

## Viewpoint

# How has the invention of the shipping container influenced marine bioinvasion?

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## Abstract

The advent of container vessel networks has revolutionized global freight transport. While numerous studies in various disciplines such as economics, law, geography, engineering, and more, have discussed the impact of the “Container Revolution”, we would like to share our insights here regarding the impact of container shipping networks on current and potential future trends in marine bioinvasion. We discuss the shift in centers and routes of high shipping intensity, and the importance of “Hub” versus “Feeder” ports, in relation to potential invasion routes. The increasing use of Ultra-Large Container Vessels (ULCV) worldwide is leading to further change in introduction dynamics: fewer vessels are now required for the transshipment of goods, as evident from our analysis of vessel movement via the Suez Canal.

An investigation of adapted maintenance regulations is thus required in order to prevent the spread of alien species as fouling communities on particular niche areas of ULCVs. ULCVs further advance the hub-and-spoke network. Hub ports are characterized by the close physical proximity of large vessels (intercontinental mainliners) to many smaller vessels (feeders), calling in at local ports, as well as to other large vessels. This vessel interface occurs on a regular repetitive weekly cycle within a relatively small maritime environment. Thus a systematic network of potential vectors of bio-invasion is being established on both regional and continental levels. The increasing development of large container ports globally, and of larger vessels, demands a thorough investigation of their effect on bioinvasion potential. An integrated study of both the commercial and the biological networks is thus essential in order to fully comprehend their interaction.

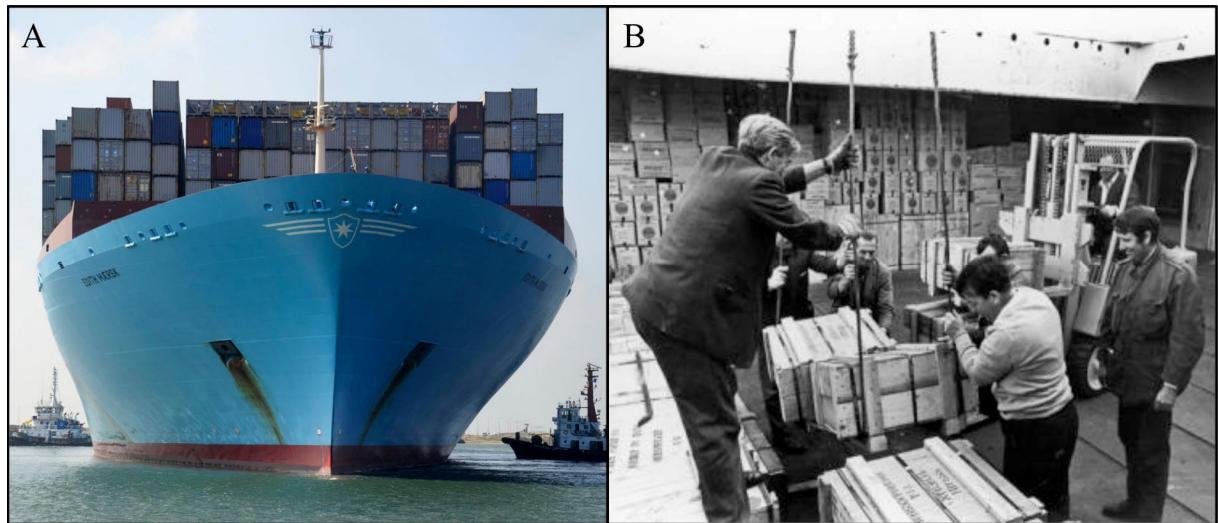
**Key words:** containerization, shipping network, Suez Canal, fouling control, Ultra-Large Container Vessels, hub ports

## Introduction

For the majority of people, the view of a shipping container on a truck driving past on highway, or being stacked up in a port, is so common that little or no attention is paid to it. The consequences of the invention of this rectangular box (Figure 1A) has nonetheless a substantial bearing on research in the field of marine bioinvasions.

