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A conceptual basis for surveying fouling communities at exposed and protected sites at sea: Feasible designs with exchangeable test bodies for in-situ biofouling collection

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ABSTRACT

The enhanced inertia load caused by biofouling on device components, such as the foundations of wind turbines or other structures at sea, modifies the hydrodynamic properties, and increases the stress to structures, predominantly in upper water layers with high impact from wave dynamics. This compromises the stability, functioning, operation as well as the durability of these devices especially in exposed environments. A main challenge is the quantification of the impact of hydrodynamic forces on irregular bodies being overgrown by soft- and hard-bodied biofouling organisms. Therefore, test bodies from the upper 1–5 m water depth and thus exposed to the strongest wave actions close to the surface shall be overgrown by biofouling and used in measurement trials in a wave and current flume. These measurements shall shed light on the varying roughness and its influence on the load bearing capacity of foundation piles. Consequently, the main aims of the present work were the development of two independent test stations as holding devices for artificial test bodies for the collection of biofouling organisms during field studies: a carrying unit floating at the surface in an exposed area (*System A*) and a sampling device with access from a land-based facility (*System B*). Both systems are relatively easy to access, exhibit straightforward handling, and are reasonable cost-effective. A Test Body Support Unit (TBSU, *System A*) was designed and mounted on a spare buoy to carry the test bodies (cylinders), which serve as substrate for the fouling. The system was sufficiently robust to withstand several periods of rough sea conditions over the first two years. This system can only be accessed by vessels. *System B* (*MareLift*) provided the robustness and functionality needed for areas exhibiting harsh conditions but can be operated from land. The here used test bodies (steel panels) exhibited a sound basis for the monitoring of succession processes in the biofouling development. *System B* offered the possibility to analyse two habitats (intertidal and subtidal) and revealed clear differences in the composition and development of their fouling communities.

Overall, both systems provide advantages in obtaining standardized biofouling samples compared to previous approaches. Such test stations play an important role in the risk management of marine sectors as they could help characterising biofouling communities over different geographical areas. *System* A and B provide a sound basis for biofouling research but potentially also for other potential research approaches in exposed areas as they provide space for future developments.

1. Introduction

The ongoing marine urbanisation, the increasing extent and diversity of installed submerged artificial structures in the environment, affects ecosystems. These effects, either positive or negative, are not fully understood yet (e. g. Airoldi and Beck, 2007; Bulleri and Chapman, 2010;

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Coates et al., 2014; Hopkins et al., 2021). On the other hand, submerged artificial structures in coastal areas and/or offshore are exposed to environmental factors (i.e., waves, currents, temperature, salinity) and those place great strain on material, affecting the robustness and durability of those structures, as well as its system design and reliability, operability, and maintenance (e.g. Uihlein and Magagna, 2016; Schoefs and Tran 2022). Moreover, any artificial structure at sea is colonized by marine organisms, which can also compromise functionality of those structures (Mangal et al., 2001; Boukinda et al., 2007; Marty et al., 2021a, b). Overall, piers, harbour walls, but also offshore structures, such as oil & gas platforms, wind energy foundations (Hopkins et al., 2021; Mavraki et al., 2021), aquaculture facilities, and ship hulls are overgrown with benthic flora and fauna, commonly referred to as biofouling. These artificial structures can have a positive impact on the marine environment, offering additional hard substrate for different taxa such as hydroids, polychaetes, amphipods, or molluscs forming communities and undergo temporal successions (e.g. Abarzua and Jakubowski 1995; Lincoln et al., 1998; Boukinda et al., 2007). Within these communities in the North Sea, organisms such as mussels or the tube mats forming amphipods (Beermann et al., 2015), might offer a secondary substrate for new colonizers. It has been previously documented that artificial reefs may provide shelter and food for other taxa such as fishes (e.g. Picken, 1985; Parks et al., 1995; Krone et al., 2013; Almeida and Coolen, 2020; Vinagre et al., 2020). Nevertheless, potential negative effects are the role of artificial structures as vectors and 'stepping stones' for the establishment and further distribution of invasive species as part of biofouling communities, which will favour those over native taxa (Ralston and Swain 2014; Loxton et al., 2017; Want and Porter, 2018).

Biofouling communities are considered as one of the most productive and diverse macroorganism- assemblages being distributed worldwide (Canning-Clode, 2008). They are predominantly represented by the same taxonomic groups on a global scale: hard shelled colonizers such as tubeworms, barnacles, mussels, oysters, and soft colonizers such as hydroids, soft cold-water corals, sea anemones, moss animals, sea-quirts, algae and kelps, even if by different species (e.g. North Sea: Parks et al., 1995, Mallat et al., 2014; De Mesel et al., 2015; West Africa: Boukinda et al., 2007; Gulf of Mexico: George and Thomas, 1979; Lewbel et al., 1987; Gulf of China: Yan and Yan, 2003; Yan et al., 2006). Environmental factors (i.e., waves, currents, water temperature, nutrients, light, tides, depth) determine the composition and structure of fouling communities (Abarzua and Jakubowski, 1995) therefore, these display significant differences between and within ecoregions (Vinagre et al., 2020). Further, other aspects such as distance to the shore, type and orientation of substrate also influence the fouling dynamics (e.g. Holloway and Connell, 2002; Momber et al., 2015; van der Stap et al., 2016; Want and Porter, 2018; Almeida and Coolen, 2020). Epibiota assemblages on artificial substrates commonly differ taxonomically to natural communities (Wilhelmsson and Malm, 2008) while spatial differences in communities on smaller and larger scale depend also on the complexity of the available habitats (e.g. Perkol-Finkel et al., 2006; Fitridge et al., 2012; Bender et al., 2020).

In temperate areas such as the North Sea, spawning and growth is almost restricted from spring to autumn with higher water temperatures (Almeida and Coolen, 2020; Vinagre et al., 2020). Further, increased nutrient concentration in the seawater in summer implies fouling biomass to increase on artificial hard substrata (Momber et al., 2015; Almeida and Coolen, 2020). Consequently, North Sea biofouling assemblages can be highly variable in composition, structure, and biomass between seasons (e.g. Schröder et al., 2008; Momber et al., 2015; Loxton et al., 2017; Want and Porter, 2018).

The effects of biofouling on man-made structures diminishing their efficiency and reliability results in economic consequences for sectors (e. g. energy, aquaculture) therefore, this requires studies on the development and composition of those communities (Wagh et al., 1988). Biofouling research is fundamental for growing sectors such as marine renewable energy (MRE), where devices are partly composed of moving components and/or new materials, which have never been deployed in marine environments (Want et al., 2017; Want and Porter, 2018).

Previous studies revealed the promotion of localized corrosion on metal surfaces by micro- and macrofoulers (e. g. bacteria, oysters, mussels) (Little and Wagner, 1995; de Brito et al., 2007; Blackwood et al., 2010); these impacts are considered extremely harmful as they damage the material itself (de Brito et al., 2007) or its protective coatings (Kiil et al., 2007). Together with the enhanced risk of corrosion fatigue, the increased inertia load of fouling communities adds weight, thickness (and thus hydrodynamic mass), and higher rugosity to device components such as foundation piles and mooring lines, which compromises the structure stability especially in rough seas (Relini et al., 1998; Loxton et al., 2017; Want and Porter, 2018; Marty et al., 2021a).

