Differences between artificial structures and natural reefs in recruiting non-indigenous and native species

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Summary

The growing urbanization of coastal zones is providing more artificial hard substrate structures that create new habitats for non-indigenous and native species to settle. These artificial structures provide different habitats compared to natural rocky reefs that are more susceptible to invasions of Non-Indigenous Species (NIS). Only it is unclear why artificial structures are more suitable for NIS and what the differences are for native species.

This report consist out of a literature study that is comparing natural rocky reefs with different artificial structures and their orientation on the composition of non-indigenous and native species. The study showed that natural rocky reefs and artificial structures are different habitats due to their variations in habitat features and environmental conditions. It also showed that floating artificial structures are more susceptible for NIS compared to other artificial structures and that NIS will dominate vertical artificial surfaces compared to native species who tend to dominate horizontal surfaces. All this information can be used in the design and placement of artificial structures to make them repel NIS and attract. But there needs to be more research on the effect of orientation of different substrates on non-indigenous and native species and the danger of floating artificial structures in different conditions outside of ports and marinas.

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Introduction

Urbanization surrounding coastal zones is increasing worldwide as the human population is growing. This is leading to the construction of more hard substrate artificial structures such as break walls pilings, sea walls and harbours that are used for protection, recreational or commercial purposes (Moschella et al., 2005; Bulleri & Chapman, 2010; Dafforn et al., 2015). These artificial structures can drastically influence surrounding marine habitats and therewith alter the composition of native and Non-Indigenous Species (NIS). But the influences of the different artificial structures on the surrounding habitats can differ between artificial structures and the material they are constructed from. The artificial structures can be divided in two main groups, the moving artificial structures and the stationary artificial structures. Examples of moving artificial structures are fast moving structures such as boats and slow moving structures such as pontoons. Examples of stationary artificial structures are harbours, sea walls and reefs.

Stationary artificial structures with hard substrates such as breakwaters are often placed along sedimentary shores to reduce the intensity of wave action and increase the safety of harbours. Breakwaters consist out of hard materials such as rock or concrete and will change the habitat from a sedimentary ecosystem to and artificial rocky ecosystem. This will cause habitat loss and fragmentation of the sedimentary ecosystem and can alter the local biodiversity due to the change in abiotic factors (Moschella et al., 2005; Dafforn et al., 2015). The construction of artificial structures on rocky shores also influences the local ecosystem. Compared to natural rocky reefs consist artificial structures only out of a few mobile species that can quickly colonize the structure and often lack rare species. This will result in habitats with a low species richness that is susceptible for invasions of non-indigenous species (Marraffini & Geller, 2015). Most of the time when a NIS is introduced in a habitat they do not have a large impact on the local ecosystem. But sometimes NIS can become invasive and outcompete native species which can lead to ecological damage, this is only almost never predictable before the new NIS is settled (Kulhanek et al., 2011).

The purpose of artificial reefs is to enhance local biodiversity. Artificial reefs can, however, enhance the spread of NIS and serve as corridors in new areas when the wrong design, substrate or placement is chosen (Bulleri & Airoldi, 2005; Bartholomew et al., 2022). There are several examples of artificial reefs facilitating the spread of non-indigenous species, such as corals, green algae and ascidians in the Mediterranean and other areas worldwide (Bulleri & Airoldi, 2005; Neill et al., 2006; Sheehy & Vik, 2010; Salomidi et al., 2013).

Due to the impact that artificial structures can have on native specie and on the introduction and spread of non-indigenous species, is it important to know what makes artificial structures more suitable for NIS than natural rocky reefs and how this can be prevented. Therefore, in this report the effect of different artificial structures and substrates on the composition of native and Non-Indigenous Species will be compared to natural rocky reefs. To answer this question the differences between natural rocky reefs and artificial structures on the settlement of native and non-indigenous species are researched. Furthermore, are the differences in biodiversity between different structures and substrates researched and why artificial substrates are more likely to attract NIS compared to native species. Also, the effect of the introduction pathway on the invasion of artificial structures and natural rocky reefs will be studied. Lastly, the differences between vertical and horizontal surfaces on the composition of NIS and native species will also be researched. In this report sandy natural reefs and artificial reefs will not be taken in account due to significantly differences in habitat features and purpose of the reef. This study will show the most important factors between artificial structures and natural reefs that make the artificial structures more susceptible for NIS.

