An inter-site study of biofouling recruitment on static immersion panels in major ports of South East Asia and India

Chin Sing Lim1*, Zuliza Haji Jolkifli2, Alina Jair3, Noorizan Karim4, Ranimah A. Wahab5, Dattesh V. Desai6, Venkat Krishnamurthy7, Lidita Khandeparker8, Kaushal Mapari9, Subhash Sawant10, Hikmah Thoha11, Hadiyanto Hadiyanto12, Dirhamsyah13, Soukaseum Dalasane14, Kongneun Chounlamongtry15, Lee Siang Hing16, Shahruddin bin H. Yusof17, Myint Myint Khaing18, Hildie M. E. Nacorda19, Nero Austero20, Rhodora V. Azanza21, Cesario Pagdilao22, Sumana Kajonwattanakul23, Ratchanee Puttapreecha24, Sombat Poovachiranon25, Hoang Mai Le26, Thanh Thuy Tran26, Van Cu Nguyen27, Koh Siang Tan28, and Arga Chandrashekar Anil29

1St John’s Island National Marine Laboratory, Tropical Marine Science Institute, National University of Singapore, Singapore 119227
2Department of Fisheries, Ministry of Industry and Primary Resources, Jalan Mentri Besar, Berakas BB 3910, Brunei Darussalam
3CSIR - National Institute of Oceanography, Dona Paula, Goa 403004, India
4Research Center for Oceanography, Indonesian Institute of Sciences, JL. Pasir Putih 1, Ancol Timur, Jakarta 11048, Indonesia
5Ministry of Public Works and Transport, Lao PDR
6Ministry of Natural Resources and Environment, Vientiane, Lao PDR
7Department of Marine Science, Faculty of Maritime Studies and Marine Science, Universiti Malaysia Terengganu Mengabang Telipot 21030, Terengganu, Malaysia
8National Oceanography Directorate Ministry of Science, Technology and Innovation Federal Government Administrative Centre, 62662, Putrajaya, Malaysia
9Remote Sensing Department, Mandalay Technological University, Ministry of Science and Technology, Mandalay, Myanmar
10School of Environmental Science and Management (SESAM), University of the Philippines Los Baños College, Laguna 4031, The Philippines
11Marine Science Institute, College of Science, University of the Philippines, Diliman, Quezon City 1101, The Philippines
12Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development, Department of Science and Technology, PCAARRD, Paseo de Valmaya, Timugan, Economic Garden, Los Baños, Laguna 4030, The Philippines
13Department of Marine and Coastal Resources, The Government Complex, Ratthagrasanabhaakti Building, 6th floor 120 Chiangwattana Road, Thungsonthong, Lakski Bangkok 10210, Thailand
14Southern Marine and Coastal Resources Research Center, 158 Moo 8, Prawong, Muang District Songkhla 90100, Thailand
15Center for Planning, Surveying and Assessing Marine Environment and Resources, Vietnam Administration of Seas and Islands, MONRE Building, 10 Ton That Thuyet Str, Cau Giay, District, Hanoi, Vietnam
16Department of International Cooperation, Science and Technology Vietnam Administration of Seas and Islands, Ministry of Natural Resources and Environment, MONRE Building, 83. Nguyen Chi Thanh, Ha Noi, Vietnam
*Corresponding author: tmslimc@nus.edu.sg

KEYWORDS
Biofouling diversity
India
Invasive species
South-East Asia
Static immersion

ABSTRACT Limited knowledge of native marine biodiversity hinders effective biodiversity management to safeguard South and Southeast Asia’s marine coastal environment against the threat of invasive species transfer through shipping. In particular, sessile marine biofouling organisms in South East Asian ports are poorly known. Through the support of the ASEAN-India Cooperation Project on the Extent of Transfer of Alien Invasive Organisms in South/South East Asia Region by Shipping, a coordinated effort to examine diversity of biofouling organisms in major port areas in Southeast Asia and India was made using polyvinylchloride (PVC) panels as recruitment surfaces in a static immersion study for a period of 12 months. Not surprisingly, the study revealed that fouling patterns differed between ports possibly as a result of dissimilar hydrographic conditions. However, there were also underlying similarities that reflected a regional uniformity in the composition of fouling communities. At the same time, the alien Caribbean bivalve Mytilopsis sallei was detected in Manila Bay (Philippines), Songkhla Port (Thailand) and Singapore. This is a first simultaneous biofouling survey involving scientists and government stakeholders from India and ASEAN nations of Brunei Darussalam, Indonesia, Lao PDR, Malaysia, Myanmar, Singapore, Thailand, Philippines and Vietnam.

© The Author(s) 2018. This article is distributed under a Creative Commons Attribution-ShareAlike 4.0 International license.