Antifouling treatments are unfeasible for most artificial large structures, as in the case of wind turbines, since they have to be repeated over time (Hopkins et al., 2021). Further, other effective maintenance strategies are time consuming and result in higher labour costs comprising regular cleaning activities on artificial structures to continuously maintain the performance (Miller and MacLeod, 2016; Loxton et al., 2017; Want and Porter, 2018). A preventive measure in the construction of wind turbines and its foundations is based on heightened design criteria those to be build more robust to withstand fouling in terms of load-bearing capacity and safety in spite of biofouling (Klijnstra et al., 2017).

For the estimation of hydrodynamic forces such as wave and currents on stationary artificial pile structures the potential impact caused by marine biofouling is considered. By means of the Morison approach (1950), marine forces are estimated with dimensionless coefficients, drag (Cd) and inertia (Cm), that help to adjust to overgrown conditions concerning the effects of surface roughness (Morison et al., 1950; Al-Yacouby et al., 2014). The determination of the impact of hydrodynamic forces on irregular bodies and the assessment of those coefficients is a major challenge (Gieschen et al., 2021; Landmann et al., 2021) but the current lack of detailed knowledge on applied coefficients indicates the need of their precise determination. The role and potential effects of irregular shapes of fouling communities on moorings or cables were studied with realistic shape models (3d printing covers) (Marty et al., 2021a, b) and offshore monopiles and components by modelling of marine growth thickness and reliability assessment (e.g. Schoefs and Tran 2022). Nevertheless, the diverse biofouling communities show high variability amongst others in their heights, flexibility and stiffness (Marty et al., 2021b) including the randomness of biofouling with all its uncertainties makes more measured experimental data necessary also with regard to the modelling approaches (Schoefs et al., 2022). The application of more realistic load coefficients obtained by measurement trials of naturally fouled materials in seawater wave and current flumes offers much potential for the renewable energy sector. This includes the reduction of the dimensioning of artificial structures, could result in more reliable and profitable constructions, and allows a more realistic determination of their service life.

Therefore, it is important to gain knowledge on the characteristics of the biofouling composition and succession process, at the geographical and temporal level. Ideally, this data will be obtained at the locations where wind turbines are actually placed. These structures can be installed close to the shore or offshore; they can occur in sheltered water bodies as well as in high-energy environments. Thus, ad hoc "test stations" need to be developed for the investigation of fouling at those specific sites as permanently moored systems reflecting the real environmental and biological conditions over time (Caspers 1952). Additionally, "test stations" shall be also usable for other research purposes apart from the marine renewable energy sector (e.g. test of materials, moveable parts, marine ecosystem-based studies) and therefore, providing the possibility for further developments and modifications regarding the requested necessities. They shall be applicable in other offshore and harbour areas, being sufficiently robust to withstand harsh conditions at sea. They shall permit regular, standardized and reproducible sampling procedures, and shall be easy to operate. Test bodies (panels, tubes or other forms of varying materials), acting as artificial substrate to allow colonisation of biofouling, will be attached to carrier units (i.e., buoys). For the present study test bodies must be light enough to be fixed on a moored buoy, easy to handle during sampling, transport and measurement trials.

Considering the above explained challenges and requirements in open waters, this work aims to design and conceptually develop test systems during field studies in exposed and sheltered environments that enable the reliable collection of marine growth for further testing. The specific objectives of this study are:

1 The study on biofouling needs the development of new technical approaches that can cope with harsh weather conditions in the open ocean.
2 System designs should be installed on both, the offshore floating buoyancy device (a buoy) and the land-based installation. These can be easily handled, maintained, processed, and sampled by personnel in a certain range of ocean currents, wave heights and regardless of tides.
3 The test bodies should be installed in such a way that fouling organisms can settle unhindered in both habitats, the permanent immersion zone and the tidal zone. The test bodies should be easy to remove without damaging the fouling ensuring comparable succession studies on settlement, and the assessment of organism density and biofouling community parameters over time.

This work exemplifies two test stations that were developed. For offshore environments *System A* shows a buoy equipped with steel carrier unit and for rather sheltered coastal waters *System B* a steel lifting unit, both complying requirements to accessibility, handling, and economic costs. By means of these developed systems, test bodies shall be exposed to the same conditions as monopile and jacket foundations in offshore windfarms in the southern North Sea to obtain representative marine biofouling communities.

2. Material & methods

In the following, the two different sampling devices for biofouling *System A* (offshore test facility) and *System B* (onshore test facility) are discussed. Both systems were installed in different environmental conditions, exposed and sheltered, respectively. Test bodies of *System A* are intended to be used for measurement trails in a saltwater wave and current flume (SWWC-flume) comprising a recirculating aquaculture system (RAS) to ensure almost natural conditions for the survival of the biofouling community on the test bodies. Sampling periods for *System A* were planned to be from after >6 months to after >1 year to achieve differently developed communities. Test bodies from *System B* were used for the biological monitoring on a monthly basis and were processed shortly after sampling.

The development of these test facilities, the identification of the system design, the associated iteration process as well as the construction, testing and operation with O&M required an interdisciplinary team of coastal engineers, oceanographers, material scientists as well as marine biologists.

2.1. Hydrodynamic conditions in the southern North Sea (German Bight) site

Selected sites, owing to their accessibility and distinct environmental conditions, are located within the North Sea, an area also characterized by the intensity of storm events mainly occurring from September to April (Bell et al., 2017; Grabemann et al., 2020).

Over the North west European shelf, a counter-clockwise semidiurnal tidal wave propagates resulting from co-oscillations with autonomous tidal waves of the North Atlantic Ocean (Sündermann and Pohlmann, 2011; Jänicke et al., 2021). In the North Sea currents are of tidal origin as well as wind-driven being highly location dependent (Quante et al., 2016). Wind patterns observed reflect the prevailing westerly winds with occasionally reversed pattern of easterly winds (Sündermann and Pohlmann, 2011). Owing to its topography the North Sea basin affects the resonance of the semidiurnal tidal forces with significant spring-neap rhythms (Sündermann and Pohlmann, 2011). This produces strong tides with turbulent vertical and horizontal exchanges, high current speeds, well mixed water masses and a lack of stratification in the shallower parts of this basin (Becker et al., 1992; Sündermann and Pohlmann, 2011).

2.1.1. Environmental conditions at mooring site of offshore test station: System A

The mooring site of *System A* is located in the shallower part of the German Bight (southern North Sea) within the area of "Nordergründe", which is characterized by shoals, sandbanks and gullies and water depths ranging from 3 to 22 m (Dörjes et al., 1970; BSH, 2019; Fig. 1). Mean tidal range in this area is 3 m (Jänicke et al., 2021). Measured maximum surface currents at the Nordergründe location and the adjacent eastern area range from 60 to 150 cm/s (Neumann and Meier, 1964; Dörjes et al., 1970; Buck 2007) with NW to SE direction and vice versa (Buck, 2007). Mean wave heights are below 1 m (January to December 2021) propagating mainly in westerly and northwesterly direction (BSH, 2022), however, maximum wave heights of almost 6 m may occur (Buck, 2007).

At Nordergründe sediment loads are dominated by fine sand with varying parts of silt and medium sand (Dörjes et al., 1970; Zeiler et al., 2018). In areas under the influence of the estuaries of Jade, Weser and Elbe a highly dynamic sediment transport is observed but the direction of these transports is considered inconsistent with varying sediment displacements (Putzar and Malcherek, 2015; references in Zeiler et al., 2018). Additionally, models indicate that especially areas exposed to swell such as Nordergründe exhibit strong alterations in sediment deposits (Putzar and Malcherek, 2015).