Influence of ships on the introduction of non-indigenous species

Historical shipping is the biggest accidental distribution method for marine NIS due to hull fouling and ballast water in both commercial and recreational ships (Katsanevakis et al., 2013; Bailey, 2015; Ferrario et al., 2017). Shipping is for example responsible for introducing more than 50% of the NIS in European seas (Katsanevakis et al., 2013; Nunes et al., 2014). New regulations and adaptations such as anti fouling paint and the use of ballast water management systems decreased the survival of NIS but large numbers of organisms are still introduced with these pathways (Bailey et al., 2022; Santos-Simón et al., 2022; Bradie et al., 2023). A study in Germany where more than 250 species were identified showed that in ballast water 38% of the species were NIS and on the hull 96% of the fouling species were NIS (Gollasch, 2002).

Due to the high levels of NIS on ships and their danger of introducing NIS, a lot of research is done on the presence of NIS in different harbours, marinas and ports for recreational and commercial ships. These studies have shown that harbours, marinas and ports can house high densities of NIS in both temperate and tropical climates (Lambert & Lambert, 1998; Glasby, 1999a; Ros et al., 2013; López-Legentil et al., 2015). When looking at the purpose of ships that are responsible for introducing NIS, long distance commercial and recreational ships tend to be vectors for introduction and short distance recreational shipping tend to be a vector for dispersal to marinas in the surrounding areas (Ros et al., 2013; Ferrario et al., 2017). There is also a difference between the design of the harbour, the different areas in the harbour and the purpose of the harbour related to the presence and composition of NIS. So was there a higher number of fouling from NIS on boats that were stationed in marinas that are enclosed by break walls than marinas that were not enclosed by break walls (Floerl & Inglis, 2003). Research in the Western Mediterranean showed that in commercial harbours the main taxa of fouling organisms were autotrophic organisms such as macroalgae and in tourist harbours it was heterotrophic sessile organisms such as bryozoans, mussels, ascidians and sponges (Tempesti et al., 2022). The same study showed that harbours had a higher number and abundance of NIS compared to marinas and that the touristic harbour had higher numbers, abundances and percentages of NIS compared to the commercial harbour (figure 1) (Tempesti et al., 2022).
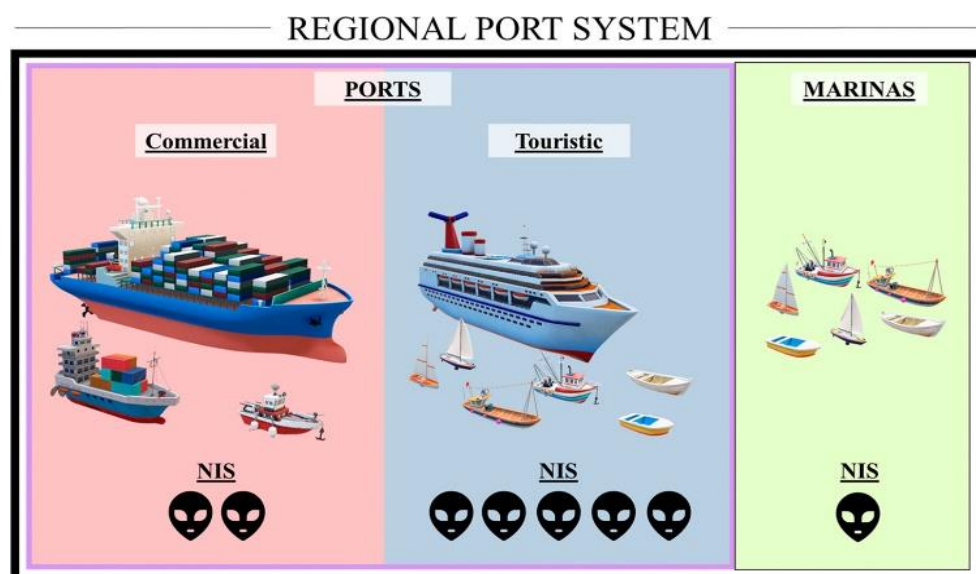

Figure 1: The invasion pressure of non-indigenous species from commercial and touristic ports and marinas (Tempesti et al., 2022).

