The effects of COVID-19 induced lockdown measures on maritime settings of a coastal region

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HIGHLIGHTS

- Veneto Region was one of the first EU maritime region affected by lockdown measures.
- National lockdown measures with effect on maritime settings were reviewed.
- A spatial and temporal comparative analysis on vessel traffic during lockdown is performed.
- Lockdown measures decreased vessel activity in the assessment period.
- Fishery and passenger vessels are the most affected by lockdown measures.

GRAPHICAL ABSTRACT
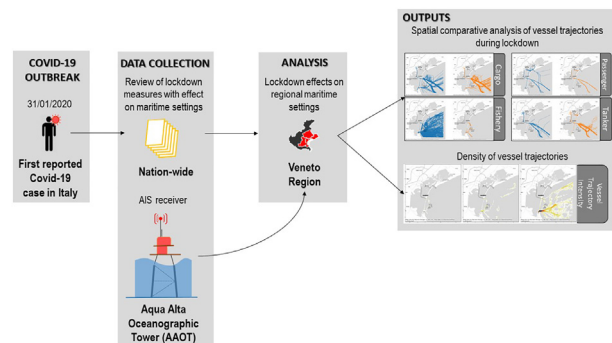
ABSTRACT

The spread of coronavirus (COVID-19) caused an unprecedented implementation of lockdown measures across world's nations. Veneto Region, located in North-Eastern Adriatic Sea was one of the first maritime regions in Italy and Europe subjected to progressive lockdown restrictions. We systematically analyse the effects of national lockdown policies on maritime settings of the region using Automated Identification System (AIS) data from fishing vessels, passenger ships, tanker and cargo vessels collected through the Aqua Alta Oceanographic Tower (AAOT). We derive consequences on vessel activities during the March–April 2020 lockdown, by using a data-driven, comparative spatio-temporal analysis of vessel trajectories. Results show that compared to the same period of 2017, vessel activity were reduced by 69% during the lockdown, fishing activities reduced by 84% and passenger traffic by 78%. We register a restart of fishing activity in the third week of April 2020. We suggest that the presented conceptual and spatial assessment protocol can guide future research on environmental and socio-economic effects of COVID-19 on marine realms and contribute to further interdisciplinary research with other marine scientific fields.

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1. Introduction

The global spread of the COVID-19 had unpredictable effects on the world's society, economy and sanitary systems. With the exponential increase of the contagion, progressive restrictions were enforced across maritime activities in European countries and around the globe. For instance the maritime tourism industry was one of the first sectors to be

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affected by the outbreak with worldwide reporting cases of COVID-19 among crew members and passengers on cruise ships (Moriarty et al., 2020). In Yokohama (Japan) on February 032020, an outbreak of COVID-19 among passengers and crews led to a quarantine of 3700 persons (Kakimoto et al., 2020). About 2000 passengers of the MSC Opera due to dock on March 042020 in the Greek Island of Corfu were forced to stay on board (The Telegraph, 2020). On March 192,020, in Australia the cruise ship Ruby Princess docked in Sydney after returning from New Zealand reporting four people tested positive to COVID-19 (Health.nsw, 2020). In European cruise terminals this has led in the second half of March to a partial or full suspension of cruise tourism (e.g. 19 March – Italy, 20 March – Croatia; 25 March – Spain; EU, 2020). Other countermeasures followed in other maritime sectors and port activities with the aim to ensure safety at terminals, stevedores, logistic activities and operating personnel (EU, 2020). The fishing and aquaculture sectors were jeopardized by COVID-19, leading to several consequences, such as voluntary fishing cessation, suspension/reduction of fish farming with evident effects on the supply chain of fish food products (EU, 2020).

As a response, the global scientific community has promptly deployed information technology for continuous monitoring of COVID-19 spread (Ting et al., 2020) or application of GIS through big data (Zhou et al., 2020). Also initial assessments of lockdown effects on the environment (Collivignarelli et al., 2020; Yunus et al., 2020), society (Usher et al., 2020) and economy (Sarkis et al., 2020) are increasing. The European Space Agency and NASA have deployed remote sensing technology using Sentinel5P data to monitor variation of nitrogen dioxide emission in the Po Valley (including Lombardy) and Wuhan, sites at the epicentre of the pandemic spread (ESA.net, 2020). Google's community report based on Google Maps services provided useful information for public health officials (Google Mobility, 2020). As a consequence of travel restrictions and national lockdowns, massive restrictions on air traffic were investigated by Eurocontrol (2020). Although this steady growth on literature, most of the efforts so far neglect methods and

analysis procedures to address the effects of COVID-19 lockdown measures on maritime settings.