Data on temperature and salinity recorded at the "Alte Weser"-Lighthouse located within the Nordergründe area exhibit minimum and maximum values of −0.1 and 21.7 °C (mean 11.1 ± 5.6 °C, values taken from January 2010 – December 2020) and 25.7 and 34.3 PSU (mean 30.8 ± 1.2 PSU; values from January 2010 – December 2020), respectively (WSA Jade-Weser-North Sea, 2021).

The test site at Nordergründe is located between much-frequented

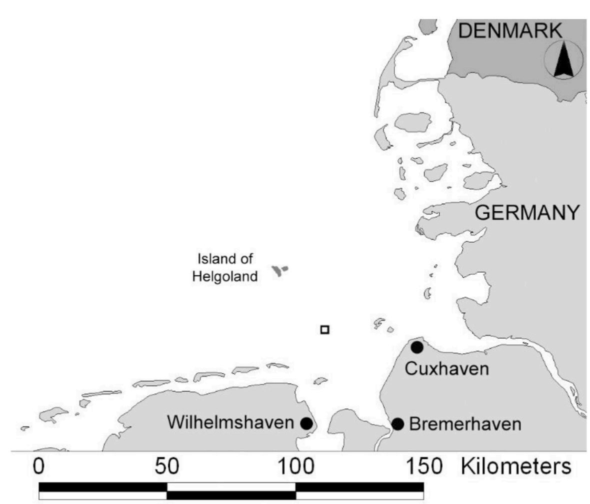

Fig. 1. Study areas in the southern North Sea for the installation of both *Systems* (*A* and *B*), mooring of the spar buoy with the TBSU (black square) and the Island of Helgoland.

shipping waterways with the Elbe approach in the North and the shipping routes directing to Jade and Weser estuaries in the South. Additionally, along with the established nearshore wind farm “Nordergründe” (18 monopiles, 110 Megawatt; area 3.5 km^2, BMWE, 2021) the area Nordergründe is also an important fishing area for more than 20 fishing companies targeting shrimps with beam trawls year-around including locations close to the mooring site (pers. comm. National Board of Fisher, Bremerhaven 2021).

2.1.2. Environmental conditions at Helgoland installation site of sheltered test station: System B

Helgoland Island is situated in the shallower part of the German Bight about 60 km off the coast and the estuaries of the rivers Elbe and Weser (Gebühr et al., 2009; Fig. 1). Helgoland represents the only natural hard substrate location in the south-eastern North Sea, which is usually characterized by sandy and muddy bottoms (BSH, 2017) and rarely found coarse-grained sediments up to coarse boulders (Bartholomä et al., 2020). The waters around this Island are affected by the influx of higher saline offshore North Sea water or by lower saline coastal waters owing to daily tidal mixing and changing currents over the year (Wiltshire et al., 2010). Long-term mean data (over 50 years) from Helgoland exhibits minimum and maximum values for salinity being measured in April (31.2 PSU) and December (32.7 PSU), respectively (Wiltshire et al., 2015). These data records indicated lowest long-term (1962–2011) mean values for surface water temperature in February/March (3–4 °C) and the highest mean value in August (17 °C) (Wiltshire et al., 2015). This already comprises the increasing surface water temperature (by 1.67 °C since 1962) observed during the long-term monitoring programme (Wiltshire et al., 2010). The study site in the Northeast harbour is considered as “sheltered” as it is mostly protected from waves by the harbour's walls except the entrance in the Northeast. The maximum wave heights (0– 1 m) and weak tidal currents (0.1 m s^{-1}) observed for the southern harbour of Helgoland (Buck and Buchholz 2004; Beermann, 2013) are also suggested for the Northeast harbour. The mean tidal range for Helgoland is 2.3 m (Lüning and Dring, 1979).

2.2. Definitions and characteristics of the planned test stations (System A and B)

To achieve the objectives, the following requirements [R] for both systems A and B and for the attached fouling test bodies are defined (Table 1).

System A offers the possibility to provide test bodies of different dimensions overgrown by natural biofouling. In the new test facility marine growth on e. g. jacket structures can be investigated in the context of hydraulic loads on structures of differently sized (dimensioned) test bodies (Damiani et al., 2016; Ying et al., 2018; Aggarwal et al., 2019). Additionally, the spatially rather small dimensions of here used steel tubes of different diameter and used larger steel panels shall also indicate potential effects of these dimensions in relation to the detected biofouling community (e.g. succession patterns, composition).

3. Results

3.1. Construction requirements of test stations System A and B

The individual development steps and their line of argumentation will describe how final versions of both systems (*A* and *B*) were achieved by means of field studies, which could assist potential future developments. Relevant modifications during the iteration process concerning design requirements listed above, detailed for *System A* (Table 2) and *System B* (Table 3), are referred to in brackets.

3.1.1. Buoyancy device for System A

During the iteration process, it was decided to choose a buoy with a large immersion depth. This allows test bodies to be placed at the water surface/splash zone and further test bodies to be placed at deeper levels in the water column (permanent submersion zone) to identify possible vertical differences in the fouling organisms and their distribution. A spar-type buoy (in the following spar buoy) from the local water and shipping agency (WSA Jade-Weser-North Sea, Bremerhaven), responsible for deployment and management of buoy network in these waters, fulfilled these characteristics. Following Clearman (1988) the classification of “spar buoys” comprise a large range of buoys, which he generally considered as narrow and elongated, but national classification systems may partly differ from this general pattern. Conventional spar buoys can be used for various purposes, such as marking coastal and offshore waterways, marking of hazardous areas (e.g. wracks, shallow or rocky areas, any underwater obstacle with low extension) (Clearman, 1988) as well as a device to collect data on abiotic and biotic parameters (Relini et al., 2000; Yan et al., 2003; Langhamer et al., 2009; Zhang et al., 2015). While the colour of spar buoys indicates their function, this is supported by the use of different top marks or the type of lighting; in the present case, the buoy was deployed as data acquisition system to collect biofouling organisms on given surfaces (test bodies). This chosen spar buoy was 5,060 mm in height (top to bottom) with a maximum diameter of 1,600 mm of its float, which itself had a height of 1,500 mm. The wall thickness of the buoy body was estimated with 8 mm of steel showing a total weight of about 1,500 kg. The top of the buoy was equipped with a radar reflector and a yellow top mark. Two lateral lifting lugs on the side walls and one mooring lug at the bottom of the lower mast was attached. Further, a ballast weight in the lower part of the float was integrated to support an upright position during strong currents and wave forces (Fig. 2, Suppl. Material: S1, S2). Overall, the buoy with these characteristics provided enough additional buoyancy with a displacement of about 3,700 kg (0.5 m of the buoy-body without mark above water). This still provided enough lift for the load of the Test

Table 1
Requirements for two systems to study biofouling in an exposed and sheltered area.

Requirement/ System	*System A*	*System B*
R1: Robustness of system device	offshore buoy carrying Test Body Support Unit (TBSU) able to withstand rough weather conditions and severe sea states	ensured functionality of construction and components despite rough weather and sea conditions
R2: Weight of entire system device	keeping weight of construction as low as possible → enable handling even by smaller scientific vessels and naval cranes	keeping weight of construction as low as possible → enable handling during installation by smaller wheel loaders/fork lifts or cranes
R3: Test unit features	appropriate for: attachment and growth of biofouling, transfer to and measurements in the seawater flume	appropriate for: attachment and growth of biofouling and easy handling
R4: Simplicity & ease of use	enable user-friendly handling of carrier frames and test bodies under sea conditions (e.g. swell). Diverse applicability: adaptation of TBSU and components to different kinds of buoys and test bodies for potential other research topics, deployment in diverse marine environments	enable user-friendly handling of test bodies independently of sea or weather conditions, requiring less personnel (max. 2 persons). Diverse applicability: adaptation to different vertical quay wall designs (e.g. steel, concrete), adaptation of components (e. g. sledges) to other kinds of test bodies for other research topics; installation in diverse marine environments
R5: Costs	should be economic to allow this kind of research even with smaller budgets and in countries/areas with lower financial support	should be economic to allow this kind of research even with smaller budgets and in countries/areas with lower financial support

Table 2
Structure analysis on the iteration process of the development of the *System A* (TBSU).