Harbours and marinas are large sources for NIS in new areas, yet it is relatively unclear whether the dispersal of NIS to surrounding natural habitats is significant. Some research has shown that there is no significant dispersal from NIS that are located in marinas to surrounding natural habitats (Ros et al., 2013; Megina et al., 2016; Afonso et al., 2020). These studies have suggested that there are barriers that prevent the spread of NIS such as salinity or the inflow of freshwater. Other research has shown that there is an increasing amount of NIS in habitats that surround ports or even have a higher number of NIS outside the marina than inside the marina (Chainho et al., 2015; Afonso et al., 2020). But researchers agree that marinas and harbours are stepping stones for NIS to enter new areas.

The differences in species composition of natural rocky reefs and artificial structures

There is a difference between the habitat composition of natural rocky reefs and different artificial structures. For example, break walls have different habitat features, substrates and qualities than pontoons. Compared to natural rocky reefs lack artificial structures habitat complexity, have small spatial extent and are relatively young (Lawrence et al., 2021; Moschella et al., 2005; Anderson & Underwood, 1994; Loke & Todd, 2015). Most artificial structures are also constructed out of smooth hard material such as aluminium, fibreglass or plastic, all of which have homogenous surfaces and therefore make it harder for species such as molluscs to settle (Anderson & Underwood, 1994; Moschella et al., 2005; Cacabelos et al., 2016). This, among others, results that natural reefs and artificial structures have differences in biodiversity and abundance of their species. These are not only differences between NIS and native species but there are differences in taxa that inhabit different structures (Glasby & Connell, 2001; Moschella et al., 2005; Perkol-Finkel & Benayahy 2007). For instance, an experiment form Perkol-Finkel & Benayahy (2007) showed that on artificial reefs more filter feeders such as bryozoans, bivalves, sponges and tunicates, settled compared to the natural reef. On the natural reef also settled more hard corals compared to the artificial reef where more soft corals settled. It is expected that differences in conditions such as the current and sedimentation along with different abundances of sponges, tunicates and bryozoans on the natural reef and artificial structures has resulted in the difference between soft and hard coral settlement (Perkol-Finkel & Benayahu, 2007). Experiments in temperate regions have shown that on rocky reefs in Sydney the dominant taxa were encrusting bryozoans, red filamentous algae and spirorbid polychaetes but on pontoons the dominant taxa tend to be barnacles, bryozoans and polychaetes (Connell & Glasby, 1999; Glasby, 1999a; Glasby & Connell, 2001). The smoothness of the material tends to have an effect on the settlement of different species, so have algae a larger colonisation on materials with larger pores than materials that were smoother (Harlin & Lindbergh, 1977). Barnacles in contrast tend to settle better on smoother surfaces compared to surfaces with higher roughness (Petersen et al., 2020). The colour of the material also tends to have an effect on the settlement of species. For example, barnacle larvae tend to settle in larger numbers on surfaces that have a darker colour than surfaces that have a lighter surface (Pomerat & Reiner, 1942).

When looking at the difference of different materials and their species composition. Research on the use of different waste materials (wood and metal) and natural sandstone has shown that there is no significant difference in the settle speed and composition of algae and fish species between the natural and artificial substrates. But the type of material had a large impact on the settlement of sessile species. So settled more taxa of sessile species on vertical wooden structures compared to the other substrates (Chapman & Clynick, 2006).

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The composition of non-indigenous and native species on natural rocky reefs and artificial structures

As discussed in the previous heading species have different recruitment rates on different substrates and structures. There are also differences between species between the ratio of non-indigenous and native species that settle on different structures and substrates. Research has shown that NIS have higher abundances on artificial structures than on natural rocky reefs compared to native species (Ignacio et al., 2010; Airoldi et al., 2015; Bumbeer & Rocha, 2016; Gauff et al., 2023). Not only is there a difference between the abundance of species there is also a difference in the community. On artificial structures different taxa of native species settled compared to natural reefs surrounding the artificial structure (Airoldi et al., 2015; Gauff et al., 2023). Native species were for example twice as abundant on natural rocky reefs compared to artificial structures that were build close to the natural reefs. However, native species were almost absent on artificial structures that were build along sedimentary coasts and these artificial structures had a completely different species composition than the artificial structures that were build nearby the natural rocky reefs (Airoldi et al, 2015). Another study showed that when artificial structures and natural reefs are first colonized both the non-indigenous and native species developed in equal abundances on the natural reefs but on the artificial reefs the non-indigenous and native species developed equally in the start but non-indigenous tunicates dominated the native species over time (Tyrrell & Byers, 2007).