The effect of ballast water, which is used to stabilize vessels at sea, on the transportation of alien fauna has been well documented (Carlton 1985). Ballast water is pumped in and out to maintain safe operating conditions during a voyage. This practice reduces stress on the hull, provides transverse

stability, improves propulsion and maneuverability, and compensates for weight changes in various cargo load levels due to fuel and water consumption. However, water taken on board may contain thousands of organisms (Carlton and Geller 1993), with larger vessels requiring greater volumes of seawater exchanges in order to maintain stability. Fouling organisms attached to submerged areas of marine vessels (Ruiz et al. 2000; Minchin and Gollasch 2003), and the opening of the Suez Canal (Galil 2000) are both also considered as major vectors of introduction of non-indigenous invasive species. We therefore acknowledge the huge expansion in global trade, and its backbone of maritime traffic, as the main contributor to the increasing rate of introductions of marine



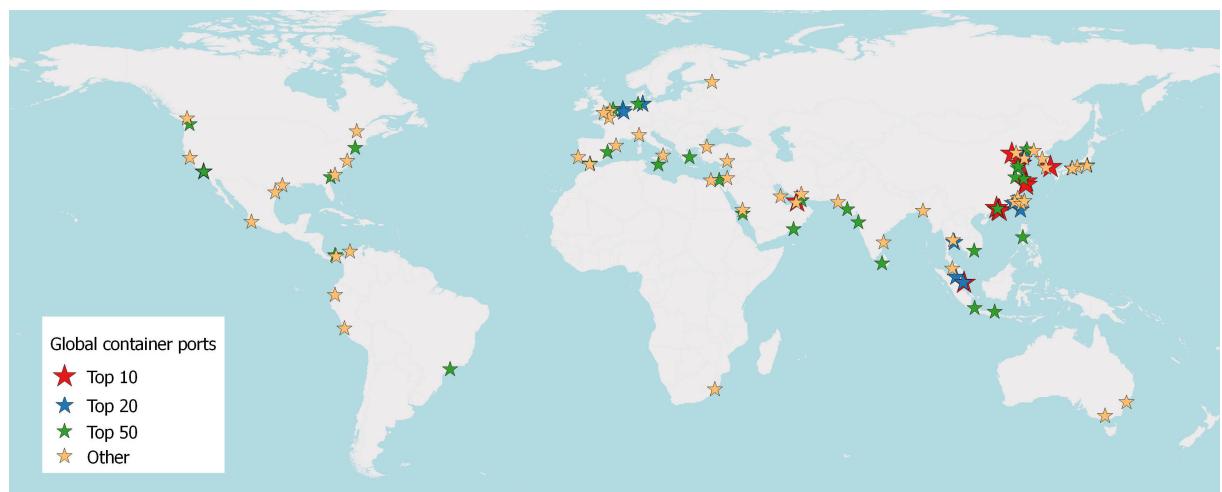
**Figure 1.** (A) The container ship Edith Maersk crossing the Suez Canal at the East Port Said Port, Photo credit: Suez Canal Authority; (B) Stevedores loading cargo in the late 1960s. Photo credit: National Maritime Museum, London.

species worldwide (Hulme 2009; Davidson et al. 2016; Seebens et al. 2016). What, however, is it that has made shipping such a desirable mode for the transportation of goods across the globe? The answer: the invention of the shipping container. This simple low-tech box has had a catalytic impact on global trade, revolutionizing transport in the second half of the twentieth century (Bernhofen et al. 2016). Numerous publications and books in various disciplines such as economics, law, geography, engineering, and more, have discussed the impact of the “Container Revolution” (e.g.: Bernhofen et al. 2016; Levinson 2016). Here, we would like to share our insights regarding the impact of the shipping container revolution on global trade, and on the current and potential future trends in marine bioinvasion. Our aim is to provide data that will contribute to our understanding of the patterns and dynamics of alien species introductions into marine environments.

The invention of the commercial shipping container is attributed to a former truck driver from North Carolina, named Malcom McLean. McLean was searching for a solution to the inefficient and money-wasting manual method of physically loading and unloading cargo by longshoremen (Figure 1B). Since the sailing of the first commercial container ship, the *SS-Ideal-X*, a converted World War II oil tanker, on April 1956 from Port Newark, New Jersey, to the Port of Houston, Texas, vast quantities of goods have been transported around the world using containers, influencing not only our day-to-day

lives, but also their effect and our consequent research on alien species.

