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Managing the risk of non-indigenous marine species transfer in Singapore using a study of vessel movement

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ABSTRACT

Shipping is recognized as a major vector for the global transfer of non-indigenous marine species (NIMS). As a major transshipment port, Singapore can minimize the risk of NIMS transfer by implementing pragmatic management strategies, such as using vessel movement information to assess the risk of NIMS transfer.
Findings from vessel movement information in a major port terminal in Singapore showed that vessel residence time is short, with >92% of vessels spending seven days or less. There was little variation in vessel residence time to vessel arrival numbers, while the top three last ports of call were found to be from regional ports. Using two key features obtained from vessel movement records, 1) vessel residence time and 2) biogeographic origin of the vessels' last port of call, a simple risk assessment matrix was constructed and applied to assess the level of risk of NIMS transfer by transiting vessels.

1. Introduction

1.1. The network of shipping and its implications for marine biosecurity

The commercial shipping network, (i.e., containerized vessel movements) are governed strongly by global markets, such as location of global manufacturing centers (e.g., labor market and factories) and economic supply and demand. Hence, shipping transport are usually serviced by fixed shipping routes aimed at optimal travel time and efficiency within international or regional ports along the coastal environment (Capineri and Randelli, 2007; Kaluza et al., 2010). The confluence of increasing shipping volume and the capability of major ports to efficiently handle larger transshipment vessels has led to the development of a global shipping network resembling a hub and spoke model (Notteboom and Rodrigue, 2005; Wang and Wang, 2011), forming transshipment routes to link regional ports to facilitate trading with major hub ports. Therefore, these also make existing ports and the surrounding natural marine environment the most vulnerable to impacts of NIMS introduction by shipping. Earlier studies by Kaluza et al. (2010) and Keller et al. (2011) highlighted global shipping movement patterns as a key factor in determining the risk of bio-invasion in risk assessment models. A study by Seebens et al. (2013) that focused on vector-based modeling using vessel trading patterns, environmental heterogeneity (e.g., temperature and salinity differences) and biogeographic distribution to model bio-invasion probability, also indicated Singapore and the South-East Asia (SEA) region as a bio-invasion hotspot. According to Carlton (1985), world patterns of ballast water movement (over the past 100 years) have probably paralleled the changing patterns of world shipping routes. These routes or patterns are complex and are dependent on the distribution of the worlds' economies, markets, population, location of industries and resources. In addition, he found that reduced vessel duration in port led to reduced ship biota (i.e., biofouling) as a result of faster port handling (Carlton, 1985), hence it is plausible that the risk of transfer of NIMS will be increased by prolonged vessel duration in port. In some vessel management strategies (e.g., Craft Risk Management Standard, 2014, MPI, New Zealand), vessel time spent in port is also highlighted as a key component that address inspection criteria necessary to determine acceptable vessel hull cleanliness. These findings are important as they suggest that vessel movement along the shipping network, which are connected by coastal ports functioning as nodal points, have varying density and diversity (i.e., port connectivity). Port connectivity will likely drive vessel movement patterns that may directly influence risk of NIMS transfer along certain routes and biogeographic regions due to increased propagule pressure.

1.2. Challenges of managing bio-invasion in Singapore

In Singapore, most of the published literature on non-native species has been on terrestrial flora and fauna (Pandit et al., 2006), avian (Lim et al., 2003; Brook et al., 2003) and freshwater aquatic flora and fauna (Ng et al., 2014). According to the Global Invasive Species Database (Global Invasive Species Program), Singapore has 55 introduced non-

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indigenous species (not including native species that have spread to other countries). A breakdown of the numbers revealed that a majority of the number of species belonged to plants and fishes (19 and 17 respectively), followed by insects (8), birds (5), amphibians (2), snails (2) and mammal (1). There was only one marine representative (i.e., *Mytilopsis sallei*). However, a recent review of estuarine and marine non-indigenous species (Jaafar et al., 2012) listed a total of 17 species, including two bivalve molluscs, one polychaete worm, two dinoflagellates and 12 fish species, although the study did not take into consideration whether the species cause harmful impact on the environment. Overall, there is a shortage of published literature on marine invasive species and its impacts in Southeast Asia (e.g., marine plankton and invertebrates), including Singapore, where there is a focus mainly on terrestrial or freshwater aquatic environment (Peh, 2010), and in particular invasive species that have agricultural impacts. Although a recent paper (Nghiem et al., 2013) estimated the total economic cost arising from invasive species impact in Southeast Asia based on published invasive species database, no marine invasive species was used in the model. In addition, it has been recognized that the loss of native biodiversity in Singapore has largely been attributed to urbanization (e.g., land conversions) rather than from direct competition with invasive species. The failure of invasive species to establish themselves against native biodiversity (Ng et al., 1993) also suggest that anthropogenic disturbances are more likely to impact the native environment than as a result of non-native species competition, although it is not certain if this is true for marine aquatic species. As a result of this lack of understanding of marine biodiversity in Singapore and in general the SEA region, the status of native and alien species in the region and its associated impacts are poorly understood and is likely to impede political urgency and development in action plans to address marine bioinvasion occurrences. However, Hewitt (2002) suggested that the rich biodiversity in tropical environment do not support pattern of lower invasion risk or environmental resistance (i.e., biodiverse regions are also susceptible to invasions). Therefore, there is a need to recognize the potential impacts both in Singapore coastal environment and the country's role as a major transshipment port to manage NIMS transfer.

