CHARTING A DYNAMIC SEAFLOOR:
how an excellent survey becomes a poor data set, and what to tell the mariner

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INTRODUCTION

Hydrographic offices that chart a seafloor with dynamic behaviour are faced with the challenge how to resurvey and rechart such areas. As an example, we present a tidal sand wave field with wavelengths of several hundreds of metres and heights of up to several metres, a rhythmic pattern found in many shallow seas. For most of such areas, it is unknown whether the observed patterns are dynamic, although time series of modern high resolution surveys have become available for more and more areas.

The most common change of a sand wave pattern is a migration, due to e.g. asymmetries in the tidal currents. In such a situation, the charted depth values remain constant, according to the nautical charting principle of shoal biasing: the shallowest values are selected for visualisation in the chart, implying that these values represent the shallowest values that are likely to appear in the surrounding area. Consequently, the mariner will not notice the migratory character of the sea floor, and has to trust the prudent monitoring of pattern development by the hydrographic office.

This is acceptable as long as the hydrographic office is able to maintain a safe resurvey frequency for the area, and as long as there are no large-scale human interventions in the greater region of the sand wave field, with the potential to disturb the sediment processes. National hydrographic survey budgets are under pressure, though, which translates into a reduction in bathymetric survey capacity.

Yet the mariner expects accurate and recent information. Users of digital products are often not even aware that the source data could be less accurate due to survey age. Moreover, ship owners are aiming for a maximum quantity of cargo, allowing for a minimum under keel clearance. In seas with heavy maritime traffic, sensitive ecosystems and a flourishing tourism industry, such risks are not acceptable.

It is the responsibility of the hydrographic community to tell the mariner that his expectations may be unrealistic. Besides general education, nautical products need detailed quality information that the mariner can find, understand and visualize. He can react to limited bathymetric quality with navigational decisions: changing the ship's course, reducing speed (decreasing dynamic draught), changing passage time to a calmer day (less motion effects on draught) or waiting for higher tides. In the worst case, a decision should have been made in the planning stage: the ship has to take less cargo to reach a port. This is where economic impact comes in: to maintain port accessibility, a coastal state may need to invest in more frequent hydrographic resurveys.

IHO has formed a working group to achieve better communication with mariners about the limited quality of hydrographic data: the Data Quality Working Group (DQWG). This article informs about the way forward proposed by the group, to include seafloor dynamics with a unified approach. This is illustrated with an example in an extremely challenging area: the Port of Rotterdam approach in the Southern North Sea. Using this example, we will discover that the proposed way forward also provides hydrographic offices with a useful planning tool.

CURRENT DATA QUALITY VISUALIZATION IN NAUTICAL CHARTS

For ENCs produced in the current S-57 data model, the "Zone Of Confidence" indicator is in use for the visualisation of the overall data quality of an area. The indicator specifies various categories for the Zone Of Confidence ("CATZOC"). It is not populated in a consistent manner by national hydrographic offices, mainly due to lack of guidance about including the effect of a changing sea floor. For a migrating sand wave field, different arguments about the appropriate CATZOC value can be made. On one hand, one may argue that depth anomalies cannot be expected, as the charted depth values remain constant. Such an argument ignores the changes in surveyed depth values, which it justifies by pointing out that CATZOC applies to the charted product, not to the observed data set. Advocates of this argument even fear that degradation of such a "safe" sand wave area to a CATZOC of e.g. C could tempt mariners to enter other CATZOC C areas with insufficient care.

On the other hand, one may argue that the mariner should be informed about the mobile character of the sea floor, especially if human activities may change the hydrodynamics that drive the sea floor dynamics. Hydrographic offices may not have the resources to resurvey the area with a sufficiently high frequency to detect changes in the behaviour of the pattern in time, or may otherwise not be willing to accept the risk of assigning the area with a CATZOC value of A or B. This would indicate the potential danger of mobile areas, rather than give a potentially false indication of a highly accurate depiction of the seafloor.

There could also be a sense of pride among hydrographic professionals: a product with lower CATZOC values could incorrectly be interpreted as a product with an inferior quality, especially if there have been heavy investments in survey capacity. Nobody likes to see lower CATZOC values in its domestic waters than in the bordering foreign waters. CATZOC inflation could lead to unrealistic quality values, which in turn may lead to overconfidence in the data by mariners, potentially followed by accidents and legal claims. The good quality of the survey should be given by populating other S-57 attributes, so that the deteriorating quality of the data could be described using CATZOC.

