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Development of a Geo-spatial Analysis Methodology for Assessing the Adequacy of Hydrographic Surveying and Nautical Charts

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SUMMARY

IHO Publication C-55 (*Status of Hydrographic Surveying and Nautical Charting Worldwide)* contains information about the progress of hydrographic surveying and nautical charting for a country with navigable waters under its jurisdiction. Listed primarily as percent coverage, it is difficult to use this information to determine: 1) if the current level of surveying or charting is adequate or in need of action, or 2) can be used to compare different locations. An analysis and assessment methodology has been developed to assess the adequacy hydrographic surveying and nautical charting coverage. Indications of chart adequacy and completeness as depicted on current charts or sailing directions are spatially correlated with significant maritime sites/areas associated with social, environmental and economic factors. The procedure was developed in a GIS environment for Belize and Nigeria. Areas within the charts were prioritized based on zone of confidence, source diagrams, chart quality symbols/indicators, doubtful danger markings, survey completeness, navigationally-significant depths, and areas of significant maritime importance.

1. INTRODUCTION

IHO Publication No. 55 (C-55) is issued by the IHO to show the extent of hydrographic surveying and nautical charting, worldwide. The aim of C-55 is to provide base data for governments as they consider the best ways of implementing the responsibilities set out in chapter V, Regulation 9, of the Safety of Life at Sea (SOLAS) (IHO, 2004). C-55 is used by the IHO to identify and assist to prioritize requirements for progressing modern surveys and chart production. The compilation of the hydrographic data base is focused on identifying gaps in hydrographic data. A major challenge in global data compilation is obtaining hydrographic, charting and maritime safety information from developing countries.

IHO C-55 assesses available national hydrographic data using the IHO standards for hydrographic surveys (IHO S-44) criteria and other methodical classification of hydrographic data sources (IHO, 2004). The resulting report includes three classes: adequately surveyed areas, areas requiring survey at a larger scale and areas that have never been systematically surveyed.

This classification provides only the extent for each area in terms of percentage coverage and is too vague to determine high priority areas that are in need of hydrographic surveys and improved nautical charts.

IHO C-55 document indicates that many coastal states lack the capacity to plan and implement a prioritized survey program. IHO also recognizes that "relatively few IHO countries have satisfactory arrangements in place to ensure that surveys are carried out" (Ward, 2012). In particular, C-55 identifies gaps in the hydrographic data for major areas in the Caribbean Sea, the coastal waters of West Africa, the Indian Ocean and adjacent seas.

This paper presents a process for evaluating the adequacy of a given navigational chart and prioritizing sea areas for survey or resurvey. The focus of the process is on the chart adequacy information and maritime significant areas available on nautical charts and sailing directions .The process identifies and prioritizes areas that require survey within a chart. The nautical charts of the territorial waters of Belize and Nigeria were used to develop this process. From the C-55, both countries were identified as having gaps in their hydrographic data.

2. CHARTING AND NAUTICAL INFORMATION

The primary mission of a hydrographic office is to provide necessary information required by a mariner to safely navigate his vessel (IHO, 2011). This information are usually provided in the form of paper nautical charts, Electronic Navigational Charts (ENCs), sailing directions and other publications that enable a mariner to make informed decisions required for safe navigation. The main document used for navigation is the nautical chart, which is a graphic representation of the ocean waters and adjacent coastal regions (IHO, 2005). It contains information on water depth, shorelines, aids and hazards to navigation, and other information necessary for safe navigation. Sailing Directions are route planning manuals that describe in more detail the navigational features of the coastal area and port approaches, and provide detailed country information for safe navigation in the area. This information includes hazard and warning systems, pilotage requirement and search and rescue. There is other information provided by the chart and nautical publications that give an indication of the accuracy of the hydrographic data from which the chart was complied. These are usually shown in the form of symbols, character type and positive warnings. Also available on the charts and in nautical publications are maritime significant areas which are delineated for navigational or other purposes.