The aim of this research is to address the effects of COVID-19 induced lockdown measures on maritime activities in the Veneto Region (Italian Adriatic Sea), to our knowledge Europe's first maritime region subjected to lockdown measures. We perform a systematic review of the effects of progressive lockdown measures on the national and regional level on maritime settings of Veneto's coastal region and then present a procedure for collection and processing of Automated Identification System (AIS) data for fishing vessels, cargo, tanker and passenger to understand the spatio-temporal movement patterns. The patterns are compared within a Business as Usual (BAU) setting (March–April 2017) and during the most restrictive COVID-19 induced lockdown setting (March–April 2020). We discuss how AIS datasets can be used for the analysis of lockdown policies on maritime circulation of goods, services and people. We synthesize results to identify research frontiers that can further interdisciplinary research with other marine scientific fields.

2. Methods

2.1. Study area

The Venice Lagoon and its surrounding coastal area belong to the most industrialized sea areas of the Mediterranean (Menegon et al., 2018a). The study area includes the Venice Lagoon (550 km^2; 37%) and the adjacent coastal areas of the Adriatic Sea (930 km^2; 63%). There are three inlets connecting the Venice Lagoon with the Adriatic Sea (Fig. 3): Lido Inlet, Malamocco Inlet and the Chioggia Inlet (Fig. 1). Its geographic location and tradition in maritime-related economies makes the region to a strategic asset on national level (PoV, 2018). Blue economy activities like seafood, shipyards, transportation and tourism in Veneto Region contributes to 2.5% to the regional GDP and in the province of Venice to 10.2% of the annual revenue
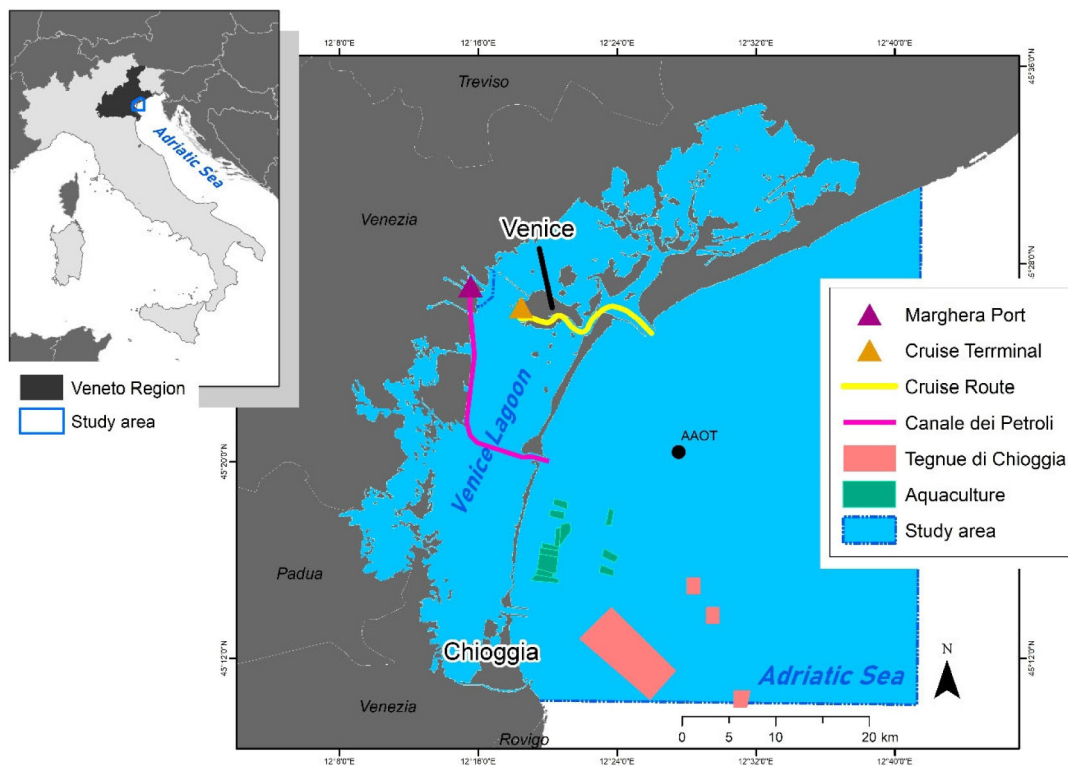
Fig. 1. Venice lagoon and adjacent coastal areas of Venice region in including main maritime infrastructure and ecological features: the "*Marittima*" Cruise Terminal and cruise route passing through the Lido Inlet, the "*Canale dei Petroli*" industrial channel passing through the Malamocco Inlet, mussel aquaculture sites in front of Pellestrina Island and the Special Protection Zones named "Tegnùe di Chioggia". Note: AAOT – Aqua Alta Oceanographic Platform.

(Unioncamere, 2017). About 1.6 million cruise passengers each year pass through the cruise terminal (about 196 thousand through ferry passengers and local transport); cargo transport from the ports Venice and Chioggia amounts to over 10.2 million tons per year and the tanker traffic from Venice terminal amounts to over 9.0 million tons of liquid bulk per year (PoV (Port of Venice), 2018). The main first sale fish food market is Chioggia, with 10.9 thousand tons of harvest in 2018 (Veneto Agricoltura, 2019).