A UNIFIED APPROACH TO DATA QUALITY VISUALIZATION OF A DYNAMIC SEAFLOOR

Within IHO, there is consensus that the visualisation of the quality of bathymetric data in Electronic Navigational Charts (ENCs) needs to be improved. At its July 2012 meeting at the University of New Brunswick (Fredericton, Canada), IHO's Data Quality Working Group accepted a proposal to degrade CATZOC in cases of seafloor dynamics, according to specific rules.

The proposed approach only applies if the character of the mobility is known. This implies that repeated surveys and/or a reliable morphological model need to be available. Moreover, this also implies that there is confidence that the observed or modeled mobility is still valid in the present and the future, even in the presence of human interventions like wind farm construction, dredging and land reclamation in other parts of the basin. And, finally, this implies that a policy is formulated and followed to monitor whether the character of the mobility changes.

A key point is whether the shallowest likely depth values in a mobile area change. If it is likely that the positions of the shallowest depth values gradually change, but unlikely that those shallowest values themselves change, the risks involved for surface navigation remain more or less constant. We elaborated this idea further in a recent paper, calculating an "*overall shoaling rate*" of an area and a "*maximum shoaling rate*" of any location within this area. In an area with an overall shoaling rate of zero or less the risk increase for surface navigation is limited. If, in addition, the maximum shoaling rate of the area also is zero or less, there is no risk increase due to a mobile seafloor.

The Data Quality Working Group accepted a list of CATZOC values for a large number of types of potentially mobile seafloors, given in Table 1. In this Table, the term "insignificant" is to be understood in relation to the specifications of the CATZOC categories. In other words: if the sum of all uncertainties plus the expected change between two consecutively charted surveys is less than specified in the columns depth accuracy and position accuracy, a change can be understood as insignificant. Further, Table 1 does not define terms like "nearby", "substantial", and "frequent". Interpretation of these terms is up to the local circumstances and therefore should be done by the national hydrographic office.

If the dynamic character of the seafloor is not known or could change, the largest motions that could be possible should be used. These can for instance be determined using literature, or series of surveys from similar areas. If no resurvey policy is in place for potentially dynamic areas, extra care has to be taken before the higher CATZOC categories are assigned to such areas.

Considerations like shipping intensity and draught are not included in the assignment process of an indicator in a nautical chart. Their role is indirect: in the determination of a safe resurvey frequency, detailed shipping information is used through AIS data. Intense traffic and small under keel clearances demand a high resurvey frequency. In turn, this will

TABLE 1. List of CATZOC values for types of potentially mobile seafloors

1 - insignificant changes to the seafloor of any type	A,B,C,D
2 - changes with an unlikely impact on the shallowest depth values in an area of any type	A,B,C,D
3 - field of dynamic sediment patterns	C,D
4 - dynamic sediment feature	C,D
5 - general sediment transport	C,D
6 - sediment extractions	B,C,D
7 - sediment dumping	C,D
8 - nearby depth maintenance activities	B,C,D
9 - nearby coastline changes	B,C,D
10 - nearby present or recent construction of offshore installation parks	B,C,D
11 - substantial risk of undetected objects on the seafloor	C,D
12 - frequent iceberg scouring	B,C,D
13 - frequent bottom trawling	B,C,D
14 - oil or gas extraction	B,C,D
15 - siltation	C,D
16 - changing nautical depth in area with fluid sediments	C,D
17 - biology induced changes (coral growth; weed growth; work of benthic organisms)	C,D
18 - frequent landslides	B,C,D
19 - frequent or continuous volcanic activity	C,D
20 - any type of event with a potentially significant impact on the shallowest depth values	D

TABLE 2. Dimensions of the two sand pits

	LARGER PIT	SMALLER PIT
size	6000 m x 2200 m	2000 m x 1300 m
depth below LAT of pit	35-40 m	30-32 m
depth below LAT of seabed	25 m	20 m
dredged volume	170 million m3	30 million m3

TABLE 3.
Total Propagated Uncertainty and sand wave migration in relation to CATZOC A2 requirements, for a sand wave pattern with a height of 5 m, a wavelength of 400 m, and a migration rate of 7.5 m/yr.

	HORIZONTAL	VERTICAL
Total Propagated Uncertainty of survey	2.9 m	0.4
migration rates	7.5 m/yr	0.2 m/yr
two years of migration	15 m	0.4 m
total	17.9 m	0.8 m
CATZOC A2 requirement	20 m	1.00 m + 2% of depth

keep observed changes relatively small, in the best case even insignificant in the sense of Table 1.

