Report on mitigation measures

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Summary

Abstract

This document describe in details all the sub-activities carried out under activity 5.4, including the following sub-activities:

i) analysis of current international and Italian and Croatian national regulations and description of anthropogenic current activities and trends ii) identification of risks for target organisms, based on soundscape modelled maps, with particular regard to Natura 2000 sites, and the expected (observed/estimated) distribution of target organisms; iii) identification of possible measures iv) feasibility analysis (environmental, technical, socio-economic, legal) of identified measures and future scenarios

1. Introduction

The SOUNDSCAPE project is funded by the 2014-2020 Interreg V-A Italy - Croatia CBC Programme funded by the European Union within the "Call for proposal 2017 Standard, Priority Axis: Environment and cultural heritage within the specific call objective 3.2 - Contribute to protect and restore biodiversity. The main objective of the project is to create a cross-border technical, scientific and institutional cooperation to face together the challenge of assessing the impact of underwater environmental noise on the marine fauna and in general on the Northern Adriatic Sea ecosystem.

Within the project, the Work package 5 aims at integrating results from the established underwater noise observing system (WP3) and the analysis of ecological targets, sensitivities and possible effects (WP4) to produce soundscape maps, carry out a preliminary risk analysis and inform possible policy actions for straightforward management of underwater noise in accordance with the MSF and MSP Directives, identifying feasible measures agreed upon with stakeholders to mitigate impacts of noise pollution on biodiversity while allowing sustainable development of maritime uses. According to the proposal, the two target species considered are *Caretta caretta* and *Tursiop truncatus*.

1.1. Workflow

The action 5.4 "Development of mitigation measures to reduce underwater noise and its effects on biological targets" includes the identification of possible measures (structural, i.e. reduction of noise generation acting on ships and other sources; behavioral, i.e. reducing ship velocity in certain areas; spatial, i.e. adapting navigation routes). This task consider the analysis of the current international, European, Italian and Croatian national regulations, with particular attention to EU directives, present strategies, framework and positions of the European Commission, and scientific bibliography, including International project outputs and gray literature.

In particular, the Activity 5.4 capitalizes from the other project activities in order to take into account the soundcapes assessed through the underwater noise propagation modeling (Action 5.2) integrated with the results of the WP4, providing a thorough definition of the sensitivities of target organisms to underwater noise, and the most recent knowledge on species and habitats distribution, with particular regard to Natura 2000 sites, gathered within WP3.

The sub-activities carried out are schematized in the conceptual framework of figure 1 and are articulated in three different phases.

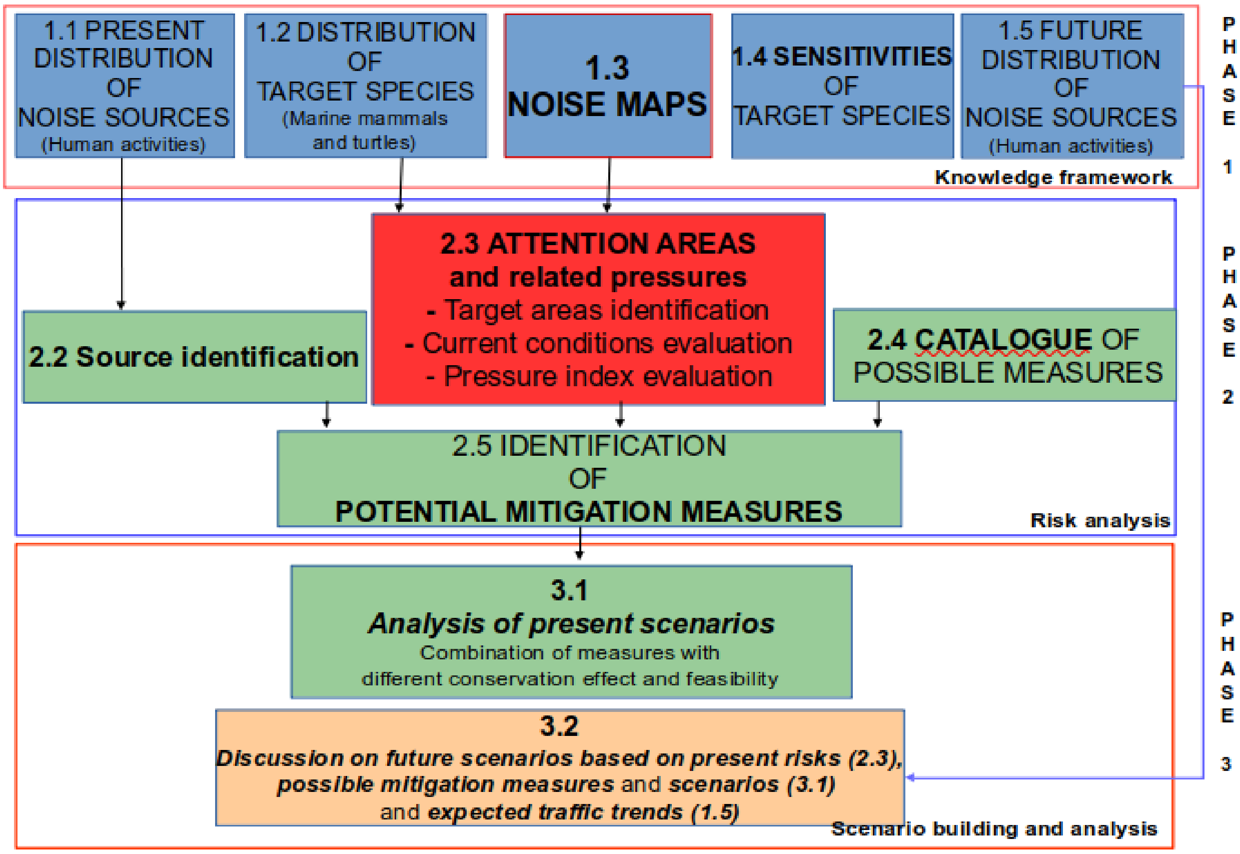


Figure 1. Conceptual workflow of the Activity 5.4

PHASE 1:

Data input refinement (action 5.1) on:

- Present and future trends on maritime traffic related noise sources;

- target species (marine turtles and mammals) distribution maps and their specific sensitivities to UWN;

- soundscape maps for the whole area.

PHASE 2:

- compilation of a catalogue of possible measures (structural, i.e. reduction of noise generation acting on ships and other sources; behavioral, i.e. reducing ship velocity in certain areas; spatial, i.e. adapting navigation routes).

- analysis of attention areas for target organisms (marine mammals and turtles), based on soundscape data, sensitivities and observed/estimated distribution, through a step-by-step approach:

- Area identification: attention areas are being identified through the analysis of baseline noise levels and statistically determined excess levels through analyses of extra noise from anthropogenic activities, in the whole cs area and within hot-spot of abundances and/or protected areas
- Pressure index evaluation: for each area the pressure functions and indexes have been calculated
- Anthropogenic sources extraction: the determination of the uwn excess levels caused by maritime traffic over natural noise levels
- Vessel type contribution: identification of the anthropogenic main sources (in particular vessel types using ais data), aimed at establishing proper mitigation measures
- Identification of proper mitigation measures to address anthropogenic UWN in the attention areas.

PHASE 3:

- analysis of present scenarios: combination of measures with different conservation effect and feasibility analysis of identified measures;

- discussion on future scenarios based on present risks, possible mitigation measures and scenarios and expected traffic trends.

2. Knowledge reference framework

2.1. Distribution of noise sources

2.1.1. Maritime traffic

Shipping, here intended as the transport of goods and passengers by sea, has a very high socioeconomic value in the Adriatic Sea, since it directly affects the development of all the Adriatic countries, also in terms of employment, and of many other sectors (such as tourism).

Shipping may raise important issues for environmental conservation and maritime spatial planning, ranging from spatial interactions with other human activities (e.g. fisheries) to the environmental challenges for sustainable maritime transport. These interactions can have ramifications for shipping in terms of safety and environmental protection and increasing demands for alteration of existing maritime routes. Maritime transport may exert a wide suite of pressures on the whole Adriatic area. The influence derives from the wide extension of the routes due to the wide presence of shipping and cruise ports at sub-basin level (e.g. ports of Koper, Venice, Trieste, Ravenna, Rijeka, Ploče, Ancona, Split). Such transboundary influences have transnational connotations to be considered in management options aimed to increase the overall sustainability of the sector.

In 2010, the North Adriatic Ports Association (NAPA) was established by the port authorities of Trieste, Ravenna, Venice and Koper with an aim of asserting position of the ports in respect of and its transport patterns. The Port of Rijeka joined the NAPA in November 2010. The Port of Ravenna resigned in November 2012 and rejoined in 2017. The association promotes the Northern Adriatic route and anticipates cooperation in the development of maritime and hinterland connections, visits from cruise lines, environmental protection, safety and information technology. The ports of NAPA also invest efforts into the coordinated planning of road, rail and maritime infrastructure, as well as the harmonization of regulations and procedures in the field of port service provision.

Italy

According to the “VIII Rapporto sull’economia del mare” (Unioncamere) among industrial activities of the Italian maritime cluster, maritime transports are in second place in terms of production value with 8.1 billion euros, above the touristic sector (14.4 billion euros) and also for number of employees and enterprises (year 2018). These data are particularly relevant for the Italian Adriatic ports of Venice and Trieste, among the most relevant in Italy. Moreover, national operators guarantee hundreds of the short sea shipping weekly departures on the motorways of the sea, linking the Italian peninsula with other Adriatic countries.

The WTO estimates the decline in world trade in 2020 at -5.3% (Europe -8%). According to the latest estimates, world container traffic in 2020 has been around 174 million TEU with a -1% compared to 2019. In the first two months of 2021, global maritime traffic grew by + 9.2% compared to same period of 2020 and + 5.7% compared to the first two months of 2019. In the 1st quarter of 2021 there was a strong increase in traffic (+ 13.5%), driven by Chinese and American ports. The situation is more variable in the Mediterranean ones, which are affected by the more difficult economic situation of European countries. The growth in the volume of trade in 2021 is expected to be + 8%. During the first quarter of 2021, Italian foreign trade to non-EU countries shows signs of recovery, with + 0.7% of exports and + 1.9% of imports over 2019.

The Italian National Strategic plan for Ports and Logistics states that Ro-Ro traffic should increase to somewhere between 85,7 and 90,8 million tons in 2020. However, the great uncertainty given by the Covid-19 pandemic effects on the current economic phase should drastically leads to a drastic revision such estimates, even in presence of positive growth forecasts for the 2021. The main Italian ports in 2020 handled 10.68 million Teu, 0.8% less than in 2019. A contained decrease compared to the country's overall crisis; however, it should be noted that the volume of containers handled by our ports has not varied significantly for years, fluctuating on values just over 10 million Teu. As for the Italian ports, in I quarter 2021 traffic remained substantially unchanged. Trieste port data was particularly positive within the National trends (+7.8%).

According to CLIA (Cruise Lines International Association) Cruise Tourism is intended as a form of travelling, involving an all-inclusive holiday on a cruise ship of at least 48 hours, according to specific itinerary, in which the cruise ship calls at several ports or cities. Until the 2020, before COVID-19 outbreak, cruise traffic in Italy had a significant growth with 12.3 million cruise passengers (+10,4% than 2018, according to "Risposte Turismo 2020 Speciale Crociere"). Data shows how the regions with the most transits of passengers were Liguria, Lazio and Veneto. In particular the Italian ports that handled the most passengers in 2019 were Civitavecchia (2.652.533, 8,6% than 2018), Venice (1.603.516, +2,8%) and Naples (1.356.320, +26,9%). Venice is confirmed first in the ranking of cruise ports for embarkation-disembarkation out of the total of traffic with over 1.39 million cruise passengers who have started or ended their cruise in the city, while the Italian Adriatic ports hosted the 22% of the National cruise traffic during 2019.

Croatia

The Croatian harbor system is allocated to ports open for public transport and ports for special purposes. According to size and importance, ports open for public transport are divided into ports of particular (international) importance for the Republic of Croatia (6 ports), ports of county importance (65 ports) and ports of local importance (369 ports). According to the activities, ports of special purposes are divided into military ports, ports of nautical tourism, industrial ports, shipyard ports, sports ports, fishing ports and others, which are additionally divided into special ports of national and county importance. Land and island coastal settlements have built fewer ports for berthing (communal berths), which are necessary for the normal life of the island population and the revitalization of islands. In accordance with the development of nautical tourism, communal berths are replaced by nautical infrastructure, which reduces the opportunities for the local population.

The most important ports according to amount of freight are the TEN-T ports of Rijeka and Ploče, ant the other ports as Split, Bakar, Omišalj, Raša and others. The leading Croatian ports according to number of passengers is Split (4,5 million), followed by Dubrovnik (2,3 million), Zadar (2,2 million), Supetar (1,8 million) and Korčula (1,8 million). Passenger maritime traffic in Croatia is extremely important, as evidenced by fact that it is most prominent in relation to other countries in the Adriatic according to number of pax and travellers. For connecting the inhabited islands, therefore, there are as many as 24 state ferry lines, 11 state shipping lines and 16 national fast-ship lines. Number of passengers transported in maritime transport has increased in the period 2013-2016 by 6,5%, and by

2016, 14,6 million passengers were recorded, mainly due to the importance and impact of the growth of tourist movements on the islands. Passenger transport is the most intensive in the counties of Split-Dalmatia, Šibenik-Knin and Zadar. The most prominent ferry lines in Croatia are Split-Supetar (1.881.052 pax in 2016) and Valbiska-Merag (1.068.453 pax in 2016).

Cruising tourism is the third fastest growing maritime activity in Croatia. The number of round trips of foreign vessels on the territory of the Republic of Croatia in 2016 increased by 7,4% compared to 2015. At the same time, the number of passengers increased by 4,2%. Most trips take place from May to October and have a seasonal character, which is why the problem of receiving capacity in destinations is also highlighted. Cruising tourism takes place in Dubrovnik, Split, Zadar, Pula, Opatija, Rijeka, Rovinj and Šibenik, but cruising tourism is far most represented in Dubrovnik, Zadar and Split. Dubrovnik is the second Adriatic port for the number of cruise arrivals with the total number of passengers of 833.588 in 2016. Strong development of cruising tourism has a twofold influence on the destination, but the negative impact is more pronounced, as is the example in Dubrovnik where there are issues of reducing the number of incoming tourists from cruise trips in order to preserve the cultural heritage.

The new trend in cruising tourism is strengthening the capacity of the port infrastructure to meet cruising tourism needs and become home-port ports. Zadar Port has invested heavily in the development of main and ancillary infrastructure in recent years to become one of the important cruise ports for cruising tourism in the Adriatic. Apart from Zadar Port, ports of Split and Dubrovnik stand out as homeports for smaller ships of up to 100 passengers.

The detailed analysis of maritime traffic in the Adriatic Sea for the year 2020, based on AIS data and divided by type of ship/vessel (i.e. cargo, tanker, passenger) is in the chapter 4.2.4. The traffic maps considered are also available on the website [link] (see also SOUNDSCAPE Report 5.3).

2.1.2. Recreational boating

Maritime tourism refers to sea-based activities such as boating, yachting, cruising, nautical sports as well as their land-based services (Ecorys, 2013).

According to Adriatic Sea Tourism Report 2017 (ASTR, 2017), the Northern Adriatic Sea is the area of the Mediterranean Sea with the highest increment of passenger traffic (cruises, ferries, catamarans and recreational boats) in 2016 compared to the previous years, and this trend is expected to continue. Many harbors (ports and marinas) are here concentrated, with highly touristic zones being exposed to high levels of recreational traffic.

Nautical tourism consists mostly of boating and yachting activities. The Adriatic is one of the top nautical tourism destinations in the Mediterranean and therefore pressures from this sub-sector are significant. In Italy there are over 200 marinas, while there are 81 in Croatia with over 16,000 moorings at sea. There are over 4,700 charter boats registered in Croatia and number of arrivals of charter guests has been steadily increasing.

Nautical tourism stands out as a vital tourism branch because it develops faster than the development of other selective forms of tourism. The existing capacity of nautical tourism in Croatia includes 139 ports of nautical tourism (out of which 58 anchorages, 71 marinas and 3 unmarked ports) (Croatian Bureau of Statistics). Nautical tourism is widespread throughout the Adriatic coast with a higher concentration in Central Dalmatia and Istria.

Seaside tourist flow is steadily increasing over the last 20 years in the study area. The tourism sector is characterized by highly positive dynamics at international level. The tourism sector in Adriatic coastal regions, both in Italy and in Croatia continued to register positive results, even in spite of Covid-19 pandemic. This significant growth is estimated to remain globally positive up to 2030. I.e., according to the national strategic plan "Turismo Italia 2020: Leadership, Lavoro, Sud", the sector is expected to grow by 2.3% per year, up to €83.4 billion - 4.7% of GDP - in 2024.

The current policies in place (EUSAIR Action Plan, Barcelona Convention, Common Fishery Policy, MSFD (2008/56/EC) and WFD (200/60/EC)) act promoting a sustainable tourism development in the study area, by diversification of products and services, reducing seasonality, improving the quality and innovation of tourism offer and enhancing the sustainable and responsible tourism capacities of the tourism actors across the macro-region etc.

The detailed analysis of maritime traffic in the Adriatic Sea for the year 2020, based on AIS data and divided by type of ship/vessel (i.e. cargo, tanker, passenger) is in the chapter 4.2.4. The recreational boating sector is characterized using "sailing" and "pleasure craft" vessel categories as a proxy but could not be fully considered in the analyses because AIS is not mandatory on boats <15 m, which constitute the majority of the sector. The traffic maps considered are also available on the website [link] (see also SOUNDSCAPE Report 5.3).

2.1.3. Fisheries

The Central-Northern Adriatic regions host old and important fishing traditions, and its fishing ports have always been a point of reference and innovation for sea fishing. The local fisheries sector features the following main activities:

- small-scale fisheries (SSFs), exerted mainly by fishing by vessels of less than 12 meters in length, mainly alternates passive fishing gears and depends on the seasonal successions and ecological features of target species

- trawling for demersal species, i.e. commercial bottom otter trawling (OTB), is legally practiced off 3 nautical miles and aimed at multi-species capture of demersal species

- trawling fishing with “rapidi”, i.e. beam trawl (TBB) fishing, with an active fixed-mouth tool specific for benthic species, typically practiced by Italian trawling fleets

- trawling for small pelagic species, i.e. commercial trawling along the water column towed by two vessels simultaneously (pelagic pair trawl, PTM), practiced by law off 3 nautical miles from the coast, for the almost exclusive catch of anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*).

The Italian Central and Northern Adriatic fleets composition highlights the importance of small-scale coastal fisheries in terms of number of fishing vessels in all GSAs, with over 600 units in GSA 17 (Northern and Central Adriatic Sea). However, trawling vessels represent an important segment of the fleet, making the Italian portions of the GSA 17 the most trawled area of the Mediterranean Sea (Russo et al., 2019).

Fisheries sector significantly of the Republic of Croatia is a relevant economic, with the share of small pelagic species targeted in purse seine fisheries, sardine and anchovy, by far dominating the overall structure (more than 86% of total landing weight in 2016).

The distribution of the trawling effort, both on the bottom and pelagic, presents different coverages and intensities in the study area. The professional fishing and harvesting activities in the Adriatic sea are mainly located inside national water limits and in portions of international waters. However, bottom otter trawling (OTB) substantially covers the whole study area, except for the 3 nautical miles band within which it is forbidden, with greater intensity in Italian and in international waters. The target fish stocks are often shared among each Adriatic country. The most recent scientific advice indicates that many target fish stocks in the Adriatic Sea are still being over-exploited and they are likely to decline further. The situation is away from sustainable fishing levels and far from the target of exploiting stocks at maximum sustainable yield (MSY) by 2020.

Within the European Maritime and Fisheries Fund, fishing fleet capacity decreased in terms of number of boats, of tonnage and of engine power (kW). The strong reduction in the profitability of the sector, stronger within the trawling sector if compared to the other fishing systems, has been caused above all by the decline of fish resources, the increase in operating costs and the competition between sectors and markets at local and transboundary level, pushing the operators to abandon the fishing sector, using the incentives provided for the definitive withdrawal. The decreasing trend is in line with that pursued at EU level. Over the next few years, with the implementation of the European Maritime and Fisheries Fund (EMFF) a further reduction in industrial fishing capacity is expected. Measure to promote the role of sustainable small-scale fisheries in the area, given its important and peculiar socio-economic value for coastal communities, and to reduce the impacts of destructive industrial fishing techniques are provided within the EMFF, taking into account also the integration between fishing and other activities with significant social and economic implications.

The detailed analysis of maritime traffic in the Adriatic Sea for the year 2020, based on AIS data and divided by type of ship/vessel (e.g. fisheries) is in the chapter 4.2.4. The fishing sector could not be fully considered in the analyses because AIS is not mandatory on boats <15 m, which constitute a relevant segment of the sector. The traffic maps considered are also available on the website [link] (see also SOUNDSCAPE Report 5.3).

2.2. Distribution of target species

2.2.1. Marine mammals

The Northern and Central Adriatic sea hosts a population of the highest density of bottlenose dolphin (*Tursiops truncatus*) in the Mediterranean. Their habitats include coastal areas, open waters, lagoons and river deltas and estuaries, where they feed mainly on fishes and cephalopods.

The northern Adriatic Sea has been recently designated as an Important Marine Mammal Area for bottlenose dolphins (IMMA, 2017) by the IUCN Marine Mammal Protected Areas Task Force (Notarbartolo di Sciara et al., 2016; UCN, 2018). Other species - the striped dolphin (*Stenella coeruleoalba*), the fin whale (*Balaenoptera physalus*), the sperm whale (*Physeter macrocephalus*), Risso's dolphin (*Grampus griseus*), Cuvier's beaked whale (*Ziphius cavirostris*) and the long-finned pilot whale (*Globicephala melas*) - are considered visitors or vagrant individuals, while the dramatic decline in numbers of the short-beaked common dolphin (*Delphinus delphis*) in the past 40 years has led to regional extinction (Genov et al. 2021), although in the recent years more frequent observations of individuals are occurring (Fortuna et al., 2015).

The lack of quantitative historical data limits defining trends in their abundance within the Adriatic Sea. Detailed information at local scales comes from a few areas where local communities of bottlenose dolphins have been studied intensively. These areas include, in example, Croatian islands (for detailed information on the distribution of bottlenose dolphin on the Cres-Lošinj archipelago and Western Istria refer to SOUNDSCAPE Report *4.1.1. Report on the distribution of target species* and *4.1.2 Map of distribution of target species within and adjacent to the Natura 2000 SCI*), the Gulf of Trieste, Veneto and Emilia-Romagna regions of Italy, and off western Istria, Croatia (Ribarič, 2018).

A coarser but wide area knowledge comes from the aerial surveys, conducted in 2010 and 2013 (Fortuna et al. 2015), with the aim of identifying the presence and distribution of cetaceans and sea turtles within the whole Adriatic basin, the first information on the overall distribution of bottlenose dolphins was given (fig. 2). As result, the uncorrected abundance estimates for the whole Adriatic Sea is 5.700 individuals (CI = 4,300-7,600; Fortuna et al. 2018). Predictive density (Figure 2) of bottlenose dolphins indicates that North and South Adriatic appear to be areas of high relevance for this species. Their abundance was found to be the highest in the north Adriatic Sea with the relative density of 0.057 individuals/km^2 (Fortuna et al. 2018).

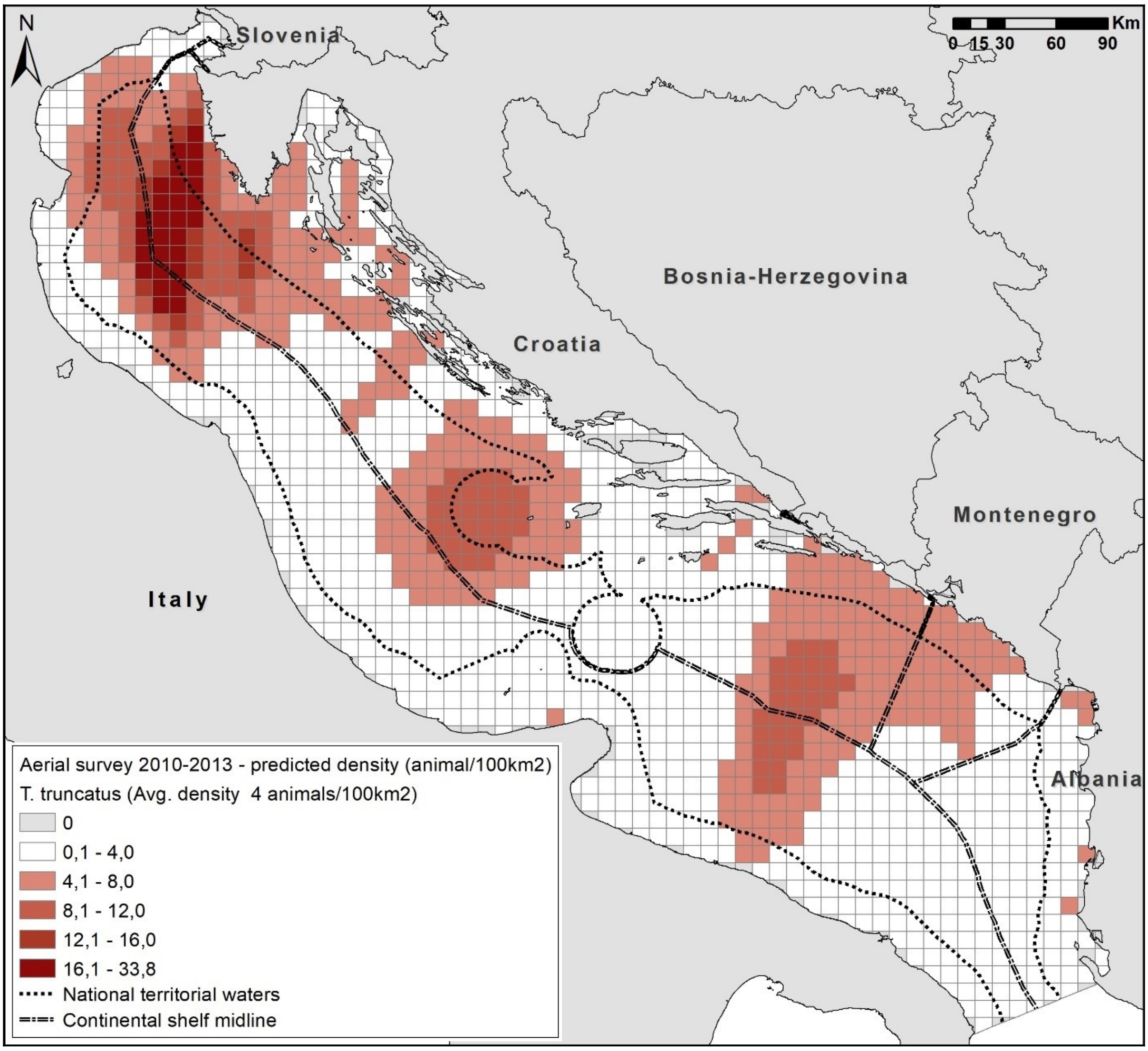


Figure 2. Predictability model of the density of bottlenose dolphins in the Adriatic Sea; Fortuna et al. 2018. Data available on the website [link] (see also SOUNDSCAPE Report 5.3).

Recently published results from aerial surveys carried out in the Adriatic Sea on July 2018 confirm the widespread distribution in the whole Central and Northern Adriatic sea, with several groups detected in the pelagic environment without apparent preference for coastal areas in summer(figure 3).

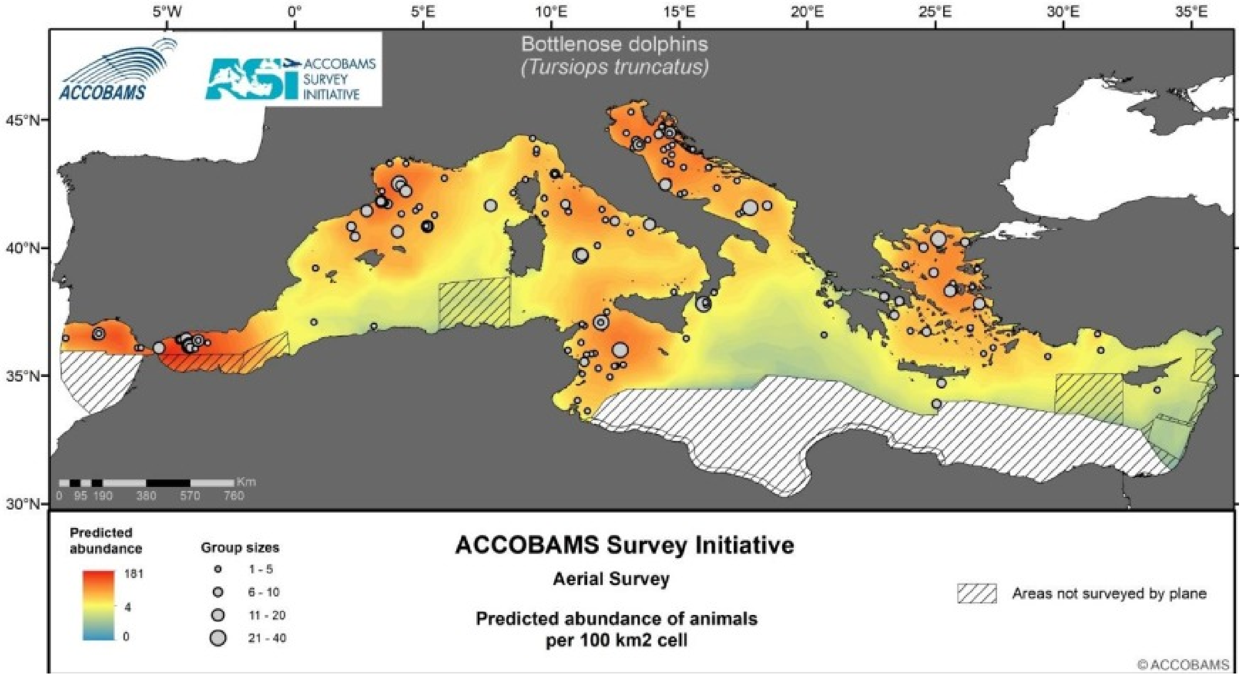


Figure 3. Predicted abundance of bottlenose dolphins; ASI ACCOBAMS 2021.

These summer surveys data confirm the north Adriatic as important bottlenose dolphin habitat, but the seasonal (e.g. east-west migration during spring-summer months) and annual variation of local distribution can be quite large (Figure 4), making determining robust boundaries complex.

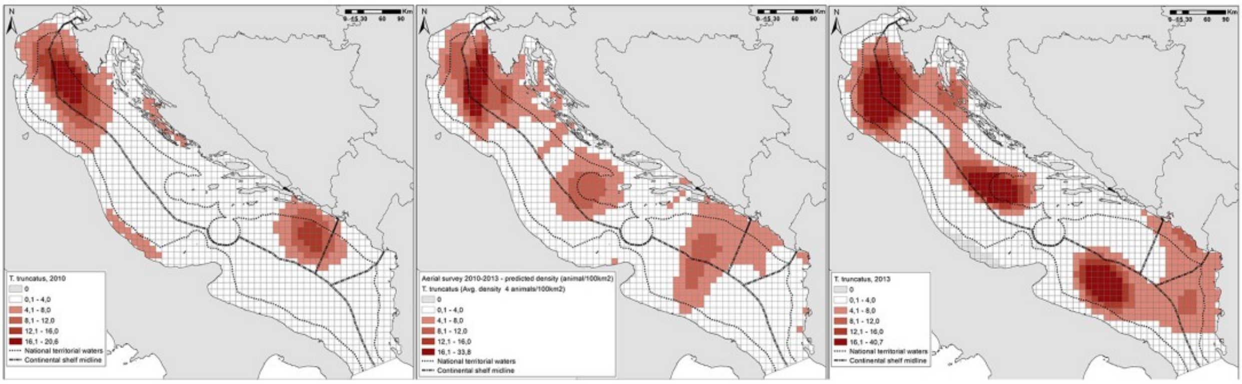


Figure 4. Bottlenose dolphin densities for the data from 2010 (left); 2010–2013 (center), and 2013 (right); Fortuna et al. 2018.

The ecological reasons for these temporally variable higher density areas are poorly understood. They could be related to food resources (especially in the more homogeneous northern Adriatic) and/or for the complex inteactions with the anthropogenic activities.

The North Adriatic relatively high density strongly indicate that they contain critical habitats required for the conservation of the species and, given the observed decline of the species during the last few decades, further reiterate the need for basin-wide protection measures.

2.2.2. Marine turtles

Three species of sea turtles have also been reported in the Central and Northern Adriatic Sea (Fortuna et al. 2015; Lazar et al. 2008; Lazar et al. 2004a): loggerhead turtle (*Caretta caretta*), green turtle (*Chelonia mydas*, mainly present in the southern part) and the Leatherback turtle (*Dermochelys coriacea*), regular in the Mediterranean but with rare occurrence in the Adriatic Sea. Loggerhead turtle is the most abundant sea turtle specie in the Adriatic Sea. Spatio-temporal analysis indicates their whole-year presence within the Adriatic with strong seasonal variability in abundances and the existence of diverse habitats within this region. The Adriatic Sea is one of the most important feeding grounds in the Mediterranean of the Loggerhead turtle, *C. caretta*. The loggerhead turtle movements in the Adriatic Sea include the adult breeding migration from foraging (e.g. from southern and eastern areas to the Po delta area in spring and summer) to breeding grounds (e.g. Croatian islands; for detailed information on the distribution of *C. caretta* on the Cres-Lošinj archipelago and Western Istria refer to SOUNDSCAPE Report 4.1.1. Report on the distribution of target species) and vice-versa, seasonal migrations of both adults and juveniles with southward movements from the northern Adriatic when temperatures fall in the cold season. Generally the Northern Adriatic Sea, especially in it's western coasts, is not considered a nesting area for *C. caretta*, even if recent events (i.e. nesting on Emilia-Romagna and Veneto sandy shores during summer 2021) occurred, possibly due to increased attention to turtles protection but, also, to effects of warmer waters in consequence of climate changes.

The uncorrected abundance estimates for the whole Adriatic Sea is based on the aerial survey data from 2010 and 2013 and is 27,000 individuals (CI = 24,000–31,000; Fortuna et al. 2018; Figure 5).

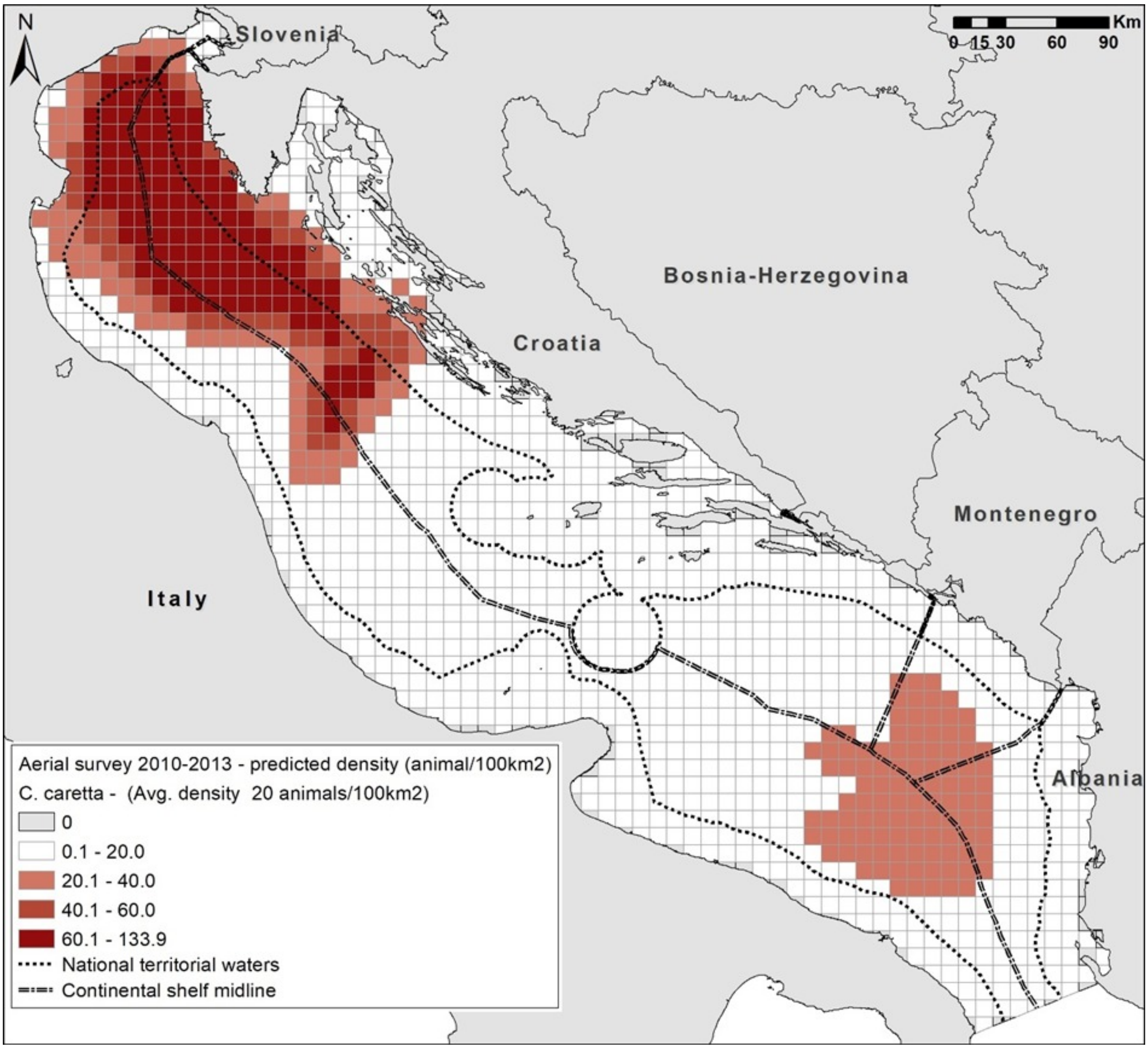


Figure 5. Predictive density of loggerhead turtle in the Adriatic Sea; Fortuna et al. 2018. Data available on the website [link] (see also SOUNDSCAPE Report 5.3).