2.2. Lockdown measures with effect on maritime settings of the study area

We performed a systematic review of the lockdown measures using regional and national ministerial decrees and resolutions (Fig. 2), starting with the first reported COVID-19 case in Italy (31/01/2020, Rome), its progressive contingency measures and conclude the review at the 26/04/2020, where phase 2 ("*Fase 2*") was declared. The assessment period of the analysis covers 39 days (19/03/20–26/04/20). We consider the period as crucial, due to the drastic lockdown measures put into place and especially in relation to their specificity to maritime activities in the study area. According to the timeline presented in Fig. 2, there have been a progressive regional restrictions after Decree of the President of the Council of Ministers (DPCM) n. 11 of the 08/03/2020, that declared 14 provinces (including the provinces of Venice and Padova) as "*orange zones*". This was followed up by DPCM n. 14 oF the 09/03/2020 declaring the provinces as "*red zones*" and "*laying down urgent measures to contain and manage the epidemiological emergency brought on by COVID-19*".

The declaration of nation-wide red zone was imposed through DPCM of the 11/03/2020. The lockdown measures with effects on regional maritime settings include the suspension of passenger traffic from the islands Sardinia (14/03) and Sicily (Ministerial Decree 118/2020 of 16 March 2020). This was followed up by a decree providing safety measures for passengers and personnel and concluding with Ministerial Decree (MD) 125/2020 of the 19 March 2020, where cruise services for Italian passenger ships are suspended and the arrival of cruise ships flying a foreign flag in Italian ports were blocked. The M.D. 120/2020 n.18 entitled "*Cura Italia*" (17/03/2020) declared the shutdown of non-essential production activity including commercial fishery and aquaculture activity, resulting into a voluntary cessation of fishing activities and reduction of aquaculture activities, while cargo activities of goods was guaranteed. In the Supplementary material (Annex 1), a detailed list of lockdown measures at the basis of Fig. 2 is provided.

2.3. Vessel traffic data & temporal settings

AIS (Automtaed Identification System) is an automatic tracking system for identifying and locating ships by exchanging data with other nearby ships and AIS base stations. There is increasing research on the AIS data mining for visualization of spatial distribution regularities in ships (Willems et al., 2009) or abnormal ship identification for maritime control (Zhao and Shi, 2018). We use the AIS data in the study area to monitor the vessel trajectories for four vessel types (cargo, fishing, passenger and tanker based on EMODnet, 2019) in coastal areas of Veneto Region by comparing two different temporal settings over a time period of 39 days:

(1) *Business as usual setting* (*BAU*). A normal setting, assuming a pre-pandemic execution of maritime activities and operations for the time period 19/03/2017 to 26/04/2017.

(2) *COVID-19 induced lockdown setting*. A new-normal setting triggered by COVID-19 induced lockdown measures with effect on maritime activities and operations for the period 19/03/2020 to 26/04/2020.

The AIS data was obtained from AISHub (www.aishub.net, 2020). AISHub is a free AIS data sharing services, providing access to real time

ship positions for vessel tracking systems. At the actual state AIShub provides a network of 731 receivers worldwide. The available AIS received in the study area is installed on the Aqua Alta Oceanographic Tower (AAOT; CNR-ISMAR, 2020), located 15 km off the Venice Lagoon (Bastianini et al., 2012). The data recording was downsampled to 2 min, which was considered as sufficient temporal resolution for the purpose of the analysis. The total amount of records for both assessment periods is over 460 thousands units. Verification of data gaps was performed by cross-checking AIS data from other AIShub receivers in proximity of the AAOT, located in Koper (Slovenia) and Pula (Croatia).

2.4. Vessel trajectory analysis

The analysis of trajectories of people movement and transport of goods and services is an emerging field of scientific research. In the COVID-19 crisis, this information has increased value to guide decision-makers and authorities to understand infection patterns (Gatto et al., 2020) and the effects on mobility changes resulting from lockdown policies (Pepe et al., 2020). In maritime settings vessel trajectory analysis is major instrument for shipping traffic planning and anomalies analysis (Zhang et al., 2018). We define in this context trajectory, as the discrete time series of measured locations (Demšar et al., 2015). We combined the Python libraries scikit-Mobility (Pappalardo et al., 2019) and MovingPandas (Graser, 2019) to pre-process position data received from the AAOT and to reconstruct and represent the vessel trajectory in the lockdown assessment period. To characterize movement measures or parameters for individual moving objects, we use five components devised by Dodge et al., 2016:

- *Spatial primitive* (*position*, x/y): the geographic position of the vessel (latitude, longitude) transmitted by AIS systems.
- *Temporal primitive* (*timestamp*, t): the temporal position (year-month-day hour:min:sec; in UTC) transmitted by AIS systems.
- *Spatial primary derivative* (*distance*, *dist*): the travel distance (in nautical miles) operated by the vessel in the study area and within the defined time period.
- *Temporal primary derivative* (*duration*, d): the permanence (in hours) of the vessel in the study area.
- *Spatio-temporal primary derivative* (*speed*, *knots*): rate of change of the object's position (knots).