A possible explanation for the difference between non-indigenous and native species is that artificial structures give native species a less suitable habitat compared to NIS. This can be due to abiotic factors or differences in the type and intensity of the biotic interactions on artificial and natural habitats (Ivesa et al., 2010; Marzinelli et al., 2012). So are the levels of predation larger on artificial habitats compared to natural reefs and this can influence the growth of algae which will influence native species that feed on these algae (Moschella et al., 2005; Airoldi & Bulleri, 2011; Chebaane et al., 2023). Artificial structures are generally located close to the shore or surface and are often more maintained and therefore tend to have higher levels of disturbance from wave action and maintenance. These disturbances can damage native species that are not adapted to these conditions and give space to non-indigenous opportunists that are adapted to live in rougher habitats (Airoldi & Bulleri, 2011).

On natural rocky reefs NIS are less abundant compared to artificial structures and more often are not dominating the habitat. Different studies have shown that NIS are less successful on invading natural reefs when a community is already formed compared to native species (Tyrrell & Byers, 2007; Dafforn et al., 2012). However, a study from Bumbeer & Rocha (2016) showed that in well-established artificial and natural habits in estuarine areas, 17.6% of the species were NIS in artificial habitats compared 18.6% was NIS for the natural habitats, meaning that on the natural reef a higher abundance of NIS were settled than on the artificial reef.

There are not only differences between artificial structures and natural reefs. When looking at different artificial structures that are located close to each other there are also differences. During a study from Gauff et al. (2023) the species composition of pontoons and docks were studied in the Mediterranean. The results showed that the pontoons had a higher number of NIS compared to the docks. This corresponds with other research showing that pontoons have a lower biodiversity and a higher abundance of NIS compared to sea-walls and natural rocks (Connell, 2001; Dafforn et al., 2009; Nall et al., 2015; Megina et al., 2016). A possible explanation for this can be because pontoons and

other floating structures have different biotic and abiotic factors compared to natural rocky reefs. For example the light availability, the levels of wave action and levels of disturbance are different on floating structures compared to a natural reef (Connell, 2000; Dafforn et al., 2009). The location and the form of a pontoon are also different from a reef. So are pontoons located on the surface and do not touch the bottom directly, they also have vertical smooth surfaces what makes it harder for benthic species that live on the sea floor to settle (Scheltema, 1986; Connell, 2000).

The influence of the surface orientation of species composition

There is a difference between the surface orientation (horizontal or vertical) of the reef or structure and the quantities and composition of species that settle on the surfaces. Research has shown that on vertical jetties a higher number of species and fish mass was measured compared to horizontal natural reefs (Rilov & Benayahu, 2000). Other studies have shown that invertebrates cover a larger area on vertical surfaces, but on horizontal reefs higher number of sponges and ascidians were measured (Knott et al., 2004). However, for algae the preference differs per study, in some studies algae show a preference for horizontal surfaces and in other studies there is no difference between horizontal and vertical surfaces (Witman & Sebens, 1985; Baynes, 1999; Knott et al., 2004; Dafforn et al., 2012). The position of the different surfaces also influences the composition of species. On suspended surfaces barnacles, bryozoans and sponges are more abundant but on fixed surfaces algae are more abundant (Glasby & Connell, 2001).

The difference between the vertical and horizontal surfaces is also visible in the ratio of NIS that recruit on the different surfaces. For example, the invasive corals *Tubastrea tugasensis* and *Tubastrea coccinea* dominated the natural reef wall compared to native corals that dominated the natural reef top (Miranda et al., 2018). In addition, native invertebrates tend to dominate both horizontal and vertical natural reefs but non-indigenous invertebrates dominated vertical artificial structures such as pontoons and pilings (Dafforn et al., 2012). Researchers suspect that the difference in domination between horizontal and vertical reefs are partially caused by the levels of sedimentation, light intensity and dept (Irving & Connell, 2002; Dafforn et al., 2012). Different studies have shown that sedimentation can limit the habitability of horizontal reefs for invertebrates (Irving & Connell, 2002; Gibson et al., 2003). Furthermore, light intensity also has an effect on different taxa. A study from Miller & Etter (2008) showed that shaded horizontal reefs were dominated by invertebrates such as ascidians, barnacles and bryozoans. In contrast, unshaded plots were dominated by macroalgae, which were almost absent on the shaded plots. The influence of depts is not only visible for the taxa of species that settle but also for the ratio of non-indigenous and native species. Non-indigenous invertebrates were more abundant on settlement plates that floated at 0.5 m compared to native species that were more abundant on settlement plates places at 2 m dept (Dafforn et al., 2009). Other studies confirmed that fouling tend to decrease at increasing depth. For example, the invasive bryozoan *Bugula neritina* decreased in abundance from 15 cm to 1 m deep and the colonial ascidian *Didemnum candidum* was more abundant on 15 cm depth compared to depts of 1-6 m (McDougall, 1943; Hurlbut, 1991).

