



Marine protected areas and electronic navigational charts: legal foundation, mapping methods, IHO S-122 portrayal, and advanced navigation services

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Received: 8 January 2022 / Accepted: 5 January 2023
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Abstract

A strategic instrument for the sustainable conservation of the fragile marine ecosystem is the designation of Marine Protected Areas (MPAs), within which various regulations exist for the protection of highly vulnerable species and habitats. These regulations can be depicted on Electronic Navigational Charts (ENCs) based on the new International Hydrographic Organization (IHO) S-100 series of standards, which support Marine Information Overlays (MIOs) that enrich the portrayed information by including both static and dynamic information, such as vessels traffic, tides, currents, and weather conditions, as well as essential information for the regulation of MPAs. Although, the new IHO S-122 Product Specification introduced specifically for the MPAs has been developed to encapsulate geospatial information for these regulations, the present edition does not specify portrayal. This paper reviews the legal foundation for the protection of marine mammals as well as the mapping methods used in selected study cases and builds upon these to present new, intuitive portrayal symbols for depicting the type of MPAs in combination with the regulations to be enforced on ENCs. Moreover, to support the global efforts for the protection of marine biodiversity, contemporary navigation systems aboard vessels can be used to enforce environmental regulations, and operations centers ashore can also monitor vessels' passage and activities in MPAs. In that respect, this paper also discusses the concepts of Ecosystem Protection Zones and Environmental Risk Contours that can facilitate environmental risk-based voyage planning and preventive alarm services through Electronic Chart Display and Information Systems (ECDIS).

Keywords Electronic Navigational Chart (ENC) · Marine Information Overlay (MIO) · Electronic Chart Display and Information Systems (ECDIS) · ENCs portrayal · IHO S-100 standard · Environmentally Sensitive Sea Areas (ESSA) · Marine Protected Areas (MPA) · IHO S-122 product specification · Ecosystem Protection Zone (EPZ) · Environmental Risk Contour (ERC)

Responsible Editor: Mohamed Ksibi.

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Introduction

Around 70% of the Earth's surface is sea, which consists of very diversified ecosystems that provide a large spectrum of benefits to civilization, such as food, clean air, transportation, energy, and recreation (Buonocore et al. 2021). Human activities such as overfishing, habitat destruction, and pollution of the oceans and the coasts are degrading the rich marine ecosystems (Polinov et al. 2021; Singh et al. 2015). Oil spills from shipping accidents, such as collisions, groundings, and sinkings, are also a major threat to the sustainability of the marine environment (Burgherr 2007).

The safety of seafarers and the avoidance of marine pollution to ensure seamless cargo transits in the international seas, are the most critical challenges of the maritime

sector. To accomplish this, the International Maritime Organization (IMO), a specialized United Nations agency responsible for regulating shipping, is supported by two very strong foundations, i.e., the international conventions of the Safety Of Life At Sea (SOLAS) (IMO 2022a) and the prevention of Marine Pollution (MARPOL) for the protection of people and the environment, respectively, from shipping accidents.

For the protection of the marine environment, Marine Protected Areas (MPAs) are often utilized. MPAs are “areas of intertidal or subtidal terrain together with its overlying water and associated flora, fauna, historical and cultural features, which have been reserved by law or other effective means to protect part or all of the enclosed environment” (IUCN 1998). They are designated geographical areas that are monitored and managed to accomplish specified sustainability and conservation goals for their ecosystems. They can range from modest declarations to preserve a resource to highly regulated regions. The effect of environmental laws on shipping varies depending on where the MPAs are located with respect to the maritime zones, as regulated by the United Nations Convention on the Law of the Sea (UNCLOS) (1982).

For the safety of navigation, the nautical or navigational chart is used by mariners to plan routes as well as for vessel positioning and route monitoring (NOAA 2022). The information on a nautical chart includes depths, rocks, shipwrecks, conspicuous landmarks, seabed quality, installations, light sectors, and other navigation-related features. The basic tasks performed by the seafarer on a printed chart were the drawing of lines (e.g., route planning, drawing of area boundaries), the measurement of distances and angles, and the ship position fixing.

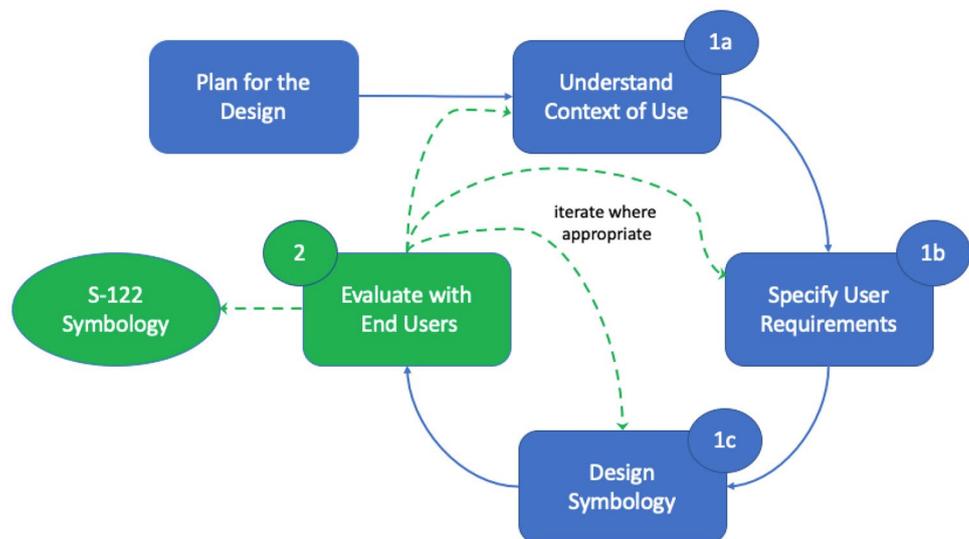
The evolution and dissemination of digital systems that took place at the end of the 20th century revolutionized the process of collecting and processing data from the coastal and marine environment, and consequently, the field of nautical cartography. In the 1980s, the hydrographic offices, realizing the possibilities offered by the advent of information technology, turned to the development of electronic charts, initially in raster and later in vector format. The Electronic Navigational Charts (ENCs) are special purpose datasets created by the national hydrographic offices following IHO’s standards and specifications. ENC information is structured in thematic levels with the various objects divided into spatial and descriptive. The spatial features are used to locate physical objects using coordinates, while the descriptive features are used to provide information and properties for these objects (e.g., color, sector, and period of illumination for lights). The characteristics corresponding to each descriptive object depend on the category of the object (i.e., “light” in this particular example) and are defined by the IHO standards.

The electronic chart soon became a basic tool for the seafarer, and eventually part of the carriage requirements of IMO. ENCs must conform to standards defined by the IHO to be used within Electronic Chart Display and Information Systems (ECDIS) as specified in the IMO relevant resolutions. ECDIS is a geographic information system integrated on the bridge of vessels and used for navigational purposes. An ECDIS is accepted as meeting IMO chart requirements, while for certain types of SOLAS vessels, ECDIS is mandatory to carry (Kastrisios and Pilikou 2017). These vessels use ENCs for cartographic background and may be connected to radar and other available navigational sensors and positioning systems. ECDIS are interactive and dynamic charting systems that allow the user to perform tasks for the navigation of the vessel, intervene in the charts settings, and change the cartographic portrayal, as well as the type and the amount of information displayed during the voyage (Kastrisios and Tsoulos 2016). The planning process and the measurements in ECDIS systems are performed faster and with higher accuracy compared with the use of paper charts. Route plans are carried out by entering the turning points, which are connected by course legs and for which their length and azimuth are automatically calculated. In addition to the ability to perform basic tasks, ECDIS systems offer interactive and dynamic capabilities that allow the user to configure the chart display according to personal choices to plan, monitor, and complete the navigation of the vessel from port to port (Kastrisios and Tsoulos 2016).

Both ENCs and ECDIS can help mariners onboard and the operations centers onshore to follow, monitor, and enforce environmental regulations in MPAs. IHO has developed the S-122 Marine Protected Areas Product Specification with the aim to encapsulate geospatial information about MPAs, but the current edition does not specify portrayal. Users are allowed to select the technique and style of representation that they believe is most suited to their requirements. Edition 1.0.0 states that “future versions of S-122 may contain a portrayal catalog, thus any implementer should plan for this and make adequate preparations in any system that supports S-122.” Besides its importance in nautical cartography, S-122, as part of the S-100 family, can support Coastal Zone Management (CZM) and Marine Spatial Planning (MSP) (see Contarinis and Kastrisios 2022). Intuitive, easily understood symbology is important for the effective management of MPAs by ECDIS users and the various CZM and MSP stakeholders.

With the aim to support the global efforts for the protection of marine biodiversity, this work presents new intuitive ENC symbology for the MPA categories and regulations to address the gap in the current version of the relevant IHO Standard (S-122) that has not yet defined portrayal. Additionally, it discusses two concepts, the Ecosystem Protection Zones (EPZs) and Environmental Risk Contours

Fig. 1 User-centered design methodology. (Modified from ISO 9241–210:2019(en) Ergonomics of human–system interaction—Part 210: Human-centred design for interactive systems—<https://www.iso.org/obp/ui/#iso:std:iso:9241:-210:ed-2:v1:en> (accessed 10.12.2022))



(ERCs), both of which are simple to comprehend and easy to use in requirements analysis for designing MPA regulations. They can be utilized to map MPAs restrictions on the electronic nautical charts and facilitate route planning in avoiding restricted areas, as well as to initiate automated alarm services, through ECDIS systems on the vessels and through Vessel Traffic Service (VTS) systems at the monitoring stations onshore. The research follows a user-centered design based on ISO 9241-210 methodology—ergonomics of human–system interaction—divided into two phases. The first phase, presented in this work, comprises the understanding of the context of use, the user requirements, and the symbology design, as shown in Fig. 1. The second phase will follow as part of future work that will focus on making improvements to the initially developed symbology based on user feedback and evaluation.