1.3. Managing the risk of NIMS transfer as a major transshipment hub port

National economic interests present a challenge for preserving native marine habitats and biodiversity. Given that global shipping requires vessels to operate in different parts of the world, abiding by international shipping guidelines like the IMO Convention makes it easier for vessels coming to Singapore to be regulated through a uniform set of rules or guidelines, including managing the risk of NIMS transfer on vessels to environmentally sensitive areas. This may involve requiring vessels to adopt ballast water or biofouling management plans. Singapore has not ratified the 2004 International Convention for the Control for the Management of Ship's Ballast Water and Sediments (BWM Convention) to date. As a major shipping hub for transshipment in the SEA region, Singapore may need to recognize and manage the risk of NIMS transfer on transoceanic vessels transiting through its ports to sensitive marine environments, if the BWM Convention comes into force. This will likely require the port authorities to implement reasonable measures to ensure vessels comply with international guidelines regarding the management of ballast water. Similarly, the management of biofouling on vessels may also require Singapore to take on a proactive role in mitigating high-risk vessels transiting through the port.

The study of NIMS has fueled the understanding of the dynamic process of distribution and spread of potential invaders, leading to the drafting and adoption of international and national environmental instruments aimed at protecting the marine environment against the risks of bio-invasion by shipping, particularly in vessel management strategies. From a management perspective, an informed decision on the overall risk of biofouling or ballast water is also important to guide policy planning, for example in the implementation of protocols (i.e., imposing frequency of or prioritizing inspection) for ballast water sampling or biofouling inspection. A risk assessment model that is based on vessel movement information may be a pragmatic and timely approach to estimate the overall risk factor of a vessel likely to harbor NIMS, aiding vessel management strategies in Singapore (i.e., inspection for non-compliance).

2. Methods

2.1. Approximating vessels residence time in Keppel Terminal, Singapore

A parameter such as vessel turnaround time has been used before in transport economic studies (Ducruet and Merk, 2013) to calculate a port efficiency index. It is defined as the time between arrival and departure at a port so that a vessel can complete its loading, unloading and other servicing operations. Here, it is proposed as a means to estimate the vessel port residence time of containerized vessels present in a major port terminal. Vessels position in Keppel Terminal were recorded every day for an hour for three one-month periods (taken to be 30 days for this study); the first period from 29 Apr 2014 to 28 May 2014 (May 2014), the second period from 3 Nov 2014 to 2 Dec 2014 (Nov 2014) and the third period from 24 Jan 2015 to 22 Feb 2015 (Feb 2015). The vessels recorded in this study included instances where vessels were alongside the berths, as well as inactively moored just off the berths. This was achieved through live records of vessel positions through the open access option on www.fleetmon.com, which provided real-time ship positions in port and basic technical information about the vessel from terrestrial Automatic Identification System (AIS) receiver stations for live vessel tracking. Four classes of vessels (bulk carriers, containers, general cargo and RORO) were recorded from these data. These were chosen because the vessels generally follow fixed routes with varying degrees of patterns according to Kaluza et al. (2010). Tankers tend to move less predictably between ports and the number of ports frequented is also limited as they transport mainly oil products (Kaluza et al., 2010). The total number of vessels in port, vessel type, the vessel IMO registered number, the represented flag state and the deadweight tonnage of the vessels were recorded each day.

Documenting ship positions over a 24 h interval each day allowed an approximation of ship status in time, so that overall vessel traffic flow through the terminal could be observed. However, as the recording was only performed for a relatively limited time of 1 h every day for a month, not all vessel arrival or departure per day may be recorded in port. One assumption made was that vessels spent >24 h in port on each arrival. This assumption may be valid as the container vessel average turnaround time (ATT) — an index for port handling efficiency related to the amount of time a vessel could complete its operations, for Singapore was 1.16 days in 2011 (Ducruet and Merk, 2013). This provided a basic record of vessel positions in port for Keppel Terminal. By tracking individual vessels in port, vessel arrival and departure dates from Keppel Terminal could be estimated and approximated as the duration that an individual vessel spent in port over the observed periods. The duration of each vessel record in port was approximated to be 24 h, as the records taken from the vessel monitoring website was taken at every 24 h interval. This duration was taken to be the vessel residence time.

Although AIS information is available over other websites (e.g. www.marinetraffic.com), the website employs a sea boundary to define every port in the database. Given that the vessel traffic volume in port is expectedly high, having a clear zone to define the port area allows a clear record of arrival and departure in port. This option was chosen as obtaining travel records of vessels and operational data including ballast discharge and uptake volume from shipping registries was severely limited and costly.

2.2. Vessels' last port of call

For two periods from Nov 2014 and Feb 2015, the last port of call of vessels prior to arrival in Singapore were recorded using an open source