Research Article

Current trends in ship movement via the Suez Canal in relation to future legislation and mitigation of marine species introductions

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Abstract

The opening of the Suez Canal in 1869 created a tremendous impact both on the shipping industry, by shortening navigational routes, and on ecological communities in the Mediterranean Sea, by facilitating numerous introductions of non-indigenous species (NIS). These impacts are deeply intertwined as the majority of Mediterranean Sea introductions are ship-facilitated. Here we analyzed shipping data for the Canal between 2011–2018, and characterized the shipping trends of the Canal in relation to global shipping trends and to the introduction of NIS. We differentiated the data analysis between ballast-weighted ships and cargo laden ships according to nine ship categories: Tankers, LNG (Liquid Natural Gas) Ships, Bulk Carriers, General Cargo, Container Ships, Ro/Ro (Roll on/ off) ships, Car-Carriers, Passenger Ships, and Others. We used statistical tests to determine whether the August 2015 expansion influenced shipping trends and discuss our findings with respect to patterns in species introductions. Our findings show that although there has been an increase in tonnage being shipped through the Canal, this is a consequence of an increase in ship dimensions, while the actual number of ships for some categories has decreased. This pattern was particularly evident in the container ship category, which had the highest global growth compared to other ship categories. A few categories, such as bulk carriers and tankers, had more traffic in particular directions of passage. Only passenger ships and bulk carriers revealed significant seasonal transit trends, with higher transfers during spring and autumn for passenger ships and summer/autumn for bulk carriers. An increase in average ship size was evident for almost all categories. Larger ships imply a longer turnover time spent in ports and a larger available wetted surface area that is susceptible to fouling, thus potentially providing a larger fouling community with more time to propagate and settle in a novel habitat. Our findings emphasize the importance of identifying current shipping trends that may pose a threat to the Mediterranean Sea biodiversity in order to construct a follow-on policy to mitigate the transfer and delivery of NIS via the Suez Canal. Specifically, enforcement of antifouling regulations is highlighted as a significant contribution to the European Union Marine Strategy Framework Directive goals to achieve a good environmental status.

Key words: container ships, shipping networks, Mediterranean Sea, fouling control, biofouling, ballast water

Introduction

Since its opening in 1869, the Suez Canal has served as a key waterway of ever-increasing importance. Over ten percent of the world's maritime trade passes through the canal. Following its expansion in 2015, according to some studies the share of world trade transiting the canal is expected eventually to more than double (Kenawy 2015). The world fleet is growing in numbers, with over 90,000 registered ships (UN CTAD 2018a). Moreover, shipping companies are placing orders for ships with increasing dimensions, seeking to maximize profitability with economy of scale (Cullinane and Khanna 2000). The greater capacity and dimensions of ships, that are becoming increasingly common, are forcing ports and facilities around the globe to prepare and adjust their infrastructure to accommodate these ships (Merk et al. 2015). For instance, over 18,000 ships passed through the Suez Canal in 2018, with a total tonnage of over 100 million tons (Suez Canal Authority). The movement of these ships around the world may pose an increasingly serious threat to biodiversity by connecting distant and distinct eco-regions and their biota (Coutts and Taylor 2004; Keller et al. 2011; Seebens et al. 2013). Non-indigenous and invasive species (NIS) are one of five major risks to the world's biodiversity, alongside pollution, climate change, over-exploitation, and habitat destruction (Convention on Biological Diversity 2006). In marine environments, a greater influx of invasive species, caused by a larger world fleet, is expected to pose a growing threat to marine biodiversity (Carlton 2010).

Since its opening, the Suez Canal has facilitated the passage of hundreds of invasive species from the Red Sea into the Mediterranean Sea, resulting in a dramatic change to the Mediterranean Sea biodiversity (Zenetos et al. 2017). According to Katsanevakis et al. (2013), circa 40% of non-indigenous species in the Mediterranean were introduced by means of direct passage through canals and waterways, mainly the Suez Canal, and over 50% of these species were introduced via shipping. Shipping-related introductions can occur in two different ways: by ballast-water discharge or by fouling of submerged ship surfaces. The International Maritime Organisation (IMO) has recognized the importance of ballast water as an invasion vector and has established standards and regulations for ballast-water treatment and discharge protocol. According to the "International Convention for the Control and Management of Ships' Ballast Water and Sediments" (BWM), as of September 2017, all ships must have a specific ballast management plan, keep a record book of ballast discharge, and possess a government issued certificate (International Maritime Organization (IMO) 2017).

However, while ballast-water management has been regulated in order to minimize the transfer of alien species and pathogens, hull-fouling is yet to be thoroughly addressed. The problem is emphasized by the findings of several studies: that fouling is in fact a more common and significant vector of introduction than previously thought (Katsanevakis et al. 2013; Miller et al. 2018). Furthermore, while ballast water is treated as a strictly environmental issue, hull-fouling is also of economic importance, because of its effect on ship drag, speed, and fuel consumption efficiency.

According to the IMO "Ship under water surfaces not protected by anti-fouling systems may gather 150 kg of fouling per square meter in less than six months of being at sea. On a Very Large Crude Carrier with 40,000 square meter underwater areas, this would add up to 6,000 tonnes of fouling." (IMO 2002).

The amount and diversity of fouling organisms varies with ship size, maintenance regime, journey history, and hull design (Coutts and Dodgshun 2007). Especially important are the spatial features of the ship body, such as propellers, sea-chest intake gratings, rudders, and any other feature that may provide protection from the drag and currents that the hull itself faces (Davidson et al. 2009; Gewing and Shenkar 2017). These unique niche areas in the submerged areas of the ship can reach a significant proportion of its wet surface area (WSA) and are key to organism settlement, survival, and later introduction (Moser et al. 2017).