Discussion

Urbanisation is increasing the amount of artificial structures along coastlines worldwide (Connell & Glasby, 1999). This results in changes of local marine habits and their biodiversity because artificial structures create different hard substrate habitats compared to the natural rocky shores that were there originally. In these new habitats Non-Indigenous Species (NIS) can also settle who sometimes have the strength to outcompete native species and become a threat for the local biodiversity. For this reason is in this report a comparison of natural rocky shores and different artificial structures and their effect on non-indigenous and native species.

Artificial structures have a higher risk of introducing NIS compared to natural reefs due to different substrates and habitat features they posses. One study in contrast showed natural reefs a higher abundance of NIS compared to artificial structures (Bumbeer & Rocha, 2016). However this study was carried out in an estuarine area which is different from the other studies that were carried out in coastal areas or open sea. Estuarine areas have higher levels of natural and anthropogenic disturbances which give the area different habitat conditions compared to coastal habitats. They are also known to be more susceptible to invasions of NIS compared to coastal areas (Ruiz-Velasco et al., 2023). These habitat differences can have influenced the results of the study. Another possibility is that the research area contained NIS that preferred the conditions of natural rocky reefs to the conditions that the artificial structures provided.

Floating artificial structures are a higher risk for the introduction of NIS compared to other artificial structures. This is because in general floating artificial structures have higher abundances of NIS, lower abundances of native species and a lower biodiversity compared to fixed artificial structures (Connel, 2001; Dafforn et al., 2009; Nall et al., 2015; Megina et al., 2016; Gauff et al., 2023). A possible explanation for this is that the proximity of the seafloor largely effects the settled communities. Floating artificial structures also have lower levels of sedimentation and higher light levels which are preferred by NIS (Glasby, 1999b; Dafforn et al., 2012). Floating artificial structures can also be located close to the ships and therefore have a higher propagule pressure of NIS larvae from ballast water and hull fouling (Clark & Johnston, 2009). In the literature most studies to the danger of floating artificial structures happens on pontoons inside marinas and ports where the pressure from NIS is high. There is little research of floating artificial structures outside of these locations along coasts where there are less NIS and can give different results.

Horizontal reefs and artificial structures are generally dominated by native species. A possible reason is that higher levels of sedimentation affect NIS more negatively than native species (Irving & Connel, 2002; Gibson et al., 2003). This is because sedimentation increases the change that recruits will be smothered or that filter feeding invertebrates will be clogged and native invertebrates tend to be adapted to these local conditions and have a higher tolerance (Ostroumov, 2005; Vermeij & Dudley, 2000). In contrast, NIS tend to have higher tolerances for stressors like salinity, oxygen and temperature due to the higher fluctuations of these stressors during the introduction compared to sedimentation stress (Dafforn et al., 2009; Lenz et al., 2011). But more research to the effect of surface orientation and how to prevent NIS from settling is required so artificial structures can be designed to become less suitable for NIS and more suitable for native species.

Vertical artificial structures are a larger risk for NIS because they are generally dominated by non-indigenous invertebrates. This can be explained because vertical artificial surfaces have the same orientation as the hull of a ship and can consist out of the same materials, such as metal and plastic. Vertical surfaces also have reduced sediment stress, compared to horizontal surfaces, that creates a better habitat where NIS can settle faster due to their more colonizing traits (Leclerc et al., 2023). In

particular, vertical wooden surfaces are very susceptible to fouling, this is because in the past most ships consisted out of wood and were ideal for wood-boring fouling species to settle (Reise et al., 1998; Chapman & Clynick, 2006). This resulted that these species were transported worldwide before the wooden hulls got replaced by steel hulls and antifouling coatings (Godwin, 2003; Minchin et al., 2005). Most studies that compared horizontal and vertical surfaces of natural reefs and artificial structures compared pontoons or docks with natural reefs. But pontoons and docks are completely different habitats compared with other artificial structures and give different results meaning that the effects from orientation can also have different reasons.