1. INTRODUCTION

Biofouling, or the settlement of undesirable marine organisms on natural and man-made submerged bodies, accounts for significant operational and re-mediation costs in shipping (Schultz et al. 2011) and other coastal assets including desalination and power plants (Booy et al. 2017). The spread of non-native species to new marine environments via biofouling on commercial shipping vessels is a major transport pathway for species introduction (Eldredge and Carlton 2002; Coutts and Dodgshun 2007; Seebens et al. 2013). Such introductions may cause loss of marine biodiversity and irreplaceable damage to the marine ecosystem as a result of competition with native biota (Crowl et al. 2008).
The diversity of marine biota on submerged bodies was the subject of several papers published in India and Southeast Asia (SEA). In particular, detailed studies of biodiversity and seasonal variation of fouling at several ports and harbours in India have been undertaken (e.g. Gaonkar et al. 2010; Swami and Udhayakumar 2010; Pati et al. 2015; Nandhini and Revathi 2016) including Mumbai, India, which was selected as one of the six demonstration sites (including Dalian, China; Khark Is., Iran; Odessa, Ukraine; Saldanha, South Africa; Sepetiba, Brazil) in the Global Ballast Water Management Programme (GlobalBallast-IMO 2000) to reduce the transfer of non-native species via shipping ballast, and had garnered motivation in the study of biofouling community in ports and harbours in India. In SEA, Low et al. (1991) examined the seasonal variation of the dominant fouling species, *Perna viridis* (Asian green mussel) along the East Johor Straits, a shared waterway between Malaysia and Singapore, where shipyards and docks are located. Seasonal and successive colonization of macrofouling species affecting fish-cage nettings in Malaysia (Madin et al. 2009) were examined, while recent studies of biofouling and epibiotic diversity (marine growth) on navigational buoys, marina pontoons and jetty pilings in Singapore (Ong and Tan 2012; Lee et al. 2013; Toh et al. 2017) also highlighted the potential of submersed structures to support a diversity of marine organisms.

Biofouling communities around vessel-frequented areas are therefore of particular interest, as man-made infrastructure (e.g. pilings, pontoons) in the port or marina may support a diversity of organisms. These may include non-native species that could have been introduced through arriving vessels, especially vessels operating between international and regional ports or marinas. Areas around ports and marinas have therefore been the subject of many invasive species surveys to examine species introduction and vector causes (Hewitt 2002; Hutchings et al. 2002; Gaonkar et al. 2010).

In a collective study of the potential negative impacts of non-native species on agriculture, human health and the environment (e.g. urban built-up areas) in SEA, Nghiem et al. (2013) estimated the total costs to around US$33.5 billion. However, the study focused on specific agricultural pests (e.g. golden apple snail), human diseases (e.g. SARS virus) and urban pests (i.e., pigeons and cats), where comprehensive data were more readily available. The model or estimated costs in the study did not consider the impacts of non-native species to the marine environment. Given that regional ports in SEA were identified as potential bio-invasion hotspots due to their high shipping intensity (Seebens et al. 2013), a better understanding of the impact of non-native marine species on the environment is needed. High marine biodiversity in the SEA region, coupled with a vast maritime area, has hindered progress (Peh 2010; Lee et al. 2013). This can be improved by a coordinated approach to examine biofouling organisms, where regional cooperation and communication can enhance monitoring efforts to manage the spread of non-native species. This is especially so in light of the 2011 Biofouling Guidelines for the Control and Management of Ship Biofouling to minimize the Transfer of Invasive Aquatic Species (Biofouling Guidelines), where States are encouraged to ‘provide ships with any available information on particular invasive aquatic species that may be present in a port and could attach to a ship as biofouling (in a timely manner).

Through the support of the ASEAN-India Cooperation Project on Extent of Transfer of Alien Invasive Organisms in South/South East Asia Region by Shipping, biofouling surveys in major ports in Southeast Asia and India were carried out using polyvinylchloride (PVC) panels as recruitment surfaces in a short term static simultaneous immersion study. There were two main objectives: one, to understand the local marine flora and fauna, particularly in relation to biofouling on hard substrata in the vicinity of their port of study; two, to recognize the seasonal variation in the major and dominant fouling species present. This ‘bottom-up’ approach allowed capacity building in identification of fouling species and development and also raised awareness for invasive species transfer through shipping. The results from this study represented for the first time a joint survey carried out simultaneously with scientists and government stakeholders from India and ASEAN nations of

**Figure 1.** Port sampling locations in India and ASEAN countries. Countries are arranged in alphabetical order. (A) Muara, Brunei; (B) Goa, India; (C) Tanjong Priok, Indonesia; (D) Vientiane, Mekong River, Lao PDR; (E) Kertih, Malaysia; (F) Yangon, Myanmar; (G) Manila Bay, Philippines; (H) Singapore; (I) Songkhla, Thailand; (J) Hai Phong, Vietnam. Map downloaded from www.d-maps.com.
Table 1. Monthly fouling data collected from ports in India and ASEAN countries between May 2012 and December 2013. Diamonds indicate sampling months. Panels were examined after one month and replaced with a new panel each month.