Further, we evolve vessel trajectory analysis based on AIS data with a vessel trajectory intensity (*VTI*) analysis. The *VTI* uses AIS data from fishing, but can be applied for any vessel and has the aim to quantify the variation of traffic intensity across different lockdown stages. Based on the GeoPandas library the spatial procedure creates hexagon tiles, spatial joins the tiles with the vessel trajectories and extracts the trajectory vessel length for each cell unit.

The $VTI_{i,j}$ for vessel type i in lockdown stage j is defined as the travel distance in nautical miles (d) operated by vessel type i during lockdown stage j; A is the assessment area in square nautical miles per day (t) in lockdown stage j:

$$VTI_{i,j} = \frac{d_{i,j}}{A \times t_j}$$

The lockdown stages j, are calibrated according to three key lockdown intervals in the assessment period as follows: *Stage 1* (19/03–31/03) - fishing cessation and aquaculture activity reduction; *Stage 2* (01/04–14/04) - extension of lockdown restrictions of stage 1 and *Stage 3* (14/04–26/04) - second extension of lockdown measure from stage 1.
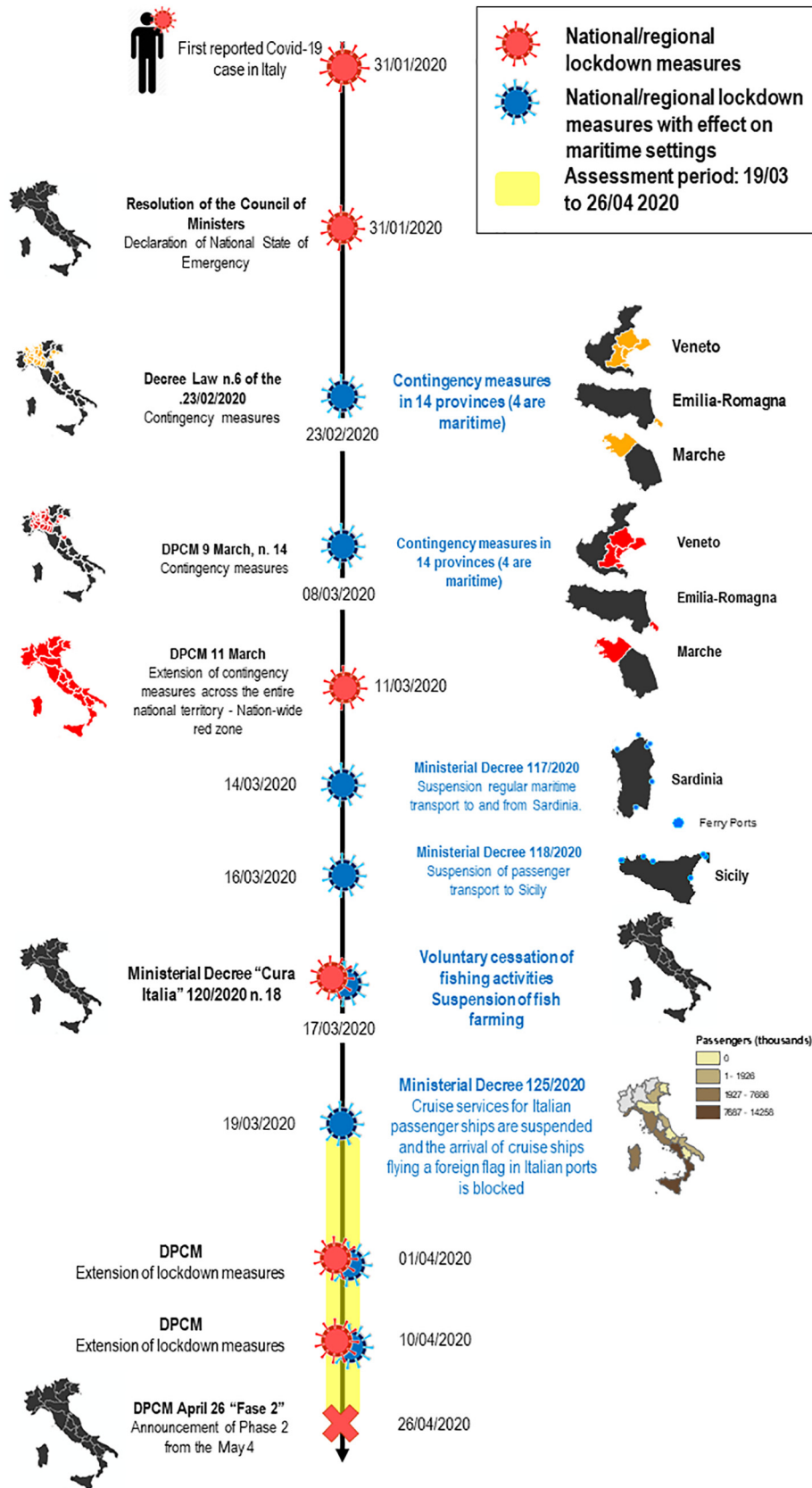
Fig. 2. Timeline of progressive national and regional lockdown measures with effects on maritime settings in the study area. The assessment period of vessel trajectory analysis highlighted in yellow: March 19 to April 26, 2020. In the Supplementary material (Annex 1) we provide detailed table of lockdown measures used to construct Fig. 2.