Today the container is at the core of a highly automated system for moving goods from anywhere to anywhere, at minimum cost and impedance (Levinson 2016). Currently, modern container ports constitute enormous assembly lines occupying large areas on both land and sea. For example, in December 2017 China initiated trial operations of the world’s largest automated container terminal, the Shanghai Yangshan deep water port, with berth depths of up to 17.5 m, in order to handle today’s largest container ships. It has a 2,350 m shoreline and covers an area of 2.23 km<sup>2</sup> (Yinglun 2017). This highly sophisticated port system has significantly reduced the amount of time that container vessels need to spend in ports, referred to as “turnaround time”. According to the OECD study published in 2014 (Ducruet et al. 2014), the average ship turnaround time of the world’s container ports was 1.03 days, with most ports achieving an average of less than two days. Asian ports had a turnaround of less than one day; Japan half a day; while ports in Africa generally had longer ship turnaround times (more than three days) (Ducruet et al. 2014). Taking into consideration the variety of sessile marine organisms “hitchhiking” as hull fouling, the short turnaround time at the main container ports around the world greatly influences the propagule pressure of these “hitch-hiking” organisms as a potential vector of introduction (Davidson et al. 2016), as will be discussed below.



**Figure 2.** Global distribution of the top 100 container ports around the world in 2016 (following Lloyd's List 2017). Map created by qGIS version 2.18. (qGIS Development team 2018)

Although there are numerous types of maritime vessels sailing globally, such as passenger ships, oil tankers, gas carriers, military vessels, and others, all of which greatly contribute to species introductions, we have chosen here to focus on container vessels due to their global reach to even the most rural areas in need of goods (Figure 2). Container ships moreover, are characterized by regularly repeated paths, in contrast to bulk dry carriers or oil carriers that move less predictably between ports (Kaluza et al. 2010).

### Shift in centers and routes of high shipping intensity

The transition to a global trade based on container shipping has demanded a rapid adaptation of the ports to this system. Harbors such as Busan and Seattle moved into the front ranks of the world's ports, and massive new ports were built in places like Felixstowe in England and Tanjung Pelepas in Malaysia, where none had previously existed (Levinson 2016). Small towns distant from large population centers could now attract factories with their cheap land and low wages, once they no longer needed to be near a port in order to enjoy cheap transportation (Levinson 2016). In contrast, cities that had once been centers of maritime commerce for centuries, like London and Liverpool, witnessed a rapid decline in their waterfronts as they were unsuited to the container trade. This of course greatly influenced the main routes of travel around the globe, and hence also the introduction of alien species via the maritime routes of container vessels. Figure 2 demonstrates the huge

intensity of maritime traffic from numerous locations in Eastern Asia today. Only one of the ten busiest ports (following Lloyd's List 2017) is not in Asia. These ports may function as both "donors" and "recipients" of introduced organisms as there may be a high match between their existing environmental conditions (Hewitt and Hayes 2002). With the anticipated development of the global economy and international trade, and consequent continued intense development of container ports and route networks, the shipping network intensity is also anticipated to accelerate. Thus more ships are being required in the maritime trade lanes served by the container liner networks. Such liner networks provide regular scheduled weekly services with fixed published port calls, enabling global logistics to plan and implement global supply chains.

It is important to bear in mind that in the search for shortcuts in shipping routes, the use of the Northwest Passage (NWP) across northern Canada, as well as the Northeast Passage (NEP) across northern Russia, might become attractive in the future for global trade, as global warming begins to affect the melting of ice for longer periods (Smith and Stephenson 2013; Miller and Ruiz 2014). Indeed, on April 2016 a shipping guide to the NWP route was published by China's maritime safety administration (The Guardian, <https://www.theguardian.com/world/2016/apr/20/china-northwest-passage-trade-route-shipping-guide>). Greater use of the NWP and the NEP in the future might thus negatively impact the use of the Panama and Suez Canals, and further facilitate additional species introduction through the

NWP and NEP (Lambert et al. 2010; Miller and Ruiz 2014; Ware et al. 2014). In June 2016 a third set of locks was opened in the Panama Canal, larger than the original two. This changed the size limit for ships traveling through the Panama Canal (often referred to as Panamax versus post-Panamax for the new larger canal) allowing ships as wide as 49 meter, 366 m in length, and with a draft of 15 m, to use this route.

With the improvement of shipping conditions in both the Suez Canal and the Panama Canal in the past few years, and the potential use of the NEP and NWP, shifts in routes of high-shipping intensity are anticipated to result in changes in ballast discharge and the transport of hull fouling organisms (Muirhead et al. 2015).