To understand the context of use, “[Legal foundation for the protection of endangered marine species](#)” reviews the legal foundation for the protection of endangered marine species, the establishment of MPAs, and other relevant initiatives as tools to achieve sustainable development of their ecosystem, while “[Marine protected areas \(MPAs\)](#)” reviews the types of Marine Protected Areas, as well as initiatives to record them at a global scale. In “[Use cases of protection measures](#)”, the requirements of management bodies of MPAs are specified through use cases of unconventional mapping methods for the protection of marine mammals in the Mediterranean and other geographic regions. To initiate the design process, the relevant IHO S-122 is analyzed in “[MPAs in Electronic navigational charts](#)”. The design considerations and the results of the S-122 MPAs symbology are presented in “[New S-122 MPAs symbology](#)”, while “[Discussion](#)” discusses the concepts of the Ecosystem Protection Zones (EPZs) and Environmental Risk Contours (ERCs), as well as issues for consultation during the evaluation phase.

Legal foundation for the protection of endangered marine species

Conventions for the conservation of marine ecosystems

After World War II, several international and regional conventions focused on the protection of marine mammals and ecosystems (Table 1). On the international level, the Convention for the Regulation of Whaling (ICRW) was an early treaty intended at preserving whale stocks and allowing for the orderly growth of the whaling trade (IWC 2022). The Convention on Wetlands is one of the oldest multilateral international conservation conventions, named after the city of Ramsar in Iran, where the convention was signed in 1971 (Ramsar 2016). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) aims to ensure that commerce in wild animal and plant species does not endanger the existence of their population (CITES 2022).

The Convention on the Conservation of Migratory Species of Wild Animals (CMS), commonly known as the Bonn Convention, is an environmental agreement sponsored by the United Nations Environment Programme (UNEP), which provides a worldwide forum for the protection and responsible use of transitory wildlife species (CMS 2022). The Convention on Biological Diversity (CBD) has three major goals: the preservation of biological variety, the sustainable utilization of resources, and the fairness in the distribution of benefits derived from them (CBD 2022). More recently (1999), the multinational agreement on the International Dolphin Conservation Program (IDCP) aims to decrease accidental dolphin fatality rates in tuna purse-seine fishing along the region to near-zero levels by establishing yearly quotas (IATTC 2022).

Table 1 Marine ecosystems conservation conventions

International	Regional/national
1946 International Convention for the Regulation of Whaling (ICRW)	1972 US Marine Mammal Protection Act (MMPA)
1971 Convention on Wetlands of International Importance as Waterfowl Habitat (Ramsar)	1972 India's Wildlife (Protection) Act
1973 Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES)	1973 US Endangered Species Act (ESA)
1979 Convention on the Conservation of Migratory Species of Wild Animals, CMS (Bonn Convention)	1988 China's Wildlife Protection Law (WPL)
1982 United Nations Convention on the Law of the Sea (UNCLOS)	1992 EU Directive on Conservation of Natural Habitats of Wild Fauna and Flora (Habitats Directive)
1992 United Nations Convention on Biological Diversity (CBD)	1999 Australian Environment Protection and Biodiversity Conservation Act (EPBC)
1999 International Dolphin Conservation Program (IDCP)	2008 European Marine Strategy Framework Directive (MSFD)

Respectively on the national level, the Marine Mammal Protection Act (MMPA) (NOAA Fisheries 2018, 2021) banned the exploitation of marine mammals in the USA, as well as the importation of their products. The MMPA was established in 1972 in response to growing concerns that some marine mammal species and populations were on the verge of extinction as a result of human activity. The act established a strategy to protect cetacean species population stocks from falling to the point that they cease to be functional components of the ecosystems in which they live.

On the other side of the Atlantic, the directive of Natural Habitats of Wild Fauna and Flora of 1992 (the Habitats Directive), supports the growth of a diverse range of scarce, endangered, or endemic wildlife species (EU 2022a). It is the cornerstone of the European Union's environmental conservation program, for the establishment of the EU Natura 2000 network of protected areas. Lately, the European Marine Strategy Framework Directive (MSFD) intends to apply a cautious and comprehensive ecosystem-based framework to manage and regulate European maritime waters (EU 2022b). Sea turtles, dolphins, and other cetaceans are seen as a group and are being monitored and evaluated under the Biodiversity descriptor, although this is not always successful (Rogan et al. 2021).

UN life below water goal

To protect and utilize marine resources in a sustainable manner for long-term development, the United Nations introduced in 2015, the 14th Sustainable Development Goal on "Life Below Water" (UN 2022a). Three main targets of the Goal are the:

- protection and restoration of marine ecosystems by strengthening their resilience (Target 14.2),

- protection of marine and coastal areas, in accordance with national and international conventions and treaties,¹ based on accurate scientific data (Target 14.5), and
- compliance with the United Nations Convention on the Law of the Sea (UNCLOS) (1982), the international treaty that serves as the legal foundation for all marine and maritime operations (Target 14.c).

Convention for the prevention of marine pollution

The MARPOL convention, which came into effect in 1973 and was amended in 1978 (IMO 2022b), aims to ensure that shipping is the least environmentally damaging mode of transportation (Marine insight 2021). It includes measures for the protection of the maritime environment from pollution. The convention consists of six annexes as the official regulations for the prevention of pollution by hazardous substances that can be released by ships. The first annex was published in 1983 with measures to protect from oil spills, followed by annexes for the control of pollution from noxious liquid substances (1987), harmful substances carried at sea in packaged form (1992), garbage and sewage from ships (1998 and 2003 respectively), and for the prevention of air pollution (2005).

Red list of ecosystems and threatened species

The International Union for Conservation of Nature (IUCN), a nonprofit, multinational organization dedicated to environmental protection and the efficient management of natural resources, specializes in collecting and analyzing data,

¹ Treaties are the principal source of Public International Law. <https://unimelb.libguides.com/internationallaw/treaties> (accessed 03.01.2022).

environmental studies, and field and training activities. The IUCN Red List of Ecosystems is an instrument for monitoring the status of ecosystems globally (IUCN-CEM 2022). It is a tool for assessing biodiversity risks, with the goal of assisting preservation, resource utilization, and administration strategies by recognizing ecosystems most vulnerable to species extinction. The Red List of Ecosystems is built around a set of criteria, such as being transparent, objective, scientifically rigorous, and easily understood by the public, and categories, such as collapsed, endangered, and vulnerable, that give a systematic framework for assessing the danger of ecological collapse. It is intended to be broadly relevant across habitat types and geographical locations, as well as open and methodologically validated (Bland et al. 2017). Complement to the Red List of Ecosystems is the Red List of Threatened Species, the largest and most influential database of living species' conservation status globally, which utilizes a set of criteria to assess the danger of extinction for multiple species and variants. Three endangered species in the IUCN's Red List are the Mediterranean Monk Seal, the *Caretta caretta* sea turtle, and the Right Whale. More information on the three species, the challenges they are facing, and assumed protection measures are discussed in "Use cases of protection measures."

Marine protected areas (MPAs)

Marine Protected Areas are designated geographical areas that are monitored and managed to accomplish specified sustainability goals for their ecosystem. MPAs are increasingly being recognized as a strategic instrument on a worldwide scale (Gubbay 1995; Reuchlin-Hugenholtz 2015) for the sustainable conservation of the marine environment and the use of its resources. MPAs can range from modest declarations to preserve a resource to highly regulated regions. The effect of environmental laws on shipping varies depending on where the MPAs are located in respect to the maritime zones, as they are regulated by UNCLOS. The majority of MPAs are designated in territorial waters of coastal nations (Salomon and Markus 2018), where vessels monitoring is viable, but they are also found within exclusive economic zones or international waters (high seas), e.g., the cetacean sanctuary in the Ligurian Sea in the Mediterranean (Notarbartolo-di-Sciara et al. 2008). There are different types of MPAs that are relevant to shipping, such as Particularly Sensitive Sea Areas (PSSAs), Special Areas, Emission Control Areas, Areas to be Avoided, No Anchoring Areas, and Mandatory Ship Reporting Areas (NOAA 2020).

A collaborative initiative between UNEP and IUCN to record the MPAs on a global scale is the World Database of Protected Areas (WDPA). It is a biodiversity dataset of marine and terrestrial protected areas, updated regularly,

and made available through the Protected Planet website (UNEP-WCMC and IUCN 2021). It is being used by scientists, businesses, and governments for policy-making, spatial planning, and management. As of January 2022, the global coverage of marine protected areas was 7.92% (Protected Planet 2022), with a UN target of 10%. Almost 18.5% of waters of national jurisdiction, which represent 39% of the global ocean, are established as protected areas, whereas only 1.2% of high seas have been designated as protected areas (Fig. 2).

A type of MPA that pertains specifically to shipping is the PSSA. A PSSA is a comprehensive management instrument for regions that are vulnerable to international maritime activities. The IMO adopts PSSAs when three criteria are present, namely: the region must have special ecological, socioeconomic, or scientific characteristics; it must be vulnerable to shipping pollution; and there must be mechanisms in place to preserve the area (IMO 2005). The designation of a PSSA incorporates associated protective measures (APMs) (Kachel 2008) that are activities to be validated and endorsed by IMO, such as ship reporting, routing zones, or a specified area to be bypassed. Currently, only 17 areas around the globe have been designated as PSSA (Kim 2021) (Fig. 3). The IMO's Marine Environment Protection Committee is in charge of designating new PSSAs, in response to applications from interested coastal states.²

Use cases of protection measures

This Section presents examples of protection measures for the endangered species of monk seal, *Caretta caretta* sea turtle, and right whale in support of the "specify user requirements" task (step 1b in Fig. 1).

National marine park of Alonissos and northern Sporades

The Mediterranean monk seal, the sole member of the genus *Monachus* and related to the critically endangered Hawaiian monk seal and the extinct Caribbean monk seal in the Phocidae family, is categorized as endangered on the Red List of Threatened Species (Karamanlidis et al. 2019). It is estimated that less than 700 seals exist in a few fragmented subpopulations, and more particularly in the Aegean Sea in Greece, the Madeira islands in Portugal, and the Cabo Blanco peninsula in Mauritania (Karamanlidis et al. 2016; Martínez-Jauregui et al. 2012). In Greece, the

² Criteria for the identification of PSSAs: <https://www.biodiversity-z.org/content/particularly-sensitive-sea-area-pssa> (accessed on 03.01.2022).