The shipping industry responds to global trends and economic factors, with the impact of the accompanying NIS that are transported by them. Identification of the existing and emerging trends that influence shipping regimes may help to predict the threats to biodiversity caused by NIS introduction (Lenzen et al. 2012; Seebens et al. 2013; Ricciardi 2016). Therefore, the current and expected increase in ship movement in the Suez Canal, along with the increase in ship size and the associated niche areas, may have a significant effect on the influx of NIS into the Mediterranean (Boero 2002; Galil et al. 2015).

The European Union has established a Marine Strategy Framework Directive (MSFD) in which standards have been laid down for the member states in order to maintain a good environmental status (GES). According to the MSFD, by the year 2020 marine invasive species should be kept to such levels that they will not alter the ecosystem (Lyons et al. 2010).

Suez Canal Expansion

When referring to the Suez Canal expansion it is important to note that this expansion actually constitutes the creation of a second canal parallel to the original one. This two-way canal facilitates the simultaneous navigation of ships in both north and south directions and minimizes the waiting time for transiting ships (Figure 1). According to the Suez Canal Authority, the project was intended to increase the total ship throughput capacity of the canal, while reducing transit times. Furthermore, the deepening and widening of the Bitter Lakes and the Ballah bypass enable the passage of ships almost without size limit. The expansion has reinforced the canal's status as a main passageway, appealing to shipping companies by increasing its efficiency and hence reducing the costs for major operators. (Baccelli et al. 2015).

In this study we conducted a meticulous analysis of the shipping data through the Suez Canal between 2011–2018. We present the trends following the expansion of the Canal in August 2015, and discuss our findings with

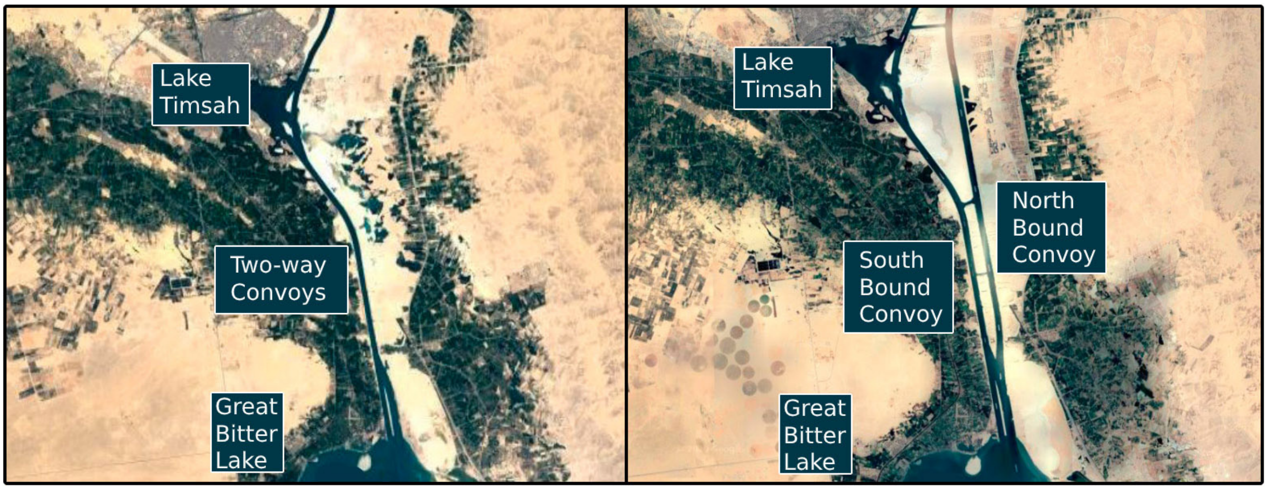

Figure 1. Satelite images (source: Google maps) of a section of the canal prior to (left) and after (right) the expansion, displaying the new second route of navigation between the Bitter Lakes and Lake Timsah in contrast to the one route prior to the expansion.

respect to patterns of biological introductions into the Mediterranean Sea. We further consider the main issues of concern with a view to determining the appropriate tools for management and control of future introductions related to ship movement through the Suez Canal.

Materials and methods

Data on traffic through the Suez Canal were obtained from the Suez Canal Authority official website (www.suezcanal.gov.eg). These data are available for the period of 2011–2018, as monthly summaries. For each month the data are divided between ballast-weighted ships and cargo-laden ships (with cargoes of different types). Whether a ship is ballast weighted or cargo laden will be referred to as "ship type". The data are divided into nine "ship categories" (each category with both ballast and laden types): Tankers, LNG (Liquid natural gas) Ships, Bulk Carriers, General Cargo, Container Ships, Ro/Ro (Roll on/ Roll off) ships, Car Carrier, Passenger Ships (cruise ships), and Others. A tenth category, Combined Carriers appeared only until December 2015, but was later discontinued as a separate category and was therefore removed from the analyses. The data include both "Total ship numbers" and "Total ship tonnage" (Suez Canal Net Tonnage, SCNT). All the data were transferred onto Microsoft Excel 2016 spreadsheets (Supplementary material Table S1). The totals of ship tonnage and ship numbers were used to calculate "Average ship tonnage" per month as a third parameter. These three attributes were plotted to search for specific trends occurring during the studied period. In addition, to accurately quantify the traffic of ships for each ship type, separate analyses were performed.

Direction of passage

An ANOVA test was used to check for significant differences between north-to-south versus south-to-north passages. Separate tests were performed for each ship category and for ship numbers, total tonnage, and average tonnage. Additionally, a model was fit incorporating the ship type (ballast or laden) and its interaction with passage direction. Data for ship count and tonnage were analyzed separately.

Seasonality of passage

A similar test examined seasonality by dividing the period into four seasons (three-month quartiles) and checking for differences between them using an ANOVA model. Again the test was performed separately for each ship category and separately for ship number, total tonnage, and average tonnage.

Ballast vs. Laden Ships

To determine differences between numbers of cargo-laden and ballast-weighted ships data for each ship category, noting ballast-weighted against cargo-laden ships were analyzed with separate ANOVAs. This test was also performed separately for ship number, total tonnage, and average tonnage.

