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ORIGINAL RESEARCH ARTICLE

Impact of artificial coastal protection structures on Ascidians settlement along the Tamil Nadu coast, India

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Summary Ascidians are one of the dominant marine sedentary filter feeders recorded more frequently as introduced species than other taxa. It is renowned that artificial structures offer novel niches to the non-native species. A yearlong investigation was carried out to understand the role of ascidian colonization on various artificial structures located along 84 stations stretched on the 1076 km long Tamil Nadu coast of South India. It revealed the occurrence of 26 ascidian species, among these18 specimens were identified to species level, 8 were identified to genus level based on morphological characters. As on origin and nativity, out of the total 26, 3 species were classified as introduced, 8 species were classified as native and 15 as cryptogenic species. Interestingly, *Polyclinum isipingense* and *Diplosoma variostigmatum* were reported first time in Indian waters. The cryptogenic and colonial forms of ascidians are dominant in the artificial structures. There were significant differences observed between artificial structure type, geographic locations ($p = 0.0071$) and between ascidians forms as well as geographic areas ($p = 0.00375$). This study also confirms the artificial structures offer new niches for non-native ascidian colonization. The influence of the substrate (structure type) as well as geographic locations on the biotic assemblage was also observed.

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1. Introduction

The urban sprawl near the coasts is one of the most extreme and widespread human impacts (Mckinney, 2006). It leads to severe landscape changes, species extinctions, homogenization of biota at local, regional and global scales (Mckinney and Lockwood, 1999). The anthropogenic impact on coastal areas occurs in the form of coastal structures for erosion prevention, which offer novel niches to the introduced species. However, their role in the subsequent invasions into native habitat remains unknown (Dumont et al., 2011). The enduring effect of artificial structures on the diversity of coastal biota at the regional level has started to increase along with the controversies of the lower diversity of native species and higher diversity of non-native species on these structures (Airoldi et al., 2015).

The colonization of artificial structures by native species was influenced by many factors — such as structural types, environmental factors etc. In some areas, colonization of the artificial structures by non-indigenous organisms exceeds the native forms (Dafforn et al., 2009; Firth et al., 2015; Glasby et al., 2007). Even though maritime activity distributes non-native species all around the globe, the triggering factor inducing the invasive nature ascertained between the prime entry point and the adaptability to the favorable new environment remains unclear (Hewitt et al., 2009). After a successful invasion, the local fishing and recreational boating activities potentially facilitate further expansion (Davidson et al., 2010). Thus, the harbors and marinas play a crucial role from the initial inoculation to the successful establishment by spreading to adjacent places (Forrest et al., 2009). Interestingly, there are limited reports available on further expansion of non-native organisms to the natural habitats.

It is well documented that introduced species were more frequently found on the artificial hard substrate in estuaries and bays than on the open coasts (Wasson et al., 2005). The occurrences of numerous cracks and gaps on these structures act as a shelter and protection from predation, desiccation, wave action and other stresses for the animals. Hence, non-indigenous species are more abundant on the artificial structures than in the natural rocky systems. Since the world is connected by the growing transport networks and infrastructure, the spread of the non-indigenous species (NIS) became a common problem (Minchin and Gollasch, 2003). Moreover, these artificial hard networks are considered to be the biggest threat to biodiversity after a habitat loss (Wilcove et al., 1998). Significant investment in reducing invasion opportunities in the form of managing the transport vectors or border control were found to be ineffective and lead to an upsurge in the eradicating cost (Hulme, 2009).

The ascidians are the common sessile filter feeders often recorded as introduced species, mostly occupying the artificial coastal defense structures and (Aldred and Clare, 2014; Lambert and Lambert, 2003). Their successful proliferation is based on flexibility to survive in varying temperature, salinity (Nagar and Shenkar, 2016) and pollution (Beiras et al., 2003). Some of the invasions have deleterious economic (McKindsey et al., 2007) and ecological (Lutz-Collins et al., 2009) impact on the surrounding environment.

Short-lived, non-feeding, low-dispersal larval stageofascidians are considered an indicator of invasion if found miles from its known habitat and are spreading through ballast water transport and hull fouling dispersion (Lambert, 2007). These invasive ascidians are acting as strong spatial competitors by frequently displacing native anemones, mussels, algae and other fouling community, where the mechanism of eradication is complicated (Lindeyer and Gittenberger, 2011). They foul various artificial structures like jetties, ship hulls, floating docks, buoys, floats, cables and other human-made structures (Lambert, 2005). Hence, the study of the ascidians communities is necessary for monitoring the non-indigenous species.

Numerous researches have been carried out worldwide to ascertain the negative impacts of ascidians colonization on the artificial structures but few studies concerned species conservation (Ferrario et al., 2016; Firth et al., 2014). In India, sporadic studies on location-specific non-indigenous ascidians species on certain structures and harbor were carried out (Ali et al., 2009; Jaffar et al., 2016). Hence, an extensive survey along the entire stretch of the Tamil Nadu coast was conducted to comprehend the distribution of the ascidians species on various types of artificial coastal defense structures.