Fig. 2 World MPAs (source: authors with data from UNEP-WCMC and IUCN 2021)

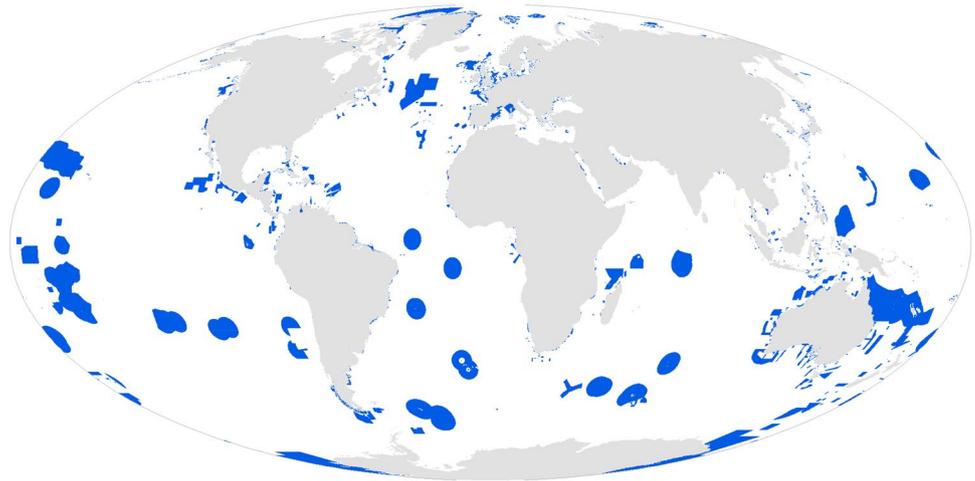
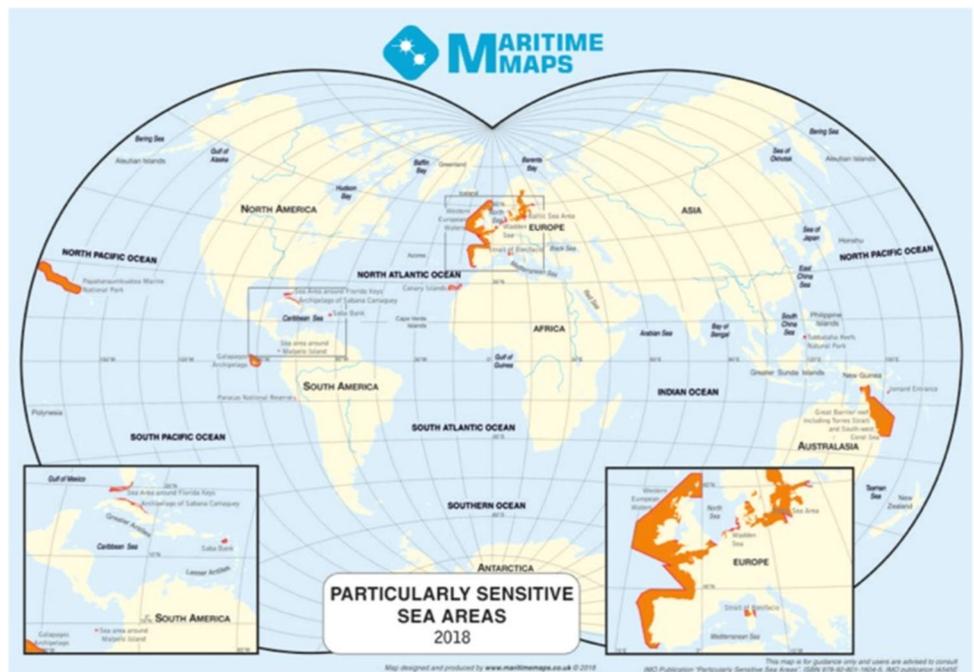


Fig. 3 PSSAs designated by IMO. (Reproduced from GIS Datasets—Data for the maritime industry: <http://www.maritimemaps.co.uk/Datasets/datasets.html> (accessed on 04.01.2022))



largest population of the species lives and reproduces; it is estimated at about 300 seals, distributed across almost all coastal areas of the country.

The largest and most studied local seal populations in Greece are found in the greater area of Alonnisos, in northern Sporades (about 50 seals), as well as the Kimolos–Polyaigos archipelago in the southwestern Cyclades (with a similar population). Significant breeding populations have also been recorded in the area of North Karpathos and Saria in the Dodecanese, with about 25 seals, and in the Ionian islands of Zakynthos and Kefalonia. In recent years, a very important population of Mediterranean seals, estimated to be at least 60 seals, has been discovered in the small Cyclades island of Gyaros. The study of the distribution of

the Mediterranean seal in Greece has been driven by MOM (2020), a nongovernmental environmental organization dedicated to the study and protection of the monk seal, through mapping the seal appearances and observations recorded by the national Rescue and Information Network (RINT). Three breeding colonies have been identified and monitored, with the estimated number of births being at 20 pups per year. Significant threats have been identified for the species (Camps 2015):

- Habitat depletion due to coastal development
- Accidental entanglement in fishing gear
- Purposefully killing them to avoid them destroying fishing nets and stealing fish

- Reduced food availability as a result of overfishing
- Unusual events such as diseases, algal blooms, rock-slides, cave falls, or oil spills
- Inbreeding distress, which leads to decreased reproduction and infant survival
- Marine pollution

The efforts to protect the Mediterranean monk seal in the Sporades area began in the early 1970s. In 1986 the first resolution was signed, with the aim to protect the species and their natural habitat. These initiatives were shortly followed by governmental acts regarding the conservation of the Sporades wildlife reserve. The area was designated as a “National Marine Park”³ in 1992. The administrative body of the park, registered in Alonissos, engaged adequately educated scientific and technical staff in 2007 for preservation, research, and public awareness programs. The National Marine Park of Alonissos is one of Europe’s largest MPAs and a member of the Mediterranean Protected Areas Network (MedPAN). Within its zones (Fig. 4), the main prohibited activity is the passage of vessels under certain conditions:

- At a speed of no more than 10 knots at a distance of less than 0.5 nautical miles from the shores of the islands of zone A (where access is allowed). Around Piperi Islet, which is considered the heart of the National Marine Park, it is prohibited for any vessel to approach at less than 3 miles, without special permission.
- at a speed of no more than 10 knots at a distance of less than 0.1 nautical miles from the shores of the islands of zone B.
- Of tankers carrying more than 500 tons of oil and any vessel carrying dangerous toxic substances.

National Marine Park of Zakynthos

Another species in the Red List of Threatened Species found in the Mediterranean is the sea turtle *Caretta caretta* (Casale et al. 2011). This species emerges along the beaches of the Laganas Gulf on the Greek island of Zakynthos. *C. caretta* usually spawns on the same beach where it was born, therefore it is critical to preserve these areas for nest survival to prevent the species from extinction.

The National Marine Park of Zakynthos (NMPZ) was established in December 1999 for the protection of this endangered species. Within its boundaries are included the most significant breeding beaches of *Caretta caretta*. The NMPZ was Greece’s first officially recognized protected area, it is part of the Natura 2000 network and includes

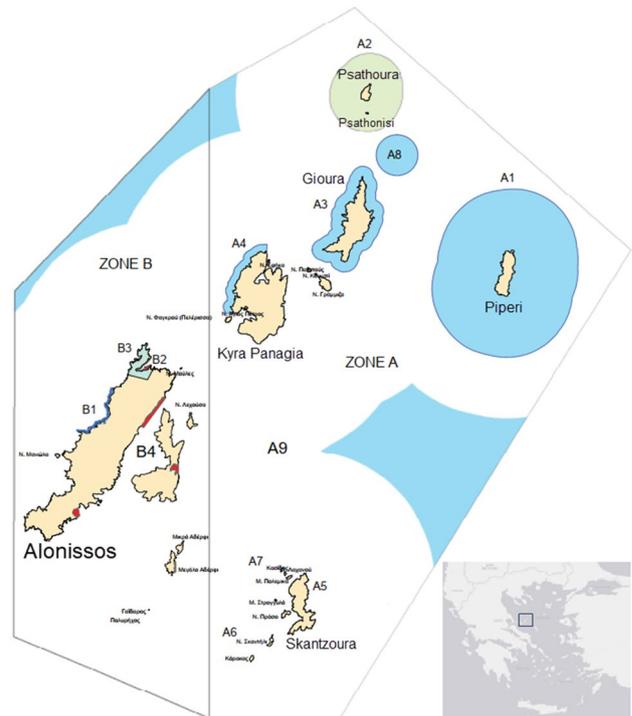


Fig. 4 Alonissos marine park zones in the Aegean Sea, Greece. Modified from Marine Park Visitors Flyer—https://alonissos-park.gr/wp-content/uploads/2016/07/flyer_EN_web-compressed.pdf (accessed on 03.01.2022)

marine and terrestrial priority areas, as well as diverse flora and fauna. The area of approximately 126 km² is seeing rapid tourist growth, with more than one million visitors per year, as well as a wide spectrum of human activities, such as agriculture and fishery. Due to the diverse anthropogenic pressures, effective management and conservation of the entire protected area became a priority. Therefore, a management body has been in operation since 2000, specifically dedicated to the conservation and sustainable development of the area (Sourbès 2015).

The Park is active for the preservation of *Caretta caretta*; however, effective conservation of migratory marine animals such as the loggerhead turtle is inherently difficult due to the multiple dangers that must be tackled. Different restrictions for marine activities are employed in the three zones of Fig. 5. In the most strictly protected area of Zone A, no boats are allowed, and entry is limited to researchers who have been granted special authorization. In zones B and C, entry is allowed with a speed limit of 6 knots, while anchoring is only allowed in Zone C.

³ Official Website: <https://alonissos-park.gr> (accessed 03.01.2022).