2.1 Chart Adequacy and Completeness Information

Chart adequacy and completeness information are represented by symbols, abbreviations and warnings used to inform mariners on the level of confidence that should be given to data on a nautical chart. The accuracy of a nautical chart is dependent on the accuracy of the hydrographic survey data used to compile the chart (IHO, 2005); and the skill of the cartographer compiling the chart (Calder, 2003). The chart maker takes the limitation of each hydrographic data into consideration when compiling the chart by including symbols and warnings to reflect the

inadequacies in the hydrographic survey data (IHO, 2011). All efforts in making the chart are made to draw the attention of the mariner to possible dangers to navigation such as shoals and wrecks. The type and number of symbols to warn about the inadequacies or inaccuracy of a hydrographic data and the dangers they portend depends on the charting standards of a given hydrographic office and the judgment of the cartographer. The chart adequacy and completeness information can be evaluated by five main data classes: reliability diagrams (zone of confidence or source diagram), chart quality symbols/indicators, doubtful-danger markings, survey completeness and depths areas.

Reliability indicators are often provided on paper nautical charts. They include Category of zone-of-confidence (CATZOC) and source diagrams. The CATZOC is a qualitative assessment of the total error budget of hydrographic survey data and charting standard used to compile a chart. The source diagram provides information on the origin, scale and spatial limits of the hydrographic data used to prepare the chart from which the quality of the survey data can be inferred. The quality of survey data used to compile the chart can be deduced from both diagrams. Although IHO adopted CATZOC over 15 years ago (IHO, 1996), most hydrographic offices that prefer using source diagrams (Heeley, 2003) rather than providing CATZOC diagrams. Only a few hydrographic offices provide CATZOC with electronic charts (Parker, 2003).

Chart completeness is directly related to the thoroughness of a hydrographic survey that was conducted. This is shown on the chart by the use of completeness warnings and cautionary notes. They can also be inferred from the distribution of soundings. Chart completeness warnings are positive warnings and cautionary notes used to draw the attention of mariners to certain areas that pose a greater degree of danger to navigation which may otherwise not be obvious to them (IHO, 2011). These types of warnings include ‘unsurveyed areas’, ‘incomplete survey’, and ‘inadequate survey’. The distribution of sounding may be used to estimate the level completeness of a survey. Evenly distributed soundings show that a systematic methodological procedure has been used to collect the data and may likely have a high level of completeness. However, when the soundings are sparse with blank spaces, the sounding may be from non-hydrographic survey sources and the level of completeness will be poor.

Chart quality symbols/indicators are cartographic symbols on a chart that supplement depth information and are used to draw attention to the dangers inaccurate depth data portend (IHO, 2011). Chart quality symbols are expected to be clear and conspicuous so that they can easily be seen. Chart quality symbols include depth contours, broken depth contours, coastlines and broken coastlines. Doubtful danger abbreviations are abbreviations used to indicate the positional or depth inaccuracies of features in a nautical chart (IHO, 2011). Where the positional or depth accuracy of a feature within a survey is beyond the error margin for the required order of survey, doubtful position abbreviations are used to draw the attention of chart users to this fact. The doubtful danger abbreviations are shown in italics on the chart.

Depth areas are sea areas whose depth range is determined by the navigational considerations of vessels transiting though the area. Traditionally contours were drawn to show mariners the limits within which to safely navigate their vessels in relation to their draught. Here, contours are

drawn with respect to the draught of vessels expected to use the waters. The contour depths are inferred from the depths of dredged channels, ports and other sources of information that may give an idea of the type of vessels transiting through such areas.