2. Material and methods

The 1076 km coastal stretch of Tamil Nadu is located in the southeastern part of the Indian Peninsula and it forms a part of the Coromandel Coast on the Bay of Bengal and the Indian Ocean. This coastal corridor comprises 15 marinas and harbors. The entire coastline is occupied by numerous artificial structures and protective groins that provide habitat for a wide variety of marine organisms. Based on utility, these structures were classified into four types. (1) The artificial structures in the fishing harbor, such as breakwaters, groins, etc. are organized under "Fishing". (2) The structures with function in the fish farming, salt pan, are categorized under "Commercial". (3) The structures with a role in the development of tourism (surfing, boat riding, etc.) are organized under "Recreational". (4) The artificial structures like sea wall and groins used for the shoreline armoring and urban coastal protection are classified under the "Coastal armoring" category

Series of field surveys were conducted through SCUBA diving and Snorkelling at low tide, at depths ranging from 1 to 5 m (Jebakumar et al., 2015) at seven sampling zones during January, May, and September 2016. Each zone included 8 to 18 sampling stations (total of 84 stations) along the Tamil Nadu coast (Fig. 1). Investigated habitats comprised artificial substrates such as boulder piles, groins, caissons, tetrapods, fishery jetties, pipeline trestles, and harbor breakwaters along the entire shoreline of Tamil Nadu. The entire structure at each station was surveyed completely to collect the ascidian samples. Hand tools were employed to remove animals from solid surfaces of the artificial structures.

Representative ascidians were photographed in situ. In the case of large colonial ascidians, a portion of the colony was collected after inspecting the structure and dimension of the whole colony. In the case of ascidians, after collecting representative specimens identified in the field, others were transported to the laboratory for detailed study. The

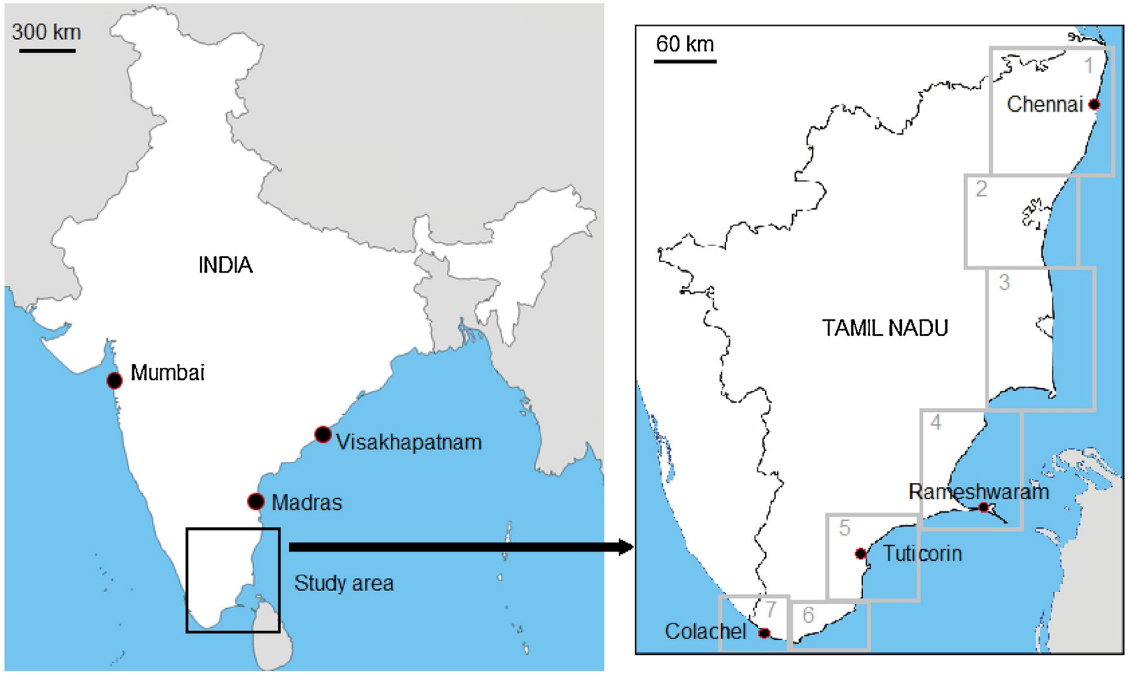

Figure 1 Study Area: The Tamil Nadu coast in southern India; grey squares indicate the seven sampling zones where the 84 sampling stations were placed (see supplementary material Table S1 for coordinates).

collected samples were narcotized in menthol crystals up to two hours for colonial ascidians and three hours for solitary ascidians. After narcotization, the specimens were fixed separately by quickly adding one part of 40% formaldehyde to nine parts of fresh sea water, and preserved in 70% ethanol. The samples were sorted and identified up to species, or the lowest possible taxa by observing all the taxonomical characters using various microscopes, e.g. Olympus, (Germany), compound (Labomode, Vision 2000) and stereo microscopes (Micros, Austria). The taxonomical keys and all the observed characters were compared with previously published data (Kott, 1985; Millar, 1975; Monniot and Monniot, 1996; Renganathan, 1986; Tokioka, 1967). Voucher specimens were deposited to Zoological Survey of India, Chennai.

