Tracking the global reduction of marine traffic during the COVID-19 pandemic

David March[1*], Kristian Metcalfe[1], Joaquin Tintoré[2,3], Brendan J Godley[1]

[1]Centre for Ecology and Conservation, University of Exeter, Penryn Campus, Penryn TR10 9FE, UK

[2]ICTS SOCIB – Balearic Islands Coastal Observing and Forecasting System, Parc Bit, Palma de Mallorca, Spain

[3]IMEDEA (CSIC-UIB), Mediterranean Institute of Advanced Studies, Esporles, Spain

*Corresponding author: David March, email: D.March@exeter.ac.uk. Present address: Centre for Ecology and Conservation, University of Exeter, Cornwall Campus, Penryn TR10 9EZ, United Kingdom.

Abstract

The COVID-19 pandemic has resulted in unparalleled global impacts on human mobility. In the ocean, ship-based activities are thought to have decreased due to severe restrictions and changes in goods consumption, but little is known of the patterns of change, which sectors are most affected, in which regions, and for how long. Here, we map global change of marine traffic during the COVID-19 pandemic and assess its temporal variability at a fine-scale in one of the most affected regions, the Mediterranean Sea. Nearly 44.3% of the global ocean and 77.5% of national jurisdictions showed a decrease in traffic density during April 2020, when strictest confinement measures took place, showing a clear disruption in comparison with previous trends and future projections. Decreases mainly occurred in coastal areas and were more marked and longer lasting in sectors other than cargo and tanker shipping. Our results provide guidance for large-scale monitoring of the progress and potential effects of COVID-19, or other global shocks, on the blue economy and ocean health.

Keywords: COVID-19, Human mobility, Automatic Identification System (AIS), Vessel traffic, Big data, Blue economy, Ocean health

Introduction

The coronavirus disease (COVID-19) pandemic has emerged as both a global health and socio-economic crisis, with many countries implementing unparalleled mobility restrictions to control the spread of the virus. This unprecedented event, which has been referred to as the “anthropause”, a period of reduced human mobility[1], has led to sudden and often dramatic reductions in transport, energy consumption and consumer demand resulting in significant changes in the scale and extent of human stressors and their associated impacts on the natural environment[2–6]. To better understand the potential effects on the environment and biodiversity, there is an urgent need to quantify the magnitude and patterns of the changes in human activities.

In particular, the behaviour of human activities in the ocean have been radically altered by the COVID-19 pandemic, with port restrictions and changes in consumption patterns impacting multiple maritime sectors, most notably fisheries, passenger ferries and cruise ships[7–10]; sectors which rely heavily on the movement of people and goods. As with previous economic recessions[11,12], changes in vessel movement associated with COVID-19 are also likely to result in significant short- and long-term effects on multiple anthropogenic pressures, such air pollution[12–15], the spread of invasive alien species[16,17], or collisions with marine animals[18,19]. Localised studies have already reported reductions in underwater noise[20], water turbidity[21] and fishing effort[8] as a result of the reduction of the vessel activity during the COVID-19 outbreak. However, as mobility restrictions vary among countries and maritime sectors, the effects of COVID-19 on ship-based activities and their influence on the marine environment are still unclear at a global scale.

Fortunately, recent technological advances associated with automatic identification system (AIS), now means that ship-based mobility patterns can be monitored on a global scale[22–24], thereby providing a unique opportunity to monitor the location of large ocean-going ships, passenger liners, and fishing vessels anywhere in the world at high temporal resolution[25–27]. Consequently, AIS can provide unparalleled insights into shipping-derived impacts and conservation planning at multiple spatial and temporal scales[4,27–31]. In view of COVID-19, AIS has recently been employed to assess the potential spread of the virus[10,32,33] and to describe the reductions in marine traffic at local scale[8].

Here, we use AIS data to conduct a comprehensive assessment of the short-term changes on ship-based mobility patterns in response to COVID-19 across multiple sectors and at different spatio-temporal scales. First, we illustrate our approach by conducting a global assessment using monthly traffic density maps to evaluate changes in vessel activity across multiple regions and maritime sectors. Then, we assess the high temporal variability (i.e. daily basis) in the Western Mediterranean Sea, a key region for the global liner shipping network[34] and cruise tourism[35], which includes three countries most impacted by the COVID-19 outbreak in Europe (i.e. Italy, Spain and France). Our approach quantifies the magnitude and patterns of changes in ship-based activities, providing guidance for large-scale monitoring of the potential socio-economic and environmental effects of COVID-19 on the world's ocean.

Results

Global changes in the spatial distribution of traffic density

Lockdown measures across coastal countries (n = 133) reached their maximum levels (i.e. strictest confinement measures) during the month of April (Stringency index = 79.5 ± 15.5, mean ± SD; Fig 1a and 1b), though China, the reported source of the outbreak, had started to ease lockdown restrictions (Fig 1c). Consequently, we analysed global changes in marine traffic using monthly AIS data from April 2020 and quantified the absolute and relative changes in comparison with April 2019, thus accounting for seasonal variability of ship-based activities. Global marine traffic in April 2020 was present in nearly 76.9% of the ocean, with high traffic areas (i.e. 80th percentile - equivalent to 42.9×10^{-3} vessels km^{-2}) concentrated in 15.4% of the ocean (Fig 2a). In comparison with 2019, there were more areas of the ocean that experienced decreases (44.3%) than those that showed increases (36.8%), with a general reduction of 1.4% in their occupancy (1.6% in high traffic areas) (Table S1). Changes were unevenly distributed across the globe (Fig 2b). Major changes in traffic density were mainly found in coastal areas from the northern hemisphere (Fig S1). In Europe, there was an almost universal decrease in vessel traffic (Fig 2c), whilst patterns in other regions (e.g. increases in China and decreases in South Korea, Fig 2d), and around main shipping lanes (e.g. Arabian Sea; Fig 2e) showing a mixture of increased and decreased vessel activity. Conversely, other regions showed overall increases in traffic density (e.g. Indonesia; Fig 2f). At the local level, our analysis captured profound decreases around marine protected areas (e.g. Galapagos islands in Ecuador, Fig 2g) or near the vicinity of port areas (e.g. Port of Vancouver in Canada; Fig 2h).

Global marine traffic in April 2020 was present within 80.3% of the surface covered by Exclusive Economic Zones (EEZs, national waters up to 200 nautical miles), showing a global average decrease of 3.3% (equivalent to 2.9×10^{-3} vessels km^{-2}) in comparison with April 2019. There was an overall decrease in traffic density in 75.7% of national jurisdictions ($n = 255$; Fig 3a; Supplementary Data 1). The largest average decrease in absolute difference for all vessels was in Singapore (734.0×10^{-3} vessels km^{-2}, 9.4% relative decrease), followed by small EEZs from EU countries. On the contrary, the largest average increases were found in the northern Indian Ocean and East Asia, with Bahrain (213.6×10^{-3} vessels km^{-2}) and China (145.2×10^{-3} vessels km^{-2}), experiencing relative average increases of 35.0% and 8.7%, respectively. Outside EEZs, global marine traffic was present in 73.9% of the surface covered by Areas Beyond National

Jurisdictions (ABNJ; Fig 3b; Supplementary Data 2). Whilst we found reductions in 11 (52%) of the 21 ABNJ subregions, there was a global average increase in marine traffic of 2.4% (0.4×10^{-3} vessels km^{-2}) on the high seas.