2.2 Maritime Significant Areas

Maritime significant areas are areas delineated for their navigational importance as they help to maintain lines of communications in support of commerce and other economic activities, such as ports, harbors, navigational channels, anchorages. Maritime significant areas also comprises areas of cultural and natural importance as defined by a nation, such as maritime protected areas (MPA), military restricted areas, and areas for exploration and exploitation of natural resources. In contrast to chart adequacy and completeness information that is defined based on the survey accuracy and coverage represented in the chart, marine significant areas are based on the current usage and needs of the nation. Thus, the coverage of an area may change with time regardless of any hydrographic update. In the context of nautical charting and safety to navigation, the maritime significant areas are divided into navigational significant areas and non-navigational maritime significant areas. In this study, only navigation significant areas will be considered for the priority scale. This is due to the relatively clear spatial definition of these areas in the chart and the sailing directions.

3. METHODOLGY

The Chart adequacy and completeness information was evaluated based on five evaluation criteria (classes): reliability diagram, chart quality symbols/indicators, doubtful danger markings, survey completeness and depth area. Each class was further sub-divided into various elements that can be used to assess the adequacy of the chart for navigation. A weighted percentage was allocated to each class based on their assessed importance in the navigation of a vessel. Each element was numerically rated by the degree of danger it poses to the safety of navigation, ranging from 1 to 5, where a value of 1 is equal to the least danger to the safety of navigation, and a value of 5 is the most dangerous to the safety of navigation. The class layers were combined into one layer based on the rating factor of each element within the class using *ArcGIS*. The classes were summed together into a chart adequacy class layer using a weighted overlay table.

Maritime significant areas were evaluated based on two main classes: navigational significant and non-navigational significant areas. Each class is divided into elements according to the use of the area. Although the rating procedure allows the use of weighted percentage for each class based on their importance to navigation, the classes of the maritime significant areas are rated based on a Boolean logic. Areas that are important to navigation are rated as 1 (true) and all other areas are rated as 0 (false). The classes are summed together into a maritime significant area class layer.

Areas on the chart are then prioritzed for survey by cross referencing (one layer was multiplied by the other) using a raster calculator (Spatial Analyst, *ArcMap*). The results of the

cross referencing will yield priority areas with a range of 0 to 5. Areas with the highest scores have higher priority for survey. The result was classified into three priority groups; low priority, priority and high priority groups.

4. RESULTS

4.1 Rating of chart adequacy information class

In order to assess the chart adequacy for navigation, the class layers were compiled together into one layer using *ArcGIS*. The resulting sea areas are ranked "not adequate", "low", "moderate" and "high adequacy" based on manual classification method derived from empirical observation of chart 1797 and 3321. The study results show that 21% (1277 km^2) of the total marine area (5933km^2) in UKHO Chart 1797 of Belize and 27% (571km^2) of the total marine area (2112 km^2) in UKHO Chart 3321 of Nigeria are rated as "not adequate". The rating results for Chart 1797 are presented in Figure 1, where 4% (225 km^2) are rated as low adequacy, 12% (3408 km^2) are rated as moderate adequacy and 63% (3743 km^2) are rated as high adequacy. The rating results for Chart 3321 are presented in Figure 2, where 41% (875 km^2) are rated as low adequacy, 10% (201 km^2) are rated as moderate adequacy and 22% (465 km^2) are rated as high adequacy. It is worthy of note that some unsurveyed areas east of the great barrier reef within chart 1797 and areas about 20 NM off the coast of chart 3321 were rated as moderate and high adequacy for navigation. The reason for this rating is that the seafloor is more than 40 m deep and is not considered a danger to mariners. However, there is still a possibility of potentially hazzardous objects projecting from the seafloor.