Current version	Conceptual and technical considerations
V.1	Robustness of the TBSU was approved during the first year after being partly subjected to harsh environmental conditions: the TBSU is unharmed (R1). The buoyancy of the buoy was ensured despite the mounted steel construction, and TBFs could be handled quite well (R2, R4). Overall, the steel structure TBSU (V.1) performs well, and additional minor modifications do not increase financial expenditure considerably (R5). Issue 1.1 A month after deployment of the buoy, part of the cylinders moved freely up and down on the threaded rods owing to loosened nuts. Therefore, the nuts were retightened and the tread underneath the nut was punch marked to avoid loosening. Issue resolved. Issue 1.2 The removal and cleaning of the biological material on the buoy after one year revealed fissures and small cavities on the float body and especially in the weld seam, which was constantly below the water surface. This was probably worsened by the cleaning process but also showed the susceptibility of old often used buoys (The buoy was built in 1979). Issue 1.3 While two welding points were damaged due to an accident (see below) most other welding points were heavily corroded (especially the ones below the water surface). In part the diameter of the drill holes was distinctly enlarged, which produced a constant movement of the MSFs and TBFs and increased the risk of loss of TBSU parts. Issue 2.1 Slightly inclined position of the buoy, with one TBF approx. one quarter out of water. The buoy always turns around in the same position independently of the prevailing tidal current. Cause unknown, issue not solved yet. Issue 3.1 A heavy corrosion of the test bodies resulted in the large-scale loss of attached fouling organisms. Issue 4.1 The threading of the TBFs in the MSF can be hampered in rough sea conditions; probably two small protrusions (upper and lower) instead of three (as currently mounted) would improve the insertion in the lateral guiding rails. Otherwise, without the middle protrusions the TBF may have excessive clearance during the handling when trying to thread it in the guiding rails. Issue 4.2 Work on the steel construction e.g. fixing screws had partly been done being on the buoy-body secured by lifejacket and a rope connected to the dinghy. Though, body surface was quite slippery owing to algae growth and the buoy should be equipped with a safety device e.g. safety mat, kick-plate.
V.2	For the second project year several modifications were performed trying to solve the issues described above. Though, the overall design of the TBSU and its subdivisions was maintained including the SPUs, which were still undamaged. In order to address issue 1.2 first, the buoy was completely cleaned of former coatings by sandblasting. Afterwards the buoy was completely refitted by closing fissures and cavities and the lower weld seam on the float body was re-welded. The old welding points were removed and replaced by thicker welding points (160×67.3 × 20 mm, EN 1.0038). The buoy was primed again with a base coat (twice) and the buoy was painted. Additionally, for the attachment of the MSF the screws were equipped with a washer made of glass-fibre reinforced plastic (GFRP) and a heat-shrink tubing to diminish the contact between the welding points and the stainless steel (screws, MSF). Owing to the thicker welding points the mounting of the SUPs resulted more difficult and their fixing points had to be pressed below the welding points. Unfortunately, for the SUP-welding-point connections the use of washers between the contacts of stainless and mild steel was not possible. These measures addressed issue 1.3. All test bodies except the small panels were exchanged with test bodies made of stainless-steel addressing issue 3.1. Due to the use of stainless steel, star-shaped metal sheet in the cylinders were not equipped with flange sleeves to insulate it from the threaded rod. In order to reduce the potential corrosion pressure on the buoy mild steel panels (130 × 115 mm) were fixed with cable ties to cross struts of the MSF and fixing points of the SUPs, where panels were very close to the float body and should act as sacrificial anodes. Instead of cylinders one TBF was be equipped with large panels (108 × 65 × 3 mm). This modification could be made easily by welding on two additional metal sheets at which the panels were mounted by bolted threaded rods. This measure addressed the easy adaptation to other test bodies (R4). Concerning issue 4.1 we decided to keep all three protrusions on the TBF; for now, the issue is considered solved. With respect to Issue 4.2 a safety grating made of glass fibre reinforced plastic (GRP) was fixed on the buoy surface.

Table 3
Structure analysis on the iteration process of the development of *System B* (*MareLift*).

Current version	Conceptual and technical considerations
V.1	The robustness and the proper/perfect functionality of MareLift was approved during the first year even the construction was partly subjected to harsh environmental conditions (R1). The installation of the girder to quay wall was made with the help of a rentable wheel loader and forklift, which enabled the fixation to the four prepared flat bars (R2). The stainless-steel test bodies exhibited a well-developed biofouling community, being considered as appropriate for these studies (R3). The lift could be handled very well (Video 1) and requires two persons only (R4), although the weight of the tiltable arm and test bodies is quite high (see Issue 1.2). The installation of the construction could be done by means of a wheel loader/excavator/small crane on the pier and a small boat on the water for fixing the steel components to the quay wall. With slight modifications, this design should be applicable to vertical structures of various materials in the marine environment. (R4). Overall costs of manufacture and installation do not result in very high expenditures (R5). Issue 1.1 During the first year we detected a sidewards freedom of movement of the tiltable arm at the connection point (steel hinge) between the main girder and the arm. Currently, the mounting of two additional supports on both sides have not been thought through. Not solved yet. Issue 1.2 Concerning the overall weight of the tiltable arm (ca. 109 kg; incl. sledges, test bodies without potential biofouling weight) turning over and placing the arm in the upright position requires a certain exertion even for two persons. Currently, the idea of mounting two pneumatic springs to facilitate the handling is recommended.

Body Support Unit (TBSU), which was circumferentially attached to the buoy walls.

3.1.2. Main steel construction and sub-units for the attachment of artificial test bodies

In the first concept the steel construction consisted of 16 steel bars (8 at the upper, 8 at the lower buoy floatation body) with one end should be welded directly on the buoy floating body. The other end pointing away from the buoy should be welded on two steel rings on the upper and lower end of the floating body forming a wreath (Fig. S1). Above and below outer steel bars extended beyond the edge of the steel ring and on the lower buoy body steel bars should be provided with a welded eyelet for the fixation of the test bodies (cylinders).

Though, the overall design was rejected in particular owing to the fact that it was too delicate considering the environmental conditions at the mooring site. Furthermore, the cylinders fixed at the buoy body would be unprotected towards swimming objects (e.g. flotsam, boats) and during the actual sampling procedure. Additionally, concerning the sampling logistics this design obliges the sampling of single cylinders which was considered as impractical.

