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Biological recruitment on static and boat hull panels coated with non-toxic fibre flock

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Abstract

Marine biofouling, the settlement of aquatic organisms on submerged surfaces, creates an estimated cost of 20 billion USD annually for the shipping industry in increased fuel consumption due to overgrowth. However, the existing antifouling solutions are being restricted by international organisations due to their adverse effects on the marine environment. In recent years, the research focus has shifted to non-toxic methods highlighting the importance of settlement cues of invertebrates. Biofoulers, such as invertebrate larvae and algal spores have been shown to respond to physical cues such as surface structure. The aim of this study was to test the environmentally friendly antifouling method fibre flock that could be used for vessels. Fibre flocking is a process that adds electrostatically charged micro-fibres to an adhesive coated polyester carrier film. Two experiments were conducted to evaluate the effectiveness of flocking on recruitment: (1) dock and (2) boat hull in Arendal, Norway, over a 3-month exposure period. To determine the effect of hydrodynamic pressure on the performance of fibre antifouling, fibre panels from the dock and boat hull were compared. Each experiment was comprised of three types of test panels: control (untreated), copper paint, and fibre. Additionally, a systematic review was conducted to assess the prevalence of the fibre flock method in the scientific literature. Specific hypotheses were: (1) abundance of all live cover would be significantly lower on fibre compared to control treatments; (2) abundance of all live cover and barnacles would be lowest on boat hull treatments; and (3) abundance of barnacles would be higher on control treatments. The results indicate that fibre flock could reduce 81.6% of all live cover and 84.4% of barnacles on a boat hull and 28.2% of all live cover, and 1.8% of barnacles on the dock experiment. The systematic review revealed a clear gap of fibre flock research in the literature, identifying the need for further exploration. These findings highlight that fibre is an effective antifouling method to some extent, even for static structures.

Keywords: Biofouling, antifouling, self-cleaning, fibre, flocking, recruitment

Introduction

Marine biofouling is the undesirable recruitment of aquatic organisms on submerged artificial structures. Overgrowth of biofouling communities on marine artificial structures costs the shipping industry 20 billion USD and the US navy 56 million USD annually (European Patent Office, 2019; Schultz et al., 2011). Biofouling communities negatively impact ecological, evolutionary, economic, and societal aspects (Bulleri et al., 2012; Callow and Callow, 2002; Davidson et al., 2021; Maréchal and Hellio, 2009). For example, overgrowth of biofouling communities can cause an increase in fuel consumption by up to 40% due to increased weight and drag as well as extend dry-docking intervals, lead to transport delays, and increase the need for hull repairs (Chambers et al., 2006; Champ, 2000; Davidson et al., 2021; Fitrdge et al., 2012; Maréchal and Hellio, 2009). Biofouling can further lead to the spread of invasive species that might induce competition between native and non-native species, which could result in the extinction of local species or cause damage to pipes, aquaculture equipment, and vessels (Porter et al., 2015). Thus, an effective antifouling method is crucial to both the environment and the industry.

The carbon dioxide concentration in the earth’s atmosphere is steadily rising through anthropogenic activities emitting greenhouse gases (Dobretsov et al., 2019; IPCC, 2021). Vessels with biofouling on their hull that travel over long distances have been found to raise the content of CO2 release to 14-31%, further leading to an increase in greenhouse gases (Shevalkar et al., 2020) causing chemical and physical changes in the water (such as water temperature, ocean acidification, alteration of nutrients and salinity; Poloczanska and Butler, 2010). These environmental changes result in changing marine biofouling distribution, community structure, and intensity of fouling (Poloczanska and Butler, 2010). Therefore, the management of fouling will become an even greater problem with climate change (Dobretsov et al., 2019).

Antifouling coatings are applied to vessel hulls to prevent the settlement of biofouling organisms. Most antifouling paints release unsustainable biocides that can potentially cause harm to the environment (Clare and Aldred, 2009). The organotin compound acts as a biocide in Tributyltin-oxide (TBT) and is, to date, the most effective antifouling paint component. A worldwide ban of TBT was issued in 2008 by the International Maritime Organisation (IMO, 2019) because a number of researchers concluded that the chemical negatively impacted the growth of algae, invertebrates, crustaceans, and fishes (Amara et al., 2018; Konstantinou and Albanis, 2004), weakened immunological systems in fishes and has been shown to accumulate in mammals (Almeida et al., 2007). Furthermore, research has shown that TBT induces imposex, an irreversible pseudohermaphroditism disorder, which can lead to female gastropods, such as the common dogwhelk Nucella lapillus, to produce non-functioning male genitalia (Gibbs et al., 1991; Schøyen et al., 2019). Additionally, it has been shown that TBT decreases juvenile growth in bivalves (Chagot et al., 1990; Ruiz et al., 1994) and shell-shape variation in gastropods (Bigatti and Carranza, 2007; Márquez et al., 2011). Antifouling methods have been well studied (Hellio and Yebra, 2009), revealing their environmental impact and further highlighting the urgency for an environmentally friendly solution.