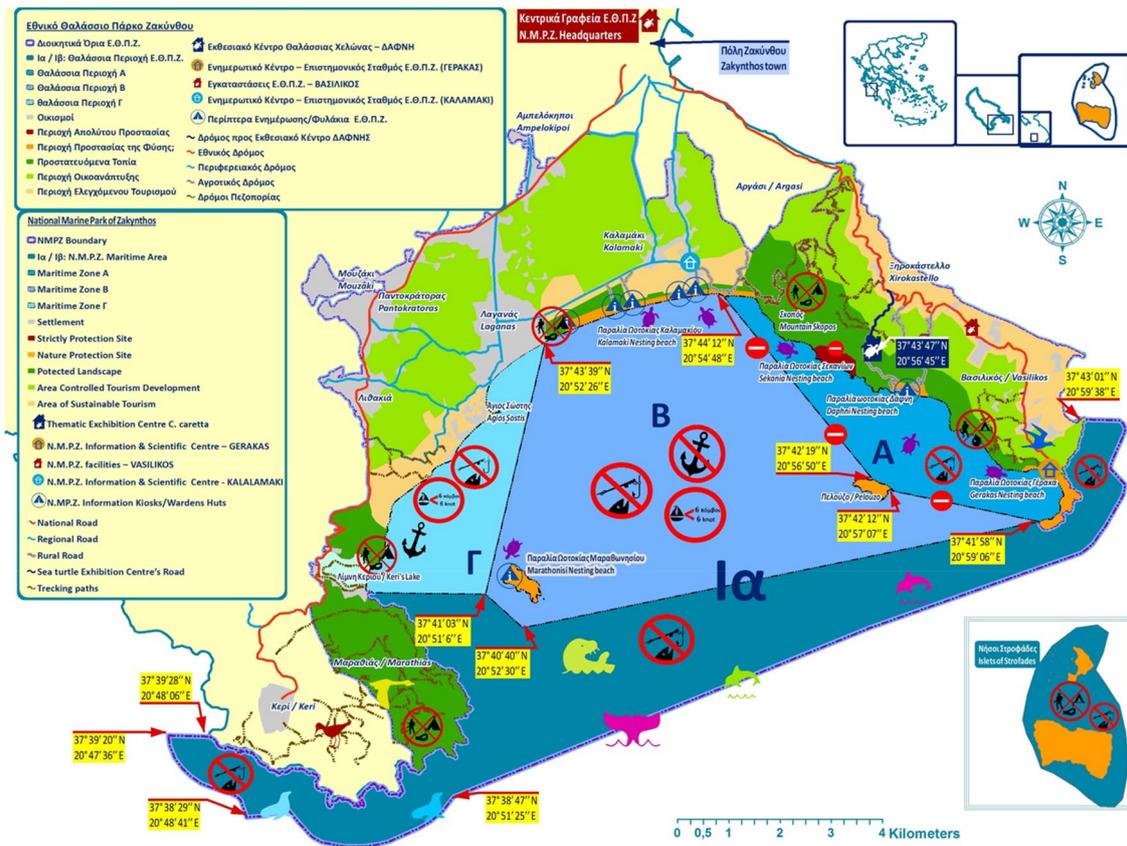


Fig. 5 Zakynthos Marine Park protection zones official map. Reproduced with permission from NPMZ [Official Website: <http://www.nmp-zak.org/> (accessed on 03.01.2022).]

Right whales slow zones in seasonal or dynamic management areas

The right whale is another species listed as endangered in the IUCN's Red List (Duff et al. 2013). It was once abundant on both sides of the Atlantic, but it now appears to be extinct in the eastern North Atlantic. Right Whale Slow Zones is a program of the United States National Oceanic and Atmospheric Administration (NOAA) that notifies vessel traffic operators where vessels should maintain speeds less than 10 knots to protect the whales from vessel striking (NOAA Fisheries 2022). NOAA supplies charts and geographical coordinates indicating the locations where right whales have been observed, and announce the slow zones to vessels through its standard maritime communication. To decrease the probability of fatalities and major injury to endangered North Atlantic right whales, Seasonal Management Areas (SMAs) are designated where obligatory speed limits are enforced at specific times of the

year (Silber et al. 2014) (Fig. 6). In addition, Dynamic Management Places (DMAs) are designated where right whales are seen, and slow zones can be established on an as-needed basis.

MPAs in electronic navigational charts

As discussed in the "Introduction," a nautical chart is a map that depicts depths, coastline, hazards, conspicuous objects, seabed quality, and other details of the marine and coastal environment that are utilized by seafarers for route planning and navigation. Electronic charts were first used on ships' bridges using paper (raster) charts and later, as the information technology advanced, with vector Electronic Navigational Charts (ENCs). The data format utilized for the dissemination of digital hydrographic data is called S-57 IHO Transfer Standard for Digital Hydrographic Data. Since its official adoption in May 1992, S-57

Fig. 6 NOAA fisheries slow zones. Modified from https://twitter.com/naaafish_garfo/status/1368892755028578310 (accessed on 11.09.2021)



has served as the foundational standard for ENC's; however, it suffers from things such as an inflexible regime and its inability to support gridded bathymetry or time-varying information. In response to the identified limitations, in 2000 the IHO approved a major revision to S-57 that led to the development of a new framework for hydrographic geospatial data standards, the S-100 Universal Hydrographic Data Model (Kastrisios et al. 2022).

Marine Information Overlays (MIOs) are the additional layers of geospatial information for the electronic navigational charts that complement the baseline information required by the IMO ECDIS performance criteria. The new S-100 Universal Hydrographic Data Model supports MIOs via additional product specifications (coded as S-xxx). The main product specification that is based on S-100 is the S-101 (IHO 2018b), which defines the content, structure, encoding, and the metadata necessary for ENC datasets compilation. This specification also includes the portrayal symbols and rules, available on the IHO Portrayal Registry.⁴ S-101 will gradually replace the current standard (S-57), which has been in use for over two decades. MIOs enrich the cartographic information of nautical charts by including both static and dynamic information such as vessel traffic, tides, currents, weather conditions, and information for sensitive Marine Protected Areas (Alexander and McLeay 2015). Regarding MPA's cartographic representation, while both S-57 and S-101 ENCs can specify their geographic boundaries (Choi et al. 2021), they do not include essential

information such as endangered habitats or regulated/permitted activities (Alexander 2008). The S-122 Product Specification (IHO 2019a) has been developed to encapsulate geospatial information about Marine Protected Areas, such as seas, oceans, estuaries, and large lakes, for use in ECDIS and other geographic information systems. It consists of vector datasets conforming to the specification and containing all relevant information for the area of coverage. For spatial characteristics, geographic features make use of spatial types provided in the S-122 geometry package. Datasets made out of S-122 features are characterized using metadata provided in the S-122 metadata package, and the coverage of a dataset is represented using the polygon type.

S-122 feature types

The Marine Protected Area feature type is used as an information overlay that supplements the S-101 ENCs, and it is where mariners may face fines if they infringe the specified area restrictions. Three other types of areas defined in the specification (Fig. 7) are:

- the Navigational Restricted Area, an area in which the regulations have a direct influence on the passage of a vessel,
- the Regulatory Restricted Area, an area in which the regulations have an impact on the activities that can take place,
- the Vessel traffic service (VTS) area, an area in which a monitoring service is available to ensure transportation safety and efficiency, along with environmental preservation. It can range from standard notifications to advanced

⁴ Official IHO Registry: <https://registry.iho.int/> (accessed on 04.01.2022).

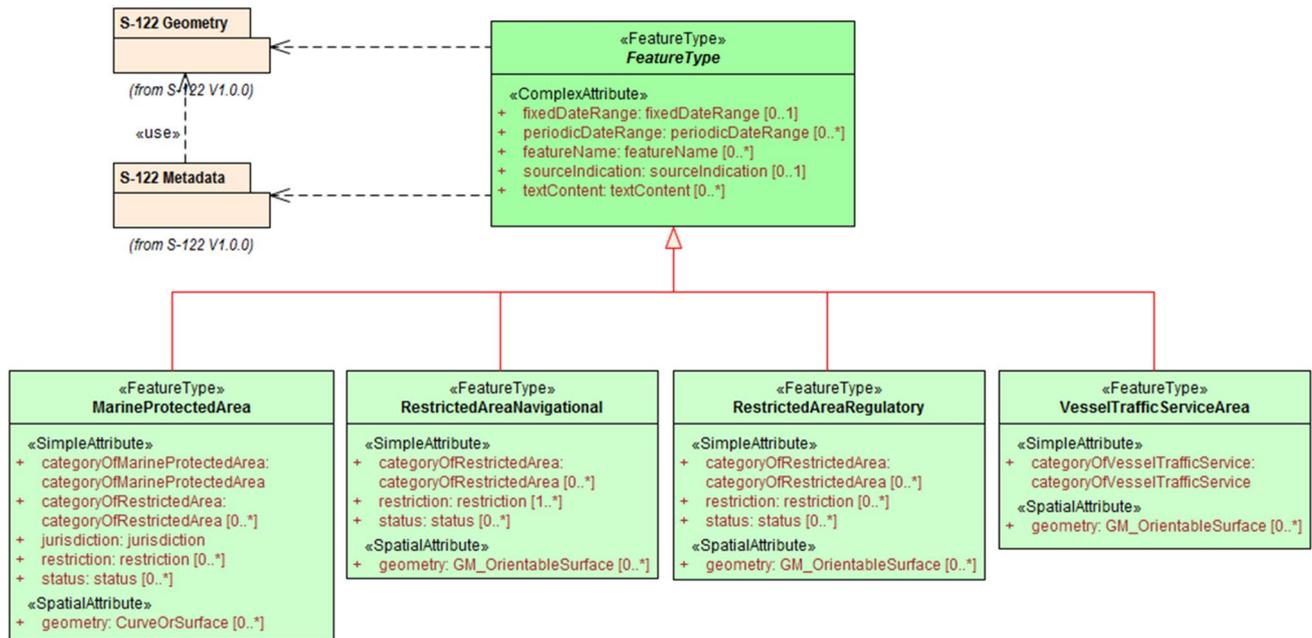


Fig. 7 S-122 feature types. Reproduced from IHO (2019b)

traffic management incorporating national or regional jurisdictions.

S-122 information types

The specification also includes three information types that describe regulations, restrictions, and recommendations, as well as a fourth one for nonspecific information. The classes are primarily designed for encoding textual information derived from original sources such as national or local legislation, and official documents in general. More specifically (Fig. 8):

- the Regulations class reflects data collected from legislation, national regulations, navigation restrictions, and other official sources.
- the Restrictions class is used for limitations originating from sources other than legislation.
- the Recommendations class is designed for recommendatory information, this may include suggested speed restrictions, look-out requirements for marine animals, and so on that have not been established as formal rules.
- the Nautical Information class is meant for remarks or other material that does not fit into one of the other three types.