Therefore, first, the steel frame construction should include bumpers and a kind of “crash cage” protecting the test bodies and secondly, the new design should allow the sampling of a higher number of cylinders at once. Secondly, in order to ease the assembly of the main steel construction including crash protection on the buoy body, it should consist of several parts, two at least. The local WSA (Jade-Weser-North Sea,

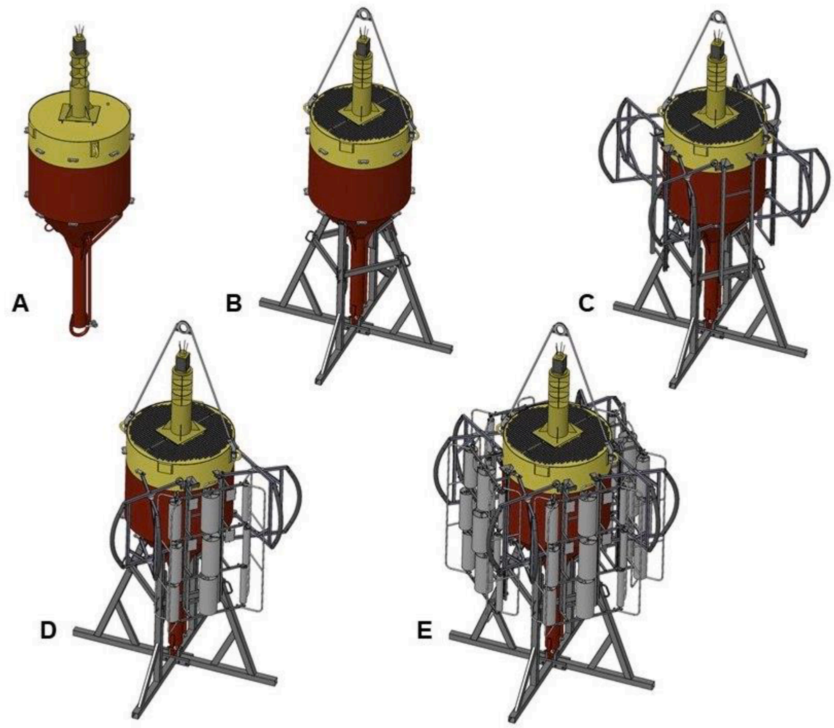

Fig. 2. Steel construction mounted on the spare buoy. (**A**) 16 welding points as basis for fixation of TBSU. (**B**) Buoy fixed in a holding frame fitted a removable lifting arc and safety grating on top of the buoy body. (**C**) Attachment of main steel frame (MSF, racks), skirting protections (SUPs) between the four MSF. (**D**) One side of the buoy with mounted test body frame (TBF) and two SUPs. (**E**) Buoy with fully mounted test body support unit (TBSU).

Bremerhaven) recommended to use welded on flat bars being the interface/attachment point for the main steel construction, where latter shall be bolted.

For the preparation of the steel construction on the buoy sixteen welding points each with two drillings and made of mild steel were welded on the float body (Figs. 2A, B; S2A-C). The entire buoy mantle was painted twice with a primer coat afterwards (Fig. S2A, C). The whole TBSU is made of stainless-steel, except the test bodies themselves. It consists of a main steel frame (MSF; Figs. 2C; S2D, E) and the skirting protection unit (SPU; Figs, 2C–E; S2E, F; S3B), respectively, both directly bolted to the buoy mantle fixing each to four welding points. The contact points between stainless steel (TBSU) and mild steel (welding points) were insulated by Teflon flanges at the bolts, to diminish galvanic flow and associated increased corrosion between the two different steel components. The MSF are four racks, made of U-shaped steel, each providing a funnel-shaped insertion aid from top to bottom to ease the insertion of the test body frames (TBFs) on lateral guide rails (Figs. 2C, D; S3B). The SPUs made of square tube steel equipped with curved PE 100-tubes were placed between the racks to protect the TBFs and test bodies during operation and sampling from damage by the ship's side. The attachment of the whole steel construction increased the weight of the buoy to a total weight of approx. 1,800 kg.

The TBFs were made of square tube steel, each laterally equipped with round steel parts (lateral spacers) to protect the test bodies. Owing to the strong tide currents, the work at the buoy was mainly conducted during the short backwater period. Consequently, the developed TBF ensured the quick removal and reinsertion of a sufficient number of test bodies at once. The TBFs could be re-equipped with new test bodies, which offers the possibility for reproducible and standardized samplings. Each TBF consisted of four horizontal bracings equipped with three welded metal sheets with two drill holes for the installation of the test bodies (cylinders). A lifting lug on top was welded on to ease removal and re-insertion from the MSF (Figs. S2E; S3A). Three small protrusions in the upper, middle, and lower part of the back sides of the TBF were used to aid the insertion and fixing of the TBF in the lateral guiding rails of the MSF (Fig. 3SB). Additionally, the lower protrusions impede a lateral sliding of the TBF while the upper protrusion snaps in a tapering within the guide rail of the MSF which impedes an up-and-down-movement of the TBF while at sea. A locking device at the rack above the funnel-shaped insertion aid prevents a slipping out of the TBF during severe sea states.

3.1.3. *Test bodies*

Initially, for the measurements of loads in the SWWC-flume dimensions of the designed steel tubes were 2,000 mm in length and 100, 250 and 500 mm in diameter. This would result in an assessed weight being up to >100 kg when including attached biofouling organisms (i.e., for 500 mm diameter), which complicates the handling at sea and further logistics concerning the transport and preservation in seawater. Therefore, firstly, each tube was split up in three cylinders of the same length (3 × 660 mm) before being fixed in the TBFs and those parts shall be screwed together prior to measurements. An initially considered subsequent division of a 2,000 mm long tubes being overgrown by biofouling jeopardizes the continuous layer of biofouling which is crucial for the measurements in the SWWC-flume. Secondly, concerning the diameter of cylinders, test bodies of 500 mm diameter and a supposed additional biofouling layer of 100–200 mm, increase the blockage/obstruction ratio by over 20% in the planned SWWC-flume (3,000 mm total width; developed at the Leichtweiß-Institute for Hydraulic Engineering and Water Resources at the Technische Universität Braunschweig, Germany). This results in increased local backwater and the enhanced interaction between deflected currents with flow channel walls impeding valid measurements. Therefore, finally selected test body diameters were 100, 200 and 300 mm (Fig. S4), which circumvents potential problems with blockage ratio above 20% even with biofouling attached. The dimensions of those test bodies offer the opportunity to investigate biofouling in the context of hydraulic loads on structures such as jacket foundations.

Therefore, overall, each of the four TBFs (Version 1 (V1)) carried 4 small steel panels (150 × 200 × 3 mm) and 3 open steel tubes as test bodies. All test bodies were made of mild steel and no synthetic material (i. e. plastic) was used in order to guarantee the rigidity and solidity of the tubes for the planned experiments in the SWWC-flume. Test panels were fixed with cable ties while for the installation of the cylinders in the TBF at both ends of each cylinder a star-shaped metal sheet was welded on and a stainless threaded rod was inserted in its centrally drilled hole (Fig. S4). Bore holes in the welded metal sheets of two horizontal bracings above and below the cylinder served for fixing threaded rods to avoid an up- and down movement when at sea (Fig. S4). Additionally, this set-up also permits the fastening of cylinders during the planned road transport after the sampling. For the measurements in the SWWC-flume the set-up also enables to reassemble the three cylinders to one tube in order to obtain a continuous biofouling surface. The overall weight of one TBF including test bodies was approx. 145 kg.

While the small steel panels were originally thought to be used for seasonal taxonomic analysis of biofouling organisms, the tubes should be left at sea for >6 months to >1 year, respectively, to achieve a well-developed biofouling community for the measurement trials in the SWWC-flume. The attachment of the whole steel framework (TBSU) enhanced the overall weight of the buoy to 2,370 kg in total.

