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

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Article

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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.

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

58   providing a unique opportunity to monitor the location of large ocean-going ships, passenger

59   liners, and fishing vessels anywhere in the world at high temporal resolution[25–27]. Consequently,

60   AIS can provide unparalleled insights into shipping-derived impacts and conservation planning at

61   multiple spatial and temporal scales[4,27–31]. In view of COVID-19, AIS has recently been employed

62   to assess the potential spread of the virus[10,32,33] and to describe the reductions in marine traffic at

63   local scale[8].

64

65   Here, we use AIS data to conduct a comprehensive assessment of the short-term changes on

66   ship-based mobility patterns in response to COVID-19 across multiple sectors and at different

67   spatio-temporal scales. First, we illustrate our approach by conducting a global assessment using

68   monthly traffic density maps to evaluate changes in vessel activity across multiple regions and

69   maritime sectors. Then, we assess the high temporal variability (i.e. daily basis) in the Western

70   Mediterranean Sea, a key region for the global liner shipping network[34] and cruise tourism[35], which

71   includes three countries most impacted by the COVID-19 outbreak in Europe (i.e. Italy, Spain and

72   France). Our approach quantifies the magnitude and patterns of changes in ship-based activities,

73   providing guidance for large-scale monitoring of the potential socio-economic and environmental

74   effects of COVID-19 on the world's ocean.

75

76   **Results**

77   **Global changes in the spatial distribution of traffic density**

78   Lockdown measures across coastal countries (n = 133) reached their maximum levels (i.e.

79   strictest confinement measures) during the month of April (Stringency index = 79.5 ± 15.5, mean

80   ± SD; Fig 1a and 1b), though China, the reported source of the outbreak, had started to ease

81   lockdown restrictions (Fig 1c). Consequently, we analysed global changes in marine traffic using

82   monthly AIS data from April 2020 and quantified the absolute and relative changes in comparison

83   with April 2019, thus accounting for seasonal variability of ship-based activities. Global marine

84   traffic in April 2020 was present in nearly 76.9% of the ocean, with high traffic areas (i.e. 80th

85   percentile - equivalent to 42.9 x 10^{-3} vessels km^{-2}) concentrated in 15.4% of the ocean (Fig 2a).

86   In comparison with 2019, there were more areas of the ocean that experienced decreases

87   (44.3%) than those that showed increases (36.8%), with a general reduction of 1.4% in their

88   occupancy (1.6% in high traffic areas) (Table S1). Changes were unevenly distributed across the

89   globe (Fig 2b). Major changes in traffic density were mainly found in coastal areas from the

90   northern hemisphere (Fig S1). In Europe, there was an almost universal decrease in vessel traffic

91   (Fig 2c), whilst patterns in other regions (e.g. increases in China and decreases in South Korea,

92   Fig 2d), and around main shipping lanes (e.g. Arabian Sea; Fig 2e) showing a mixture of increased

93   and decreased vessel activity. Conversely, other regions showed overall increases in traffic

94   density (e.g. Indonesia; Fig 2f). At the local level, our analysis captured profound decreases

95   around marine protected areas (e.g. Galapagos islands in Ecuador, Fig 2g) or near the vicinity of

96   port areas (e.g. Port of Vancouver in Canada; Fig 2h).

97

98   Global marine traffic in April 2020 was present within 80.3% of the surface covered by Exclusive

99   Economic Zones (EEZs, national waters up to 200 nautical miles), showing a global average

100   decrease of 3.3% (equivalent to 2.9 x 10^{-3} vessels km^{-2}) in comparison with April 2019. There was

101   an overall decrease in traffic density in 75.7% of national jurisdictions (n = 255; Fig 3a;

102   Supplementary Data 1). The largest average decrease in absolute difference for all vessels was

103   in Singapore (734.0 x 10^{-3} vessels km^{-2}, 9.4% relative decrease), followed by small EEZs from

104   EU countries. On the contrary, the largest average increases were found in the northern Indian

105   Ocean and East Asia, with Bahrain (213.6 x 10^{-3} vessels km^{-2}) and China (145.2 x 10^{-3} vessels

106   km^{-2}), experiencing relative average increases of 35.0% and 8.7%, respectively. Outside EEZs,

107   global marine traffic was present in 73.9% of the surface covered by Areas Beyond National

108   Jurisdictions (ABNJ; Fig 3b; Supplementary Data 2). Whilst we found reductions in 11 (52%) of

109   the 21 ABNJ subregions, there was a global average increase in marine traffic of 2.4% (0.4 x 10^{-3}

110   vessels km^{-2}) on the high seas.

111

112   In the nearshore, 159 (73.3%) of the 217 marine ecoregions experienced overall decreases in

113   marine traffic (Fig 3c; Supplementary Data 3). The largest decrease in absolute difference for all

114   vessels was observed in the Puget Trough/Georgia Basin (139.2 x 10^{-3} vessels km^{-2}, 21.2%

115   relative decrease), followed by marine ecoregions from European Seas. Again, the largest

116   increases were observed in marine ecoregions in East Asia mirroring trends observed in vessel

117   activity within EEZs across this region. On the open ocean, 13 (68%) out of the 19 Food and

118   Agriculture Organization (FAO) major fishing areas presented reductions (Fig 3d; Supplementary

119   Data 4), with the Mediterranean and Black sea showing the highest absolute decrease (22.7 x 10^{-3}

120   vessels km^{-2}, 7.1% relative decrease).

121

122   **Spatial variation among sectors**

123   An important characteristic of the AIS data is their stratification according to ship categories, thus

124   allowing attribution of the spatial footprint of marine traffic to different maritime sectors. Merchant

125   vessels (i.e. cargo and tankers) were the most widespread categories, followed by fishing and

126   "other vessels" (e.g. service vessels, recreational), while passenger vessels presented a more

127   limited distribution (Table S1, Fig S2). Accordingly, the spatial variation of changes in traffic

128   density varied by vessel category (Fig 4, Fig S3). All categories apart from tankers, presented an

129   overall global decline, with these declines again more marked in the northern hemisphere (Fig

130   S1). Changes in merchant vessels were differentially distributed across the major shipping lanes

131   (Fig 4a and 4b). Passenger vessels were most negatively affected in both traffic density and

132   occupancy, especially in touristic hotspots like the Caribbean and the Mediterranean Seas (Fig

133   4c). Conversely, changes in fishing and "other" vessels were more diffusely spread across the

134   world's ocean (Fig 4d and 4e).

