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Updating Sea Charts and Navigational Publications

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KEY WORDS

1. Hydrography. 2. Charts.

1. INTRODUCTION. Sea charts and navigational publications are essential navigational aids. They are produced by the hydrographic organisations of various countries. The accuracy and comprehensiveness of the data shown in sea charts and navigational publications are important for the safety of navigation. The accuracy of chart depends upon the accuracy of the hydrographic surveys used to compile it and the suitability of its scale for its intended use [1]. Accuracy and currency updating is achieved by regular updating. Hydrographic organisations publish monthly or weekly corrections for charts and navigational publications [4]. Mariners and the maritime agencies require accurate, reliable and timely data. The data are collected by standardised and non-standardized methods.

The standardized data collection is by a hydrographic survey [5]. The non-standardized data collection refers to all other procedures used by hydrographic organisations not included in a hydrographic survey and referred to in this text as reambulation. Reambulation [3] (derived from the Latin *reambulatio metarum*) is defined as the boundary definition, inspection, supplementation and correction of maps and plans by additional on-site survey. The lack of non-standardized procedure in collecting data necessary for the updating of sea charts and navigational publications, if it is not the results of a hydrographic survey, directly affects the accuracy. Therefore, it is proposed that a new category of survey (reambulation) would be cost effective method of updating the data required for charts and nautical publications that would supplement existing survey methods.

2. HYDROGRAPHIC SURVEY. Hydrographic survey is one of the standard procedures used by hydrographic organizations to collect data about physical and chemical characteristics of the Earth. Hydrographic survey primarily refers to collecting data about water masses and the main activity is measuring depth. The success is directly related to the accurate positioning of the hydrographic ship during the survey. The accuracy is defined by how close the measured or calculated position corresponds to the true values. Until the Second World War visual positioning was used (Table 1), while electronic positioning systems (DECCA, HIFIX etc.) were in use until the 80s.

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Table 1. Positioning devices used in hydrographic surveys.

Period	Technology
Until 1940	Visual positioning
Until 1980	Electronic positioning systems: DECCA, HIFIX, HYPERFIX, TRISPONDER
Present day (2003)	DGPS

Nowadays DGPS is used because of its high level of accuracy when compared to the devices used 15 years ago. Modern survey vessels can achieve an absolute position accuracy of less than 10 m. The position of the sea bed or the surface objects can be defined to an accuracy of 20 m or better dependant on the date of the last hydrographic survey and on the distance from the coast. The standards of accuracy of hydrographic survey are defined in a special edition of IHO SP–44 [5]. Accordingly, hydrographic survey can be divided into four categories:

- Hydrographic surveys for special purposes. These specifically refer to areas where depths might be potentially hazardous to the ships (e.g. harbours, berthing areas and channels).
- First category. A first category hydrographic survey applies to harbours, approach channels, recommended navigation routes, inland navigation channels and coastal areas with frequent traffic, where depths under 100 m, are not hazardous to ships.
- Second category. A second category hydrographic surveys is applicable to water areas less than 200 m deep (continental shelf) that are not included in the special survey and the first category, and where the general description of bathymetric data is sufficient for the safety of navigation.
- Third category. A third category hydrographic survey refers to all other areas not included in the previous categories. The third category includes those areas with depths over 200 m.

The accuracy achieved is limited by current technological development. A hydrographic survey includes various hydrographic, oceanographic and topographical surveys. It is used to collect the various data connected to physical and chemical characteristics of the sea, seabed, land and atmosphere. It gives a full description of the underwater relief.

The frequency of a hydrographic survey is not internationally defined [5]. Hydrographic organizations have the ability to choose the frequency of their own hydrographic surveys. The frequency is influenced mainly by the financial means of the country. A hydrographic survey is a complex and costly procedure and thus is conducted infrequently. As a direct consequence there is much outdated data and there are still areas that have never been included in a survey. Despite this the data is used for new publications as well as new editions of existing charts and navigational publications. A direct consequence is that charts and navigational manuals do not necessarily represent the actual conditions.