To compare the ascidian diversity and structure types, the results were visualized with the help of the non-metric multidimensional scaling (nMDS) plot. The analyzes were carried out using the software PRIMER v7.0 (Clarke et al., 2014). The Bray-Curtis similarity matrices were transformed to the distance for input into the PRIMER v7.0. to perform a nMDS plot (no transformation to the original data was applied, as it was semi- quantitative). The analyses were carried out by comprising all the species (native, introduced and cryptogenic) obtained from each structure. The nMDS performs 20 different random starts and compares them to find a stable solution. Additionally, the non-parametric Kruskal—Wallis test was also performed using the software PAST 3 (Hammer et al., 2001), to find the significant correlation between the structure types and the abundance of native, introduced and cryptogenic ascidian species. The same datasets were also analyzed using the single factor ANOVA to test for the difference between the structure types and ascidian species abundance in detail.

3. Results

An extensive survey on the presence of ascidian species was carried out in 84 stations comprising the artificial coastal defense structures along the 1076 km coastal stretch of Tamil Nadu (the south-eastern coast of India) three times a year (January, May, and September). During the survey, 26 different ascidian samples belonging to 8 families under three orders were collected and identified (Table 1). Out of 26 samples, 18 were identified at the species level, and the remaining eight specimens identified at genus level due to invisible key morphological characters. Among the surveyed artificial structures, the highest species richness was observed in the Colachel fishing harbor (CFH) (n = 13) followed by Punnaikayal left arm (PKLA) (n = 11), Muttam fishing harbor (MFH) (n = 11) and Thondi (TDMV) (n = 10). There are almost 57 artificial structures out of the 84 surveyed with zero ascidian species recorded (Table S1). The artificial structures used in fishing harbor recorded the highest species richness (n = 24) followed by the Recreational (n = 8), Armor (n = 6) and Commercial (n = 2) (Fig. 2).

After identification of the ascidian samples, each species was classified into one of the following groups: native, cryptogenic and invasive, depending on their origin (Carlton, 1996). If the species' origin, distributional and genetic data exists, it can be classified as Introduced. The species endemic to Indian subcontinent was classified as Native. Finally, when supportive data of nativity or geographic origin was not available, it was classified as cryptogenic species (Jaffar et al., 2016). In the artificial coastal defense structures cryptogenic species were highly abundant (n = 15), followed by native (n = 8) and invasive (n = 3) species (Fig. 3). The species abundance pattern along the geographical locations is represented in Fig. 4. Further, out of 26 ascidian species, 24 species were

Table 1 Distribution of Ascidian species along the study area.

Sl.No	Order	Species	Origin	Accession number	Structure type
1	Aplousobranchia	*Polyclinum indicum*	Native		1
2		*Polyclinum isipingense**	Cryptogenic	NZC/MBRC/M.327	1
3		*Didemnum psammatodes*	Cryptogenic	NZC/MBRC/M.328	1, 3
4		*Lissoclinum fragile*	Cryptogenic		1, 3
5		*Didemnum vexiculum*	Cryptogenic		1, 3
6		*Trididemnum miniatum*	Cryptogenic	NZC/MBRC/M.319	1
7		*Aplidium* sp.	Native		1, 2, 4
8		*Eudistoma sluiteri*	Native	NZC/MBRC/M.326	2, 3
9		*Eudistoma tumidum*	Native	NZC/MBRC/M.322	1
10		*Diplosoma variostigmatum**	Cryptogenic	NZC/MBRC/M.323	3
11		*Synoicum* sp.	Native		1
12		*Aplidium multiplicatum*	Native	NZC/MBRC/M.325	1
13	Phlebobranchia	*Corella eumyota*	Invasive		1
14		*Phallusia nigra*	Invasive		1
15		*Ascidia gemmata*	Cryptogenic	NZC/MBRC/M.320	1
16		*Ecteinascidia* sp.	Native		1
17		*Ecteinascidia venue*	Native	NZC/MBRC/M.329	1
18	Stolidobranchia	*Symplegma brakenhielmi*	Cryptogenic	NZC/MBRC/M.321	1, 3
19		*Styela canopus*	Invasive	NZC/MBRC/M.324	1, 3
20		*Symplegma* sp.	Cryptogenic		1
21		*Symplegma* sp.-2	Cryptogenic		3
22		*Herdmania momus Savigny*	Cryptogenic		1
23		*Botrylloides nigrum*	Cryptogenic		1
24		*Botryllus* sp.3	Cryptogenic		1
25		*Botryllus* sp.2	Cryptogenic		3
26		*Botrylloides* sp.1	Cryptogenic		1

* indicates the organisms reported first time in Indian waters.
Fishing — 1, Commercial — 2, Recreational — 3 and Armour — 4.