| Period | Muara, Brunei | Goa, India | Tanjong Priok, Indonesia | Kertih, Malaysia | Yangon, Myanmar | Manila Bay, Philippines | Singapore | Songkhla, Thailand | Hai Phong, Vietnam |
|--------|--------------|------------|--------------------------|-----------------|----------------|------------------------|-----------|-------------------|------------------|
| May 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Jun 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Jul 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Aug 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Sep 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Oct 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Nov 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Dec 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |

Table 2. Long term fouling data collected from ports in India and ASEAN countries between May 2012 and December 2013. Diamonds indicate sampling months. Panels were examined after one month, and the same panels were returned into the water and subsequently re-examined monthly.

| Period | Muara, Brunei | Goa, India | Tanjong Priok, Indonesia | Kertih, Malaysia | Yangon, Myanmar | Manila Bay, Philippines | Singapore | Songkhla, Thailand | Hai Phong, Vietnam |
|--------|--------------|------------|--------------------------|-----------------|----------------|------------------------|-----------|-------------------|------------------|
| May 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Jun 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Jul 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Aug 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Sep 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Oct 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Nov 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |
| Dec 2012 | *            | *          | *                        | *               | *              | *                      | *         |                   |                  |

Brunei Darussalam, Indonesia, Lao PDR, Malaysia, Myanmar, Singapore, Thailand, Philippines and Vietnam.

2. MATERIALS AND METHODS

2.1 Sampling locations

Ten ports and/or marina (sites) were selected for the panel static immersion to be carried out. These sites strategically represent major port areas where regional and transregional shipping activities were taking place, including infrastructure assets such as commercial (i.e., container), passenger and shipyard terminals. These sites were located (in alphabetical order of country) in Muara Port, Brunei Darussalam (Joliki and Wahab 2018); Goa, India (Desai et al. 2018); Tanjong Priok Port, Indonesia (Hadiyanto 2018); VTE Port, Lao PDR; Kertih Port, Malaysia (Hing et al. 2018); Yangon Port, Myanmar (Khaing 2018); Republic of Singapore Yacht Club, Singapore; Songkhla Port, Thailand (Puttapreecha et al. 2018); Manila Bay (South Harbor), Philippines (Nacorda et al. 2018); and Hai Phong Port, Vietnam (Figure 1). Of these sites, only VTE Port (Lao PDR) was located inland along the Mekong River. Access to ports was obtained from port administrators prior to commencement of immersion tests, while selection of a suitable immersion site for panel immersion was also subject to port approval (e.g., non-interference with vessels movement and personnel safety). As a permanent immersion platform was not readily available at all locations, it was necessary to modify immersion frames so that panels would be kept at a fixed
immersion depth from sea surface regardless of tidal height (i.e., submersion of frames with attached floating buoys). In most cases, immersion of panels were carried out directly from permanent jetties, with the exception of panels submerged from an existing floating test platform in Singapore. Actual data from VTE Port (Lao PDR) was not included as the site consisted of freshwater body. However, it was included as a test site in the program to raise awareness and increase capacity building for test methods in invasive pest species management.

2.2 Monthly immersion test
To examine early stage (i.e., short immersion length) fouling colonization, settlement was recorded in a static immersion test using uncoated polyvinylchloride (PVC) sheets measuring 2 mm by 100 mm by 200 mm (three replicates). These materials, together with a simple PVC frame to secure the immersion plates were prepared in Singapore and sent to respective sites where they would be simultaneously immersed from May 2012. The plates were zip-tied to the PVC frames and immersed at a fixed depth of 0.8 m below sea surface at the site i.e., on floating structures/piers where the plates were maintained at a consistent depth.

Every month, the frame was raised and fresh PVC plates were used to replace the one-month old plates, which was documented for fouling cover. Table 1 lists the months where fouling settlement was recorded at each site.

2.3 Long term immersion test
Long term cumulative fouling settlement observations to examine fouling development on a single set of PVC panels were also recorded. The fouling was documented every month from the same panels that were re-immersed after each observation. However, logistical and technical difficulties, including loss of panels due to unfavourable weather conditions prevented uninterrupted fouling settlement to be recorded. Table 2 shows the month(s) when long term fouling settlement for the respective sites were recorded.

2.4 Documentation of fouling
Upon inspection, the frames were raised and digital photographs of the plates were taken. Surface coverage and composition were obtained by a 100-point estimation method using Photogrid 1.0 according to ASTM D6990–05. 2.5 cm from the edge of the panel was discounted to reduce edge effect in settlement. Major fouling taxa (see Supplementary Table 1) at all sites were recorded for consistency and comparison. Fouling settlement (as percent cover) are shown in a stacked column detailing the organism taxa by month. For consistency, each taxon (e.g., barnacle) was shown in the same colour throughout, so that a dominant taxon may be visualised immediately. It will also be possible to monitor how the relative settlement cover have changed temporally, especially in a long term immersion period.