2.5. Comparative analysis

Based on the dataset from BAU and the COVID-19 setting, we perform a comparative analysis to understand the spatial and temporal variation of the maritime activities in the study area (Figs. 3 and 4). We dedicate a section to the *VTI* applied to fishing vessels, by calibrating AIS data stream to the lockdown stages reviewed in the assessment period (Fig. 5).
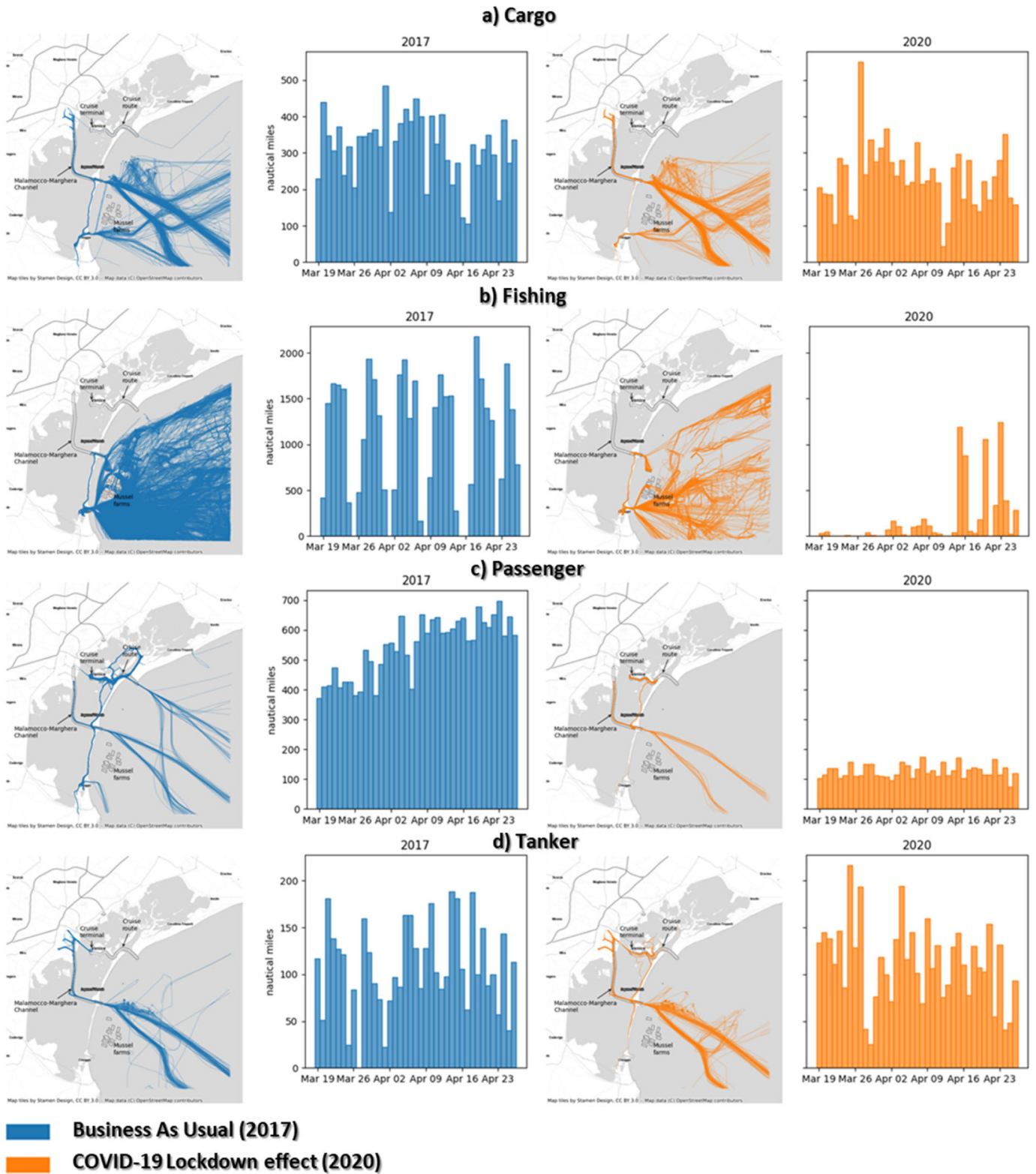