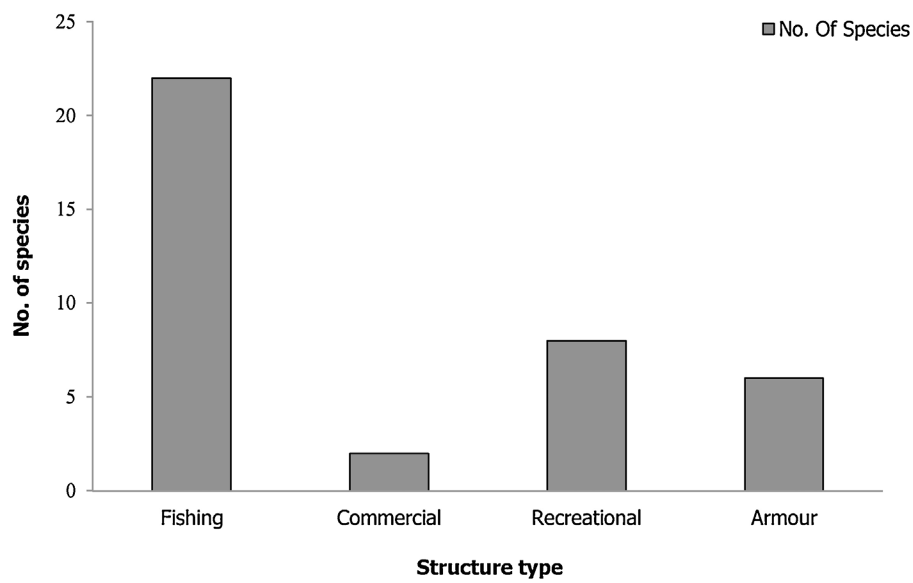

Figure 2 Number of Ascidian Species recorded at each structure type.

reported earlier in Indian sub-continent and, the remaining two species, namely *Diplosoma variostigmata* and *Polyclinum isipingense*, were reported for the first time in Indian waters. The two newly recorded species were confirmed and submitted to Zoological Survey of India to obtain accession numbers (Accession No. NZC/MBRC/M.323 & NZC/MBRC/M.327).

The population densities of native and cryptogenic species were the most dominant and prevailing in all types of artificial structures. Low density of population represented the invasive species and was limited to the specific areas. The number of ascidians species present in the fishing harbor structures was high, with an average of 3.35 species/structure, followed

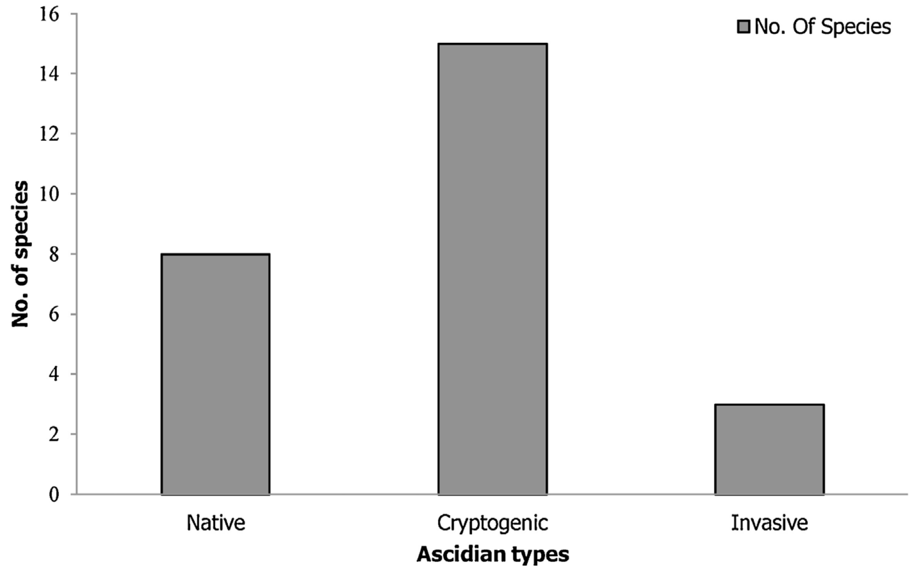

Figure 3 Total Number of Ascidian Species recorded as per type of species (Native, Cryptogenic and Introduced).