3. RESULTS

3.1 Port biofouling sampling
Cross-institution links and communication with regulatory boards and port authorities were established so that approval for immersion tests in the ports was obtained. This often necessitated the need for clarification of the impact of invasive pest species introduction on the environment and the role of vessels as a vector for transporting non-native species across ports in a shipping network. Thus, functional networks and communication were established for future monitoring and surveys to be done.

Several sampling difficulties were encountered which prevented commencement of the panel immersion at the sites simultaneously. This included gaining prior access to the port vicinity from the Port authorities and selection of a suitable immersion location on-site for panel immersion. Hence, three sites (Tanjong Priok, Kerith and Yangon) commenced the panel immersion at a slightly later date (Table 1). As there was no permanent test facility for immersion studies at the sites (except for a local marina in Singapore with an existing test platform for long term fouling studies), most of the immersion tests had to be designed on-site with approval from the port authorities. This may include temporary lines from the PVC frames to railings/mooring pins on the pier-side/jetty (Figure 2). In some cases, access to the actual sampling sites was limited from land (i.e. retrieval of frames from pier) and access by boats had to be carried out for panel inspection. This delayed some of the test sites to carry out immersion as planned.

The lack of a permanent or dedicated test facility also affected the security and safety of the frames, where some of the long-term panels and frames were lost as a result of
Figure 3. Monthly fouling composition at respective sites with periods shown: (A) Muara, Brunei; (B) Goa, India; (C) Tanjong Priok, Indonesia; (D) Kertih, Malaysia; (E) Yangon, Myanmar; (F) Manila Bay, Philippines; (G) Singapore; (H) Songkhla, Thailand; (I) Hai Phong, Vietnam. The legends are shown in each chart for easy reference, while the colours representing each taxon are marked the same.

Figure 4. Monthly fouling composition of panels in Dec 2012, except Tanjong Priok (Dec 2013) and Manila Bay (Nov 2012). (A) Muara, Brunei; (B) Goa, India; (C) Tanjong Priok, Indonesia; (D) Kertih, Malaysia; (E) Yangon, Myanmar; (F) Manila Bay, Philippines; (G) Singapore; (H) Songkhla, Thailand; (I) Hai Phong, Vietnam.
severe weather conditions at the ports (i.e. Kerthi, Hai Phong, and Songkla; Table 2). In particular, the early loss of panels (and replacement) delayed the commencement of the test at Kerthi, Malaysia until these issues were rectified.

The lack of baseline records and adequate taxonomic knowledge of fouling organisms in the ports, including the absence of trained personnel to handle organism identification, could have prevented effective inspection of the fouling organisms in some sites. This is especially beneficial if identification could be clarified on-site by the operator, given that post-process identification of the organisms on images collected may be subjected to the quality of the image taken.

3.2 Monthly fouling settlement

Monthly settlement (Figure 3) showed the presence of major taxonomic groups including e.g., Crustacean, Mollusc, Polychaete and Algae, in Muara (Brunei), Goa (India), Tanjong Priok (Indonesia), Kerthi (Malaysia), Manila Bay (Phillipines), Singapore and Songkla (Thailand) throughout the immersion period (Table 1). Heavy sedimentation and biofilm (i.e., slime) were present on panels at sites in Yangon (Myanmar) and Hai Phong (Vietnam). In addition, the large surface cover (>50%) of barnacles (Amphibalanus sp.) and calcareous polychaetes (Serpulidae) on panels in Tanjong Priok (Figure 3) in Jun 2013 and Nov 2013; barnacles (>90%) in Kerthi (Feb 2013) and barnacles (>90%) in Manila Bay (May 2013) and encrusting bryozoans (>40%) in Songkla (from Jun 2012) were striking in their rapid colonization (Figure 3). Tubeworms (Spirorbidae less than 1 mm in diameter) were ubiquitous in Singapore throughout the immersion period. Panel fouling images for all the sites in Dec 2012, Manila Bay in Nov 2012 and Tanjong Priok in Dec 2013 (Table 1) are shown in Figure 4.

3.3 Long term fouling settlement

Panel immersion for all the sites started in May 2012, except for Tanjong Priok (May 2013), Kerthi (Nov 2012) and Yangon (Aug 2012). Immersion at all the sites were carried out for at least six months, and up to a year (Table 2); inspection of the fouling on the panel was carried out monthly. New PVC panels were used for replacement midway in Songkla due to a loss of immersion plates on-site in Aug and Sep 2012 (Figure 5). Only the final settlement cover were recorded at Muara (one year duration) and Yangon (one year duration) due to a lack of monthly records taken.