AbstractRxN is an abstract superclass for the information types, where the attribute *rxnCode* allows for the optional classification of the material encoded in text content or graphics based on the kind of material and the type of

maritime activity affected by it. It also inherits the properties of the abstract superclass *InformationType*, which has attributes for fixed and periodic date ranges, needed for Seasonal Management Areas (SMAs) and DMAs, the name associated with the individual information object, source information, and an attribute that allows text notes or references to be provided for individual instances where appropriate. It is recommended that when a geographic feature class includes the restriction property, it shall be used, while explanations and specifics from regulations can be contained in the associated information class. All *InformationType* attributes are optional and derived classes may impose additional constraints, as defined in the S-122 Data Classification and Encoding Guide (IHO 2019c).

Applicability of restrictions

Specific regulations can apply to a different subset of vessels based on their size, type, or cargo, among other factors. This is expressed by first specifying the relevant subset of vessels and then associating that subset with the applicable feature or information type. The *Applicability* class (Fig. 9), which comprises attributes for the most frequent vessel characteristics used in nautical literature, is used to model the subset of vessels. These include measures (length, beam, draught), cargo type, displacement, and so forth. Constraints that cannot be represented using the *Applicability* properties can be stated in plain language in the information attribute. Figure 9 depicts the model elements required to carry out these requirements. Multiple values for the category of cargo and

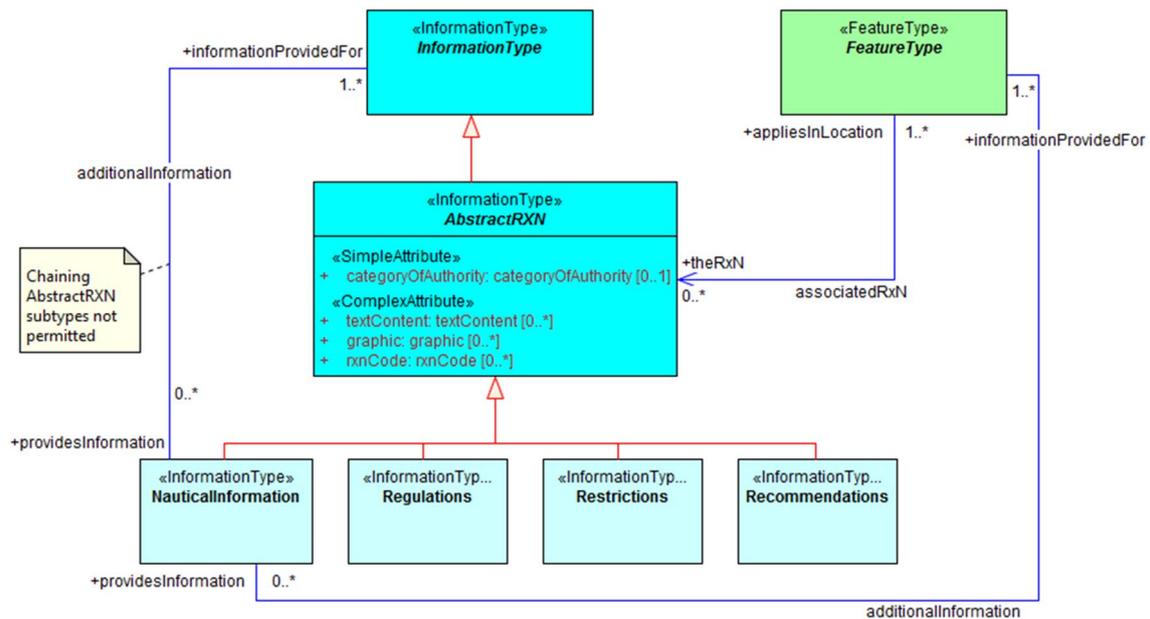


Fig. 8 S-122 restriction types. Reproduced from IHO (2019b)

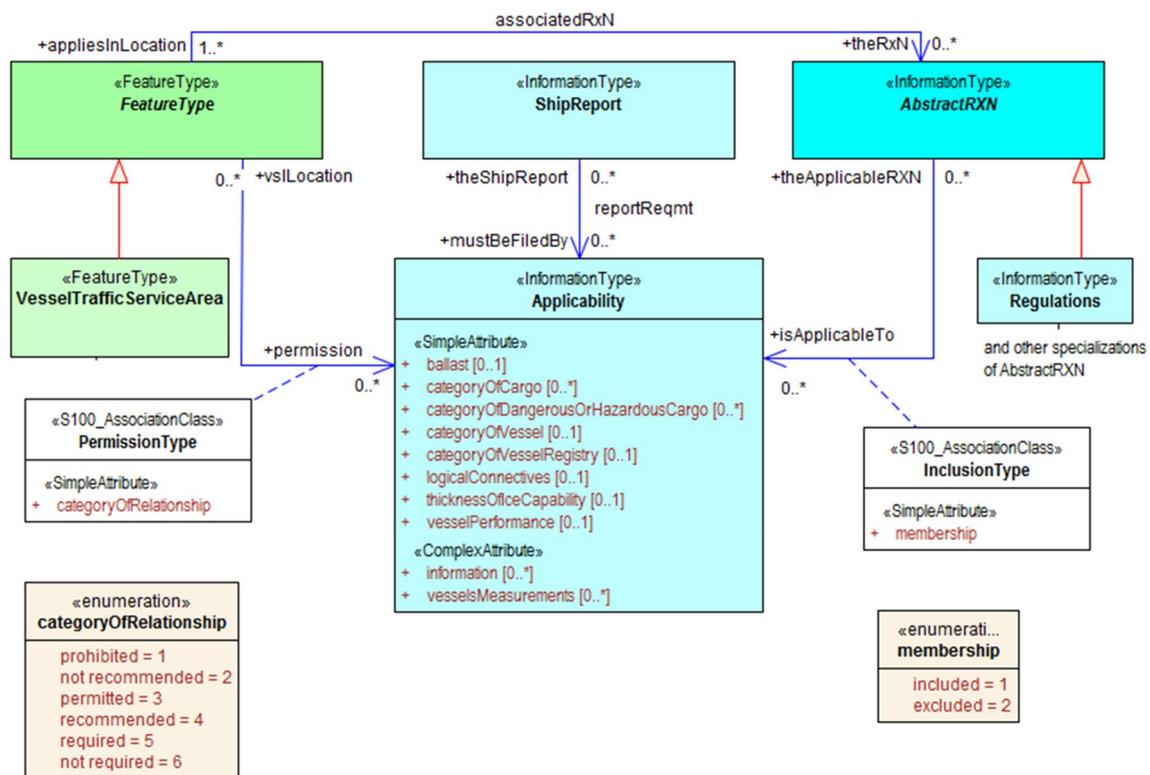


Fig. 9 S-122 Restrictions’ applicability to vessels with specific characteristics or cargoes. Reproduced from IHO (2019b)

category of dangerous or hazardous cargo should be considered as “inclusive OR” (i.e., if Category of Cargo = 1 and 2, it indicates vessels carrying either bulk or container cargo or both) (IHO 2019c). The association name *associatedRxN*,

inherited from their common *AbstractRXN* supertype, is used to link the Information Types to the relevant features. This association’s roles at the endpoints are *appliesInLocation* and the RxN that refers to the Restriction, Regulation, etc. If

the rule only applies to a certain class or mentions an exempt class, the *InclusionType* association class is used to encode an additional association to an *Applicability* object.

New S-122 MPAs symbology

The present edition of the S-122 Marine Protected Areas Product Specification does not specify portrayal. Users are allowed to select the technique and style of representation that they believe is most suited to their requirements. In addition, in S-122 edition 1.0.0 (IHO 2019a) it is stated that “future versions of S-122 may contain a portrayal catalog, thus any implementer should plan for this and make adequate preparations in any system that supports S-122.” In the previous section, we reviewed MPAs portrayal methods in thematic maps and the new S-122 classes relevant to MPA symbology on nautical charts. A nautical chart is indispensable as a medium for both position fixing and route finding, as well as for the avoidance of dangers and for the safety and ease of navigation (Schmidt 1979). Navigationally useful information that cannot be shown on charts must be provided in other nautical publications, e.g., the coast pilot; however, there are increasing efforts by the hydrographic community to integrate this information into the ENC database. A characteristic example is the MPAs that will be integrated into the new S-101 ENCs following the S-122 product specification. A mariner looks to the chart to locate routes and conspicuous marks; to differentiate important information from the whole; and rank, classify, and attribute measurable characteristics to the features portrayed. Being the main spatial communicative medium for the safety of navigation, the nautical chart should be understood almost instantly and intuitively to be effective. It must provide answers to seafarers’ questions without being visually overwhelming; therefore, visual hierarchy is of utmost importance for charts to achieve their scope. In symbol design, colors, shapes, and iconography are important parts of the design process toward this goal.

Design principles

Just as speech has grammar and syntactic rules, so does visual language. The knowledge of graphical semiology is the concept that was defined, analyzed, and codified by Jacques Bertin (Bertin 1983). Bertin theorized that map elements are a graphics system with a set of six fundamental variables (shown in Fig. 10), further extended by Morrison (1974) and MacEachren (1995).