Post-expansion analysis

We also sought to compare the traffic through the Canal prior to and after its expansion in August 2015. Therefore, a general comparison was performed using a two-way ANOVA model, with indicators for before or after expansion and ship category as a contrasting factor. In order to further characterize the differences before and after the Canal expansion, a linear regression model was fitted for the number of ships against the number of months passed since starting the observations. The model predicts traffic after August 2015 using the data on traffic prior to the expansion. By subtracting the model-predicted traffic from actual traffic numbers, the difference can indicate whether the trend and pace of trend are similar or different. A difference between predicted and actual numbers may indicate that a certain category has been affected by the Canal's expansion.

Statistical analyses were performed using rStudio 1.1.463 (R core team Vienna, Austria) using R 3.4.0 and package ggplot2 (www.tidyverse.org). Full ANOVA results are provided in Table S2.

Results

General trends

Our complete database of ship movement via the Suez Canal between January 2011 and December 2018 documented movements of over 121,000 ships in total (Table S1). Table 1 and Figures 2 and 3 show general trends and changes in the traffic through the Suez Canal between 2011 and 2018 for each ship category. Specific ship categories displayed different trends throughout the observation years. For example, container ships decreased in total ship number but increased in total tonnage, resulting in an increase

Table 1. General comparison of traffic in the Suez Canal between first year of observations (2011) and last year of observations (2018). Numbers are yearly totals for both passage directions and for both ship types (ballast and laden).

Ship Type	# of Ships			Total Tonnage (1000 Ton)			Average Ship Tonnage		
	2011	2018	Change (%)	2011	2018	Change (%)	2011	2018	Change (%)
Container Ships	7179	5706	−20.52	519299	631154	+21.54	72.33	110.61	+52.91
Bulk Carriers	2601	3821	+46.90	83529	137611	+64.74	32.11	36.01	+12.14
LNG Ships	1083	691	−36.19	121831	73481	−39.68	112.49	106.34	−5.47
General Cargo	1394	1330	−4.59	15142	14537	−3.99	10.86	10.93	+0.62
Tankers	3509	4724	+34.62	115186	212009	+84.05	32.82	44.88	+36.72
Car Carrier	1013	868	−14.31	60490	54813	−9.38	59.71	63.15	+5.75
Ro/Ro	255	315	+23.53	5479	7656	+39.73	21.48	24.30	+13.11
Passenger Ships	96	96	0	2908	4009	+37.86	30.29	41.76	+37.86
Others	653	623	−4.59	4102	4359	+6.26	6.28	6.99	+11.38
Total	17783	18174	+2.19	927966	1139629	+22.80	378.40	444.98	+17.59

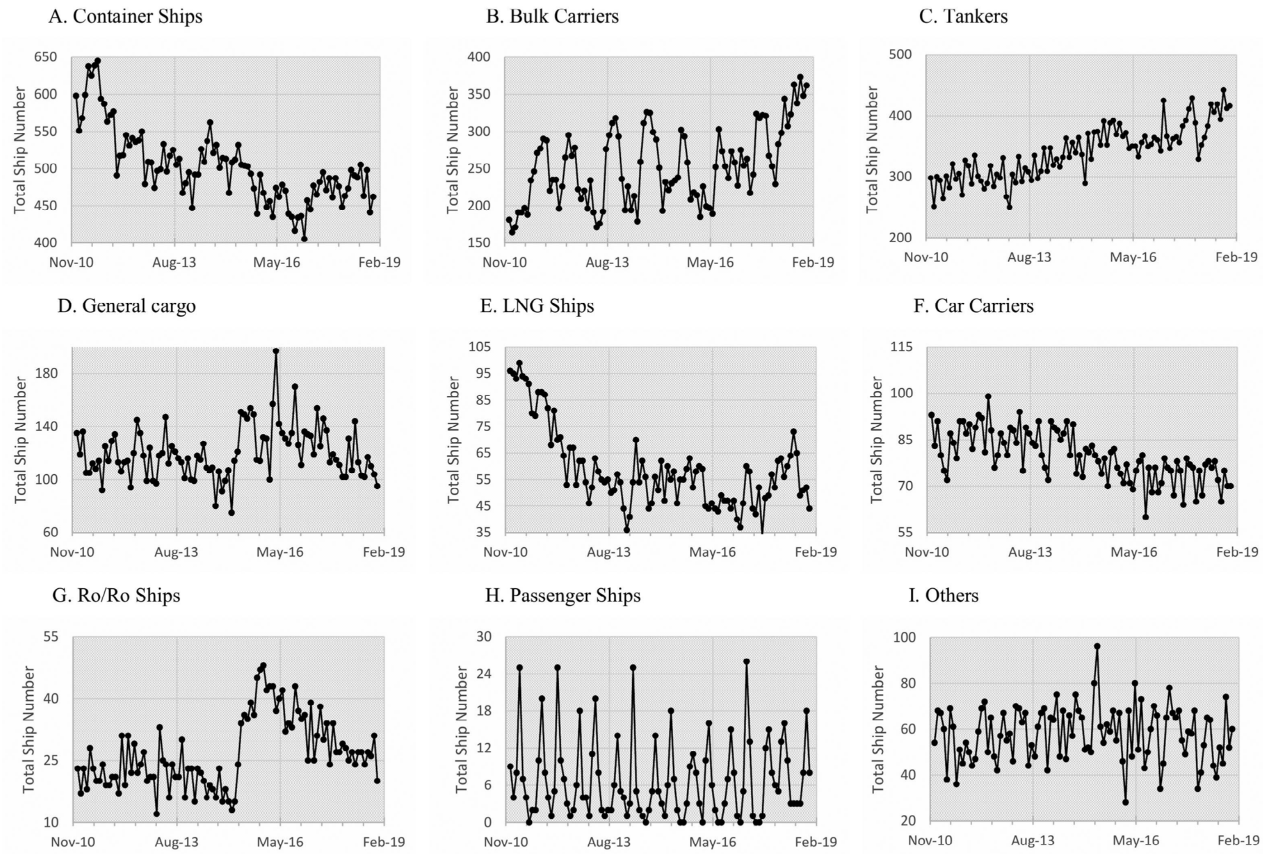

Figure 2. Transit of ships across the Suez Canal between January 2011 – December 2018. Y axis represents total ship numbers (summing both directions and both ship types, laden and ballast-weighted). Charts are separate for each ship category: A – Container Ships, B – Bulk carriers, C – Tankers, D – General Cargo Ships, E – LNG ships, F – Car Carriers, G – Ro/Ro ships, H – Passenger Ships, I – Others (notice different scales for the Y axis).