135

136   Average changes within national jurisdictions also reflected an uneven response among different

137   vessel categories (Fig S4, S5 and S6). Relative changes for merchant vessels were less marked

138   than those for other categories (Fig S4 and S5). However, they had large contributions in terms

139   of absolute changes to the variations across EEZs (Fig S6). Both passenger and "other" vessels

140   presented decreases in most EEZs. On the other hand, fishing vessels presented increases in

141   some national jurisdictions, mainly in lower income countries (Fig S4d and S5e). In the Areas

142   Beyond National Jurisdiction, the magnitude of changes was lower than within EEZs, with fishing

143   and "others" showing a slight increase of traffic density across multiple subregions (Fig S7).

144   Marine ecoregions presented a high variability of increases and decreases across multiple sectors

145   (Fig S8). Among the multiple FAO regions, which extended from the nearshore to the open ocean,

146   the Mediterranean Sea constituted one of the areas with the greatest decreases across most

147   sectors (Fig S9).

148

149   **Temporal changes in the Mediterranean Sea**

150   The Western Mediterranean Sea was found as one of the areas with the highest reduction in

151   shipping activities at a global scale (Fig 3c, Supplementary Data 3). To analyse the temporal

152   variability of marine traffic during 2020, we counted the number of vessels underway on a daily

153   basis. Moreover, we considered an additional ship category, recreational vessels, which

154   constitutes an important sector in one of the world's tourist hotspots. The multi-annual distribution

155   of the number of vessels in the Western Mediterranean was consistent through time for merchant

156   and fishing vessels (Fig S10). Conversely, temporal variation showed a marked seasonality in

157   passenger, recreational and "other" vessels, with a peak during the boreal summer, and a growing

158   trend in the number of vessels across years (Fig S10). In 2020, daily counts of the number of

159   vessels showed a significant reduction after the World Health Organization (WHO) declared a

160   pandemic on 11th March, a pattern that was consistent across all sectors (Fig 5). When compared

161   to pre-disturbance baselines (i.e. equivalent periods of 2019), the number of vessels sharply

162   decreased in the first days of mobility restriction. Maximal reductions ranged from 24.3% (tankers)

163   to 276.9% (recreational vessels), with an overall drop across all categories of 97.5% during mid-

164   April (Table S2). Similarly, we found an uneven recovery rate among sectors. Cargo, tanker and

165   fishing vessels showed a relatively swift recovery in vessel activity in the proceeding months, in

166   contrast to passenger and recreational vessels which remained at low levels for a longer period

167   (Fig S11). By 30th June, after easing of lockdown restrictions in Spain, France and Italy (Fig 1c),

168   merchant and fishing vessels were close to pre-lockdown values, and recreational vessels

169   exhibited a sharp recovery, but passenger vessels still remained at levels less than 50% of

170   expected (Table S2).

171

Discussion

173   Our oceans are responsible for the carriage of around 80% of world trade and are the lifeblood of

174   many national economies which rely heavily on fishing and tourism[27,34,36,37]. Here, using electronic

175   vessel monitoring systems we quantify and map changes in ship-based activities to provide a

176   comprehensive overview of how multiple national lockdowns to counter COVID-19 have impacted

177   maritime traffic. Our data-driven approach shows that a global slump in demand for goods and

178   services has led to an unprecedented impact at global and regional scales across all sectors -

179   leading to a general decrease in vessel traffic, and varied changes in the operating behaviour of

180   different sectors of transport, fishing and recreational vessels. This is the first time that it has been

181   possible to monitor and map the response of shipping to such a global disruption in near real time.

182

183   At the global scale our analyses reveal a decline in global marine traffic during the pandemic, a

184   pattern mirrored across multiple maritime sectors at varying scales. The magnitude of change

185   was higher across EEZs and marine ecoregions, than in areas beyond national jurisdiction.

186   European Seas, and in particular the Mediterranean Sea, were regions dominated by the greatest

187   reductions in marine traffic highlighting the dramatic and rapid impact of lockdown measures had

188   on the movement of vessels. East Asia, however, evidenced a mixture of patterns and general

189   increase of marine traffic particularly within China's EEZ, which likely reflects an upturn in

190   economic activity associated with the general and earlier easing of lockdown measures relative

191   to other countries which suffered outbreaks later.

192

193   The global ocean has historically played a key role in transport of goods and services and more

194   recently oil and gas exploration and tourism. Prior to the COVID-19 outbreak, there was a long-

195   term acceleration of maritime activities in intensity and occupancy, including shipping and cruise

196   tourism among others[35,36], with increasing rates of shipping in 92% of the EEZs[30], and forecast

197   increases of the global shipping network of 240-1,209% by 2050[17]. Our analyses thus provide an

198   unparalleled opportunity to assess changes on the blue economy at global and regional scales.

199   Most notably, our findings reveal that the COVID-19 outbreak has led to significant disruptions

200   and regional slowdown in vessel activity that was sustained for several weeks along established

201   transport routes across Asia, Africa and Europe. This was particularly evident along the main

202   trade corridors of the China's Maritime Silk Road Initiative (MSRI; e.g. [38]), including key areas like

203   the Strait of Malacca. However, the impact on the maritime transport sector (i.e. cargo vessels

204   and tankers) was lower in comparison to other sectors directly influenced by the lockdown

205   measures and restrictions on travel; with the demand for oil tankers in particular rising due to a

206   fall in oil prices[39]. In contrast, the most heavily impacted sectors were the tourism and recreation

207   industry, with major declines and slower recovery rates in vessel activity at global and regional

208   scale. Such disruptions have the potential to turn into far reaching and significant social and

209   economic impacts on tourism dependent economies for several years to come. For fisheries, we

210   reveal that the impact of the outbreak has been uneven across different fishing fleets, with notable

211   declines in coastal areas. Regional analyses in the Western Mediterranean, however, reveal that

212   fishing vessel activity is closer to pre-lockdown levels, suggesting that the industrial fisheries

213   sector, which is often well-resourced and heavily subsidised in some countries[40], is less likely to

214   be affected than the more vulnerable small-scale fisheries sector that dominates fisheries in many

215   lower-income countries[7,41]. Further work is needed to ascertain the impact of the COVID-19

216   outbreak on the behaviour of small-scale fisheries sector.

217

218   Changes in maritime activities can be driven by multiple factors such as regulations (e.g. marine

219   protected areas, speed limits, traffic separation schemes), socio-economic changes, piracy,

220   environmental changes or by cultural and political events[26,27,42,43]. Moreover, these drivers can

221   affect single or multiple sectors, and span across multiple spatial and temporal scales. Previous

222   economic recessions, for instance, have shown long-term changes in maritime traffic (e.g. as a

223   consequence of fuel prices[43]). Our temporal assessment in the Mediterranean is consistent with

224   the changes in confinement measures in EU countries. Similarly, universal decreases in marine

225   traffic across regions and countries with a high degree of lockdown measures during April 2020

226   (e.g. EU countries, India) can also be associated to COVID-19 as well as increases after easing

227   of lockdown measures. However, not all changes observed in our global assessment were

228   necessarily related to COVID-19. For example, large increases of fishing vessels in Indonesia

229   could be attributed to a recent regulation that entered into force in August 2019 on AIS usage.