Cartographic designers use these visual (or *graphic*) variables to design the symbology and visual appearance of map components. Visual strategies are utilized to produce esthetic visualizations, communicate geographic

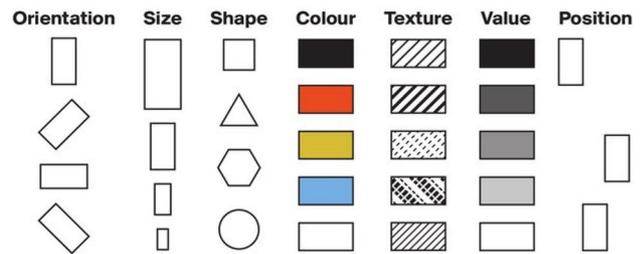


Fig. 10 Visual variables by Jacques Bertin. Reproduced from Kilchör (2014)

information accurately, and produce a visual hierarchy that the map viewer can comprehend. Depending on the application (and in many cases, culture as Ware 2012 points out), visual variables may carry certain meanings that designers need to incorporate into their strategies. For instance, in terms of color, red is often used to symbolize stop, hot, love, and danger; brown is earthy and natural; green is used for go, safety, freshness, health, and renewal; black is solid, powerful, and death; white represents peace and purity; blue is cold, calming, and protecting (see, e.g., Ware 2022). Regarding shapes, circle is infinite or protective; square is stable, solid, and honest; triangle suggests tension and direction; while a shield-shaped symbol often signifies protection, authority, and enforcement (see, e.g., Bradley 2018). Similar, strong, conventions exist in the nautical charting domain, established by the long-lasting cartographic practice. For instance, mariners intuitively understand that on ENCs, brown represents land, shades of blue the depth areas, and green is for environmental features. Also, saturated and bright colors denote a higher risk to navigation. Shallow depth areas in ENCs are visualized with a saturated blue, whereas deep waters with a grayish shade of blue. Soundings shallower than the own ship’s safety depth are portrayed in black, whereas those shallower than the safety depth are in gray. Likewise, many dangers to navigation are also in black, such as rocks and wrecks. It is noted, however, that the above pertain specifically to ENCs as some differences can be found on paper charts. For example, on paper charts, the deep-water area is white to allow for the repeating task of plotting lines, fixes, and notes, and the erasing of them before the next voyage (as well as to maintain high contrast between them and the chart background). Another example is the use of different tones of brown or yellow for the land on charts of different producing nations.

Publication S-4, Regulations for International (INT) Charts and Chart Specifications, (IHO 2021) provides detailed specifications for nautical chart symbols as shown in Fig. 11, that this work was based upon. S-4 is the fundamental IHO document for nautical chart compilation. It provides guidelines for every aspect of chart compilation including: chart construction (dimensions, scale, title, notes,

Width of Bounding Box: 4.02
 Height of Bounding Box: 5.03



Symbol Colours:



Comments:

Line weight 0.3 mm

Fig. 11 Typical ENC symbol (Reproduced from IHO S-4)

compass rose, source diagram); utilized units (positions, bearings); use of color (black, magenta, yellow, grey, blue, and green); requirements for the representation of topography (land, natural coastline and man-made constructions, buildings, landmarks, etc.); hydrography and aids to navigation (depths, depth curves, recommended tracks and fairways, etc.); generalization guidelines for various chart features; text (language, geographic names, numbers, styles, and fonts); chart maintenance; etc. (Kastrisios et al. 2022).

In the design process, we focused on developing icons representative of the MPA type and regulations, rather than abstract symbols, and the selection of symbol color, enclosing shape and size. As explained in the previous paragraph, the nautical chart is highly regulated; its high level of standardization provides a wealth of information one can build upon. A review of existing symbols shows that for symbols with an enclosing shape, their physical size varies from 6 to 12 mm. The symbols presented in the following sections are 9 mm at the chart scale. In terms of enclosing shape, all different shapes are used, e.g., circles, triangles, squares, diamonds, and hexagons, while many of the symbols are without an enclosing shape (e.g., that in Fig. 11). Considering the connotations of shapes described previously, and to maintain consistency for all MPAs symbols and avoid confusion with existing chart symbols (see e.g., the generic anchorage symbol in Fig. 11), we focused on developing symbols with a circular enclosing shape. In terms of color, magenta is used on charts for dangers and other information. Magenta has the advantage of being one of the four ENC basic colors and is established as the color utilized to attract mariners' attention to important information. Therefore, for the symbols in the following sections we use saturated magenta to denote restricted and prohibited activities (thus informing mariners about the MPA becomes important) and less saturated magenta (*magenta faint*) for the less important (visually and navigationally) permitted activities (IHO 2015).

Categories symbols

There are numerous challenges associated with the design and placement of MPAs on charts, including whether they are adjacent to hazards such as urban areas, fishing grounds, or marine traffic districts. Due to the open character of the marine environment, MPAs should be large enough for ecological reasons. Larger MPAs have a higher capacity to allow for a multitude of activities and degrees of protection, host a broader variety of species, and maintain healthy populations and ecosystem dynamics. Smaller MPAs, on the other hand, will be better accepted by the locals and the maritime community, and would be easier to implement. Regardless of size, MPAs' layout characteristics may include location, shape, buffer zones, boundary position, ecological representation, and connectivity with other MPAs (IUCN 2004; Dimarchopoulou et al. 2018). In terms of representation, pictorial symbols representative of the species being endangered, historical or cultural submerged sites, and the ability for vessel surveillance within the MPA zones, such as those in Fig. 12, may be used.

The symbols in Fig. 12 depict the objects of the *categoryOfRestrictedArea* enumeration discussed in the previous section. They have been designed with the primary criterion being the ease of understanding by the end user, e.g., a seal, turtle, or whale for the respective sanctuaries, a sloped mast, and hull for a wreck, and a computer screen with a vessel for vessel surveillance.

Regulations symbols

Figure 13 illustrates representative pictorial symbols for charting various MPAs permitted activities such as anchoring, small- and large-scale fishing, passage for various types of vessels, and vessel traffic services. Likewise for the symbols for MPA types presented in Fig. 12, the regulations symbols of Fig. 13 have been designed with the primary criterion being the ease of understanding by the end user. Also, for better understanding, the symbols for the regulations are proposed to be depicted as pairs, i.e., side by side with the symbols for the MPA category.

Combined symbols

Figure 12 and Fig. 13 show separately the developed symbols for the MPA category and MPA regulations. S-122 *categoryOfRelationship* attribute expresses constraints or requirements on vessel actions or activities, such as permitted, prohibited, and restricted, in relation to a geographic feature, facility, or service. Thus, normally, the developed symbols should be combined into double, triple, or even more complex symbols. Figure 14 illustrates a few examples



Fig. 12 Indicative ENC symbology for MPAs types (attribute *categoryOfRestrictedArea*)

Fig. 13 Sample ENC symbols for permitted activities in MPAs

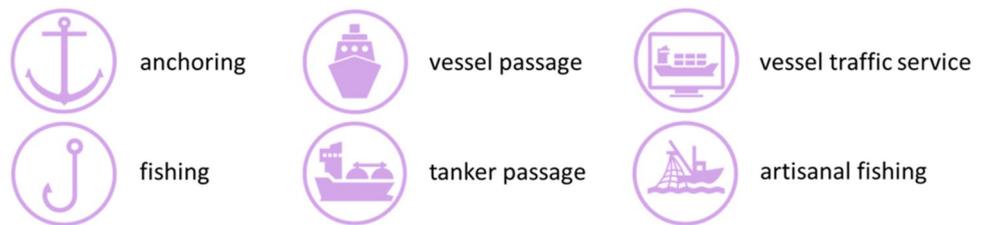


Fig. 14 Combined ENC symbols for MPAs categories and regulations



of double and triple symbols, e.g., the restricted symbolization refers to speed limit restrictions for a specific type of MPA, forming a double symbol, which may be combined with, e.g., the type of vessel (leisure, vessel, tanker, etc.) to form a triple symbol as deemed necessary.

MPA testbeds

“Use cases of protection measures” discussed existing measures for the protection of *Caretta caretta* turtles in Zakynthos marine protected area and of *Monachus monachus* monk seals in the Alonissos national park. In the former, a detailed map showing the zones’ limits with

illustrative symbols for the specific regulations is available, whereas in the latter, the available map on the MOM website presents the letters and zones’ limits, while the regulations are provided as separate, textual information. Furthermore, as expected, existing nautical charts of the Hellenic Navy Hydrographic Service, the official Greek nautical charting authority, do not include either of the two MPAs. Using web mapping technologies (Contarinis et al. 2022), we developed two testbeds of the above two use cases of “Use cases of protection measures”, to test the visual placement of the symbols on ENCs. Figures 15a and 16 illustrate the relevant MPA category and regulations for the Alonissos National Marine Park whereas