3. DATA FOR UPDATING.

Sea charts and navigational publications contain topographic and hydrographic data. The sequence involved in the updating of

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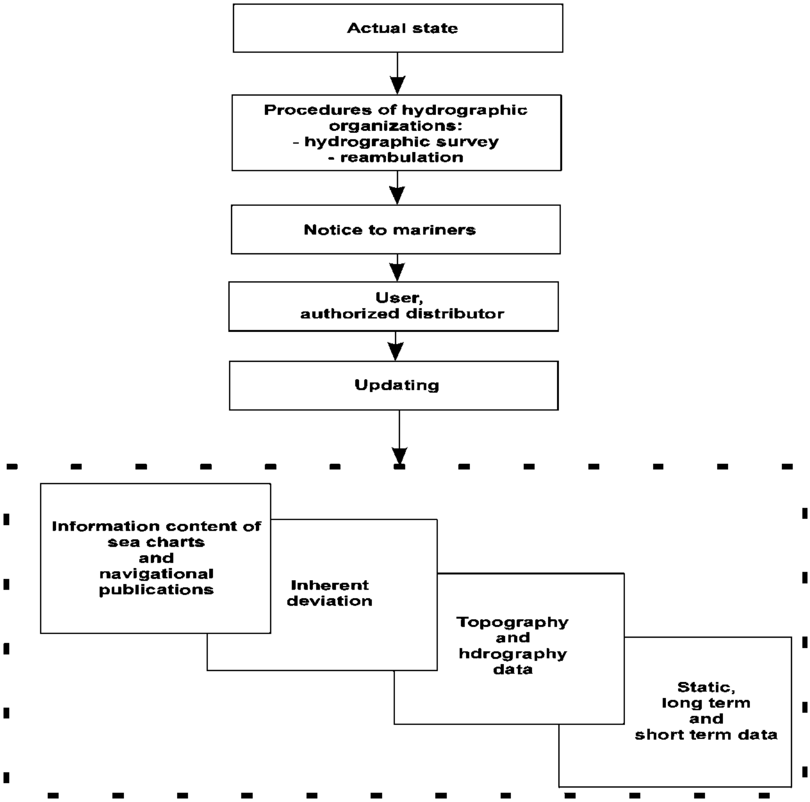

Figure 1. Actual situation and data content of sea charts and navigational publications.

data to reflect new or more accurate information is shown in Figure 1. It is only after completing the hydrographic surveys or a reambulation and then publishing the relevant data in notices to mariners that the changes in reality are entered in charts and navigational publications.

The data changes to the charts and navigational publications include:

- Static data: their properties do not change over a long period of time (land, islands, cliffs, shallows, etc.). These features can be changed by a natural disaster, human activities or war and the like. Their accuracy is generally satisfactory.
- Long term data: their main characteristics change over a long period of time (climatic and biological changes, sea currents, etc.). These effects change faster than static data but slower than short term ones. Their accuracy is generally satisfactory.
- Short term data: their main characteristics change frequently. It is either not possible to predict their changes, or the data accuracy is low (availability of berths and bitts, construction works, abandoned objects in sea bed, critical depths, legal regulations, authorities, maintenance works, etc.). These types of changes are not recorded frequently enough. Their accuracy is not satisfactory.

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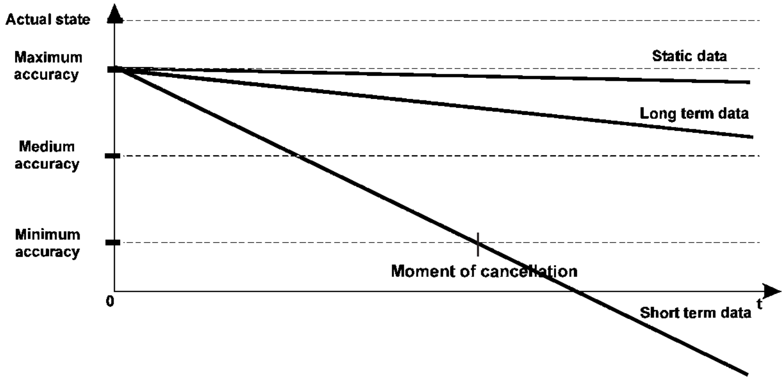

Figure 2. Actual changes during time.

After being published, sea charts and navigational publications can only be changed through the process of updating. The accuracy of a sea chart and navigational publications can be shown as a function of time and updating. In the course of time the accuracy of a sea chart and navigational publications changes and decreases. Accuracy depends on updating as well, so it can be shown in the function:

$$T = f(t, A), \tag{1}$$

where: t – time, A – updating procedure. The more accurate the data used for updating, the longer the charts and navigational publications can be in use.

Theoretically, the reduction in accuracy of the data content of charts and navigational publications in comparison to the actual condition can be presented by curves, the most convenient form being a series of straight lines as shown in Figure 2.