Fouling settlement at the end of the long term immersion revealed that several taxonomic groups were common at the different sites. These included 1) barnacles (possibly Amphibalanus sp.) at Muara (Brunei), Goa (India), Tanjong Priok (Indonesia), Kerthi (Malaysia), Manila Bay (Philippines), Singapore and Songkla; 2) molluscs; Ostreidae at Muara (Brunei), Kerthi (Malaysia), Singapore and 3) bivalves (Perna viridis) at Tanjong Priok (Indonesia).

4. DISCUSSION

4.1 Inter-site study of biofouling settlement – Building a monitoring program

Vessel biofouling is one of the most successful vectors for alien species transfer (Bax et al. 2003, Coutts and Dondshun 2007; Molnar et al. 2008). In particular, crusta-
ceans and molluscs, which are often found as sessile biofouling (e.g., barnacles and bivalves) are widely represented in many global invasive databases (Cohen and Carlton 1998; Eldredge and Carlton 2002; Molnar et al. 2008). To mitigate the transfer of alien invasive organisms by shipping, a knowledge of prevailing or baseline biofouling community in the environment (e.g. port area) facilitates detection of alien species which may pose a risk of infesting vessels while in port. Timely detection of biofouling pests will enable greater success of mitigation methods for vector management such as those outlined in Floerl et al. (2005), e.g. prevention of species exposure to vectors. This is also in line with the Biofouling Guidelines (Article 9.2), where port states are encouraged to communicate the presence of high risk species to in-coming vessels.

The results of the inter–site study of biofouling settlement enabled each site to identify dominant, rapid colonising organisms (Figure 3). The monthly settlement showed that barnacles (Amphibalanus sp.) were common in all sites except Yangon (Myanmar) and Hai Phong (Vietnam). In particular, barnacle cover on immersion plates was almost complete in Kertih, Malaysia (Feb 2013) and Manila Bay, Philippines (May 2012). Serpulid tubeworms had high abundance (>80% cover) in Tanjong Priok, Indonesia (Nov and Dec 2013). Molluscs (i.e. oysters, mussels and other bivalves) were not common on the monthly plates, where the frequent changing (disturbance) of plates likely prevented these organisms from settling or detected.

The heavy monthly fouling settlement at Tanjong Priok (Indonesia), Kertih (Malaysia), Manila Bay (Philippines) and Songkla (Thailand) was reflected in the long term cumulative fouling at these sites. These sites experienced rapid (almost) complete hard cover consisting of barnacles and molluscs (Figure 5C, D, F, H). Even though a fresh set of panels at Songkla were replaced in Aug 2012, they were rapidly colonized by encrusting bryozoans. It is likely that Goa (India) and Singapore were experiencing a more gradual increase in panel cover (Figure 5B and G) unlike the other sites, where the panels were rapidly taken over by a dominant group in a single month. In particular, P. viridis at Tanjong Priok (Figure 6C) swiftly settled over the earlier barnacle cover from Sep to Oct 2013 (Figure 5C). Even though monthly images of the long term panels were not recorded at Muara (Brunei), monthly fouling at the site (Figure 3A) and the final image taken after a year (Figure 6A) suggested that the recruitment was also gradual. Panels at

**Figure 6.** Long term fouling settlement at the end of immersion test at (A) Muara, Brunei; (B) Goa, India; (C) Tanjong Priok, Indonesia; (D) Kertih, Malaysia; (E) Yangon, Myanmar; (F) Manila Bay, Philippines; (G) Singapore; (H) Songkla, Thailand; (I) Hai Phong, Vietnam.

**Figure 7.** The Caribbean dreissenid bivalve Mytilopsis sollei at Songkla Port.
Yangon (Myanmar) and Hai Phong (Vietnam) consisted largely of soft-bodied organisms like algae and annelid worms, although there was also ~10% cover of serpulid tubeworms at the end of the test in Hai Phong (Vietnam).

The identification of a dominant taxa (or species) can allow for greater chance of detection of high-risk species by port personnel. Timely port monitoring can further inform vessel owners of the risk of exposure to prevent introduction of these organisms to their vessels. For example, the presence of the invasive Caribbean bivalve, Mytilopsis sallei in Songkhla Port (Figure 7), Singapore (e.g., monsoon canals; Tan and Morton 2006) and Manila Bay South Harbor, should raise awareness of the potential risk of these mussels hitch-hiking on vessels. In addition, the recent records of another alien invasive mussel, Mytilopsis chironomus (as chartwana d’Orbigny, 1846) in 2014 in Manila Bay (Vallejo et al. 2017), and 2016 in Singapore (Lim et al. 2018) pointed out the need for urgent regional attention towards mitigating species transfer.