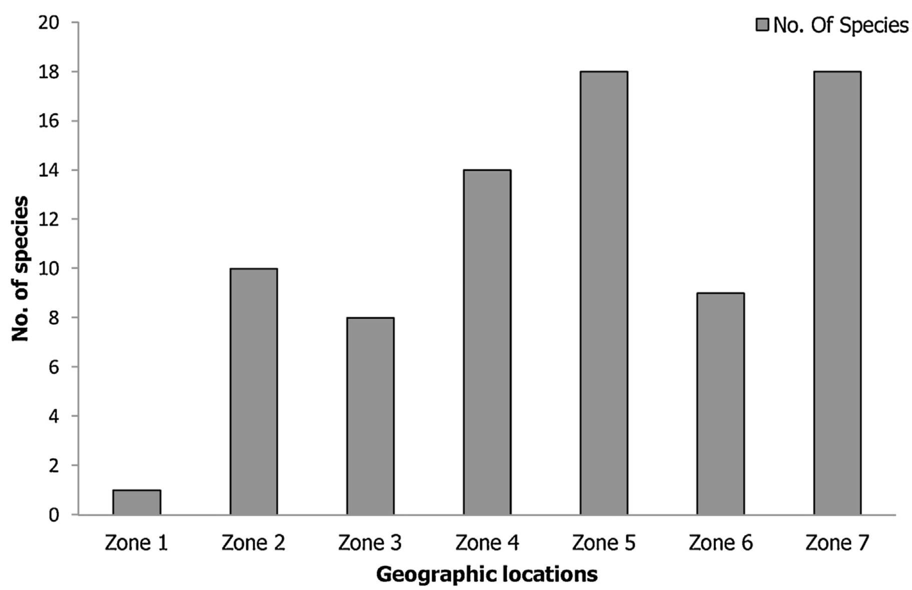

Figure 4 Total number of Ascidian species recorded at each sampling zone, Tamil Nadu.

by commercial (0.2 species/structure), armor (0.588 species/structure) and recreational (0.5 species/structure). Among widely distributed colonial and solitary forms of ascidians, the colonial forms dominated the artificial structures during the entire study period. Also, most of the cryptogenic species belonged to the colonial forms, whereas the invasive belonged to the solitary type. Further, there was no significant correlation observed between the types and forms of ascidians. The *D. passamodes*, *L. fragile* and *D. vexiculum* were the most common colonial ascidians to occupy the several artificial structures. Of the *L. fragile* recorded in the 15 structures, *D. passamodes* recorded in the 14 structures and the *D. vexiculum* was recorded on 12 structures. Surprisingly, the solitary ascidians such as *C. eumyte* was observed on three structures, *P. nigra* and *H. savingy* were observed on four structures.

When the permutational analysis was done considering the geographical location (zone wise), and structural types (Fishing, Armor, Commercial and Recreational), results showed a significant effect of both factors on the ascidian community structures ($p = 0.0071$). Likewise, the Kruskal—Wallis test also showed a substantial difference in ascidian community, with geographical locations and structure types ($p = 0.00064$).

Similarly, significance ($p = 0.00375$) was observed between geographic location (zone wise) and the ascidian types (Native, Cryptogenic, and Introduced) when permutational analysis of the community structures with the location only was performed. In addition, Kruskal—Wallis test was carried out, and this result proved a significant difference between the geographical location and ascidian type ($p = 0.00495$).

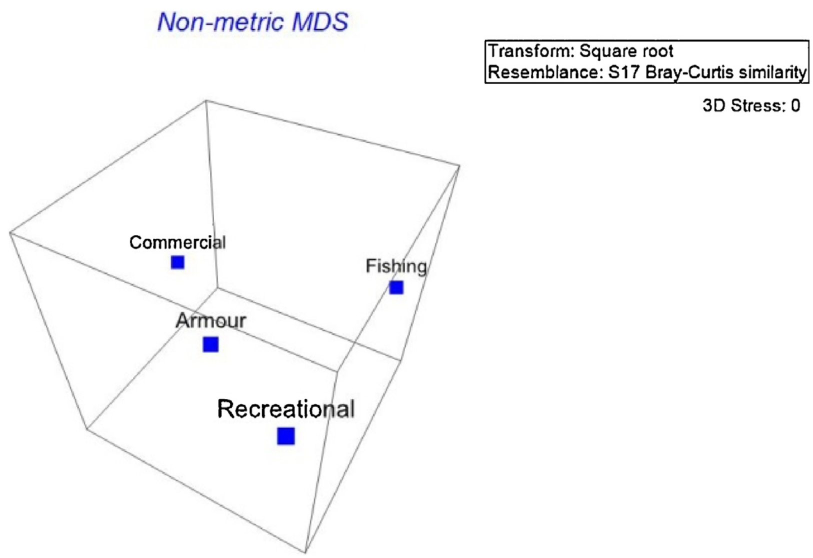

Figure 5 Non-metric MDS plot obtained from the Bray-Curtis similarity index for the whole dataset (structure types and ascidian abundance in each type).

The non-metric MDS plot constructed from relative abundance data (using Bray-Curtis index) showed improved differentiation among the types of structures (Fig. 5). The significant difference observed in ANOVA, and Kruskal—Wallis test between the different structures and the geographical locations (zone wise) is represented graphically with the separation of structures. By considering the four types of structures alone for statistical treatment, the Recreational, Commercial and Armoring structures showed linearity, whereas the Fishing structure was apart from the other three in the graph.