in average ship tonnage of over 50%. Bulk carriers, tankers and Ro/Ro ships displayed an increase both in ship number and in tonnage. LNG ships, general cargo ships, and car carriers displayed a decrease in both ship number and total tonnage. Passenger ship numbers did not change, although total tonnage and average ship tonnage increased by over 37%. (Table 1).

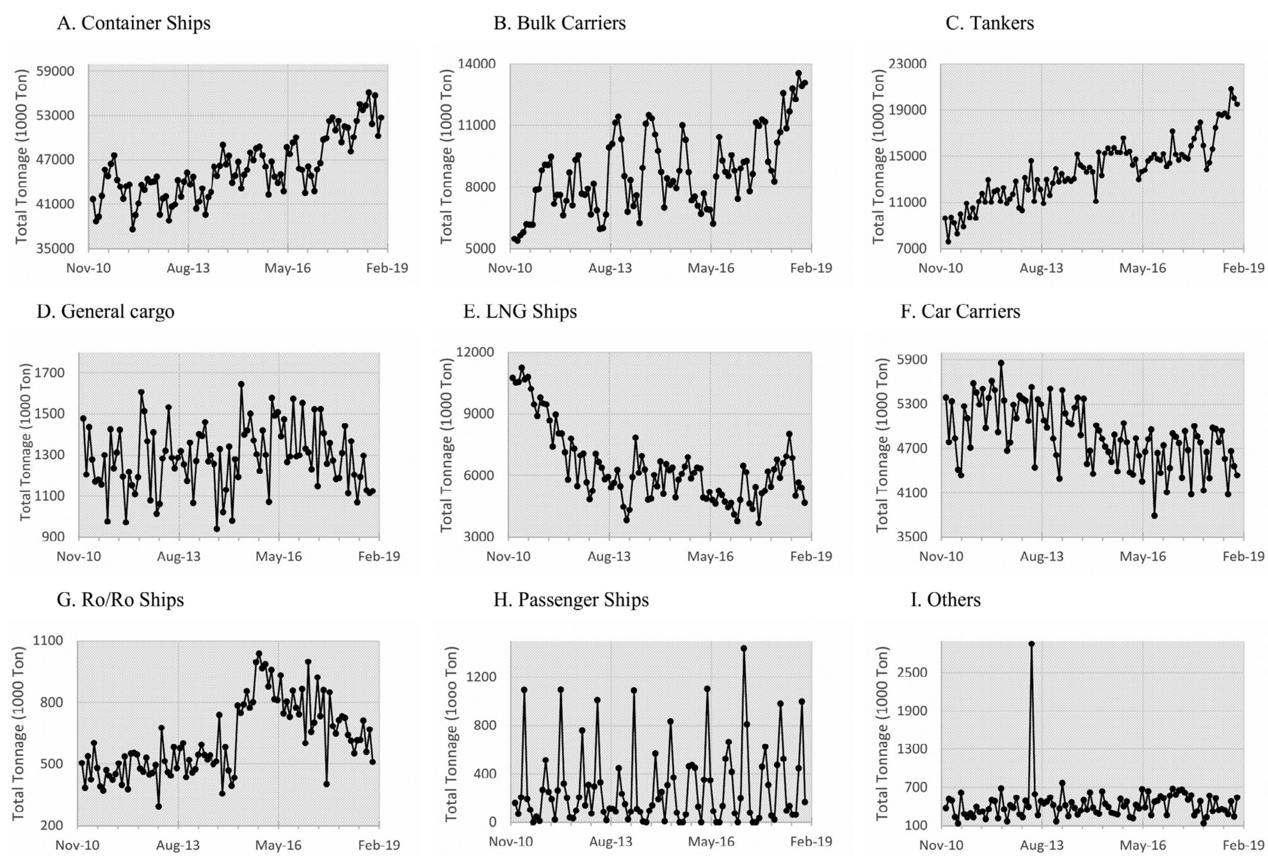

Figure 3. Total tonnage (in 1,000 tons) of ships across the Suez Canal between January 2011 – December 2018. Y axis represents total tonnage (summing ships from both directions and from both ship types, laden and ballast-weighted). Charts are separate for each ship category: A – Container Ships, B – Bulk carriers, C – Tankers, D – General Cargo Ships, E – LNG ships, F – Car Carriers, G – Ro/Ro ships, H – Passenger Ships, I – Others (notice different scales for the Y axis).

Sailing direction

There were no significant differences (more traffic going one way or another) between ship direction (north-to-south *vs.* south-to-north, two-way ANOVA, $p > 0.05$) in either the total number or the total tonnage for the majority of ship types (Figure 4), suggesting no overall differences in direction of traffic. For some categories, however, significant values were obtained, suggesting that there is more traffic of ships or tonnage in a certain direction. Bulk carriers (traveling north more than south) and tankers (traveling south more than north), showed significant differences for direction for the total ship count ($p < 0.01$ for both) and tonnage ($p < 0.01$ for both) as well as average tonnage ($p < 0.01$ for both). Car carriers (more south-to-north) and general cargo (more north-to-south) revealed significant differences only for ship number ($p < 0.01$ for both) and tonnage ($p < 0.01$ for both). The interaction between direction and type was non-significant ($p > 0.05$) for both tonnage and ship numbers, suggesting there is no relation between passage direction and whether a ship is weighted by cargo or ballast.