Due to the high level of NIS in ports and harbours there is also the danger that they disperse outwards to surrounding artificial structures and natural reefs. Studies have shown that there were increasing amounts of NIS surrounding ports or there were even higher amounts of NIS outside marinas than inside marinas (Chainho et al., 2015; Afonso et al., 2020). A few studies have shown that there was little to no dispersal from NIS in marinas to natural reefs (Ros et al., 2013; Megina et al., 2016; Afonso et al., 2020). One of these studies looked at the dispersal of non-indigenous and native caprellid species in Mallorca (Ros et al., 2013). They showed that non-indigenous caprellids stay mostly on artificial structures inside marinas and not on natural reefs outside like the native caprellids. There explanation for this is that the non-indigenous species are not adapted to live in the exposed areas and preferer the sheltered areas inside the marinas (Ros et al., 2013). Another study that also showed that NIS had less dispersal to natural reef surrounding marinas concluded that this was most likely due to the fact that there was a freshwater source close to the marina that decreased the salinity outside of the marinas (Afonso et al., 2020). This corresponds with studies that showed that hard substrate NIS had higher settlement rates when there were higher salinity levels compared to low salinity levels (Jimenez et al., 2018). This shows that the dispersal of NIS is influenced by multiple factors, differences between abiotic conditions inside and outside marinas and harbours can prevent NIS to disperse but when the conditions are similar they can disperse from artificial structures inside marinas and harbours to natural surrounding reefs. Therefore more research to the factors that prevent NIS from dispersal to natural reefs is important to decrease the dispersal and introduction of NIS in habitats outside of marinas and harbours.

The location were the natural reef or artificial structure is located also influences the NIS abundance. NIS were more abundant and native species were less abundant on artificial reefs that were located in sedimentary habitats compared to natural rocky reefs or artificial structures close to these rocky reefs (Airoldi et al, 2015). This forms a risk because most artificial structures such as break walls are located close to sedimentary habitats (Bishop et al., 2017; Snelgrove et al., 2014). These artificial structures will not only become sources for NIS but will also destroy the sedimentary ecosystem that was initially there and prevent native soft sediment species to settle.

There are not only differences between the habitats in which the artificial structures and natural reefs are located. When natural reefs are colonized this happens in equal abundance between non-indigenous and native species, but when an artificial reef get colonized it is in the beginning in equal abundance but over time NIS dominate (Tyrrell & Byers, 2007). This can be explained that artificial structures sometimes have different properties and dimensions than natural reefs such as different orientations and locations (Lawrence et al., 2021; Moschella et al., 2005; Loke & Todd, 2015). Therefore, when artificial structures are placed in a location with high levels of NIS, such as ports and marinas, there needs to be thought of the effect of different orientations, materials and the location so that it generates a habitat that is less suitable for NIS and that native species have an advantage.

Conclusion

During this literature study there has been made a comparison between native and non-indigenous species on different natural and artificial structures and surfaces. Therefore there has been studied what the differences are in biodiversity between different structures and substrates, why artificial structures attract more NIS compared to native species and what the different effect there is between horizontal and vertical surfaces on NIS and native species.

The study concluded that artificial structures are different habitats compared to natural rocky reefs due to their differences in complexity, environmental factors and roughness. Comparing different artificial structures concluded that floating artificial structures are the largest hotspots for NIS but that there needs to be more research on floating structures that are not located in high NIS locations such ports or marinas to give a representation of the impact of floating artificial structures on NIS in general. Furthermore, horizontal surfaces create better habitats for native species due to the unfavourable conditions for NIS and vertical artificial surfaces create better habitats for NIS with their lower sedimentation stress and higher light intensity. This information can be used to improve designs of ports and marinas with high levels of artificial structures that are hotspots for the introduction of NIS. When these stepping stones become less suitable for NIS to settle the changes of a new NIS invading an area and outcompeting native species will decrease. It also shows that artificial structures can not be used to generate "new" natural rocky reefs due to there differences in environmental conditions and taxa of species that settle on these structures. So in the end there are differences between artificial structures and natural rocky reefs for NIS but both create their own habitats with there own environmental conditions and help different species.

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