3.1.4. Buoy preparation for transport and deployment at sea

As the TBSU covered the two lifting eyes on both sides of the float body a removable lifting arc (30 kg weight; Figs. 2B- E, S2D-F, S5A) made of stainless steel was welded, which had to be long enough to reach over the buoy lighting above. Additionally, the process of attaching the different components to the buoy required the construction of a holding frame, where the buoy is fixed. This allowed an upright deployment of the boy also for the transport, which was vital in order to heave up the construction easily at sea as well as to prevent that the steel framework broke under the weight such as would be the case in a horizontal/lying position of the buoy (Figs. 2B-E, S2D-F, S5B).

The deployment in the holding frame enhanced the overall weight of the buoy to 2.6 t as well as the diameter and the lateral width to 3,153 and 3,710 mm, respectively. Therefore, the predicted maximal load/stress of the lifting arc was well within the safety levels (5 times the total weight of the buoy and holding frame: 13 t).

3.1.5. Deployment at sea and handling

In April 2020 the test-buoy was moored by the local Water and Shipping Agency (WSA) in the area Nordergründe for the first time, (coordinates: 53° 50,4400 'N; 008° 11,5200 'E; Fig. 3). The buoy was deployed by an offshore buoy tender approx. 7 nmi off the northeast coast of the federal state Lower Saxony and less than 1 nautical mile east but outside of the buffer zone of the nearshore wind farm "Nordergründe". The buoy was moored at about 11 m depth with an anchor chain (link diameter 36 mm) of 40 m length and a concrete block (3 t).

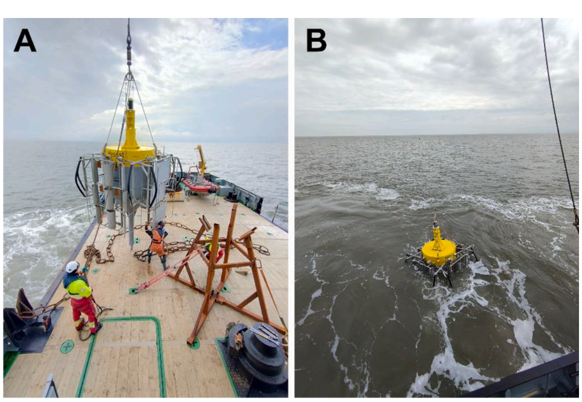

Fig. 3. (**A**) Buoy fixed at lifting arc hauled out from the holding frame right before attachment of the mooring chain onboard the buoy tender (May 2021). (**B**) Buoy moored shortly afterwards. (Images: Crew buoy tender *Nordergründe*, WSA Bremerhaven.).

The first mooring of the buoy was carried out without any difficulties. The holding frame turned out to be highly useful for the transport on board the buoy tender and for lifting out the buoy easily without damaging any part of the steel construction. The buoy exhibited a good buoyancy despite the TBSU and although an inclined position was maintained during the first year. Considering the overall buoy weight, a yearly inspection of the construction could be planned and was conducted once in 2020 with the RV *Heincke* (LoA: 54.59 m, W: 12.50 m) being equipped with cranes lifting between 2.5 – 5 t weight, while the characteristics of the smaller research vessel RV *Uthörn* (LoA: 30.50 m, W: 8.50 m; lifting arm max. 1.5 t) were sufficient for the prospective samplings of the TBFs. During the first test sampling trials, in the beginning a main challenge was the handling of the buoy owing specifically to strong tide currents in the Nordergründe area.

The first trials in June 2020 were done during the turn point of the tide and good weather conditions, fixing the buoy starboard mid-ships. Though, this limits the time for handling significantly and the sudden onset of the tide were problematic to hold the position of the ship, which resulted in damages of the TBSU happened once. During these trials the ship collided with the buoy damaging two MSF and TBFs, while the SPUs resulted highly robust without showing any defect. Additionally, this collision severely damaged two welded-on eyes being undetected until the following buoy inspection, where one of the MSF and a TBF were missing. Therefore, the solution for this issue was the buoy attachment at the stern (October 2020) during the tide currents and with the ship positioned in the current direction moored in front of the buoy. Trials were done distinctly before the tide turn point providing us with sufficient time for the removal and insertion and an overall efficient handling of TBFs. For the sampling of the test bodies still more details have to be clarified concerning the preservation on board and the transport to the final destination, the SWWC-flume at the Technische Universität Braunschweig. For the transport steel drums with steel lids will be used, filled with sea water, and aerated by ventilators usually installed in aquaria. In comparison to cheaper synthetic drums, steel drums permit the fixation of a test body by means of the threaded rods and star-shaped metal sheets on the drum bottom and at the lid. Similar to the fixation in the TBF test bodies shall be mounted on the threaded rods with the centrally drilled hole in the star-shaped metal sheet above and below and fixed to avoid an up- and down movement during the whole transport. This fixation system shall also be used in the RAS at the Technische Universität Braunschweig.

3.1.6. Development and growth of biofouling

Owing to logistical problems with the research vessel and the cancelation of ship time the first inspections of the buoy and the attachment and growth of biofouling on the test bodies could not be made before June and October 2020. Although several different taxa (e. g. brown and green algae, hydrozoans, acorn barnacles, blue mussel) could be observed on some test bodies of the two inspected TBFs upon visual inspection, clear signs of corrosion could be discerned with some test bodies exhibiting almost no fouling (Fig. 4). The lifting of the complete buoy out of the water in October and December 2020 confirmed this large-scale loss of the fouling biomass from most of the test bodies caused by heavy corrosion. Therefore, it was concluded that mild steel without any corrosion prevention measure seems not to be appropriate for the main aim to achieve the development of a comprehensive biofouling community. Currents or even heave motions of the buoy and the lifting of the TBFs out from the MSF could easily produce these losses as large areas of the substrate below the biofouling corroded and fell off.

Therefore, in the winter 2020 all TBFs with their test bodies were removed from the buoy. Additionally, in spring 2021 the buoy was brought ashore for a thorough revision, owing also to the strong corrosion of the buoy body. The stainless-steel framework was refitted, TBFs were re-equipped with stainless-steel test bodies (tubes) and larger

Fig. 4. Images of MSF and test bodies on board removed recently from the TBSU in December 2020. (A) complete MSF with test bodies, (B) and (C) test bodies with clear signs of corrosion and missing biofouling (Images: Düffert, Isbert).

panels (108 × 65 × 3 mm), and the buoy was moored again at the same site in May 2021 (see also Table 2). The panels were selected as larger structure dimensions in relation to biofouling growth for the planned measurement trials in the SWWC-flume to represent segments of pile structures. This approach offers the opportunity to investigate if smaller posts (e. g. in jacket structures) exhibit a different community than extensive structures (wind piles) with potential consequences for the loads and load flows.

Due to the lack of ship time a complete lifting and inspection of this buoy could not be conducted in 2021. The lifting of single TBFs for inspection was planned only in case of an emergency (possible damage to the frame), as there is always a risk when removing or reinserting single frames into the MSF, e.g. damaging test bodies or the growing fauna. Additionally, it was not deemed necessary as regular sampling and analysis of stainless-steel panels (115 × 130 mm) on a second spar buoy (*Buoy II*) moored close by (position: 53° 50,40,902′ N; 008° 11,59,697′ E) exhibited an excellent attachment and growth of biofouling on these test bodies. Therefore, it can be supposed that similar fouling attachment and growth proceed on the stainless-steel tubes and panels in the TBFs.