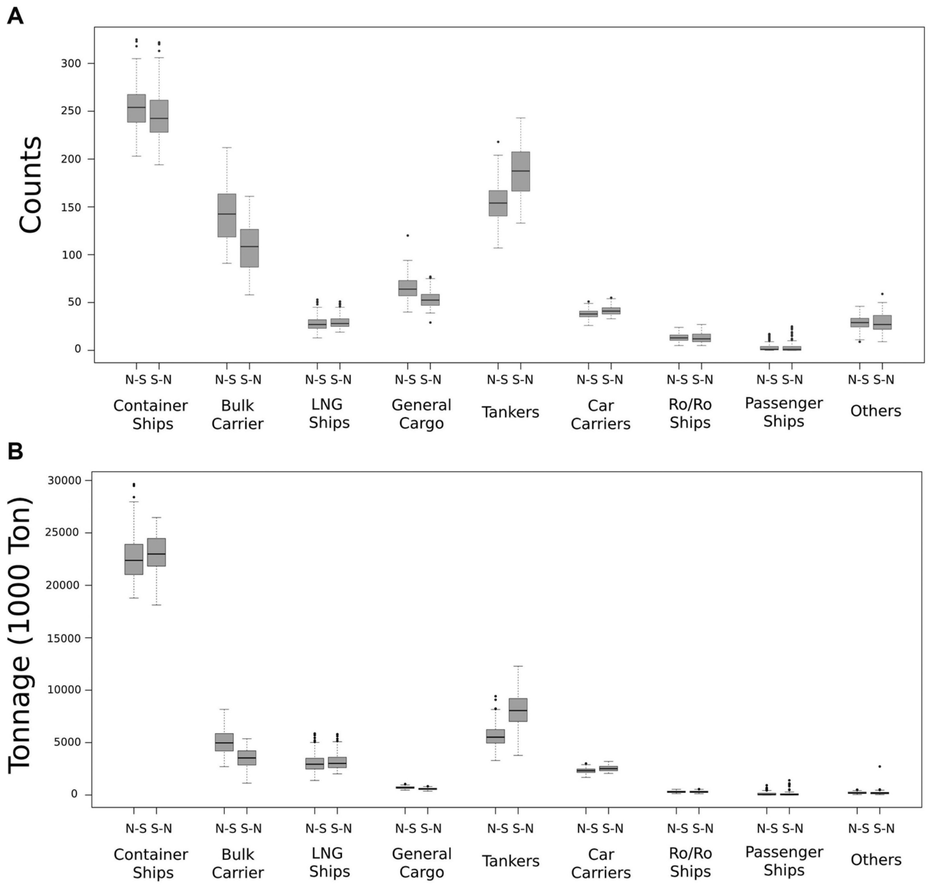

Figure 4. Ship passage direction, each boxplot represents monthly average for number of ships (a) or total tonnage (b) for each direction (plus standard deviation). Separated by ship category as a total sum throughout the years of observation. N – North, S – South.

Shipping seasonality

Seasonality was found to be significant for both passenger (cruise) ships, with higher values in spring and autumn, and for bulk carriers, with higher values in summer and autumn, for both tonnage (p < 0.01) and ship number (p < 0.01), suggesting more ships and more tonnage cross the Canal in certain seasons.

Highest values for Bulk carriers were during autumn 142.12 ± 86.96 std ships over a tonnage of 4,958.06 (1000 tons) ± 3,075.73 std *vs.* lowest values presented in spring of 110.69 ± 83.68 std ships over a tonnage of 3836.71 ± 2907.85 38 std (1000 tons). Passenger ship numbers had highest values during spring of 5.42 ± 6.86 std ships weighing 259.38 (1000 tons) ± 385.59 std and lowest during summer of 0.71 ± 0.82 std ships weighing 21.81 (1000 tons) ± 34.97 std. Container ship tonnage had highest values in summer of 24042.21 (1000 tons) ± 24254.56 std and lowest in winter of 21629.52 (1000 tons) ± 21877.84 std. For RO/RO ships total ship number had highest values in autumn of 14 ± 13.48 std ships and lowest in winter of 12.75 ± 12.79 std (tonnage was non-significant), indicating that for these categories there is a season with the highest number of ships crossing. For all other analyses, seasonality was not significant (Figure 5).