4.2 Establishing functional networks and communication with port agencies

The ASEAN-India Cooperation Project on Extent of Transfer of Alien Invasive Organisms in South/South East Asia Region by Shipping was incepted in December 2010 with the goals of building capacity in invasive species awareness and robust scientific sampling methods for vessel ballast water and port bio fouling organisms. The project aimed to create key partnerships and dialogue between regulatory agencies, shipping industry and personnel to foster functional networks and communication, while promoting regional cooperation in sampling, monitoring and communication of national strategies in invasive pest management. This is to align regional interests, identify limitations and foster development and integration of National Action Plans in South/South East Asia with global environmental instruments such as the 2004 International Convention for the Control and Management of Ships’ Ballast Water and Sediments (BWMC Convention). The methods and results in this paper focused mainly on the study of bio fouling diversity in ports located in South/South East Asia, where the risk of invasive species transfer by vessels in the SEA region (Kaluzza et al. 2010; Seebens et al. 2013) remains a key concern, both as recipient and donor ports.

The bio fouling study using immersion plates demonstrated that the selection of a secure and safe location will be advantageous for the safe inspection of plates, preventing loss of panels (or potential personnel injury) while accessing the plates with ease. This was the case, given that loss of panels were reported early in Kerth and Songkhla, as a result of strong sea conditions damaging ropes and frames securing the plates; while some of the sites had to be accessed by boat or treading in the water. This hindered timely inspection and maintenance of the frames or plates whenever necessary, but more importantly, may cause injurious accident while attempting to access the frames. The site should therefore be accessible safely and conveniently by personnel, cause no interference with vessel or port activity and be in an area where the bio fouling diversity may likely be representative in the port (e.g., a location that is too shallow may not capture organisms (e.g., larvae) in the water column); however, this will most often require some baseline knowledge of the fouling on-site, which may not always be known without prior access. Therefore, coordination with port agencies will be key to facilitating a suitable site for any monitoring programs to be carried out. Nonetheless, all the sites benefited from communication exchanges leading up to the commencement and duration of the study, with all the sites acknowledging technical support from the port authorities, which will bode well for future phase-in programmes. Likewise, settlement data could be accurately captured if personnel undertaking the collection of the information have knowledge or recognition of bio fouling organisms, which will be useful when inter-site comparison are made on a common exchange platform. General awareness and confidence in invasive pest monitoring, using a port baseline bio fouling recruitment and direct training of port authorities and personnel, were raised in this program. These are key drivers to build a framework for functional processes in invasive pest monitoring and management (e.g., Piola and McDonald 2012).

4.3 Future steps – regional integration and action plans

The outcome of the study here highlighted the groundwork made to facilitate a baseline study of bio fouling status at the respective sites, and allowed for the first time, a systematic way to record and share the information on a common platform such as the website set up by the National Institute of Oceanography, Goa (see below for link to website). Across regional sites, a long term monitoring program will greatly benefit from harmonization of methods for bio fouling inspection, for example in the use of bio fouling recruitment plates or traps, and collection of data when information are shared on a regional platform. Continued training are also beneficial for overall confidence in organism identification.

While these remain early stages in formulating a specific regional plan to manage invasive species transfer by shipping, one of the secondary outcomes was that sites were able to examine the physical environment and hydrology in the port areas, as well as gaining an understanding of the vessel traffic patterns within the region. These observations are critical to understanding the implications for invasive species, sedimentation, vessel movement, and threat of pest invasion to natural wildlife reserves nearby (e.g. Cat Ba Biosphere Reserve and Red River Delta Biosphere Reserve, Vietnam).

The baseline information on bio fouling community can form part of a National/Regional Port Baseline Repository (http://bampi.nio.org/Global20MainAsian/species.htm), collecting long term fouling records that aid in knowledge of seasonal recruitment for organisms (e.g., bivalves). These can support vector management policies and strong cooperation among regulatory bodies (e.g., ship owner and port agency) which are necessary when managing alien invasive organism transfer or incursion via shipping (Strayer 2009; Piola and McDonald 2012). While there are no formal global instruments currently aimed at bio fouling control in shipping to manage invasive species transfer (unlike the BWMC Convention), the Bio Fouling Guidelines (IMO) prescribe responsible practices in shipping operation to prevent invasive species transfer by bio fouling. Several regional and national bio security doctrines are reviewed by Dahlstrom et al. (2010) and are similarly guided by the IMO principles (e.g. inspection of vessel bio fouling and maintenance of hull cleanliness). The Ministry for Primary Industries (New Zealand) has also specifically crafted bio fouling standards (e.g., Craft Risk Management Standard), on vessels to manage invasive species introduction. Port states in South/SEA can do well to adopt and align interests with these instruments. One example may be to mandate vessel inspection and cleaning when bio fouling recruitment of certain species are
known to be high (e.g. Perna viridis; Piola and McDonald 2012).

Risk assessments involving shipping network and volume have also continuously highlighted the potential threat faced by ports as a result of connectivity (e.g., Liu and Tsai 2011; Keller et al. 2011; Lo et al. 2012). With the support from port authorities, future studies in South/South East Asia may also utilize vessel movement patterns within/beyond the region, based on the eco-region concept (Spalding et al. 2007), as an aid to implement vector management plans to prevent risk of invasive organisms transfer (Lim et al. 2017).