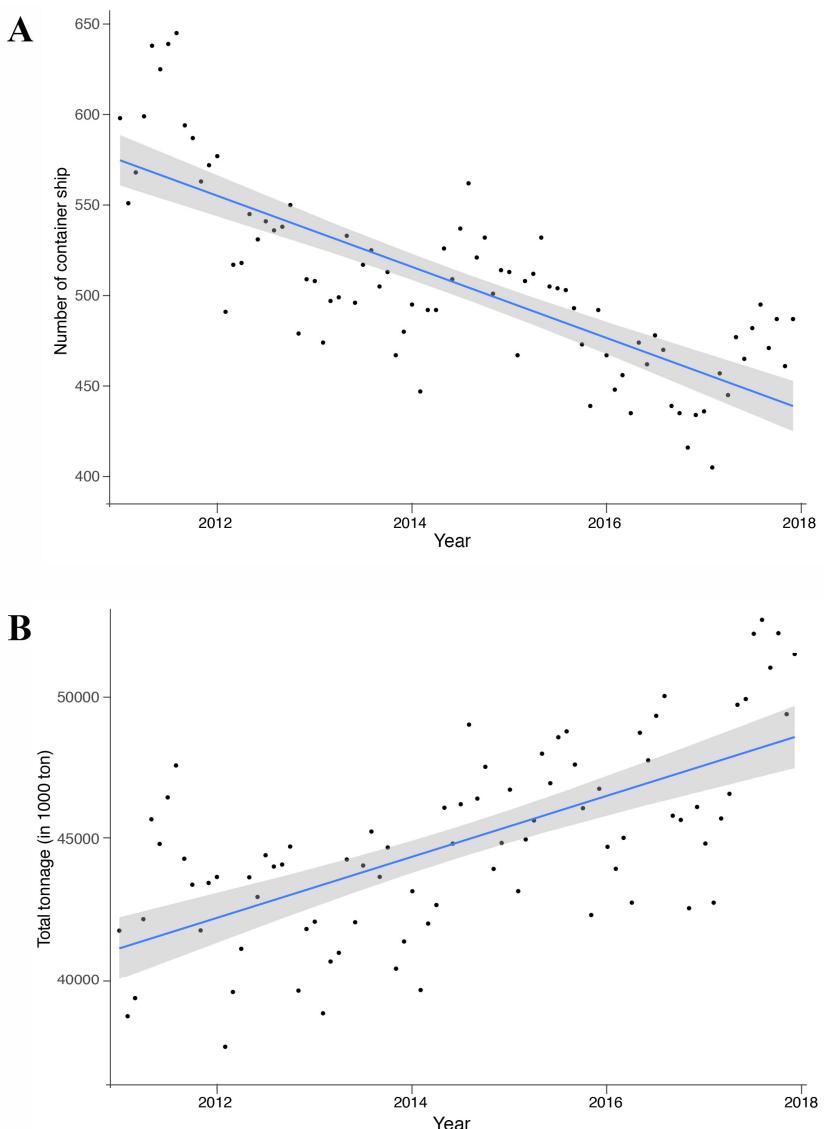
### **Importance of “Hub” versus “Feeder” ports**

Indeed, the uniqueness of container shipping (liner shipping) versus other maritime sectors such as bulkers, passenger ships or tankers, lies in their global coverage and predicted routine travel routes (Kaluza et al. 2010; Davidson et al. 2018). In relation to the context of species introduction, it is important to distinguish between Hub Ports vs. Feeder Ports. Such distinction enables us to understand the differences in shipping intensity, which may correlate to propagule pressure of alien species hitch-hiking on the vessels, as either part of the fouling community or in ballast water (Davidson et al. 2009, 2016). In addition, this distinction between the two types of ports can influence our analysis of potential native source populations of major hub ports, to their primary site of introduction into other hub ports, and as vectors of secondary spread to feeder ports (Minchin and Gollasch 2002; Blackburn et al. 2011). “Hub ports” are large ports that enable trans-shipment: the process of transferring containers from large vessels to the smaller vessels that enable containers to reach their final destination. This enables a larger reach of the shipping network in terms of where a shipping container can be transported. “Feeder ports” are ports where the large ocean vessels do not call, either because there are not enough containers to load or because the port is not suited to handle the large ocean vessels due to its limited size and water depth. Often the large financial investment required to handle larger vessels is not justified by the port’s low container throughput. Nevertheless, feeder ports generate enough cargo to require shipping services, and they are important for serving the local markets (Monios 2017).

Feeder ports and feeder vessels play a significant role in the worldwide transportation of containers, and hence may contribute greatly to the increasing dispersal of alien species (Minchin and Gollasch 2002;

Davidson et al. 2016). For example, when we consider vectors of introduction into the Eastern Mediterranean via the Suez Canal, we can see that container vessels such as the Emma Maersk, with a capacity of 15,000 TEU, sail every week directly from main hub ports in East Asia to the main container ports in the Eastern Mediterranean, calling in at the Suez Canal Container Terminal (SCCT) in East Port Said, Egypt. From the SCCT, smaller container vessels with capacities of about 2,500 TEUs transport containers to other, smaller, ports in the Eastern Mediterranean (<http://www.apmterminals.com/operations/europe/port-said>).