In the nearshore, 159 (73.3%) of the 217 marine ecoregions experienced overall decreases in marine traffic (Fig 3c; Supplementary Data 3). The largest decrease in absolute difference for all vessels was observed in the Puget Trough/Georgia Basin (139.2×10^{-3} vessels km^{-2}, 21.2% relative decrease), followed by marine ecoregions from European Seas. Again, the largest increases were observed in marine ecoregions in East Asia mirroring trends observed in vessel activity within EEZs across this region. On the open ocean, 13 (68%) out of the 19 Food and Agriculture Organization (FAO) major fishing areas presented reductions (Fig 3d; Supplementary Data 4), with the Mediterranean and Black sea showing the highest absolute decrease (22.7×10^{-3} vessels km^{-2}, 7.1% relative decrease).

Spatial variation among sectors

An important characteristic of the AIS data is their stratification according to ship categories, thus allowing attribution of the spatial footprint of marine traffic to different maritime sectors. Merchant vessels (i.e. cargo and tankers) were the most widespread categories, followed by fishing and “other vessels” (e.g. service vessels, recreational), while passenger vessels presented a more limited distribution (Table S1, Fig S2). Accordingly, the spatial variation of changes in traffic density varied by vessel category (Fig 4, Fig S3). All categories apart from tankers, presented an overall global decline, with these declines again more marked in the northern hemisphere (Fig S1). Changes in merchant vessels were differentially distributed across the major shipping lanes (Fig 4a and 4b). Passenger vessels were most negatively affected in both traffic density and occupancy, especially in touristic hotspots like the Caribbean and the Mediterranean Seas (Fig

4c). Conversely, changes in fishing and “other” vessels were more diffusely spread across the world's ocean (Fig 4d and 4e).

Average changes within national jurisdictions also reflected an uneven response among different vessel categories (Fig S4, S5 and S6). Relative changes for merchant vessels were less marked than those for other categories (Fig S4 and S5). However, they had large contributions in terms of absolute changes to the variations across EEZs (Fig S6). Both passenger and “other” vessels presented decreases in most EEZs. On the other hand, fishing vessels presented increases in some national jurisdictions, mainly in lower income countries (Fig S4d and S5e). In the Areas Beyond National Jurisdiction, the magnitude of changes was lower than within EEZs, with fishing and “others” showing a slight increase of traffic density across multiple subregions (Fig S7). Marine ecoregions presented a high variability of increases and decreases across multiple sectors (Fig S8). Among the multiple FAO regions, which extended from the nearshore to the open ocean, the Mediterranean Sea constituted one of the areas with the greatest decreases across most sectors (Fig S9).

Temporal changes in the Mediterranean Sea

The Western Mediterranean Sea was found as one of the areas with the highest reduction in shipping activities at a global scale (Fig 3c, Supplementary Data 3). To analyse the temporal variability of marine traffic during 2020, we counted the number of vessels underway on a daily basis. Moreover, we considered an additional ship category, recreational vessels, which constitutes an important sector in one of the world's tourist hotspots. The multi-annual distribution of the number of vessels in the Western Mediterranean was consistent through time for merchant and fishing vessels (Fig S10). Conversely, temporal variation showed a marked seasonality in passenger, recreational and “other” vessels, with a peak during the boreal summer, and a growing trend in the number of vessels across years (Fig S10). In 2020, daily counts of the number of vessels showed a significant reduction after the World Health Organization (WHO) declared a pandemic on 11th March, a pattern that was consistent across all sectors (Fig 5). When compared to pre-disturbance baselines (i.e. equivalent periods of 2019), the number of vessels sharply decreased in the first days of mobility restriction. Maximal reductions ranged from 24.3% (tankers) to 276.9% (recreational vessels), with an overall drop across all categories of 97.5% during mid-April (Table S2). Similarly, we found an uneven recovery rate among sectors. Cargo, tanker and fishing vessels showed a relatively swift recovery in vessel activity in the proceeding months, in contrast to passenger and recreational vessels which remained at low levels for a longer period (Fig S11). By 30th June, after easing of lockdown restrictions in Spain, France and Italy (Fig 1c), merchant and fishing vessels were close to pre-lockdown values, and recreational vessels exhibited a sharp recovery, but passenger vessels still remained at levels less than 50% of expected (Table S2).

Discussion

Our oceans are responsible for the carriage of around 80% of world trade and are the lifeblood of many national economies which rely heavily on fishing and tourism[27,34,36,37]. Here, using electronic vessel monitoring systems we quantify and map changes in ship-based activities to provide a comprehensive overview of how multiple national lockdowns to counter COVID-19 have impacted maritime traffic. Our data-driven approach shows that a global slump in demand for goods and services has led to an unprecedented impact at global and regional scales across all sectors - leading to a general decrease in vessel traffic, and varied changes in the operating behaviour of different sectors of transport, fishing and recreational vessels. This is the first time that it has been possible to monitor and map the response of shipping to such a global disruption in near real time.

At the global scale our analyses reveal a decline in global marine traffic during the pandemic, a pattern mirrored across multiple maritime sectors at varying scales. The magnitude of change was higher across EEZs and marine ecoregions, than in areas beyond national jurisdiction. European Seas, and in particular the Mediterranean Sea, were regions dominated by the greatest reductions in marine traffic highlighting the dramatic and rapid impact of lockdown measures had on the movement of vessels. East Asia, however, evidenced a mixture of patterns and general increase of marine traffic particularly within China's EEZ, which likely reflects an upturn in economic activity associated with the general and earlier easing of lockdown measures relative to other countries which suffered outbreaks later.

The global ocean has historically played a key role in transport of goods and services and more recently oil and gas exploration and tourism. Prior to the COVID-19 outbreak, there was a long-term acceleration of maritime activities in intensity and occupancy, including shipping and cruise tourism among others[35,36], with increasing rates of shipping in 92% of the EEZs[30], and forecast increases of the global shipping network of 240-1,209% by 2050[17]. Our analyses thus provide an unparalleled opportunity to assess changes on the blue economy at global and regional scales. Most notably, our findings reveal that the COVID-19 outbreak has led to significant disruptions and regional slowdown in vessel activity that was sustained for several weeks along established transport routes across Asia, Africa and Europe. This was particularly evident along the main trade corridors of the China's Maritime Silk Road Initiative (MSRI; e.g. [38]), including key areas like the Strait of Malacca. However, the impact on the maritime transport sector (i.e. cargo vessels and tankers) was lower in comparison to other sectors directly influenced by the lockdown measures and restrictions on travel; with the demand for oil tankers in particular rising due to a fall in oil prices[39]. In contrast, the most heavily impacted sectors were the tourism and recreation industry, with major declines and slower recovery rates in vessel activity at global and regional scale. Such disruptions have the potential to turn into far reaching and significant social and economic impacts on tourism dependent economies for several years to come. For fisheries, we reveal that the impact of the outbreak has been uneven across different fishing fleets, with notable declines in coastal areas. Regional analyses in the Western Mediterranean, however, reveal that fishing vessel activity is closer to pre-lockdown levels, suggesting that the industrial fisheries sector, which is often well-resourced and heavily subsidised in some countries[40], is less likely to be affected than the more vulnerable small-scale fisheries sector that dominates fisheries in many lower-income countries[7,41]. Further work is needed to ascertain the impact of the COVID-19 outbreak on the behaviour of small-scale fisheries sector.