THE PORT OF ROTTERDAM APPROACH

The approach to the Port of Rotterdam is an area with a challenging mix of human activities and critical depth values. The largest ships can only enter during high tide, which puts serious constraints on the quality of the survey and the chart, both in terms of measurement accuracy and in terms of update frequency. The sea floor is characterised by a dredged channel through an extensive field of rhythmic patterns with different wavelengths. Deep draught ships are led into the channel by pilots, taking advantage of the maintained depths in the channel. This guarantees that ships with a critical depth will avoid the sand wave field.

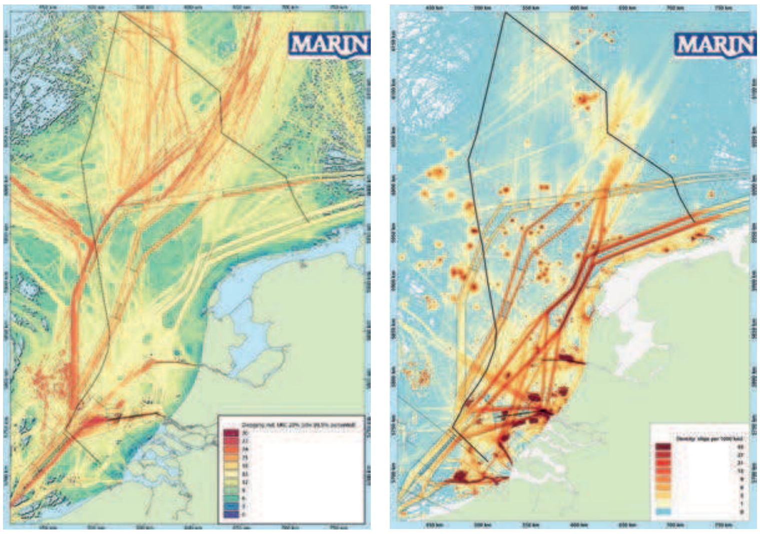

Figure 1.

Maritime traffic in the Dutch part of the North Sea in 2009, based on AIS data. Visible are shipping intensity (left) and deepest draught including a 20% margin for under keel clearance (right). Note the disappearing tracks beyond the EEZ boundaries, due to the limited coverage of the coastal antennas. [figure courtesy of the Maritime Research Institute of the Netherlands (MARIN)]

The area of the example not only facilitates intercontinental shipping through the English Channel, but also regional traffic. There is an inshore traffic zone towards Belgian and French ports, the Maas Northwest Traffic Separation Scheme (TSS) towards English and Scottish ports, and the Maas North TSS towards German and Danish ports, and further on to the Baltic Sea. The traffic is visualised in Figure 1.

In the area of the example, several human interventions are in progress. The coastline changes, due to the Maasvlakte 2 extension to the Port of Rotterdam, are of such a scale that the tidal currents change. The sandy sediment that the project uses is taken out of sand pits (Figure 2). These pits are sufficiently extensive to affect the tidal currents, potentially inducing a corresponding change in the dynamics of the sand wave pattern. Their dimensions are given in Table 2. The Table shows that the total dredged volume is about 200 million cubic metres.

Bathymetric details of the area are given in Figure 2, uncertainty details in Figure 3, and two editions of the relevant ENC in Figure 4. Obviously, the sand pits are not relevant for surface navigation. Hence they did not generate new editions of nautical charts or Notices to Mariners. Also, the dredged channels are visible, as well as a dredged emergency turning circle. The dominant rhythmic pattern consists of tidal sand waves, although smaller patterns (weather-dependent megaripples) and larger patterns (static long bed waves and sand banks) are also present.

Figure 2.

Bathymetric data of the May/June 2012 survey of the approach area to the Port of Rotterdam. Overview (left), detail of the sand wave field (center), detail of the main sand pit (right). Notice the small megaripple pattern superimposed on the sand wave pattern, and the dredging tracks in the sand pit. [figures courtesy of crew HNLMS Snellius, Netherlands Hydrographic Service]

The tidal sand waves in the deeper, Western part of the area are found to be hardly dynamic, while the sand wave pattern in the shallower Eastern part shows a clear migration of up to 7.5 m/yr. The heights of the sand waves are generally found to be constant, which implies that the shallowest likely depth values in the area do not change.

DATA QUALITY ASPECTS OF THE EXAMPLE

The dredged channel to the Port of Rotterdam currently has a CATZOC value of A1, and the sand wave field a CATZOC value of A2. Category A indicates that "significant seafloor features [were] detected and [their] depths measured". Subcategory A1 and A2 differ only in their requirements for survey accuracy. Frequent resurveys are done by Rijkswaterstaat (the dredged channel, several times a year to once a month) and the Hydrographic Service (the sand wave field, once every other year).