These data confirm that the north Adriatic, as a whole, is an important area for the conservation of *C. caretta*, at least in Summer (Fortuna et al. 2018), as a key neritic habitat for loggerhead turtles.

Aerial surveys carried out in the Adriatic Sea on July 2018 confirm the widespread distribution in the whole Central and Northern Adriatic sea (ASI ACCOBAMS 2021, figure 6), with turtles mostly encountered in offshore waters.

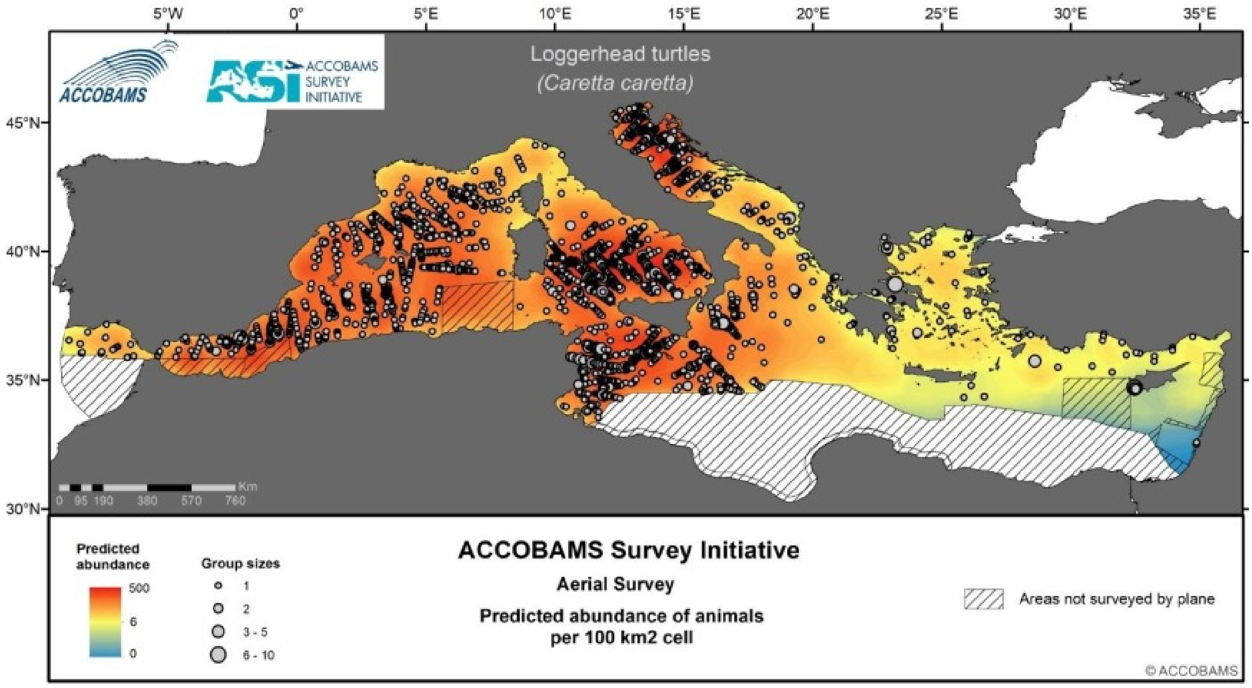


Figure 6. Predicted abundance of loggerhead turtles; ASI ACCOBAMS 2021.

Genetic diversity indexes indicate that the Adriatic sea area receives individuals mostly from the Greek rookeries followed by western Turkey, and Crete, Cyprus and Eastern Turkey rookeries. No Atlantic rookery contribute. This indicates that eventual pressures exerted on the aggregation areas of the North Adriatic sea would provoke a strongest impact on the status of the populations belonging to these rookeries, most specifically the Greek ones. Sea turtles are one of the most endangered marine organisms due to their frequent entanglements in fishing gear and continuous degradation of their habitats fishing activities such as bottom trawling. No nesting locations or reproductive sites have been identified along the Croatian and Northern Italian coasts. Further details on the *C. caretta* life cicles within the Adriatic Sea are within the SOUNDSCAPE Report *D 4.2.1. Gap-analysis report based on existing knowledge of the sensitivity of target species to sound and the potential effects of noise*.

2.3. Sensitivities of target species

The ecological impacts of chronic exposure to pervasive anthropogenic noise on fishes, invertebrates, reptiles, mammals, and whole marine ecosystems may be extremely various, with ample evidence that noise pollution may compromise hearing ability, induce physiological changes, elicits evasive actions and displaces marine animals (Duarte et al. 2021). Anthropogenic noise can interfere with natural auditory signal processing by marine animals, an effect known as "masking", which reduces their communication space, potentially resulting in loss of social cohesion, missed opportunities for feeding, or failure to avoid a predator. Indeed, anthropogenic noise overlaps with the frequency band of hearing of marine animals across increasingly broad areas of the ocean (fig. 7).

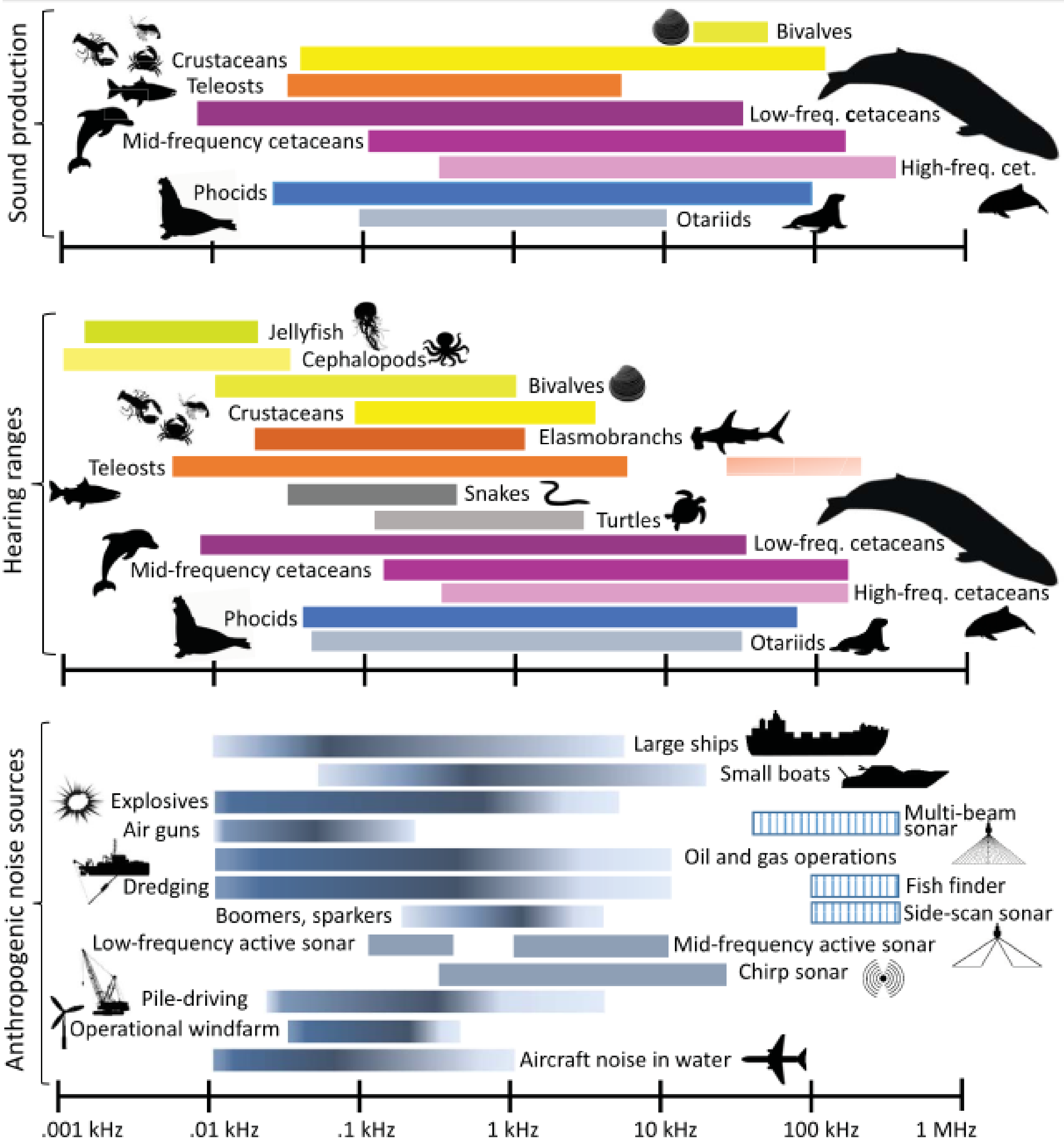


Figure 7. Approximate sound production and hearing ranges of marine taxa and frequency ranges of selected anthropogenic sound sources. These ranges represent the acoustic energy over the dominant frequency range of the sound source, and color shading roughly corresponds to the dominant energy band of each source (from Duarte et al. 2021).

In particular, the frequency of vessel noise overlaps considerably with the hearing ranges of marine fauna, particularly those with sensitivity in relatively low-frequency ranges (e.g., fishes, some marine mammals, and reptiles). Below is a brief description of the best knowledge available on *C. caretta* and *T. truncatus* sensitivities to anthropogenic noise, extracted from the detailed review reported in the SOUNDSCAPE Report *D 4.2.1. Gap-analysis report based on existing knowledge of the sensitivity of target species to sound and the potential effects of noise*.

2.3.1. Marine mammals

In bottlenose dolphins both short –term reactions (changes in acoustic behavior, surface behavior, diving intervals, group formation and orientation as well as those long-term (abandonment of noisy habitats) have been reported in relation to anthropogenic underwater noise. While short-term reactions have been well studied, the effects of a long-term exposure are yet to be fully determined, particularly at the population level.

Man-made noise has the potential to induce a stress response in marine mammals (Erbe et al. 2019). Acoustic overexposure to noise may cause changes in various hormones in the blood, including cortisol, to bottlenose dolphins. These stress hormones can have a variety of effects on immune function, such as suppressing immunity that in the long term may affect the survival of the individuals. Other example of severe physiological responses found in bottlenose dolphins after exposure to seismic air-gun noise (44–207 kPa or 213–226 dB re 1 µPa peak pressure) included a significant increase in aldosterone and a significant decrease in monocytes. Moreover, sound can cause non-auditory effects by making the air-filled cavities vibrate at their resonant frequencies, which causes trauma to the surrounding tissue.

Hearing sensitivity loss is defined as threshold shift. While a temporary threshold shift (TTS) is a reversible effect and is considered auditory fatigue, a permanent threshold shift (PTS) is irreversible and considered an injury. The scientists at the Hawaii Institute of Marine Biology used continuous random noise as a stimulus to measure TTS in bottlenose dolphins. The stimulus used had a broadband received level of 179 dB rms re 1 µPa, which was about 99 dB above the animal's pure-tone threshold of 80 dB at the test-tone frequency of 7.5 kHz. More recent studies (Nachtigall et al. 2015) have shown that although intensity of stimulus was strongest below 11 kHz, TTS was the greatest at 16 kHz in response to 30 minutes of a 160-dB rms re 1 µPa fatiguing stimulus. The complete recovery occurred within 45 min. Both TTS and PTS negatively affect foraging efficiency, reproductive potential, social cohesion, and ability to detect predators. A TTS also has the potential to decrease the range over which socially significant communication takes place, for example, between competing males, between males and females during mating season, and between mothers and offspring.

Another effect of elevated noise levels on marine mammals is interference with biologically important sounds. This “masking” affects the animals’ range of communication as well as the quality of transmitted information. Masking has been identified as the primary auditory effect of vessel noise on marine animals. In bottlenose dolphins and other odontocetes, the most typical reactions to masking involve shifts in frequencies to increase the efficiency and detectability in the transmission of acoustic signals, increased vocalizing rate, and increased duration of calls. Dolphins also produce whistles at varying frequencies with greater modulations in less noisy habitats. Conversely, when ambient noise is greater, they produce whistles of lower frequencies with fewer frequency modulations, and therefore show high ability to adapt to diverse habitat conditions.

There has been a variety of behavioural responses documented in marine mammals exposed to noise. Behavioural reactions generally depend on whether the animals are habituated to a particular sound, and are therefore less prompt to react or more likely to respond to it (sensitization). The magnitude of the reaction is generally related to the familiarity of the sound and perception of its proximity, and varies according to the differences between species, age-sex classes, and the motivational state of the animals.Although the presence of noise may not always elicit dramatic behavioural changes, it is important to consider both the short-term (temporary changes) and the long-term effects that may have implications on animals' survivorship and reproduction. Abandonment or displacement from critical feeding and breeding grounds have been documented in bottlenose dolphins exposed to boat noise. Typical behavioral reactions include changes in diving behavior, modifications of movement speed and orientation, changes in vocalization, and temporary or permanent habitat displacements Bottlenose dolphins perform shorter dives and increase group cohesion when approached by boats, which can be a result of boat physical and acoustic boat disturbance. Avoidance of noisy areas can be related to a reduced communication range, which reflects on the habitat quality.

The presence of noise does not always seem to evoke significant behavioural effects, and changes in behaviour are not always clearly detectable; however, a decrease in foraging efficiency from modifications in diving behavior such as shorter dives, and longer surfacing intervals may in the end compromise the welfare of not only individuals, but entire populations.

2.3.2. Marine turtles

Sea turtles are one group of endangered marine organisms that are likely to be impacted by anthropogenic sound production. Although little is known about the use of sound in sea turtles, the proposed functions of their hearing include navigation, locating prey, avoiding predators, and general environmental awareness. For loggerhead turtles, the acoustic environment changes with each ontogenetic habitat shift. In the inshore environment, where juvenile and adult sea turtles generally reside, the environment is noisier than the open ocean environment of the hatchlings. This inshore environment is dominated by low frequency sound from shipping and recreational boating and seismic surveys, which are becoming more commonplace. Unfortunately, effects of noise on sea turtles remain poorly investigated.

Preliminary research on the effects of anthropogenic noise on marine turtles indicates their avoidance of the sound source. In sea turtles, hearing damage may lead to a reduced ability to avoid natural and anthropogenic threats, such as fisheries by-catch and vessel collisions. However, due to a lack of research, it is not known what levels of sound exposure (or frequencies) would cause permanent or temporary hearing loss or what effect this may have on their reproduction or survival.

Death and injuries may result from exposure to high-powered acoustic sources. Rapid pressure changes induced by powerful sound can lead to barotrauma with two possible outcomes: lethal injuries of the exposed individual or less severe injuries with the possibility of recovery. Death in case of barotrauma can be direct or result in the behavioural changes that jeopardize animal's health and lead to increased susceptibility to predators and sickness.

No studies have so far assessed hearing loss or effects of acute noise on sea turtle hearing. Nothing is known on TTS in sea turtles and there is no research conducted on the damages and disappearance of sensory hair cells located on the basilar membrane of the ear of sea turtles or whether they can be recovered after exposure to acute noise. Moreover, the consequences of masking in marine turtles are still not fully investigated. Most likely, the noise can reduce the range of detection of some biologically relevant sound or make some sound less audible. Although the masking effect is generally of short duration, still when evaluating the long-term effects it is important to consider cumulative effects due to multiple emission of such impulsive sounds.

Until now, there is very little information available on the behavioral reactions of sea turtles to noise. Avoidance of low frequency noise was found on the captive sea turtles. These include behavioral changes that include increased surfacing and changes in their swimming patterns found in captive animals when exposed to air gun sound of 166 dB (RMS) re 1 µPa. Avoidance of the air guns was observed upon first exposure, however, after three separate exposures to the air guns, the turtles habituated to the stimuli.

From the conservation perspective, direct short-term effect of anthropogenic noise on an individual level is less concerning in comparison to the effects of long-term chronic exposure on the population level, especially when combined to other anthropogenic stressors including fisheries interaction. Anthropogenic noise can cause changes in the behavior and activity of resident populations and negatively affect coordination and orientation of animals, their migration patterns, efficiency of their movement in the water, velocity and direction of movements, surfacing intervals, efficiency in finding food and reduced ability to avoid predators or to orientate. Non-lethal changes may still have effects on the growth and survivorship of individuals and have negative consequences on the overall health of the animal. Anthropogenic noise represents an additional source of stress for sea turtles in the Adriatic Sea because they are already facing many threats in this region, as previously mentioned. Due to the lack of research on this subject, it is still not possible to quantify changes induced by anthropogenic noise in sea turtles.

3. Catalogue of possible mitigation measures

3.1. Introduction

The Adriatic sea is heavily populated by intensive maritime activities (from commercial ports and medium-small touristic marinas), a complex fishery system integrated with an extensive offshore gas extraction, making this area subjected to intense anthropogenic underwater noise pressure that affect its valuable ecological resources (e.g. nursery and spawning grounds of species of high commercial interest, seasonal hotspots of Species of Community Interest such as *C. caretta* turtles and marine mammals, mainly *T. truncatus*).

The present study considered maritime traffic (including shipping and passenger vessels, cruise ships, fishing vessels and small boats) as the main source of underwater noise, thus in presence of other relevant uses, present (i.e. gas extraction, infrastructures development) and/or future (e.g. hydrocarbon research and prospection, offshore wind farms, relict sand deposits exploitation).

Shipping noise has been reported to disrupt traveling, foraging, socializing, communicating, resting, and other behaviors in marine mammals, reptiles and fishes, potentially leading to increased mortality and reduced ability to learn to avoid predators (Duarte et al. 2021). Underwater noise mitigation may require a wide and diversified range of actions to be addressed. In order to guarantee systematicity to the framework of management measures identified by the study, a series of categories of measures were identified, as reported below:

Main measures (defined as measures that directly affect noise emissions):

1. Strategic measures

2. Spatial-Temporal measures, regulating activities with reference to specific areas and/or periods

3. Behavioral measures, sustaining good practices and minimizing environmental impacts

4. Technical and technological improvements, concerning ships and their components, methods of navigation, tools, devices, products, processes and any element useful to improve the sustainability of activities

Support measures (defined as measures that do not directly generate a decrease in noise emissions but are functional to the effective implementation of the main measures):

5. Monitoring, control and surveillance, aimed at measuring the trend of parameters relating to underwater noise and the characteristics of marine ecosystems.

6. Economic, financial and other measures: measures encouraging the active participation in decision-making and management processes, dealing with economic aspects (including taxation) and aimed to identify financial resources to support the performance and sustainability of activities, together with measures aimed at training of operators on specific technical topics.

For each considered measure, the following attributes were defined:

- Typology: the measures are categorized in governance, technical (permanent) or operational (temporary)

- Description

- Applicability: focus on how the measures can be implemented in all and/or specific ship types (e.g. cargo, tankers, cruises, passenger, fishing, touristic vessels) according to their features in both new building as well as retrofit projects and Adriatic fleets specificities.

- Possible implementation issues (e.g. times, costs, uncertainty of effectiveness, enforcement, voluntary approaches)

- Examples, experiences and good practices (when available).

The catalogue was compiled taking into account existing strategies (i.e. EU policies, IMO agreements, ACCOBAMS reports), the results of relevant international projects (e.g. AQUO, SONIC, JOMOPANS) and an extensive review of the scientific literature. The number of possible mitigation measures is summarized in tab. 1.

Table 1. Synthesis of the possible mitigation measures for each category and typology

Type of measure	**Code**	**Name**	**Short/Medium/ Long Term (S/M/L)**
Strategic	1a	Include specific noise mitigation objectives within maritime plans	M
	1b	Coordinated port development plans in the whole area	M/L
	1c	Dynamic Ocean Management of maritime traffic	M
Spatial-Temporal	2a	Rerouting	S
	2b	Establish “Particularly Sensitive Sea Areas” (PSSAs)	S/M
	2c	Establish “Areas To Be Avoided” (ATBAs)	S/M
	2d	Limitations to recreational boating	S

Behavioural	3a	Speed reduction	S
	3b	Convoy	S
	3c	Using tugs	M
	3d	Optimize Ship Handling	S/M
	3e	Regular hull and propeller maintenance polishing	S
Technical/ Technological	4a	Install ducted propellers	M
	4b	Install skewed propellers	M
	4c	Reduction of propeller speed per Knot (TPK)	M
	4d	Install water jets or pump jets	M
	4e	Install CLT propellers	M
	4f	Electric machinery	M/L
	4g	Machinery treatments	M
	4h	New hulls designs	L
Monitoring, control and surveillance	5a	Live mapping of underwater noise sources and intensity	S/M
	5b	Development of a pilot registration system through transparent management and live use of AIS data for all the vessels (including leisure boats).	S/M
	5c	Better knowledge Continuous mapping of the distribution of target species, their variability and their life cycle, and understanding of their responses to noise exposure	S/M
Economic, financial and other supporting measures	6a	Promote and finance innovative technologies geared to noise emission reduction	S/M
	6b	Offer best practice training programs to shipping companies	S
	6c	Literacy and awareness raising (e.g. local communities, nautical sector, citizens)	S

3.2. Strategic measures

1a: Include specific noise mitigation objectives within maritime plans

Typology: strategic

Description: Comprehensive ecosystem based marine plans are under development EU countries, and provide an opportunity to address underwater noise as a highly concerning pressure on the Mediterranean marine environment. Specific conservation targets could be included in marine plans, fostering the management, limitations and possible exclusion of noisy activities altogether from certain habitat areas. Criteria for designating such areas could include their identification as critical or important habitat for at-risk species deserving priority for conservation

Applicability: the strategic measure is proposed in compliance Maritime Strategy Framework Directive (MSFD 2008/56/EC) Descriptor 11 “Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment” and the Maritime Spatial Planning Directive (MSPD 2014/89/EU).

Possible implementation issues: common political strategies should be fostered to properly set up shared transboundary actions.

Examples, experiences and good practices: within the final proposal for the Marine spatial plans for Baltic Sea (Swedish Agency for Marine and Water Management, Proposal to the Government reg. no 3628-2019, 16/12/2019), risk of disturbing the noise-sensitive and threatened species in the area was assessed and management choices about offshore installations (i.e. offshore wind-farms) and re-routing of maritime traffic were included in the plan.

1b: Coordinated port development plans in the whole area

Typology: strategic

Description: The Adriatic Sea provides a priority maritime route from Asia, via Suez, to Europe and the northern Adriatic ports are located in close proximity to each other. Due to their geographical characteristics they hold a special position in the European ports system, operating in a relatively closed system. In the area most relevant transboundary interactions of shipping, besides the environmental pressures and economic competition of the activity, are related to operational, administrative and custom procedures, safety and security taking into account also international regulations and the policies and strategies of the EU. In particular, the legal framework of the maritime transportation sector in the Adriatic Sea is not homogeneous. However, Croatia, Italy and Slovenia, as Member States of the EU, are bound to the European legal framework, which includes Directive 2002/59/EC (as modified by Directive 2009/17/CE) that established the SafeSeaNet mechanism to harmonize the monitoring of traffic and the information exchange. The trends in the development of maritime activities seem to lead to an increased density of traffic in Adriatic Sea during the next years, as well as important changes in the nature of traffic. In consequence, the management and planning for maritime transport should take in account the strong influence derived from the other shipping and cruise ports in the wider Adriatic and Ionian area. Transboundary approaches are therefore called for the management of underwater noise in the Adriatic basin, throughout:

- Clustering port activities/services throughout the region, harmonizing the ports processes through a common ITS (Intelligent Transport System).
- Improving and harmonizing traffic monitoring and management, strengthening exchange of information between coastal countries through the development of a Common Adriatic-Ionian Vessel Traffic Monitoring and Information System
- Developing ports, optimizing port interfaces, infrastructures and procedures/operations.

Applicability: the strategic measure is proposed in compliance with EUSAIR Action Plan, Pillar 2 (COM(2014) 357 final).

Possible implementation issues: commercial competition between ports could make collaborative activities, clustering and joint development complex, in the absence of common political strategies conveyed by medium-long term transboundary actions.

Examples, experiences and good practices: the North Adriatic Ports Association (NAPA) was already established by the port authorities of Trieste, Ravenna, Venice, Koper and Rjeka with the aim of collaborating in the development of shipping activities in the area.

1c: Dynamic Ocean Management of maritime traffic

Typology: strategic

Description: dynamic ocean management is defined as 'management that changes rapidly in space and time in response to the shifting nature of the ocean and its users based on the integration of new biological, oceanographic, social and/or economic data in near real-time' (Maxwell et al., 2015). Dynamic ocean management more closely aligns management response times with the scales of variability in the environment, in marine species movements, and in resource use. Static management approaches can lead to large areas being placed off-limits to maritime traffic, possibly generating a considerable economic cost, while proper dynamic ocean management can result in smaller, dynamic management boundaries, providing protection equal to large-scale closures but with less impact on resource users, i.e. rapid communications to users, e.g. using hand-held technology may allow vessels to adapt their behavior in relation to ecological observations, showing the presence of highly mobile species of concern in specific areas.

Applicability: the reliability of technology and data capacity (e.g., remote sensing, live modeling, communication technology) to apply dynamic ocean management is strongly dependent on the assumptions and the quality of the available data. Improvements should be fostered on the processing and analytical capability, integration of datasets, production of reliable forecasts at appropriate timescales, and communication with vessels at sea, permitting resource users to adapt to management measures in near real time. The expansion of low-cost cellular coverage makes the application of dynamic management applications feasible.

Possible implementation issues: application of dynamic management requires a shift from static management measures to near real-time management. The available knowledge on activities, pressures and environmental components can be limited, thus limiting the availability of accurate quantitative data. The complexity of data driving dynamic management may vary, from simple compilation of user-generated data, to complex habitat modeling approaches, and all incorporate new data on time scales from days to months. To address these concerns several additional gaps need to be filled, including international legislative instruments (i.e. data-sharing, confidentiality, data security and enabling policies), and development of support tools. The construction of an information system to support planning and adaptive management is a necessary step in order to achieve DOM.

Examples, experiences and good practices: dynamic ocean management has been applied across several sectors using both voluntary and compulsory measures. TurtleWatch is a program developed by the NOAA Pacific Islands Fisheries Science Center designed to reduce bycatch of sea turtles in Hawaii. NOAA scientists determined the temperature preferences of loggerhead turtles using satellite tracking and highlight areas fishermen should avoid to reduce sea turtle bycatch. This information is posted online every several days. Passive acoustic buoys and aerial surveys are used to detect the real-time presence of North Atlantic right whales (*Eubalaena glacialis*) along the US East Coast to reduce lethal ship strikes of this critically endangered species. Dynamic management area locations are distributed to ship captains via mobile applications to alert them to the whales' presence and to recommend avoiding areas or reducing speeds when whales are present (Maxwell et al., 2015).

3.3. Spatial-Temporal measures

2a: Re-routing

Typology: operational

Description: routing decisions to avoid sensitive marine areas including well-known habitats or migratory pathways when in transit will help to reduce adverse impacts on marine life. Setting up traffic separation schemes (TSS) that force all vessels to follow a general direction in a given zone is are already considered to regulate the traffic at busy places, confined waterways or around capes. They are usually ruled by the International Maritime Organization (IMO) and incorporated in the International Regulations for Preventing Collisions at Sea (under rule 10). Rerouting should also be considered for small vessels traffic (e.g. fishing vessels, yachts and small boats) in presence of highly sensitive marine areas.

Applicability: TSSs have been already established in the Northern Section of the Adriatic Sea covering respective solutions in the Eastern Part and the Western Part. Traffic could be further managed exploiting bathymetry and geographical features of the Adriatic sea, establishing TSS or navigational areas in shallow waters and eventual canyon areas in order to benefit from bottom absorption, surface waves diffusion and to confine the noise generated by the vessels.

Possible implementation issues: further static management tools such as TSS should be properly planned and sustained by in-depth knowledge on activities, hydrological features and environmental components to match the needs of avoiding sensitive marine areas. For example, even if Adriatic marine mammals and turtles have been regularly observed in the area, systematic monitoring and mapping activity on seasonal basis is still scarce. As a consequence, their spatial distribution with reliable estimates of their seasonal abundances and densities are not available, and could be insufficient to propose TSSs. Within TSS, compulsory technological and behavioral measures (i.e., vessel speeds and regulated distances between vessels) could be enforced. Frequency and method of position monitoring that has been decided must be adhered to at all times.

Examples, experiences and good practices: in 1998, TSS was approved close to the he Cabo de Gata-Níjar Natural Park (Alboran Sea, Spain) by the IMO, after consultation with stakeholders from the fisheries, commercial and recreational sectors. In 2006 the IMO approved the repositioning of the TSS from 5 to 20 nautical miles off the coast, to make navigation safer and protect the ecological value of the Cabo de Gata Natural Park. This was achieved through a proposal from the Spanish Directorate General of Merchant Marine to the IMO, and was supported by UNESCO (Randone et al., 2019).

2b: Establish "Particularly Sensitive Sea Areas" (PSSAs)

Typology: governance

Description: a Particularly Sensitive Sea Area (PSSA) is an area that needs special protection through action by IMO because of its significance for recognized ecological / socioeconomic / scientific reasons and which may be vulnerable to damage by international maritime activities. When an area is approved as a particularly sensitive sea area, specific measures can be used to control the maritime activities in that area. A PSSA can be protected by ships routing measures, e.g. for certain typologies of ships.

Applicability: Proposals for new PSSAs must come from coastal states, and need to be formally recognized and adopted by the International Maritime Organization (IMO). The process is coordinated between the IMO Marine Environment Protection Committee (MEPC) and state governments. To allow areas to be designated a PSSA a number of criteria is required, including ecological criteria (e.g. unique or rare ecosystems, diversity of the ecosystem or vulnerability to degradation by natural events or human activities) social, cultural and economic criteria (e.g. significance of the area for recreation or tourism) and scientific and educational criteria (e.g. biological research or historical value).

Possible implementation issues: Cross-border cooperation between national authorities is needed to achieve the designation of a new PSSA from the IMO. The PSSA designation could be limited without further analysis of shipping data, particularly at the local level, and by more detailed ecological research in coastal and high water areas, in order to match the required criteria.

Examples, experiences and good practices: the only PSSA in the Mediterranean Sea is the Strait of Bonifacio, located between the islands of Corsica and Sardinia. The Strait represents one of the most significant environmental regions in the western Mediterranean, populated by many endangered and endemic species. The Strait is also part of the Pelagos Sanctuary and, since 2001, it has been on the list of Specially Protected Areas of Mediterranean Importance (SPAMI). The designation of the Strait of Bonifacio as a PSSA in 2011 allowed the introduction of additional measures and recommendations to strengthen the protection from marine traffic hazards, such as ship routing, improved ship reporting and navigation information and recommended qualified pilots for ships transiting the Strait.

2c: Establish “Areas To Be Avoided” (ATBAs)

Typology: governance

Description: Commercial vessel traffic in the Adriatic Sea is increasing, and the use of areas to be avoided (ATBAs) offers one mechanism to help achieve underwater-noise mitigation objectives. an ATBA is a particular type of ships' routing measure, defined by IMO as “an area within defined limits in which either navigation is particularly hazardous or it is exceptionally important to avoid casualties and which should be avoided by all ships, or certain classes of ship”. ATBAs may be mandatory or recommendatory in nature. Vessels are urged not to travel within the boundaries of a recommendatory ATBA, while vessels are generally prohibited from traveling within the boundaries of a mandatory ATBA. In general, ships show high compliance with IMO-designated ATBAs even when they are recommendatory, making ATBAs a strong contributor to effective governance of vessel traffic. ATBAs may eliminate or reduce the risk of these noise-related impacts by not allowing vessels - or specific types of vessels, e.g. vessels not adopting specific technical noise mitigation measures - in a specific area. Although acoustic disturbance may spread into an ATBA, the relative risk of impact is reduced as fewer vessels transit these areas (Huntington et al., 2019).

Applicability: the establishment of an ATBA follows the submission of a proposal by local authorities responsible for marine traffic to the IMO, which then takes charge of reviewing and approving the proposal, and gaining it official recognition at international level. Once the ATBA is established, its limits and related measures are mainly communicated to maritime users by local authorities and through nautical charts. Dynamically managed ATBAs may respond and adapt in real time to environmental or biological changes, such as presence of marine mammals or intense noise occurrence. Dynamic ATBAs require the availability of relevant environmental information as well as the ability to transmit that information to vessels and ports in real time or near-real time.

Possible implementation issues: Countries proposing new ATBAs should identify the reasons and need for the ATBAs, as well as the classes of ship to which the proposed ATBA will apply, and the existence of environmental conservation areas and environmental concerns needing the establishment of such areas. IMO guidance provides that ATBAs should be designated only when lack of adequate charting or aids to navigation could cause accidents, when local knowledge is required for safety, when an essential aid to navigation may be at risk, or when there is the possibility that unacceptable damage to the environment could result from a casualty. IMO do not adopt an ATBA if it would impede ships' progress through an international strait. The availability of reliable environmental information—particularly real-time data—is one important constraint on the design and delineation of ATBAs. Effective communication among shipping companies, port authorities, marinas, scientists, and waterway managers is also essential for ATBAs to be effective. If these conditions can be met, ATBAs can become an essential component of well-regulated shipping throughout this sensitive region.

Examples, experiences and good practices: the main reason for the ATBAs adoption worldwide is the safeguard of vessels from especially dangerous location Still, ATBAs have been adopted for the primary purpose of protecting the marine environment or marine wildlife. In example, off the coast of Canada, Florida, California, Cuba, New Zealand, etc., the IMO adopted ATBAs to avoid risk of pollution and damage to the environment of sensitive areas and for reasons of conservation of unique biodiversity and wildlife (Huntington et al., 2019).

2d: Limitations to recreational boating

Typology: operational

Description: especially when operated at high speeds, small recreational vessels produce broadband cavitation noise, which has the potential to affect a wide range of marine species for which shallow coastal areas are key habitats. Specific limitations to recreational boating should be considered within and in proximity of protected sites (e.g. Marine Protected Area, Natura 2000 sites) and may include temporal institution of no access zones in highly sensitive areas.

Applicability: limitation to recreational boating should be fostered through proper education and enforcing activities, with specific inclusion within protected sites regulations.

Possible implementation issues: the efficacy of limitations could be limited in absence of proper monitoring, surveillance and stakeholder's inclusion.

Examples, experiences and good practices: monitoring and limitations to recreational boating are already implemented within and close to MPAs, albeit for other environmental objectives, producing excellent results both in the management of tourism activities and in environmental protection (e.g. Venturini et al. 2021)

3.4. Behavioral measures

3a: Speed reduction

Typology: operational

Description: ships with higher speeds radiate more UWN at a higher intensity into the marine environment (Simard et al., 2016). The main source of noise from commercial ships is cavitation and this occurs when the speed reaches the cavitation inception speed (CIS). Reduction of speed has the immediate effect of reducing UWN radiation, especially if the speed reduction reaches less than CIS, its effect becomes more significant (IMO-MEPC, 2014). Although slow steaming reduces the noise level in the area, the duration of the noise propagation in the area increases, because ships spend more time in an area (McKenna et al., 2013). The mitigation effect from slow steaming is not equal between different ambient sound conditions, species, and vessel types (Pine et al. 2018). For example for ships equipped with fixed pitch propellers, reducing ship speed can be a very effective operational measure for reducing underwater noise, according to ship size (IMO-MEPC, 2014). The largest reduction in UWN radiation per knot belongs to vessels with higher Block coefficient (Cb) such as Bulk/General Cargo vessels (2.8 dB/knot), and tankers (2.6 dB/Knot) with significant variations from ship to ship, even in the same types. Consideration should be given in general to any critical speeds of an individual ship with respect to cavitation and resulting increases in radiated noise. In general, however, model indicates a 10% reduction in speed would cut global underwater sound energy from shipping by around 40% (Leaper, 2019). Voluntary vessels slowdown trials down to 11 knots also proved significant reductions in sound levels for five categories of piloted vessels (container ships, bulkers, tankers, vehicle carrier and cruises; MacGillivray et al. 2019). In particular, the fastest vessels (container ships, cruises and vehicle carriers) exhibited the greatest reductions (mean reductions in broadband between 11.5 and 9.3 db), whereas slower vessels (tankers and bulkers) exhibited smaller reductions (approximately 6 dB). These noise reductions were highly frequency dependent, with the minimum reductions at 100-1000 Hz range and the largest at the low and high ends of the frequency range. Authors speculated that while cavitation noise increase with speed at all frequencies, the machinery noise dominates at mid-frequencies and has a weaker speed dependence.