Changes in maritime activities can be driven by multiple factors such as regulations (e.g. marine protected areas, speed limits, traffic separation schemes), socio-economic changes, piracy, environmental changes or by cultural and political events[26,27,42,43]. Moreover, these drivers can affect single or multiple sectors, and span across multiple spatial and temporal scales. Previous economic recessions, for instance, have shown long-term changes in maritime traffic (e.g. as a consequence of fuel prices[43]). Our temporal assessment in the Mediterranean is consistent with the changes in confinement measures in EU countries. Similarly, universal decreases in marine traffic across regions and countries with a high degree of lockdown measures during April 2020 (e.g. EU countries, India) can also be associated to COVID-19 as well as increases after easing of lockdown measures. However, not all changes observed in our global assessment were necessarily related to COVID-19. For example, large increases of fishing vessels in Indonesia could be attributed to a recent regulation that entered into force in August 2019 on AIS usage. Moreover, the shape of displacements in fishing vessels intensity suggests several shifts in the fishing grounds (e.g. in high seas near Peru). In addition, increases in tanker density in some areas are likely due to the fall in oil price supporting crude oil exports. Determining whether observed changes were driven by COVID-19 or other factors will require further regional and local assessments.

Monitoring the movements of marine traffic in near real-time at a global scale is now possible as a result of unprecedented technological advances in the domains of big data and nano-satellite communication systems leading to global AIS coverage. It is noteworthy that during the most recent comparable global shock, the 2008 financial crisis and associated recession, such a study as ours would not have been possible. Despite issues and limitations of AIS data (e.g. small vessels not included, errors in vessel's characteristics), there is much further work that can be done. In this study, we used gridded density maps at the finest data resolution (0.25 degrees) available at global scale and provided on an operational basis. Such resolution was larger than several EEZs, hence limiting analysis at finer scales. There are additional characteristics that could be derived from raw AIS data (e.g. port calls, individual vessel trajectories) that warrant further attention. Furthermore, changes in the properties of the global shipping network are essential to better understand the effects of COVID-19 on world trade, assess the risk of biological invasions[17,34] or the transmission of future diseases[32,33]. Moreover, using trajectory information to quantify changes in vessel behaviour would allow the mapping of changes of multiple human pressures (e.g. underwater noise, fishing effort, boat anchoring, air pollution), assess their interactions and potential effects on wildlife[1,31] and quantify their cumulative impacts on marine ecosystems[30,44]. While there are open-source datasets at supraregional areas at higher resolutions (e.g. EMODnet Human activities) there is, as yet, no international body providing open access to shipping tracking data at a global level. Such data products will prove essential to allow large-scale monitoring of the progress and potential effects of COVID-19 and other future shocks.

The spatial and temporal heterogeneity found in this study is highly relevant for further studies aiming to assess the effects of COVID-19 on marine ecosystems. Whilst the COVID-19 pandemic has brought a dramatic global health and socio-economic crisis, the reduction of maritime activities in affected regions and locations may provide some positive outcomes for the marine environment[5]. Commercial fishing and shipping, in fact, contribute significantly to overall cumulative human impacts on the ocean[44] and information about their spatial patterns is of paramount importance for conservation planning[45,46]. Previous economic crises have shown positive effects on fisheries[11], or air pollution[12], and have contributed to reduce vessel speeds (i.e. due to fuel price[43]), one of the most effective measures for achieving lower CO_2 and air pollutant emissions, risk of collisions with cetaceans, and to lessen ocean noise[47]. The unprecedented disruption during COVID-19 offers new opportunities for research[1]. Our global assessment is congruent with recent focal studies that have reported reductions of marine traffic in the Port of Vancouver and Venice during COVID-19, resulting in improvements in underwater sound[20] and water turbidity[21], respectively. Such agreement suggests that our global dataset could be used to identify impacted and control locations for comparison in other environmental studies. Our results also suggest that marine protected areas from coastal areas could benefit from a decrease in marine traffic. Equally, an associated reduction of surveillance effort presents a higher risk for potential increases of illicit activities (e.g. illegal fishing, trafficking of drugs), especially in lower-income countries[41,48]. In fact, our results show there were increases in fishing activity in the national waters of low-income countries.

Changes in marine traffic have been shaped by policy actions related to COVID-19 restrictions on human mobility and reductions of consumer's demand on food and trade. Response of marine ecosystems to COVID-19 will depend on the intensity and duration of the reduction of human pressures. In the northern hemisphere, marine traffic intensity is higher during the boreal summer and AIS data will allow us to monitor the recovery during the coming months. There is, however, a degree of uncertainty around future scenarios and long-lasting impacts. The scientific community needs empirical observations in order to better understand the socioeconomic impacts on maritime sectors and the environmental consequences of COVID-19 on marine ecosystems. The pandemic has also constrained the capacities of research institutions to pursue monitoring programs (e.g. on research cruises) underscoring the need to advance implementation of real-time autonomous monitoring systems to survey the ocean, including anthropogenic impacts. Future AIS studies should address temporal variability of spatial patterns at a global level and our global assessment can be extended forward and backwards in time to facilitate insights into the longer-term impacts of COVID-19. Such assessments will prove essential to allow large-scale monitoring and insights into the effects of the current pandemic, or other global shocks, on the blue economy and ocean health.

Methods

Stringency Index

The Oxford COVID-19 Government Response Tracker (OxCGRT) provides a transparent, real-time monitoring system that allows comparison of government measures between countries[49]. In order to account for the variation in containment and closure policies at national level, we used the Stringency Index (Index methodology version 3.1). This index is an additive score of nine policy decision indicators, rescaled to vary from 0 to 100, which records the strictness of the lockdown measures per country. A global average of the Stringency Index indicated that April was the month with the strictest measures experienced across all available coastal countries (n = 133).

AIS data

The automated identification system (AIS) is a vessel identification system that transmits real-time information on routes of vessels via a VHF transceiver. AIS is required on all ships of 300 gross tonnage or more engaged on international voyages, all cargo ships of 500 gross tonnage or more, and all passenger ships irrespective of size. In addition, individual countries may require further AIS usage. For example, AIS is required for EU fishing vessels >15 meters in length.

Moreover, AIS is also increasingly used on a voluntary basis by many other vessels, including smaller leisure and fishing vessels. AIS signals can be detected by nearby vessels, terrestrial antennas (T-AIS) or satellite stations (S-AIS). Land-based antennas have a horizontal range of about 40 nautical miles, while S-AIS has global coverage.

For global analyses, satellite AIS (S-AIS) data for April 2019 and 2020 were obtained from exactEarth Ltd (http://www.exactearth.com/), a space-based data service provider which operates a constellation of 65 microsatellites to provide global AIS coverage at a highly frequency rate (< 5 min average update rate). The latest upgrade in the constellation entered into production in February 2019, thus S-AIS coverage was equivalent for both periods (exactEarth Ltd. pers comm.). Values represented the monthly number of unique vessels within grid cells of 0.25 x 0.25 degrees. Vessels were classified into five categories: cargo, tanker, passenger, fishing, and “other”. The category “other” included any other vessel not covered by the preceding explicit categories (e.g. vessels conducting surveys and logistic services for industry, research vessels, recreational vessels). We calculated the vessel density as the number of vessels per unit area, considering the difference of cell size across the latitudinal gradient[25]. Grid cells from the Caspian Sea and with <10% ocean area were removed from the analysis, based on the GADM Database of Global Administrative Areas (version 3.6, https://gadm.org/). Further quality control procedures included the removal of grid cells with speed values above a given threshold (i.e. 99th percentile) and small clumps of isolated cells (i.e. < 100 cells). Finally, marine traffic density maps were converted to the Mollweide projection with a WGS84 datum as it is an accurate single global projection that preserves geographic area and allows data transfer and analysis among operating systems and software.