Class	Weight	Element	Rating	Total rating
Navigation significant depth	50%	Deep waters	1	0.5
		Moderate deep	3	1.5
		Shallow	4	2.0
		Very shallow	5	2.5
Source diagram	20%	A1	1	0.2
		B1	2	0.4
		B2	3	0.6
		B3	4	0.8
		B4	5	1.0
Chart completeness	15%	Complete	2	0.3
		Incomplete	4	0.6
		Unsurveyed	5	0.75
Doubtful danger	5%	Position Approximate	4	0.2
		Sounding Doubtful	4	0.2
		Existence Doubtful	5	0.25
		Reported	5	0.25
Chart quality symbols	10%	Slanting sounding	2	0.2
		Upright sounding	5	0.5

Table 1 - Chart adequacy information class rating: illustrates the weighted percentages allocated to each chart adequacy class based on the importance of each layer to navigation and each element of a class rated by the degree of danger it poses to navigation.

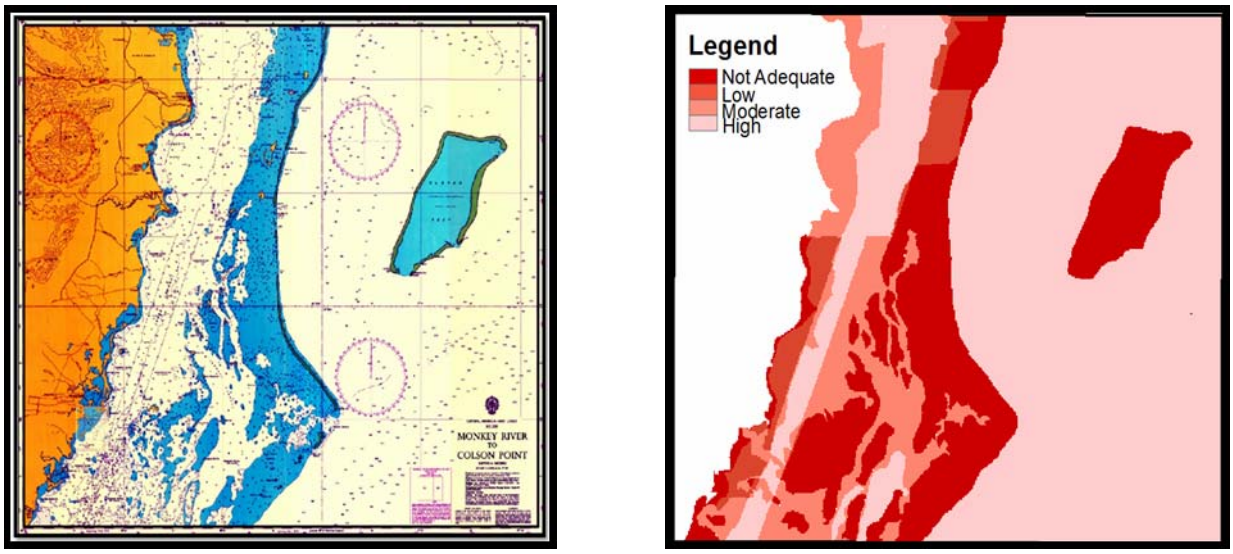

Figure 1 - Chart adequacy of Big Creek, Belize. (left - UKHO Chart 179, right - analysis result showing the rating into chart adequacy areas).