Applicability: When re-routing shipping lanes are not possible, reducing vessel speed may be the only alternative method to mitigate UWN immediately (Vakili, 2018). For ships equipped with controllable pitch propellers (e.g. cargo, tankers and passenger medium-size ships), there may be no reduction in noise with reduced speed or cause, in particular conditions far from the optimal design ones, increase noise levels with decrease of speed. Therefore, consideration should be given to optimum combinations of shaft speed and propeller pitch.

Possible implementation issues: The reduction in navigation speed can lead to an increase in transport and management costs for ports and shipping companies, thus generating potential resistance to its widespread application, in particular in areas with high traffic density, and in the absence of appropriate economic and management incentives.

3b: Convoy

Typology: operational

Description: recommending target speeds of the vessels entering the route-systems (e.g. TSSs) in order to guarantee a minimum and/or a maximum distance between successive vessels, and/or to form groups of vessels capable of sailing at the same speed. Transiting in convoys could increase the received level above current typical maxima at any particular point of closest approach, even if outside of the time lapse in which the convoy passes there might be long periods in which no ship would elevate ambient noise levels (Williams et al. 2019). This would increase maxima occasionally, but the expected result would be a reduction in the number of hot-spots of underwater noise and smaller amplitude between the maxima and minima of underwater noise in the map.

Applicability: convoying ships requires the reduction of the ship speed.

Possible implementation issues: setting up traffic separation schemes (TSS) could be a necessary step to apply convoy.

3c: Using tugs

Typology: operational

Description: the tugs may play a significant role in developing the sustainable shipping in port areas. It requires more efficient, and quieter tugs to be used in the area. Using tugs with LNG and methanol engines, or using fuel cells and hybrid batteries on the tugs can have significant roles in reducing both emissions and the UWN radiation.

Applicability: this measures requires more efficient, and quieter tugs (e.g. LNG and methanol engines, or using fuel cells and hybrid batteries).

Possible implementation issues: extensive towing activities may cause large delays and endanger the safety of the navigation, requiring local scale studies on the possible socio-economic side effects.

Examples, experiences and good practices: Vakili (2018) analyzed scenarios of underwater noise emissions within the Porto of Vancouver (Canada), highlighting that tugs escorting with constantly low speed towing could provide less fuel consumption, costs, UWN and CO_2 emissions in the area.

3d: Optimize Ship Handling

Typology: operational

Description: Variable loading of the ship alters the propeller depth from its design and, consequently affects in the inception of cavitation. Ballast ships are usually not in their loaded condition and, consequently, the propellers may be properly not immersed, with their tip closer to the surface. The lower pressure due to less hydrostatic head causes more cavitation and noise propagation (Ligtelijn et al., 2014; Vakili 2018). Furthermore, the increased astern trim change the wake field to the propeller and more cavitation may occur. In consequence, ships should be handled at proper specific speed and load conditions. Optimum trim for specified draft and speed and ballast for trim and steering conditions could help in optimizing fuel consumption and reduce noise propagation.

Applicability: the need for proper and optimized ship handling is particularly compelling for tankers or bulk carriers.

Possible implementation issues: The relationship of these factors to noise propagation requires further studies and, during the design period, the trade-off should be considered (Vakili 2018).

3e: Regular hull and propeller maintenance polishing

Typology: operational

Description: marine fouling increases the ship's hull resistance, fuel consumption and operational costs. Propeller polishing done properly removes marine fouling and vastly reduces surface roughness helping to reduce propeller cavitation. Marine fouling can be formed on the the propeller after a period of time. Furthermore, the fouled ship's hull provides an uneven wake field to the propeller and leads to cavitation and UWN radiation. Propeller polishing can remove the marine fouling and reduce surface roughness and help in cavitation reduction. Maintaining a smooth underwater hull surface and smooth paintwork may also improve a ship's energy efficiency by reducing the ship's resistance and propeller load, while the fouled ship's hull provides an uneven wake field to the propeller and leads to cavitation and UWN radiation. Hence, it will help to reduce underwater noise emanating from the ship. Effective hull coatings that reduce drag on the hull, and reduce turbulence, can facilitate the reduction of underwater noise as well as improving fuel efficiency. Regular hull and propeller maintenance can improve efficiency and reduce UWN by up to 1- 2 dB (Baudin and Mumm, 2015).

Applicability: all vessels.

Possible implementation issues: Hull polishing cost depends on ship size and must be completed regularly.

3.5. Technical and technological improvements

3.5.1. Propulsion level improvements

The propeller is a significant underwater noise source especially when it cavitates (at higher propeller load and speed, above the cavitation inception speed). The noise is made up of broad-band noise up to very high frequencies and can be 20dB noisier up to 10 kHz when compared to a non-cavitating propeller. Non-cavitating noise (distinct tones at blade frequencies and its multiples) and also wideband noise due the excitation of blades by turbulent flow, may also occur. Cavitation can be reduced under normal operating conditions through good design, such as optimizing propeller load, and careful selection of the propeller characteristics such as: diameter, blade number, pitch, skew and sections. Noise-reducing propeller design options are available for many applications and should be considered. However, it is primarily intended for consideration for new ships and cannot always be employed due to technical or geometrical constraints. It is also acknowledged that design principles for cavitation reduction (i.e. reduce pitch at the blade tips) can cause decrease of efficiency. Ensuring as uniform water flow as possible into propellers can be influenced by hull design. For effective reduction of underwater noise, hull and propeller design should be adapted to each other.

4a: Install ducted propellers

Typology: technical

Description: A ducted propeller uses a duct around the perimeter of the propeller to modify the propulsion performance and noise characteristics of the propeller.

Applicability: the cost of replacing conventional propellers with ducted propellers is three to five times the cost of a conventional propeller, while its fuel efficiency can be similar or higher than conventional propeller at low speeds. This type of propeller is estimated to be 5 dB (ref 1µPa), more silent than conventional propellers but only a low speeds. Therefore, speed limitations should be also considered.

4b: Install skewed propellers

Typology: technical

Description: Propeller with high skew is affected by the ship generated wake field in a more gradual manner, improving cavitation patterns and resulting in the reduction of propeller cavitation and increased cavitation inception speed. This could help achieving a reduction of underwater noise up to 10 dB (ref 1µPa), depending on wake field characteristics, especially in the low frequency range (40-300 Hz).

Applicability: Its fuel efficiency and its cost is similar than conventional propellers for new ships and and economically and technically feasible for existing ships which makes it the best option for retrofitting, especially for tanker, cargo, cruise ships and passenger vessels.

Possible implementation issues: Increased design effort for new builds and potential 10-15% higher cost than conventional propellers.

4c: Reduction of propeller speed per Knot (TPK)

Typology: technical

Description: Reducing propeller rotational speed per knot of speed causes a reduction of the flow velocity at the blade tip. The effect is to increase cavitation inception speed and to mitigate all forms of propeller cavitation (especially propeller tip cavitation). This could help achieving a reduction of underwater noise at all frequencies.

Applicability: This solution enhances efficiency and is recommended for the new build of all the ship types and to both fixed and control pitched propellers (CPP).

Possible implementation issues: Increased design effort, requiring a larger propeller diameter, and potential slightly higher coasts.

4d: Install water jets or pump jets

Typology: technical

Description: Noise reduction promoted by the higher cavitation inception speed and by isolating the propeller from the sea, in all frequencies noise can be up to 15 dB (ref 1µPa) compared to conventional propellers.

Applicability: both water jets or pump jets are applicable to new builds of high-speed ships. In fact, this solution is also used for some naval ships (high speed corvettes and frigates), it is applicable to fast passenger vessels and could also enhance efficiency at high speed, especially for fast, shallow draft vessels.

Possible implementation issues: higher cost than conventional propellers and reduced efficiency at low speeds, since the cost of fuel is increased at lower speeds and the cost of replacing conventional propeller to water jets in existing ships can be up to five to six times the cost of a conventional propeller, including increased maintenance costs.

4e: Install CLT propellers

Typology: technical

Description: designed with an end plate which reduces the tip vortices, thereby enabling the radial load distribution to be more heavily loaded at the tip than with conventional propellers. In turn, this means that the optimum propeller diameter is smaller, and there is the possibility of reducing cavitation.

Applicability: The cost of this type of propellers, good for improvements on cargo, tankers and passenger vessels, is estimated 20% higher than conventional propellers.

3.5.2. Reduction of machinery noise

Proper onboard machinery along with appropriate vibration control measures, location of equipment in the hull, and optimization of foundation structures may contribute to reducing underwater radiated and onboard noise. The most common systems of propulsion on board ships is the diesel engine, widely used as main engine is around thew 90% of the ships recently built (e.g. cargo, tankers, bulk carriers and container vessel. Turbines (used in specialized vessels such as nuclear-powered vessels, LNG and coal carriers) are generally considered to give less excitation and to be quieter than diesel engines because their operation is smoother but also because the noise spectrum shows mainly high frequencies content. Moreover, gas/steam rotating turbines generally have lower fuel efficiency and higher capital cost than diesels, but allows reduced emissions, space demands and enhancing comfort and an high contribution in the reduction of underwater noise. However, a high reduction of RPM is required for coupling with the propeller and it can be an important source of underwater noise at frequencies around 300-1000Hz. A way around this problem is the use of turbines for electricity generation and electric motors for propulsion. Vibration isolation mounts should also be considered for reciprocating machinery such as refrigeration plants, air compressors, and pumps. Vibration isolation of other items and equipment such as hydraulics, electrical pumps, piping, large fans, vent and AC ducting may be beneficial for some applications, particularly as a mitigating measure where more direct techniques are not appropriate for the specific application under consideration. As an example, the application of dampening tiles integrated into the structure of a vessel, absorbing vibration energy, highly contributes in the reduction of URN in new builds.

Applicability: suitable four-stroke engines (i.e. cruise ships, ferry and passenger vessels, fishing vessels) specific solutions to reduce the structure-borne noise (elastic mountings, flexible couplings) as well as the airborne noise (acoustic enclosures) may significantly reduce underwater noise levels. Four-stroke engines are often used in combination with a gear box and controllable pitch propeller. The gearbox can produce high level of noise at its gear teeth mesh frequency (commonly above 200-300Hz), a frequency the hull better radiates than lower ones, requiring to isolate the source from the hull.

4f: Electric machinery

Typology: technical

Description: Electric transmission enables and facilitates many noise reduction approaches, from the use of mounts and enclosures to active noise cancellation, rather than mechanical. A wider range of propulsor selections are available, with highly variable costs and benefits.

Applicability: New builds.

Possible implementation issues: Electrical transmission has reduced efficiency than mechanical, and capital costs are higher so its use is generally in vessels where other benefits outweigh these costs (e.g. improved maneuverability, reduced space demand, reduced weight).

4g: Machinery treatments

Typology: technical

Description: Machinery treatments for both new builds and retrofit could highly reduce the the transmission of vibration energy from machinery, and the generation of energy into the water from the hull. For effective noise reduction, consideration should be given to mounting engines on resilient mounts, possibly with some form of elastic coupling between the engine and the gear box. Vibration isolators are more readily used for mounting of diesel generators to foundations. Vibrations generated by the engine is transmitted to the hull of the ship and into the ocean, with a significant low frequency content (below 40Hz) in presence of high harmonics. A Double stage vibration isolation system could be considered using one or several pieces of machinery mounted on an upper layer of mounts supported by a raft (steel structure) which is further supported on the hull girder on a lower level set of mounts. This reduces noise by creating an extra impedance barrier to the transmission of vibration energy. It is often used for engine/gearbox or engine/generator. Small diesel and gas turbines may also adopt acoustic structures designed to enclose a specific piece of machinery, absorbing airborne noise, reducing the transmission of energy and the generation of URN from the hull.

Applicability: New builds and retrofits.

Possible implementation issues: Large two-stroke engines used for most ships' main propulsion (i.e. container, carriers and tankers ships) are not suitable for consideration of resilient mounting, due to the size and the rigid connection to both the ship hull and the propeller shaft. Large engines, in fact, require many mounts and higher installation costs, with increased weight and space demands. Reft foundation is not applicable to 2-stroke diesels due to higher weight, space demands and installation costs.

3.5.3. Ship concepts - hull and structure improvements towards quieter vessels

4h: New hulls designs

Typology: technical

Description: UWN radiation from the mainly origins from the vibration and noise of parts onboard the ship, which transfers to the ship's hull and radiates into the sea and various pressures which apply on the hull due to the cavitation on the ship's hull. In consequence, hydrodynamically efficient hull forms reduce power requirements and therefore both machinery and propulsor noise. This will reduce cavitation as the propeller operates in the wake field generated by the ship hull. While flow noise around the hull has a negligible influence on radiated noise, the hull form has influence on the inflow of water to the propeller. Design innovation such as hatches for the hollows in the bow, aft thrusters and stabilizers fins (closed during sailing), together with damping treatment to the hull and bulkheads would form better interactions between the hull and the propeller and UWN radiation can be mitigated. The use of lightweight materials, such as fiber reinforced plastic (FRP) composites for craft with length up to about 50 m (e.g. patrol and pleasure craft, sailing yachts, small passenger vessels) and aluminum alloys for vessels up to about 120 (e.g. passenger vessels and car ferries), could allow to require less power which will imply to a reduction in the ship's acoustic signature, mainly through reduction of propulsion power, if properly designed.

Applicability: primarily intended for consideration for new ships. For effective reduction of underwater noise, hull and propeller design should be adapted to each other

Possible implementation issues: Cost-benefits trade-offs and influence on fuel consumption should be carefully analyzed.

3.6. Monitoring, control and surveillance

5a: Live mapping of underwater noise sources and intensity

Typology: operational

Description: The adoption of the Marine Strategy Framework Directive (MSFD 2008/56/EC) which descriptor 11 focuses on underwater noise, requires the development and application of noise monitoring systems and prediction tools. Passive acoustics monitoring (PAM) systems allow underwater acoustic data to be acquired and analyzed from this perspective. Estimating the spatial-temporal distribution of noise levels generated by human activities at sea and assessing the source contributions to the global noise field could help the dynamic management of an area trough faster and efficient application of management measures, especially close to protected areas.

Possible implementation issues: commercial solutions already available are often very expensive.

5b: Development of a pilot registration system through transparent management and live use of AIS data for all the vessels (including leisure boats).

Typology: operational

Description: the optimization of maritime space management processes requires information on the distribution and intensity of maritime activities and the estimation of their impacts on the marine ecosystems. In order to enforce surveillance and monitoring, the introduction and integration of VMS and AIS systems could allow the improvement of the quality and descriptive capacity of data on maritime traffic and the distribution of different types of vessels, especially in the coastal areas where smaller vessels operate most, throughout the expansion of the use of the AIS system to small boats (over 12 m) and the adoption of a low cost systems (e.g. 4G/NB-IoT or LoRa) for vessels under 12m. Filling this information gap is essential in the preparation of adequate and dynamic management hypotheses.

Applicability: The measure will make it possible to fill the descriptive gaps of the current monitoring systems support local and international management plans and enforce the compliance with existing rules. An adequate and efficient use of traffic monitoring technologies will also significantly reduce the overall cost of traditional control and surveillance operations.

Possible implementation issues: The application requires a coordinated effort between the Adriatic countries in order to ensure the complete coverage of the area, taking particular account of the insular nature of the Croatian coasts and the need to equip the port infrastructures with adequate technological support and direct access to networks. The inclusion and use of existing networks (i.e. www.aishub.net) could facilitate a uniform application in the short to medium term, at least for boats equipped with AIS, thus requiring an extension of the obligation from at least 12 meters long, with adequate regulatory tools.

5c: Better knowledge of the distribution of target species, their variability and their life cycle, and understanding of their responses to noise exposure

Typology: operational

Description: the available knowledge on species and habitats can be limited when they have been poorly surveyed as a whole, thus limiting the availability of accurate geo-referenced maps and detailed quantitative data. Consequently, main risks derived from underwater noise cannot be adequately assessed. For example, even if Adriatic marine mammals and turtles have been regularly observed in the area, systematic monitoring and mapping activity is still scarce. As a consequence, their spatial distribution with reliable estimates of their seasonal abundances and densities are not available, with the significant exception of aerial surveys performed in the whole Adriatic Sea within the NETCET project (Fortuna et al. 2015; Fortuna et al. 2018; ACCOBAMS 2021), implementing the risks of wrong assessments when such coarse scale data are used in small areas within broader ecological domains. This could result in an inadequate representation of species distribution. Is therefore a compelling need the design of a network of Adriatic marine observatories and monitoring systems for continuous mapping of species distribution and assessing of environmental risks as a co-ordinated and trans-national effort.

Applicability: Monitoring the area implementing mitigation measures whenever necessary could foster the proposal for shared visual monitoring protocol, e.g. through observers, and infrared technologies and passive acoustic monitoring (PAM) to detect and localize cetaceans both surfacing and deep diving (ACCOBAMS-MOP7/2019/Doc 31Rev1). The data collection of abundance, distribution and behavioral data throughout the survey would also support dynamic management if properly connected to modeling and data sharing networks.

Possible implementation issues: Basin scale visual census, tagging and monitoring campaigns of wide range species such as those considered can have very high costs and require complex organizational efforts.

Examples, experiences and good practices: the ACCOBAMS Survey Initiative (ASI) project aimed at establishing an integrated, collaborative and coordinated monitoring system for the status of cetaceans and other species of conservation concern at the whole ACCOBAMS area level, to provide strong capacity building and training and to ultimately strengthen the conservation effort and governance across the Region. After being launched officially in 2016, field work was carried out in summers 2018 and 2019, involving several scientist, researchers and experts from the ACCOBAMS region (ACCOBAMS, 2021).

3.7. Economic, financial and other supporting measures

6a: Promote and finance innovative technologies geared to noise emission reduction

Typology: strategic

Description: Gaps and barriers (i.e. cost, technology, uncertainty, split incentive, safety issues, and reliability) exist in utilizing technologies and operational procedures. Design optimization in ship’s hull and propeller, insulating the engine and refitting or considering operational measures such as reducing speed to less than Cavitation Inception Speed (CIS), hull and propeller maintenance, rerouting and using technologies to reduce noise are some actions that can be considered to mitigate URN pollution (IMO-MEPC, 2013). Creating incentive (e.g. discounts on the port dues and operation costs in port) can encourage companies to utilize mitigating measures.

Examples, experiences and good practices: in 2007, the Vancouver Fraser Port Authority (VFPA) through its Eco Action gave support and incentives (discounts on port dues) to vessels that had a variety of fuel, technology and environmental management practices, in order to reduce polluting emissions. In 2017 the Port of Vancouver considered extending this incentive to quieter ships (Vancouver Fraser Port Authority POV-FEE Document, 2018), qualifying ships for gold, silver or bronze levels by voluntarily meeting industry best practices. The conditions required to be placed in the Gold, Silver, or Bronze ranking mainly concern air emission but are also effective in reducing noise (Vakili, 2017).

6b: Offer best practice training programs to shipping companies

Typology: operational

Applicability: Training and engagement of operators, could improve the effectiveness of specific technical topics and encourage the active participation in decision-making and management processes.

6c: Literacy and awareness raising (e.g. local communities, nautical sector, citizens)

Typology: operational

Applicability: Education on the possible effects of noise-related pressures on ecosystems and key species, together with the information on good-practices and behaviors in order to minimize impacts, could foster the the voluntary adaptation to the new rules, the effectiveness of specific technical topics and encourage the active participation in decision-making and management processes.

4. Underwater Noise spatial analysis to inform planning and management

4.1. Method

The analysis to address mitigation and management actions in order to reduce anthropogenic disturbance and the possible effects of noise from maritime traffic has been focused on identifying the correspondence between the presence of sources and altered soundscapes, i.e. increases in noise levels with respect to natural levels, with the basic aim of understanding how it is possible to reduce anthropogenic noise in these areas.

The analysis was carried out starting from the soundscape maps produced in the context of activity *5.2 Soundscape modelling for the Northern Adriatic Sea*. The modelling of underwater noise addressed two components of the total noise: 1) the cumulative effect of multiple vessel noise derived from AIS data; 2) the natural noise generated by wind, waves and rain. The model produced results for specific frequency bands covering the hearing of fish, reptiles and mammals. The procedure adopted for calibrating the noise maps was based on the comparison at each hydrophone position of the acoustic levels measured and predicted in order to reduce the uncertainty on sparse or fuzzy environmental parameters and to provide locally valid assessment of modelled predictions. In detail, monthly maps of Natural noise and baseline noise soundscapes from January to December 2020, covering 4 third-octave bands (63 Hz, 125 Hz, 250 Hz and 4kHz), seven percentiles (5th , 10th, 25th, 50th, 75th, 90th and 95th exceedance levels) and three depth ranges (Surface to -15m, 30m to the bottom, and the full water column).

The methodology for the analysis of the soundscape maps was developed with a step-by-step workflow with the primary objective of determining which are the areas of attention for the excess levels of anthropogenic noise in the north-central Adriatic. This “noise attention assessment” workflow is based on “extra noise” maps. The “extra noise” maps should be intended as low-quality alternatives of the “dominance” maps (as described within Jomopans project, see Kinneging and Tougaard, 2021), requiring data with higher temporal resolution than the hereby considered on monthly basis. Hence, if available, the “dominance” maps should be preferable. However the proposed workflow has been designed to support both map types as input parameters.

According to specific sensitivities to frequencies for *C. caretta* and *T. truncatus* (see chapter 3.3 and SOUNDSCAPE Report *D 4.2.1. Gap-analysis report based on existing knowledge of the sensitivity of target species to sound and the potential effects of noise*), the analyses were restricted on two representative frequencies (250 and 4000 Hz, respectively for marine turtles and mammals).

STEP 1 - Target areas identification

The whole north-central Adriatic has been considered as the base reference area for the analysis. For each target species, the best knowledge on their distributions was taken into account (Fortuna et al. 2018, see chapter 3.2). Contiguous areas (clumps) for *C. caretta* (4, fig. 8) and for *T. trucatus (4, fig. 9)* having the same presence class has been identified.

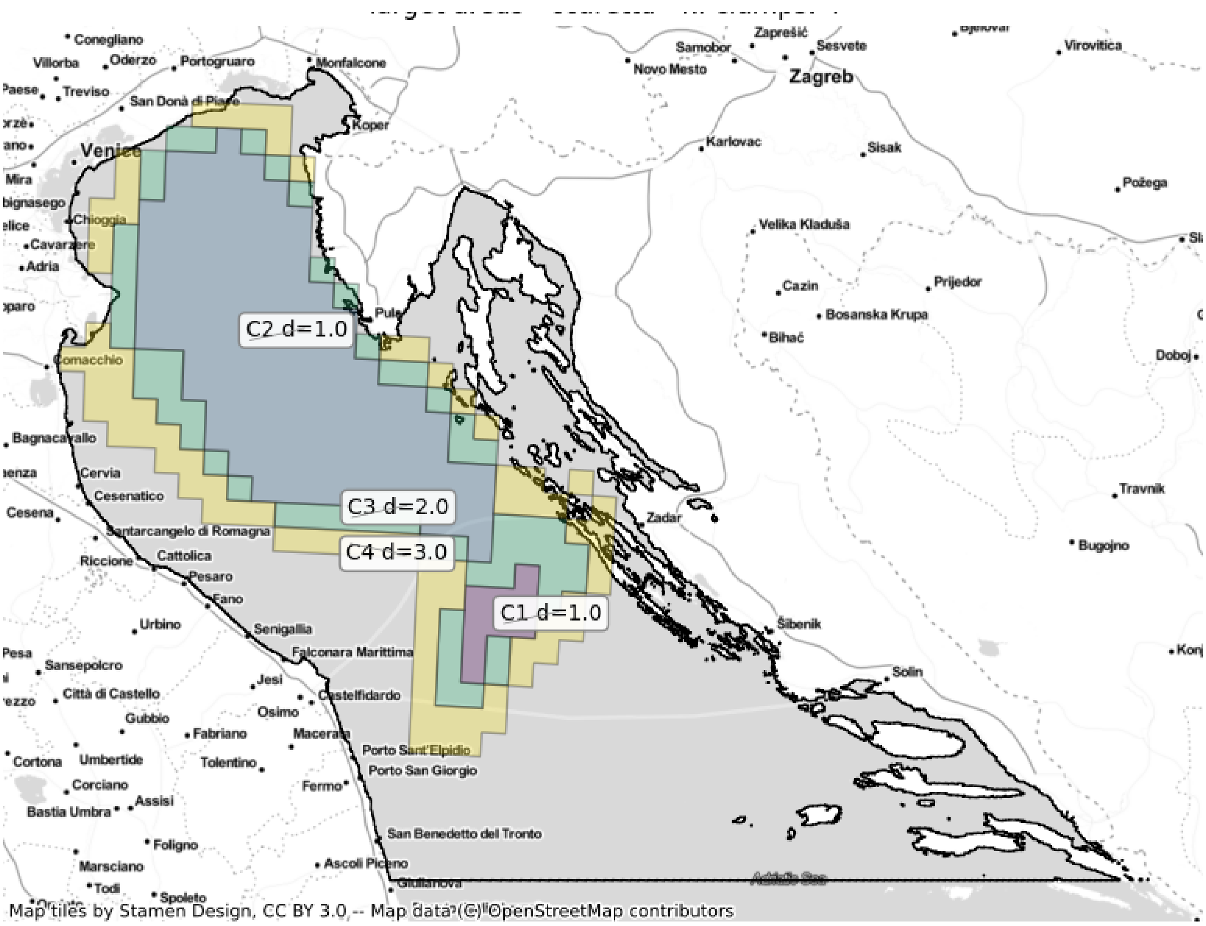


Figure 8. Map representing clumped areas for *C. caretta*. Data from Fortuna et al. 2018. Densities (d) are expressed in animal/100km^2: 1 = 60.1-133.9, 2 = 40.1-60, 3 = 20.1-40.0. Clumps areas (km^2): C1 = 900, C2 = 12000, C3 = 5700, C4 = 7500.

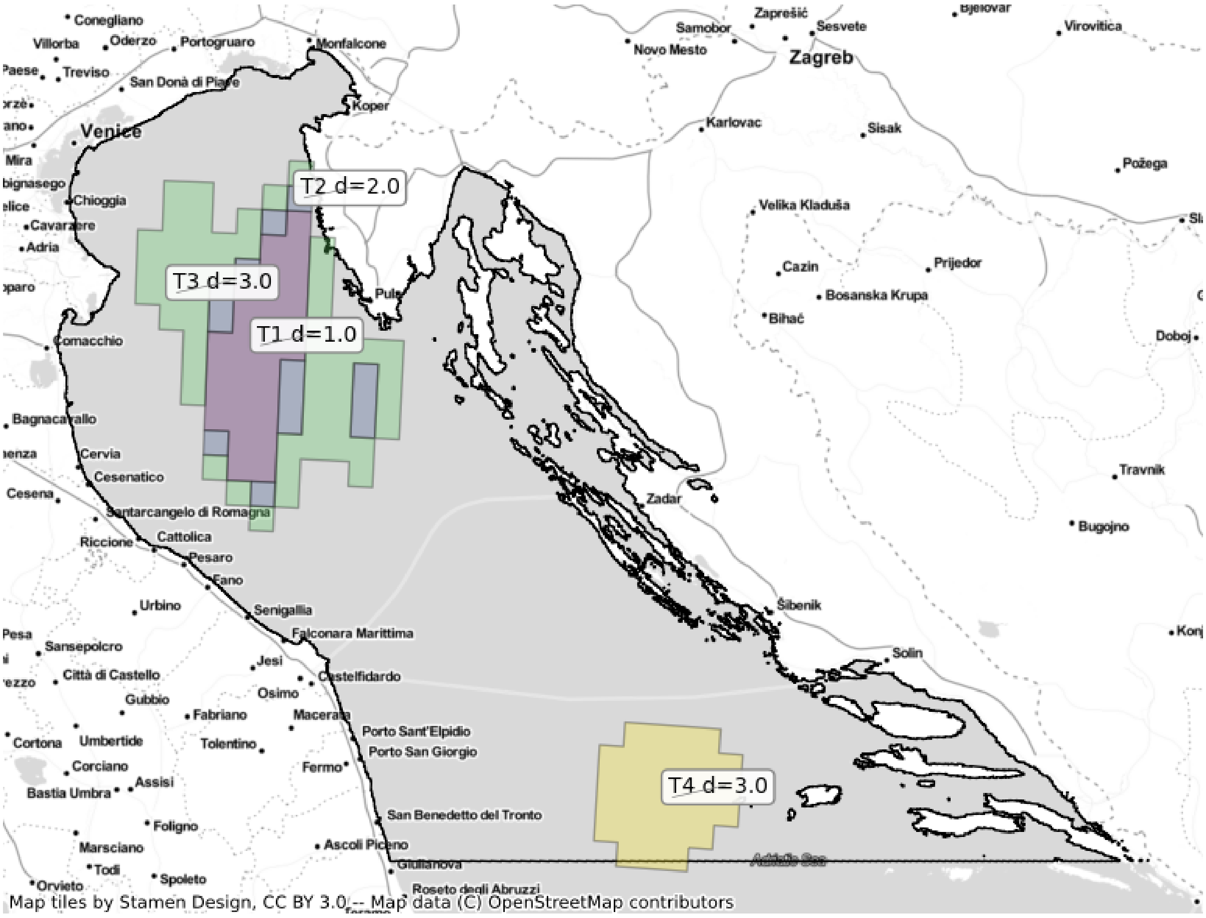


Figure 9. Map representing clumped areas for *T. truncatus.* Data from Fortuna et al. 2018. Densities (d) are expressed in animal/100km^2: 1 = 16.1-33.8, 2 = 12.1-16.0, 3 = 8.1-12.0. Clumps areas (km^2): C1 = 2800, C2 = 1300, C3 = 5100, C4 = 3000.

Marine Natura 2000 sites were also taken into account as focus areas for the analyses. The sites were selected for the specific indication of *C. caretta* and/or *T. truncatus* steady occurrence within their Natura 2000 Standard Data Forms (EEA, release End 2020) and eventually grouped taking into account their proximity (fig. 10).

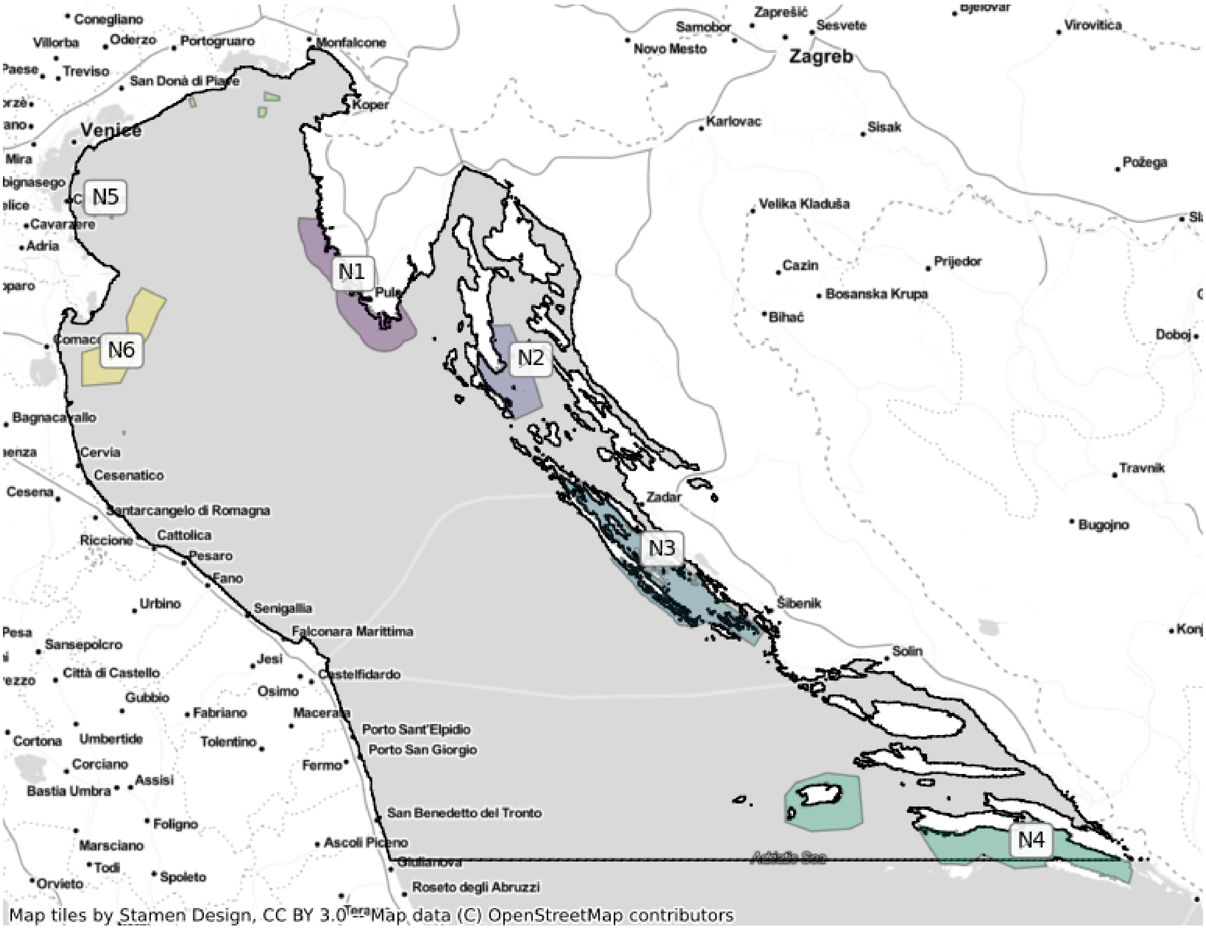


Figure 10. Map representing areas of Natura 2000 sites considered. Clumps areas (km^2): N1 = 726, N2 = 523, N3 = 1068, N4 = 1602, N5 = 57, N6 = 537.

The target areas are summarized in Tab. 2.

Table 2. Synthesis of the identified target areas

Area code	Typology	Density (classes)	Density	Area (km2)
WA	whole_area	NaN	NaN	60409.0
C1	*C. caretta*	1.0	60.1-133.9	900.0
C2	*C. caretta*	1.0	60.1-133.9	12000.0

C3	*C. caretta*	2.0	40.1-60	5700.0
C4	*C. caretta*	3.0	20.1-40.0	7500.0
T1	*T. truncatus*	1.0	16.1-33.8	2800.0
T2	*T. truncatus*	2.0	12.1-16.0	1300.0
T3	*T. truncatus*	3.0	8.1-12.0	5100.0
T4	*T. truncatus*	3.0	8.1-12.0	3000.0
N1	n2000	NaN	NaN	726.0
N2	n2000	NaN	NaN	523.0
N3	n2000	NaN	NaN	1068.0
N4	n2000	NaN	NaN	1602.0
N5	n2000	NaN	NaN	57.0
N6	n2000	NaN	NaN	537.0

STEP 2 - Current conditions evaluation

Current Condition is defined as the acoustic state where both natural sound and anthropogenic noise are present (MSFD Common Implementation Strategy - Technical Group on Underwater Noise - TG-NOISE Methodology report). Current conditions are expressed as percentile distributions (P5, P10, P25, P50, P75, P90, P95) and estimated mean (Nm) of the modelled values per noise frequency, month and cell. The noise mean (Nm) is estimated as follows (eq.1):

$$Nm = \frac{p_5 + 2p_{10} + 4p_{25} + 5p_{50} + 4p_{75} + 2p_{90} + p_{95}}{19}$$

eq. 1

The equation has been derived adapting the method proposed in Wan et al. (2014) for estimating the mean noise from the quantiles p_5, p_{10}, p_{25}, p_{50}, p_{75}, p_{90}, p_{95} , and obtaining a nearly unbiased estimate of the true sample mean. The arithmetic mean of the sound levels of the Current Condition is used to quantify the acoustic status of a certain area and at a monthly time frame.

For the case study area, plots summarizing the variation of current conditions (baseline and natural noise levels) above the coverage areas and the temporal intervals (months) has been generated as:

- percentile variation of spatial coverage above stepped decibel thresholds;
- temporal variation (expressed as percentile) of spatial coverage above a noise threshold.

STEP 3 - Extra noise spatial analysis and pressure index evaluation

Difference between the mean of baselines [Nm(baseline) - i.e. Current conditions] and the mean of naturals [Nm(natural) i.e. Reference conditions] for each grid cell, expressed in dB, for each representative frequency and month. For each target area the pressure functions and indexes (integral/area subtended by the concave/convex pressure functions) have been calculated (Kinneging and Tougaard, 2021).

STEP 4 - Identification of attention areas

The attention areas are hereby defined as the main areas of recurring noise disturbance that may need proper management in order to avoid risks of effects on the target species according to par.2.3 considerations. Attention areas are identified analyzing the pressure indexes within the whole case study area and each target area. As described in step 1, target areas take into account both the distribution of target species and the presence of protected areas (Natura 2000 sites with presence of target species).

STEP 5 - Source identification and description

Vessel trajectories have been reconstructed using AIS data (see SOUNDSCAPE Reports *D 5.1.3 Data on traffic collection and elaboration and using AIS data*, *D5.2.1* and *D5.2.2*) within a grid of 250 x 250 meters cell size and a maximum time-gap between signals of 30 minutes, both by month and vessel type group. The noise source assessment have been performed using RANDI 3.1 model (Breeding et al. 1996). This analysis is carries out to allow a quali-quantitative weighting and ranking of underwater sound sources in the different attention areas.