Terrestrial AIS (T-AIS) data from the Western Mediterranean (map inset Fig 5a) were collated by the Balearic Islands Coastal and Forecasting System (SOCIB[50]) using a real-time operational system connected to a web-service provided by Marine Traffic (https://www.marinetraffic.com/). The database used in this study contained AIS data from 1st January 2016 until 30th June 2020 at 5-minute intervals (> 545 million AIS messages). In addition to the vessel tracks, the database also included information associated with each vessel, such as the vessel type or length. A first pre-processing of the raw data included the removal of duplicates, invalid identification numbers (i.e. Maritime Mobile Service Identity -MMSI- codes without 9 digits) and codes outside the correct numerical range (i.e. MMSI codes with first digits between 2 and 7 are those intended for individual ships). In order to address inconsistencies in the vessel and MMSI combinations (e.g., changes of MMSI across years), we selected the more frequent combination of MMSI and vessel characteristics (e.g. vessel name and vessel type) for each calendar year. We used a similar vessel categorization as the S-AIS dataset, but were able to derive a sixth category from the AIS metadata, separating “recreational” vessels from “other” vessels. Therefore, vessels were classified into six categories: cargo, tanker, passenger (included high speed crafts and passenger vessels), fishing, recreational (included sailing vessels and pleasure crafts), and others (included all other ship types). We excluded ship type codes 20 to 29 (i.e. wing-in-ground-effect and search and rescue aircraft), as well as codes that had an invalid value (i.e. empty or null) or the value was not listed in the previous type codes. We calculated the number of vessels per day considering only those that were underway, thus removing moored vessels inside ports that were inactive. T-AIS coverage was not homogenous in the study area[51] due to a non-uniformly distribution of antennas (i.e. few antennas in north Africa, see www.marinetraffic.com). Consequently, we filtered vessels within the coastal zone (44.4 km, ~24 nautical miles) of EU countries (i.e. a total area of 164,318.2 km^2 comprised by Spain, France and Italy), thus reducing potential bias due to temporal gaps in signal reception.

Changes in response to COVID-19 at global level

We calculated the change in traffic density between April 2019 and April 2020 on a grid cell basis to assess the absolute and relative differences in a spatial context. In order to achieve greater symmetry between relative increases and decreases, we calculated relative differences using logarithmic percentage change (L%)[52]. We assessed the changes across multiple regions and maritime boundaries that are typically used to divide the global ocean into management or reporting units and used to define the unique ecosystems that comprise the global ocean. We summarized the differences of traffic density by exclusive economic zones (EEZ)[53], areas beyond national jurisdiction (ABJN)[54], marine ecoregions[55], and Food and Agriculture Organization (FAO) major fishing areas[56]. We averaged per-pixel values, allowing direct comparison among regions despite large differences in size[44]. We filtered out EEZs from Caspian Sea and joint regimes and obtained information on income levels per country from the World Bank. Despite several EEZs being smaller than the grid size (0.25 degrees), we included them in the analysis. The rationale for this is the diffuse nature of various environmental pressures (i.e. air pollution, underwater noise).

Changes in response to COVID-19 at regional level

We compared the unique number of vessels on a daily basis. Our dataset showed a marked annual cycle, reducing in the boreal winter and year on year increasing annual trend for some sectors (Fig S8), hence we compared the 2020 values (since 1st January to account for pre-quarantine period) with the same periods of 2019. In order to take into account the dynamics of ship-based activities through time, the comparison between the datasets of the two years was adjusted so the same days of the week were being compared and to allow for the extra day in 2020, being a leap year. We calculated a 7-day moving average and then computed the log percentage change (L%)[52].

Data and code availability

Stringency index data is available from the Oxford COVID-19 Government Response Tracker (www.bsg.ox.ac.uk/covidtracker). Raw AIS data are available from SOCIB and Exact Earth. Anonymized and aggregated data from terrestrial AIS are available (https://doi.org/10.6084/m9.figshare.12667256). Density maps on satellite AIS were purchased from Exact Earth, are used under license and cannot be publicly shared by the authors. We provide the global difference maps publicly available (https://doi.org/10.6084/m9.figshare.12676070). All analyses were coded in R. Code which is available from Github (https://github.com/dmarch/covid19-ais).

Supplementary Information

Supplementary Information

Supplementary Data 1. Average difference in marine traffic density between April 2020 and April 2019 for each EEZ.

Supplementary Data 2. Average difference in marine traffic density between April 2020 and April 2019 for each High Seas

Supplementary Data 3. Average difference in marine traffic density between April 2020 and April 2019 for each marine ecoregion.

Supplementary Data 4. Average difference in marine traffic density between April 2020 and April 2019 for each FAO area.

Acknowledgements

We thank Marine Traffic and Exact Earth for their support with AIS data. D.M. acknowledges support from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement no 794938.

Author contribution

D.M. and B.J.G. conceived and designed the study. D.M. performed the analysis. D.M. and B.J.G. wrote the manuscript with input from all authors. All authors gave approval to the final version of the manuscript.

Competing interests

The authors declare no competing interests.

References

1. Rutz, C. *et al.* COVID-19 lockdown allows researchers to quantify the effects of human

activity on wildlife. *Nat. Ecol. Evol.* (2020). doi:10.1038/s41559-020-1237-z

2. Bates, A. E., Primack, R. B., Moraga, P. & Duarte, C. M. COVID-19 pandemic and associated lockdown as a “Global Human Confinement Experiment” to investigate biodiversity conservation. *Biol. Conserv.* 108665 (2020). doi:10.1016/j.biocon.2020.108665
3. Corlett, R. T. *et al.* Impacts of the coronavirus pandemic on biodiversity conservation. *Biol. Conserv.* **246**, 108571 (2020).
4. Le Quéré, C. *et al.* Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nat. Clim. Chang.* (2020). doi:10.1038/s41558-020-0797-x
5. Pearson, R. M., Sievers, M., McClure, E. C., Turschwell, M. P. & Connolly, R. M. COVID-19 recovery can benefit biodiversity. *Science* **368**, 838–839 (2020).
6. Zambrano-Monserrate, M. A., Ruano, M. A. & Sanchez-Alcalde, L. Indirect effects of COVID-19 on the environment. *Sci. Total Environ.* **728**, 138813 (2020).
7. Bennett, N. J. *et al.* The COVID-19 Pandemic, Small-Scale Fisheries and Coastal Fishing Communities. *Coast. Manag.* 1–11 (2020). doi:10.1080/08920753.2020.1766937
8. Depellegrin, D., Bastianini, M., Fadini, A. & Menegon, S. The effects of COVID-19 induced lockdown measures on maritime settings of a coastal region. *Sci. Total Environ.* **740**, 140123 (2020).
9. Rocklöv, J., Sjödin, H. & Wilder-Smith, A. COVID-19 outbreak on the Diamond Princess cruise ship: estimating the epidemic potential and effectiveness of public health countermeasures. *J. Travel Med.* **27**, (2020).
10. Ito, H., Hanaoka, S. & Kawasaki, T. The cruise industry and the COVID-19 outbreak. *Transp. Res. Interdiscip. Perspect.* **5**, 100136 (2020).
11. Tsikopoulou, I., Smith, C. J., Papadopoulou, N. K., Eleftheriadou, E. & Karakassis, I. A fishing ground benthic ecosystem improved during the economic crisis. *ICES J. Mar. Sci.* **76**, 402–409 (2018).