Fig. 3. Spatial and temporal comparative analysis of vessel trajectories for four vessel types (cargo, fishing, passenger ships and tanker) within the assessment period 19/03–26/04 in a BAU setting 2017 and COVID-19 induced lockdown setting 2020. Plots illustrate the vessel trajectories in nautical miles operated within BAU setting (2017) and COVID-19 induced lockdown setting (2020).
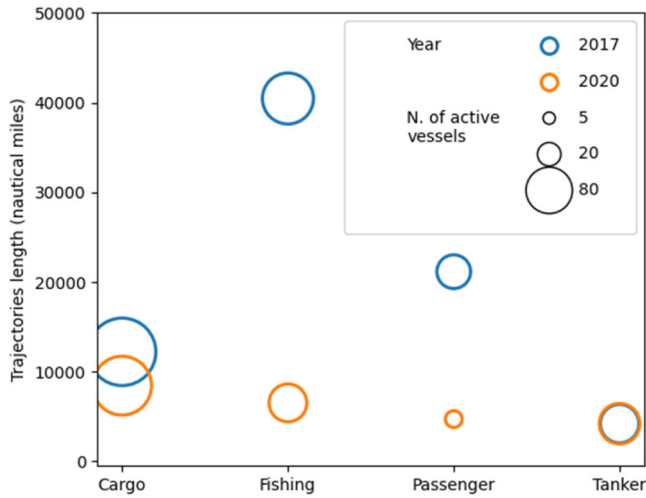
Fig. 4. Comparative analysis of trajectory lengths (in nautical miles) by vessel type and respective number of active vessels in BAU (2017) and during lockdown setting (2020). In Supplementary material (Annex 3) additional variables were assessed.

3. Results

Fig. 3 presents the spatio-temporal comparison of vessel trajectories and the daily breakdown of trajectory length (in nautical miles) operated by the four different vessel types under consideration of BAU (March–April 2017) and the COVID-19 induced lockdown setting (March–April 2020). The analysis shows that the lockdown setting had considerable variations from BAU in line with some of the progressive lockdown measure implemented in the assessment period. Commercial fishing vessel trajectories (Fig. 3b) that derive from the main fishing port (Chioggia) were almost absent till the 14/04/2020, with exception of vessel trajectories in proximity of the mussel farming sites in front of Pellestrina Island. This can be primarily related to the Ministerial Decree of the 17/03 declaring a voluntary cessation of commercial fishing activities and reduction of aquaculture activities. Passenger vessel trajectories (Fig. 3c), which were one of the first maritime activities affected by COVID-19 restriction measures worldwide (Moriarty et al., 2020), show to be absent of trajectories coming in from Lido Inlet through the Giudecca Chanel to "Marittima" cruise terminal. In the assessment period, two cruise ships scheduled to arrive to Venice, the Viking Star (Viking Ocean Cruises; 25/03 arrival) and Costa Deliziosa (Costa Crociere; 27/03 arrival) have been denied docking Venice Passenger Terminal (Terminal Passeggeri Venezia, 2020) due to sanitary risks and in line with the Ministerial Decree 125/2020, suspending cruise services. The maritime transport of goods and services represented by cargo and tanker vessel trajectories (Fig. 3a and d) do not show particular trajectory variations.

The cumulative trajectory duration (Fig. 4) of vessels for the two assessment periods indicate a total of 575 days for 2017 versus 266 days during 2020 lockdown setting, with a variation of −53%. The overall variation of vessel trajectory (in nm) for the assessment period corresponds to −69%.

Fishing vessels register the highest negative variation of trajectories length of −84% ($n_{BAU} = 97$ vessels in 2017 vs $n_{C19} = 53$ vessels in 2020). Passenger vessels had a decrease of trajectory length of −78%
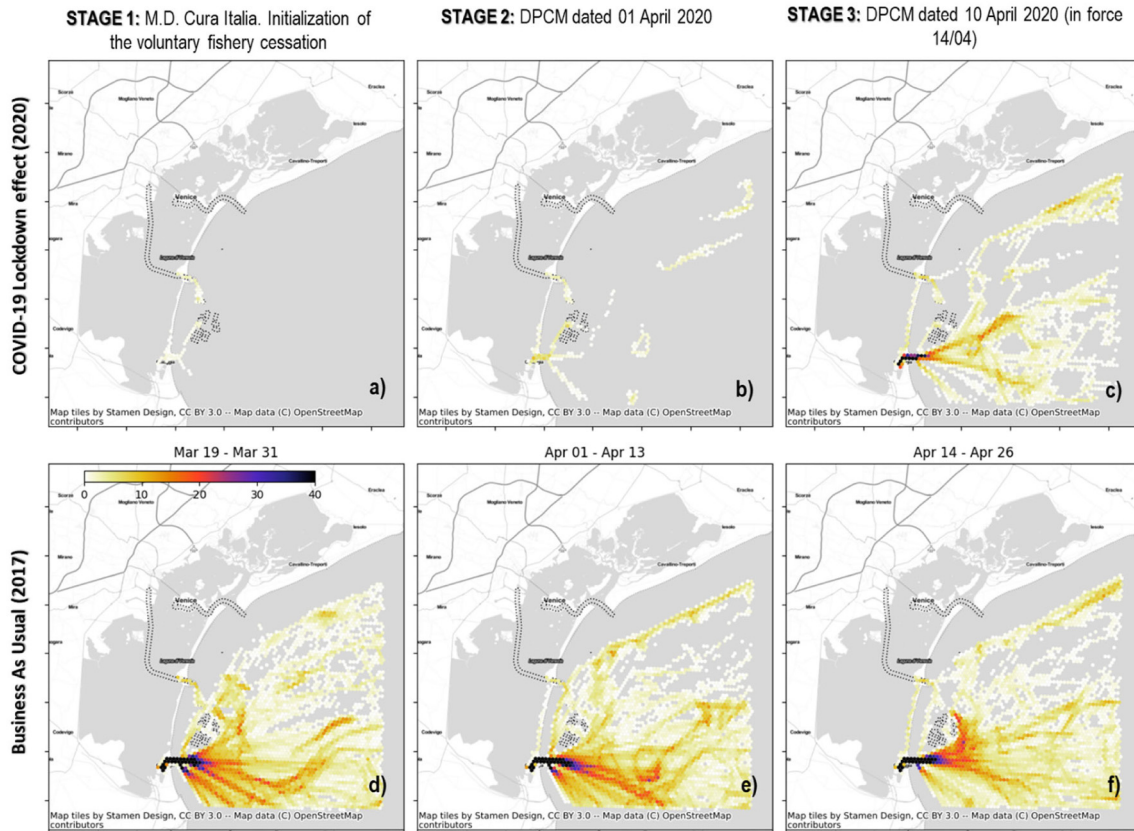
Fig. 5. Variation of fishing vessel density through three lockdown stages of the 39 days assessment period: a to c fishing activity during COVID-19 induced lockdown and d to f fishing activity during BAU (Comparative assessment period 19/03 to 26/04). Stage 1 (19/03/20–31/03/20) - fishing cessation and aquaculture reduction; Stage 2 (01/04/20–14/04/20) - extension of lockdown restrictions of stage 1 and Stage 3 (14/04/20–26/04/20) - second extension of lockdown measure stage 1. In the Supplementary material (Annex 4), an overview of the mean VTI scores for the comparative assessment periods of 2017 and 2020 is provided. Note: DPCM – Decree of the President of the Council of Ministries.