The noise spectrum (LS) modelled by RANDI 3.1 is given by:

$$LS(f) = LS0(f) + 60 * log_{10}(\frac{s}{12}) + 20 * \log_{10}(\frac{l}{300}) + df(f) * dl + 3.0 \quad \text{eq. 2}$$

where:

- f is the frequency in Hz

- s is the vessel speed in knots
- l is the vessel length in feets
- LS0(f) is the noise base spectrum given by:

$$LS0(f) = \begin{cases} -10\log_{10}(10^{-14.34-1.06\log_{10}(f)} + 10^{-21.425-3.32\log_{10}(f)}), & \text{for } f < 500\text{Hz.} \\ 173.2 - 18\log 10(f), & \text{otherwise.} \end{cases}$$

- df is a continuous low-frequency weighting function given by:

$$df(f) = \begin{cases} 8.1, & \text{for } f < 28.4\text{Hz.} \\ 2.3 - 9.77\log_{10}(f), & \text{for } 28.4 \le f < 192.6\text{Hz.} \\ 0, & \text{otherwise.} \end{cases}$$

- and dl is given by:

$$dl(f) = \frac{l^{1.15}}{3643}$$

RANDI 3.1 model is applied to the reconstructed vessel trajectories for the most relevant vessel types for the case study area (e.g. Passenger, Cargo, Tanker, Fishing, Pleasure craft, High Speed craft) in order to estimate the underwater radiated noise from each vessel track.

Summary statistics for each month and target area are calculated:

- distribution of vessel speed (histogram)
- distribution of radiated noise at 250 Hz and 4000 Hz (histograms).

All statistics have been weighted using the trajectory duration (in hours).

4.2. Results

4.2.1. Current conditions evaluation

The following maps have been modelled within SOUNDSCAPE Activity 5.2 (see related reports for further details on modelling and calibration), with the exception of the monthly estimated means, for the entire water column (EWC).

Maps and related statistics are summarized here in order to better describe the noise levels condition of the whole Central-Northern Adriatic Sea during the 2020.

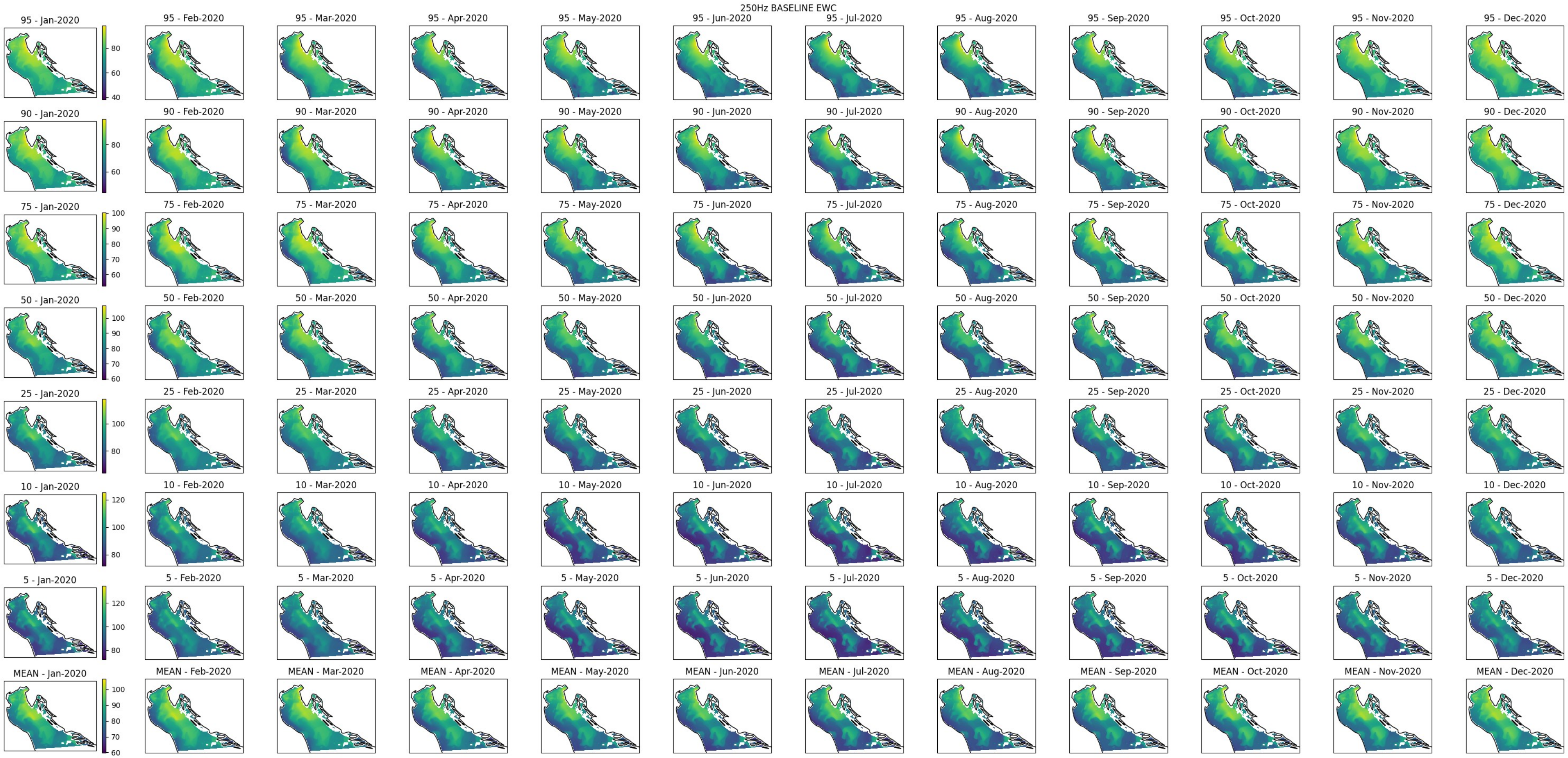


Figure 11. 250 Hz Baseline Noise Levels maps (expressed in dB ref 1μPa^2 1/3 octave)

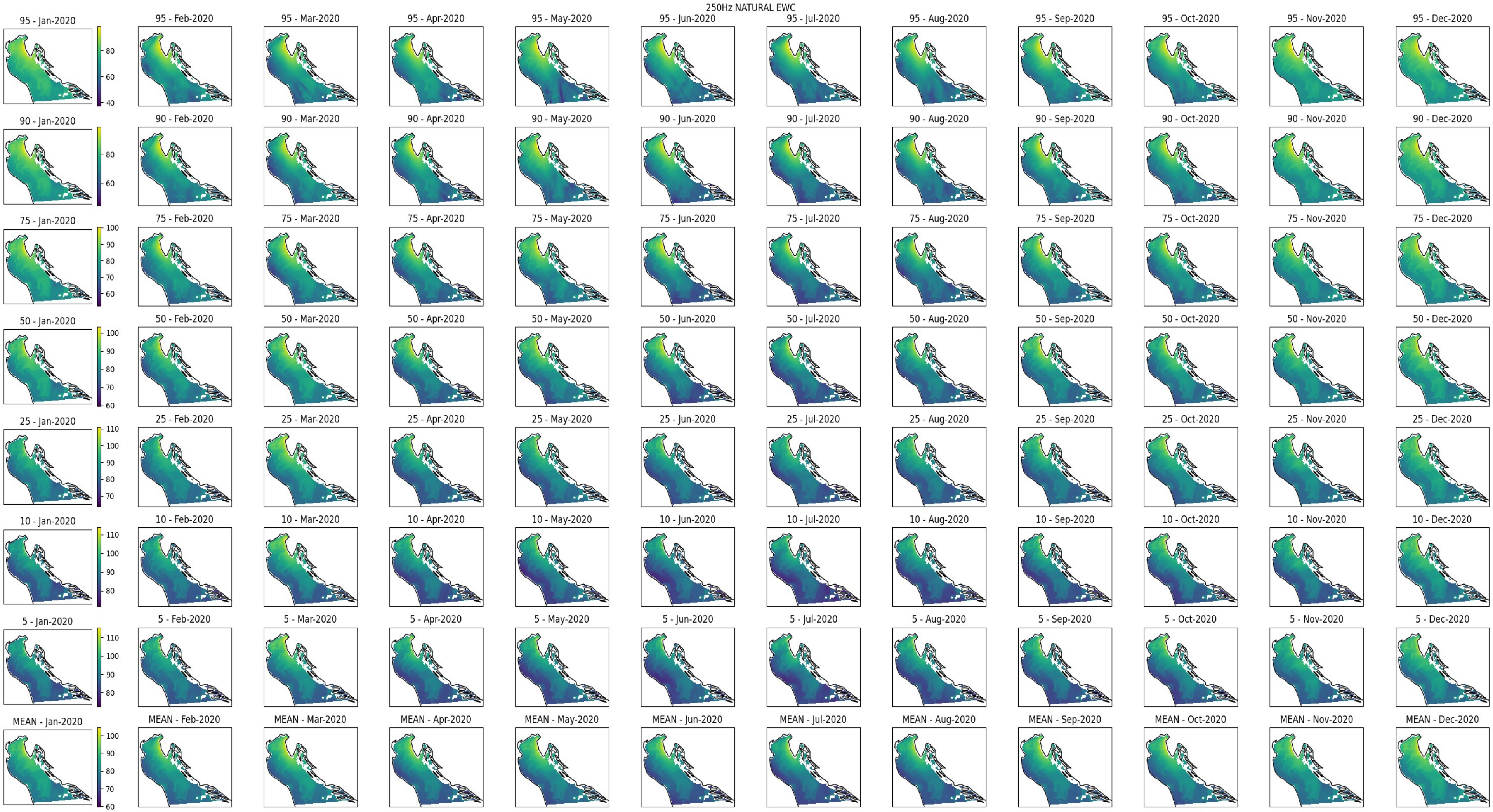


Figure 12. 250 Hz Natural Noise Levels maps (expressed in dB ref 1μPa^2 1/3 octave)

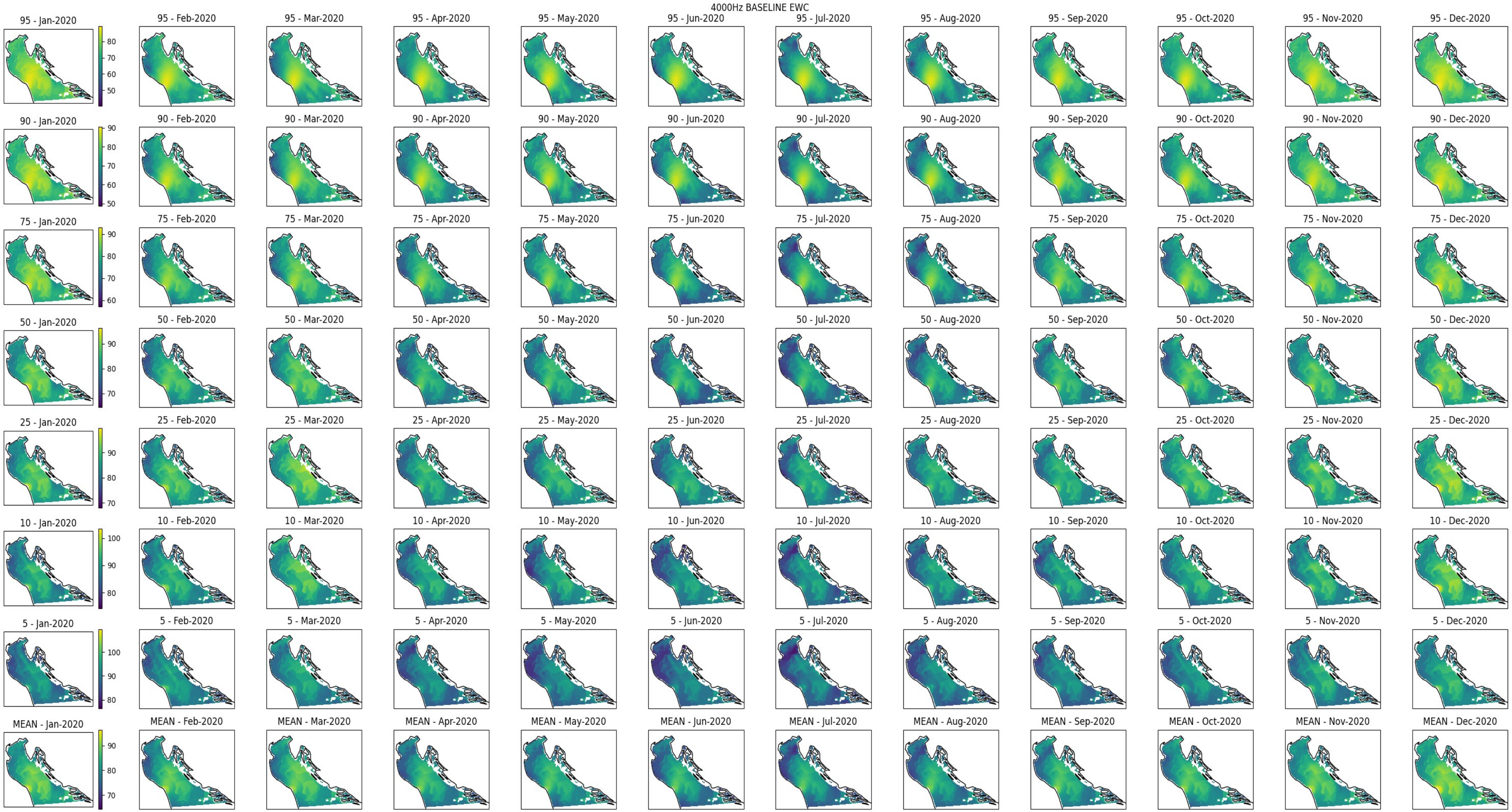


Figure 13: 4000 Hz Baseline Noise Levels maps (expressed in dB ref 1µPa^2 1/3 octave)

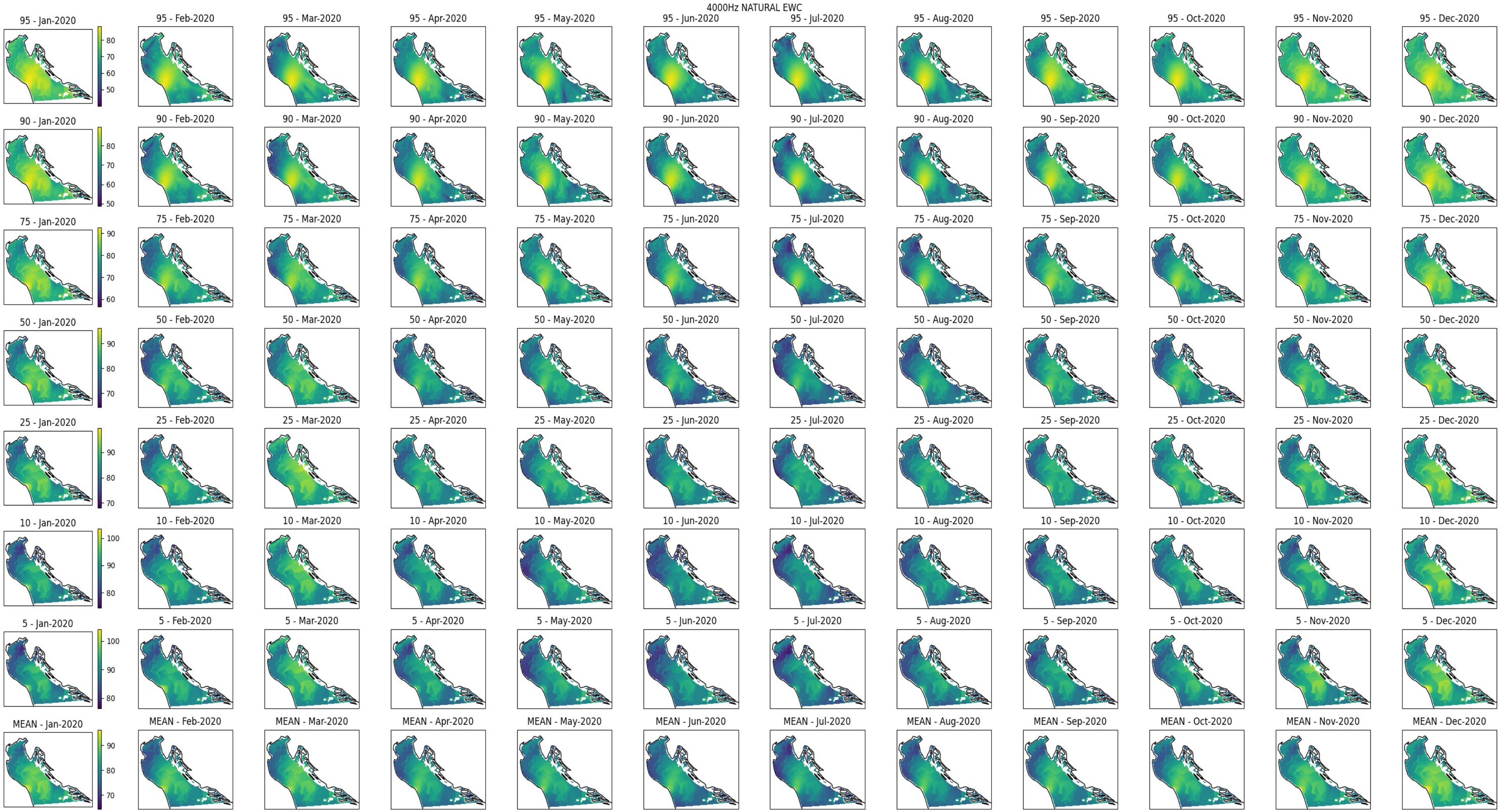


Figure 14. 4000 Hz Natural Noise Levels maps (expressed in dB ref 1μPa^2 1/3 octave)

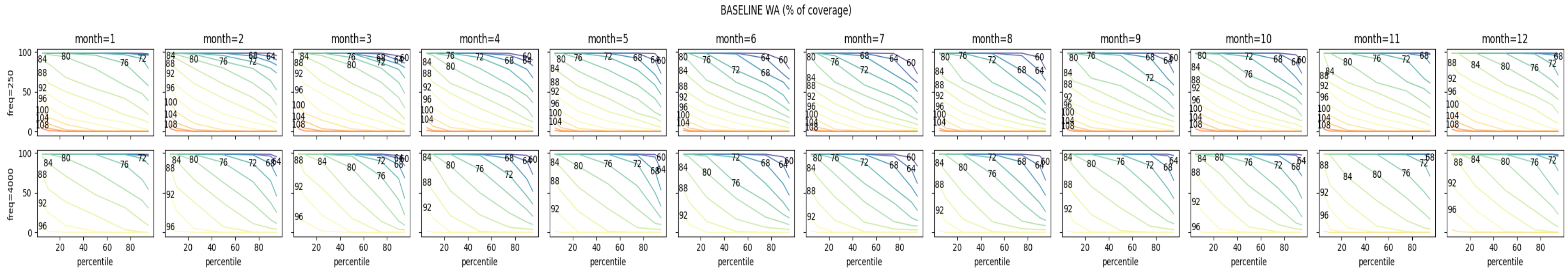


Figure 15. Percentile variation of Baseline Noise Levels spatial coverage (expressed in percentage of the case study area) above stepped decibel thresholds.

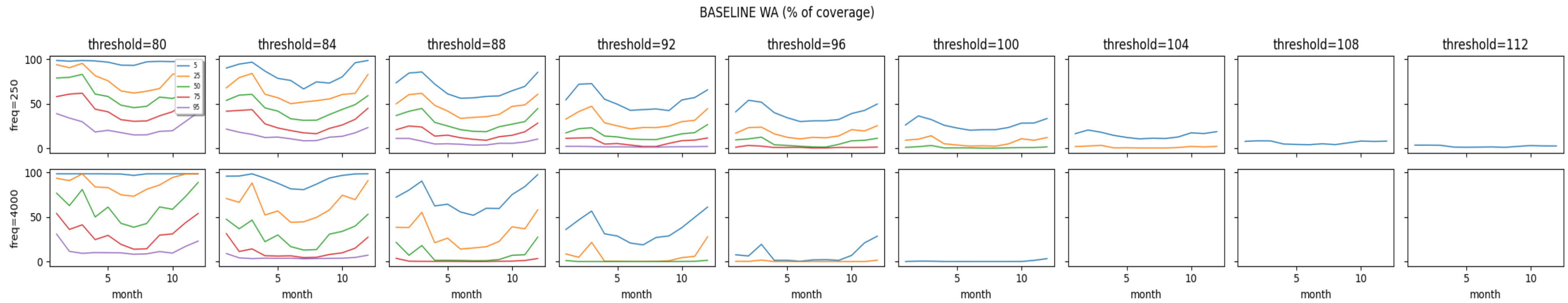


Figure 16. Temporal variation (expressed as percentile) of Baseline Noise Levels spatial coverage (expressed in percentage of the case study area) above a noise threshold.

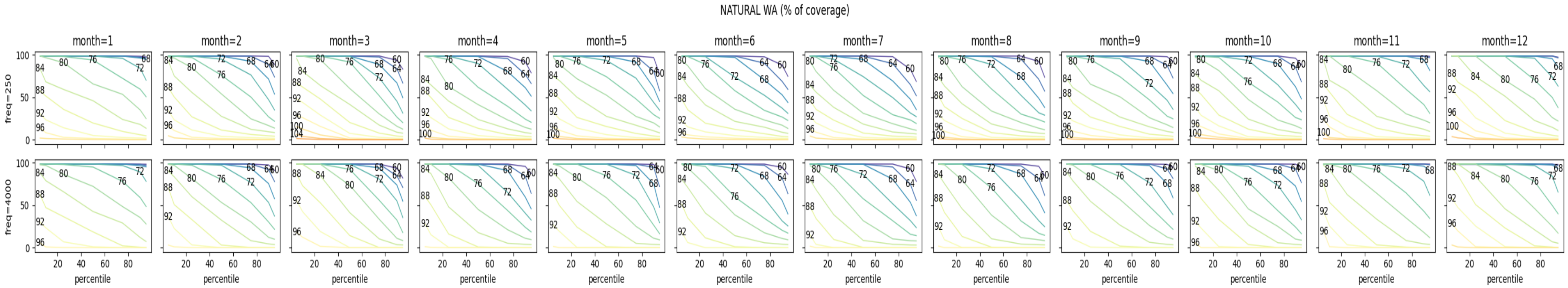


Figure 17. Percentile variation of Natural Noise Levels spatial coverage (expressed in percentage of the case study area) above stepped decibel thresholds.

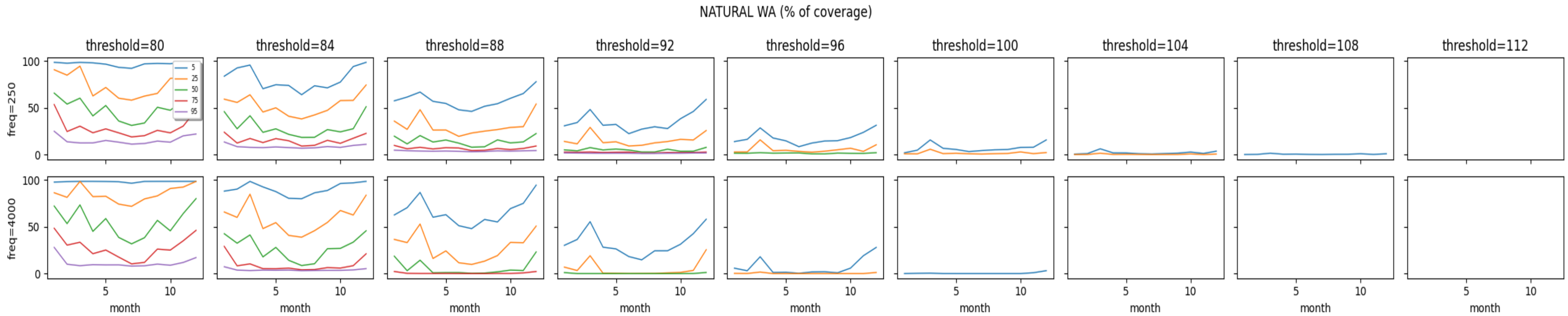


Figure 18. Temporal variation (expressed as percentile) of Natural Noise Levels spatial coverage (expressed in percentage of the case study area) above a noise threshold.

4.2.2. Extra noise spatial analysis

Estimated monthly average "extra noise" maps for the whole case study areas are reported below:

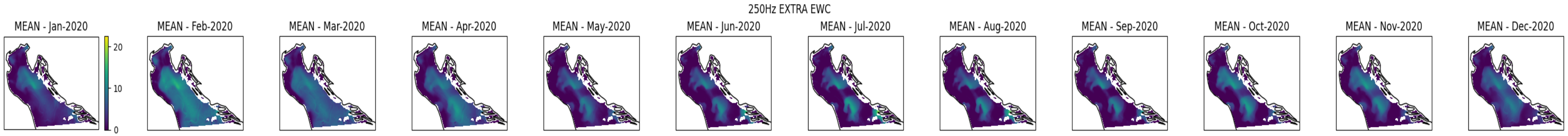


Figure 19. Monthly extra noise maps at 250 Hz (expressed in dB ref 1µPa^2 1/3 octave).

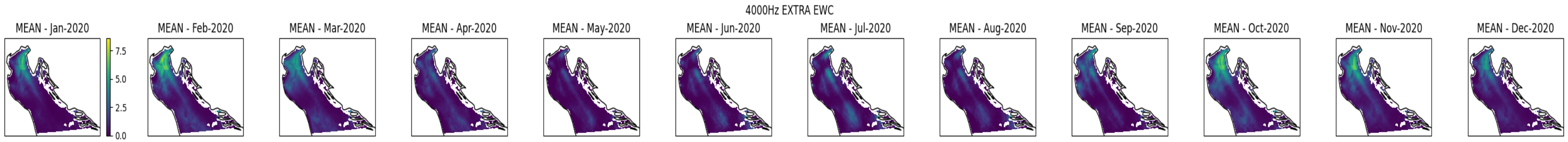


Figure 20. Monthly extra noise maps at 4000 Hz (expressed in dB ref 1µPa^2 1/3 octave).

Results show the substantial differences in the distribution of the extra noise at the two different frequencies. Extra noise at 250 Hz results higher (up to 20 dB) than extra noise at 4000 Hz, confirming the spatial distributions shown in both baseline and natural noise level maps. The extra noise estimated at 250 Hz is concentrated mainly in the areas of the Northern and Central Adriatic IMO corridors, with more variable localized peaks into the gulfs of Trieste, Venice and close to the other main Italian (i.e. Ravenna, Ancona) and Croatian (e.g. Rijeka) ports. Extra noise at 4000 Hz shows a slightly different distribution, with higher values in the Northern basin, in particular within the Gulf of Trieste and along the Istrian peninsula, and a constant pattern apparently linked to the main traffic routes. In both the analyzed frequencies, a strong seasonal variability results evident, probably due to the different oceanographic condition, in particular water temperature, salinity, and the occurrence of the summer thermocline, to traffic intensity variations due to the COVID pandemic, seasonal trends (e.g. for cruise) and trawling fishing activities summer ban.

4.2.3. Identification of attention areas

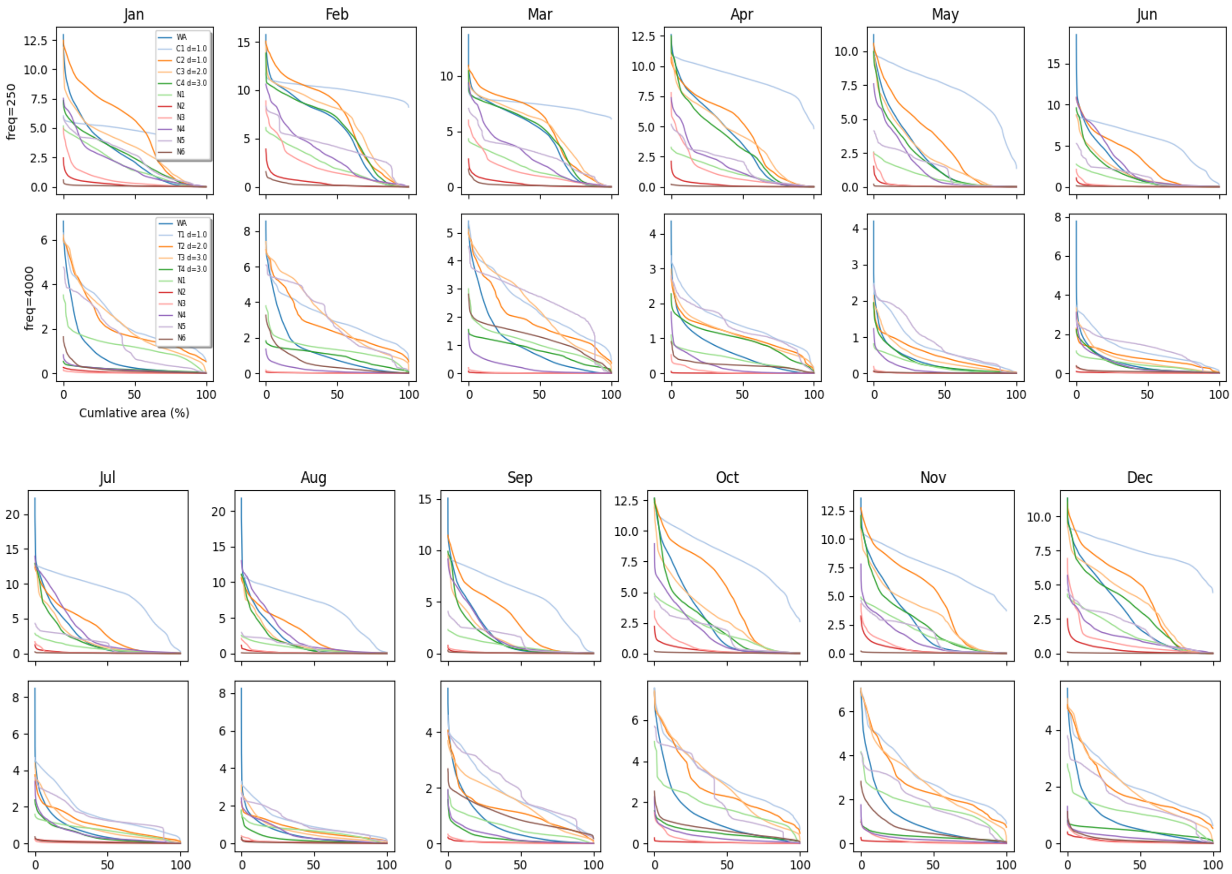


Figure 21. Extra noise pressure curves for the whole case study area (WA, blue line) and for each target areas at 250 (top row) and 4000 (row below) Hz.

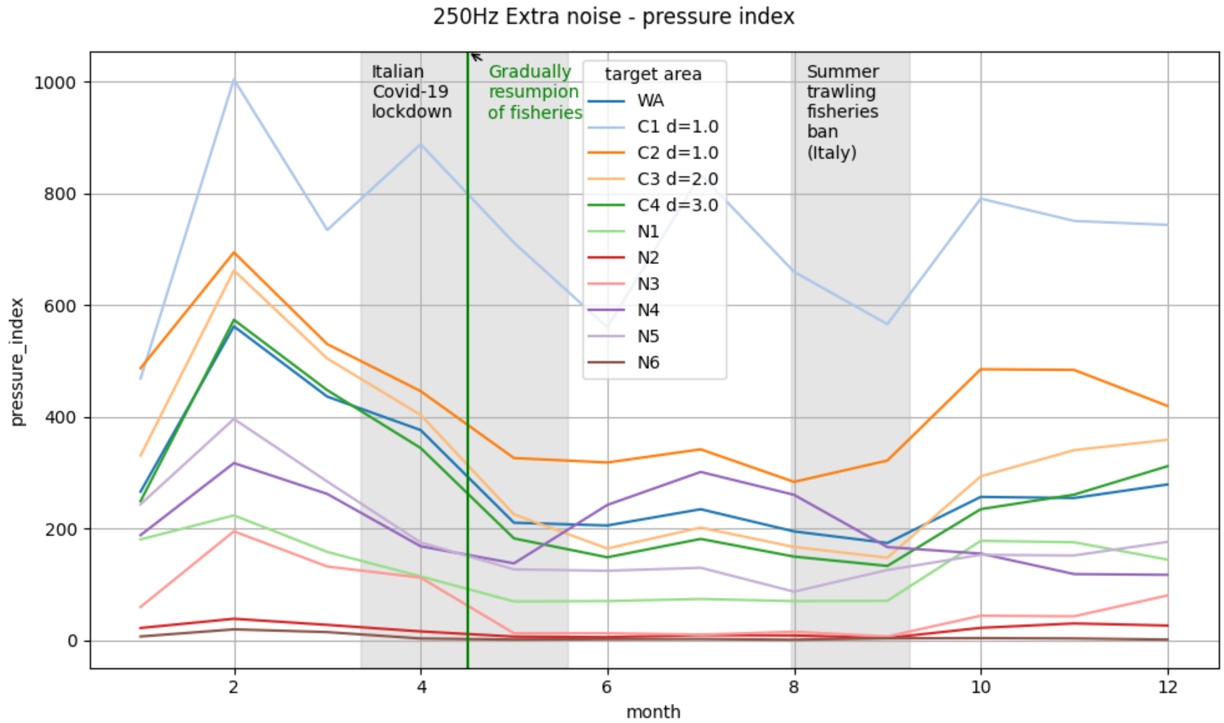


Figure 22. Extra noise pressure index at 250 Hz considering the whole case study area (WA, blue line) and for each target area for high densities of *C. caretta* and Natura 2000 sites.

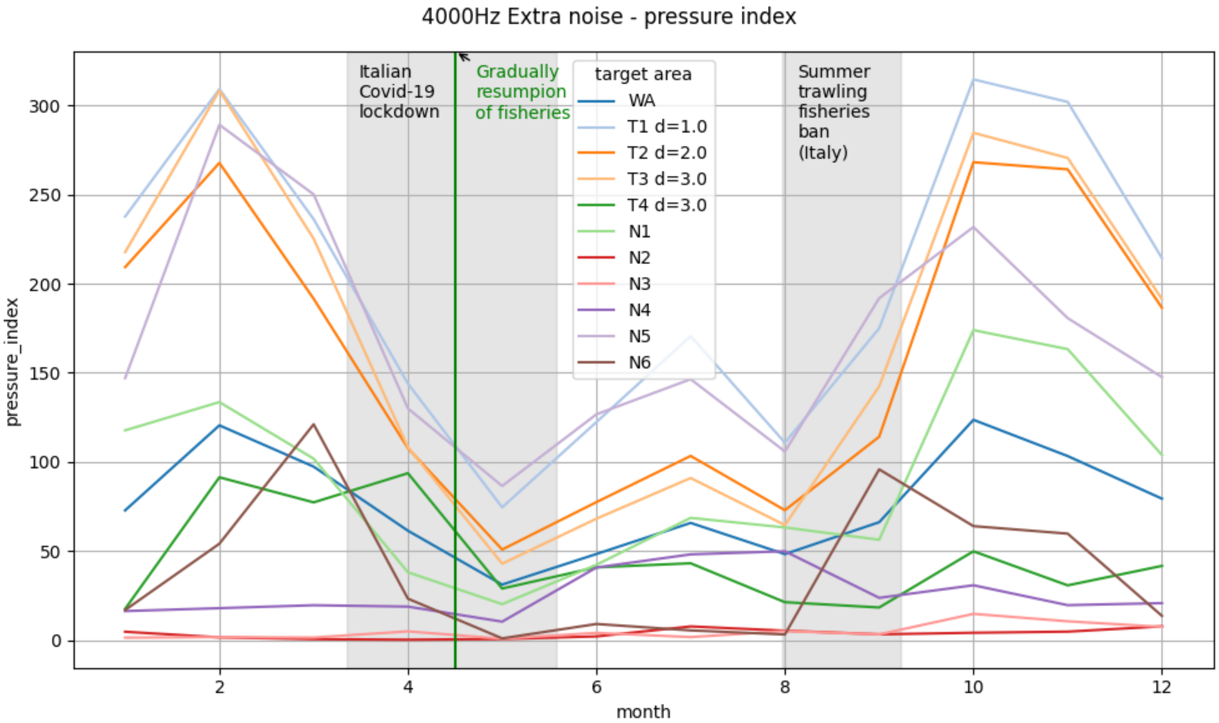


Figure 23. Extra noise pressure index at 4000 Hz considering the whole case study area (WA, blue line) and for each target area for high densities of T. *truncatus* and Natura 2000 sites.

The pressure index curves for 250 Hz show how among the considered areas only C1 and C2 (higher densities of *C. caretta*) feature a constant pressure index above the whole area pattern, while C3 and C4 (respectively medium and low densities of *C. caretta*) are more consistent with the general case study area one. Among the Natura 2000 sites, N4 (composed by the two SCIs "Lastovski i Mljetski kanal" and "Viški akvatorij") feature a pressure index above the WA pattern, but only during summer months, while the other Natura 2000 sites (almost all coastal) result exposed to lower pressure indexes.