The survey vessels of the Hydrographic Service are equipped with multibeam echosounders in combination with a side scan sonar and a magnetometer. The a priori total propagated uncertainties of the last survey of the example area are given in Table 3. The Table shows that the horizontal accuracy requirement of CATZOC A2 is just met, and the vertical accuracy requirement is easily met.

But what if the dynamics change? This will not be discovered until the next survey, two years later. As the combination

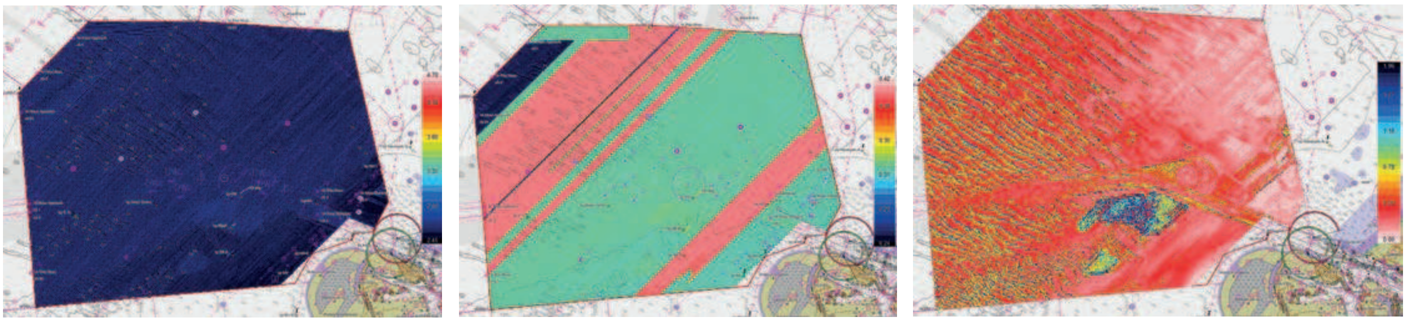

Figure 3.

Metadata of the May/June 2012 survey of the approach area to the Port of Rotterdam at a 95% uncertainty level. A priori Total Horizontal Uncertainty (left), a priori Total Vertical Uncertainty (center), and a posteriori variation per grid cell of 2.6"x2.6", i.e. 80 m x 50 m. (right). THU values are approximately constant, except where the outer beams were used, when the survey vessel had to avoid buoys. TVU values are strongly weather-dependent (water level reduction, sea state). Small spatial variations in depth (Figure 2) dominate the a posteriori values. [figures courtesy of crew HNLMS Snellius, Netherlands Hydrographic Service]

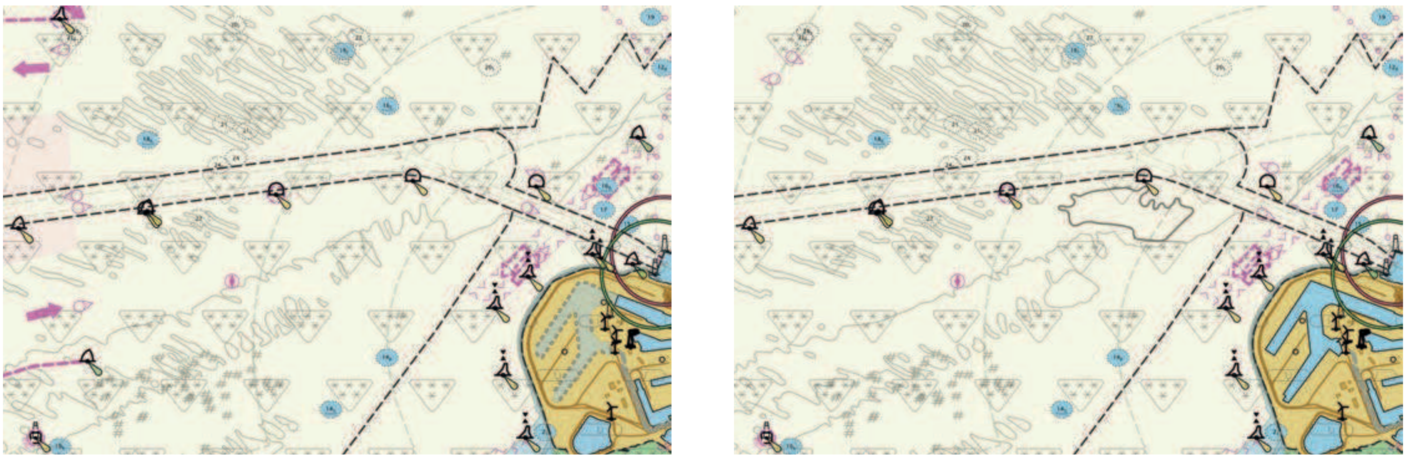

Figure 4.