4. Discussion

The present study was a pioneering attempt to compile an up-to-date list of ascidian species along with the Non-Indigenous species (NIAs) found on the various artificial coastal defense structures along the 1076 km coast of Tamil Nadu, India. Among the 84 artificial coastal defense structures surveyed, 26 different types of ascidian species were recorded. Among them, 18 species were identified at the species level and the remaining were identified at the genus level. The two species, namely *Polyclinum isipengense* and *Diplosoma variostigma* were reported for the first time in the Indian waters. These newly recorded species were observed only on the Fishing and Recreational types of structures. It leads to the conclusion that the introduction of the species happened through hull fouling and was followed by spreading through the local vessel movement. The *D. variostigma* was observed in Japan (Hirose and Oka, 2008), whereas the *P. isipengense* was observed at South Africa (Sluiter, 1898). However, the nativity of these species remains unclear. Therefore, these two species observed in the present study were categorized as cryptogenic species, though they are non-native to Indian waters. In general, the cryptogenic species dominated the native and introduced forms along the artificial structures, with the maximum record of 15 species. In the case of introduced species, the artificial structures sheltered only three species, whereas eight native ascidian forms have also been recorded. During the past systematic fauna studies, the ascidian species attracted little attention, hence the lacuna in nativity records for most of these species (Ali et al., 2009). Thus the cryptogenic species outnumbered the non-indigenous species (López-Legentil et al., 2015). This applies the general understanding that the artificial structures are not a suitable habitat for the native ascidian species. Among the different types of structures, the lowest number of 2 ascidian species was recorded on the Commercial structures, followed by six species on the Armoring structures, eight species on the Recreational structures and the maximum of 24 species were recorded on the Fishing harbor structures. The abundance of the ascidian settlements on the Fishing harbor structure was due to the occurrence of exclusively cryptogenic and introduced species. The observed preference of the non-native ascidians for the Fishing harbors structures, which are considered a hotspot for exotic species, was also reported by Murray et al. (2012) and López-Legentil et al. (2015).

The permutational analysis and Kruskal—Wallis test showed the significant difference when the comparison is done between the abundance of ascidians types (native, introduced and cryptogenic) with the geographic locations (zone wise). The significant difference might be due to the presence of fishing harbors at some zones — the harbors are considered to be a hotspot for non-indigenous species. The frequent ship movement along the Fishing harbor structures facilitated the settlement of the non-native ascidian species from the hulls of vessels. Furthermore, the Zones 5, 6 and 7 contained a higher number of non-native ascidian species (Table S1) than the native species. It has been confirmed by the permutational analysis and revealed that the structure types had significant effects on the ascidian settlements. The structure types and ascidian types showed the significant difference, which was further confirmed by Kruskal—Wallis test. The overall results evidently show that the fishing harbor structures are supporting the non-native species more than the native species. In general, the colonial ascidian forms outnumbered the solitary forms whereas most of the cryptogenic ascidians observed are colonial forms. It has been established that several colonial species were introduced worldwide through hull fouling and aquaculture (Lambert, 2002).

Further, reduction in the vessel movement around the Commercial, Recreational and Armoring structures lead to a deficiency of non-native species. The distance from the fishing harbor and the sparse movement of the vessels along the other three type of structures limited the secondary spread. This result supports the hypothesis that non-indigenous species (NIAs) thriving on artificial structures in the proximity to vector but failing to spread on other structures (Lambert, 2002).

The n-MDS plot constructed by using the Bray-Curtis Index showed, that the structure types mostly drove the settlement of ascidian types and forms. Among the various types of structures studied, fishing harbor structures were distinct and stood out compared to the other structures (Fig. 5). The separation of the fishing structures from the remaining structures was explained by the presence of some exclusive species such as *Botrylloides nigrum*, *Herdmania momus saving* and *Symplegma* sp. or the most exclusive species like *Polyclinum isipingense*, *Synocium* sp., *Corella eumyota* and *Phallusia nigra*. The current scenario of augmented recreational sailing and the proliferation of marinas and artificial marine structures in recent decades provided additional sites for the colonization of non-indigenous species (NIAs), even those with low dispersal abilities (Shenkar and Loya, 2009). Many studies substantiated that the artificial coastal defense structures serve as an asylum for the NIAs (Airoldi et al., 2015; Shenkar and Loya, 2009). The observations in the present study are comparable with the earlier researches. However, the artificial coastal defense structures proved to be a novel niches for the colonization of marine organisms and developed unique ecosystems (Ferrario et al., 2016; Firth et al., 2014). The study clearly depicted that the distribution and diversity of the ascidian species largely depend on the type of structure and a proximity between them. This detailed study also put forth the idea, that the artificial coastal defense structures can help in the development of the coastal ecosystem. Therefore, the better understanding, proper planning and appropriate utilization of the artificial structures along the coast will reduce the settlement of the non-native species and will also help enhance the presence of native species.

5. Conclusion

Despite the variations in structures, the ascidians species (Native, Cryptogenic, and Introduced) occupied almost all types of structures. The artificial structures hold all three varieties of ascidians forms of both solitary as well as colonial types. The cryptogenic species was more dominant than the native and introduced species. However, the diversity of the native species was similar to the abundance of the cryptogenic form. In the results, it was apparent that the structures with substantial vessel traffic harbor non-native species and vice versa in the case of structures with the fewer or no vessel traffic. It necessitates continuous monitoring of the non-native species on these artificial coastal defense structures, which should be considered a hotspot for bio-pollution monitoring. This study warrants in-depth studies on physiology, life spawn, larval settlement pattern, prey-predation and fouling efficiency, which would help prepare a proper management plan for the artificial coastal defense structures.