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support and funding provided by the ASEAN-India Cooperation Fund; ASEAN Secretariat and ASEAN Sub-Committee on Marine Science and Technology (SCMSAT).

REFERENCES

ASTM D6990 - 05 (reapproved 2011). Standard practice for evaluating biofouling resistance and physical performance of marine coating systems. Copyright ASTM International.

Bax N, Williamson A, Aguero M, Gonzalez E, Gieves W. 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy 27:333–323.

Booy O, Cornell L, Parrott D, Sutton-Croft M, Williams F. 2017. Impact of biological invasions on infrastructure. In: Vilà M, Hulme P, editors. Impact of biological invasions on ecosystem services. The Netherlands: Springer International Publishing. p. 235–247.

Cohen AN, Carlton JT. 1998. Accelerating invasion rate in a highly invaded estuary. Science 279(5350):555–558.

Coulls ADM, Dogdushen TJ. 2007. The nature and extent of organisms in vessel sea-chests: a protected mechanism for marine bioinvasions. Marine Pollution Bulletin 54:875–886.

Craft Risk Management Standard: Biofouling on Vessels Arriving to New Zealand. 2014. Ministry for Primary Industries, New Zealand.

Crowl TA, Crist TO, Parmenter RR, Belovsky G, Lugo AE. 2008. The spread of invasive species and infectious disease as drivers of ecosystem change. Frontiers in Ecology and Environment 6(5):238–247.

Dahlstrom A, Hewitt CL, Campbell ML. 2010. A review of international, regional and national biosecurity risk assessment frameworks. Marine Policy 35:208–217.

Desai DV, Krishnamurty V, Anil AC. 2018. Biofouling community structure in a tropical estuary of Goa on the west coast of India. ASEAN Journal on Science and Technology for Development 35:37–42.

Eldredge LG, Carlton JT. 2002. Hawaiian marine bioinvasions: a preliminary assessment. Pacific Science 56(2):211–212.

Flerel O, Inglis GJ, Marsh HM. 2005. Selectivity in vector management: an investigation of the effectiveness of measures used to prevent transport of non-indigenous species. Biological Invasions 7:459–475.

Gaoankar CA, Sawant SS, Anil AC, Venkat K, Harkantra SN. 2010. Mumbai harbour, India: gateway for introduction of marine organisms. Environmental Monitoring and Assessment 163:583–589.

GloBallast. 2000. Removal of barriers to the effective implementation of ballast water control and management measures in developing countries. Global Ballast Water Management Programme. International Maritime Organization, Global Environment Facility, United Nations Development Programme.

Hadyanty H. 2018. Fouling polychaetes in Tanjung Priok Port of Jakarta, Indonesia. ASEAN Journal on Science and Technology for Development 35:79–88.

Hewitt CL. 2002. Distribution and biodiversity of Australian tropical marine bioinvasions. Pacific Science 56(2):213–222.

Hing LS, Bhubalan K, Tan PY, Husain RM. 2018. Composition of ballast water from ships arriving at Kerith Port, Malaysia with observations on port and offshore waters, and notes on settlement patterns of fouling organisms. ASEAN Journal on Science and Technology for Development 35:89–100.

Hutchings PA, Hilliard RW, Coles SL. 2002. Species introductions and potential for marine pest invasions into tropical marine communities, with special reference to the Indo-Pacific. Pacific Science 56(2):223–233.

International Maritime Organization. 2004. International convention for the control and management of ships' ballast water and sediments. London, UK.

International Maritime Organization. 2011. Biofouling guidelines for the control and management of ship biofouling to minimize the transfer of invasive aquatic species. Annex 26. Resolution. MEPC 207 (62).

Jolifif Z, Wahab RA. 2018. Plate settlement: Determination of fouling organisms in Brunei. ASEAN Journal on Science and Technology for Development 35:11–16.

Kaluza P, Kölesch A, Gastner MT, Basius B. 2010. The complex network of global cargo ship movements. Journal of the Royal Society Interface 7:1093–1103.

Keller RP, Drake JM, Drew MB, Lodge DM. 2011. Linking environmental conditions and ship movements to estimate invasive species transport across the global shipping network. Diversity and Distribution 17:93–102.

Khing MM. 2018. Marine fouling panel survey and assessment of marine alien invasive species in Myanmar. ASEAN Journal on Science and Technology for Development 35:101–106.

Lee SSC, Teo SLM, Lambert G. 2013. New records of solitary ascidians on artificial structures in Singapore waters. Marine Biodiversity 6:1–18.

Lim CS, Leong YL, Tan KS. 2017. Managing the risk of non-indigenous marine species transfer in Singapore using a study of vessel movement. Marine Pollution Bulletin 115:332–344.