The approach area to the Port of Rotterdam in Electronic Navigational Chart NL400122: edition 14 (left) and current edition 16 (right). The CATZOC indicator is visible as the stars within the triangles. (Five stars means category A2.) Notice the presence of the dredged channels and the emergency turning zone in both editions, and the sand pits for infrastructural projects like the Maasvlakte 2 in the new edition only. [figures courtesy of Publications department, Netherlands Hydrographic Service] of such a large-scale sand extraction and a major coastline change in close proximity of a dynamic sand wave field is unique, the Netherlands Hydrographic Service cannot rely on other, similar areas to apply the significance-criterion, and needs a process-based impact study. A pre-emptive change in CATZOC value seems overly cautious and limiting to the accessibility of the Port of Rotterdam.

USE OF CATZOC FOR RESURVEY PLANNING

An advantage of the list of CATZOC values for types of potentially mobile seafloor is that the CATZOC assignment process could be turned around: what would be the minimum resurvey frequency for which the CATZOC value remains unchanged? In our example, a CATZOC value of A is defendable because the resurvey frequency is sufficient to keep all changes insignificant in relation to the requirements of this Category (type 1 in Table 1).

In case we would sufficiently reduce the resurvey frequency, type 1 cannot be selected anymore. We discuss three virtual situations:

1. Because of the potentially disturbing effect of the sand pits and coastline changes, the situation should be classified as a general dynamic pattern (type 3), or even general sediment transport (type 5). The CATZOC value would need to be changed to, at best, C.

2. If there would have been no sediment patterns, but the human activities are present, the situation would classify as sediment extractions (type 6), depth maintenance (type 8), and coastline changes (type 9). In such a case, the CATZOC value would need to be, at best, B.

3. If there would have been migrating sand wave patterns, but no human activities, the relevant behaviour would become type 2 as the shallowest likely depth values do not change. A CATZOC value of A would be possible.

The present situation of the example is the first one. A reduction in resurvey frequency without an adjustment of the CATZOC value is not possible for this situation. For the second situation, we could still have a CATZOC value of A if we would invest in process-based studies, and if these studies would conclude that the changes remain insignificant.

CONCLUSIONS

In its Canada meeting, IHO's Data Quality Working Group has proposed a way to uniformly assign CATZOC values in cases of potentially dynamic seafloors. This will give the mariner what he expects: the quality of the charted data at the moment that he navigates. This is in contrast to current practice, characterized by decisions on the national level if and how sea floor changes are included in CATZOC.

Hydrographic offices may need to reconsider their CATZOC values, to include the largest dynamics that could be expected. Detailed studies of sea floor behaviour in critical areas will result in a better quantification of the true dynamics, thereby reducing the size of the dynamics that could be expected. Consequently, such an investment could lead to a higher CATZOC value, which means that prudent mariners can safely use smaller under keel clearances, which in turn means that the accessibility of the ports of a region improves.

As the example illustrates, hydrographic offices could also use the list of CATZOC values for potentially dynamic seafloors as a planning tool: how frequently should a survey vessel return to a critical area with a dynamic sea floor in order to maintain the current CATZOC value? A reduction of resurvey frequency in such an area will create additional survey capacity to e.g. survey poorly charted areas with modern techniques.

NOTE

IHO's Data Quality Working Group reaches out to anyone to discuss this topic further, and calls upon the audience of Lighthouse to share these concepts with all natucial professionals in their network. Also, the author has based this article on a set of reference publications, which he would like to share upon request. Please contact Leendert Dorst at LL.Dorst@mindef.nl.

BIOGRAPHY

Leendert Dorst is Head of the Geodesy & Tides department at the Hydrographic Service of the Royal Netherlands Navy. He earned his MSc degree in Geodetic Engineering from Delft University of Technology, and his PhD in Water Engineering & Management from the University of Twente. Leendert is the vice-chairman of IHO's Data Quality Working Group. Also, he is an editor for Hydro International. His work includes technical assistance for maritime boundary delimitation processes, responsibilities for horizontal and vertical references at sea, development of methods for accurate water level forecasting, and involvement in projects on dynamics of the sea floor.