. Surveys meeting ZOC A2 requirements are generally undertaken in those port areas used by smaller vessels (such as outside the dredged channel), as well as port approach areas and coastal shipping routes. ZOC A2 areas may be subject to a program of periodic re-survey but this is likely to be less frequent. The positions of charted seabed features should be better than 20 metres. In practical terms, mariners should only require a relatively small allowance for an under-keel clearance in a ZOC A2 area, approximately twice as much as for ZOC A1. For a 10–20 m draft ship this would be an allowance of at least 1.2 to 1.4 m in a ZOC A2 area, plus allowances for squat, settlement, ship motion and the accuracy of tidal predictions (if real-time tides are unavailable). If the Master considers that there is the possibility of undetected features, such as in an area where depths may change due to silting, it may be wise to allow an additional 2 m safety margin.

ZOC B (4 stars)

ZOC B typically includes well-conducted coastal surveys prior to the late 1990s. Many sea lanes regarded as adequately surveyed carry a ZOC B classification, and have proven entirely suitable over time. Some surveys are still conducted to this standard away from shipping routes. While the vertical accuracy of charted depths (the 'known' depths) is the same as for ZOC A2, the difference is in the size of seabed objects which may not have been detected and therefore are not charted. The size of possible undetected features is not specified. However, in assigning ZOC B to an area, the national hydrographic office responsible for the ENC has assessed that 'undetected features hazardous to surface navigation are unlikely but may exist'. In making that assessment, they are likely to have considered 'surface navigation' as shipping that draws no more than 15 metres when underway (even though vessels with greater draft now exist). This draft estimate is likely to vary from one hydrographic office to another. The positions of charted seabed features should be better than 50 metres. As a general recommendation, it would be prudent to allow at least an additional 5 metres under-keel margin in ZOC B areas covering well used shipping routes, and more in other ZOC B areas. These margins should be increased in or near reef or rocky areas or in areas subject to change (such as a sand-wave area).

ZOC C (3 stars)

It is the expectation that uncharted features hazardous to surface navigation are likely to exist that is the key difference between this category and ZOC B. ZOC C covers a broad range of surveys, including:

- relatively modern surveys which may be very thorough but just fail to meet the higher positional accuracy of the ZOC B standard;
- older systematic surveys best described as 'historic' and likely to have either missed shoals, or not fully investigated shoals that have become significant over time as the size of ships has increased;
- passage sounding (as long as they are not just isolated tracks).

The positions of charted seabed features should be better than 500 metres. A typical ZOC C area is unlikely to have included a comprehensive sonar sweep to cover the gap between adjacent survey lines. As the distance between survey lines may be from 250 m to as much as a kilometre (0.6 Nm), it is highly likely that seabed features may remain undetected between those lines. A ZOC C survey may be considered 'inadequately surveyed', particularly for depths of 30 to 40 metres or less. Caution is therefore advised when navigating close to shore or adjacent reefs or rocky areas, where depths may rise rapidly from the sea floor, or where the seabed appears subject to change.

ZOC D (2 stars)

Soundings in ZOC D areas are similarly sourced from historic surveys, but in this case conducted with large distances between adjacent survey lines, or simply soundings collected on an opportunity basis by ships undertaking routine passage.

Large depth anomalies may include:
- uncharted features rising from the seafloor to the surface in coastal areas – 20 and 50 metre high pillars rising to a metre below the surface have been found in former ZOC D areas;
- uncharted seamounts or very poorly positioned coral atolls in oceanic areas;
- uncharted shoals in Arctic and Antarctic areas, rising several hundred metres from the seafloor, with gradients too steep for a vessel at sea speed to stop or turn away in time.

The positions of charted seabed features are likely to be worse than 500 metres. Although many ZOC D areas will appear blank (unsurveyed), some may show a few broken depth contours or isolated depths. These should not be considered an invitation to disregard the ZOC D assessment. In attempting to navigate a ZOC D area, while following a line of depths on the chart may be better than navigating the white space between, it remains a very poor precaution. Passage soundings typically come from low accuracy and often very old sources – the earlier ship may have passed close to, but not detected, a significant shoal. Equally, the true track followed by the original ship may be well over 500 metres from where they reported it to be.