230   Moreover, the shape of displacements in fishing vessels intensity suggests several shifts in the

231   fishing grounds (e.g. in high seas near Peru). In addition, increases in tanker density in some

232   areas are likely due to the fall in oil price supporting crude oil exports. Determining whether

233   observed changes were driven by COVID-19 or other factors will require further regional and local

234   assessments.

235

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.

256

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

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261   environment[5]. Commercial fishing and shipping, in fact, contribute significantly to overall

262   cumulative human impacts on the ocean[44] and information about their spatial patterns is of

263   paramount importance for conservation planning[45,46]. Previous economic crises have shown

264   positive effects on fisheries[11], or air pollution[12], and have contributed to reduce vessel speeds (i.e.

265   due to fuel price[43]), one of the most effective measures for achieving lower CO_2 and air pollutant

266   emissions, risk of collisions with cetaceans, and to lessen ocean noise[47]. The unprecedented

267   disruption during COVID-19 offers new opportunities for research[1]. Our global assessment is

268   congruent with recent focal studies that have reported reductions of marine traffic in the Port of

269   Vancouver and Venice during COVID-19, resulting in improvements in underwater sound[20] and

270   water turbidity[21], respectively. Such agreement suggests that our global dataset could be used to

271   identify impacted and control locations for comparison in other environmental studies. Our results

272   also suggest that marine protected areas from coastal areas could benefit from a decrease in

273   marine traffic. Equally, an associated reduction of surveillance effort presents a higher risk for

274   potential increases of illicit activities (e.g. illegal fishing, trafficking of drugs), especially in lower-

275   income countries[41,48]. In fact, our results show there were increases in fishing activity in the

276   national waters of low-income countries.

277

278   Changes in marine traffic have been shaped by policy actions related to COVID-19 restrictions

279   on human mobility and reductions of consumer's demand on food and trade. Response of marine

280   ecosystems to COVID-19 will depend on the intensity and duration of the reduction of human

281   pressures. In the northern hemisphere, marine traffic intensity is higher during the boreal summer

282   and AIS data will allow us to monitor the recovery during the coming months. There is, however,

283   a degree of uncertainty around future scenarios and long-lasting impacts. The scientific

284   community needs empirical observations in order to better understand the socioeconomic impacts

285   on maritime sectors and the environmental consequences of COVID-19 on marine ecosystems.

286   The pandemic has also constrained the capacities of research institutions to pursue monitoring

287   programs (e.g. on research cruises) underscoring the need to advance implementation of real-

288   time autonomous monitoring systems to survey the ocean, including anthropogenic impacts.

289   Future AIS studies should address temporal variability of spatial patterns at a global level and our

290   global assessment can be extended forward and backwards in time to facilitate insights into the

291   longer-term impacts of COVID-19. Such assessments will prove essential to allow large-scale

292   monitoring and insights into the effects of the current pandemic, or other global shocks, on the

293   blue economy and ocean health.

294

Methods

295

Stringency Index

296

297   The Oxford COVID-19 Government Response Tracker (OxCGRT) provides a transparent, real-

298   time monitoring system that allows comparison of government measures between countries[49]. In

299   order to account for the variation in containment and closure policies at national level, we used

300   the Stringency Index (Index methodology version 3.1). This index is an additive score of nine

301   policy decision indicators, rescaled to vary from 0 to 100, which records the strictness of the

302   lockdown measures per country. A global average of the Stringency Index indicated that April was

303   the month with the strictest measures experienced across all available coastal countries (n = 133).

AIS data

304

305   The automated identification system (AIS) is a vessel identification system that transmits real-

306   time information on routes of vessels via a VHF transceiver. AIS is required on all ships of 300

307   gross tonnage or more engaged on international voyages, all cargo ships of 500 gross tonnage

308   or more, and all passenger ships irrespective of size. In addition, individual countries may require

309   further AIS usage. For example, AIS is required for EU fishing vessels >15 meters in length.

310   Moreover, AIS is also increasingly used on a voluntary basis by many other vessels, including

311   smaller leisure and fishing vessels. AIS signals can be detected by nearby vessels, terrestrial

312   antennas (T-AIS) or satellite stations (S-AIS). Land-based antennas have a horizontal range of

313   about 40 nautical miles, while S-AIS has global coverage.

314

315   For global analyses, satellite AIS (S-AIS) data for April 2019 and 2020 were obtained from

316   exactEarth Ltd (http://www.exactearth.com/), a space-based data service provider which operates

317   a constellation of 65 microsatellites to provide global AIS coverage at a highly frequency rate (<

318   5 min average update rate). The latest upgrade in the constellation entered into production in

319   February 2019, thus S-AIS coverage was equivalent for both periods (exactEarth Ltd. pers

320   comm.). Values represented the monthly number of unique vessels within grid cells of 0.25 x 0.25

321   degrees. Vessels were classified into five categories: cargo, tanker, passenger, fishing, and

322   "other". The category "other" included any other vessel not covered by the preceding explicit

323   categories (e.g. vessels conducting surveys and logistic services for industry, research vessels,

324   recreational vessels). We calculated the vessel density as the number of vessels per unit area,

325   considering the difference of cell size across the latitudinal gradient[25]. Grid cells from the Caspian

326   Sea and with <10% ocean area were removed from the analysis, based on the GADM Database

327   of Global Administrative Areas (version 3.6, https://gadm.org/). Further quality control procedures

328   included the removal of grid cells with speed values above a given threshold (i.e. 99th percentile)

329   and small clumps of isolated cells (i.e. < 100 cells). Finally, marine traffic density maps were

330   converted to the Mollweide projection with a WGS84 datum as it is an accurate single global

331   projection that preserves geographic area and allows data transfer and analysis among operating

332   systems and software.

333

334   Terrestrial AIS (T-AIS) data from the Western Mediterranean (map inset Fig 5a) were collated by

335   the Balearic Islands Coastal and Forecasting System (SOCIB[50]) using a real-time operational

336   system connected to a web-service provided by Marine Traffic (https://www.marinetraffic.com/).