In spite of updating, the accuracy of static, long term and short term data in sea charts and navigational publications changes and decreases in the course of time right up to the moment of cancellation.

4. REAMBULATION.

Reambulation is a procedure for collecting maritime safety information and data about navigation areas with the aim of updating sea charts and navigational publications. It is divided into site data collection and the subsequent processing in a hydrographic organization. Site works are performed in the area of a hydrographic survey (sea navigational areas). The equipment used includes various instruments for measuring position, depths, heights and distances as well as photographic and video recording equipment. An individual or a team of qualified professional reambulators can conduct reambulation.

The technique is used primarily to check data on the coastline. As it is possible to reach the site from the coast by various vehicles, there is no need for a hydrographic vessel. After conducting the analysis and processing of the reambulation data within hydrographic organizations the data for updating charts and navigational publications are selected and published in notices to mariners. The process of reambulation is used to check the compliance of the actual situation with the data shown in sea charts and navigational publications. The state shown is based on the results of a hydrographic survey (including the process of updating). Reambulation reduces to the lowest extent the differences between the actual situation and information

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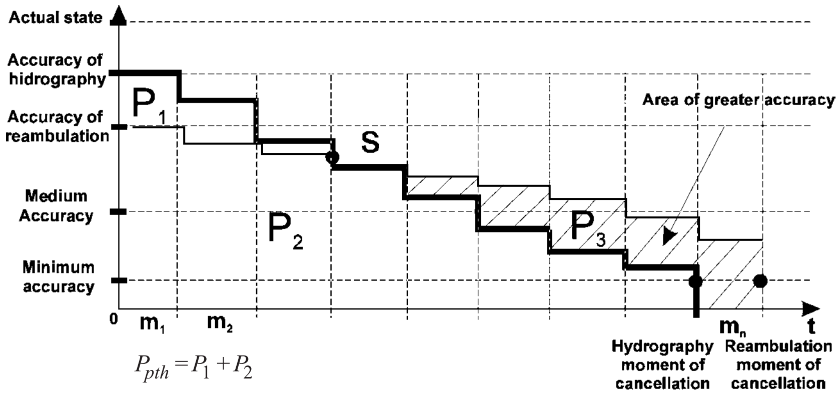
Table 2. Reambulation categories.

Category	Special	First	Second	Third
Typical areas	Harbours, berthing areas, critical channels with minimum depth under the keel	Harbours, approaching channels, recommended navigational routes, some coastal areas with up to 100 m depths	Areas not included in special survey and first category with depths up to 200 m	Areas of open sea not included in special survey, first and second category



$$P_{pth} = P_1 + P_2$$

$$P_{ptr} = P_2 + P_3$$

Figure 3. Meeting point of technologies of hydrographic survey and reambulation.

content of sea charts and navigational publications. Therefore, it is reasonable to categorize reambulation with the same the categories of a hydrographic survey [5] and relevant to the same conditions and areas. These categories and relevant areas are shown in Table 2.

In order to distinguish the measurements taken during reambulation from the measurements made in a hydrographic survey it is necessary to apply control measurements. For all the categories of reambulation it is necessary to apply the accuracy standards of control measurements. They are determined according to the valid standards of a survey [5].

The accuracy of the control measurements of position (P) has to equal the requirements of the horizontal accuracy in the hydrographic survey special category. Similarly the control measurement accuracy of the depth (D) has to equal the accuracy requirements of the measurements of reduced depths within a 95 % reliability of the hydrographic survey special category. It is suggested that standardized international reambulation standards should be set to define the accuracy and frequency of reambulation.

5. THE RATIO BETWEEN A HYDROGRAPHIC SURVEY AND REAMBULATION.

The ratio between a hydrographic survey and reambulation is shown in Figure 3. Theoretically, the area (P_{pth}) can be taken as hydrographic

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accuracy area. The surface equals the sum of final number of single particular areas surface.