12. Jalkanen, J.-P., Johansson, L. & Kukkonen, J. A Comprehensive Inventory of the Ship Traffic Exhaust Emissions in the Baltic Sea from 2006 to 2009. *Ambio* **43**, 311–324 (2014).

13. Russo, M. A., Leitão, J., Gama, C., Ferreira, J. & Monteiro, A. Shipping emissions over Europe: A state-of-the-art and comparative analysis. *Atmos. Environ.* **177**, 187–194 (2018).

14. Alahmadi, S., Al-Ahmadi, K. & Almeshari, M. Spatial variation in the association between NO2 concentrations and shipping emissions in the Red Sea. *Sci. Total Environ.* **676**, 131–143 (2019).

15. Boersma, K. F., Vinken, G. C. M. & Tournadre, J. Ships going slow in reducing their NOx emissions: changes in 2005–2012 ship exhaust inferred from satellite measurements over Europe. *Environ. Res. Lett.* **10**, 074007 (2015).

16. Seebens, H., Schwartz, N., Schupp, P. J. & Blasius, B. Predicting the spread of marine species introduced by global shipping. *Proc. Natl. Acad. Sci.* **113**, 5646–5651 (2016).

17. Sardain, A., Sardain, E. & Leung, B. Global forecasts of shipping traffic and biological invasions to 2050. *Nat. Sustain.* **2**, 274–282 (2019).

18. Pirotta, V., Grech, A., Jonsen, I. D., Laurance, W. F. & Harcourt, R. G. Consequences of global shipping traffic for marine giants. *Front. Ecol. Environ.* **17**, 39–47 (2019).

19. Schoeman, R. P., Patterson-Abrolat, C. & Plön, S. A Global Review of Vessel Collisions With Marine Animals. *Front. Mar. Sci.* **7**, 292 (2020).

20. Thomson, D. J. M. & Barclay, D. R. Real-time observations of the impact of COVID-19 on underwater noise. *J. Acoust. Soc. Am.* **147**, 3390–3396 (2020).

21. Braga, F., Scarpa, G. M., Brando, V. E., Manfè, G. & Zaggia, L. COVID-19 lockdown measures reveal human impact on water transparency in the Venice Lagoon. *Sci. Total Environ.* **736**, 139612 (2020).

22. Dunn, D. C. *et al.* Empowering high seas governance with satellite vessel tracking data.

Fish Fish. **19**, 729–739 (2018).

23. Rowlands, G., Brown, J., Soule, B., Boluda, P. T. & Rogers, A. D. Satellite surveillance of fishing vessel activity in the Ascension Island Exclusive Economic Zone and Marine Protected Area. *Mar. Policy* **101**, 39–50 (2019).
24. Cope, S. *et al.* Application of a New Shore-Based Vessel Traffic Monitoring System Within San Francisco Bay. *Front. Mar. Sci.* **7**, 86 (2020).
25. Eguíluz, V. M., Fernández-Gracia, J., Irigoien, X. & Duarte, C. M. A quantitative assessment of Arctic shipping in 2010–2014. *Sci. Rep.* **6**, 30682 (2016).
26. Mccauley, B. D. J. *et al.* Ending hide and seek at sea: New technologies could revolutionize ocean observation. *Science* **351**, 1148–1150 (2016).
27. Kroodsma, D. A. *et al.* Tracking the global footprint of fisheries. *Science* **359**, 904–908 (2018).
28. Metcalfe, K. *et al.* Using satellite AIS to improve our understanding of shipping and fill gaps in ocean observation data to support marine spatial planning. *J. Appl. Ecol.* **55**, 1834–1845 (2018).
29. Svanberg, M., Santén, V., Hörteborn, A., Holm, H. & Finnsgård, C. AIS in maritime research. *Mar. Policy* **106**, 103520 (2019).
30. Halpern, B. S. *et al.* Recent pace of change in human impact on the world's ocean. *Sci. Rep.* **9**, 11609 (2019).
31. Queiroz, N. *et al.* Global spatial risk assessment of sharks under the footprint of fisheries. *Nature* **572**, 461–466 (2019).
32. Wang, Z., Yao, M., Meng, C. & Claramunt, C. Risk Assessment of the Overseas Imported COVID-19 of Ocean-Going Ships Based on AIS and Infection Data. *ISPRS Int. J. Geo-Information* **9**, 351 (2020).
33. Hoffmann Pham, K. E. & Luengo-Oroz, M. From plague to coronavirus: vessel trajectory data from ship automatic identification systems for epidemic modeling. *J. Travel Med.*

(2020). doi:10.1093/jtm/taaa072

34. Xu, M., Pan, Q., Muscoloni, A., Xia, H. & Cannistraci, C. V. Modular gateway-ness connectivity and structural core organization in maritime network science. *Nat. Commun.* **11**, 2849 (2020).

35. Vicente-Cera, I., Acevedo-Merino, A., López-Ramírez, J. A. & Nebot, E. Use of AIS data for the environmental characterization of world cruise ship traffic. *Int. J. Sustain. Transp.* **14**, 465–474 (2020).

36. Jouffray, J.-B., Blasiak, R., Norström, A. V, Österblom, H. & Nyström, M. The Blue Acceleration: The Trajectory of Human Expansion into the Ocean. *One Earth* **2**, 43–54 (2020).

37. Golden, J. S. *et al.* Making sure the blue economy is green. *Nat. Ecol. Evol.* **1**, 17 (2017).

38. Ascensão, F. *et al.* Environmental challenges for the Belt and Road Initiative. *Nat. Sustain.* **1**, 206–209 (2018).

39. Helm, D. The Environmental Impacts of the Coronavirus. *Environ. Resour. Econ.* **76**, 21–38 (2020).

40. Sumaila, U. R. *et al.* Updated estimates and analysis of global fisheries subsidies. *Mar. Policy* **109**, 103695 (2019).

41. Naidoo, R. & Fisher, B. Reset Sustainable Development Goals for a pandemic world. *Nature* 198–201 (2020). doi:10.1038/d41586-020-01999-x

42. Tournadre, J. Anthropogenic pressure on the open ocean: The growth of ship traffic revealed by altimeter data analysis. *Geophys. Res. Lett.* **41**, 7924–7932 (2014).

43. Moore, T. J. *et al.* Exploring ship traffic variability off California. *Ocean Coast. Manag.* **163**, 515–527 (2018).

44. Halpern, B. S. *et al.* Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nat. Commun.* **6**, 7615 (2015).

45. Jones, K. R. *et al.* The Location and Protection Status of Earth's Diminishing Marine

Wilderness. *Curr. Biol.* **28**, 2506–2512 (2018).

46. Jones, K. R. *et al.* Area Requirements to Safeguard Earth's Marine Species. *One Earth* **2**, 188–196 (2020).

47. Leaper, R. The Role of Slower Vessel Speeds in Reducing Greenhouse Gas Emissions, Underwater Noise and Collision Risk to Whales. *Front. Mar. Sci.* **6**, 505 (2019).