337   The database used in this study contained AIS data from 1st January 2016 until 30th June 2020

338   at 5-minute intervals (> 545 million AIS messages). In addition to the vessel tracks, the database

339   also included information associated with each vessel, such as the vessel type or length. A first

340   pre-processing of the raw data included the removal of duplicates, invalid identification numbers

341   (i.e. Maritime Mobile Service Identity -MMSI- codes without 9 digits) and codes outside the correct

342   numerical range (i.e. MMSI codes with first digits between 2 and 7 are those intended for individual

343   ships). In order to address inconsistencies in the vessel and MMSI combinations (e.g., changes

344   of MMSI across years), we selected the more frequent combination of MMSI and vessel

345   characteristics (e.g. vessel name and vessel type) for each calendar year. We used a similar

346   vessel categorization as the S-AIS dataset, but were able to derive a sixth category from the AIS

347   metadata, separating "recreational" vessels from "other" vessels. Therefore, vessels were

348   classified into six categories: cargo, tanker, passenger (included high speed crafts and passenger

349   vessels), fishing, recreational (included sailing vessels and pleasure crafts), and others (included

350   all other ship types). We excluded ship type codes 20 to 29 (i.e. wing-in-ground-effect and search

351   and rescue aircraft), as well as codes that had an invalid value (i.e. empty or null) or the value

352   was not listed in the previous type codes. We calculated the number of vessels per day

353   considering only those that were underway, thus removing moored vessels inside ports that were

354   inactive. T-AIS coverage was not homogenous in the study area[51] due to a non-uniformly

355   distribution of antennas (i.e. few antennas in north Africa, see www.marinetraffic.com).

356   Consequently, we filtered vessels within the coastal zone (44.4 km, ~24 nautical miles) of EU

357   countries (i.e. a total area of 164,318.2 km^2 comprised by Spain, France and Italy), thus reducing

358   potential bias due to temporal gaps in signal reception.

359

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].

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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).

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Supplementary Information

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Supplementary Information

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Supplementary Data 1. Average difference in marine traffic density between April 2020 and April

2019 for each EEZ.

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Supplementary Data 2. Average difference in marine traffic density between April 2020 and April

2019 for each High Seas

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Supplementary Data 3. Average difference in marine traffic density between April 2020 and April

2019 for each marine ecoregion.

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409   Supplementary Data 4. Average difference in marine traffic density between April 2020 and April

410   2019 for each FAO area.

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Acknowledgements

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Author contribution

419   D.M. and B.J.G. conceived and designed the study. D.M. performed the analysis. D.M. and

420   B.J.G. wrote the manuscript with input from all authors. All authors gave approval to the final

421   version of the manuscript.

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Competing interests

424   The authors declare no competing interests.

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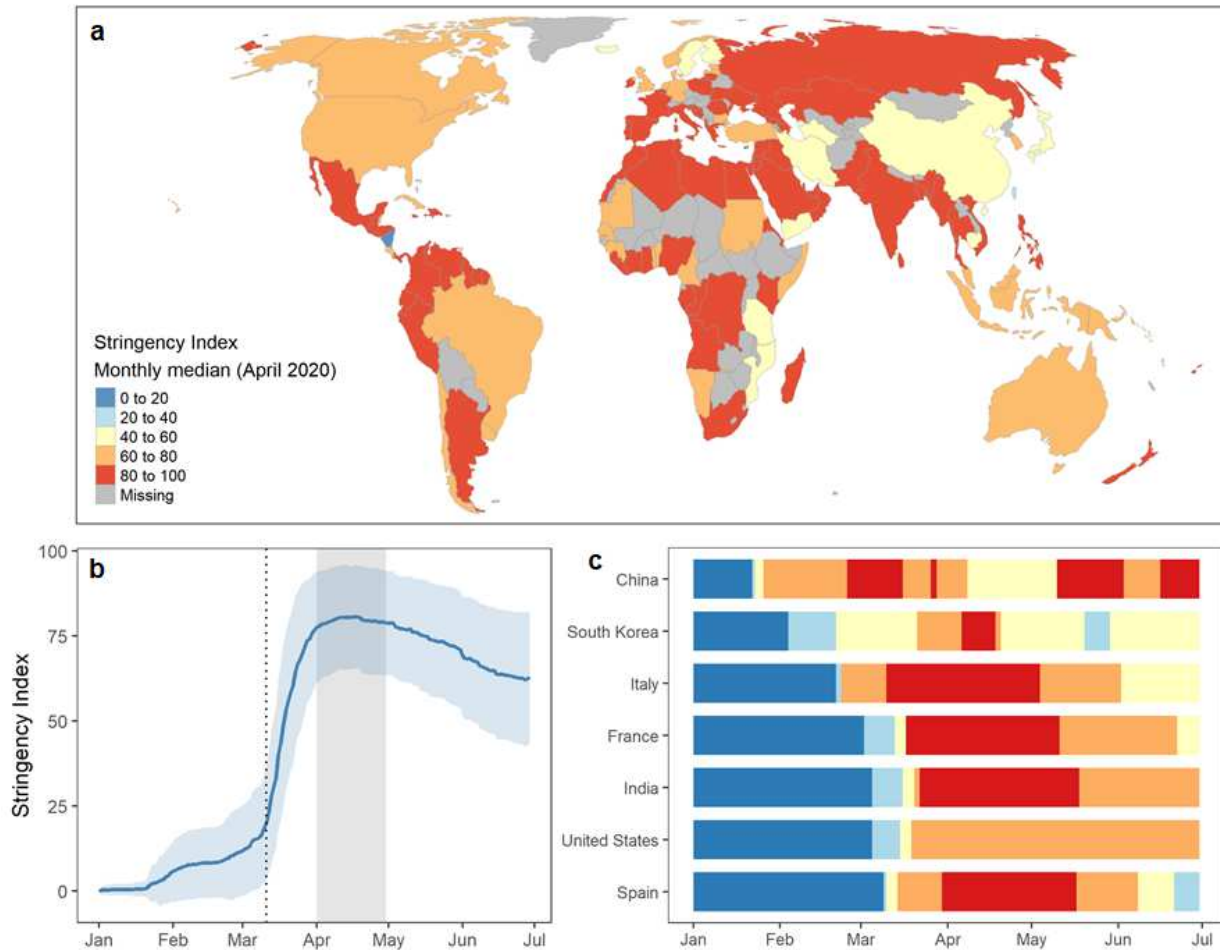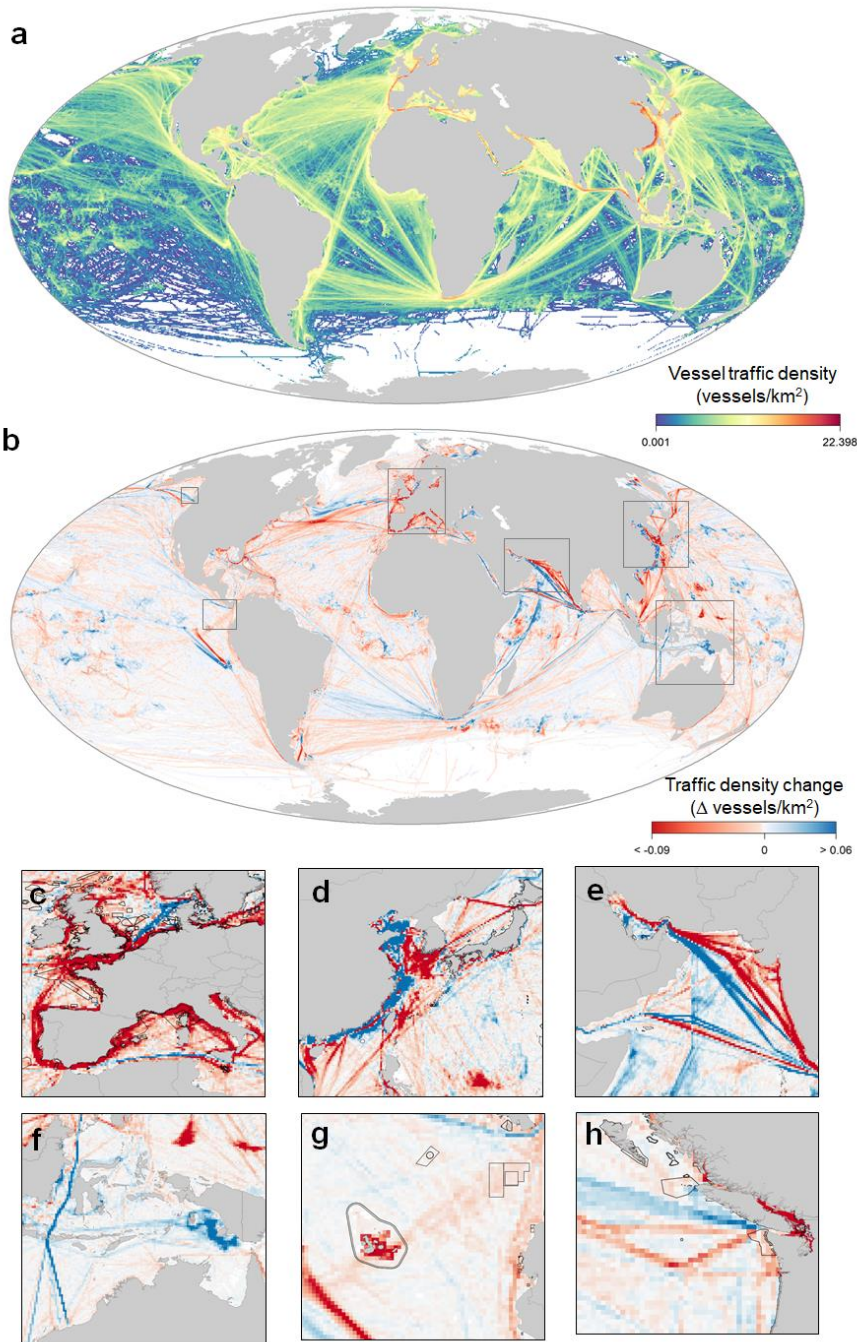557 56. FAO. FAO Statistical Areas for Fishery Purposes. (2019).