Curves for 4000 Hz evidence a general lower pressure than those at 250 Hz. Among the higher pressure indexes are the areas T1 (Northern Adriatic high waters, high densities of *T. truncatus*), N5 (the SACs "Tegnùe di Chioggia", "Tegnùe di Porto Falconera", "Trezze San Pietro e Bardelli"), T2 and T3 (Northern Adriatic, respectively medium and low densities of *T. truncatus*) and N1 (the SCI "Akvatorij zapadne Istre").

Both patterns highlight higher pressure indexes during cold months, with the significant exception of C1 at 250 Hz.

The spatial distribution of pressure indexes at both 250 Hz and 4000 Hz within the target areas are reported in the maps in fig. 24. The months taken into account summarize representative events during 2020.

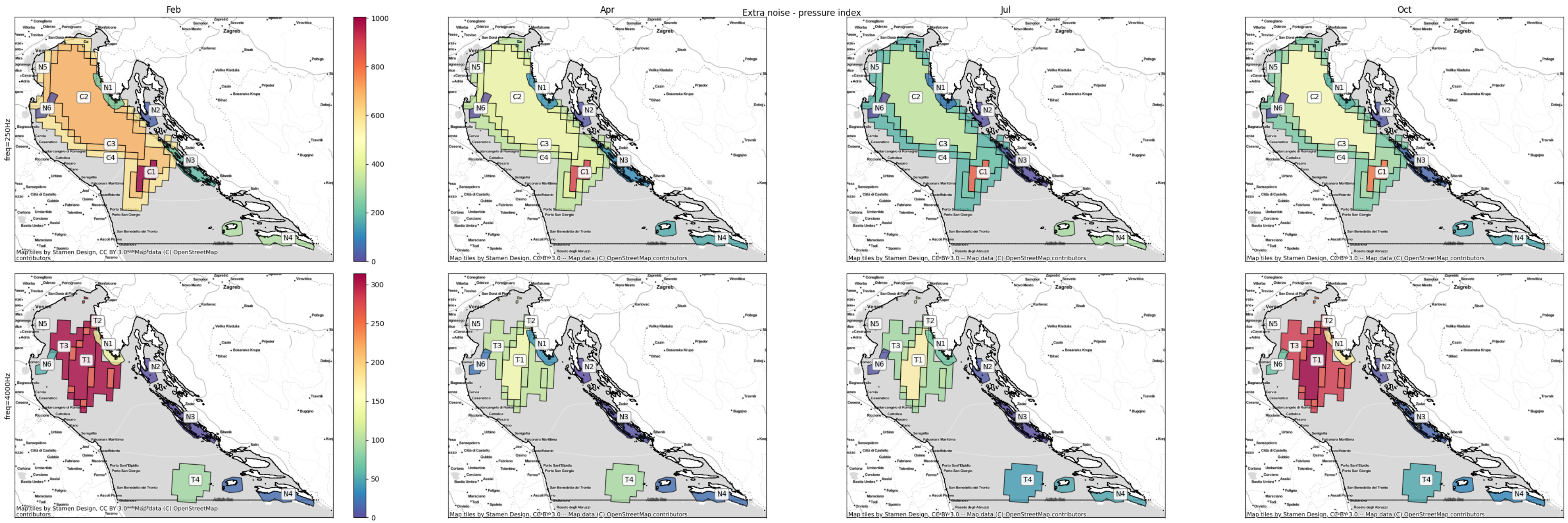


Figure 24. Spatial distribution of pressure indexes at both 250 Hz and 4000 Hz within the target areas .

4.2.4. Maritime traffic analysis

The main statistics and maps aimed at a thorough analysis of maritime traffic in the Central-Northern Adriatic and at interpreting extra noise and pressure indexes maps are listed below.

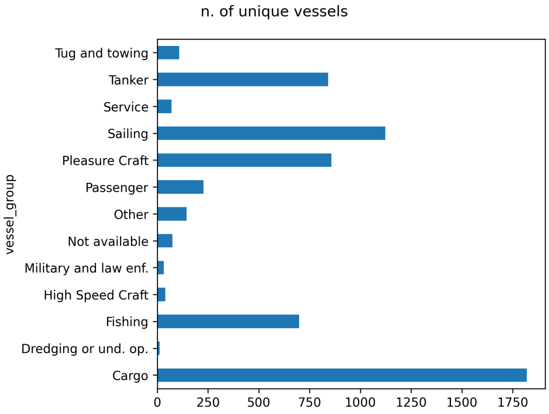


Figure 25. Number of unique vessels in the case study area during 2020 for each type group.

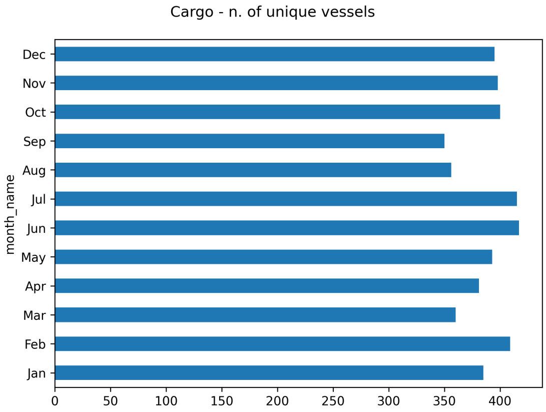


Figure 26. Number of cargo vessels in the case study area during 2020 for each month.

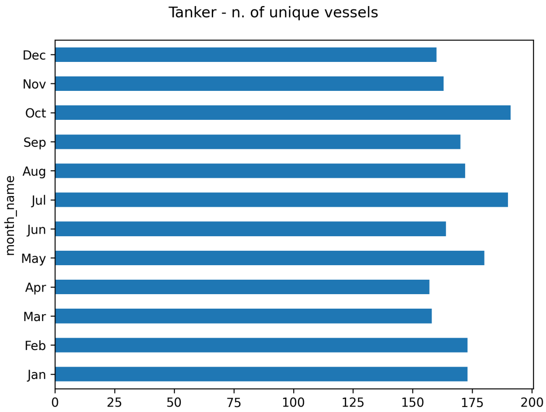


Figure 27. Number of tankers in the case study area during 2020 for each month.

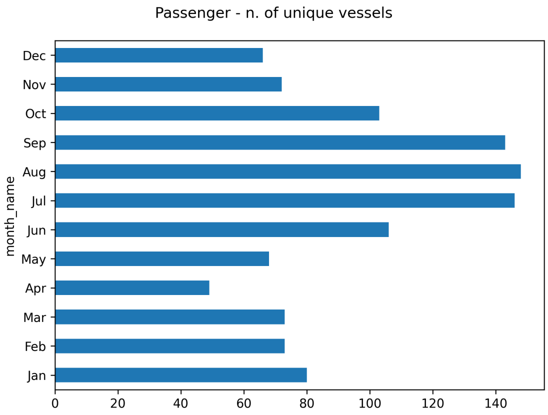


Figure 28. Number of passenger vessels in the case study area during 2020 for each month.

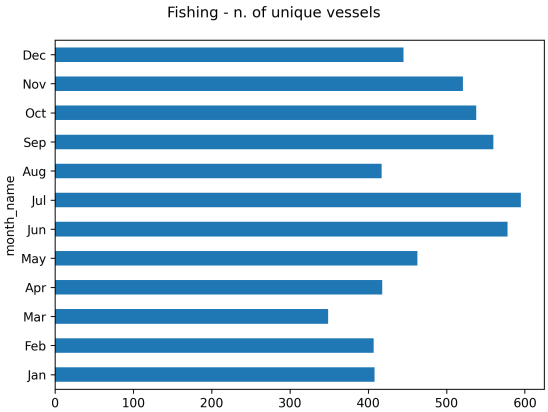


Figure 29. Number of fishing vessels in the case study area during 2020 for each month.

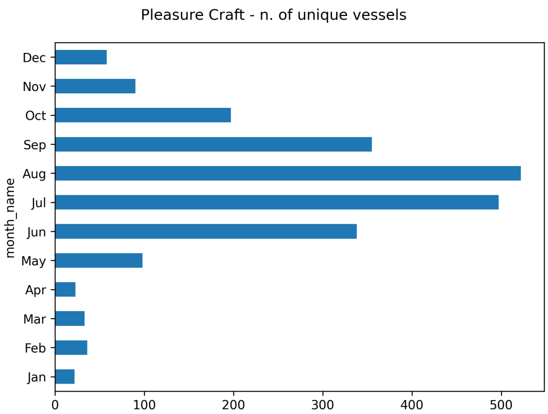


Figure 30. Number of pleasure craft vessels in the case study area during 2020 for each month.

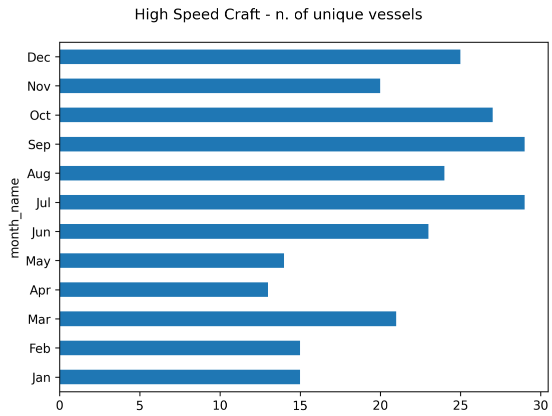


Figure 31. Number of high speed vessels in the case study area during 2020 for each month.

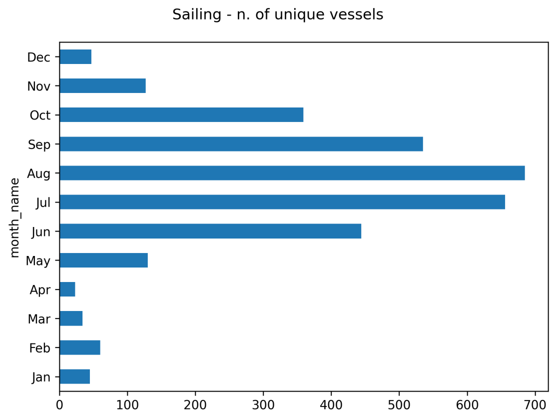


Figure 32. Number of sailing vessels in the case study area during 2020 for each month.

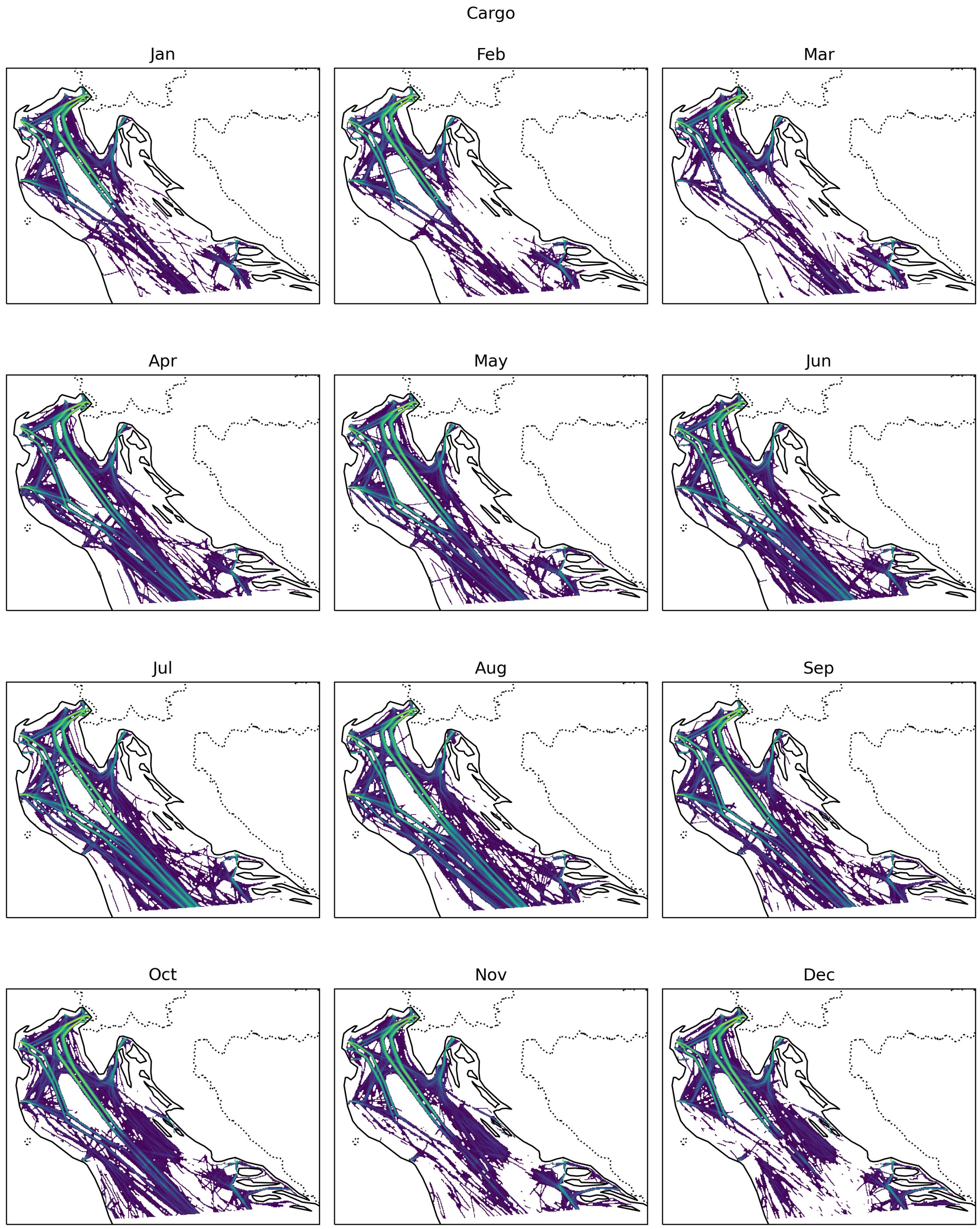


Figure 33. Trajectories of cargo vessels in the case study area during 2020 for each month.

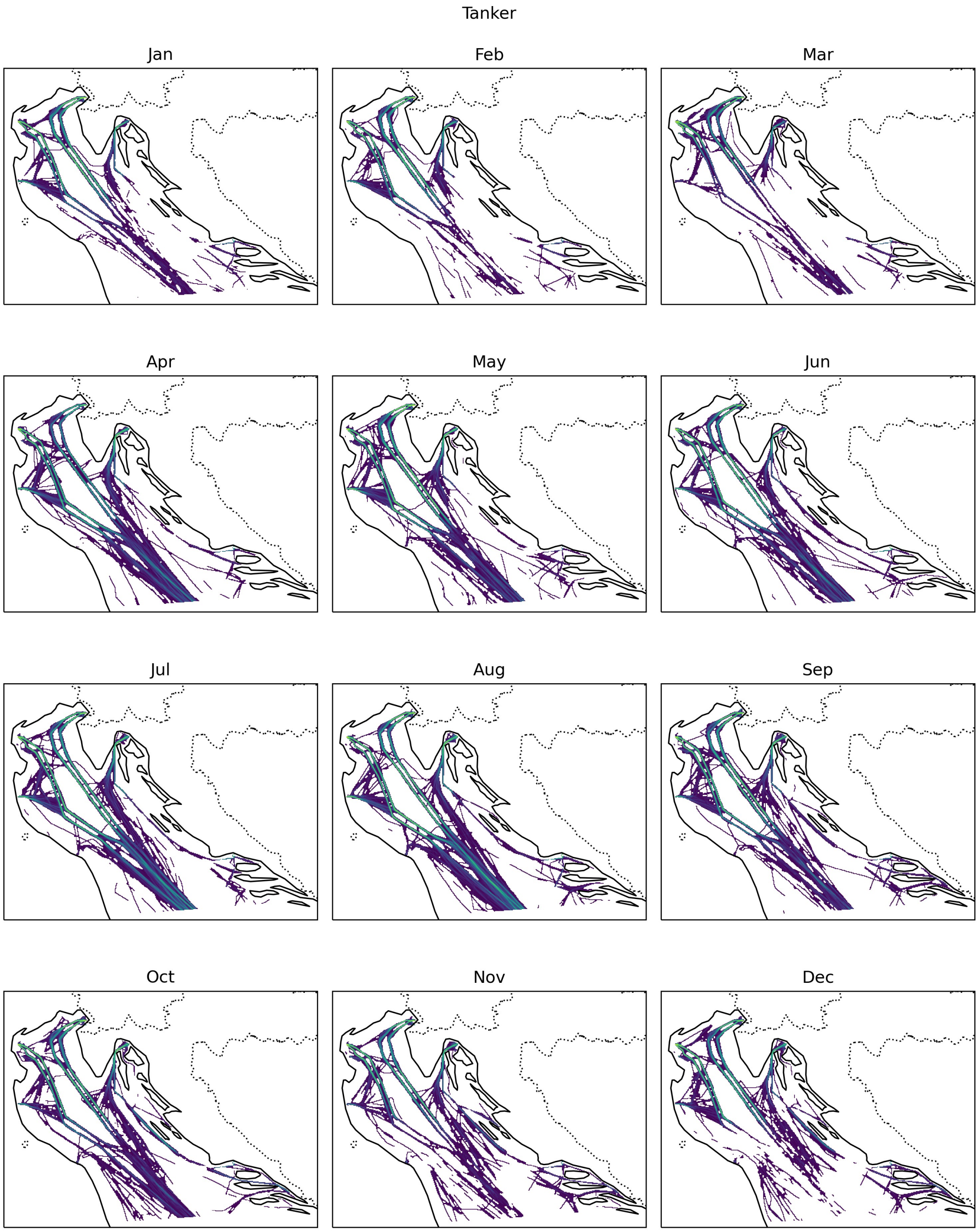


Figure 34. Trajectories of tankers in the case study area during 2020 for each month.

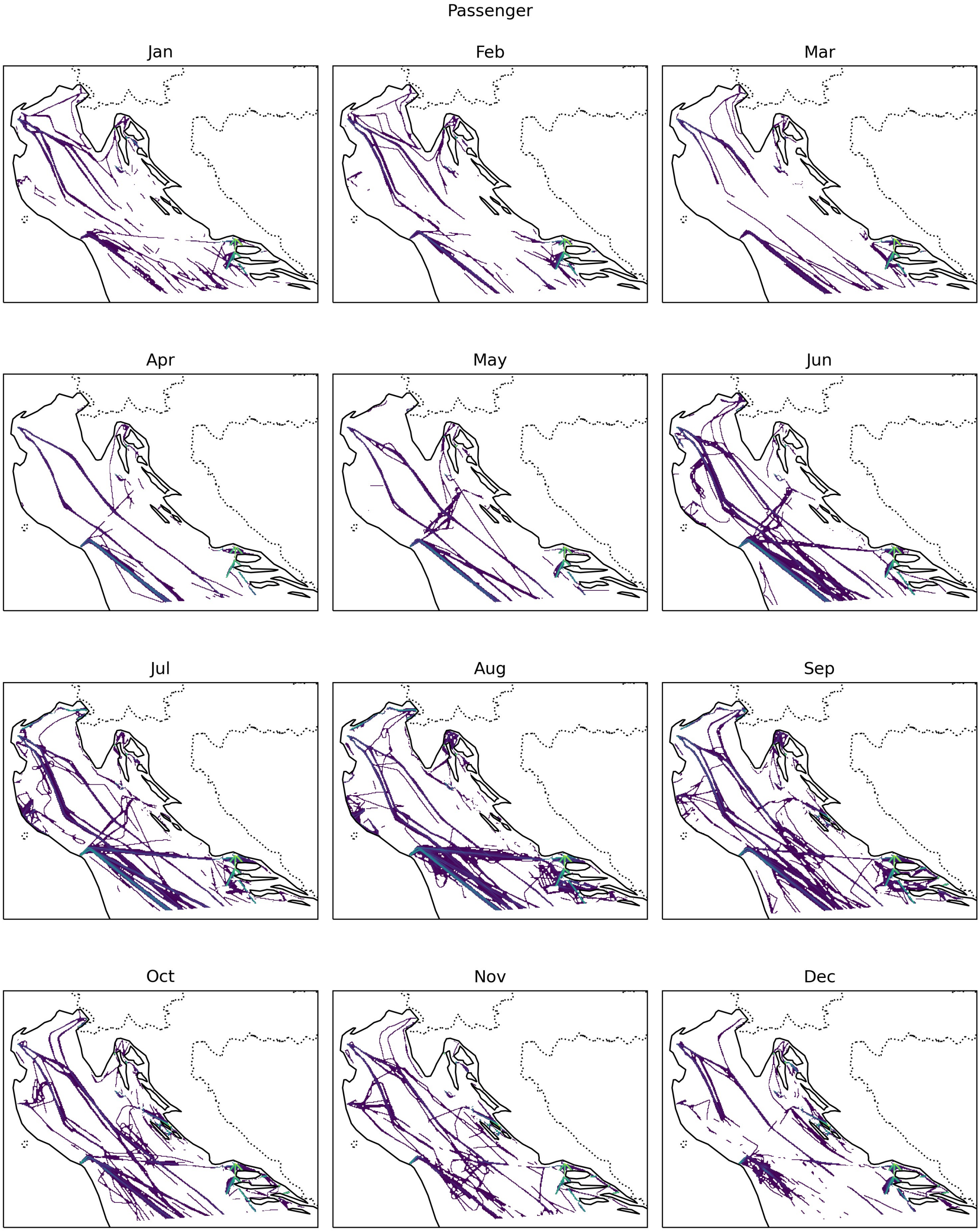


Figure 35. Trajectories of passenger vessels in the case study area during 2020 for each month.

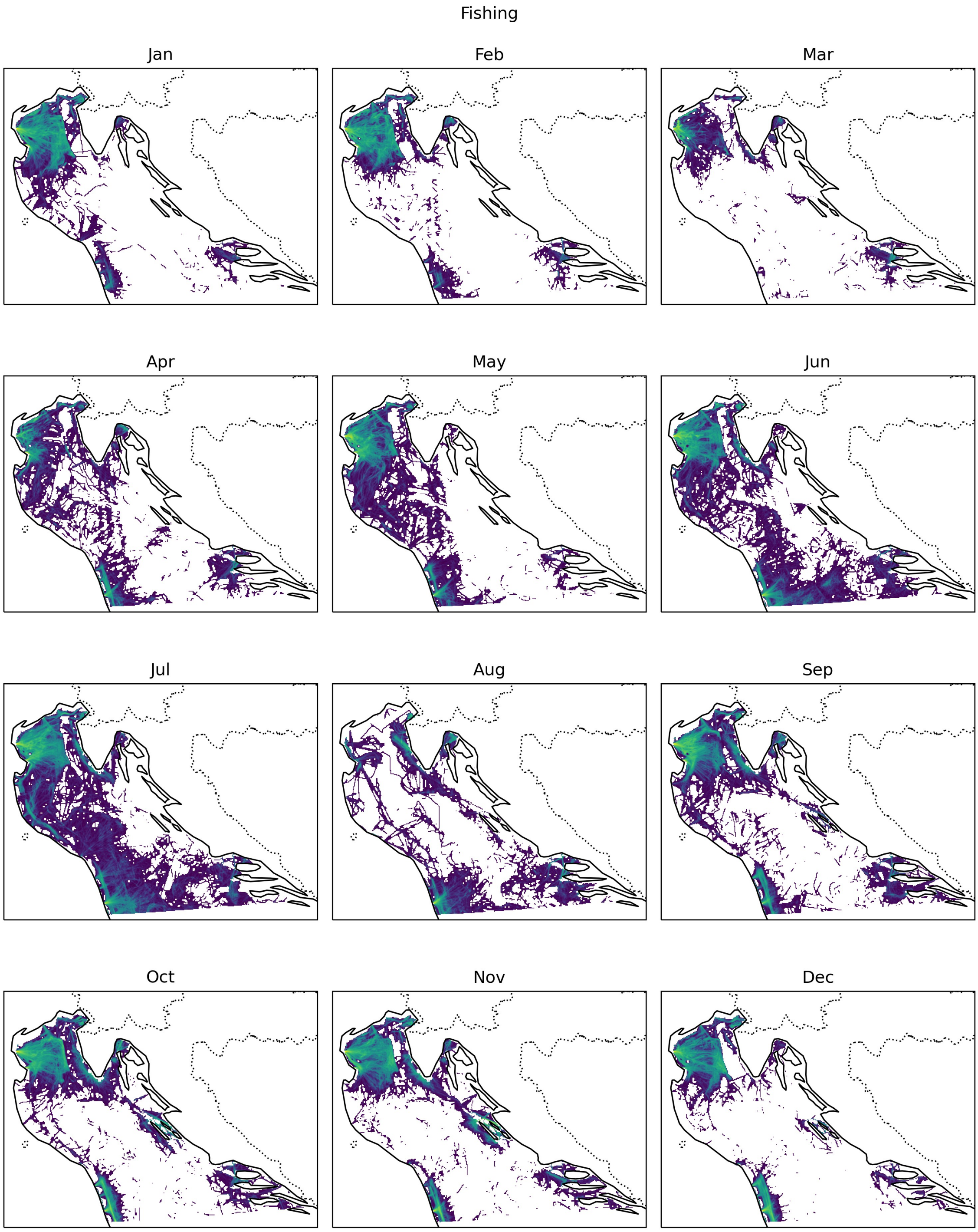


Figure 36. Trajectories of fishing vessels in the case study area during 2020 for each month.

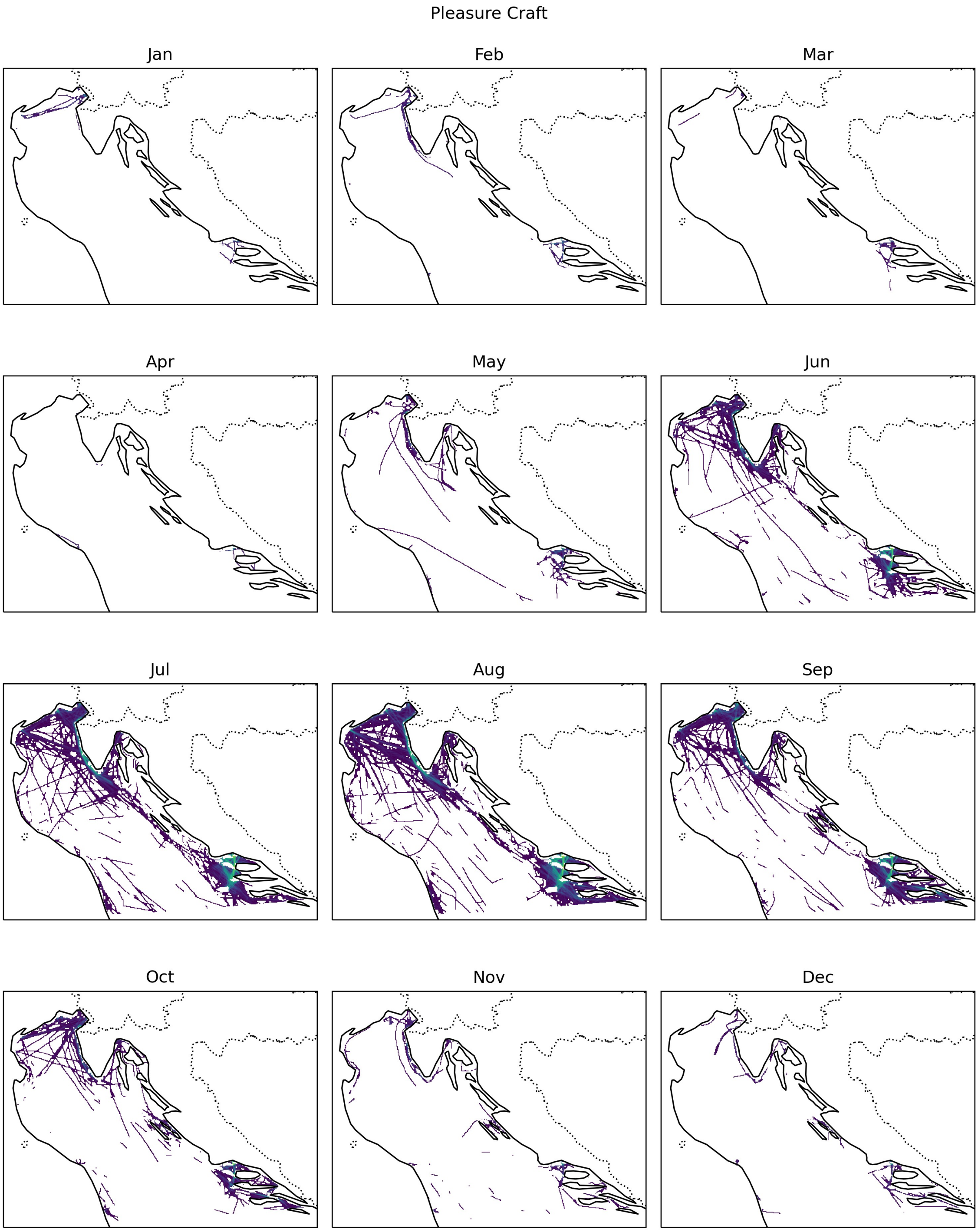


Figure 37. Trajectories of pleasure craft vessels in the case study area during 2020 for each month.

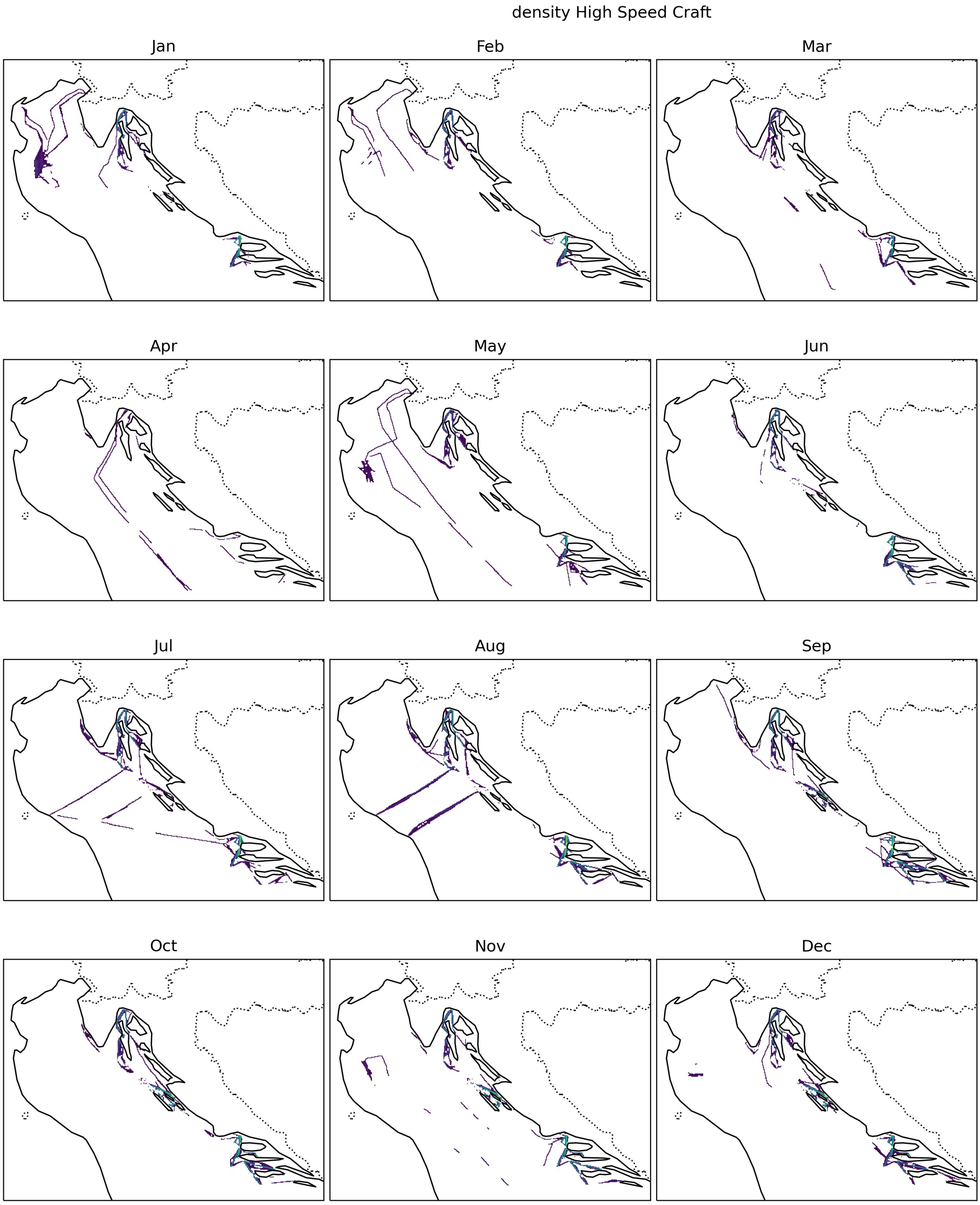


Figure 38. Trajectories of high-speed crafts in the case study area during 2020 for each month.

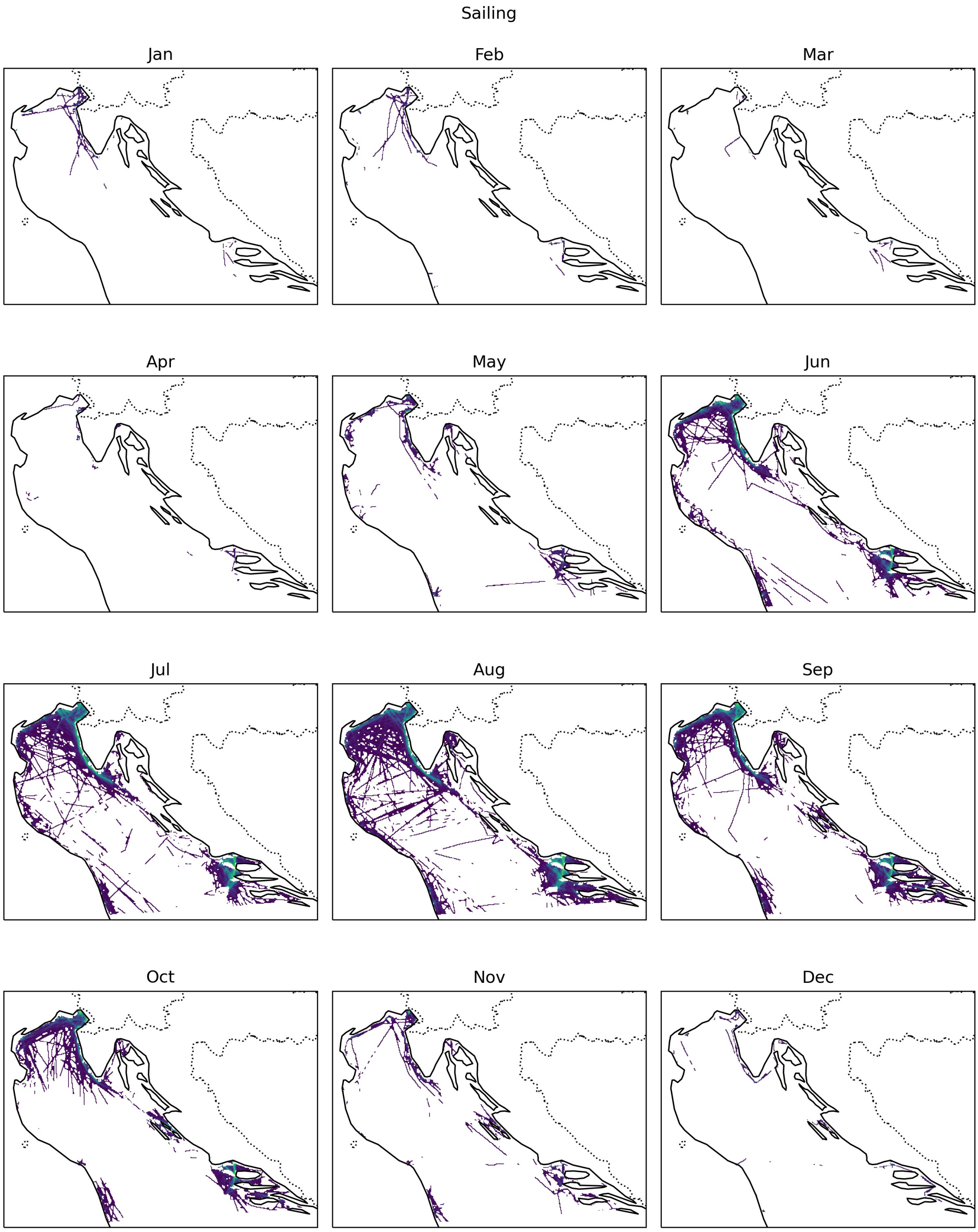


Figure 39. Trajectories of sailing vessels in the case study area during 2020 for each month.