48. Pinder, A. C., Raghavan, R., Britton, J. R. & Cooke, S. J. COVID-19 and biodiversity: The paradox of cleaner rivers and elevated extinction risk to iconic fish species. *Aquat. Conserv. Mar. Freshw. Ecosyst.* **30**, 1061–1062 (2020).

49. Hale, T., Webster, Sam & Anna Petherick, Toby Phillips, B. K. Oxford COVID-19 Government Response Tracker. *Blavatnik School of Government* (2020).

50. Tintoré, J. *et al.* SOCIB: The Balearic Islands Coastal Ocean Observing and Forecasting System Responding to Science, Technology and Society Needs. *Mar. Technol. Soc. J.* **47**, 101–117 (2013).

51. Holmes, S. *et al.* Where did the vessels go? An analysis of the EU fishing fleet gravitation between home ports, fishing grounds, landing ports and markets. *PLoS One* **15**, e0230494 (2020).

52. Tornqvist, L., Vartia, P. & Vartia, Y. O. How Should Relative Changes Be Measured? *Am. Stat.* **39**, 43–46 (1985).

53. Flanders Marine Institute. Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 11. (2019). doi:10.14284/386

54. Flanders Marine Institute. The intersect of the Exclusive Economic Zones and IHO sea areas, version 4. (2020). doi:10.14284/402

55. Spalding, M. D. *et al.* Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. *Bioscience* **57**, 573–583 (2007).

56. FAO. FAO Statistical Areas for Fishery Purposes. (2019).

Figures

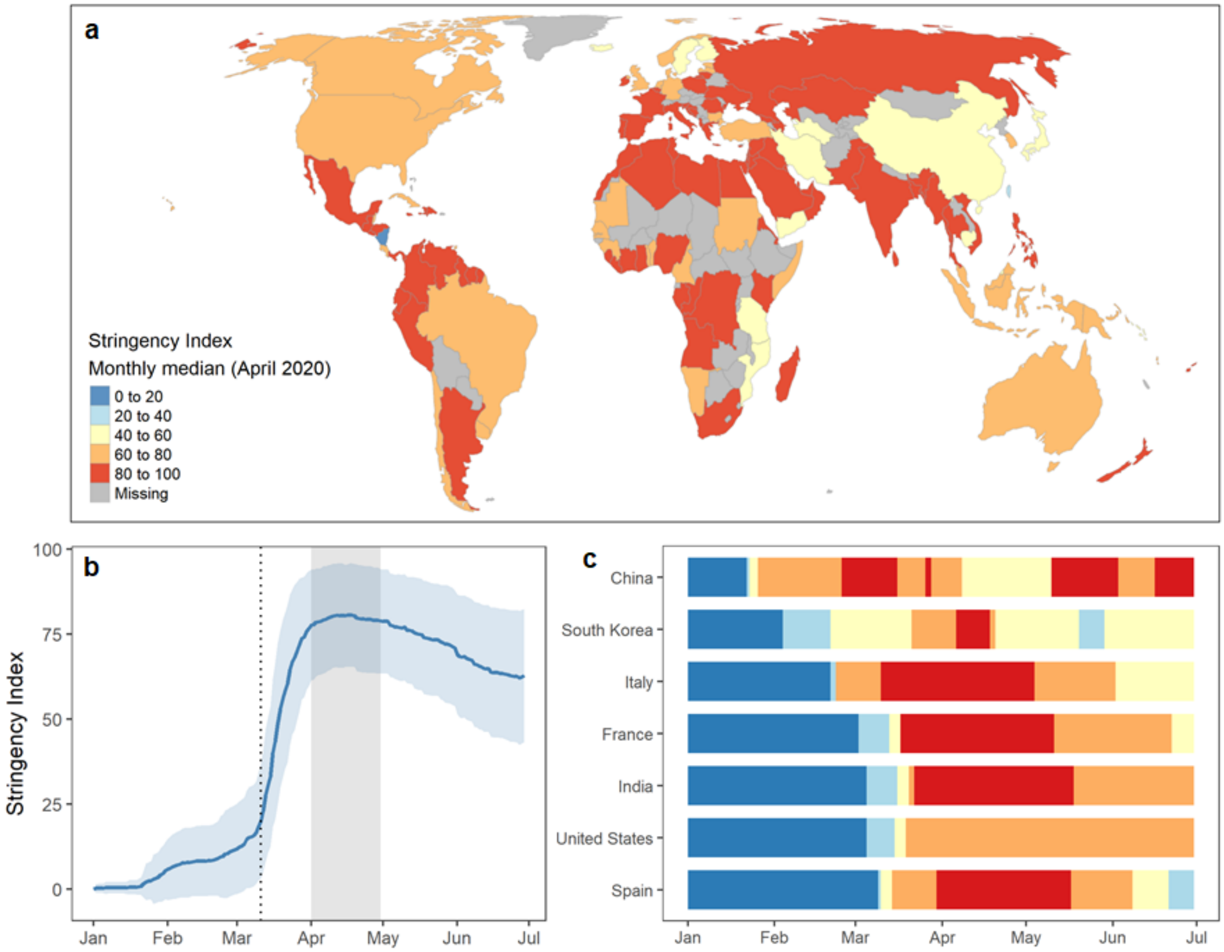

Fig 1. Spatial and temporal variation of the confinement measures in coastal countries. We use the Stringency Index (100 = strictest response) as an indicator of confinement measures for all available coastal countries (n = 133). (**a**) Monthly median per country for April 2020. (**b**) Global daily average and standard deviation from 1st January 2020 until 30th June 2020. The shaded area in grey highlights the month of April, as used for the large-scale assessment. Vertical dotted line represents the World Health Organization pandemic declaration on the 11^{th} March 2020. (**c**) Individual series for selected countries, ordered according to the first date when the Stringency Index was above the first quintile. Colors represent the same Stringency Index classes used in panel a. Note that data was not available for all coastal countries.