(n_{BAU} = 42 vessels in 2017 vs n_{C19} = 10 vessels in 2020). Cargo vessels had a decrease of trajectory lengths of −31% (n_{BAU} = 170 vessels in 2017 vs n_{C19} = 129 vessels in 2020). Tankers are the only vessel type that register a stable vessel trajectory length (n_{BAU} = 55 vessels in 2017 vs n_{C19} = 61 vessels in 2020).

Fig. 5 illustrates the effects on lockdown restrictions on fishing vessel traffic in the 39 days (19/03 to 26/04) of the assessment period. The VTI score ranges from 0 to 40, with highest scores in coastal areas of port of Chioggia and the Malamocco Inlet. In the lockdown stage 1 and 2 (Fig. 5a and b) the effects of the voluntary fishing cessation are evident, with a respective mean VTI score in the study site of 0.04 and 0.23. In stage 3 (Fig. 5c) a restart of fishing activities is evident with a mean VTI = 1.88.

4. Discussion

To our knowledge, this is the first research analysing the effects of COVID-19 mitigation measures on maritime settings in one of the first European maritime regions affected by the pandemic spread. The analysis of maritime mobility is an emerging field of research (Huang et al., 2020; Zhang et al., 2018) and will have substantial importance in future studies to understand ecological and socio-economic consequences of lockdown measures for coastal communities, blue economies and the marine ecosystem. The data-driven, spatio-temporal assessment protocol proposed in this research (data collection, resampling and analysis) is fully based on open source software frameworks, open-source AIS data sharing communities and therefore has the substantial advantage to increase replicability and knowledge exchange in sea areas being part of the global AISHub monitoring system.

The assessment is not free of limitations. First of all the spatio-temporal availability of the data will require further monitoring for a more comprehensive and targeted evaluation of shipping mobility effects throughout the entire lockdown period and the restart to a new-BAU. We expect that a complete AIS monitoring dataset for the year 2020 in the study area can lead to a more extended understanding of the unprecedented conditions maritime sectors faced during lockdown in a new-BAU. Also the analysis on vessel trajectories using a stop-go approach could help to detail vessel behaviour during specific lockdown phases when approaching the entrance to Venice Lagoon (e.g. approaching velocity, temporal decelerations/accelerations, stop points and duration of temporary anchoring). The study of the Veneto coastal region should be extended to other sea areas or ideally cover a nation-wide assessment to compare effects for sea areas with different marine environmental and socio-economic settings.

In Italian regions of the Adriatic Sea compulsory fishing cessations (in ital. "*fermo pesca*") are put in place annually for 30 consecutive days, usually planned in the period July – August 2019 (Venetoeconomia, 2019). The analysis on cargo and tanker vessels shows little variation in the number of vessels. This reflects also the lockdown measures as declared through the Ministerial Decree (M.D.) *Cura Italia* (17/03/2020), where vessels ensuring to the transport of essential goods was guaranteed (Supplementary material, Annex 1). Although not directly affected by restrictions, safety measures in the freight load/unload from cargo vessels may have caused delays, accumulation of cargo or interruptions in transit compared to a BAU setting. This may result to additional financial implications to all parties involved in the shipping transaction (Lockton, 2020) and in the supply chain. Although the analysis demonstrates very little variation on tanker mobility in the comparative periods, there has been a significant increase of 77% (Supplementary material, Annex 3) of the trajectory duration (hours of vessel movement) for tankers during the lockdown. In order to address if there is a potential delay or bottleneck in the logistic chain, the trajectory model can be flexibly extended by including the anchoring time and the destination port of the vessels.