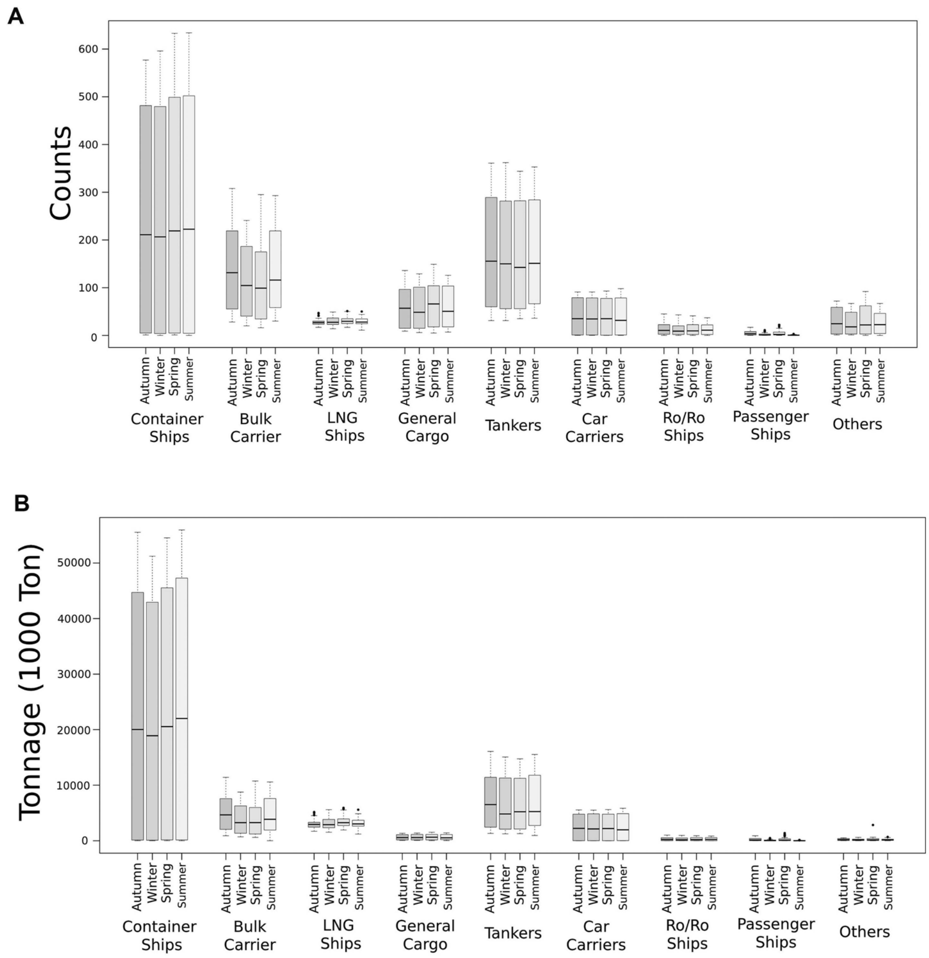

Figure 5. Ship seasonality, each boxplot represents seasonal (quartile) average for number of ships (a) or total tonnage (b) for each quartile (plus standard deviation). Separated by ship category as a total sum throughout the years of observation.

Ship types – Ballast vs. Laden

A comparison of ships in ballast-weighted *vs.* cargo-laden ships by types, proved significant for all categories, indicating that there are more cargo-laden than ballast-weighted ships ($p < 0.01$). As an example of the smallest difference the monthly ship number average difference ranged from 26.96 (± 8.6 std) ballast-weighted ships against 31.89 (± 7.33 std) cargo-laden ships for the LNG ships category; while the largest difference was 4.77 (± 2.39 std) for ballast-weighted and 498.17 (± 49.37 std) for cargo-laden ships in the container ship category.

New Suez Canal effect regression model

The regression model used to predict traffic after the Canal's expansion showed for certain ship categories the pace of traffic increase after August 2015 remained constant, while for other categories there was an increase or decrease in the pace predicted by the model (Figure 6). The model showed a bias towards an increase or decrease in movement for several ship categories. For example, general cargo and Ro/Ro ships that demonstrated increasing trends in movement, also had a bias towards further increase

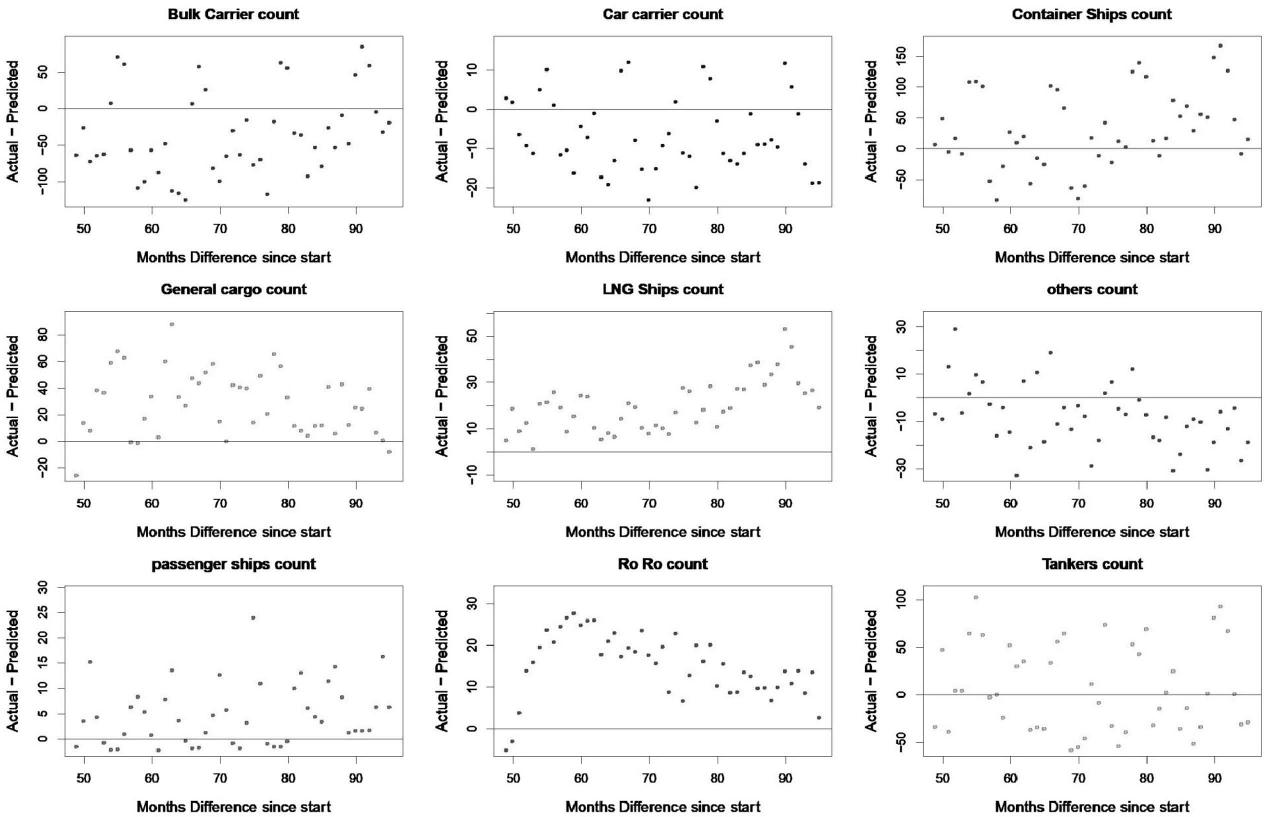

Figure 6. Regression model predicting Canal traffic following its expansion (August 2015) derived from traffic prior to the expansion. The y = 0 line depicts an accurate prediction, points above it suggest a growing trend, and vice versa. X axis is months after beginning of observations, Y axis is difference between actual and model-predicted values.