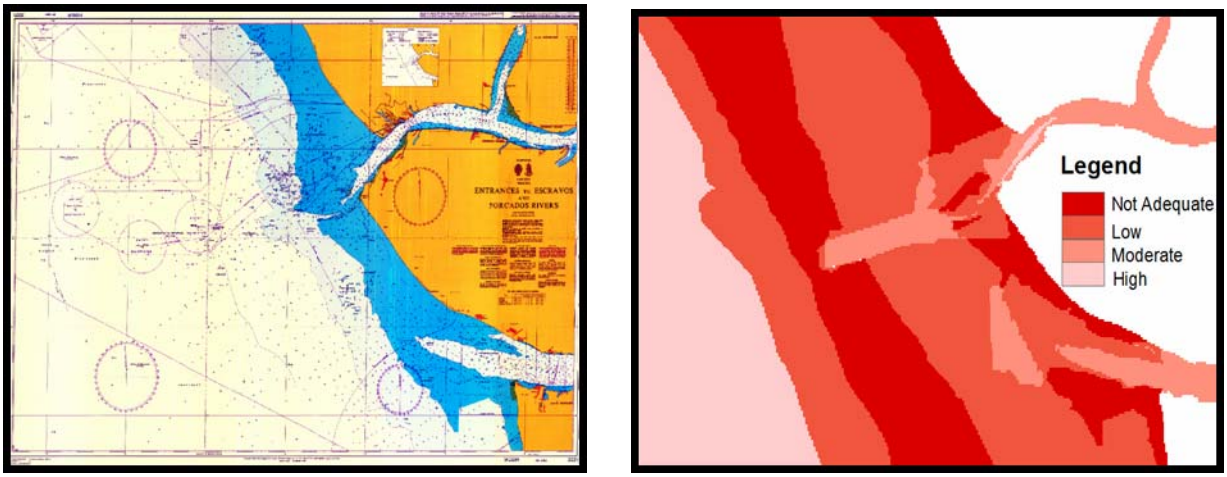

Figure 2 - Chart adequacy of Escravoes, Nigeria. (left - UKHO Chart 3321, right - analysis result showing the rating into chart adequacy areas)

4.2 Rating of Maritime Significant Areas

The navigation and non–navigation significant classes were compiled into one layer using *ArcGIS*. The study results show that 6% (352 km^2) of the total marine area (5933km^2) in UKHO Chart 1797 of Belize and 21% (441 km^2) of the total marine area (2112 km^2) in Chart 3321 of Nigeria are ranked as "navigational significant". The rating results for Chart 1797 and Chart 3321 are presented in Figures 3 and 4, respectively.

Class	Weight	Element	Rating	Total rating
Navigation significant	100 %	Port/Harbor	1	1
		Channel	1	1
		Anchorage/Roadstead	1	1
		Anchorage prohibited area	1	1
Non- navigation significant	0%	Maritime protected area	0	0
		Offshore mineral development area	0	0
		Fishing ground	0	0
		Other sea area	0	0

Table 2 - Maritime significant area class rating: Illustrates the evaluation of maritime significant areas is by two main classes: navigational significant and non-navigational significant areas. Each class is divided into elements according to the use of the area.

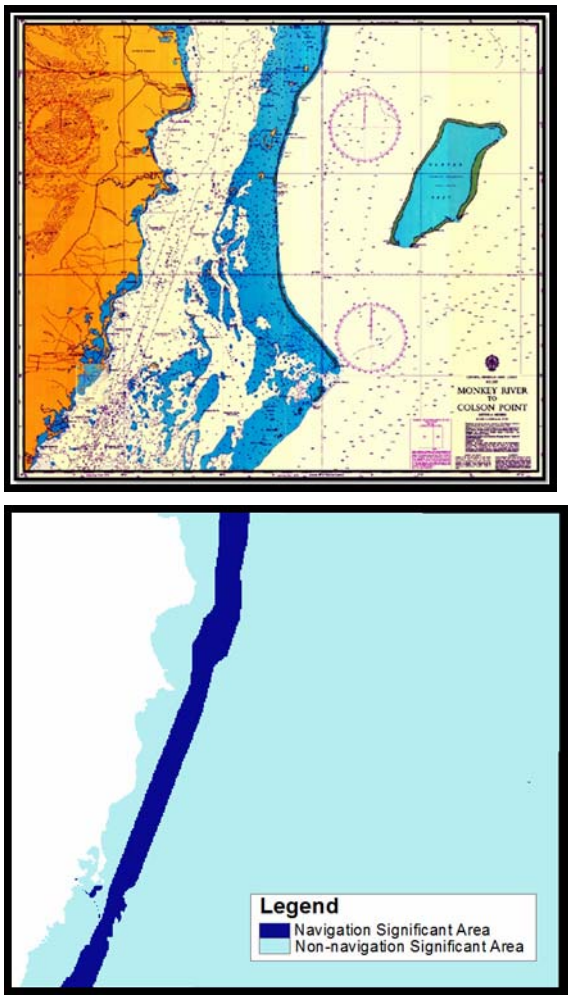

Figure 3 - Maritime significant area Big Creek, Belize. (left - UKHO Chart 1797, right - Rating of navigation and non-navigation significant areas)