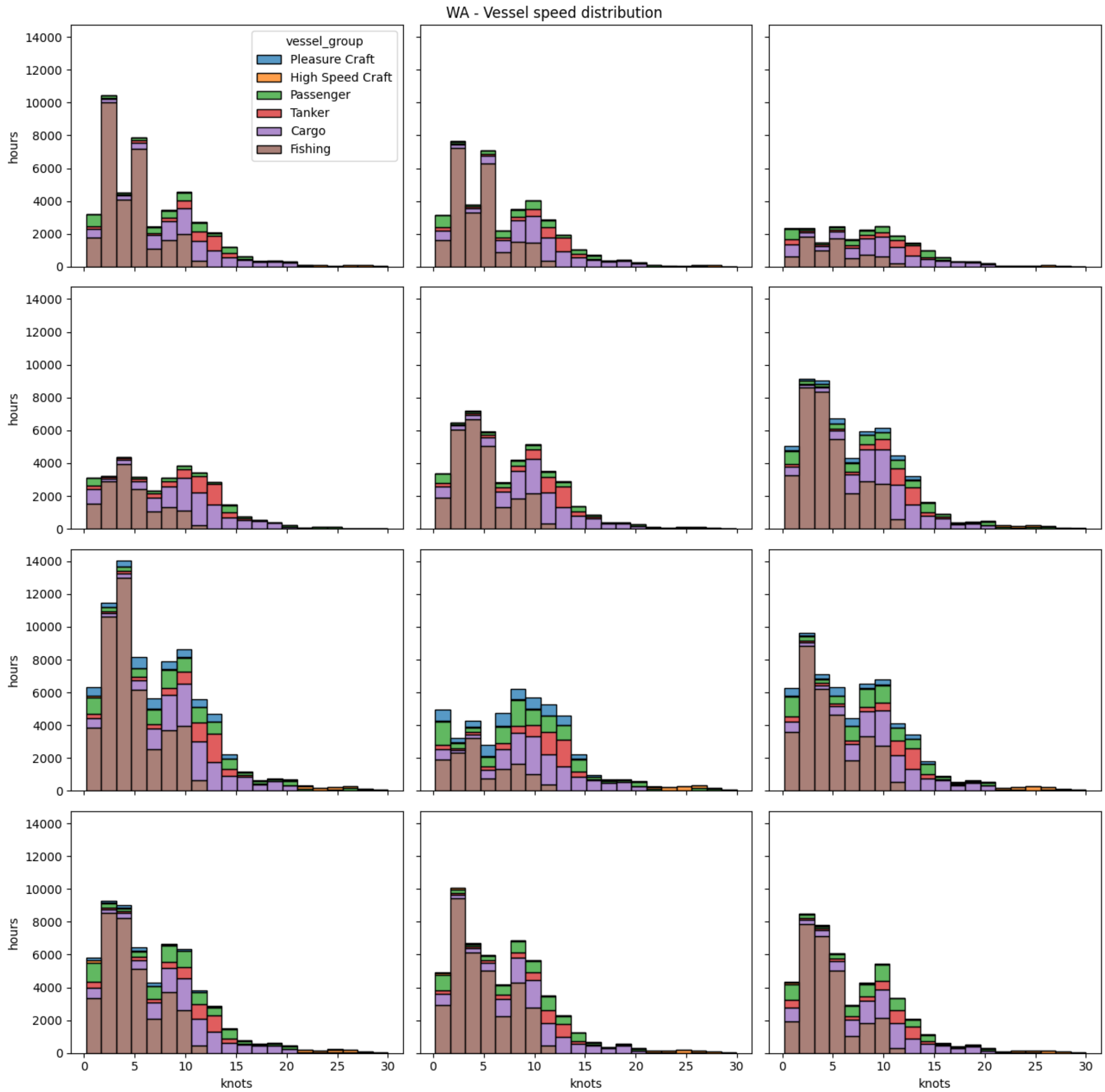


Figure 40. Histogram of the vessel speed distribution during 2020 for each month in the whole area.

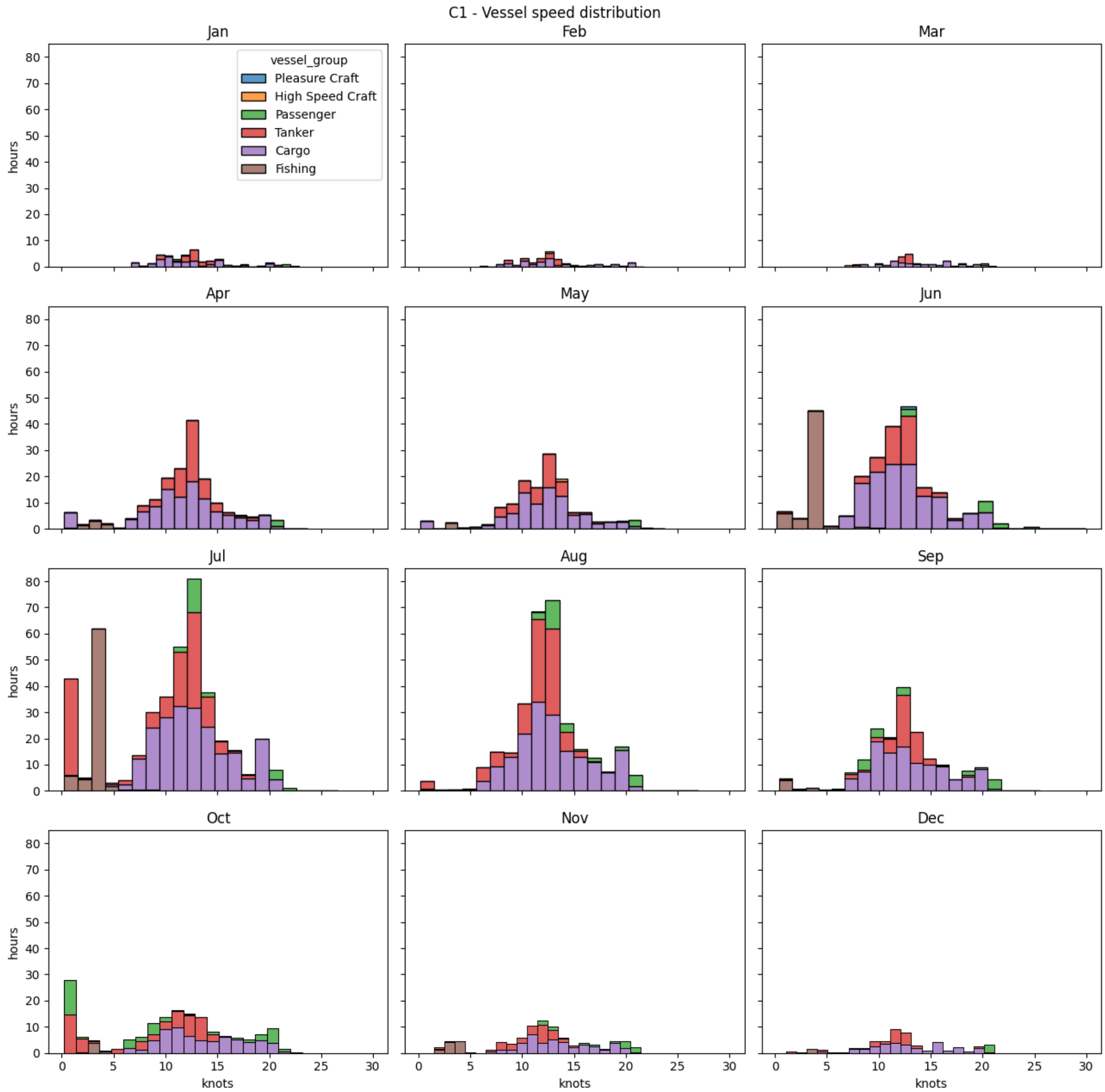


Figure 41. Histogram of the vessel speed distribution during 2020 for each month in the C1 area.

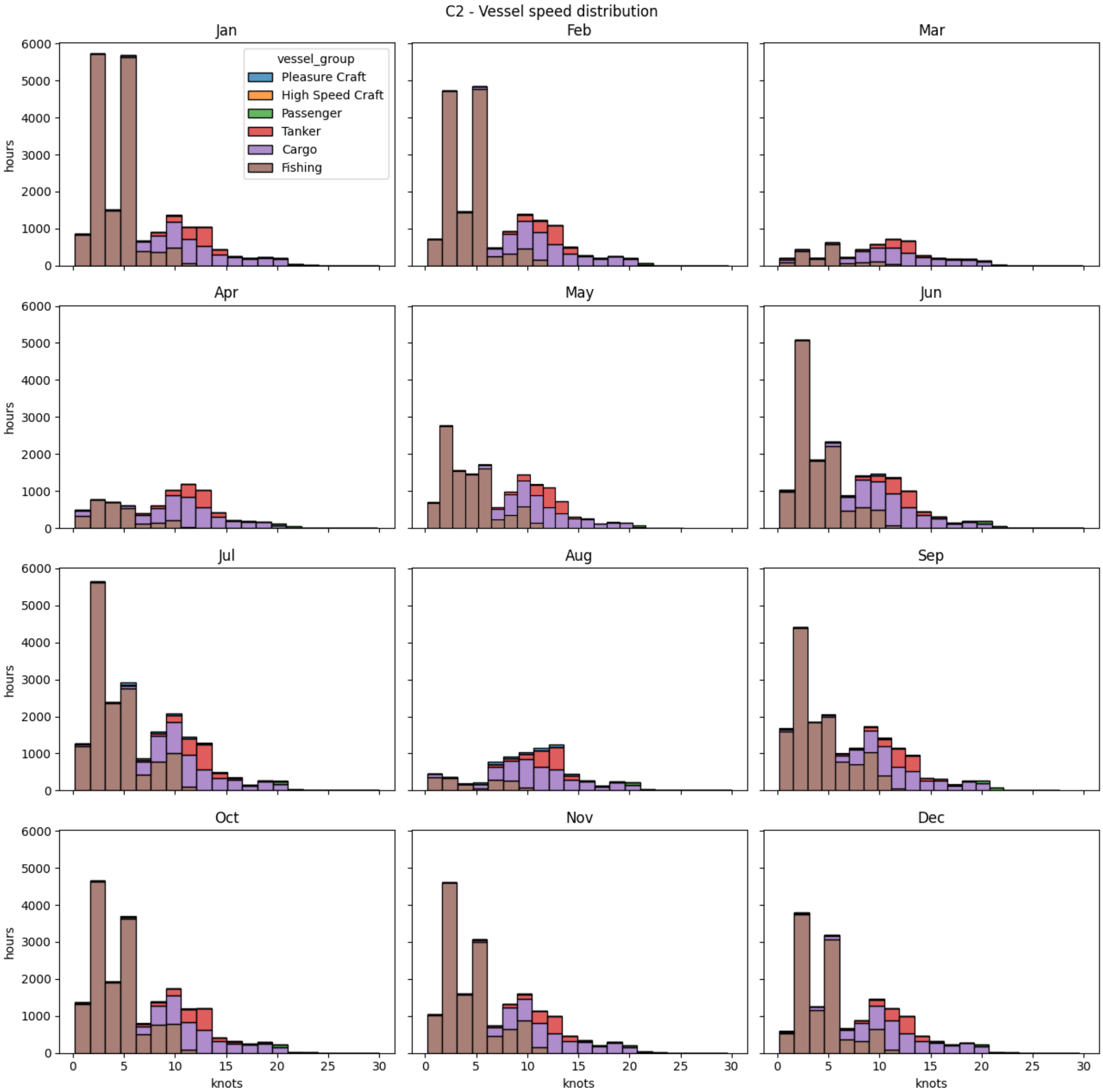


Figure 42. Histogram of the vessel speed distribution during 2020 for each month in the C2 area.

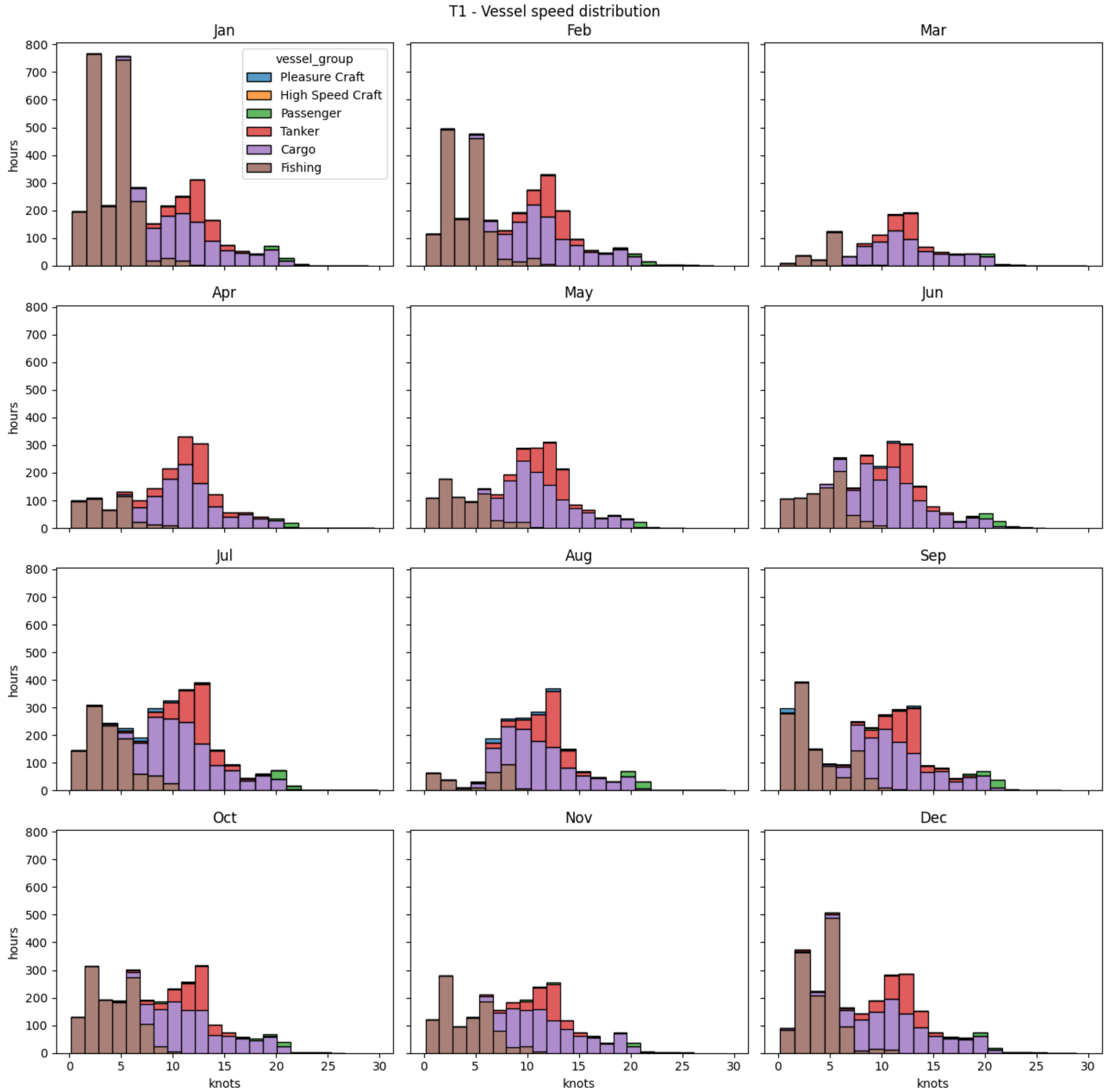


Figure 43. Histogram of the vessel speed distribution during 2020 for each month in the T1 area.

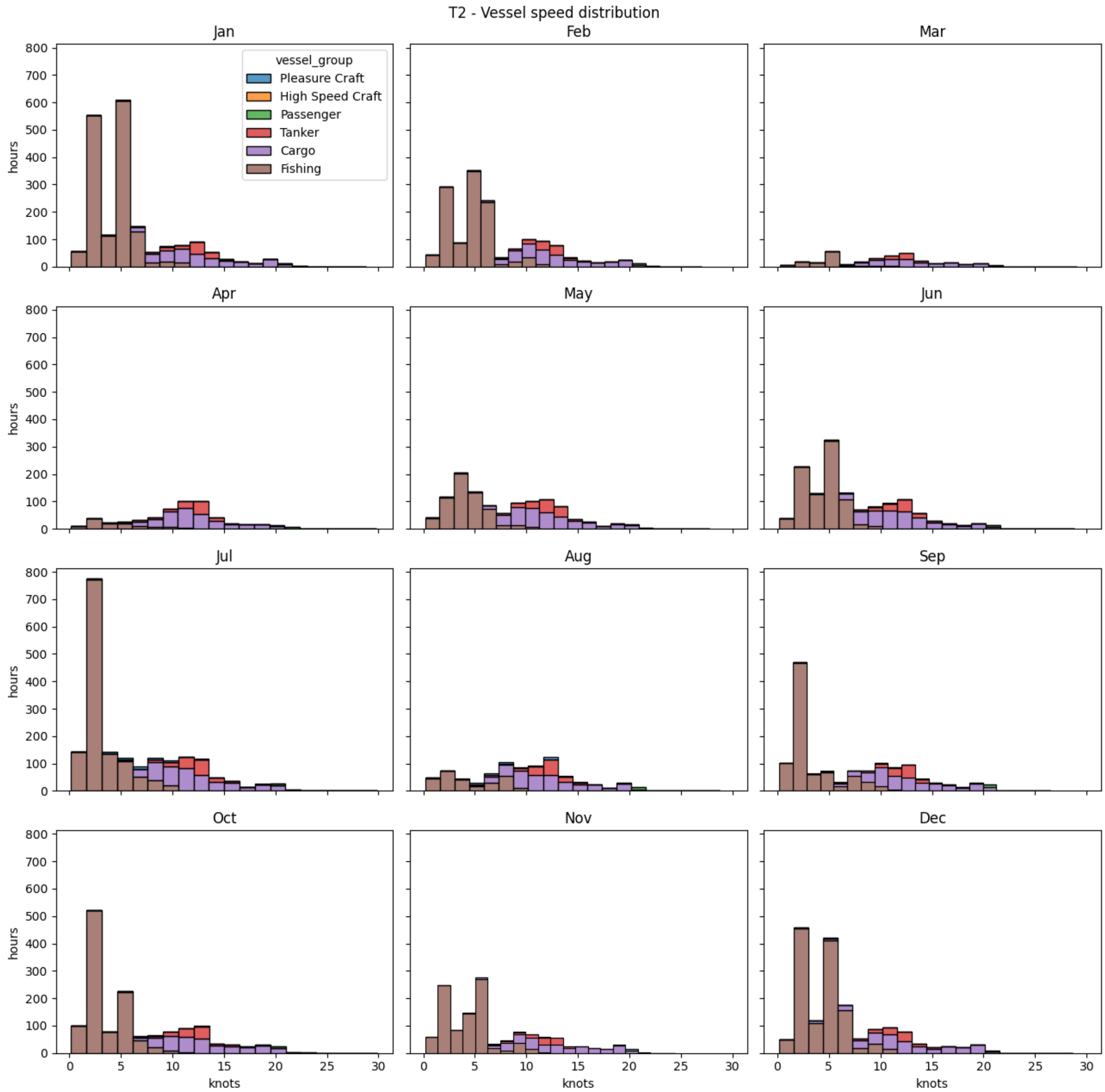


Figure 44. Histogram of the vessel speed distribution during 2020 for each month in the T2 area.

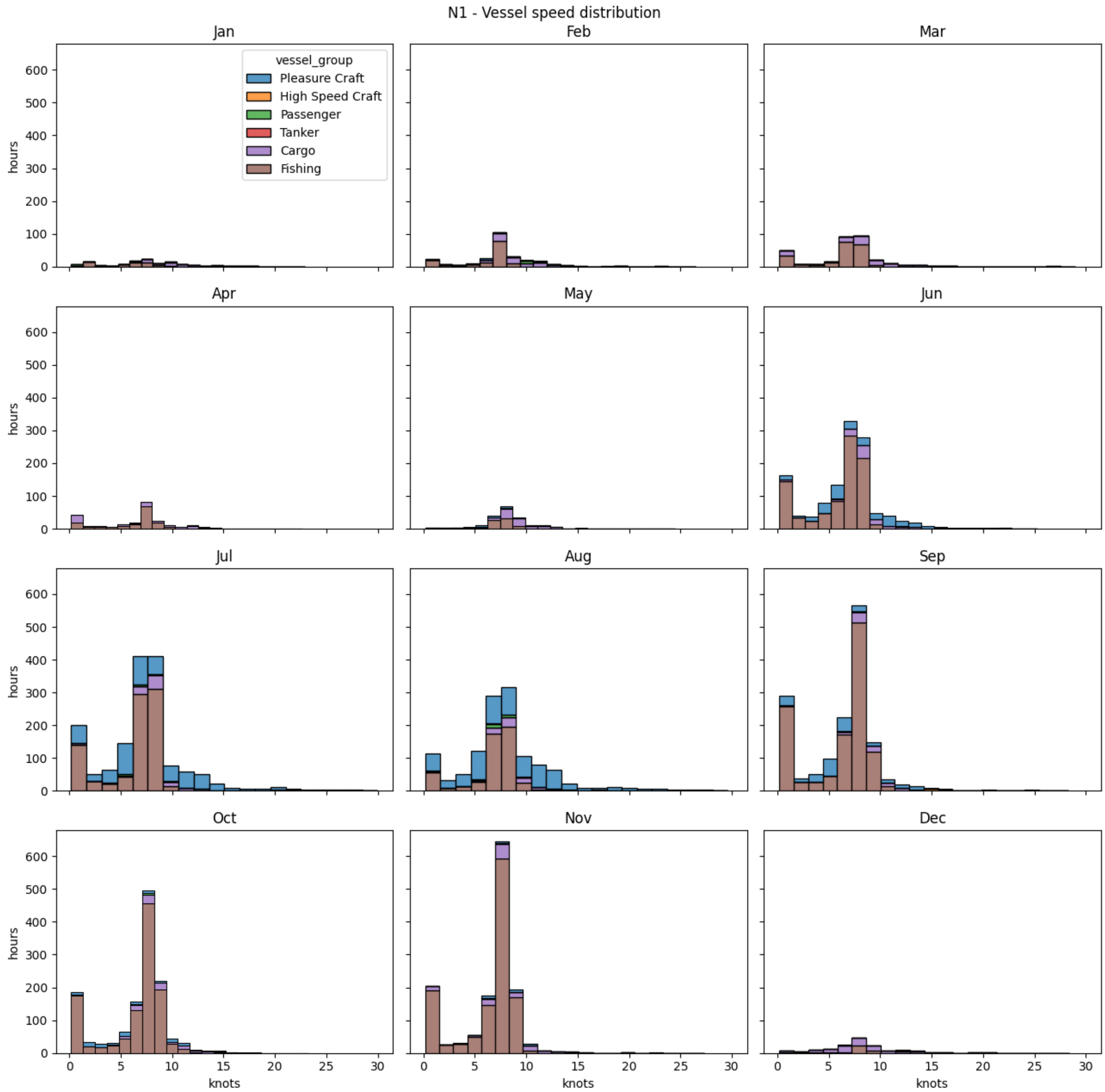


Figure 45. Histogram of the vessel speed distribution during 2020 for each month in the N1 area.

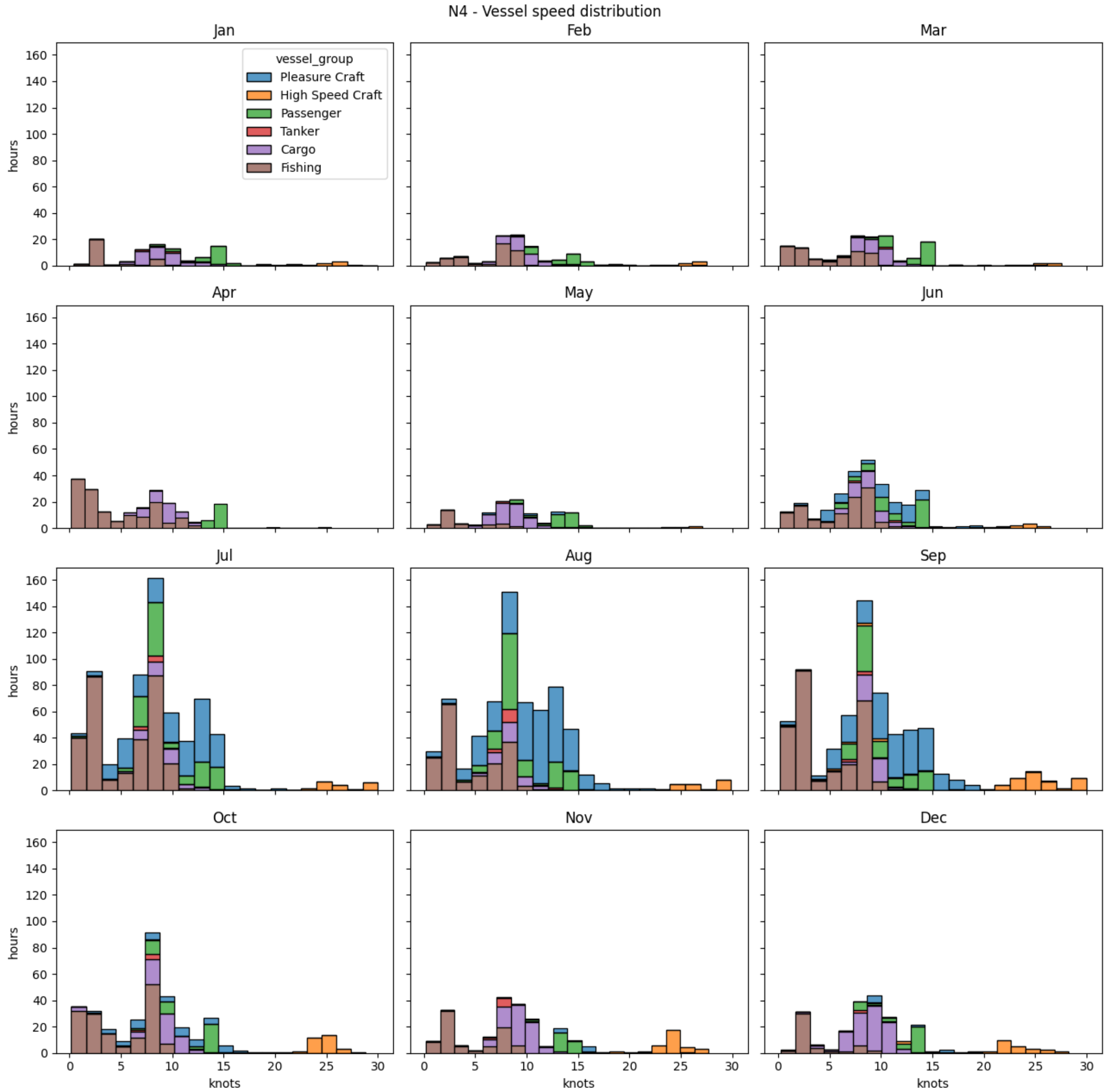


Figure 46. Histogram of the vessel speed distribution during 2020 for each month in the N4 area.

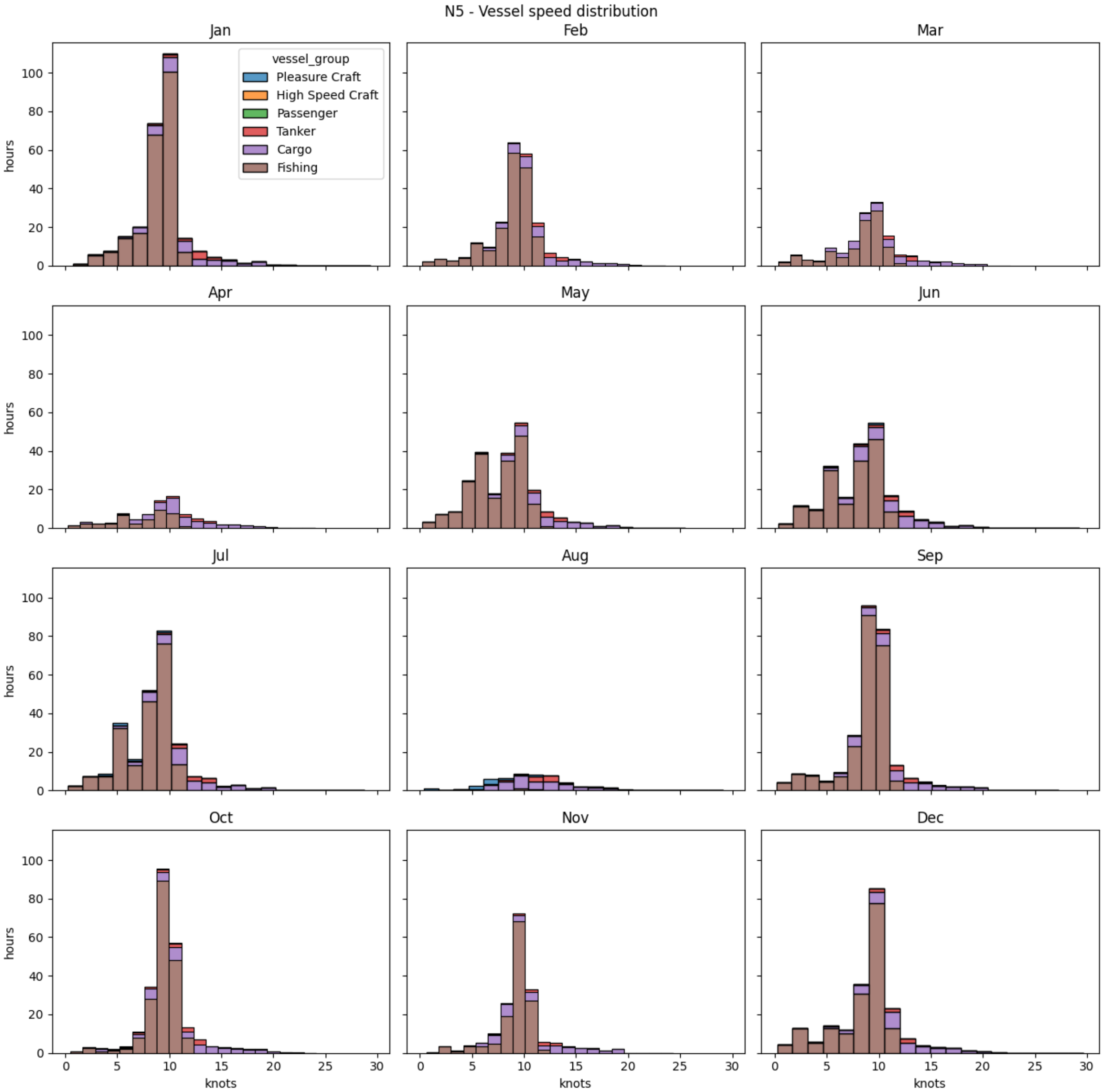


Figure 47. Histogram of the vessel speed distribution during 2020 for each month in the N5 area.

4.2.5. Source identification

The outputs of the run of the RANDI 3.1 model to AIS trajectories in the whole case study area are shown below:

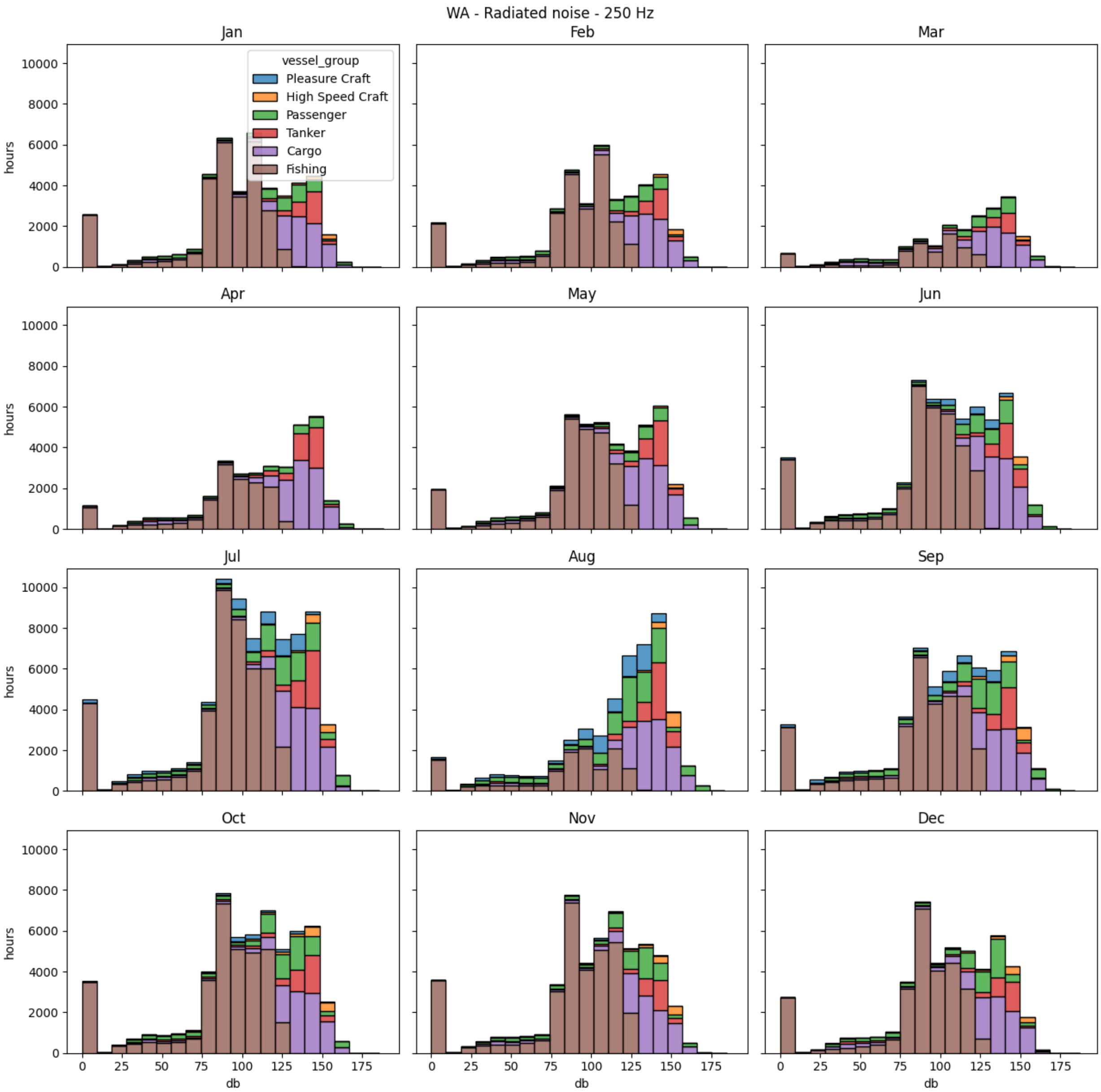


Figure 48. Histogram of the modelled radiated noise through RANDI 3.1 at 250 Hz during 2020 for each month.

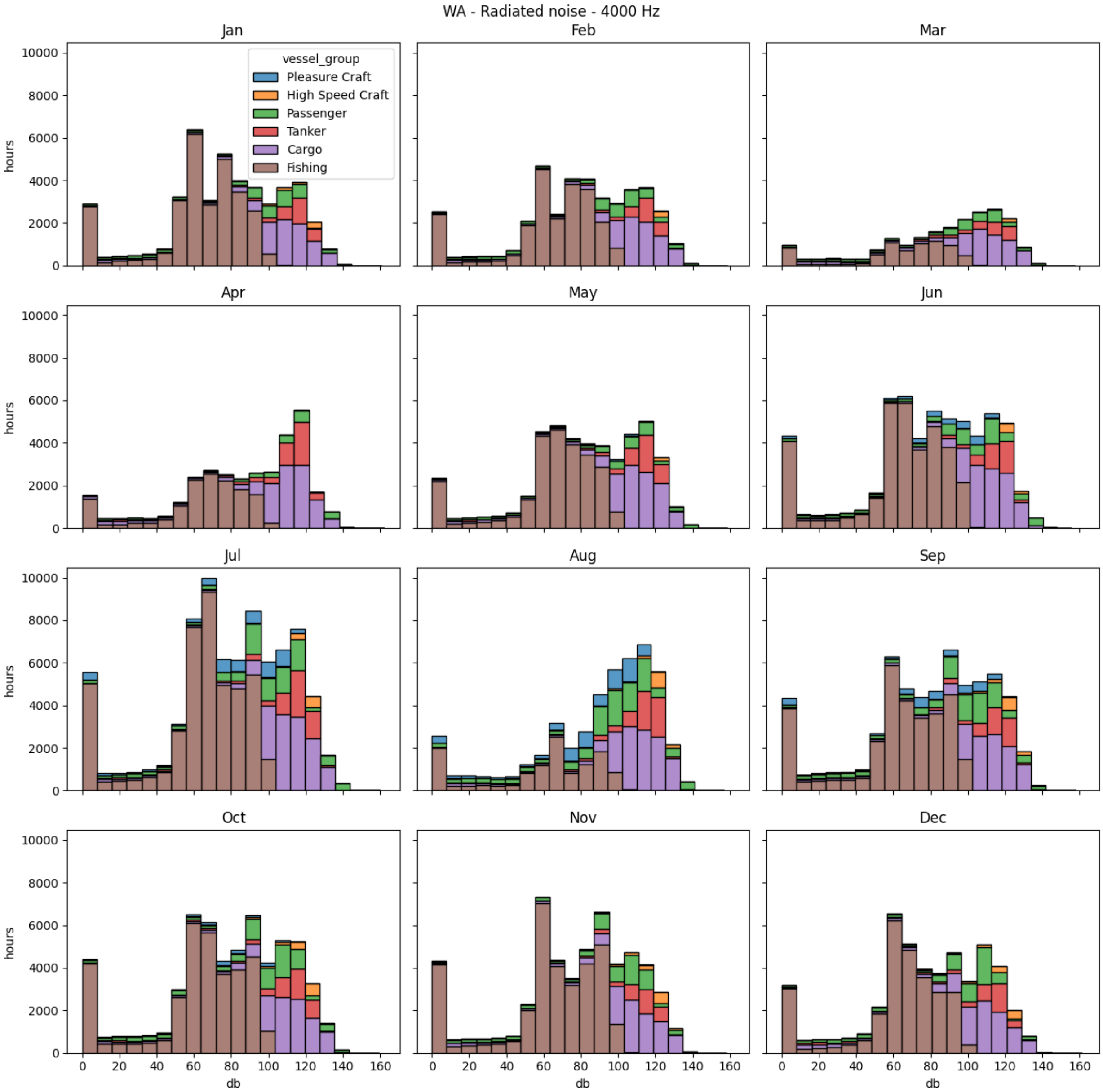


Figure 49. Histogram of the modelled radiated noise through RANDI 3.1 at 4000 Hz during 2020 for each month.