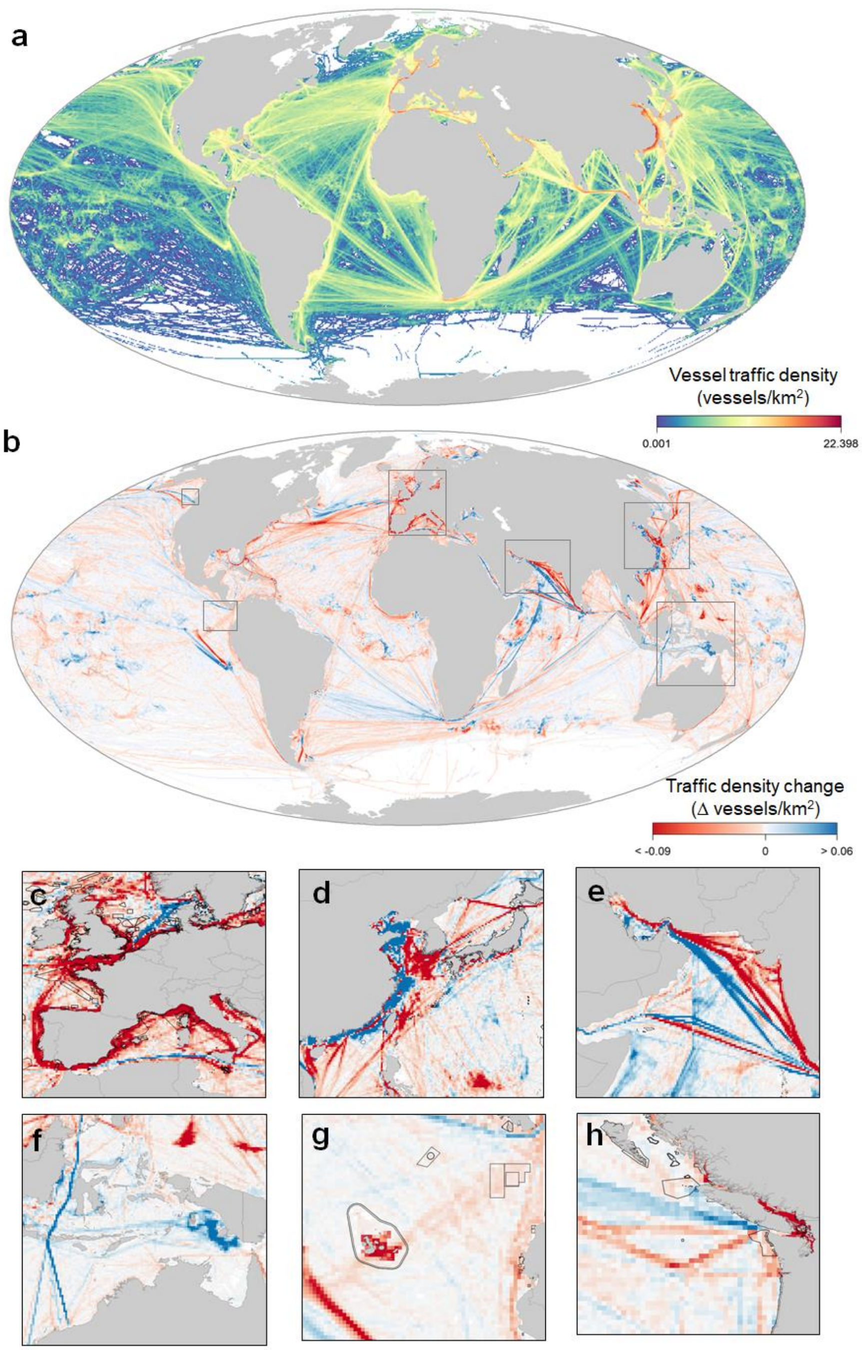

Figure 2. Global changes in vessel traffic density during COVID-19 pandemic. (**a**) Monthly traffic density in April 2020. Note a logarithmic color scale is used to highlight main shipping lanes. (**b**) Absolute difference in traffic density in relation to April 2019, derived using cell-by-cell subtraction. Negative (red) cells indicate a reduction in April 2020. Scale values reflect min and max raster 99th quantile values (−0.09 and 0.06). (Insets) Regional changes in Europe (**c**), East China Sea (**d**), Arabian Sea (**e**) and Indonesia (**f**). Local changes in Galapagos Islands marine protected area (**g**), and Port of Vancouver (**h**). Black lines in insets represent the boundaries of marine protected areas. Scales values are the same from panel b.

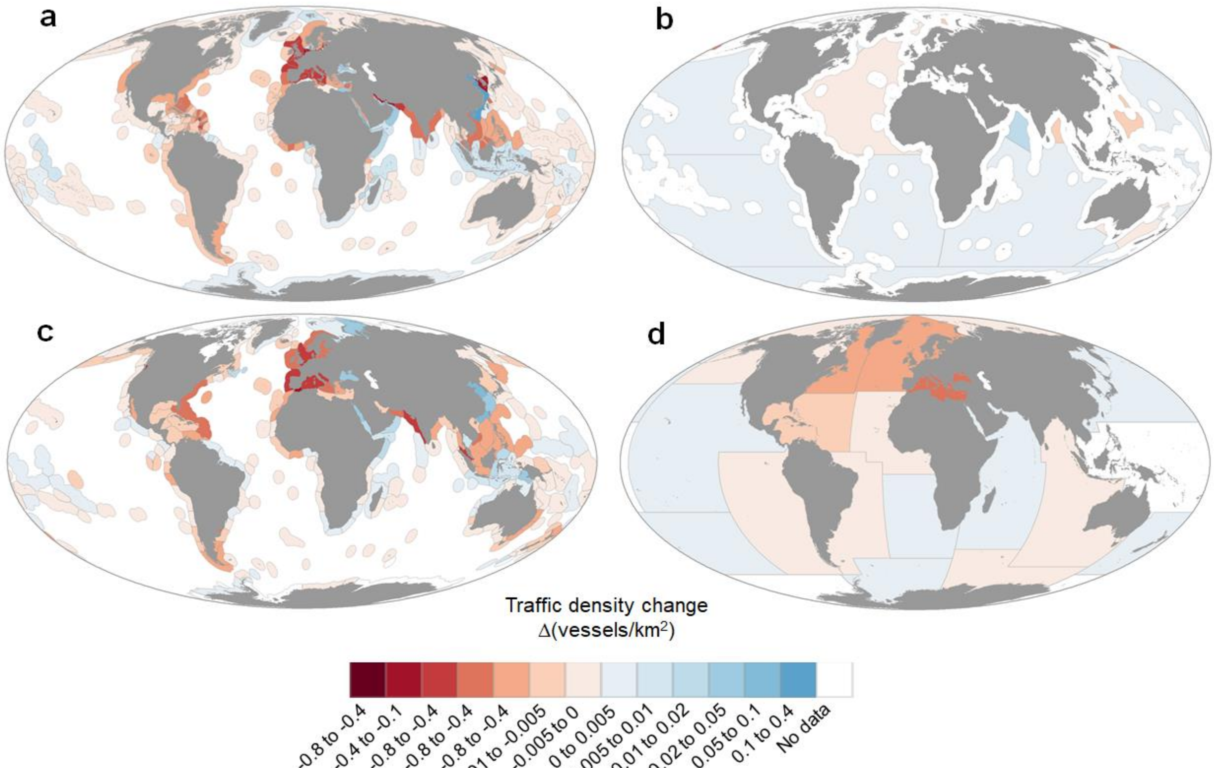

Fig 3. Global changes in vessel traffic density across multiple regions of the ocean. (**a**) Exclusive Economic Zones (EEZ; n = 255), (**b**) Areas beyond national jurisdiction (ABJN; n = 21), (**c**) marine ecoregions (n = 217), (**d**) Food and Agriculture Organization major fishing areas (n = 19).