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Figures

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

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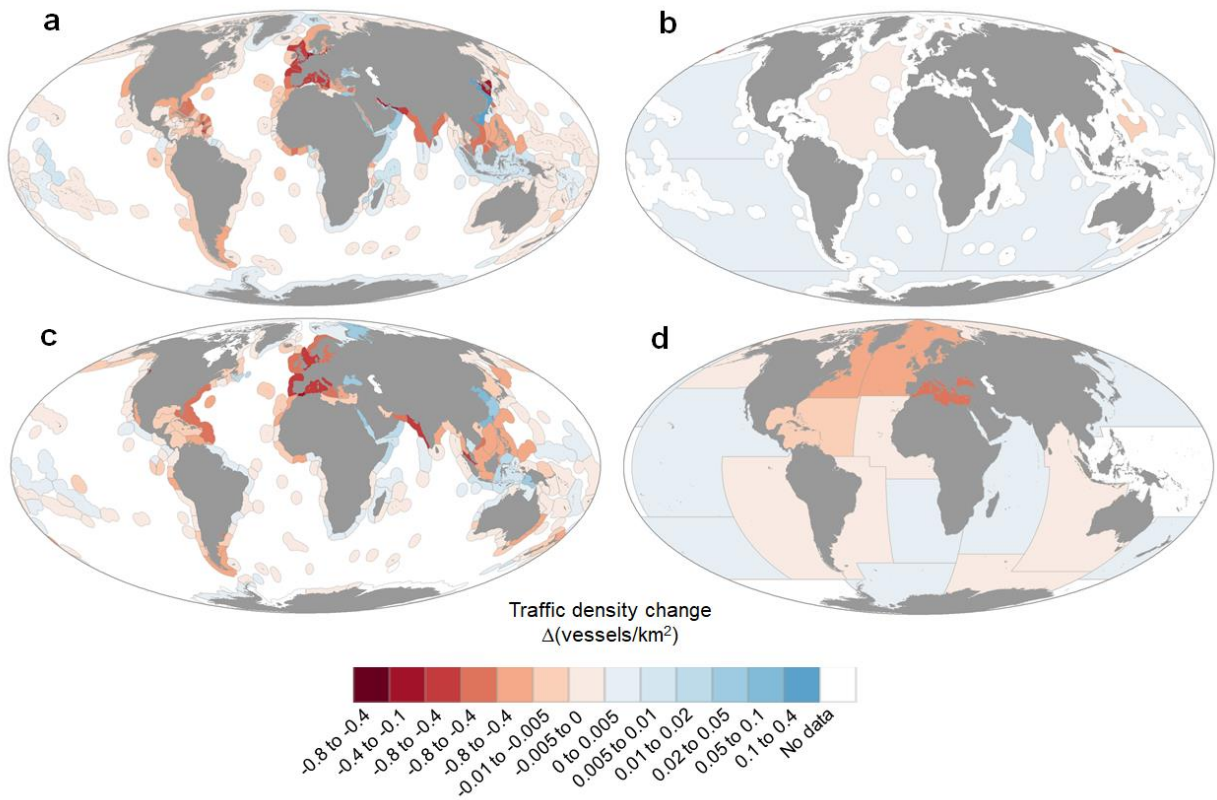
Fig 3. Global changes in vessel traffic density across multiple regions of the ocean. (a)
Exclusive Economic Zones (EEZ; n = 255), (b) Areas beyond national jurisdiction (ABJN; n =