The analyses highlight how, in decreasing order, cargo, tanker and passenger ships represent the most pervasive sources of high levels noise at both frequencies during the whole years. Even if at slightly lower levels, fishing vessels resulted to be an extremely pervasive source of continuous noise at both frequencies during the whole years, with the significant exception of the COVID lock-down months

(March and April) and during the trawling ban of August. The noise emitted by pleasure crafts and passenger vessels significantly increase during the summer months.

According to the identification of attention areas (see par. 4.2.3) the analysis of the modelled radiated noise at the source through RANDI 3.1 has been also conducted for the trajectories falling within the identified attention areas (C1, C2 and N4 at 250 Hz and T1, T2 and N5 at 4000 Hz).

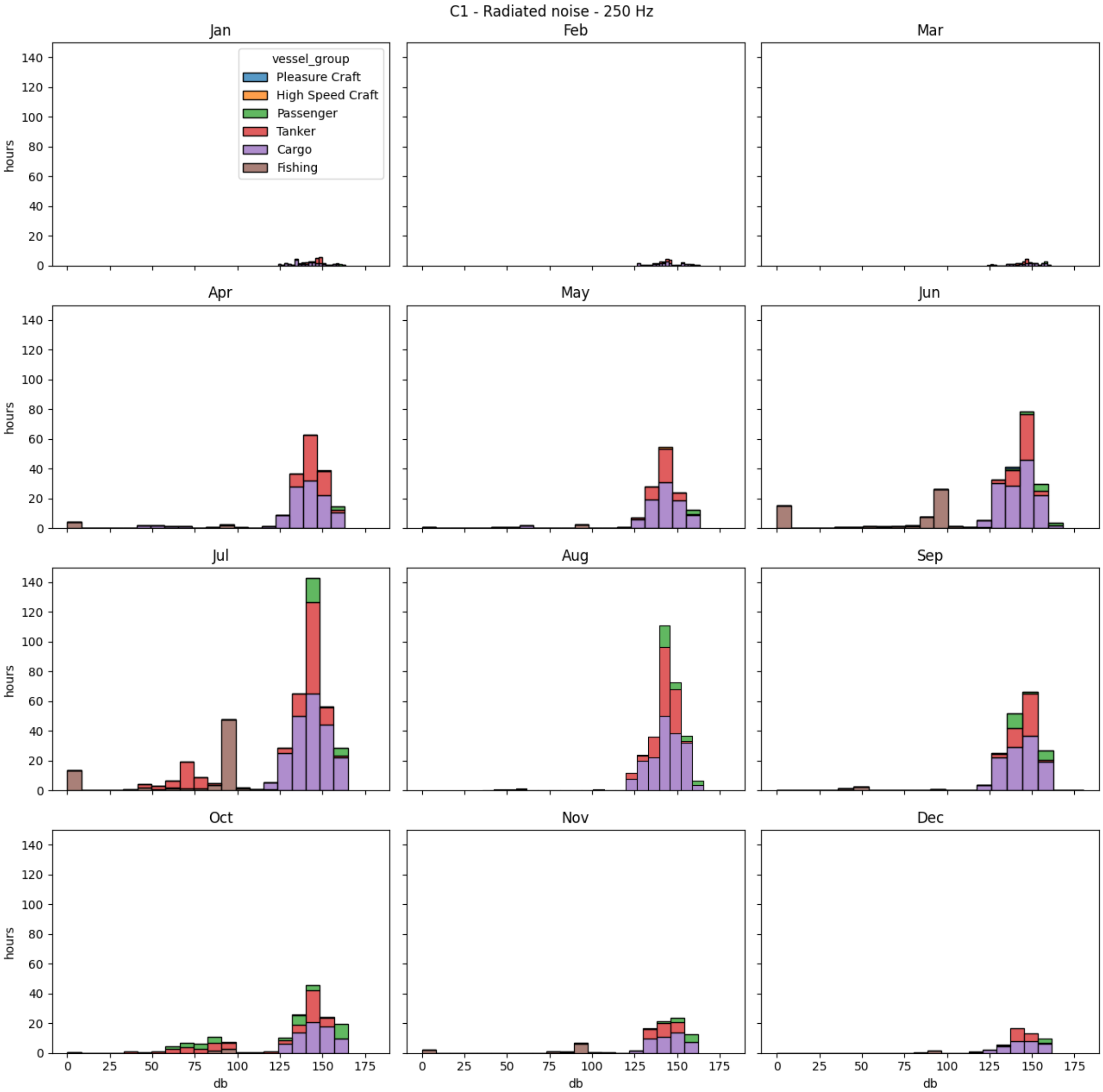


Figure 50. Histogram of the modelled radiated noise through RANDI 3.1 at 250 Hz in the area C1 during 2020 for each month.

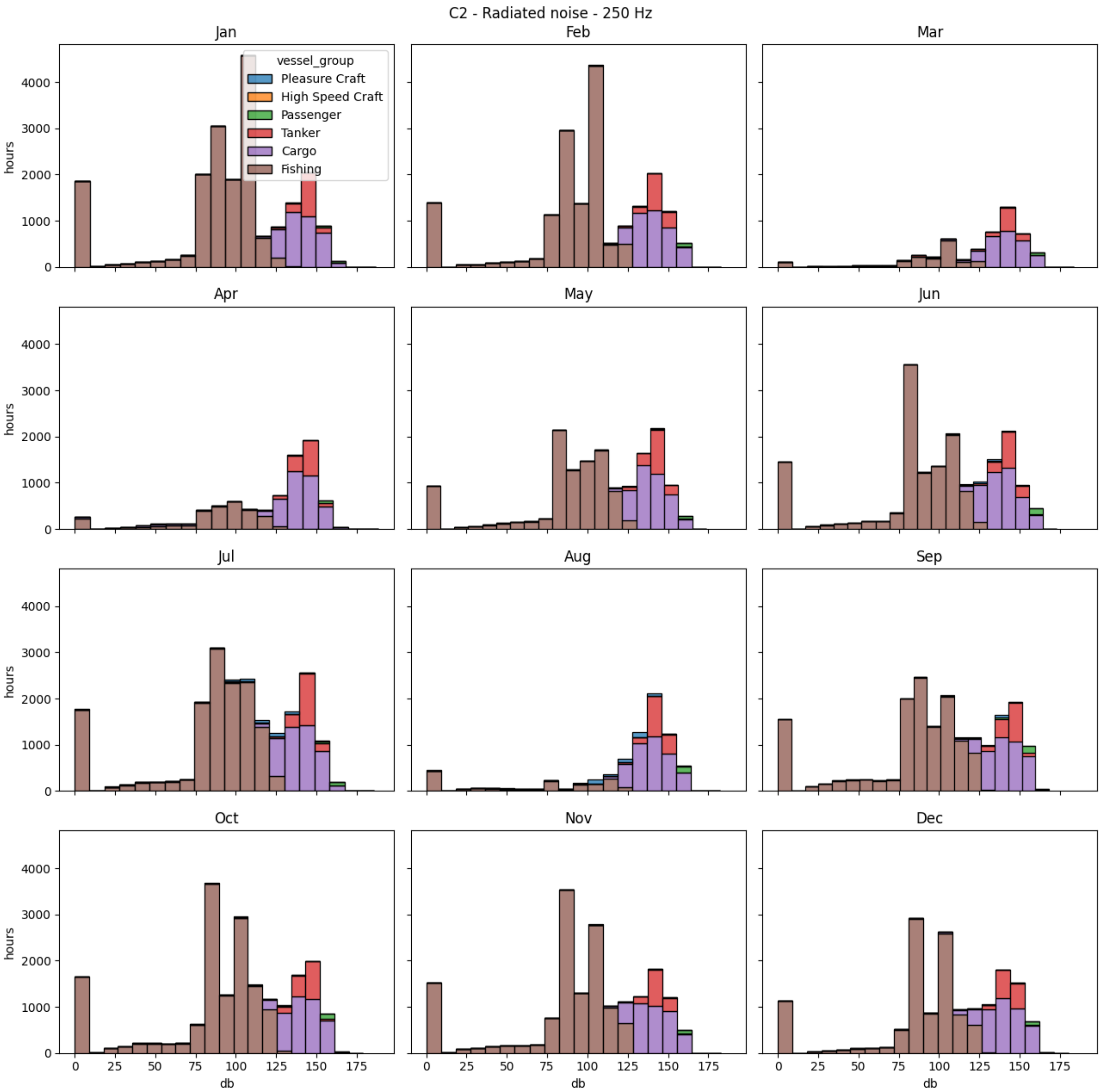


Figure 51. Histogram of the modelled radiated noise through RANDI 3.1 at 250 Hz in the area C2 during 2020 for each month.

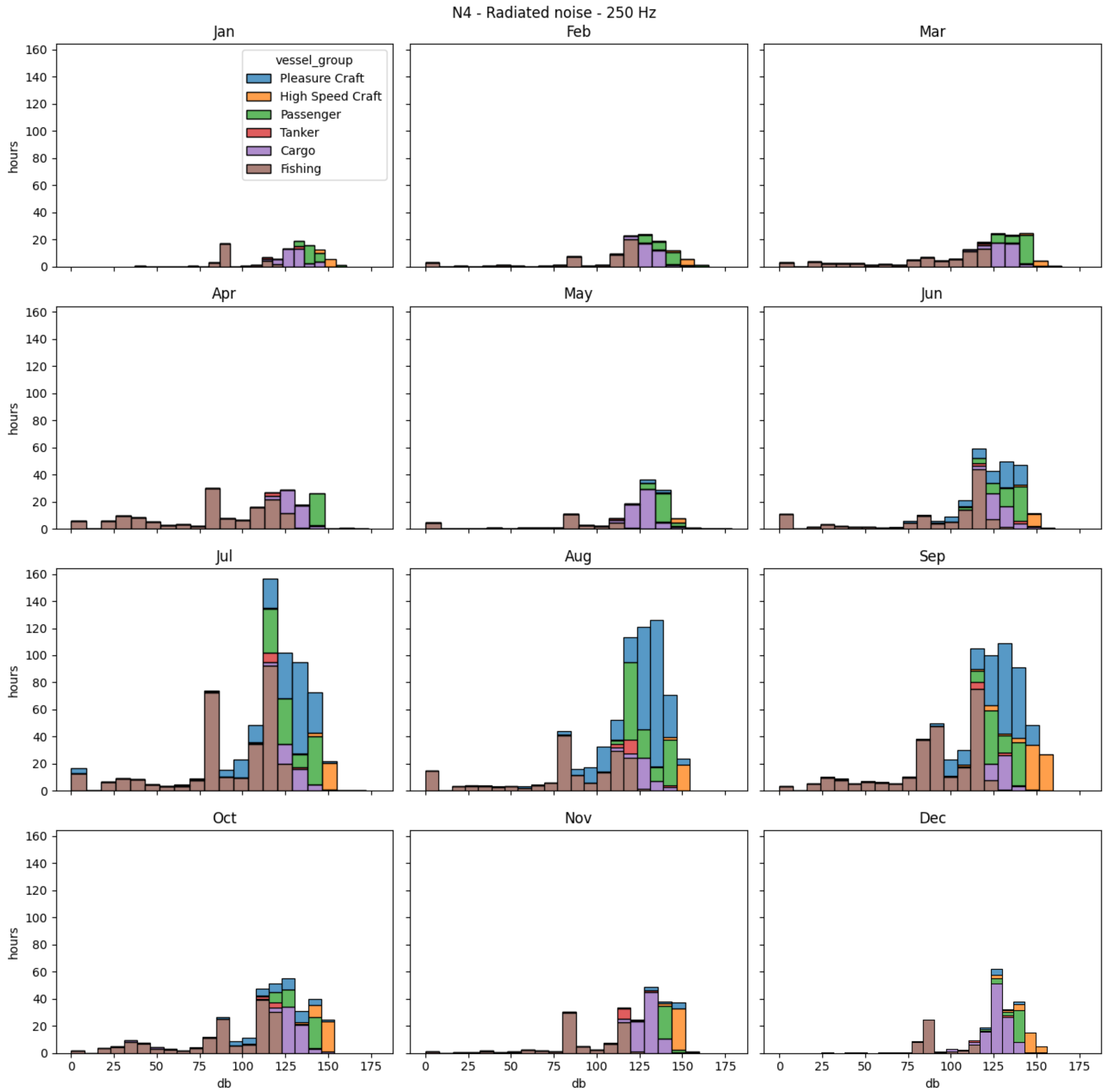


Figure 52. Histogram of the modelled radiated noise through RANDI 3.1 at 250 Hz in the area N4 during 2020 for each month.

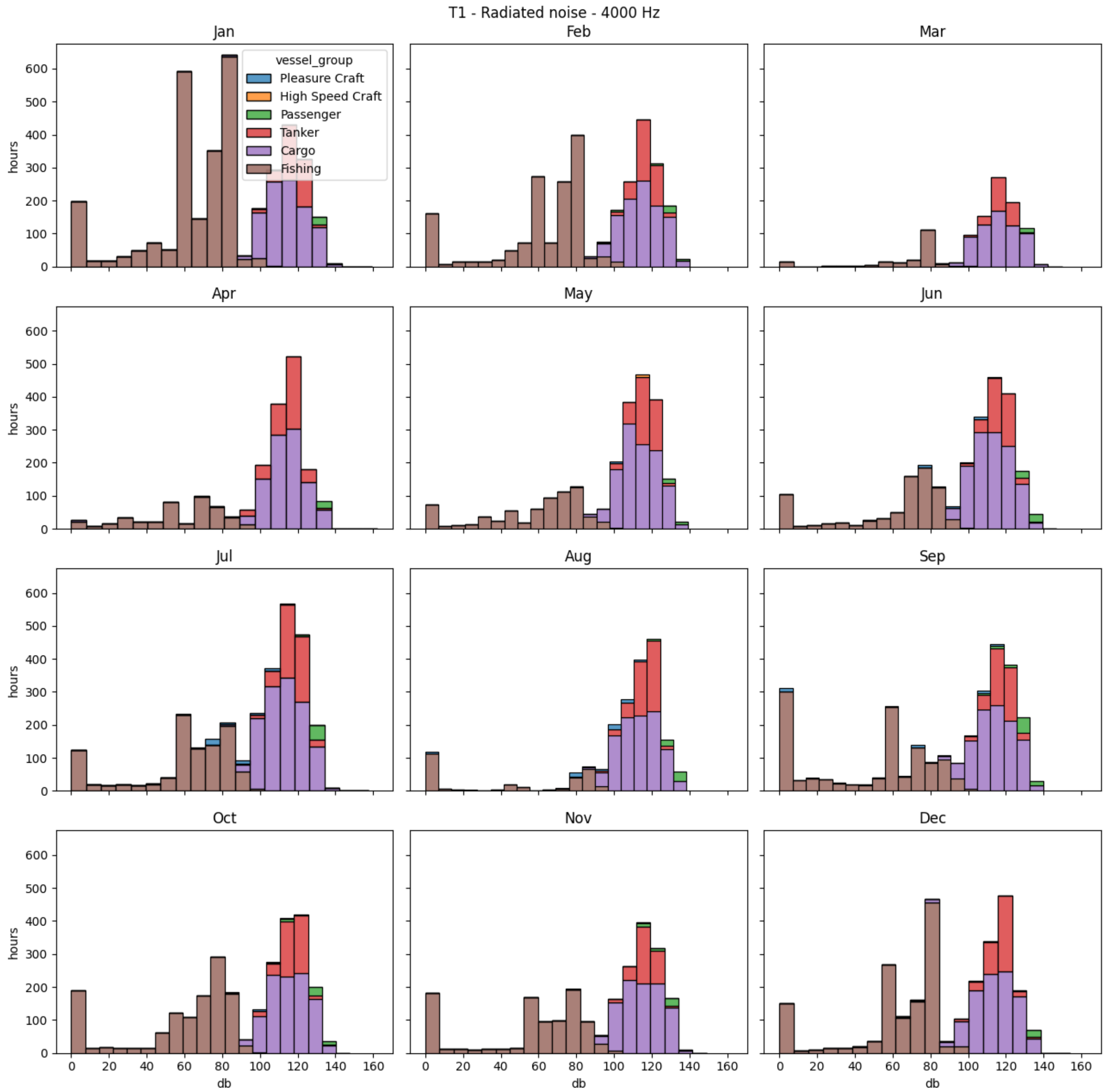


Figure 53. Histogram of the modelled radiated noise through RANDI 3.1 at 4000 Hz in the area T1 during 2020 for each month.

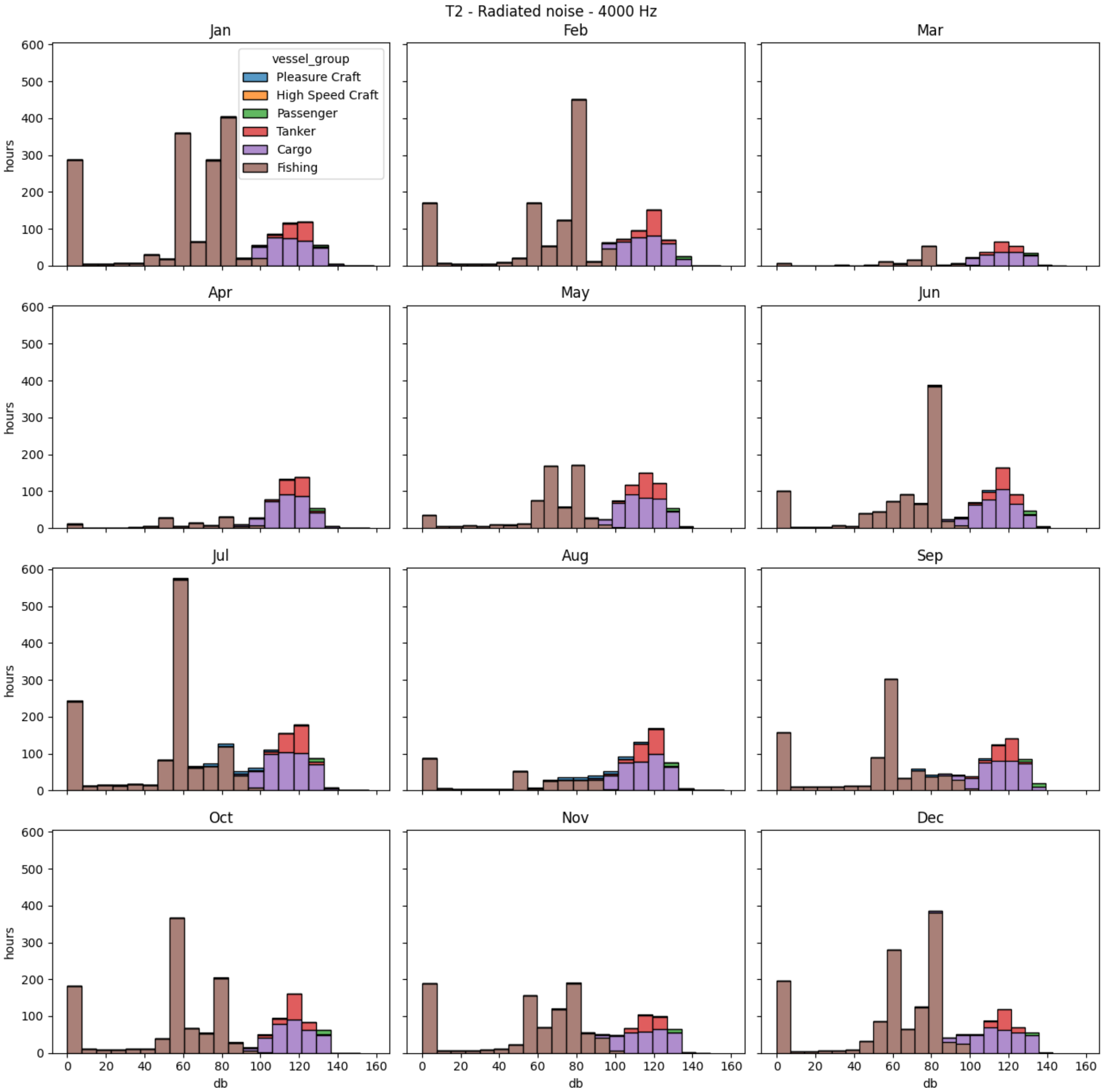


Figure 54. Histogram of the modelled radiated noise through RANDI 3.1 at 4000 Hz in the area T2 during 2020 for each month.

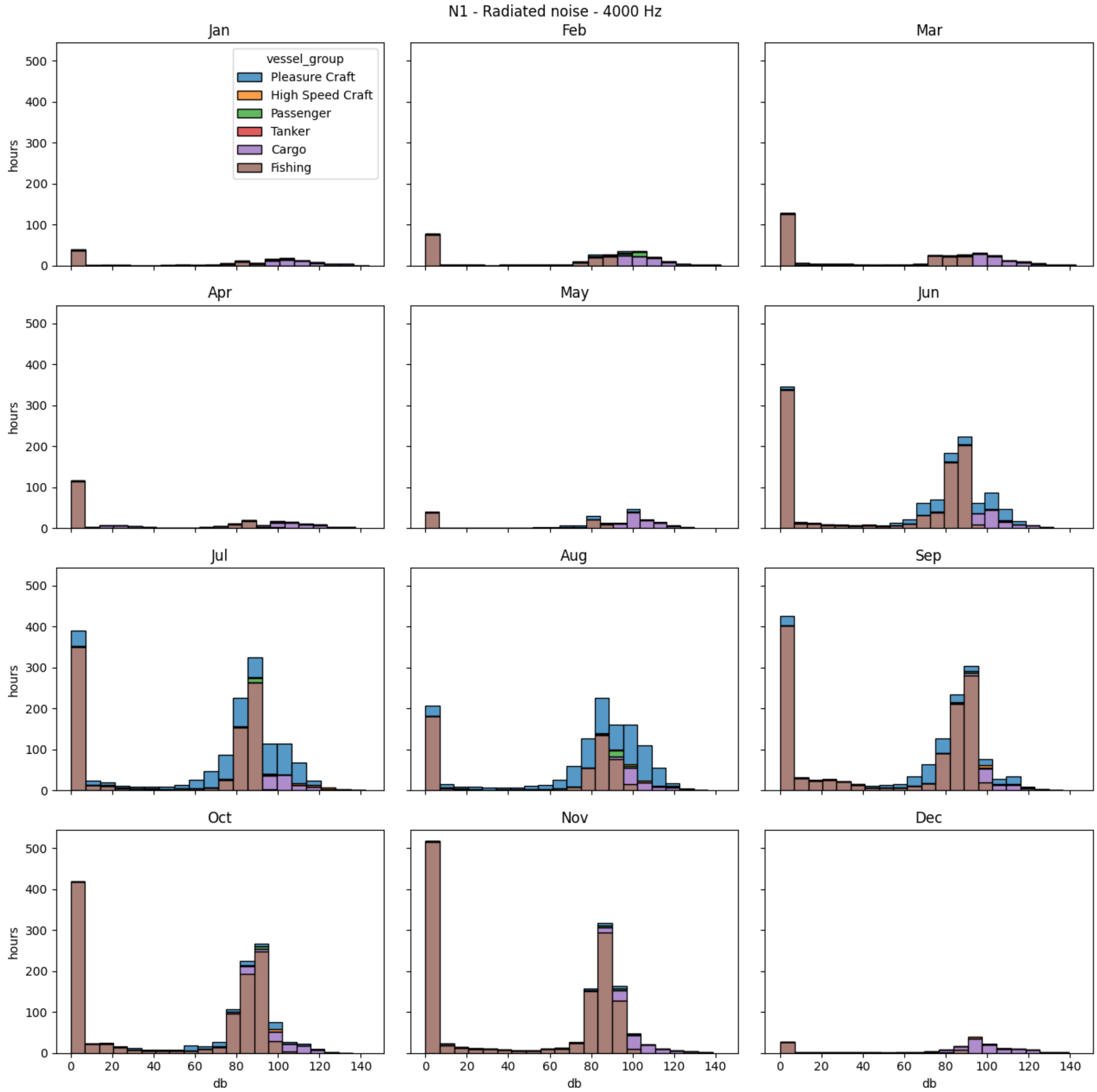


Figure 55. Histogram of the modelled radiated noise through RANDI 3.1 at 4000 Hz in the area N1 during 2020 for each month.

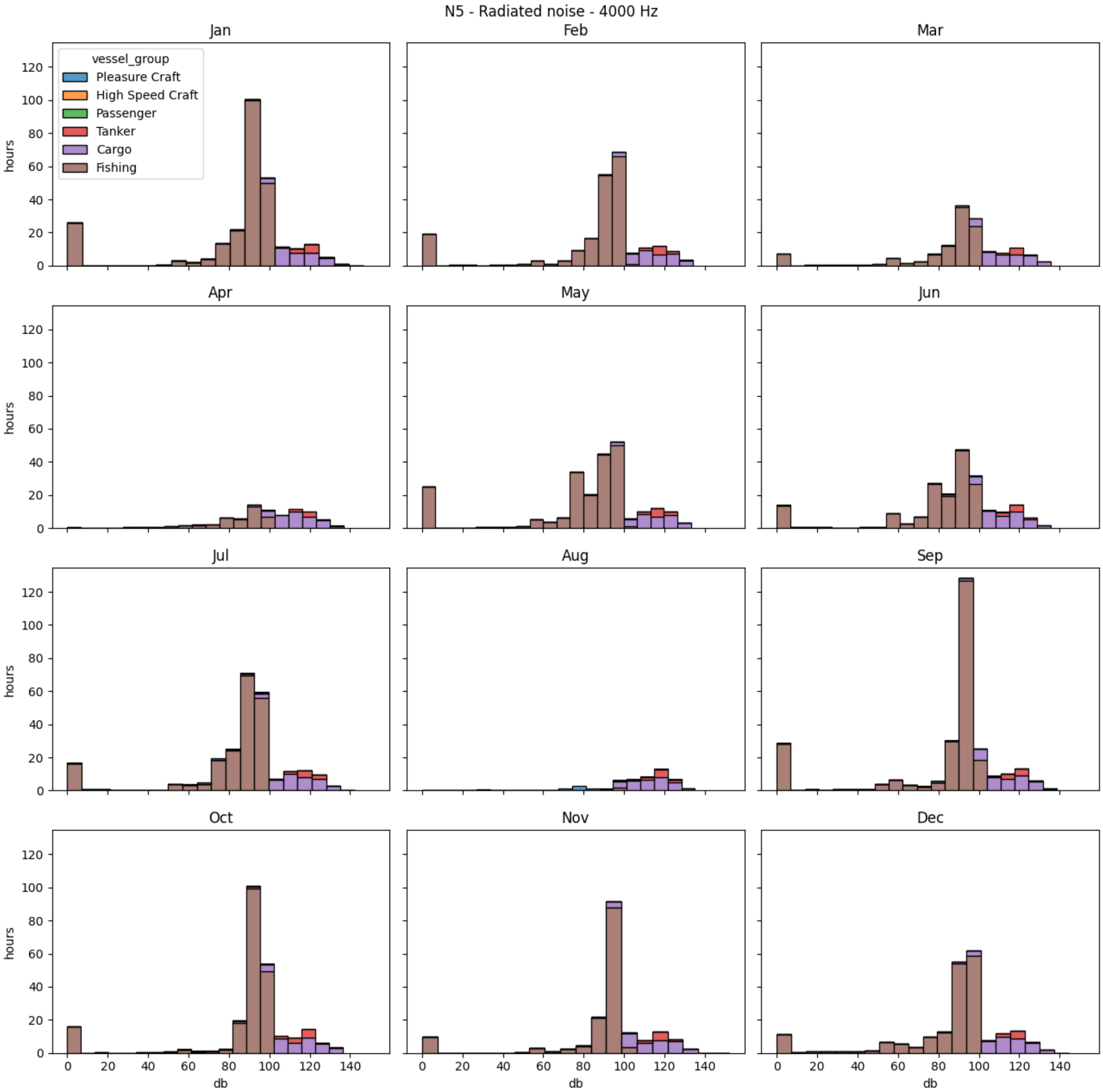


Figure 56. Histogram of the modelled radiated noise through RANDI 3.1 at 4000 Hz in the area N5 during 2020 for each month.

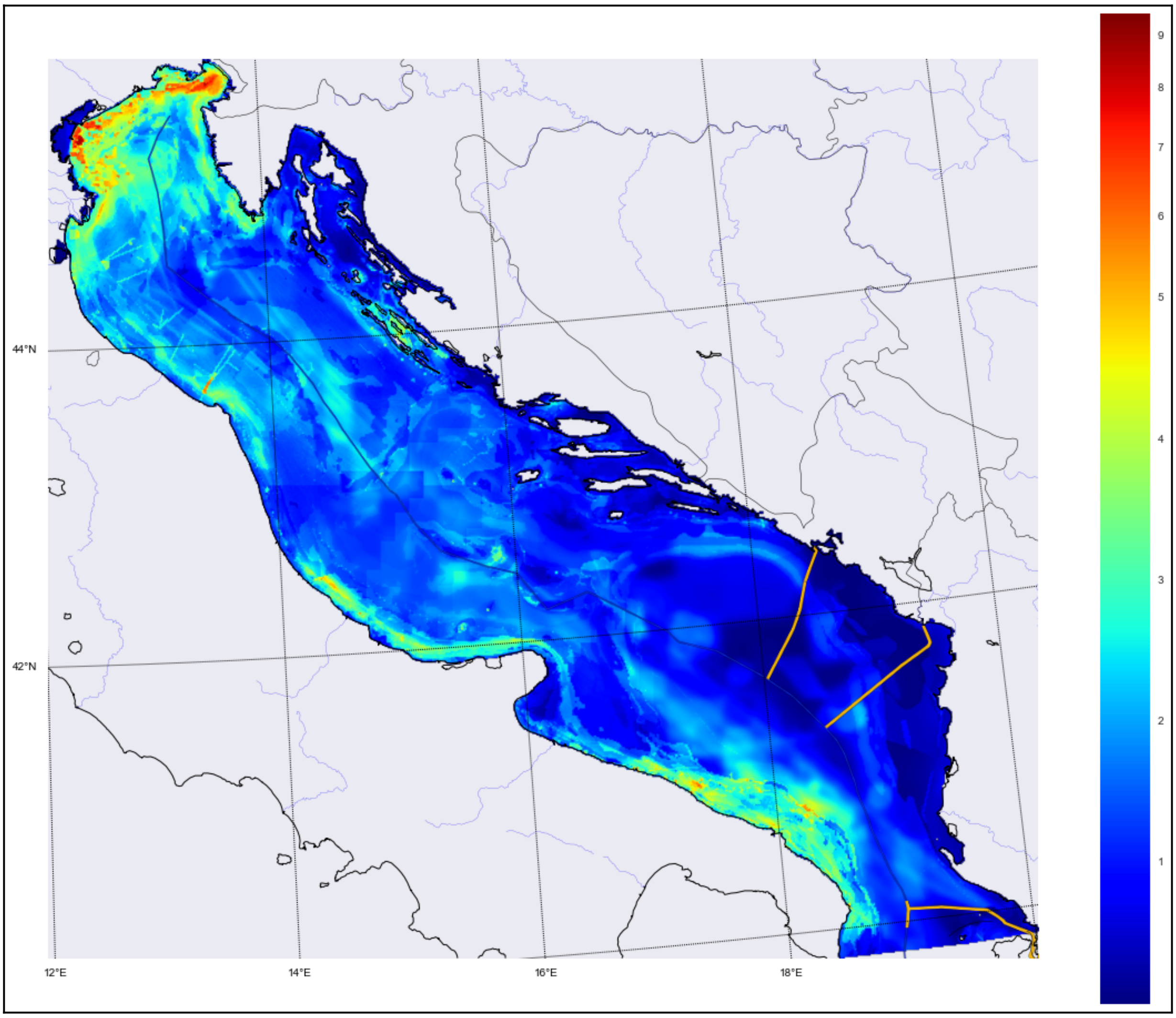
Results highlight how cargo and tankers are the most relevant sources of high levels and continuous noise at both at 250 Hz and 4000 Hz. Almost all the areas also feature, even if at lower intensities, a pervasive influence of the UWN emissions from fishing vessels. Passenger vessels, pleasure and high speed craft also contribute significantly to high levels of UWN but with more spatial variability and especially during spring/summer months (e.g. N1 and N4). Concerning the analyses within Natura 2000 sites, the modelled radiated noise of overlapped trajectories could underestimate the importance of the difference vessel sources in disturbing the sites. This is because such areas are usually coastal and/or relatively small and consequently we expected a not negligible influence of the trajectories surrounding the analyzed areas (i.e. N5 sites). In consequence, particular attention should be posed at monitoring the UWN generated outside the areas that spread within and/or the one from vessels within AIS.

5. Scenario building

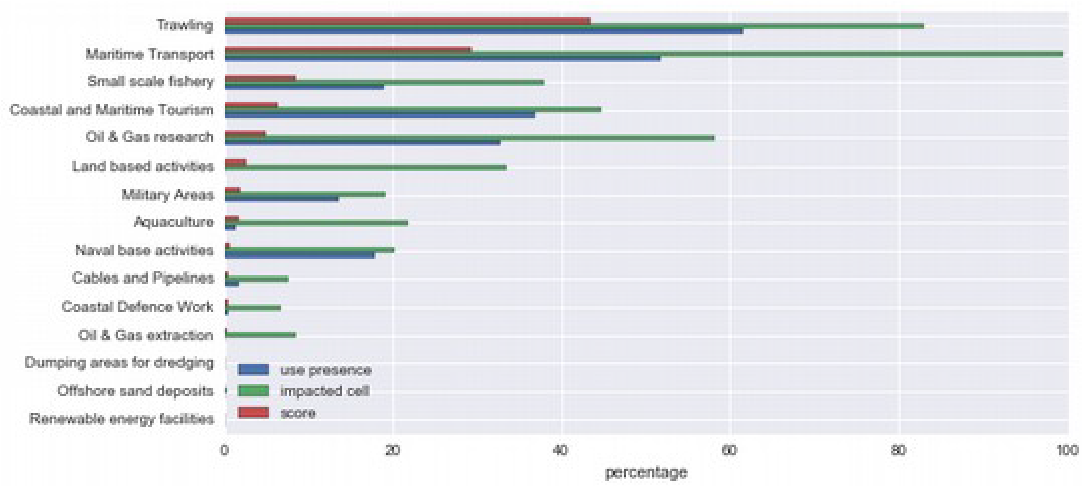
5.1. Identification of possible mitigation measures

5.1.1. Present scenario

The Northern-Central Adriatic hosts major urban settlements, intensive maritime activities (commercial ports and medium-small marinas), a complex fishery system integrated with a growing marine farming activity and extensive offshore gas extraction, that along with increasing touristic pressure makes the basin the most affected by cumulative human pressures in the Mediterranean Sea (Micheli et al. 2013; Menegon et al. 2018, fig. 57).



44°N
42°N
12°E
14°E
16°E
18°E
9
8
7
6
5
4
3
2
1



Trawling
Maritime Transport
Small scale fishery
Coastal and Maritime Tourism
Oil & Gas research
Land based activities
Military Areas
Aquaculture
Naval base activities
Cables and Pipelines
Coastal Defence Work
Oil & Gas extraction
Dumping areas for dredging
Offshore sand deposits
Renewable energy facilities
use presence
impacted cell
score
0
20
40
60
80
100
percentage

Figure 57. Mean Cumulative Effect Assessment in the Adriatic waters and human activities relative contributions (Menegon et al. 2017).

Multi-source intense anthropogenic pressures affect its valuable ecological resources and are a known source of impacts that affect bottlenose dolphins and turtles in the Adriatic sea, potentially determining a wide set of consequences on species and population, from direct mortality to behavioral changes. Among these, the awareness of the impacts of underwater noise is increasing and expanding from the high level anthropogenic sound emission (i.e. military sonar, seismic surveys, marine explosions), which may result in critical events (i.e. mass strandings and direct mortality of marine animals) to the persuasive and prevalent impacts of chronic exposure to noise across the whole basin. While critical events derived from noise have been rarely been observed in the Adriatic sea, continuous anthropogenic noise may put at risk the whole Adriatic ecosystems through numerous interfering mechanisms, such as masking of signals from conspecifics, preys or predators, that could result in multiple potential impacts at population and ecosystem levels to fishes, invertebrates, reptiles and mammals (Duarte et al. 2021). In an heavy anthropized marine environment as is the Adriatic Sea (Gissi et al. 2017), these impacts could be of important for population and ecosystems already affected by the cumulative pressure exerted by the multiple human activities insisting in the basin. Efforts to map the potential noise sources in the Northern Adriatic confirmed the diffusive effects of noise, highly contributing to the overall potential cumulative effect of anthropogenic pressures to environmental receptors (Menegon et al. 2018; fig 58).