(above y = 0 line) suggesting their increase had become more rapid after the expansion. Other increasing movement categories such as bulk carriers and tankers did not demonstrate such bias, indicating that the pace of increase had remained similar and was not affected by the Canal's expansion. Categories of decreasing numbers, such as for container ships and LNG ships, also appear noticeably above the y = 0 line, suggesting that although they continued to decrease after the expansion, this was at a more moderate pace. The tankers, passenger ships, and "others" categories presented no discernible bias, suggesting that their traffic and movement trends were not influenced by the Canal's expansion. The two-way ANOVA model revealed significant ($p < 0.05$) results for all categories except the passenger ships and the 'others' category, indicating for the rest of categories a significant difference in traffic before and after the Canal expansion.

Discussion

As the global economy and connectivity continue to expand, the vast chain of supply and demand for goods is also expanding. The maritime shipping industry, as the main transporter of goods, is becoming more prevalent and dominant than ever before (UN CTAD 2018a). Canals and waterways can shorten previously long sea voyages, reducing costs and connecting vastly distant countries and regions (Mostafa 2004). Not only do they enable the transport of commercial goods, but they have also proven crucial in transferring alien and invasive species, altering the ecosystems along the shipping routes (Carlton 2010; Chapman el al. 2017). Marine bioinvasions have distinct implications for the economy, health, welfare, and local biodiversity (Lovell et al. 2006; Olenin et al. 2007; Pysek and Richardson 2010). The identification of those industries and economic trends that exert a greater influence on bioinvasions can assist decision-makers and policy-makers to prioritize and legislate in such a way that will help to mitigate future invasions (Lenzen et al. 2012).

Our analyses of the shipping data through the Suez Canal have revealed current trends in the maritime traffic and how these vary according to ship category. According to UN CTAD (2018a) in 2017 alone the volume of global maritime trade exhibited a 4% total increase. This pace of increase was expected to repeat in 2018 and to remain at a similar level of annual growth until 2023 at least. However, the global COVID-19 crisis may significantly influence this prediction. The 4% increase is evident mainly in the two most dominant shipping categories globally, bulk carriers and oil tankers. In light of the above, the general cargo category is facing a relatively small decline (1%) as a transition towards more specialized vessels is evident. Trends for the Suez Canal mirror those seen worldwide, with a general trend towards an increase in the intensity of shipping. Indeed, our findings revealed that bulk carriers, tankers and Ro/Ro ships in the Suez Canal reflected the increase in both ship numbers and in tonnage. Categories such as LNG ships, general cargo ships and car carriers seem to be in a decline in numbers in the Suez Canal. Moreover, in 2017 global containerized trade has increased by 6.4% compared with 2016, representing the largest increase among all the ship categories. Container ships have gained importance as a major shipping method, demonstrating a growth from 2% of maritime traffic in the early 1980s to over 17% in 2018 (UN CTAD 2018b). However, as previously discussed in Shenkar and Rosen (2018), the expansion of the global economy and of traffic through the Canal for container ships is not expressed in more ships but, rather, in greater tonnage. During the seven years of observations, total tonnage of all transit through the Suez Canal increased by 22%, almost half of that increase in 2017 (compared to 6.4% global). However, container ship numbers increased by only 2% (Table 1). Most noticeable is the net decrease in the number of container ships passing through the Canal, in spite of a vast increase in the total tonnage transferred by containerized shipping. This receives further reinforcement from the 52% increase in tonnage of the average container ship passing through the Canal. Considering the fact that container ships carry over 50% of the global cargo movement through the Canal, a higher ship tonnage means a bigger ship and potentially more niche areas to be colonized by fouling organisms (Muirhead et al. 2015; Miller et al. 2018). The importance of container ships as a main focal point for the expected transfer of non-indigenous species is magnified by the route networks of mainliners and feeder vessels connections along the route (Shenkar and Rosen 2018).

While the direction of passage and transit seasonality proved insignificant for the majority of categories, those ship types demonstrating a bias towards a particular direction or season may play an important role in the influx of invasive species if these correspond to the breeding seasons or increased directional passage of ships (Seebens et al. 2013; Ricciardi 2016). The seasonality of passenger ships (cruise lines) may be of special interest as this remains constant, coinciding with the seasons of tourism. While the number of passenger ships crossing the Canal did not increase in our findings, their average capacity (total tonnage divided by number of ships) increased by over 37%. Passenger ships have substantial water treatment systems for on-board production, waste-water treatment and bilge water collected from machinery spaces. Indeed, Miller et al. (2018) noted that passenger ships have the largest percentage of wetted surface area that can function as hospitable niche areas for fouling organisms (27%). Larger cruise ships provide larger niche areas for fouling organisms, which may further facilitate the introduction of non-indigenous species.

The majority of ships of all categories traveling via the Suez Canal do not use ballast water to stabilize the ship as they travel with cargo (laden). The annual average number of ships transiting the Canal is 15,374 ± 404 std for cargo-laden ships and 1,976 ± 120 std for ballast-weighted ships. While ballast treatment and exchange regulations are already under active steps of implementation toward a reduction in invasive species' success (Paolucci et al. 2017), the regulation of ship hull-mediated invasion is still lacking in Mediterranean countries and in the EU, despite the recognized contribution of such invasion to the global introduction of non-indigenous species (Frey et al. 2014; Davidson et al. 2016).