The invasion potential of hub ports, in relation to shipping intensity, is consequently much greater in comparison to that of feeder ports. This relates not only to the number of vessels visiting the port but also to the variety of origin and destination ports. Hub ports provide multiple origins of propagules, which increase the invasiveness potential of certain alien species by introducing adaptive genetic variation from numerous areas and habitats (Ghabooli et al. 2013). For example, the Port of Singapore has connections to over 600 ports and 123 countries globally. It handles around one-fifth of the global container trans-shipment worldwide (<https://www.ship-technology.com/projects/portofsingapore/>). The SCCT Hub port at Port Said has maritime connections to 70 ports and 30 countries and has functioned as a primary trans-shipment center for the Eastern Mediterranean since it began operating in 2004. A smaller feeder port, such as the Port of Venice, has indirect global connections via hub ports such as SCCT. The constant increase in the size of mainline container vessels themselves will lead to a further division of container ports into hub and feeder ports (Nam and Song 2011). With container ships on the main routes becoming larger, and container drops at each port of call increasing, “hub-and-spoke” and interlining networks have become more complex (Wilmsmeier and Monios 2013; Monios 2017). For economic reasons, as a free trade zone, new ports such as the Port of Tanjung Pelepas and Port Klang in Malaysia are gaining popularity in port competition as gateways to southern Asia, adding future new high-risk sites for alien introductions (Figure 2). Container shipping networks have become important components in global supply chains, necessitating complex route planning that takes both maritime and inland factors into consideration (Tran et al. 2017). For example, in 2013 Maersk switched its 9000 TEU vessels from Asia-Europe to Asia-United States East Coast using the Suez Canal, rather than using the shorter route of the Panama Canal (Ship & Bunker News 2013). Such strategic decisions will further affect port routing, and the future dynamics of marine species introductions.

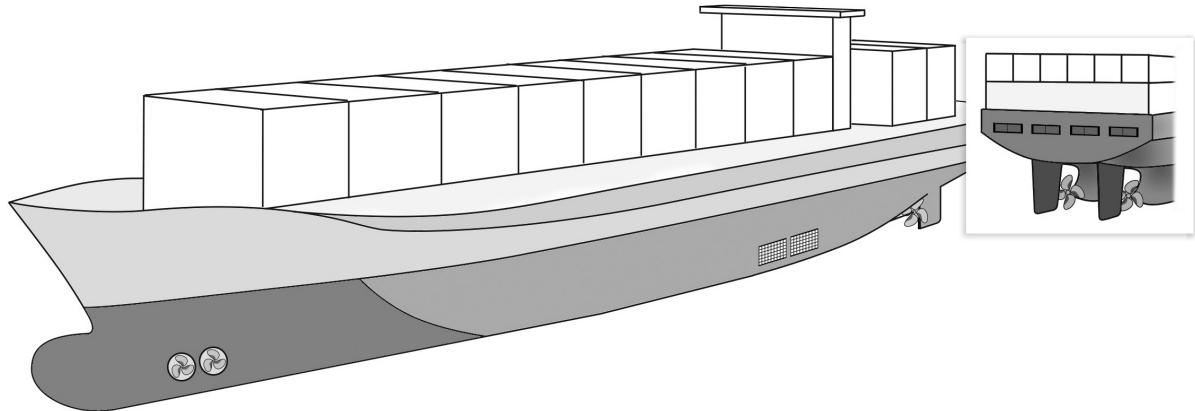


**Figure 3.** Number of container ships travelling through the Suez Canal (A), and net tonnage (in 1000) (B) from January 2011 to December 2017. Data obtained from the Suez Canal Authority website, available in the Supplementary material.