ZOC Unassessed (U)

This category is used to indicate areas where survey information included has not been assessed for accuracy. This may occur when:
- newly received information has been included, as an urgent precaution, prior to the data being fully assessed;
- the national hydrographic office has only limited resources, so has initially published a large number of their first-generation ENC faster than their survey assessment teams can complete assessments;
- the area depicted is on a small scale ENC (smaller than 1:500,000 – a carry-over from some nations' paper charts), though the same area may be covered by one of the other categories within an overlapping larger scale ENC. In these cases mariners should refer to the larger scale ENC for precise detail.

Summary

Put in simple terms, mariners should be able to navigate with confidence in areas with ZOC A1 and A2 classifications. It is also unlikely that an uncharted danger affecting surface navigation exists in ZOC B areas. In ZOC C areas, mariners should exercise caution since hazardous uncharted features may be expected, particularly in or near reef and rocky areas, or areas of mobile seabed. A very high degree of caution is required for areas assessed as ZOC D, as these contain either very sparse data or may not have been surveyed at all. Finally, it is good practice for mariners to treat ZOC U areas with the same degree of caution as ZOC D areas. Within ports, the Pilot or Harbour Master may advise that higher accuracy surveys have been conducted that allow for smaller under-keel clearances (subject to tides, weather, speed, and manoeuvring margins). In the absence of this advice, smaller under-keel safety margins should not be assumed.

As mentioned in the section titled *Zones of Confidence categories*, in coastal shipping areas the most common assessments likely to be encountered are: ZOC B – around 30%; ZOC C – around 20%; ZOC D – around 20%; and ZOC U – around 25% of the world's coastal waters. While these percentages may vary from place to place, the key point to note is that the standards of surveying in port are only very rarely encountered outside those ports. Ships are therefore at greatest risk away from ports, even though depths may be deeper. An understanding of how much confidence can be placed in the data within an ENC is therefore most important.

Conclusions

We should be aware of this and always remember that ENC's do not mean New! ENCs that are on the market today do not always depict the real world as accurately as would be desired. ENCs (and paper charts) are compiled from multiple data sources, some modern and comprehensive, some old (even ancient) and others from all stages in between. Unfortunately CATZOCs were not well understood, nor liked, and did not allow mariners to adequately make decisions based on data quality. So, do we need to revert to paper charts in areas where the ENC Category Zone of Confidence is set to C or less? No, we don't. The same data are used for a paper chart and an ENC; therefore, neither is more accurate than the other.

In fact, an ENC can give a greater insight into the data via the 'Quality of Data' and survey reliability features. The delimitation of the different zones is added in the ENCs to always show which zone we are in.

Navigators must show great care when using (D) GPS and electronic charts in areas with older surveys, as accuracy and completeness of the depth indicators are not in accordance with modern standards. Additionally, navigators should ensure that navigation is conducted at all times with good safety margins and in accordance with proper navigational practices.

Because of the problems described above and despite the effort and resources dedicated by HOs to populate CATZOC, the IHO has agreed that it will not be used in the future S-101 ENC product specification. The IHO realises that this decision inevitably carries the risk of wasted efforts of populating CATZOC and it will do its best to find an automatic mapping from CATZOC to the new IHO S-101 quality indicators, but this comes without guarantees: the new indicators have to be useful and easy for the mariner to understand (Powell, 2011; Wyllie et al., 2017).

In summary, the paper highlights the following in respect of electronic charts: the quality of chart data is unfortunately not the best yet, so it is important to monitor CATZOC information all the time. Moreover, the significance of CATZOC is not fully understood by many operators; the use of CATZOC is an ECDIS menu option and is therefore not immediately available to the navigator; and CATZOC is unavailable on many unapproved ECS and chart plotters. Therefore, training of watchkeepers in the use of ECDIS and ECS systems is, at best, patchy and many are able to use only the systems' most basic functions.

CATZOCs do not provide the navigator with the detail currently shown in the source data diagrams on paper charts. On ECDIS displays, CATZOC data is available, but has to be operator selected. ECS displays that use official electronic charts (on non-SOLAS vessels), are not always able to display CATZOC information. Basic ECS systems that use unapproved charts may not display CATZOC at all. Numerous vessels now carry ECS as a supplementary aid to their approved paper charts, but by default it has become the primary method of navigation. However, there should be no problem with ECDIS, where access to CATZOC information should be much easier and simpler than it is today.

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