Post-expansion predictions

Based on the difference between regression model predictions and the actual transport data, we were able to demonstrate that the Suez Canal expansion in 2015 has indeed contributed to the faster pace of increase in the traffic of certain categories (Ro/Ro and general cargo ships). Moreover, the model indicates that the Canal expansion has also influenced the pace of decline in the number of container and LNG ships. In other categories the expansion seems to have had a more subtle influence. Future comparisons to shipping data from locations that remained unaffected by the Canal expansion will provide additional insights into this effect.

Even though some effects may still appear unclear, the importance of the canal expansion for the introduction of alien species cannot be ignored. The Suez Canal has already facilitated the flow of *ca*. 50% of over 800 invasive species into the Mediterranean (Zenetos et al. 2017; Bonanno and Orlando-Bonaca 2019) by dispersal alone. In recent years, shipping-mediated introductions, mostly by biofouling, are becoming increasingly prevalent compared to other pathways (Katsanevakis et al. 2013). For example, a sedentary polychaete, *Mercierella enigmatica* (Fauvel, 1923), has been found along the Croatian shores of the Adriatic Sea near port facilities, suggesting shipping-mediated introduction (Cukrov et al. 2010). Another example is an amphipod *Paracaprella pusilla* (Mayer, 1890), which was found in the Balearic Islands. This species is associated with fouling organisms such as hydrozoans, bryozoans, and algae and it is suggested that it has been introduced in association with these organisms (Ros et al. 2013). It is important to note that following the Canal expansion, the number of new species introductions has remained relatively low and constant: 4–5 new published species records per year, in comparison to 8–12 species per year between 2010–2014 (EASIN 2019). These numbers too need to be taken with caution as the study of NIS has its own flows and time-lags (Bonanno and Orlando-Bonaca 2019), furthermore, the expanded Suez Canal has yet to reach its projected capacity (Kenawy 2015).

Though the larger Canal allows for a greater volume of traffic, our data demonstrate that the number of ships has not in fact increased more than expected in accordance with the standard economic growth for most categories and for the overall trend. However, the larger Canal allows for the passage of ships of larger dimensions (Kenawy 2015), as reflected in ultra-large container ships, (ULCSs Cullinane and Khanna 2000; Merk et al. 2015) which however are relevant only for the East-Asia–Europe trade through the Suez Canal, as they are too large even for the expanded Panama Canal (Galal 2015; Merk et al. 2015). As noted previously, large ships contribute to an overall larger wetted surface area containing larger hospitable niche areas within it (Moser et al. 2017). The effects of a larger niche area on the fouling biota and their ecology and complexity are not yet fully understood (Coutts and Taylor 2004; Chapman and Underwood 2019). Furthermore, these ships require longer port operation time which may also facilitate successful invasion (Davidson et al. 2009; Yahalom and Guan 2018). This potential novel increased influx of fouling organisms on the bottom of commercial ships into the Mediterranean may pose an emerging threat to biodiversity that has yet to be addressed by legislators and policy-makers. It seems that in the first four years since the Suez Canal expansion the extent of traffic increase is yet to reach the projections. However, supply, demand, tonnage of goods, and dimensions of ships are expected to continue to increase to the maximum that port facilities and waterways will allow (Cullinane and Khanna 2000; Noble 2019). Rocha et al. (2017) have demonstrated that some alien species are more tolerant than the native species to environmental fluctuations in salinity and temperature, both in the adult and larval life stages. Additional findings have shown that invasive species tend to be more tolerant to environmental stress (Lenz et al. 2011) and to pollution than the indigenous species (Piola and Johnston 2008). This increased tolerance suggests that the 12–16 hours that it takes for a ship to cross the Suez Canal (SCA 2019) will not prove to be a sufficient abiotic barrier to halt the introduction of non-indigenous species, even though its waters and the waters of its lakes are in poor ecological condition (El-Serehy et al. 2018a, b). This presumption is reinforced by the fact that the Canal and its lakes are themselves filled with alien species (Halim and Abdel Messeih 2016). Furthermore, as suggested by Raitsos et al. (2010) anthropogenic degradation alongside a suitable salinity and temperature regime may in fact facilitate and enhance the accumulation of tropical marine alien species, rather than act as a barrier as previously suggested (Galil et al. 2018; Por 1978). Moreover, the expanded Canal enables shorter waiting times in anchorage before entering the Canal and reduces the need for long stationary periods of waiting in the Bitter Lakes as was customary prior to the expansion that enabled the two-way transit (Figure 1). The transit itself through the Canal is now more efficient and uninterrupted, which may also contribute to the fouling organisms' establishment and survival.

Once established, alien species are extremely difficult to eradicate, with little proven success in doing so in marine ecosystems (Giakoumi et al. 2019). The accurate identification of emerging shipping trends on a global scale, and via the Suez Canal in particular, may significantly promote the understanding of the local scientists and policy makers regarding shipping-related biosecurity threats to the Mediterranean Sea. Once potential threats are properly recognized, proper legislation and enforcement are the best method to prevent the introduction of new non-indigenous species, whose effects at this point we can only speculate.

Conclusions

On the basis of our research and analyses we urge the Mediterranean countries and EU legislators to take careful note of the possibilities of hull-fouling-mediated bioinvasion through the new Suez Canal. Legislation and its proper enforcement may be the only way to mitigate the threat of invasive species (Lehtiniemi et al. 2015; Epanchin-Niell 2017). Approaches to hull-fouling policy already exist in countries like New Zealand and Australia, where ships are requested to prove having a "clean hull" with respect to ship category and origin (Brenton et al. 2016; New Zealand 2018). The Mediterranean region, lacking similar policies can benefit greatly from such implementation, which may help to stabilize and restore ecosystems and meet the MSFD target for an overall good environmental status (MSFD 2018).

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Supplementary material

The following supplementary material is available for this article:

Table S1. Excel spreadsheet of the full dataset extracted from the Suez Canal Authority regarding ship numbers and tonnage between 2011–2018.

Table S2. Statistical results.

This material is available as part of online article from:
http://www.reabic.net/journals/mbi/2020/Supplements/MBI_2020_Bereza_etal_SupplementaryMaterials.xlsx