After the ban of TBT, the chemical industry declared that new antifouling paints with high concentrations of copper and herbicides (such as Irgarol 1051, diuron, chlorothalonil, dichlorofuanid and zineb) were more environmentally friendly

(Maréchal and Hellio, 2009). However, recent studies discovered a significant accumulation of these chemicals in harbours and marinas (Soroldoni et al., 2020; Turner et al., 2009), which has been shown to harm seagrass, coral, microalgae and macroalgae communities and indirectly harm mammals (Konstantinou and Albanis, 2004). Other antifouling methods are emerging rapidly due to new regulations and consumer concerns (Miller et al., 2020). These include molecular approaches with hormones and other chemicals (Clare et al., 1992), heat treatments, bacterial films, sound waves, surface textures, chemical surface alteration and fibre flocking (Hellio and Yebra, 2009; Phillippi et al., 2001). Thus far, researchers have been trying to find a satisfactory solution to biofouling involving chemicals. However, little research exists on fibre flocking as an environmentally friendly alternative to toxic antifouling paints.

Fibre flock is an antifouling method that avoids the use of harmful biocide chemicals by using structural means to mimic the natural solutions used by sea urchins (Finsulate, 2021). It consists of tiny micro-fibres (0.5 – 0.3 mm) that are densely arranged to imitate the spines of sea urchins (Finsulate, 2021; Watermann et al., 2003) and are predominantly composed of polyester, polyamide or polyacryl and attached to surfaces with glue (European Patent Office, 2019). This non-toxic method aims to interfere with the adhesion of fouling organisms, thus making it harder for biofoulers - specifically algae, barnacles and mussels - to attach. The recruitment of biofouling species on this type of antifouling method remains unclear due to limited research. Past studies on similar products are divided, with some suggesting that invertebrate species (i.e. bryozoans, hydroids and encrusting species) attach less to fibre flock than untreated or primed samples (Phillippi et al., 2001), while others indicate an increase in algae species (Watermann et al., 2003). This shortcoming of research is responsible for the lack of evidence of fibre as an effective antifouling method.

The main aim of this study was to examine the effectiveness of a non-toxic antifouling method, fibre flock, through collecting and analysing biofouling communities from three treatments (control, copper paint, and fibre flock) during two experiments; (1) dock and (2) boat hull. Fibre panels from both experiments were also compared to determine the effect of hydrodynamic pressure on the performance of fibre as an antifouling technique. Additionally, a systematic search was conducted to determine the amount of relevant research that has been published in relation to fibre as an antifouling method. Specific hypotheses were: (1) abundance of all live cover would be significantly lower on fibre compared to control treatments; (2) abundance of all live cover and barnacles would be lowest on boat hull treatments; and (3) abundance of barnacles would be higher on control treatments.

Methodology

Study area

The experiment was carried out in Arendal, Norway (Fig. 1), a sheltered coastal region on the northern Skagerrak Sea. The Skagerrak Sea is in-between the Baltic Sea and the North Sea. Water flow is anticlockwise, incorporating the mixing of several water masses such as the low-saline waters from the Baltic Sea and the southern North Sea, and the deeper waters from the Atlantic. The freshwater accumulates especially along the Norwegian and Swedish coasts (Gustafsson and

Stigebrandt, 1996). The study region is essentially non-tidal, with a tidal range of ~0.2 metres (Berntsson and Jonsson, 2003; Rodhe, 1998). The coastal geomorphology consists of rocky shores and islands, fairly sheltered with little to no wave exposure. Hydrographic measurements were obtained (daily between May-August) at the study site for the dock panel tests. The measurements reveal slight fluctuations in seawater temperature and salinity between the months, with an average salinity of 16.8 ppt (parts per thousand) and temperature ranging from 11°C to 24°C. The site has bi-directional water flow, with freshwater coming from the mountains through a small river and saltwater from the ocean. Hvass (2022), the Arendal port director, estimates 20 000 pleasure boats in and around Arendal, but the exact numbers are uncertain because the registration of pleasure boats is not mandatory.