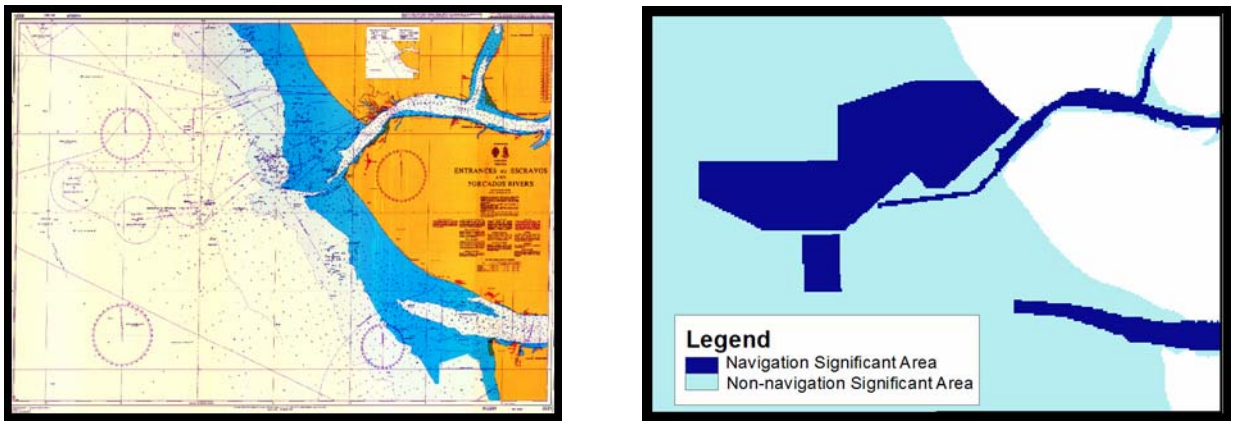

Figure 4 - Maritime significant area Escravoes, Nigeria. (left - UKHO Chart 3321, right - Analysis result (right) showing the rating into navigation and non-navigation significant areas)

4.3 Priority diagram

Priority diagram that identify areas that require attention were produced based on the chart adequacy rating (Fig. 1 and 2) and the maritime significant areas rating (Fig 3 and 4). These two layers were cross reference and the result classified into 3 priority groups. The result showed that 1 % of chart 1797(Fig 5) was high priority for survey while chart 3321 had a high priority survey area of 6 % (Fig 6). In chart 1797, most areas of high priority occurred at the shallow areas of the Inner channel and the anchorage area south of point Placentia. The areas around the Belize barrier reef system and the reef island were ranked low priority though most of the area were ranked “not adequate” and “low adequacy” for navigation. This is primarily because they occur within the non-navigation significant areas. The high priority areas in chart 3321 occurred mainly within the anchorage prohibited areas and in some parts of Escravos and Forcados channels. Large areas of the chart 3321were ranked high priority probably because of oil exploration activities and the attendant network of oil pipe lines which produced a large area of anchorage prohibited area that was rated 1. This area has not been surveyed in recent times unlike the channel possibly due to its seeming lesser importance to navigation.