The attachment and growth of fouling on the steel panels of *Buoy II* showed clear seasonal succession patterns, the dominance of single taxa (barnacles, amphipods, mussels), the increase of body length in blue mussel individuals and not any sign of large-scale losses due to corrosion. The development of the fouling community on these panels was comparable to literature describing the succession of biofouling communities in the southern North Sea.

3.1.7. Weather conditions (wind/wave) 2020 - 2021

The data for the area Nordergründe is available from 2020 (Dec.) and 2021 (Jan. - Dec.) provided by the Federal Maritime and Hydrographic Agency of Germany (BSH). The data indicated the expected westerly and northwesterly main wave direction in Nordergründe (BSH, 2022). The data for this period also exhibited absolute minimum and maximum values for wave height in 2021 of 128 cm (February) and 340 cm (December 2021), respectively. The minimum and maximum mean values were 36 ± 22 cm (June) and 77 ± 45 cm (November). Thus, the buoy and the mounted TBSU withstood several periods of harsh weather conditions and rough sea states.

3.1.8. Further remarks

Before its transport offshore and mooring, the here used and modified spar buoy was prepared following the procedure usually conducted by the WSA for steel buoys moored along marine waterways; this includes grinding, repair works (replacing steel parts), primer coat, painting. Though, in the present case after the first year (April 2020 – April 2021) it could be observed that the welded-on eyes and the buoy body showed clear signs of corrosion (Table 2) with partly small ruptures especially at the welding seams around the welded-on eyes and the buoy body.

Although a profound inspection of the buoy was not possible in 2021 the firmness and secure fit of the TBFs in the MSFs and the test bodies were controlled regularly driving along with a ship's boat. These regular controls were important as in August 2021 these inspections revealed two breakages in one TBF at the level of the water surface, which probably resulted from a faulty welding procedure and material overload. The breakages were bridged by a bolted cuff, thus stabilizing the frame structure against rough sea and cuffs were still fixed when inspecting the buoy in November 2021.

3.2. Construction requirements of System B (MareLift)

3.2.1. Main construction and installation at test site

System B was mounted at the north-eastern quay wall of the Northeast yacht harbour (depth range 3.6–4.2 m) of Helgoland close to the harbour exit.

The design developed in this work is based on a welded stainless-steel girder being the "backbone" of the lift, which was vertically mounted to the quay wall. The girder (overall length: 7,355 mm; overall width: 160 mm; 130 kg) and the tiltable arm (L: 1,700 mm; W: 160 mm; 28 kg) consist of two parts of stainless elbow steel welded on both sides of a square tube (scheme Figs. 5; S6; S7).

In order to fix the girder to the quay wall, four flat bars were dowelled with their lower part into the wall in different distances to the quay edge above (Fig. 5), by using epoxy resin and two anchor rods for each flat bar. Their upper pieces serve as counterparts to four flat bars welded on the girder were being tightly screwed together (Fig. 5).

The lowest part of the girder, the part being permanently under water, ends in a welded-on square-shaped stainless-steel panel (S7C, D). The upper part of the girder exhibits two welding eyes for the attachment of a steel hinge consisting of one curved steel piece with a central boring hole.

The steel hinge, jointed with two discs of Polyoxymethylene (POM) on both sides, is attached connecting the girder with the tiltable arm (Fig. S6A, E). The tiltable arm is the terminal for the sledges carrying the test bodies, which are pulled up, turned over for sampling and lowered again using a winch and a stainless-steel cable, which runs over a wire pulley block (Figs. S6B; S7B).

The upper end of the cable is coiled on a cable winch while the lower part ends in a thimble being attached at the lower sledge by a shackle. The winch was tightly fixed with screws to a welded "winch box" (Fig. S6C, D), where the crank could be secured by a bracket when not in use (Fig. S6D). A curved stainless-steel stick attached to the arm by a wire is plugged in a socket when sledges are in the "pulled-up"-position in order to avoid undesired slipping of the sledges (Fig. S6E, F). A second steel rod next to the steel hinge impedes the tilting of the arm and has to be pulled out in case of the intended use of the arm (Fig. S6C). Like the crank, the stick is secured by a padlock to avoid unauthorized use.

The sledges were made of stainless-elbow steel (Figs. S6B; S7B, C) being fitted with two skids and welded-on guiderails for the girder on

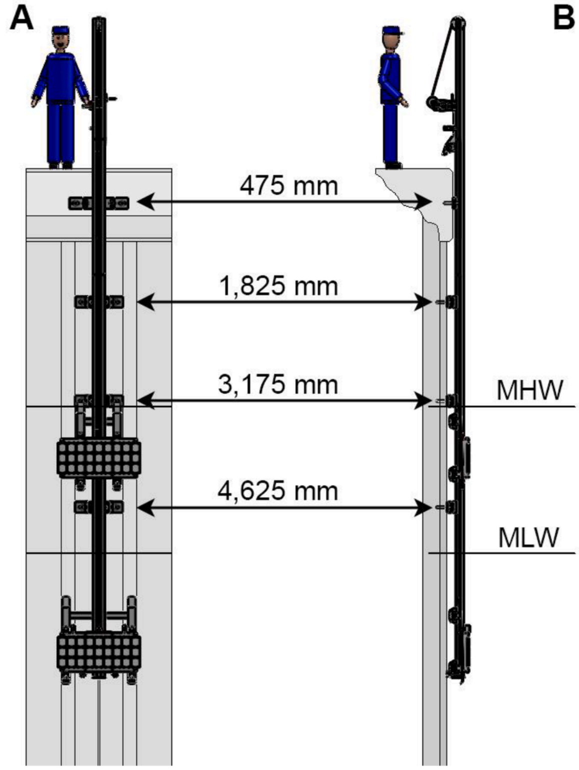

Fig. 5. Scheme of the *System B* (*MareLift*) (scale 1:10) frontal view (**A**), side view (**B**). (**A**) Details of girder fixation: Four flat bars dowelled to the quay wall (black numbers in mm indicate distance of flat bars to the quay edge from above: First: one piece: 800 × 150 × 10 mm; second to fourth: (two pieces: 380 × 150 × 10 mm (upper part), 650 × 150 × 10 mm (lower part)). Counterparts welded on the girder: first: 265 × 150 × 10 mm, second to fourth: 420 × 150 × 10 mm, fixed with threaded bolts (M20). Motherboards with test bodies on sledges in position under water. MHW – mean high water, MLW – mean low water; (drawings by Littmann).

the top and below. Sledge (A) positioned in the tidal zone (intertidal) differs slightly in its design to the lower sledge (B) (positioned below the tidal influence (subtidal)) (Figs. 5; S6B; S7C). Sledge B was equipped with a U-bolt, which is fixed with the cable by a shackle, and spacers being welded on the top (Figs. S6B; S7E, F). Using the winch both sledges are pulled up as the cable passes through a hole in the guiderail of sledge A (Fig. S7 B) and is fixed at the U-bolt of sledge B and the spacers welded (buffers) on the top push the upper sledge (A) during lifting. Ends (last 50 mm) of all skids are curved upwards (approx. 20̊) (Figs. S6B; S7B, C).

The positions of the sledges under water are determined by position-locks, where during the lowering the sledges snap into these terminals (above: A; below: B) as these position-locks can be considered as counter parts to the sledges with skids pointing upwards. Both position-locks differed in their overall width (overall W: A: 600 mm; B: 1,000 mm) and were fixed in welded-on eyes on the girder (Fig. S7A, D). On each position-locks the welded-on spacers between square tube and skids above and below (see in Fig. S7A, as seen from the quay wall edge) were different in their height and even tapered slightly on one side. The inclination of the skids ensured the snapping of the sledge into the position-locks. Additionally, in both position-locks the ends of skids were curved downwards (last 150 mm, approx. 175̊) above and below (last 50 mm, approx. 150̊) as seen from the quay wall edge (Fig. S7A).