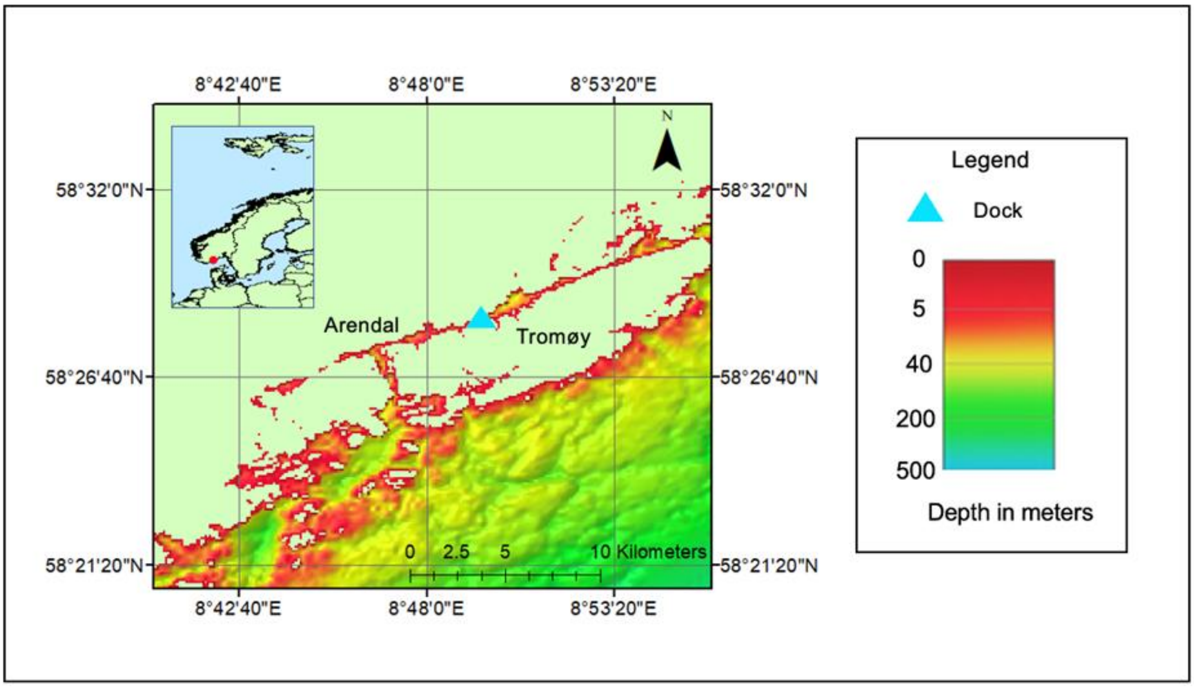

Figure 1: Experiments were conducted at a dock in Arendal, Norway (58° 27'N, 8° 47'E).

Experimental treatments

The experimental study was comprised of a dock experiment (static) and a boat hull experiment (dynamic). Both experiments tested three treatments: control, paint, and fibre flock. While control panels were left untreated, paint panels were treated with a black copper-based antifouling paint, and Finsulate Speedgrade® fibre flock was used for fibre panels. Finsulate Speedgrade® fibre flock is a cured acrylic adhesive with embedded black nylon fibres which were attached to a polyester carrier film. The adhesive consisted of a combination of resin, copolymer, stabilizer and crosslinker. The fibres were 3 mm long; >= 60 µm thick; with a density lower than 40 to mimic the spines of sea urchins that naturally deter many biofoulers (Finsulate, 2020; Materials Innovation Centre B.V., 2007). An ethics approval from the University of Plymouth was obtained for both experiments.

Recruitment assessment of biofouling communities on dock

The experimental units for this study were 15 x 15 cm flat panels cut from 0.3 cm thick grey polyvinyl chloride (PVC) plastic sheet (n= 10 for each treatment). PVC was used as a foundation to mimic a stationary plastic pleasure boat or dock. All panels were attached randomly, with respect to treatment, to a wooden frame with nylon cable ties (Fig. 2), and with 5 cm between adjacent panels. The frames were rectangular, and each frame accommodated ten panels (two deep and five across; Fig. 2), with dimensions of 115 cm x 65 cm. For added support, all corners were secured with duct tape. Each frame was tied to the dock, facing the south with the top row of panels 5 to 10 cm below the water level to ensure all panels would permanently be submerged in the water. Panels were left in the field from May to August 2021 at the dock in Arendal, Norway (Fig. 1).

Figure 2: Three wooden frames for the dock experiment included 10 PVC panels for each treatment: C= control, P= paint, and F= fibre.

Recruitment assessment of biofouling on boat hull

The boat hull-based experiment used a plastic pleasure boat (length: 5.25 metres; width: 2.20 metres) with fibre as the antifouling method. For the experiment, 15 x 15 cm patches of fibre were removed for the paint and control panels, while the fibre panels were marked with a white waterproof pen (n= 6 for each treatment; Fig. 3). The experimental patches were randomly distributed along both sides of the boat hull. The experiment was launched in June and hauled in August 2021 (three months).