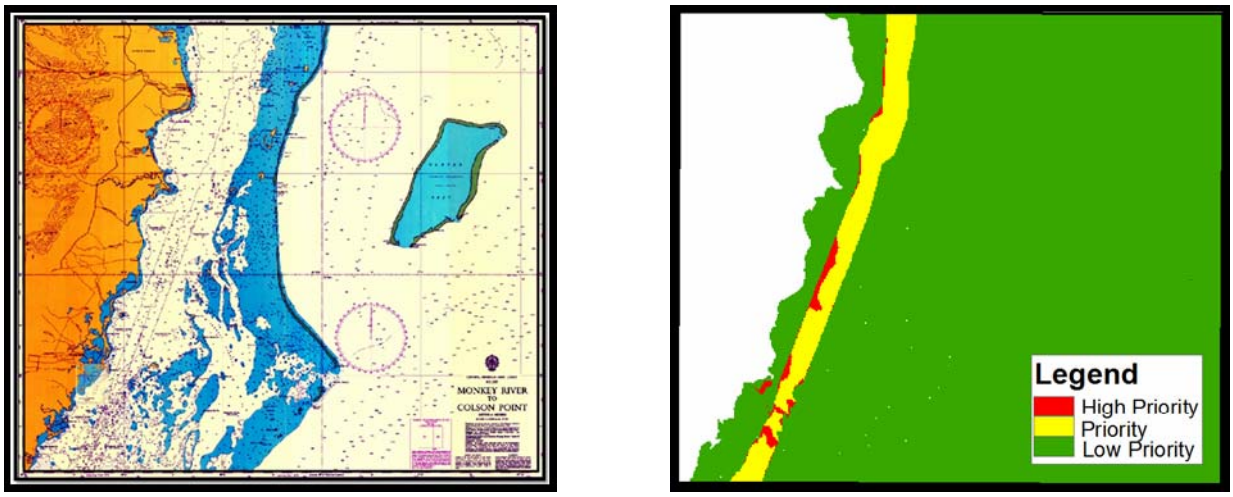

Figure 5 - Priority area for Big Creek, Belize. (left - UKHO Chart 1797, right - Analysis result showing chart 1797 prioritized areas for hydrographic survey)

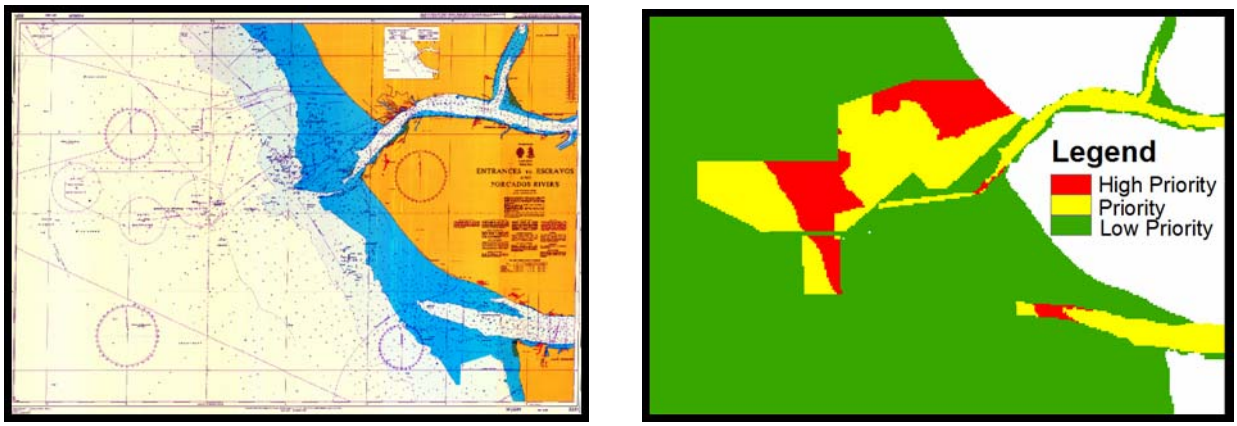

Figure 6 - Priority area for Escravos, Nigeria. (left UKHO Chart 3321, right - Analysis result showing prioritized areas for hydrographic survey)

5. DISCUSSION

This study developed a procedure for evaluating the adequacy of nautical charts for navigation with the view to prioritizing areas for hydrographic survey. The study was based on information available on charts and sailing directions which ironically are the only available sources of information regarding surveys for most developing countries. The procedure identified areas that had varying levels of adequacy for navigation ranging from not adequate areas to high adequacy areas. Furthermore, the procedure was able to reduce the 5933 SqKm chart 1797 to an area which

is 1 % its size for high priority survey. In both charts, the majority of area ranked as “high adequacy” lie within in the navigation channel. This reflects the attempts of both nations to keep the channels well surveyed.