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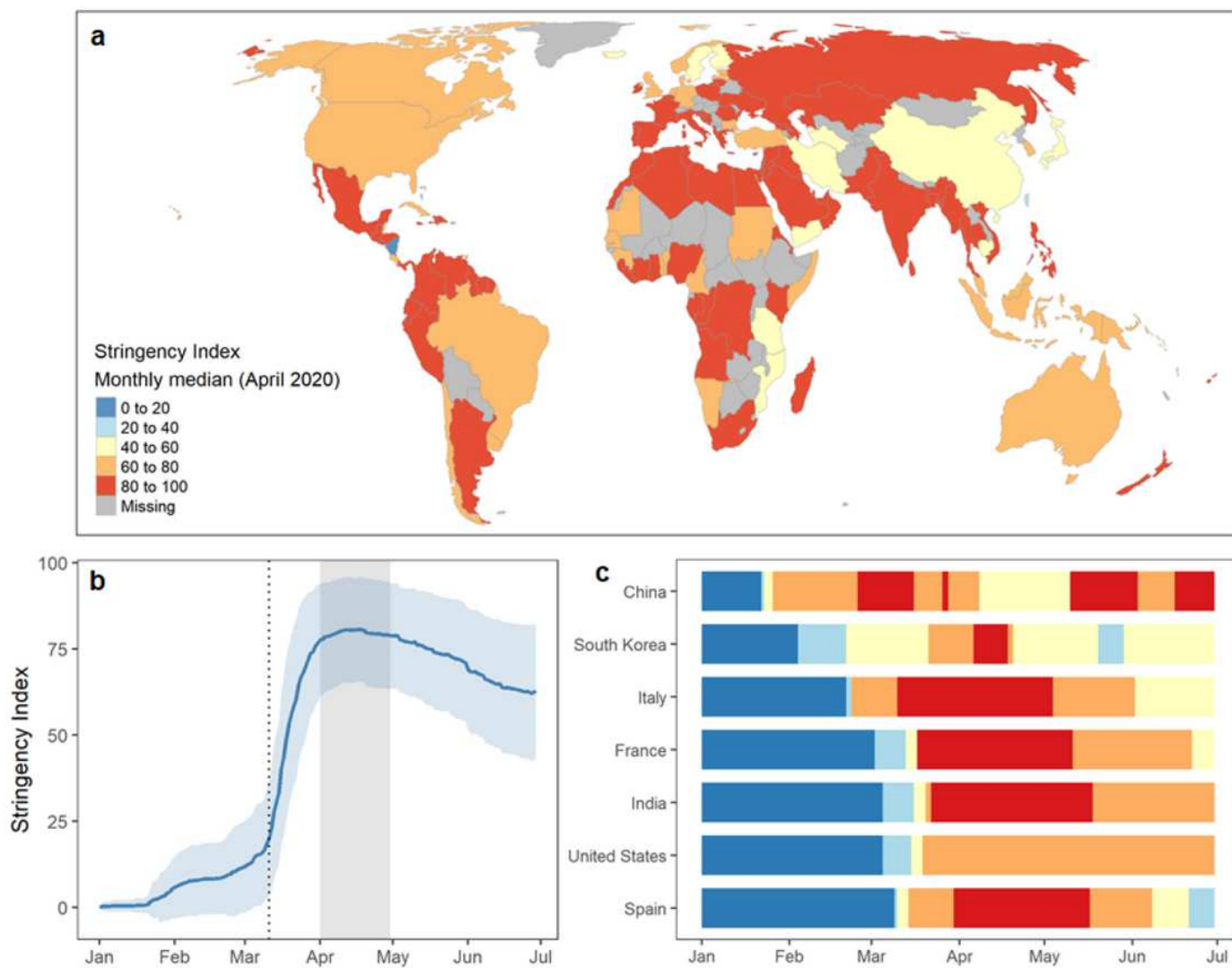(n = 19).

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

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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
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11th March 2020. Blue area in the map inset on part (a) represents the spatial extent of the regional
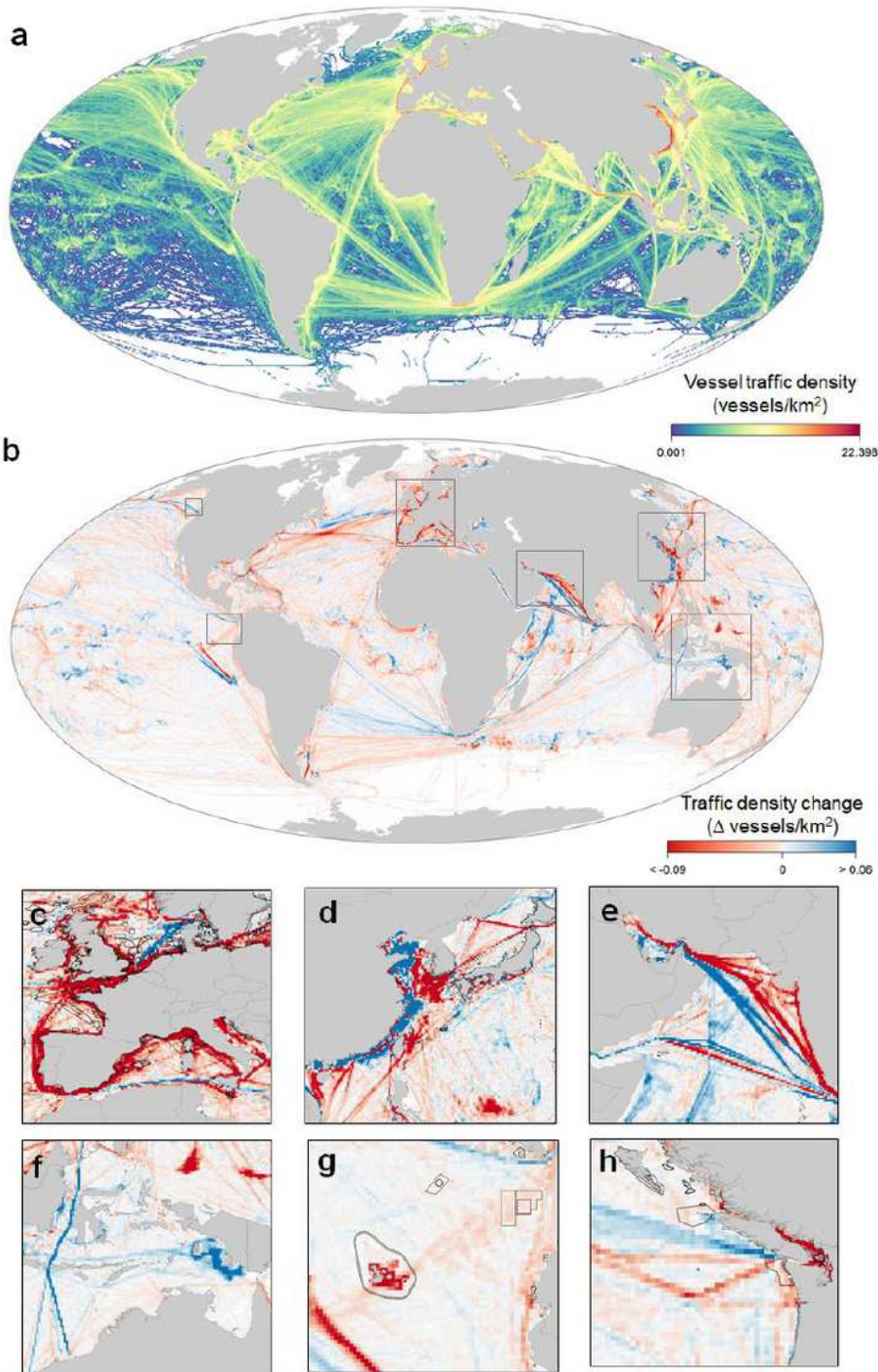AIS dataset.