The single surface is a product of accuracy of hydrographic data (T_{hpi}) and correction in time $t(m_{hi})$.

$$P_{pth} = (Thp_1 mh_1) + (Thp_2 mh_2) + \ldots (Thp_n mh_n) \Rightarrow$$

$$P_{pth} = \sum_{i=1}^{n} (Thp_i \, . \, mh_i). \tag{2}$$

Theoretically the surface (P_{ptr}) can be considered as the accuracy field of reambulation. The surface equals the sum of final number of every single surface. A single surface is a product of accuracy of an item of data of reambulation (T_{rpi}) and correction in time $t(m_{ri})$.

$$P_{ptr} = (T_{hr1} \, . \, m_{r1}) + (T_{hr2} \, . \, m_{r2}) + \ldots (T_{hrn} \, . \, m_{rn}) \Rightarrow$$

$$P_{ptr} = \sum_{i=1}^{n} (T_{rpi} \, . \, m_{ri}). \tag{3}$$

Surfaces (P_{pth}) and (P_{ptr}) have to be evaluated. The possible results of the evaluation of the surface of accuracy fields (P_{pth}) and (P_{ptr}) at a certain point of time are:

1. $P_{pth} > P_{ptr}$
2. $P_{pth} = P_{ptr}$
3. $P_{pth} < P_{ptr}$.

In case one, the hydrographic accuracy is better than the reambulation accuracy, so reambulation is ineffective. In the second case, the hydrographic and reambulation accuracies are the same and the meeting point (S) of the two accuracies is determined. In case three, the reambulation is better than hydrographic accuracy. This case is where the reambulation process is justified. It increases the accuracy of the data included in sea charts and navigational publications. The meeting point of the hydrographic and reambulation technologies depends on the type of data. The increased accuracy of reambulation first appears in short term, then in long term and static data as illustrated in Figure 3.

The results of reambulation measurements are only used for creating data for the updating of sea charts and navigational publications and cannot be the basis for a new edition of a sea chart and navigational publication [4]. The reambulation data could also be used for other needs, such as specific requirements of military authorities and the market, which are not directly connected to the publication of sea charts and associated publications.

6. SOME MEASURES FOR THE REAMBULATION.

Signs and abbreviations represent the data content of sea charts and navigational publications. They describe an object, or several objects, with one or more items of data concerning the object (e.g. A light is described by its position, description and characteristic). In order to simplify a reference or a group of data connected to a symbol and/or an abbreviation, the item entity is used. For one item of data or a group of data

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the term entity is used to refer to one sign and/or abbreviation. Entity is something that exists apart from other things, having its own independent existence [2]. Any object defined by a group of data or a single reference in sea charts and navigational publications is considered as an entity.

The regular procedures of hydrographic organizations for calculating measures of complexity and accuracy of sea charts should be applied:

- coefficient of surface load of the chart (K_p),
- chart density (G_k),
- information density (I_g) and
- coefficient of accuracy (S_t).

The coefficient of surface load of the chart (K_p) is equal to the proportion of sea surface shown (P_m) and the total surface of the chart (P_k).

$$K_p = \frac{P_m}{P_k} \,.\, 100. \tag{4}$$

E.g. sea charts where $K_p < 10\%$ can be considered as large scale charts.

The chart density (G_k) can be defined as the sum of surfaces of cartographic symbols (P_s) reduced to the surface of the chart (P_k):

$$G_k = \frac{\sum_{i=1}^{n} P_s}{P_k}. \tag{5}$$

Single legible symbols ensure the legibility of the chart if its density is "suitable". Suitable density is differently defined by various hydrographic organizations. E.g. sea charts of the same scale and area published by The USA Hydrographic Bureau have higher density in comparison to the same sea charts published by the Italian Hydrographic Institute.

Information density (I_g) can be defined as a sum of entity (e_n) reduced to the chart surface (P_k):

$$I_g = \frac{\sum_{i=1}^{n} e_n}{P_k}. \tag{6}$$

Information density defines the information importance of a sea chart. Because of contrasting various areas of a chart, information density (I_g) can be reduced to a selected item of surface (P_n) of a sea chart (e.g. at a square mile of the considered surface):

$$I_g = \frac{\sum_{i=1}^{n} e_n}{P_n}. \tag{7}$$

In the procedures conducted by hydrographic organizations, especially in a hydrographic survey and reambulation, it is useful to classify sea charts and navigational publications according to the:

- coefficient of surface load (K_p),
- chart density (G_k) and
- information density (I_g).