Figure 3: Plastic pleasure boat used for boat hull survey with six quadrats for each treatment: C= control, P= paint, and F= fibre.

Assessment and statistical analysis

The percentage cover of each quadrat was determined by estimating the coverage of biofouling species in each section of a 25-pt strung quadrat. Each species was identified to the lowest operational taxonomic unit. Organisms attached within 5 cm from the panel edge were not counted to prevent possible edge effects. The means, with one standard error, were calculated for each treatment. A one-way analysis of variance (ANOVA) was used to explore differences in mean percentage cover between treatments ($\alpha = 0.05$) for the dock and boat hull survey. Additionally, a Tukey Honestly Significant Difference (HSD) test was conducted to test for differences among groups.

Systematic review

The databases used to search for literature were Web of Science and Scopus, with the following search terms: (antifoul* OR biofoul* OR foul*) AND (fibre* OR flock*). The combination of symbols and terms allows the database to find suitable studies. For instance, the Boolean operator ‘AND’ allows both search groups to be considered, whereas the operator ‘OR’ suggests that only one of them must occur in the research. The asterisks (*) allow the search engine to consider the word with possible other endings (Bulleri et al., 2012). At the end of this search, relevant studies were exported to Mendeley® for further processing. A 4-step process was used to eliminate all unsuitable studies: 1) removing duplicate studies, 2) skimming the article title, 3) reading the abstract, and 4) reading the paper. Mendeley® was used to read titles and abstracts; afterwards, all relevant papers were downloaded. During the selection process, papers were considered based on the presence or absence of specific features. Features that were considered during the elimination process were: study type (field or lab), the scale of the study (spatial, temporal), and treatments (antifouling type).

Results

Recruitment assessment of biofouling communities on dock

Of the three treatments used in this survey, live cover was observed on all panels during the dock experiment. Total live cover abundance was highest on control (50.4%) and lowest on paint quadrats (2.7%), with fibre panels lying somewhere in the middle (22%). The only barnacle species recorded was an invasive species (Amphibalanus improvisus). Mean barnacle abundance was highest on control quadrats (1.8%), while no recruitment was observed on paint and fibre panels (Fig. 4). Increased live cover was observed on the backside of panels that were not utilised for this experiment and not exposed to direct sunlight.

ANOVA revealed significant differences between treatments for live cover ($P= 0.015$) and barnacle cover (Table 1, $P<0.001$). A Tukey’s post-hoc showed two distinct groupings: control was grouped on its own with the highest abundance; in contrast, paint and fibre clustered together with the lowest abundance for both live- and barnacle cover (Fig. 4).