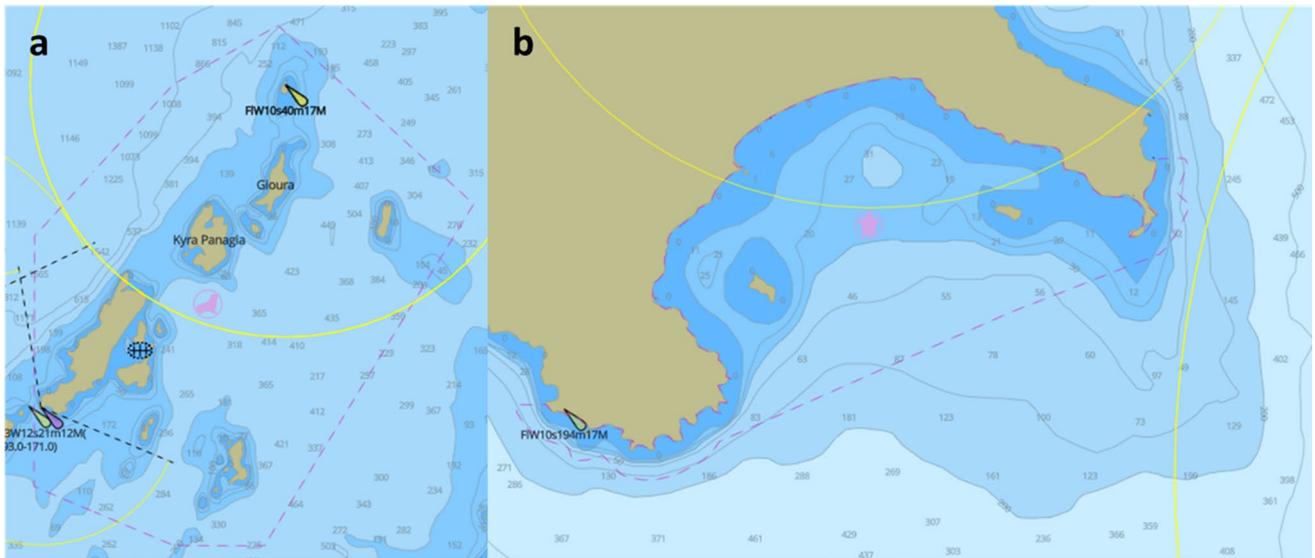
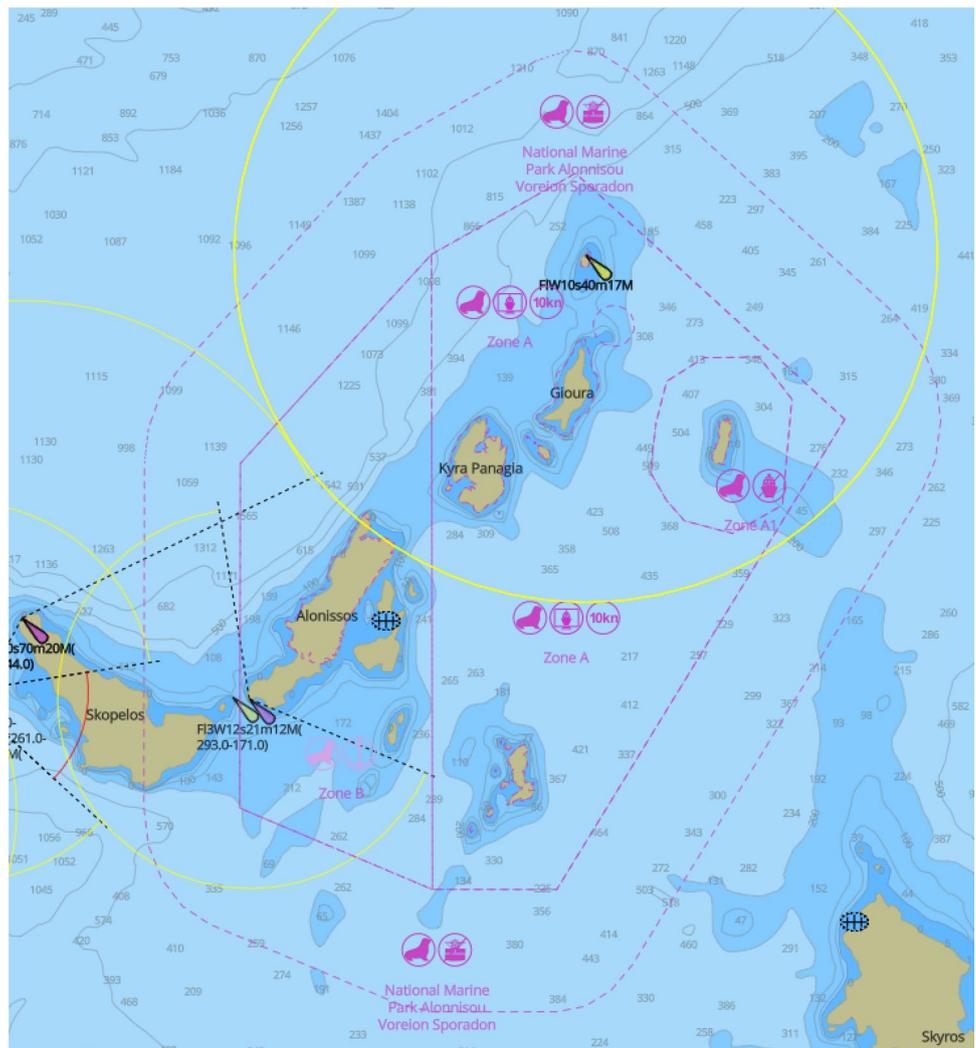


Fig. 15 Overview of a the Alonnisos and b the Zakynthos MPAs charting testbeds

Fig. 16 Monk Seal (Alonnisos) MPA charting testbed



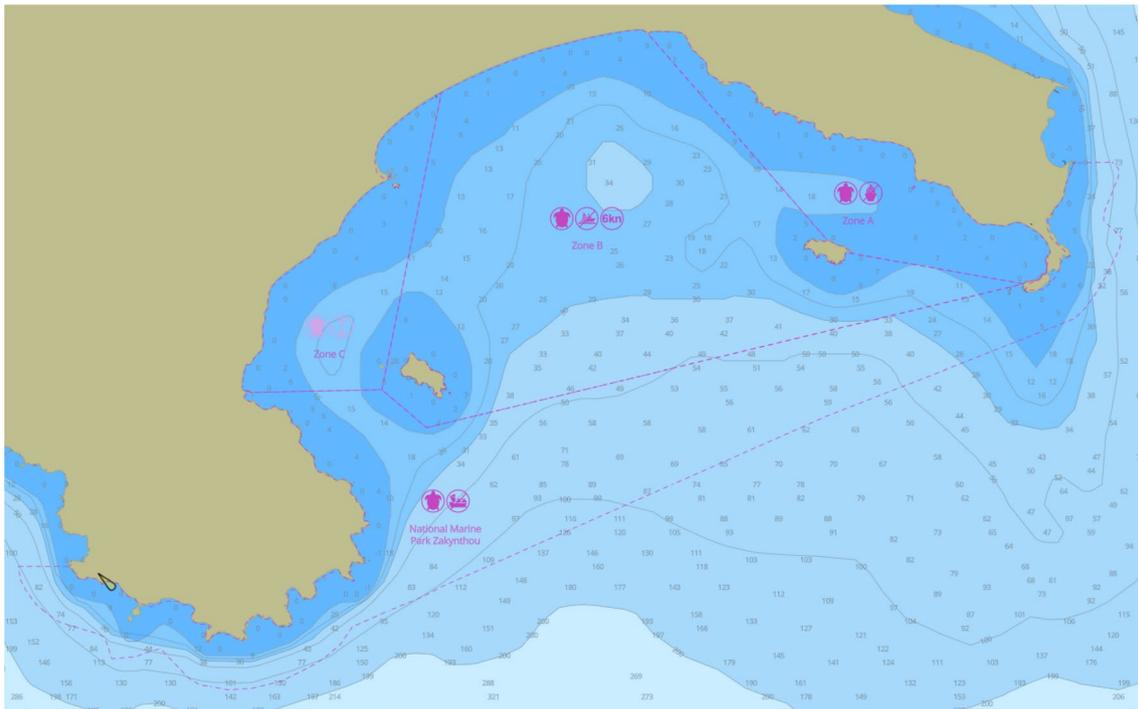


Fig. 17 Monachus turtle (Zakynthos) MPA charting testbed

Figs. 15b and 17 show those for the Zakynthos testbed, at two different viewing scales. In the overview (smaller scale) charts (Fig. 15), only the MPAs category symbol is portrayed; magenta faint is used in both cases to denote that permitted activities exist. In evaluating the larger scale charts (Figs. 16 and 17) a good visual hierarchy has been achieved in both areas as they attract attention without adding much visual weight on the chart. The saturated magenta symbols stand out as they represent more restricted regulations, whereas the faint symbols can be intuitively understood as more relaxed areas. Both testbeds provided good results and will act as a starting point for evaluations with end users in phase 2.

Discussion

Ecosystem protection zones

An important management instrument for MPAs is the use of separate marine zones, such as those illustrated in Fig. 18 (Ebreg and Greve 2000; Pierpaolo et al. 2013). They permit subregions to be designated for certain uses, such as the protection of vital habitats, research, and awareness programs, and mooring for leisure boats and fishery, as also discussed in the use cases of Alonissos and Zakynthos marine parks (Sects. 3.1 and 3.2, respectively). Zone boundaries are determined by environmental factors.

The zoning system can balance among conservation and usage, hence comprise regions with stringent protection and others with less controls. There may also be subzones that are enforced on a seasonal or temporal basis for vessels entry due to species breeding or migratory cycles, such as SMAs and DMAs respectively (see “Red list of ecosystems and threatened species”).

The different zones should be simple to describe, otherwise they may be hard to regulate, and users may have difficulties distinguishing them. The zoning plan would be desirable to be included in the management plan and specified in the relevant legislation. It could define the limits of the several zones and describe how each zone shall be used. The protection zones should be properly designated, along with the MPA’s outer limits. Precise descriptions or rules are necessary, e.g., “3 nautical miles buffer zone where fishing is restricted,” which could be interpreted as legally permissible boundaries for specific types of vessels and be easier for cartographers to design.

To accommodate the need for depicting protection zones with different restrictions (RxNs), inside or outside the perimeter of an MPA, the zoning approach can be utilized as an ENC charting method. For the realization of the *Ecosystem Protection Zones (EPZs)* concept in the S-122 product specification, the existing feature types of Navigational and the Regulatory Restricted Areas may be used, with the addition of an attribute indicating that the area is EPZ to a particular MPA object in the S-122 dataset. The

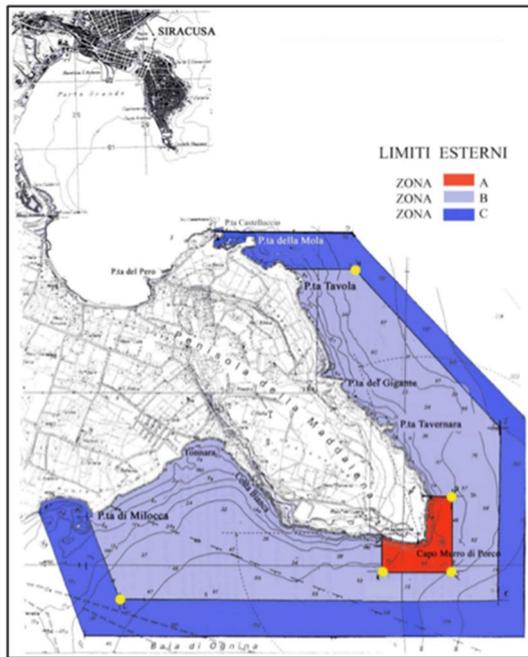


Fig. 18 Zoning in marine protected areas: the case of the Plemmirio, Italy. Reproduced from European MSP Platform (2021)

EPZ geometry may explicitly specify its boundaries as a polygon shape (GM_Surface) or, where applicable, by defining the width of the buffer zone around the respective MPA or other inner EPZ. In the latter case, either the ECDIS should calculate the exact boundaries or a tool could be developed and provided to the Hydrographic Offices to assist in designing the zones. The adoption of EPZs concept in S-122 will facilitate/ease the use of the encoded information for MPAs by mariners by generating ECDIS warnings/alerts when regulations are violated (see buffer zone in Fig. 16 for Alonissos Marine Park).