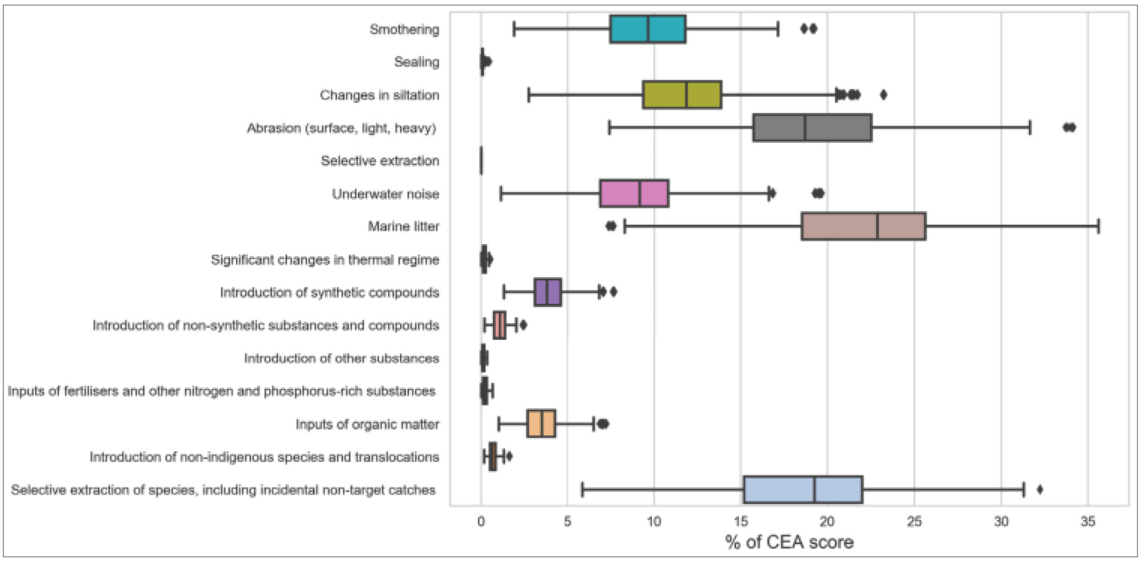


Figure 58. Boxplot illustrating the percentage contribution of pressures to the CEA score. Boxplots show maximum/minimum outliers, boxes enclose first and third quartiles and box centres define median (Menegon et al. 2018).

The conservation objectives for highly mobile and adaptable marine species such as *T. truncatus* and *C. caretta* can be achieved only through the application of systematic monitoring and adaptive management measures in such a large and connected area (Fortuna et al., 2018). This foster the need of a continuous mapping of the distribution of target species and their life cycle, together with the promotion of research strategies aimed at a better understanding of their responses to chronic noise exposure. Management should take into account the strong seasonal fluctuations of the Adriatic populations and accordingly applying specific technological measures and limitations.

Data modelled within Soundscape project highlights how average noise levels at the considered single-band frequencies (250 Hz and 4000 Hz) in the Central-Northern Adriatic Sea during the 2020 result below the levels of exposure able to induce direct damage to both bottlenose dolphins and turtles (i.e. temporary threshold hearing loss, hearing loss). Nevertheless, the analysis of extra noise derived from anthropogenic activities shows how the Adriatic soundscapes are widely influenced by the complex system of maritime transportation. Pressure index maps (figure 24) show that higher pressure areas correspond to areas having higher abundance (average values) of the considered target species. These “attention areas” are C1 and C2 for turtles and T1 and T2 for dolphins. Table 3 shows which are main underwater noise sources affecting those areas (in both cases cargoes and tankers, with persistent contribution in time from fisheries, although at lower intensities). On those areas and on those sources mitigation measures should be focused, at least as a first instance.

Maritime transport exerts a wide suite of pressures on the whole Adriatic sea, considering that this influence derives from a wide extension of the routes due to the extensive presence of multiple shipping and cruise ports at sub-basin level. Such influences have transnational connotations to be considered in management options aimed to increase the overall sustainability of the sector. Management options at the Adriatic Sea scale should promote strict limitations in accordance with the international IMO Conventions (e.g. International Convention for the Control and Management of ships ballast water and sediments, BWM), the MARPOL Convention (1973) and the European Maritime Safety Agency regulations (EC N 1406/2002). This would allow to reduce the overall traffic pressures, in particular by implementing traffic monitoring networks and drastically tackle the main risks derived by the potential pollution (e.g. marine litter release) and emissions of underwater noise.

Maritime traffic generally produce sound as a by-product. Shipping activities management should ensure that environmental impacts are avoided or minimized, through technological and/or regulatory measures, as demonstrated by recent progress in the shipping industry. Improved regulatory frameworks to manage UWN and promote efficient solutions needs to be developed focusing on the peculiar consideration that, unlike other sources of pollution, anthropogenic noise is not persistent in the environment once sources are removed and well-planned actions can have near-immediate positive effects (Duarte et al. 2021).

In first instance, regulating the speed of the vessels in the Northern Adriatic Sea could help to reduce noise (see table 3 for more details) (Chion et al., 2019; MacGillivray et al. 2019). As an example, the reduction of steaming speed for noisy vessels in the eastern Mediterranean from 15.6 to 13.8 knots between 2007 and 2012 has already proven to provide an estimated halving in the broadband emissions from these vessels (Leaper et al. 2014). This suggest that considering the speed reduction of cargo vessels (reaching the 20 Kn of speed in the case study area, see fig. 40, pag 75) and tankers (up to 16 kn), which has been determined to be the main source of UWN in the Adriatic high waters, could immediately provide an important benefit to some of the most biologically sensitive areas (e.g. C2). Speed limits application could be managed properly at the very beginning within the existing traffic separation schemes (TSS), that could also promote a coordinate effort in testing the combined effectiveness of other behavioral measures, such as convoying vessels. In addition, incentive immediate maintenance and retrofit actions for machinery treatments as a requirement for cargo vessels entering in the TSSs could reduce the UWN emissions also at mid-frequencies (e.g. 250 Hz).

At this stage there are no evidences that measures like re-routing or ATBA have to be considered.

These management options require an efficient and joint effort of the Adriatic Port Authorities, also within NAPA and in coordination with IMO, aimed at improving and harmonizing traffic monitoring and management. This especially in the framework of EU MSP directive (2014/89/EU) and MSF Directive (2008/56/EC), involving the Competent Authorities of Italy, Slovenia and Croatia. The management targets to address anthropogenic underwater noise should be included in National marine plans, guaranteeing a spatially-explicit application of strategic measures and limitations, including potential further identification as critical or important habitat for at-risk species deserving priority for conservation based on the best existing knowledge. These strategic measures should be proposed in compliance Maritime Strategy Framework Directive (MSFD 2008/56/EC) Descriptor 11 and relative Programs of Measures.

Speed reduction in attention areas could be in first instance applied on seasonal basis. This is due to the evidences of seasonal fluctuations in the species distribution, especially in Italian waters. However, the time-span of the speed limits should also carefully consider that both dolphins and turtles are almost permanently present in Croatian waters (e.g. along Istrian peninsula and in the e Kvarner Gulf) and, also, the differences in sound transmission due to the summer thermocline.

Real-time monitoring systems constitute a solid baseline in order to structure a coordinate control of maritime traffic. To meet the challenge of managing underwater noise highly mobile sources and receptors, maritime traffic management should ideally become adaptive and dynamic, integrating multiple data types (e.g. biological, remotely-sensed, traffic data, modeled species' distribution data) and modeling processes into fluid decision-making. While traditional marine spatial management techniques such as shipping lanes or area closures can achieve similar objectives as dynamic management, traditional spatial closures are not responsive to rapid changes. The continuous mapping of the spatial-temporal distribution of noise levels generated by human activities at sea and real time modeling of soundscapes could help the dynamic management of an area through faster and efficient application of management measures, especially close to protected areas. Modelling of instantaneous and cumulative sound levels at any given location requires knowledge on vessels, the level of noise produced by each and understanding their different operations. This kind of assessment of the source contributions throughout adequate modeling frameworks needs the introduction and integration of VMS and AIS recording systems in order to assess the distribution of different types of vessels, including information on typology, location, speed, length, etc.

Modelling results show how anthropogenic noise around offshore shipping lanes is dominated by large (>25 m) commercial ships, whereas shallower coastal waters and inland waterways also host many smaller vessels that are more variable in speed and highly mobile. Shallow, coastal areas are key habitats for many marine species, but are likely particularly prone to under-estimations of vessel noise levels by AIS models, as recreational vessels are common close to the coast. Motorized non-AIS vessels (primarily recreational vessels) possibly contribute with significant noise emissions in the study area, recreational vessels dominated the soundscape at low, medium and high frequency bands (Hermannsen et al. 2019). In consequence, the daytime soundscapes of this areas are often dominated by the sounds of small vessels, potentially operating in waters as shallow as <2 m depth.

Despite this, a relevant number of small vessels (i.e. recreational and coastal fishing vessels) are not required to have an AIS, and are therefore not accounted within AIS-based models. Results hence particularly compelling in the coastal areas where smaller vessels operate most an urgent expansion of the use of the AIS system to small boats (at least over 12 m).

Coastal recreational boating below 15 meters is usually without AIS, consequently the information within the modeled maps (e.g. AIS from the "pleasure craft " vessel type) does not contain all the information about the potential noise produced by recreational vessels. However, the known distribution of major recreational maritime activities requires taking into account the development of management measures to mitigate the impacts of recreational traffic on target species in terms of noise emissions, especially at higher frequencies. Recreational activities are mainly seasonal (especially in summer) and are concentrated along the Italian coasts (generally within 3nm offshore) and, with greater intensity, along the Croatian coasts.

A recommended precautionary measure is to limit the speed of recreational boats in selected areas. Negative reactions to target species can be caused by high-speed vessels, not only due to higher levels of broad-band noise associated with high speeds, but likely also because high speeds decreases the time available for an animal to react by displacement to minimise noise exposure, potentially perceiving it as an immediate threat and exhibit an erratic response (Hermannsen et al. 2019). The rise time of vessel noise may be a particular issue in shallow water, where recreational boating in warmer summer months largely overlap with the breeding/spawning periods of marine species. However, the effects on soundscapes of speed reduction could be extremely variable considering the highly different features (i.e. vessel type, design, hull type, length, engine power, engine type, propeller size, number of blades, onboard machinery) and categories of small boats and may be highly vessel-specific, thus a single speed limit may not be appropriate for all vessels. Furthermore, the often lower ambient noise levels during warmer months (due to lower wind speeds and lower precipitation in temperate areas) will cause the noise contributions and perceived loudness from vessels to be more significant. As a consequence, within protected areas and/or in the presence of species subject to protective measures, could be an appropriate precautionary approach not allowing vessels - or specific types of vessels, e.g. vessels not adopting specific technical noise mitigation measures or behaviors - in a specific area.

Developing appropriate shallow-water criteria could enhance the inclusion of small fishing boats within the modelled soundscapes. Fishing activities in the area determine significant pressures. In particular, the disturbance caused by trawling can be classified as one important source of anthropogenic impact in the Northern-Central Adriatic Sea (Farella et al. 2020, 2021), targeting mainly demersal fishes, exerting well-documented impacts on seafloor biodiversity (Santelli et al. 2017), sensitive habitats and also constituting an important threat to many endangered species. Fishing capacity increased greatly during the last decades (Bastardie et al. 2017), making the Adriatic Sea the portion of Mediterranean Sea with the highest concentration of trawlers (Russo et al., 2019). Bottom trawling, intensively exerted in particular in Northern Adriatic Italian waters (from 3nm to the midline; Ferrà et al. 2018), not only affect the fauna along the trawl pats but also heavily alters the seabed and the surrounding water column.

The trawling fishery system of the Adriatic Sea mainly relies on pair pelagic trawlers, on bottom otter and “rapido” beam trawls (Sala et al. 2019). These include the heavy trawl doors or chains attached. Trawl warps (cables connecting net to vessel) may create a humming noise in the water column due to cable tension, potentially determining an elevated high frequency content (Daly and White, 2021). Active bottom trawling may accordingly enhance the generation of noise pollution compared to a faster moving ship due to trawling’s pervasive and near ubiquitous presence in the region.

In the northern Adriatic, bottlenose dolphin exhibit a well documented habit to forage behind trawlers, modifying their behavior to take advantage of feeding opportunities provided by fishing activities (Bearzi, Piwetz & Reeves, 2019). According to Bonizzoni et al. (2020), in Italian National waters facing the Veneto region bottlenose dolphins demonstrated strong associations with active trawlers, suggesting that trawlers affect dolphin behavior and space use, potentially being an important alternative means of foraging. Prediction maps show noticeable differences in distribution between trawling and no-trawling days, dolphins being more concentrated in the southern portion of the North Italian waters (particularly off the Po river) in days of trawling, and more dispersed in days without trawling (figure 59).

In waters where prey populations have been depleted by fishing, foraging requires more time and effort, leading to less successful reproduction and poorer recruitment if the cetaceans are not willing or able to move away, facing risks of injuries and the heavy exposition to trawler's noise associated with the feeding very close, if not inside, trawling nets (Santana-Garcon et al. 2018; Bearzi and Reeves 2021).

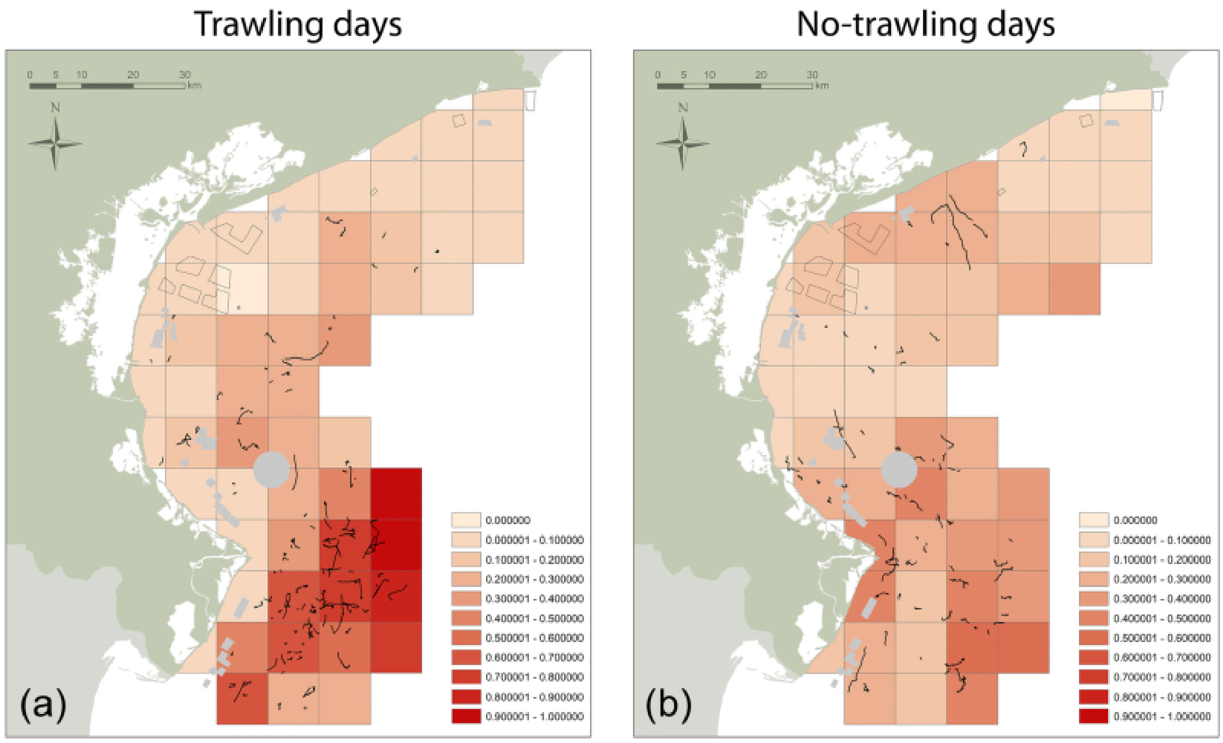


Figure 59. Cell-based maps of predicted bottlenose dolphin occurrence off the region of Veneto, Italy (darker colors indicate preferred habitat, and black lines show dolphin movements tracked during group follows); Bonizzoni et al. 2020.

Trawling fisheries contribution to the modelled soundscapes could in consequence have not been fully described since the model does not take into account the fishing vessels while trawling. Moreover, monthly averaged maps may not focus correctly on the noise generated by an activity with particularly defined and non-continuous time frames (i.e 4-5 days of effort per week).

Fisheries related noise pollution should be properly addressed as a pressure that augments fisheries pervasive impacts on marine ecosystems. Trawling related conservation measures have to strongly address such excessive pressures with an effective enforcement of fishing control, favoring a positive long-term effect on fish stocks and pelagic species in the area, also considering the implementation of further with seasonal bans and best practices to reduce mortality and potential harms. A correct application of spatial-temporal measures for the complex management of fisheries would lead to an immediate positive effect also towards the reduction of noise emissions from fishing vessels.

This should be accompanied by a general application of good behavioral practices (e.g. low speed, vessel maintenance) and application of new technologies concerning propellers, machinery, hulls and gears, both during navigation and during fishing activities. As an example, semi-pelagic and pelagic trawl doors, which have little or no contact with the seabed, could provide a reduction in trawl door dragging noise, together with the intended benefits of reduction in seafloor damage, sediment transport and reduced fuel consumption (Palanques et al., 2018). The actions towards the sustainability of fisheries foreseen by the EU Common Fishery Policy, CFP (EC 2013a,b) should hence explicitly include the reduction of noise emissions related to fishing vessels, encouraging and supporting the adoption of technological solutions and avoidance of sensitive areas.

Table 3 synthesizes mitigation measures to be considered on different target areas, and specifically in what we called “attention areas”. Mitigation measures are coded as per table x in chapter 3. Measures of strategic nature or wide relevance are reported only once to the whole case study area (WA), while other more site-specific measures are attributed to specific target / attention areas. Evaluations on expected relevance and effectiveness and on feasibility are purely qualitative at this stage, requiring more precise and quantitative analysis (as better clarified in par. 4.2 on future research needs).

The two columns on the right refer to the foreseen future scenario, as described in paragraph 4.1.2.

Table 3. Synthesis of the main mitigation measures for selected target and attention areas.

Target/ Attention Area	Target species and frequency	Main UN sources (vessel type)	Main measures to be considered	Expected relevance	Feasibility, considering readiness and potential impacts on maritime transport in the area	Other measures to be considered in the medium and long-term	Feasibility, considering readiness and potential impacts on maritime transport in the area
WA	*C. caretta* (250 Hz), *T. truncatus* (4000 Hz)	Cargo, Tanker, Passenger, Fishing, Pleasure craft	1a, 1b, 1c	+++	++	2a, 2b, 2c	++
			3d, 3e	+	++	3a, 3b, 3c	++
			5a, 5b, 5c	+++	+++	4a - 4h	+
			6b, 6c	++	++	6a	++
C1	*C. caretta* (250 Hz)	Cargo, Tanker	3a	+++	++	2a, 2b, 2c	++
						3b, 3c	++
C2	*C. caretta* (250 Hz)	Cargo, Tanker, Fishing	3a	+++	++	2a, 2b, 2c	++
						3b, 3c	++
N4	*C. caretta* (250 Hz)	Pleasure craft, High speed crafts, Passenger, Cargo	2d	+++	+	2a, 2b, 2c	++
			3a	+++	++	3b, 3c	++
T1, T2	*T. truncatus* (4000 Hz)	Cargo, Tanker, Fishing	3a	+++	++	2a, 2b, 2c	++
						3b, 3c	++
N1	*T. truncatus* (4000 Hz)	Pleasure craft, Fishing, Cargo	2d	+++	+	2a, 2b, 2c	++

Target/ Attention Area	Target species and frequency	Main UN sources (vessel type)	Main measures to be considered	Expected relevance	Feasibility, considering readiness and potential impacts on maritime transport in the area	Other measures to be considered in the medium and long-term	Feasibility, considering readiness and potential impacts on maritime transport in the area
			3a	+++	++	3b, 3c	++
N5	*T. truncatus* (4000 Hz)	Cargo, Fishing	3a	+++	++		

5.1.2. Future scenario

Anthropogenic noise is a pollutant that must be addressed in policies to mitigate human impacts on the oceans. This is particularly important given the growing focus on the ocean-based economy, which is forecast to double its contribution to global gross domestic product by 2030 (OECD, 2016).

The present analyses show how, at least at the scale of the entire basin and with exclusive regard to maritime traffic, the average conditions of underwater noise at 250 Hz and 4 kHz do not generate alarm, even though they require careful management of the activities in order minimize their impacts, especially in the context of a basin strongly affected by multiple anthropogenic pressures. However, the trends in the development of maritime activities lead to an increased density of traffic in the next years, with special emphasis on several parts of the Adriatic Sea, as well as partly to the change in the nature of traffic. Therefore, a “business-as-usual” development of the ocean-based economy will inevitably lead to ever-increasing noise from more shipping, coastal development and tourism but, also, seismic surveys, military operations, dredging, pile driving, likely contributing to increasing impacts on marine ecosystems (Duarte et al. 2021).

Future trends forecast higher traffic density in the next years, due to the increasing phenomenon of naval gigantism, and the increasing importance of Ro-Ro and containers traffic, Short-Sea Shipping and of the Mediterranean economic exchanges. Specifically, a significant increase in the volume of transport of oil and other harmful substances is expected, including liquefied natural gas (LNG). The trends in recent years show overall increase of the transshipment flows in the Mediterranean (but with no benefits for the Italian ports), and with the increasing role of giant shipping the transshipment segment could continue to grow. NAPA forecasts developed in 2012 for 2030 scenarios highlighted how a proper combination of more port capacity with deeper water and improved rail freight services provides an estimated increase in container traffic volumes in the Northern Adriatic of the 348% in twenty years (2010-2030; NAPA 2012).

Notwithstanding the uncertainties related to the Covid-19 pandemic, container traffic forecasts for Europe show a total growth of the 3.7% (TEU) in the 2023 (fig. 60), with further potential increases up to the 2030, with the the maximum size of the ships crossing and/or devoted to trade with the Mediterranean that will presumably continue to grow. Longer term forecasts (2050) vary from 1 to 3% (CAGR – Compound Annual Growth Rate) depending on the driving economic scenario considered.

Recent forecast scenarios developed for port movements in the upper Adriatic differ by a few dozen thousands. The high scenario has been developed taking into account the development of the countries' global GDP of the Euro area according to the forecasts published by the IMF, the low scenario was developed by calculating the trend of historical traffic, extrapolating the function that best suited the condition to be simulated (fig 61).

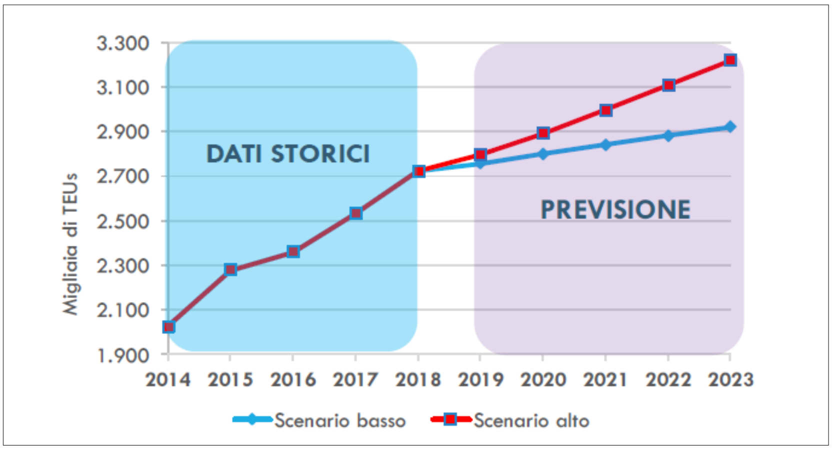


Figure 60. Recent trend and container traffic forecasts in the Northern Adriatic. Source: Rina Consulting elaborations on Drewry and IMF data. Courtesy from Piattaforma Logistica di Trieste).

Similarly, development scenarios for Ro-Ro traffic in the Northern Adriatic show an increase (fig. 61). Differences in forecasts scenarios depend on the economic data and scenario (local vs global) considered.

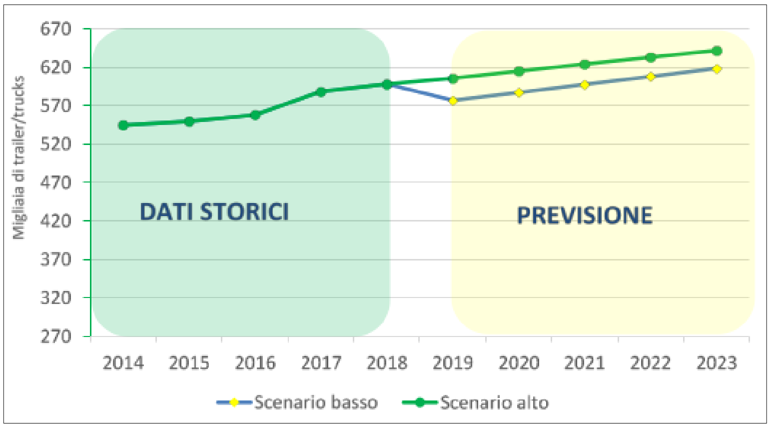


Figure 61. Recent trend and RoRo traffic forecasts in the Central-Northern Adriatic. Source: Source: Rina Consulting elaborations on Assoporti data and Adriatic Port System Authority. Courtesy from Piattaforma Logistica di Trieste).

Cruise tourism has been growing for the past 10 years at very high rates in the Adriatic sea. Based on available cruise passenger traffic data, the cruise tourism sector is expected to increase considerably up to 2030. Cruise analyses forecast for the 2020 further growth of traffic in Italy, up to over 13 million at the end of 2020. According to the current trend of increasing number of passengers in passenger Croatian public maritime transport and the trend of increasing tourist travel on Croatian islands, further increase in the number of passengers and increase in the frequency of transport is expected in the future. However, the pandemic lock-down and restrictions have strongly compromised these forecasts, with important repercussions on all ports, with relevant uncertainties for the years to come. A gradual recovery in demand is expected as early as 2021 and 2022, with a return to a level of orders in line with the average of the years 2015-19 (fig. 62).

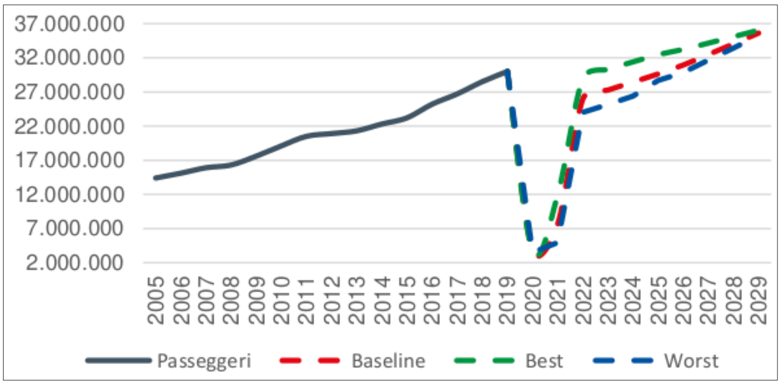


Figure 62. Trend and forecast scenarios of demand in the cruise sector. Source: Rina and Sace, 2020

The development of nautical tourism is also characterized by extremely positive trends and its future growth is expected in the future. Concerning nautical tourism countries in the Mediterranean are generally planning to increase the number of nautical ports and coastal moorings, even though there is currently a lack of suitable areas for port development. However, nautical tourism in the Adriatic sea is definitively expected to increase, therefore more pressures can be expected. It is evident that the tourism sector will grow considerably in the next few years and sustainable management practices will therefore become very important to protect the environment. Inevitably, conflicts with other sectors are expected to increase as well.

Conversely, the trend of the fishing sector in the Adriatic sea has recorded a steady decrease, especially in Italy, with a slight stabilization of the declining in the last couple of years. The maritime fleet has undergone a general and continuous reduction both in terms of number of vessels and engine power.

A successful strategy to prevent the expected increases in maritime activities, and especially in traffic, from causing an uncontrolled increase in emissions of radiated noise, should consider interactions and contributions from measures provided to achieve other objectives such as reduction of carbon emissions and improvements in energy efficiency. Noise-reducing propeller and hull design options are available for many applications and should be considered, especially for new ships. Innovative and tested design principles for cavitation reduction and uniform water flow into propellers, given by hull and propeller properly adapted to each other, could provide an effective reduction of underwater noise and, also, effective for reduced GHG emissions (Gassmann et al. 2017; see chapter 3.5 for further details). In particular, the International Maritime Organization (IMO) approved voluntary guidelines for reducing underwater noise from commercial ships (IMO, 2014). These guidelines focused on design features that could reduce the primary sources of radiated underwater noise, namely the propellers, hull form, and on-board machinery. During the following years, IMO has adopted mandatory measures to reduce emissions of greenhouse gases from international shipping, under IMO's pollution prevention treaty (MARPOL) - the Energy Efficiency Design Index (EEDI) mandatory for new ships, and the Ship Energy Efficiency Management Plan (SEEMP), n support of the UN Sustainable Development Goal 13 (https://sdgs.un.org/goals/goal13).

Mitigating climate change in accordance with the goals set by the Paris Agreement (https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement) could also help reduce further impacts from UWN anthropogenic emissions. In 2018, IMO adopted an initial strategy on the reduction of greenhouse gas (GHG) emissions from ships, setting out a vision which confirms IMO's commitment to reducing emissions from international shipping and to phasing them out as soon as possible. Reduction targets for 2030 and 2050 are:

- To reduce carbon emissions by at least 40% by 2030, pursuing efforts towards 70%, by 2050 compared to 2008's levels (IMO 2030).
- To reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out (IMO 2050).

The main measures focus on lower carbon or zero emission fuels and finding ways of utilizing renewable energy but, also, technical and operational measures such as slow steaming, weather routing, contra-rotating propellers and propulsion efficiency. Development and innovation within smart ship technology is essential in creating the framework that will facilitate the actualization of the IMO emissions targets, i.e. upgrading the fleet by investing in new hybrid and electric vessels, as well as retrofitting current ships with innovative technologies. Both newly designed and retrofitted ships aiming for reduced carbon emissions could also play a key role in the reduction of UWN emissions.

The vast majority of the international strategies and agreement focusing on underwater noise are however mainly based on voluntary acceptance of measures and often feature non binding options to member nations (Lewandowski and Staaterman, 2020). The exception is the European Union's Maritime Strategy Framework Directive (MSFD 2008/56/EC), which explicitly includes noise as a stressor and mandates that European Union member states monitor and mitigate noise pollution in compliance with Descriptor 11 ("Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment") targets for the "Good Environmental Status" (GES).

Within the implementation of MSFD and the Maritime Spatial Planning Directive (MSPD 2014/89/EU), a common strategy from Adriatic ports could support and incentive (through, in example, discounts on port dues) vessel with specific features (i.e. fuel, technologies and environmental management practices), in order to reduce polluting emissions and aiming for quieter ships. These conditions could be, adaptively and with progressive implementation, required to access specific portions of the basins, especially in presence of critical environmental conditions.

The definition of an Adriatic Particularly Sensitive Sea Area (PSSA) for the protection of species of conservation interest with an adequate multi-level governance systems, concerted between Adriatic countries, could foster the progressive application of specific technological measures and limitations. The selected areas and relative management measures should take into account the strong seasonal fluctuations of the Adriatic populations. PSSA protection regime may include areas to be avoided, compulsory ship routing, ship reporting, or recommendations on how shipping should navigate through an area. The process could be supported by the identification of the North Adriatic as Ecologically Significant Area (EBSA - UNEP/CBD/COP/DEC/XII/22, 17 October 2014). The indication for a wider Northern Adriatic managed area in the offshore for the protection of species of conservation interest with an adequate multi-level governance systems concerted between Adriatic countries (e.g. SPAMI) and relative management opportunities could also support the common enforcement of multiple measures for an efficient protection.

Further improvements in knowledge should be considered according to the growing knowledge on the insurgent consequences of climate change in the Adriatic Sea (Grilli et al. 2020, Pisano et al 2020), supporting the analysis of climate change scenarios and its influence on UWN transmission, affecting soundscape features, and interactions with human activities and marine ecosystems.

5.2. Future research activities

The activities carried out in Soundscape offer an unprecedented set of data and knowledge that: i) allows a preliminary risk analysis on the target species considered and its projection towards future scenarios; ii) sets the scene for risk analysis on other species potentially affected by underwater noise; iii) allows to identify possible mitigation measures, considering their expected benefits and their feasibility.

Nevertheless, there a numbers of limitations of present analyses and results that trigger new research activities to reduce uncertainties and refine project outcomes. This is particularly important considering the future scenarios of maritime traffic in the area (par. 5.1.2).

1) Refining soundscape model outputs

Further research is needed to develop the modelling framework, whose application has already proved efficient and reliable in many different geographical domains ranging from sea basin to sub-regional levels, tailoring it more and more to the local conditions and specific objectives (e.g. risk analysis, anthropogenic noise, effects of mitigation measures). This requires for example the improvement of the calibration and of the validation of model outputs using all available high quality data.

2) Refining modeling data inputs.

Model outputs may be very sensitive to the quality and spatial-temporal resolution of data inputs. This concerns for example high resolution bathymetry, seafloor texture and habitats, water column hydrological features (e.g. temperature and salinity), AIS data, fishing boats.

3) Considering all relevant underwater noise sources.

Significant effort has been invested in characterizing the sounds of large ships and understanding the potential drivers of source levels (Chion et al., 2019), which have been principally related predominantly to the size and speed of the vessel in the bioacoustics literature. There is a strong need to address knowledge gaps on the source levels of small vessels and on the links between the different vessel types within this size class, in order to understand how different vessel characteristics contribute to the acoustic signature (Parsons et al. 2021; see also SOUNDSCAPE Report D 3.4.2 Report on the source level assessment for recreational boats for further information).

While there is a general consensus as in recognizing trawling fisheries as one of the largest anthropogenic threats to marine ecosystems, detailed assessments on trawler noise outputs when they are actively trawling still lacks (Daly and White, 2021). Studies that have included trawl activity in underwater noise level assessment found a rise in 1/3 octave spectral values by as much as 10 dB during a bottom trawl at low-mid frequencies (Hovem et al. 2015). When assessing sound energy emitted by a fishing vessel while actively trawling, the noise sources of vessel and gear, and the relative position of each, must be considered distinctly- also considering further machinery related emissions due to the increased engine effort during active trawling. The bottom sourced gear noise contributes more efficiently to sound propagation, adding potential for trawling activity to impinge negatively on the surrounding aquatic environment. Another complexity to consider from bottom trawling compared to general shipping noise, is the use of additional equipment, such as winches on deck vibrating through the hull, or various types of gear used on the trawl itself.

4) Better knowledge and systematic monitoring of target species.

Relevant gaps in knowledge should be addressed during next years to underpin proper management decisions. More complete and integrated data would provide crucial information to help improve conservation and management/mitigation measures, which should be accompanied by effective and supporting legislation (Di Franco et al., 2020). Main gaps regards the specific sensitivities to many categories of marine organisms (i.e. invertebrates, elasmobranchs, fishes' early life stages) and their potential responses and potential for recovery, multi-stressors interactions, the efficacy of technological mitigation measures and monitoring frameworks.

5) Improve the risk analysis derived from model outputs and scenario building and testing.

The proposed “extra noise analysis” (providing monthly spatial distributions, pressure curves and pressure indexes) allows to quickly identify the areas most subjected to anthropogenic noise and, consequently, support the attention areas assessment. However, it should be intended as low-quality alternative of the “dominance” analysis (as described within Jomopans project, Kinneging and Tougaard 2021). Hence, if available, the “dominance” analysis should be preferable because provides a most powerful and tunable tool for investigating spatial and temporal variation of the underwater noise. However the proposed workflow has been deliberately designed to incorporate alternatively both analysis types (extra noise and dominance). Overall, the risk analysis needs to be improved, as well as extended to other potential targets. And from a clear understating of the risks it will be important to be able to test in a quantitative and spatially explicit way the effectiveness of different mitigation measures and scenarios, both in present and future conditions.

6) Analysis of cumulative impacts.

The application of protection criteria is nearly impossible in absence of a quantitative knowledge of the areas affected by the effects of pressures. Anthropogenic underwater noise should be analyzed and considered carefully within a a systematic procedure for identifying and evaluating the relevant effects from multiple pressures, and by identifying critical pressures or pressure combinations and vulnerable receptors. To better support decision makers and planners in the setup of noise mitigation measures, there is the need for procedures that take into account the severity of multiple impacts at species or habitat level according to the origin, frequency, intensity and duration of the anthropogenic phenomena also incorporating linear, non-linear, additive, dominant and antagonist effects of UWN with other pressures on environmental components (Menegon et al. 2018).

Nevertheless, the results (i.e. areas where to concentrate attention and management measures, inside and outside territorial waters) are consistent and may directly address local conservation measures, while the methodology should be applied at larger, transboundary scale, to inform a more complete and integrated planning effort.

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