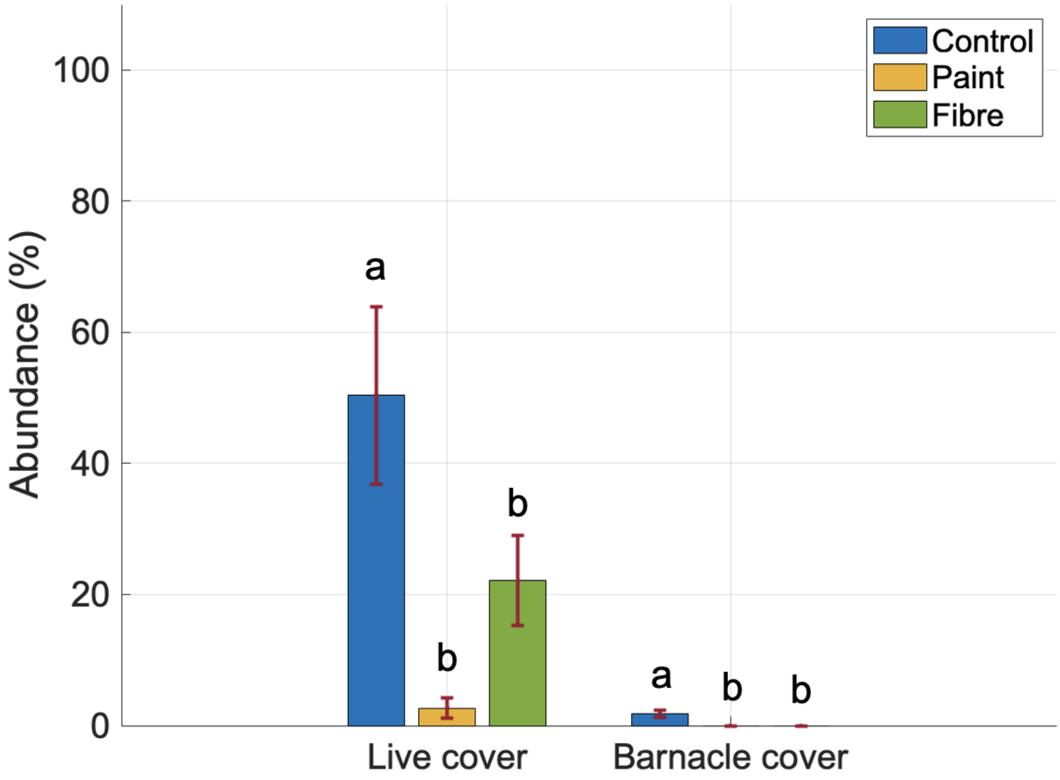

Figure 4: Mean (± 1 SE, n= 10) percentage live cover and barnacle (A. improvises) cover on dock control, paint and fibre PVC panels during the period May-August 2021. Means that do not share a letter are significantly different.

Table 1: Comparing three treatments during a static dock experiment: control, paint, and fibre (a) one-way ANOVA comparing live percentage cover and (b) one-way ANOVA comparing percentage barnacle (*A. improvisus*) cover.

	(a) Live cover				**(b) Barnacle cover**		
Source of variation	**df**	**SS**	**MS**	**F**	**SS**	**MS**	**F**
Treatment	2	11514	5756.9	9.27*	21.60	10.80	15.12**
Error	27	16774	621.3		19.28	0.7141	
Total	29	28288			40.88		

*p < 0.01, **p < 0.001.

Recruitment assessment of biofouling communities on boat hull

The boat hull experiment revealed the highest live cover abundance on control panels (100%) and the lowest on paint panels (0%). Fibre panels showed some recruitment of live cover (18.4%; Fig. 5). The control and fibre live cover consisted of 99.9% and 15.5% barnacles (*A. improvisus*), respectively (Fig. 5).

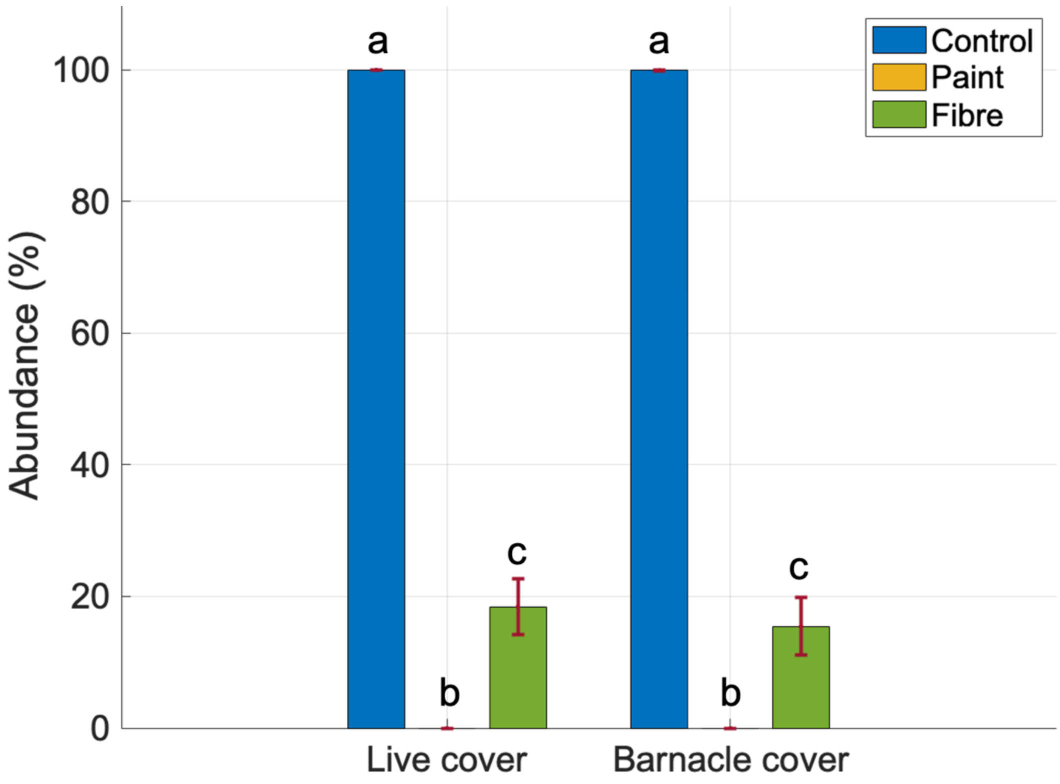

Figure 5: Mean (± 1 SE, n= 6) percentage live- and barnacle (A. improvises) cover on boat hull control, paint and fibre panels during the period May-August 2021. Means that do not share a letter are significantly different.