### Does large mean less?

The use of Ultra-Large Container Vessels (ULCV), container ships with a nominal container capacity of up to 22,000 TEUs (Twenty-foot Equivalent Units), is also changing the map of global shipping routes. These vessels are over 18-fold larger than the largest container vessel of the early 1960s (Imai et al. 2006). As of January 2018, over 450 ULCVs are in operation and the number is expected to reach nearly 600 by 2020 (Visser 2018). These gigantic vessels, about 400 m long and with a maximum width of 59 m, tend to limit their call in ports in order to save turnaround and voyage time, which further influences the development of hub and feeder networks. This network

has not only changed the geographical range of shipping on the global scale, but also potentially affects the number of vessels currently required for transferring the same (and greater) quantities of goods. For instance, the opening of the New Suez Canal in August 2015 enabled the passage of such ULCVs in greater numbers and within shorter times. Analysis of the number of container ships passing through the Suez Canal in the past seven years (Suez Canal Authority) reveals a significant 14% reduction ( $t$ -test,  $p < 0.01$ ) in the monthly *number* of container ships passing through the Canal from January 2011–August 2015 (when the wider canal services began), in comparison to the *number* from September 2015–December 2017 (Figure 3A). Nevertheless, the *net*



**Figure 4.** A schematic illustration of an Ultra Large Container Vessel (based on Maersk's Triple-E design). Note the two bow thrusters at the front, the apertures of sea chests along the hull, the area behind the vast twin propellers, and the small crevices and contact regions on the twin rudders as potential niche areas for alien organisms.

tonnage transferred via these larger vessels has significantly increased following the expansion of the Suez Canal ( $t$ -test,  $p < 0.01$ , Figure 3B), demonstrating the impact of the ULCVs: fewer vessels are now required. Regarding container ships therefore, the number of potential vectors of introduction of alien species is not increasing, despite the concern raised by scientists regarding the potential of the Suez Canal to double its capacity (Galil et al. 2015). Yet, whether this will result in an increase or decrease of non-indigenous species introductions remains to be determined.

The increasing use of ULCVs demands a better understanding of the particular design of these vessels, which may provide even more possibilities for alien species to be transported and introduced into new regions. Using the Maersk Triple-E ULCV as an example, we can observe the many attractive niche regions for the settlement of fouling organisms, such as the two bow thrusters at the front, the apertures of sea chests along the hull, the area behind the vast twin propellers, and the small crevices and contact regions on the twin rudders (Figure 4). Although the ship is highly maintained and antifouling treatments are regularly applied, these specific sites demand further and increased attention and maintenance in view of their potential to host alien fauna, as observed for other vessel types as well (Moser et al. 2017; Gewing and Shenkar 2017). While vessel designs tend to be similar, and maintenance regimes are improving, the hub-and-spoke networks and increasing ratios of large ships to many more smaller ships, are creating larger underwater surface exchanges for marine species in the hub ports.

### Recommendations for future research and mitigation

Incorporating an interdisciplinary approach, combining ecological aspects with maritime traffic dimensions, has enabled us to enhance our understanding of the impact of shipping networks on marine bioinvasions in the past, and to provide useful recommendations for future studies and potential mitigation strategies (Keller et al. 2011). The main invasion risk we anticipate regarding containership development is fouling, rather than ballast water, due to the increase in the wetted surface area of these vessels (Miller et al. 2018), which affects the total extent of the available niche area (Moser et al. 2017). This, combined with the routine travel routes of ULCVs, may increase the probability of a successful introduction, depending on the environmental match between the hub ports. In addition, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM), entered into force in September 2017. All ships are now required to have a specific detailed ballast water management plan approved by the administration of the IMO (International Maritime Organization 2018). However, this management plan is scheduled to be implemented globally only by September 2024, presenting another window of opportunity for new introductions of species. We should consider the role of hub and feeder port networks as exerting a significant influence on the sites of initial species introduction, and accordingly consider what should be the areas of focus for concentrated efforts on the early detection of alien species. The hub-and-spoke network of shipping containers also should be taken into consideration in

the risk assessment and modeling of future scenarios of the dispersal of nuisance fouling species (Seebens et al. 2016; Lins et al. 2018).

Finally, the increasing development of large container ports globally, larger vessels, and an increase in the hub-and-spoke network topology, demands a thorough investigation of their effect on bioinvasion potential. An integrated study of both the commercial and the biological networks is thus essential in order to fully comprehend their interaction.

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## Supplementary material

The following supplementary material is available for this article:

**Table S1.** Data obtained from the Suez Canal Authority <https://www.suezcanal.gov.eg/English/Navigation/Pages/NavigationStatistics.aspx> regarding number of container ships and net tonnage that passed through the Canal from January 2011 to December 2017.

This material is available as part of online article from:

[http://www.reabic.net/journals/mbi/2018/Supplements/MBI\\_2018\\_Shenkar\\_Rosen\\_Table\\_S1.xlsx](http://www.reabic.net/journals/mbi/2018/Supplements/MBI_2018_Shenkar_Rosen_Table_S1.xlsx)