Lim JY, Tay TS, Lim CS, Lee SCS, Teo SLM, Tan KS. 2018. Mytila strigata (Bivalvia: Mytilidae): an alien mussel recently introduced to Singapore and spreading rapidly. Molluscan Research 38(3):170–186.

Liu TK, Tsai TK. 2011. Vessel traffic patterns in the Port of Kaohsiung and the management implications for preventing the introduction of non-indigenous aquatic species. Marine Pollution Bulletin 62:602–608.

Lo VB, Levings CD, Chan KMA. 2012. Quantifying potential propagate pressure of aquatic invasive species from the commercial shipping industry in Canada. Marine Pollution Bulletin 64:295–302.

Low KL, Khoo HW, Koh LL. 1991. Ecology of marine fouling organisms at Eastern Johore Strait. Environmental Monitoring and Assessment 19:319–333.
Madin J, Chong VC, Basri B. 2009. Development and short-term dynamics of macrofouling assemblages on fish-cage nettings in a tropical estuary. Estuarine, Coastal and Shelf Science 83:19–29.

Molnar JL, Gamboa RL, Revenga C, Spalding MD. 2008. Assessing the global threat of invasive species to marine biodiversity. Frontiers in Ecology and Environment 6(9):485–492.

Nacorda HME, Austero NM, Pagdilao CR, Tan KS, Azanza RV. 2018. Marine biofouling communities of Manila South Harbor, Philippines. ASEAN Journal on Science and Technology for Development 35:115–124.

Nandhini S, Revathi K. 2016. Study on biofouling organisms present on the surface of boats in Royapuram, Chennai. Nature Environment and Pollution Technology 15(1):257–261.

Nghiem LTP, Soliman T, Yeong DCJ, Tan HTW, Evans TA, Mumford JD, Keller RP, Baker RHA, Corlett RT, Carrasco LR. 2013. Economic and environmental impacts of harmful non-indigenous species in Southeast Asia. PLoS ONE 8(8):1–9.

Ong JIL, Tan KS. 2012. Observations on the subtidal fouling community on jetty pilings in the Southern Islands of Singapore. Contributions to Marine Science 2012:121–126.

Pati SK, Rao MV, Balaji M. 2015. Spatial and temporal changes in biofouling community structure at Visakhapatnam harbour, east coast of India. Tropical Ecology 56(2):139–154.

Peh KSH. 2010. Invasive species in Southeast Asia: the knowledge so far. Biodiversity Conservation 19:1083–1099.

Piola RF, McDonald JI. 2012. Marine biosecurity: The importance of awareness, support and cooperation in managing a successful incursion response. Marine Pollution Bulletin 64:1766–1773.

Puttapreecha R, Kajonwattanakul S, Songkai P, Choamanee C. 2018. Survey of fouling organisms at Songkhla Port in Thailand. ASEAN Journal on Science and Technology for Development 35:147–152.

Schultz MP, Bendick JA, Holm ER, Hertel WM. 2011. Economic impact of biofouling on a naval surface ship. Biofouling 27(1):87–98.

Seebens H, Gastner MT, Blasius B. 2013. The risk of marine bioinvasion caused by global shipping. Ecology Letters 16(6):782–790.

Spalding MD, Fox HE, Allen GR, Davidson N, Ferdaña ZA, Finlayson M, Halpern BS, Jorge MA, Lombana A, Lourie SA, Martin KD, McManus E, Molnar J, Recchia CA, Robertson J. 2007. Marine eco-regions of the world: a bioregionalization of coastal and shelf areas. Bioscience 57(7):573–583.

Strayer DL. 2009. Twenty years of zebra mussels: lessons from the mollusk that made headlines. Frontiers in Ecology and Environment 7(3):135–141.

Swami BS, Udhayakumar M. 2010. Seasonal influence on settlement, distribution and diversity of fouling organisms at Mumbai Harbour. Indian Journal of Marine Sciences 39(1):57–67.

Tan KS, Morton B. 2006. The invasive Caribbean bivalve Mytilopsis sallei (Dreissenidae) Introduced to Singapore and Johor Bahru, Malaysia. Raffles Bulletin of Zoology 54(2):429–434.

Toh KB, Ng LCS, Wu B, Toh TC, Cheo PR, Tun K, Chou LM. 2017. Spatial variability of epibiotic assemblages on marina pontoons in Singapore. Urban Ecosystems 20:183–197.

Vallejo Jr B, Conejar–Espedido J, Manubag L, Artiaga KCC, Damatac II AM, Imperial ICVI, Itong TAB, Fontanilla IK, Cao EP. 2017. First record of the Charru mussel Mytilopsis charruna d’Orbigny, 1846 (Bivalvia: Mytilidae) from Manila Bay, Luzon, Philippines. Bioinvasions Records 6:49–55.