ANOVA showed a significant difference between treatments for live cover (P<0.001) and barnacle cover (P<0.001) during the boat hull experiment. A Tukey's post-hoc revealed two separate groupings: control panels with the highest abundance, while paint and fibre panels were grouped together with the lowest recruitment for both live- and barnacle cover (Table 2).

Table 2: Comparing three treatments during a dynamic boat hull experiment: control, paint, and fibre (a) one-way ANOVA comparing live percentage cover and (b) one-way ANOVA comparing percentage barnacle (*A. improvisus*) cover.

	(a) Live cover				**(b) Barnacle cover**		
Source of variation	**df**	**SS**	**MS**	**F**	**SS**	**MS**	**F**
Treatment	2	33994.2	16997.1	357.52**	32721.0	17360.5	336.95**
Error	15	713.1	47.5		772.8	51.5	
Total	17	34707.4			35493.8		

*p < 0.01, **p < 0.001.

Effects of hydrodynamic pressure on fibre

Panels were exposed to hydrodynamic pressure during the boat hull experiment. The overall live cover was similar on the dock and boat hull panels with 22% and

18.4%, respectively. The dock panels had no barnacle recruitment, however, the boat hull had 15.5% (Fig. 6).

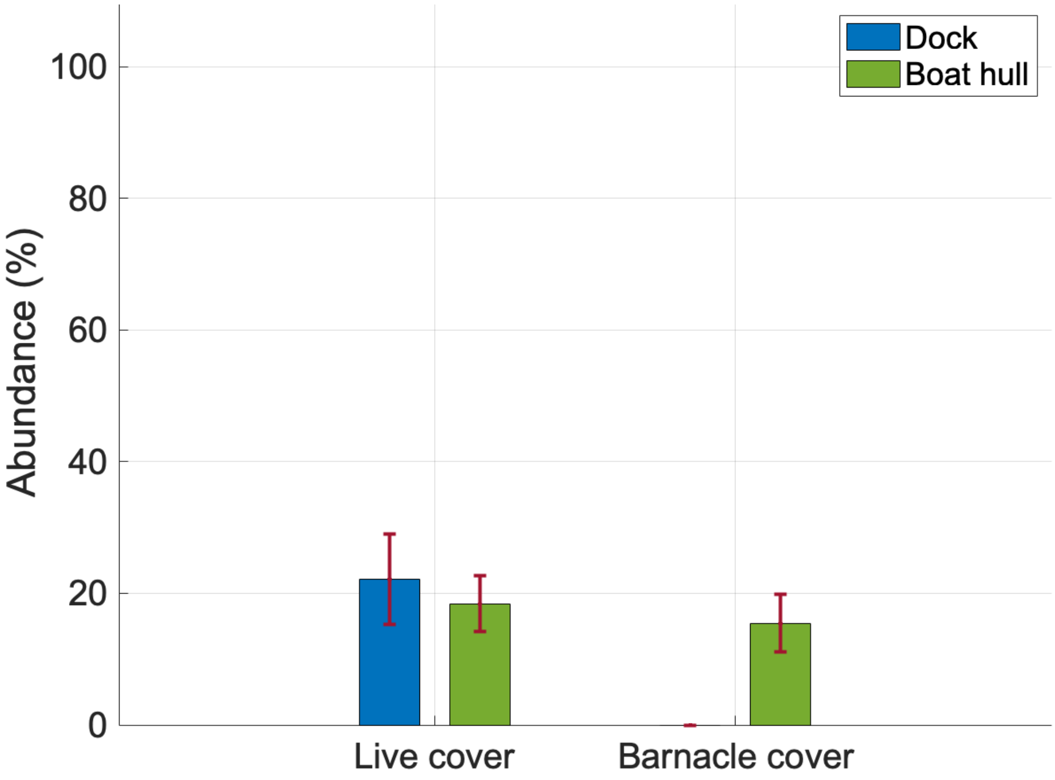

Figure 6: Mean (± 1 SE; dock n= 10, boat hull n= 6) percentage live cover and barnacle (A. improvisus) cover on fibre panels during the period May-August 2021 to determine the significance of hydrodynamic pressure.

Systematic review results

Following the 4-step process outlined above, 557 studies published between 1994 and 2021 were evaluated to ensure the connection to fibre flock. At the end of the first three steps, 19 papers were selected. Post-inspection, a total of two studies were found relevant. The first study (Phillippi et al., 2001) compared recruitment on fibre coatings to primed and untreated PVC panels in Westport River Estuary, USA, using white nylon fibres (90% 1.8 denier and 1.27 mm long, 10% 3.0 denier and 2.54 mm long). The other study (Watermann et al., 2005) was conducted in a lab, determining the settlement of barnacle larvae in coated Petri dishes, comparing different biocide-free antifouling coatings. This experiment used short, dense fibres (200-500 fibres/mm^2); however, the exact fibre dimensions were not mentioned.