Environmental Risk Contour

The navigable waters of a vessel are those that are deep enough to sail safely; their determination is the most important factor for the safety of a voyage. They are determined from the sea depths that are depicted on nautical charts and they are automatically calculated from the ENC datasets on ECDIS systems. Sea depths are measurements from hydrographic surveys, the quality of which varies based on the measuring techniques and equipment available at the time of the survey. The various depth contours on the ECDIS indicate the navigable waters, as shown in Fig. 13. The shallow contour represents the depth at which a vessel will run aground if it is crossed and is usually selected equal to the vessel's static draft. The maximum draft plus the squat for the speed and a selected safety margin (known

as “under-keel clearance”), minus the tide height is used to compute the safety depth. ECDIS uses the safety depth to determine the safety contour, that being the closest deeper available contour in ENC, and sounds alerts when is crossed. The deep contour denotes the limit of the marine region where shallow water impacts might damage a vessel, and it is thought to be twice or four times the vessel's draft (SAFETY4SEA 2021); however, isolated dangers may still exist within the deep-water areas.

Identifying safe water depth is the most crucial task for seafarers. In addition, in navigating near PSSAs or MPAs, the seafarer is responsible for considering the environmental laws recorded in the nautical publications and for drawing/digitizing lines on the nautical chart that indicate the limits that the vessel is not permitted to cross. In that respect, rather than relying on this manual process, the introduction of the *Environmental Risk Contour (ERC)* (as shown in green in Fig. 19) may eliminate the mariner's trivial duty and ensure the enforcement of the MPA regulations. ERC, as a new S-122 spatial object (GM_Curve), shall be determined from relevant S-122 restrictions. ECDIS shall calculate and depict ERC as the limit of a marine protected area (MPA) or an environmental protection zone (EPZ), that a specific type of vessel or with a specific type of hazardous cargo could approach. When that contour is crossed alerts shall be shown both to the vessel's bridge operators onboard as well as to the vessel traffic operators onshore. Moreover, the use of ERCs could eliminate any misunderstanding or conflict where it is difficult to clearly identify the limits of a marine protected zone, especially in deep seas with strong currents. The ECDIS could automatically calculate the exact boundary based on the data provided or a tool could be developed and provided to the Hydrographic Offices to assist in depicting these contours for the various types of vessels, similar to the EPZ cartographic process.

Future work

IHO S-4 (2021) proposes that details associated with ESSA should be charted either in green or magenta. Green is the color internationally associated with environmental matters and, as explained in “[Design Principles](#)”, magenta is the color used for information and dangers on charts. The use of green for the symbols has the advantage of being immediately identifiable as environment-related symbols, while reducing the amount of detail on the magenta plate and, as such, can be an effective alternative to magenta. Figure 20 illustrates sample symbols in green color, where, likewise to the use of magenta, more and less saturated green can be used for restricted and permitted activities. An alternative could be a combination of magenta for restricted activities (to attract mariners' attention) and green for permitted activities. This matter is subject to research and further

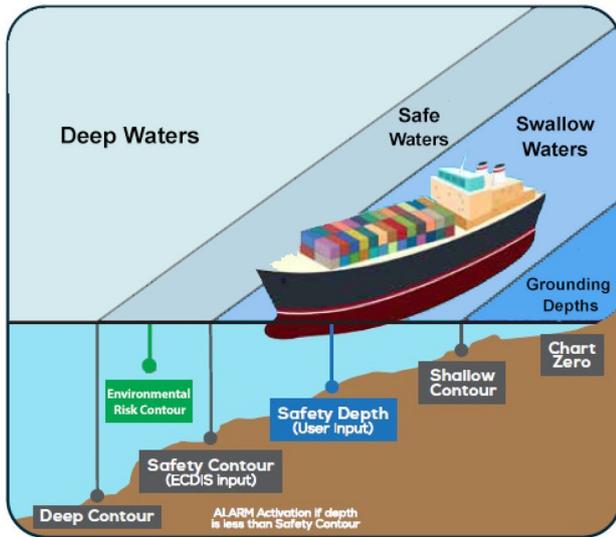


Fig. 19 Unsafe and navigable water areas, and Environmental Risk Contour (ERC). Modified from reference (SAFETY4SEA 2021)

discussion as part of phase 2 of this project and, apparently, up to the relevant IHO bodies to decide.

“New S-122 MPAs symbology” presented a set of symbols for MPA categories and regulations. However, various alternatives have been developed and will be expanded for further evaluation in phase 2. Figure 21 presents simplified alternative symbology for three of the MPA types, i.e., fish sanctuary, historic wreck area, historic submerged site, and activities such as tanker passage and vessel surveillance of the MPAs. For instance, for the vessel traffic services, the depicted computer monitor in the symbol could be with the more complex container (right) or a simpler ship icon (left). Likewise, e.g., for the tanker, one symbol shows the front viewpoint while the other shows a tanker’s side perspective.

On the other hand, fewer symbols for MPA types and regulations could be utilized, e.g., a single symbol for marine mammals instead of separate symbols for separate species. ECDIS provides additional functionalities that can alleviate the need for a plethora of symbols to cover all MPA types and regulations. In detail, generic symbols may be used, e.g., one symbol for marine mammals, one for recreational boats, and one for larger vessels, while mariners may access the respective, detailed, MPA information with a pick report.

After testing, a size of 9 mm was decided as a good compromise for the scope of this work (Fig. 22), i.e., allows for developing sufficiently detailed icons without adding much visual weight to the chart. During phase 2 of our user-centered design, visual acuities and minimum perceivable sizes (see e.g., Rytz et al. 1980; HFES 2007; Ware 2012; Lakshminarayanan 2015) for symbols will be reevaluated.

As part of our future work, consultation is planned with various stakeholders, including management bodies of



Fig. 20 Developed ENC symbols in green color



Fig. 21 Alternative symbols

marine protected areas, hydrographic offices, government, academia and research institutions, ecological organizations, and maritime operators, to improve the ideas presented in this work. That includes the improvements for ENC portrayal already discussed in this Section, as well as further analyzing and materializing the concepts of EPZ and ERC along with relevant ECDIS geospatial and alarm services. Following the consultation phase, a concise proposal will be drafted for the IHO’s Nautical Information Provision Working Group (NIPWG), which is responsible for the S-122 development.

Concluding remarks

The marine environment is frequently degraded by human activities, including overfishing, marine mammal strikes, and maritime accidents. Moreover, it is widely recognized that rising resource demand, lack of viable alternative livelihoods, overcapacity, and inadequate governance are factors

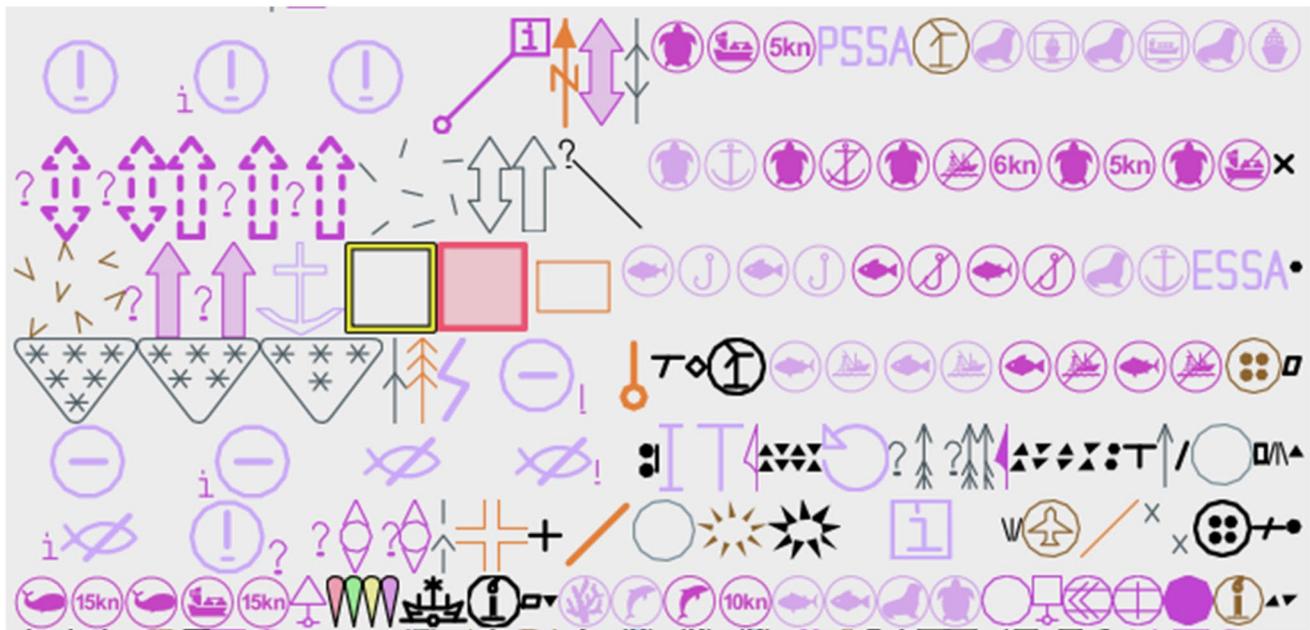


Fig. 22 New S-122 symbols along with existing S-101 ENC portrayal symbols

of biodiversity loss, ocean acidification, and climate change. The design and establishment of well-defined MPA zones and effective management plans are the response to these challenges for the long-term sustainability of the marine ecosystem. S-122 is a new, under-development geospatial standard for charting MPAs on Electronic Navigational Charts (ENC) that is subject to several improvements, with portrayal being one of them. In this paper we presented new, user-friendly, and intuitive symbology for the various MPA feature types, information types, and restrictions. The engagement of stakeholders in the next phases of this work is essential for the development of an agreed MPA symbology that will facilitate their needs, and for the further investigation and realization of the EPZ and ERC concepts introduced in this work. While buffer zones with varying levels of protection tend to be beneficial in conserving biodiversity within MPAs, the effectiveness of an MPA is determined by a high level of surveillance and enforcement (Pierpaolo et al. 2013), which both ENCs and ECDIS potentially facilitate.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s41207-023-00343-9>.

Funding Open access funding provided by HEAL-Link Greece. The work of Christos Kastrisios was supported by National Oceanic and Atmospheric Administration (Grant NA20NOS4000196).

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