Figures

Figure 1

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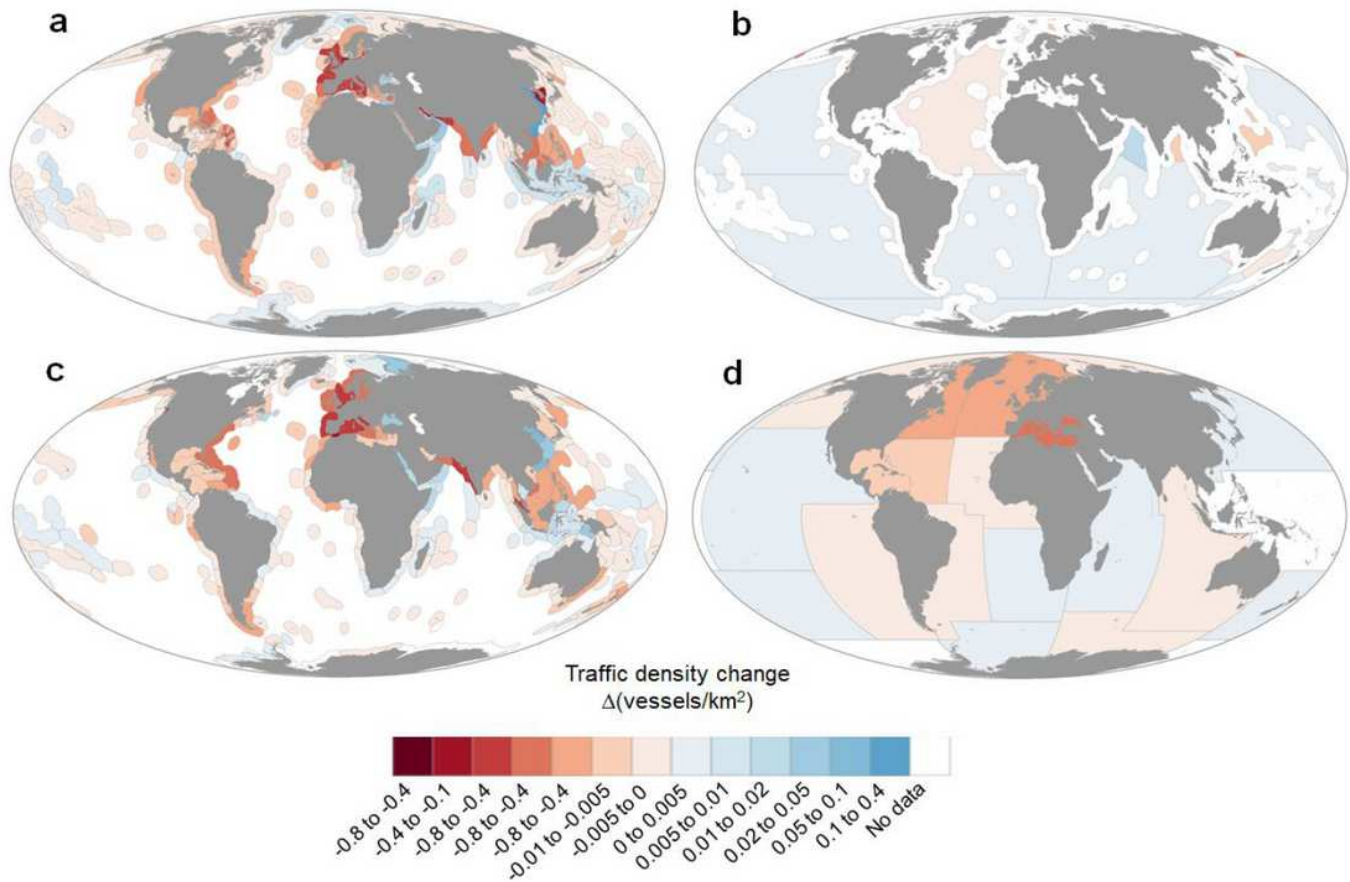
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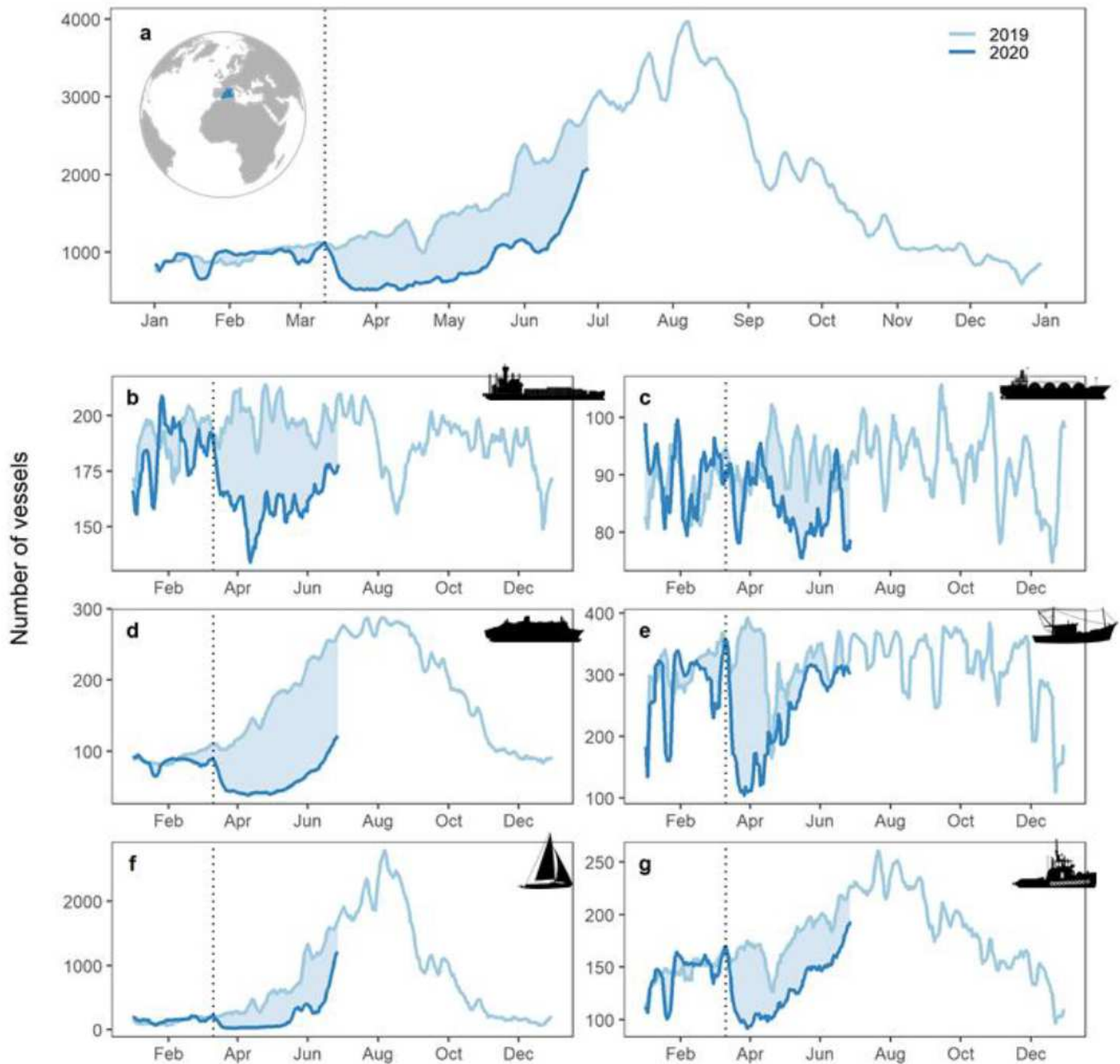