Discussion

The results from comparisons made between paint and fibre panels installed on a dock and boat hull revealed significantly lower recruitment of biofouling species on fibre flock than control panels during both experiments. Contrary to the hypothesis, there was higher recruitment of biofouling species during the boat hull experiment, especially on control panels with 100% coverage. As hypothesised, the abundance of barnacles was highest on control treatments. However, during the dock experiment, control panels had significantly less barnacle recruitment than the boat hull experiment. The systematic review showed a clear lack of research, with only two studies published on fibre flock as an antifouling method in Web of Science and Scopus over the last ~20 years.

Similar studies conducted in Sweden and the United States on the effectiveness of fibrous surfaces as an antifouling method for static objects have suggested that invertebrate species, like bryozoans and hydroids and encrusting species (like barnacles), occur less on static fibre flock panels than untreated or primed samples (Forsberg, 1994; Gyllenhammer, 1997; Larsson, 1997; Phillippi et al., 2001). Similar results were found in laboratory tests, where barnacle cyprids settled significantly less on fibre coatings than control (Watermann et al., 2005). Alm and Gyllenhammer (1999) found that fibre reduced the recruitment of hard fouling organisms like mussels, tubeworms and barnacles. They also highlighted that although some level of soft fouling organism occurred, they would be washed off if a vessel was underway. Comparing this to the results of the present study, where recruitment of all live cover was significantly greater compared to barnacles onto flocked surfaces, suggests that barnacles avoid fibrous surfaces; however, other live cover could get entrapped in the fibres but be washed off through hydrodynamic pressure.

The low recruitment of barnacles on dock panels could have resulted from the direction of the panels facing towards the sun. Cronin et al. (1999) examined how fouling mass and species diversity differ between sides of aquaculture cages and their correlation with light intensity. The side exposed to direct sunlight had greater photosynthetic biomass than the other sides. Specifically, ascidians and red algae recruited most on that side, however, bryozoans were recruiting least on the southern side (Cronin, 1995; Cronin et al., 1999). These results align with the observed recruitment on panels during this study. However, other factors could have impacted the reduction in settlement of organisms, such as chemical cues from paint panels, or small grazers could have removed spores and seedlings from the surfaces.

Previous studies on fibre flock as an antifouling method for boat hulls suggest that flocking prevents barnacle and mussel recruitment; however, it entraps macroflora such as algae (Watermann et al., 2003). During a trial of biocide-free antifouling paints on a deep-sea vessel in Germany (Watermann et al., 2001), fibre coatings were found to be effective against barnacles, but individual fibres seemed to entrap macroalgae and algal spores (Watermann et al., 2003). Nonetheless, contradictory results were recorded in this study, with an increase in barnacle recruitment and no macroflora on boat hull quadrats, indicating that hydrodynamic pressure impacted the recruitment of live cover.

The characteristics of fibre are crucial in determining the effectiveness of flocking as an antifouling method (Gyllenhammer, 1997; Larsson, 1997; Phillippi et al., 2001; Watermann et al., 2003). Gyllenhammer (1997) reported that fibres longer than 1 mm were more effective at decreasing the recruitment of hydroid and barnacle species, and shorter fibres were more successful at preventing mussel, tunicate, and algae fouling. However, this study found that fibres at 3 mm were more successful at preventing the settlement of mussels and algae compared to barnacle fouling. A long-term dynamic experiment by Watermann et al. (2003) that examined two fibre lengths, 1.1 mm and 1.3 mm, found lower barnacle growth (1%) and higher algae growth (30%), with overall lower growth on short, dense fibres. A study by Phillippi et al. (2001) obtained similar results during a static experiment that combined a mixture of short (90%: 1.27 mm) and long (10%: 2.54 mm) fibres. The mixture of fibres decreased the recruitment of encrusting animals and green and brown algae while increasing the abundance of tube-building polychaetes and solitary ascidian. These results indicate that perhaps a mixture of fibres with more long fibres than short could prevent tube-building polychaetes, solitary ascidian as well as hydroid and barnacle species from settling.