Acknowledgments

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Appendix A. Supplementary data

Supplementary material related to this article can be found in the online version at https://doi.org/10.1016/j.oceano.2018.06.005.

References

Airoldi, L., Turon, X., Perkol-Finkel, S., Rius, M., 2015. Corridors for aliens but not for natives: effects of marine urban sprawl at a regional scale. Divers. Distrib. 21, 755—768, http://dx.doi.org/10.1111/ddi.12301.

Aldred, N., Clare, A.S., 2014. Mini-review: impact and dynamics of surface fouling by solitary and compound ascidians. Biofouling 30 (3), 259—270, http://dx.doi.org/10.1080/08927014.2013.866653.

Ali, H.A.J., Sivakumar, V., Tamilselvi, M., 2009. Distribution of alien and cryptogenic ascidians along the Southern Coasts of Indian Peninsula. World J. Fish. Mar. Sci. 1 (4), 305—312.

Beiras, R., Bellas, J., Fernández, N., Lorenzo, J.I., Cobelo-Garcıa, A., 2003. Assessment of coastal marine pollution in Galicia (NW Iberian Peninsula); metal concentrations in seawater, sediments and mussels (*Mytilus galloprovincialis*) versus embryo—larval bioassays using *Paracentrotus lividus* and *Ciona intestinalis*. Mar. Environ. Res. 56 (4), 531—553, http://dx.doi.org/10.1016/S0141-1136(03)00042-4.

Carlton, J.T., 1996. Biological invasions and cryptogenic species. Ecology 77 (6), 1653—1655.

Clarke, K.R., Gorley, R.N., Somerfield, P.J., Warwick, R.M., 2014. PRIMER-E, Plymouth. In: Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. 3rd edn. 260 pp.

Dafforn, K.A., Johnston, E.L., Glasby, T.M., 2009. Shallow moving structures promote marine invader dominance. Biofouling 25 (3), 277—287.

Dumont, C.P., Harris, L.G., Gaymer, C.F., 2011. Anthropogenic structures as a spatial refuge from predation for the invasive bryozoan *Bugula neritina*. Mar. Ecol. Prog. Ser 427, 95—103.

Davidson, I.C., Zabin, C.J., Chang, A.L., Brown, C.W., Sytsma, M.D., Ruiz, G.M., 2010. Recreational boats as potential vectors of marine organisms at an invasion hotspot. Aquat. Biol. 11, 179—191, http://dx.doi.org/10.3354/ab00302.

Ferrario, F., Iveša, L., Jaklin, A., Perkol-Finkel, S., Airoldi, L., 2016. The overlooked role of biotic factors in controlling the ecological performance of artificial marine habitats. J. Appl. Ecol. 53 (1), 16—24, http://dx.doi.org/10.1111/1365-2664.12533.

Firth, L.B., Mieszkowska, N., Grant, L., Bush, L., Davies, A.J., Frost, M.T., Cunningham, P.N., Moschella, P., Hawkins, S.J., 2015. Historical comparisons reveal multiple drivers of decadal change of an ecosystem engineer at the range edge. Ecol. Evol. 5 (15), 3210—3222, http://dx.doi.org/10.1002/ece3.1556.

Firth, L.B., Schofield, M., White, F.J., Skov, M.W., Hawkins, S.J., 2014. Biodiversity in intertidal rock pools: informing engineering criteria for artificial habitat enhancement in the built environment. Mar. Environ. Res. 102, 122—130, http://dx.doi.org/10.1016/j.marenvres.2014.03.016.

Forrest, B.M., Gardner, J., Taylor, M.D., 2009. Internal borders for managing invasive marine species. J. Appl. Ecol. 46 (1), 46—54, http://dx.doi.org/10.1111/j.1365-2664.2008.01544.x.

Glasby, T.M., Connell, S.D., Holloway, M.G., Hewitt, C.L., 2007. Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? Mar. Biol. 151 (3), 887—895.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. Paleontological statistics software: package for education and data analysis. Palaeontol. Electron. 4, 9.

Hewitt, C.L., Gollasch, S., Minchin, D., 2009. The vessel as a vector — biofouling, ballast water and sediments. In: Rilov, G, Crooks, JA (Eds.), Biological Invasions in Marine Ecosystems. Ecol. Stud., Vol. 204. Springer, Berlin, Heidelberg, 117—131, http://dx.doi.org/10.1007/978-3-540-79236-9_6.

Hirose, E., Oka, A.T., 2008. A new species of photosymbiotic ascidian from the Ryukyu Archipelago, Japan, with remarks on the stability of stigma number in photosymbiotic Diplosoma species. Zool. Sci. 25 (12), 1261—1267, http://dx.doi.org/10.2108/zsj.25.1261.

Hulme, P.E., 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. J. Appl. Ecol. 46 (1), 10—18, http://dx.doi.org/10.1111/j.1365-2664.2008.01600.x.

Jaffar, H.A., Akram, A.S., Arshan, M.K., Sivakumar, V., Tamilselvi, M., 2016. Distribution and invasiveness of a colonial ascidian, *Didemnum psammathodes*, along the southern Indian coastal water. Oceanologia 58 (3), 212—220, http://dx.doi.org/10.1016/j.oceano.2016.04.002.