Figure 3

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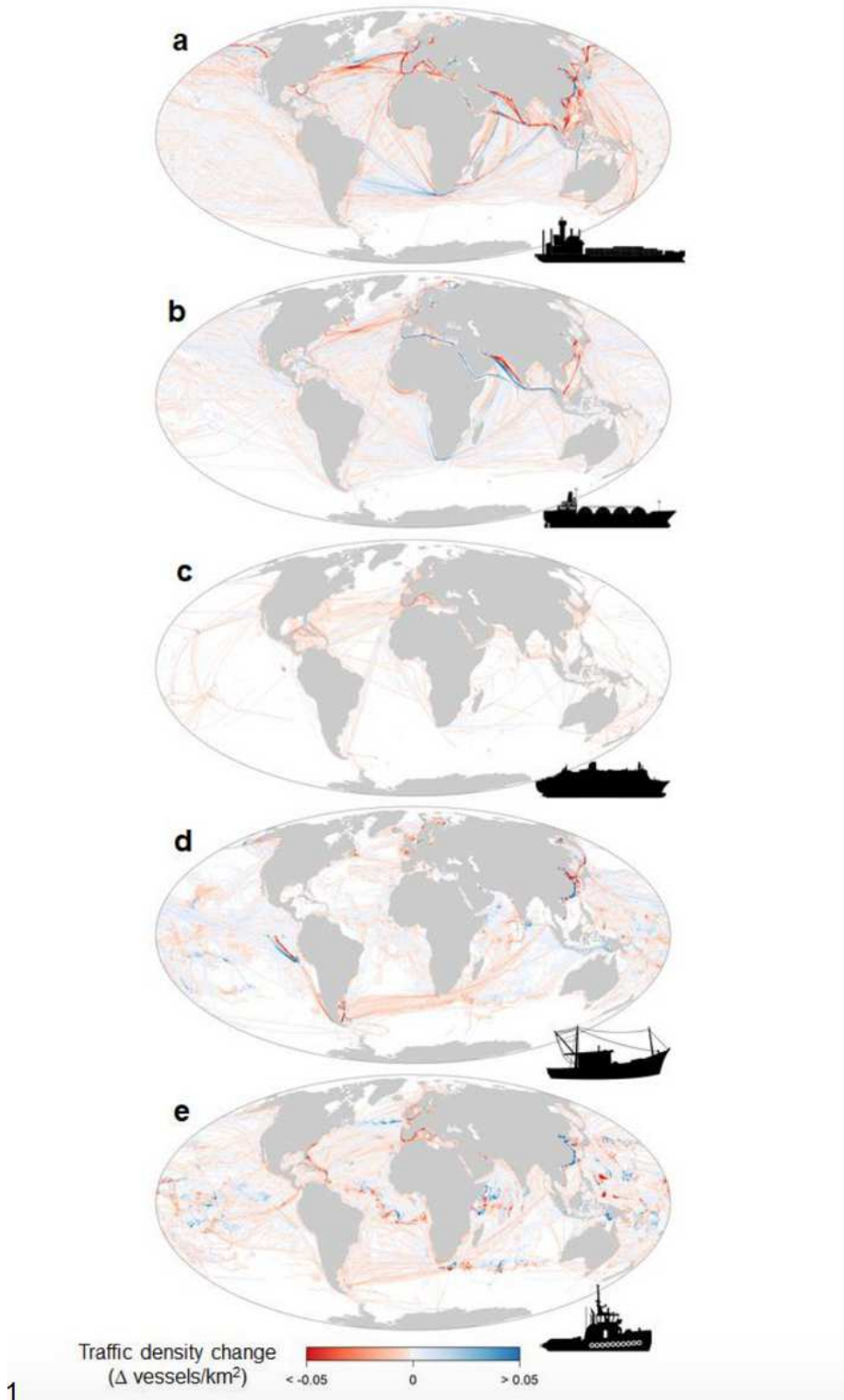
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