According to previous studies, hydrodynamic pressure should decrease the abundance of biofouling species on fibre (Zschätzsch et al., 2019; Watermann et al., 2003). In the current study, similar overall live cover on the dock and boat hull samples were observed (22% dock; 18.4% boat hull); however, the boat hull samples were almost entirely comprised of barnacles (0% dock; 15.5% boat hull). Therefore, more barnacles recruited on the boat hull, but other organism on dock panels, possibly through the movement of fibres that prevents the settlement of organisms or the direct light exposure on dock panels (Cronin, 1995; Cronin et al., 1999; Johnson and Miller, 2002). During a fibre panel test on boat hulls, Watermann et al. (2003) reported 1% barnacle growth and 30% algae growth on boat hull samples, compared to this study where the boat hull had 18.4% barnacle growth but no algae recruitment. Additionally, experimental applications of fibre flock on coastal vessels highlighted the selectivity on its performance, being more effective against barnacles and negligible algal growth even on a vessel that travelled at low speeds and spent long periods in harbour (Cameron, 2000). According to the current study, hydrodynamic pressure seems to decrease the settlement of algae and soft organisms and spores but only impacts barnacle settlement to some extent.

Aside from fibrous surfaces, research on the recruitment of biofouling species on various surface topographies gives insight into the results presented in this paper. A number of studies on microstructured polydimethylsiloxane surfaces investigate the settlement of biofouling organisms (Andersson et al., 1999; Carman et al., 2006; Petronis et al., 2000). Carman et al. (2006) recorded a ~85% decrease in zoospore settlement on finer and more complex topographies (2 μm). However, Petronis et al. (2000) examined a surface with a roughness ranging from 5 to 17 μm and observed a 67% decrease in barnacle settlement on the roughest surface. Andersson et al. (1999) also recorded similar results on surfaces with a roughness ranging from 50 to 100 μm. Comparing this to the current study results, where all live- and barnacle cover were significantly less on fibrous surfaces than control (smooth) surfaces, suggests that surfaces with higher rugosities prevent the settlement of biofouling species.

Non-native species are considered as one of the top four anthropogenic threats to marine ecosystems world-wide (Gollasch, 2006). Gollasch (2002) examined 186 ship hulls and identified 257 species, of which 57% were non-native and 19 considered potentially invasive. Invasive barnacles are especially crucial to consider in antifouling techniques due to their ability to create a rough surface texture on the vessel, which can increase weight and drag as well as fuel consumption (Uzun et al., 2020). The invasive barnacle Amphibalanus improvisus was recorded in this study, especially on control panels during the boat hull experiment. Previous studies have identified it along the southern Norwegian coast between Oslo and Kristiansand (Espelien, 2020). The fouling of ship hulls and ballast water has been associated with the introduction of new species, which can possibly become invasive and negatively impact ecological, evolutionary, economic, and societal aspects (Bulleri et al., 2012; Gollasch, 2006; Maréchal and Hellio, 2009).

Biofouling poses a threat of economic loss to the shipping industry. At present, the first application of Finsulate® fibre is 2 – 2.5 times more expensive than paint (Breur, 2022). Finsulate® fibre flock has a 5-year guarantee but has been shown to be effective for up to 10 years with minor repairs (Breur, 2022). On the other hand, vessels utilising copper paint as an antifouling method must repaint it every 2.5 years to maintain antifouling qualities (Carson et al., 2002). Therefore, the initial cost of fibre is higher but with a significantly longer lifespan, implying a potential economic advantage for the shipping industry and private boat owners.

It is suggested that future studies should investigate the long-term performance of fibre as an antifouling method, its effectiveness under various conditions as well as the implications of wider ecosystem effects of fibre. Furthermore, researchers have limited knowledge of how successful flocking is in various environmental conditions. This could be achieved through experimental use on cargo vessels while also showing the effect of this antifouling method in different environmental conditions around the world's oceans. The present study demonstrates that fibre flock is effective to some extent at preventing the recruitment of biofouling organisms.

Conclusions

This paper has investigated the effectiveness of fibre flock as an environmentally friendly antifouling method. It is found that the fibre flock coating is capable of reducing biofouling compared to control panels. From the results of the current study, it is apparent that fibre flock has the potential to replace existing toxic antifouling paints, however, additional research is necessary to determine the most successful combination of fibre lengths. Finsulate® fibre flock offers lower long-term cost for antifouling compared to copper paint, demonstrating a clear economic advantage for the shipping industry and boat owners. This study also shows the importance of effective antifouling options in relation to the spread of invasive species, and the impact it can have on biofouling communities and economic implications in relation to climate change.

The central argument for fibre flock as an antifouling method is that it does not require any harmful biocide components, making it a viable solution to boat owners, as regulations and restrictions are expected to change, especially in environmentally-conscious countries. These results fill key gaps in identifying the effectiveness of fibre as an antifouling method. However, further research is necessary to determine how all types of biofouling can be eliminated from fibre coatings to prevent an increase in fuel consumption.

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