This procedure can be used to prioritize areas within a chart that require hydrographic surveys. Thus, resources can be allocated to the area in which they are most needed in order to derive maximum benefits. Adjacent charts of comparable scale can be combined in this procedure to achieve an equivalent outcome. Similar to UKHO charts and sailing directions used for this procedure, the same can be applied to NOAA charts and coastal pilot with potentially similar results. Furthermore, the procedure in the short run, solves the problem of unavailable baseline hydrographic information from developing countries required by the IHO to update the C-55.

In the future, the accuracy of this procedure may further be improved upon with input from the hydrographic authorities by providing information which was not available on the chart and sailing direction such as traffic density, nature of seafloor, economic importance, national defense, environmental consideration etc. This will make a more realistic rating of the maritime significant area possible and subsequently produce a better prioritization of the sea areas for survey.

One drawback of this procedure is that information about current state and morphology of the seafloor since the last survey cannot be determined from the charts or sailing directions. This requires the procedure to use data that is dependent on the currency of the last survey. Thus there is the danger of prioritizing the wrong areas for survey. Furthermore, the scaling of data in the production of nautical charts leads to loss of details and resolution of soundings. Typically, less than 2 % of the soundings collected during a hydrographic survey are represented on the nautical chart. This reduces the information available for analysis when determining chart adequacy for navigation and prioritization of survey. Also, there is a possibility that significant features are lost in the data due to the reduction of soundings used to produce the chart. This shortcoming makes any method using up-to-date data a viable option for checking the accuracy of the charts for navigation. Potentially recent data derived from satellite remote sensing may be an option to overcome this drawback.

6. CONCLUSION

IHO C-55 indicates the extent of hydrographic surveys and resulting nautical chart coverage. It is intended to inform on the status hydrographic surveying among IHO member countries. This paper proposes a process for evaluating the adequacy of a given navigational chart and prioritizing sea areas for survey or resurvey. Since it is very difficult to obtain hydrographic and related information from developing countries, the focus of the process was on the chart adequacy information and maritime significant areas available only from currently available nautical charts and sailing directions.

The chart adequacy and completeness information are represented by symbols, and warnings used to inform mariners on the level of confidence to be placed on information available on charts. They were evaluated based on five evaluation criteria (classes) and a weighted percentage was allocated to each class based on their importance to navigation. Each class was further sub-divided into elements with each element numerically rated by the degree of danger it poses to the safety of navigation. Maritime significant areas were evaluated by two main classes: navigational significant and non-navigational significant areas. Each class is divided into elements according to the use of the area, and compiled into a layer in *ArcGIS*. The two layers were cross-referenced and the result showed that 1 % of chart 1797 was high priority for survey while chart 3321 had a high priority survey area of 6 %.

The procedure provides a means of checking the adequacy of existing charts being used for navigation. It can be used to prioritize sea areas within a chart for survey so that resources can be apportioned to areas of greatest need for a more efficient use of hydrographic survey capacity. This will help prevent the survey of areas that will not beneficially impact the shipping needs of a nation. The procedure can also serve as a planning tool for HO's for subsequent survey and re-survey of sea areas as their need for hydrographic data evolves. In addition, this process may serve as a stopgap measure in solving the problem of unavailable baseline hydrographic information from developing countries required by the IHO to update the C-55.

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BIOGRAPHICAL NOTES

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