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The accuracy of the data content of charts and navigational publications can be determined by a coefficient of accuracy (S_t). This is given by the ratio of the sum of corrections (with the corrections on the coastline) ($\sum_{i=1}^{n} is$) and the sum of uncertain data ($\sum_{i=1}^{n} dv$) with the total number of items of the data (P_e).

$$S_t = 1 - \frac{\sum_{i=1}^{n} is + \sum_{i=1}^{n} dv}{P_e}. \tag{8}$$

The uncertain data are all the data concerning the change of entity that are not the result of the regular processes of the hydrographic organizations (e.g. changes reported by sailors, fishermen and others). The total number of data is all the entities of the information content. The coefficient of accuracy is calculated as a percentage, which, being a numeric expression of accuracy facilitates the decisions of a hydrographic organization about when a sea chart and/or a navigational publication becomes useless.

7. CONCLUSION. Sea charts and navigational publications, the main products of hydrographic organizations, are available in paper and electronic form [6]. Despite the legal regulations and responsibilities of the hydrographic organizations in various countries, the accuracy of data content in sea charts and navigational publications of any form, is not in always in accord with reality. The inaccuracies of the information content in these publications are a direct consequence of the processes applied during the production and updating. The accuracy is functionally connected to the frequency and accuracy of updating data. The influence of short-term data has the greatest effect on accuracy. It is convenient to calculate measures of complexity of data and determine the accuracy of sea charts and navigational publications. The basis for designing a sea chart is a cartographic original made from a hydrographic original. The basis for a hydrographic original is a hydrographic survey. A hydrographic survey conducted in accordance with the valid accuracy standards of International Hydrographic Organization (IHO–SP–44) [5] gives highest accuracy data.

However, the standards do not define the frequency of a hydrographic survey. Consequently national hydrographic organizations conduct hydrographic surveys in accordance with their financial means and not the actual needs. Since the survey is a complex and costly process, it is conducted infrequently. The updating data collected through a hydrographic survey are of sufficient accuracy, but of insufficient frequency. A direct consequence is a permanent growth of disparity between the data in sea charts and navigational publications with the actual situation. The lack of a standardized procedure in collecting information necessary for updating sea charts and navigational publications, if the procedure is not the result of a hydrographic survey, presents a difficulty that directly affects their accuracy.

Therefore, based on the conducted research, it is suggested that the introduction of new category of survey standards (reambulation), similar to the standards of a hydrographic survey (IHO–SP–44) [5] would be a useful and cost effective addition to the process of collecting data for the updating of sea charts and navigational publications. A suitable draft should be presented to the International Hydrographic Organization, for coordination and acceptance. The international adoption of such a procedure would increase navigation safety worldwide.

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A Correction Concerning Marsigli

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KEY WORDS

1. History. 2. Oceanography.

Some 40 years ago Carruthers (1963) published an article containing a number of interesting stories from the history of oceanography. In this article he devotes some attention to the exploits of that remarkable man, Count Luigi Ferdinando Marsigli. For our purpose here I extract and note only the following statements about Marsigli:

(a) He worked under the aegis of France almost entirely.
(b) He was a pensioner of Queen Christina of Sweden whilst he lived in Turkey.
(c) He wrote vexedly about having to curtail observations at sea because of the arrival of an enemy ship, during which excitement his thermometer was broken.
(d) He was later captured by a Barbary Corsair and taken into slavery.
(e) He was for some years a slave gardener in Algiers.

Carruthers provided no references in this paper, though he thanks two other authors from whose writings he has drawn.

Wallace (1974) wrote a book on the development of the concept of salinity; in this he devotes some three pages to Marsigli, his observations, and his publications on marine subjects. From these I extract and note only the following statements:

(f) The largest part of Marsigli's life was spent under the aegis of France.
(g) He was a pensioner to Queen Christina of Sweden.
(h) For some years he served as a military officer aboard ship in the Mediterranean.
(i) He wrote vexedly about the interruption of his temperature measurements caused by a naval engagement with Barbary pirates, during which his thermometer was broken.
(j) In a later engagement he was captured by pirates and sold into slavery.
(k) He spent some years as a slave gardener in Algiers.
(l) Queen Christina ransomed him and he spent some years in her service.

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Wallace cites Carruthers (1963) for items (j) and (k), and perhaps by implication for others as well.

Pilson (1998) wrote a textbook on the chemistry of the sea; in a short historical introduction I included the following paragraph to liven the discussion:

(m) "The life of Marsilli contains some interesting insights into the difficulties of oceanography in those days. On one occasion Marsilli, who carried out his observations while serving as a military officer on ships in the Mediterranean, reported his annoyance when observations were curtailed because his thermometer was broken during an engagement with Barbary pirates. Later he was captured by Barbary pirates, sold into slavery, and spent some years as a slave gardener in Algiers. He was ransomed by Queen Christina of Sweden, and then worked in her service."