Although we are not aware of any reported evidence on financial effects on freight delays, a compression of oil products exchange by 1.4%

and of general cargo of 3.2% of goods is reported in the first trimester 2020 outlook provided by authorities of the port of Venice (Nordest Economia, 2020).

For public health reasons, it has been reputed unsafe to allow cruise ships to dock into Venice Cruise Terminal. Concerns were raised well before the formal national lockdown measure was declared on the 19/03/2020 by authorities of Veneto Region (Messaggero Marittimo, 2020). Based on the AIS data, this had an immediate effect on the docking of at least two cruise ship at Venice Cruise Terminal (VTP, 2020), the Viking star (arrival March 25; about 1600 passengers) and Costa Deliziosa (arrival March 28; about 2000 passengers). We consider that cruise service suspension that were extended through the lockdown M.D. 17/03/2020 imposed to May 01 had an effect on additional 33 additional cruise routes cancelled docking at the Terminal (VTP, 2020).

It is premature to address the broader socio-economic effects on regional and national maritime economy originated by the lockdown measures; however, a first set of consideration on the presented results can be addressed. Veneto Region as one of the first impacted maritime regions in Europe is on national level one of the most depending regions from marine environment. First estimations of economic losses are emerge from statistics for March 2020, having the local fishing sector subjected to 48.8% of tonnage decrease of local movement of fish food, corresponding to a −60% (~€1,5 millions) of loss of economic income compared to the same period in 2019 (Veneto Agricultura, 2020). The immediate effects on fish food supply chain was evident from the lockdown measure, as the local fish food production depends on 80% from the HORECA sector (Hotels, Restaurants, Catering; Veneto Agricultura, 2020), which will see a lifting of the lockdown measures only during Phase 2.

Keeping in mind the existing limitation of the analysis, results still suggest that the lockdown measures have caused a deceleration of anthropogenic stressors from reduced maritime activities on the marine ecosystem. In this context a further extension of the spatio-temporal monitoring intervals is needed to understand what is the short and long-term environmental response to the abrupt cessation of human activities. In particular, what concerns to the effects on the recovery of vulnerable seafloor habitats in the coastal areas usually subjected to multiple stressors such as: continued operation of fishing (Bastardie et al., 2017), maritime transport as source of underwater noise (Menegon et al., 2018b), release of synthetic/non-synthetic compounds (Depellegrin et al., 2017), marine litter (Strafella et al., 2019) or waste water discharge from the Venice Lagoon to the open Adriatic Sea (Ostoich et al., 2018). Although its not the scope of the research to analyse potential positive environmental response, the overlay analysis to the Tegnùe protected areas (Fig. 1) and the fishing density analysis (Fig. 5) in the comparative period would suggest an alleviation of vessel trajectories in the protected areas. Also in the Venice Lagoon the cruise vessels that have been passing through the Venice's historical centre causing pollution and erosion from ship wakes (Scarpa et al., 2019) have suddenly terminated their activity through the enforcement of lockdown measures (Fig. 3).

5. Conclusions

While there are unexplored trade-offs among short- and long-term effects of the human-absent environment on marine ecosystems in the study site, the unique availability of the AAOT in the coastal area provides a privileged research infrastructure for future research on the ecological and socio-economic effects induced by the lockdown. In particular, the AAOT, which is part of the Italian Long Term Ecological Research network (LTER; CNR-ISMAR, 2020) provides a suitable infrastructure to monitor the evolution of biophysical status of the study site during lockdown, the ease of lockdown and the restart of activities to a new BAU. Our proposed spatio-temporal approach evidenced the very uneven effects on the most important maritime sectors in the study area. This provides an essential starting point to

deepen the knowledge on human-marine environment interactions caused by the lockdown and ideally contribute to the design of novel strategies that can enhance ecosystem-based management of marine resources. Our systematic review of lockdown measures with relevance for maritime settings can provide a valuable information source to understand lessons learned among maritime sectors related to the sustainability of maritime activities, the health and well-being of maritime personnel and the needs of improvement of maritime-dependent supply chains.

CRediT authorship contribution statement

Daniel Depellegrin: Conceptualization, Methodology, Supervision, Writing - original draft, Writing - review & editing. **Mauro Bastianini:** Data curation, Formal analysis, Validation, Writing - review & editing. **Amedeo Fadini:** Data curation, Writing - review & editing. **Stefano Menegon:** Conceptualization, Methodology, Data curation, Formal analysis, Validation, Visualization, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing interests to this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140123.

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