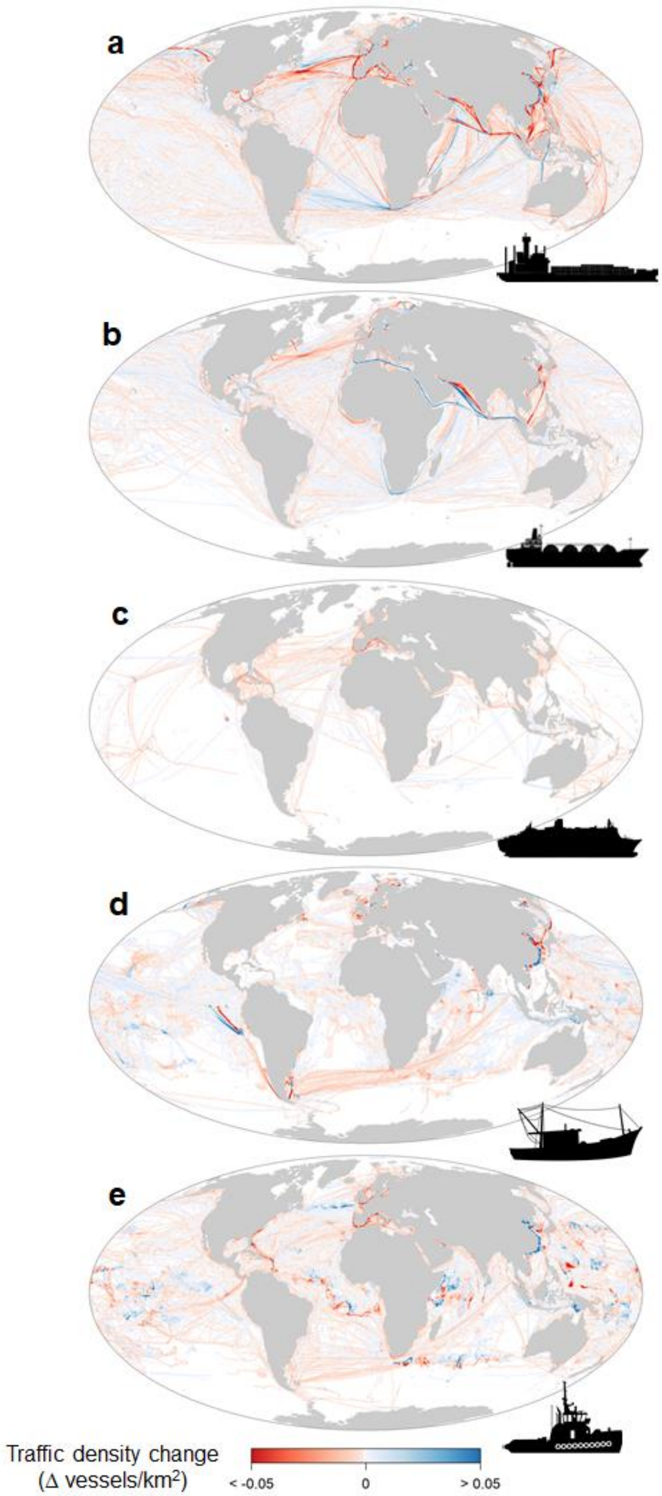

Figure 4. Global changes in vessel traffic density per vessel categories. Absolute difference in traffic density between April 2020 and April 2019, derived using cell-by-cell subtraction. Negative (red) cells indicate a reduction in April 2020. Vessel categories: (**a**) cargo, (**b**) tanker, (**c**) passenger, (**d**) fishing, (**e**) other vessels.

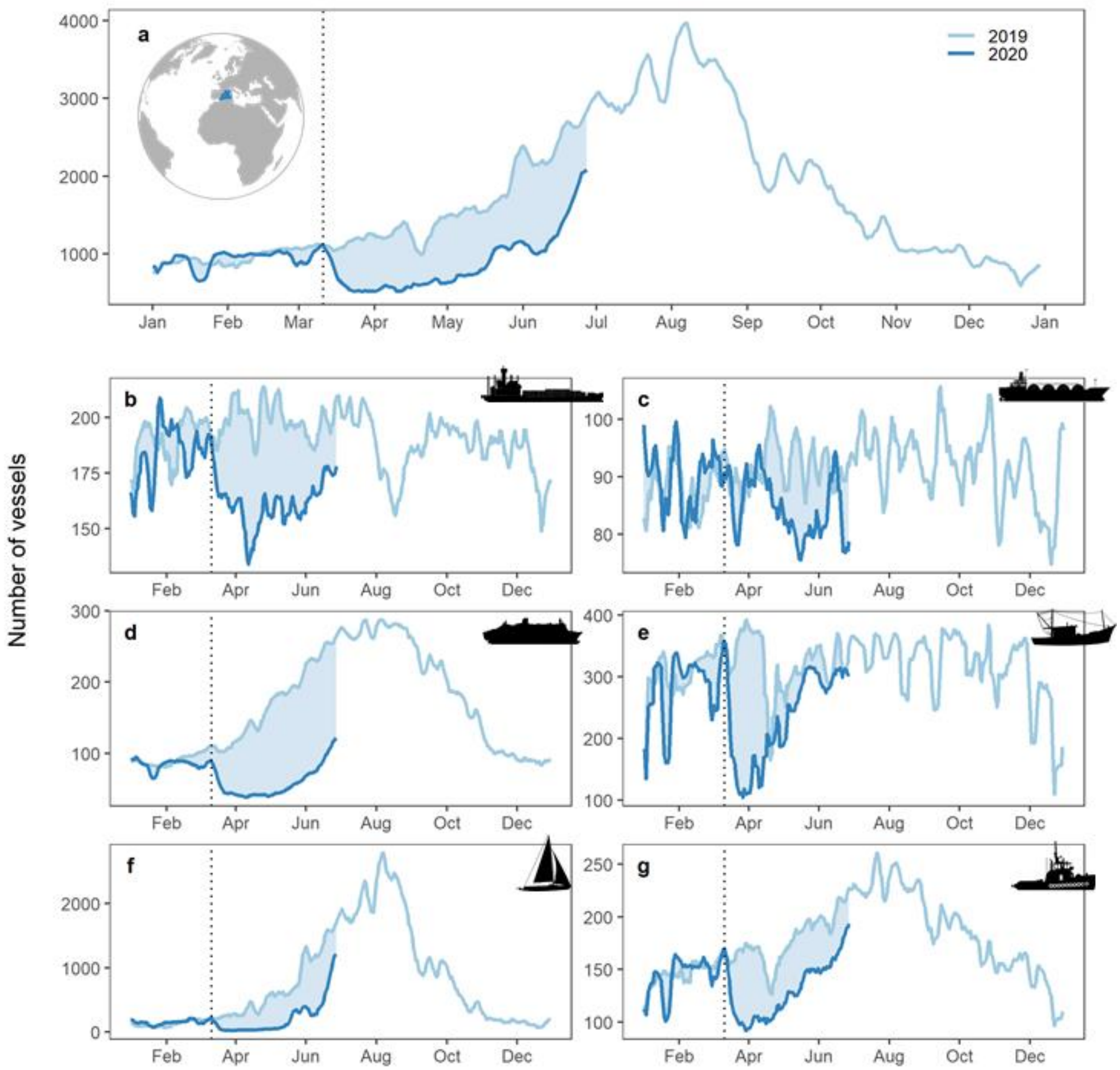

Figure 5. Temporal variation of vessels in the Western Mediterranean during COVID-19. Daily data of vessels underway within the coastal zone (24 nautical miles) of EU countries present in the study area (i.e., Spain, France, Italy) per vessel category: (**a**) All vessel types, (**b**) cargo, (**c**) tanker, (**d**) passenger, (**e**) fishing, (**f**) recreational, and (**g**) others. Daily estimates using 7-day moving average. Shaded area represents the difference between 2019 and 2020 (until 30th June). Vertical dotted line represents the World Health Organization pandemic declaration on the 11th March 2020. Blue area in the map inset on part (a) represents the spatial extent of the regional AIS dataset.