The source of this information was Wallace (1974). The material has been presented to successive generations of students for more than two decades.

The trouble is, none of the statements (a through m) in the paragraphs above is true, with the exception of (c).

Marsigli's letter to Queen Christina, describing the nature of the Bosporus and including a description of his famous experiment to illustrate the two-direction flow of the water in that strait, is perhaps responsible for the misconception that he was somehow in her employ. My colleague Bruno Soffientino is preparing what may be the first complete translation of that letter into English, and we have examined it closely. In the letter there is no suggestion that Marsigli was pensioner of Queen Christina. Marsigli was after all a person of some means, son of a wealthy family, and would have no need of financial support. In the letter Marsigli does say that he sends the letter in response to her request for information.

The circumstances of Marsigli's trip to Constantinople, in so far as they are known, are described by Stoye (1994), and much of what follows is summarized from that source. As a young man Marsigli had travelled in Italy, and hearing stories of Turkey had apparently developed an interest in that exotic place. In 1679 (he was then 21 years old and recovering from a failed love affair), he asked permission from his father to go to Turkey. Somehow (one imagines with his father's help) he became attached to the staff of Pietro Civran, the newly appointed envoy of Venice to the court of the Sultan. Civran and his party travelled to Constantinople by sea. They remained in Turkey for about a year, during which Marsigli made numerous observations on many subjects and apparently kept copious notes. He sent letters with information he had gained back to several individuals in Italy, but not to Queen Christina. The political tensions between the Ottomans and the rest of Europe made it necessary for Civran and his party to leave. Marsigli and two companions decided to travel back overland to a port on the Adriatic, which provided him the opportunity to learn much about the Balkan countryside along the way.

Queen Christina was an active patron of the arts and of all intellectual activity; her salons attracted the leading artists and thinkers in Italy and much of Europe. In 1681, Marsigli, now back from Turkey, was a frequent attendee. One imagines that he spoke often of what he had learned in Turkey, and Queen Christina suggested that he write it down.

By 1683 the Ottoman armies were on the march through the Balkans to Vienna. Marsigli volunteered his services, and his knowledge of the territory and military

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situation in those parts of the Balkans, to the court and army of the Habsburg Emperor Leopold I. He enlisted in the army, and while on a recognizance mission was captured by the Ottoman Turks and kept as a slave for the Ottoman army. Then he was sold as a slave to two Bosnian horsemen who took him home and held him for ransom. Eventually the ransom was paid by Pietro Civran, the former Venetian envoy. Returning to Habsburg military service, he was then employed as an Inspector of Engineers, with the rank of colonel, and officers' wages. Continuing in service to the Habsburgs, he travelled in 1686 on a diplomatic mission to Rome. While there he visited again with Queen Christina, who said that she valued is high qualities and offered him employment; his reply was that he could not leave the employment of Emperor Leopold in Vienna. Queen Christina died in 1689.

Marsigli continued in military service to the Habsburg empire until he was discharged under difficult and unfair circumstances in 1704. During the 22 years in military service he never served on a ship in the Mediterranean, though he did sometimes travel by boat on the Danube. He never served the French government, though in 1707 he had hoped to.

Marsigli spent the years 1707–1708 in France, in Montpellier and the port of Cassis, living on his personal funds. At Cassis he hired fishermen to take him out throughout much of the Golfe du Lion, where he made the measurements and collected the samples that led eventually to the Histoire Physique de la Mer (1725). In that document (p. 17) he refers to an event on June 30, 1707 when his boat was approached by an enemy brigantine (country not specified), and in the hurry to depart his thermometer was broken. Stoye (1994) notes that elements of the English navy were at that time preparing to attack the nearby port of Toulon; therefore this brigantine must have been English.

In June 1708 Marsigli was appointed by Pope Clement XI to be a colonel and sergeant-general in the Papal army attempting to fight against Habsburg incursions into Italy. The attempt was futile, and in 1709 Marsigli was again a private citizen. He busied himself mostly in Italy until 1721–1722, when he went to England and Holland. In Holland the arrangements were made to publish Histoire Physique de la Mer, and also his much larger work on the Danube. Back in Italy, he died in 1730.

While surely not needed by readers of this journal, this story illustrates how important it is to get the facts right, before putting them down on paper, and to cite one's sources.

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