Jebakumar, J.P.P., Nandhagopal, G., Ragumaran, S., Rajanbabu, B., Ravichandran, V., 2015. First record of alien species Eualetestulipa (Rousseau in Chenu, 1843) from the Royapuram fishing harbour at Chennai, India. Bioinvasions Rec. 4 (3), 201—204, http://dx.doi.org/10.3391/bir.2015.4.3.08.

Kott, P., 1985. The Australian Ascidiacea part 1, Phlebobranchia and Stolidobranchia. Mem. Qd. Mus. 23, 1—440.

Lambert, G., 2002. Nonindigenous ascidians in tropical waters. Pac. Sci. 56 (3), 291—298, http://dx.doi.org/10.1353/psc.2002.0026.

Lambert, G., 2005. Ecology and natural history of the protochordates. Can. J. Zool. 83 (1), 34—50, http://dx.doi.org/10.1139/Z04-156.

Lambert, G., 2007. Invasive sea squirts: a growing global problem. J. Exp. Mar. Bio Ecol. 342 (1), 3—4.

Lambert, C.C., Lambert, G., 2003. Persistence and differential distribution of nonindigenous ascidians in harbors of the Southern California Bight. Mar. Ecol. Prog. Ser. 259, 145—161.

Lindeyer, F., Gittenberger, A., 2011. Ascidians in the succession of marine fouling communities. Aquat. Invasions 6 (4), 421—434, http://dx.doi.org/10.3391/ai.2011.6.4.07.

López-Legentil, S., Legentil, M.L., Erwin, P.M., Turon, X., 2015. Harbor networks as introduction gateways: contrasting distribution patterns of native and introduced ascidians. Biol. Invasions. 17 (6), 1623—1638, http://dx.doi.org/10.1007/s10530-014-0821-z.

Lutz-Collins, V., Ramsay, A., Quijón, P.A., Davidson, J., 2009. Invasive tunicates fouling mussel lines: evidence of their impact on native tunicates and other epifaunal invertebrates. Aquat. Invasions 4, 213—220.

McKinney, M.L., 2006. Urbanization as a major cause of biotic homogenization. Biol. Conserv. 127 (3), 247—260, http://dx.doi.org/10.1016/j.biocon.2005.09.005.

McKinney, M.L., Lockwood, J.L., 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. Trends Ecol. Evol. 14 (11), 450—453, http://dx.doi.org/10.1016/S0169-5347(99)01679-1.

Mckindsey, C.W., Landry, T., O'Beirn, F.X., Davies, I.M., 2007. Bivalve aquaculture and exotic species: a review of ecological considerations and management issues. J. Shellfish Res. 26 (2), 281—294.

Millar, R.H., 1975. Ascidians from the Indo-West-Pacific region in the Zoological Museum, Copenhagen (Tunicata, Ascidiacea). Steenstrupia 3 (20), 205—306.

Minchin, D., Gollasch, S., 2003. Fouling and ships' hulls: how changing circumstances and spawning events may result in the spread of exotic species. Biofouling 19 (S1), 111—122, http://dx.doi.org/10.1080/0892701021000057891.

Monniot, F., Monniot, C., 1996. New collections of ascidians from the western Pacific and southeastern Asia. Micronesia 29, 133—279.

Murray, C.C., Therriault, T.W., Martone, P.T., 2012. Adapted for invasion? Comparing attachment, drag and dislodgment of native and nonindigenous hull fouling species. Biol. Invasions 14 (8), 1651—1663, http://dx.doi.org/10.1007/s10530-012-0178-0.

Nagar, L.R., Shenkar, N., 2016. Temperature and salinity sensitivity of the invasive ascidian *Microcosmus exasperatus* Heller, 1878. Aquat. Invasions 11 (1), 33—43, http://dx.doi.org/10.3391/ai.2016.11.1.04.

Renganathan, T.K., 1986. Studies on the Ascidians of South India. (PhD Thesis). Madurai Kamaraj University, Madurai, India.

Shenkar, N., Loya, Y., 2009. Non-indigenous ascidians (Chordata: Tunicata) along the Mediterranean coast of Israel. Mar. Biodivers. Rec. 2, http://dx.doi.org/10.1017/S1755267209990753.

Sluiter, C.P., 1898. Beitrage zur kenntnis der fauna von Sud-Afrika. Ergebnisse einer Reise von Prof. Max Weber im Jahre 1894. II. Tunicaten von South-Africa. Zool. Jahrb. Syst. 11, 1—64.

Tokioka, T., 1967. Pacific Tunicata of the United States National Museum. Bull. US Nation Museum 251, 1—242.

Wasson, K., Fenn, K., Pearse, J.S., 2005. Habitat differences in marine invasions of central California. Biol. Invasions 7 (6), 935—948, http://dx.doi.org/10.1007/s10530-004-2995-2.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A., Losos, E., 1998. Quantifying threats to imperiled species in the United States. BioScience 48 (8), 607—615.