On the lower part of position-locks B two welded metal sheets, each with a drilling, served to fix two spacers (Fig. S7A), which can be adjusted to the quay wall stabilizing and protecting the lowest part of the construction in case of swell. Both position-locks were mounted in depths ensuring that sledges remain within and below the tidal zone (Fig. 5A, B). Test bodies on the motherboards attached to the sledges were fixed with cable ties in order to facilitate a rapid and easy sampling. The total weight of the whole construction is 296 kg.

3.2.2. *Deployment in the harbour and handling*

Overall, the installation of *System B* (*MareLift*) in the harbour could be done with the assistance of a wheel loader and a forklift holding the girder until it was fixed to the quay wall. During the samplings all of the components of *MareLift* worked perfectly and no failures could be detected in the first year 2021. None of the construction parts had to be adjusted or repaired, and the material exhibited almost no signs of wears.

3.2.3. *Development and growth of biofouling*

In respect of *System B* again, the stainless-steel panels exhibited almost no signs of corrosion and there was no apparent loss of biofouling caused by corrosion. Therefore, the panels, taken during monthly samplings, clearly exhibited a sound basis for the analysis of the growth and succession pattern of the biofouling (Fig. S8). And as expected, growth and succession patterns differed clearly in their development between both habitats (intertidal and subtidal). The habitats in Helgoland differed in their dominant taxa being green algae (intertidal) compared to tube building worms and colony building tunicates (subtidal).

3.2.4. *Weather conditions (wind/wave) 2020 - 2021*

For Helgoland data on wave direction and height were incomplete for 2020 and 2021, but overall, data indicated the expected westerly and north-westerly main wave direction in waters around Helgoland (BSH 2022). The data from this area also exhibited absolute minimum and maximum values for wave height in 2020/2021 of 73 cm (January 2020) and 554 cm (December 2021), respectively. The minimum and maximum mean values were 67 ± 54 cm (June 2020) and 241 ± 136 cm (February 2020). Although conditions offshore in the southern North Sea can be harsh, this device being fixed in a harbour and above all located close to the entrance in *lee* of the quay wall was protected against waves rolling into the harbour.

4. Discussion

The manuscript describes the design process of two test stations deployed in an exposed (*System A*) and a sheltered area (*System B*) for research purposes on biofouling. During these field studies the main aims could be achieved in the development of these test systems. Both met the requirements of being relatively easily accessible, their straightforward handling, and reasonable cost-effective.

Except the severe damages produced during test trials in summer 2020, no further damages of this kind were recorded for *System A*. The single slight damage at the TBF could be assigned to errors during the manufacturing process and was not based on failures in the overall design. It is suggested that the test body support unit (TBSU) is sufficiently robust as it withstood several periods of rough weather conditions and severe sea states during 2020/21. The TBFs could be handled even by smaller scientific vessels and naval cranes, respectively, and after few test trials TBFs were considered user-friendly during withdrawal and re-insertion in the MSFs under sea conditions. Additionally, the TBFs could be modified easily to carry not only cylinders but also larger steel panels. This offers the opportunity to achieve differently sized (dimensioned) test bodies overgrown by naturally attached biofouling for subsequent measurement trials in the SWWC-flume.

As *System A* could not be lifted and inspected completely during 2021, it lacks the final confirmation for the successful attachment and growth of fouling communities on the test bodies. Though, regular superficial inspections and obtained data on biofouling growth from stainless-steel panels (Fig. S8) fixed on *Buoy II* let us conclude that *System A* should also work well in an exposed area. These panels fulfilled entirely the objective collecting biofouling from this area. The development and composition of the assemblages in these depths of 1–5 m (Fig. S8) clearly reflected the observations already done on offshore artificial structures in the southern North Sea even on slightly different substrata (e.g. platforms, wind piles) (Orejas et al., 2005; Schröder et al., 2008; Krone et al., 2013; De Mesel et al., 2015). For instance, this applies to the succession patterns within communities as well as the dominating taxa, such as tube-building amphipods and blue mussel, recorded in those assemblages later in the year.

It still lacks the realization of the transfer and the deployment of the cylinders in the RAS and the SWWC-flume. Through, considering the test body design with welded-on star-shaped metal sheets at both ends of each cylinder and the inserted stainless threaded rod, we feel confident of an easy handling during these procedures. The costs for the TBSU, test bodies and the sampling procedure with a small research vessel can be considered as comparatively low. Though, the main TBSU framework depends on the varying global market prices of stainless-steel. Furthermore, the designed system provides space to use other cheaper but also robust materials (e.g. synthetic materials) for single parts of the TBSU or even for the test bodies, depending on the research approach.

It is highly likely that the corrosion observed on the buoy body has even been increased by the mounted stainless-steel TBSU. Therefore, for the next experimental mooring it is thought about fitting the buoy with sacrificial anodes (aluminium or zinc). Though, some studies indicated the impact of biofoulers on sacrificial anodes decreasing their potential to protect cathodic steel by reducing the anode current output (Swain and Patrick-Maxwell, 1990; Eashwar et al., 2009; Blackwood et al., 2010; Zhang et al., 2014). Biofilms, often considered as basis for the establishment of macrofoulers (e.g. mussels) forming in the first days on submerged artificial structures, can even accelerate or inhibit corrosion on metal cathodes coupled with sacrificial anodes (Swain and Patrick-Maxwell, 1990; Eashwar et al., 2009). But they can also be affected by cathodic protection in its formation and growth (Miyanaga et al., 2007; Eashwar et al., 2009). There is still controversy about inhibitory effects on the attachment of biofouling on cathodically protected metal surfaces (Pérez et al., 1994; Lin and Shao, 2002; Eashwar et al., 2009). Zhang et al. (2020) observed lower abundances of biofoulers on cathodically protected steel panels compared to unprotected, while Blackwood et al. (2010) detected no significant effects on the extent of biofouling except biofouling was easier to remove from the substrate. In contrast, Eashwar et al. (1995) observed even a "greatly enhanced" settlement of barnacles, oysters and a calcareous alga. Therefore, test trials fitting the steel buoy with sacrificial anodes on one side at least, could indicate potential effects on biofouling on the test bodies and the progressing corrosion of the buoy.

In general, *System A* can be considered as a basis for other research topics in exposed areas, such as testing materials used by the industry (wear and tear of synthetics, metals, porosity of surfaces to attract or avoid fouling), exposition of metals and/or alloys under conditions at sea concerning aspects of corrosion or for the monitoring of marine abiotic parameters by data loggers.

System B (*MareLift*) provided the robustness and functionality which is adequate for regular sampling procedures in a sheltered area. The device can be accessed and used regardless of the tidal and weather conditions and samplings need less staff employment.

The stainless-steel test panels on *System B* revealed an excellent growth and succession of fouling organisms during the first year (Fig. S8). Under consideration of slightly different sheltered study areas (other Helgoland harbour) and partly other artificial substrates (e.g. PVC, perspex) used, the composition and seasonal appearance of fouling taxa observed in other studies were comparable to those observed on present panels (Harms and Anger, 1983; Schröder et al., 2008; Beermann, 2013). In contrast, latter were expectedly different to substrates such as steel surfaces moored in rather exposed areas (buoys around Helgoland, Caspers, 1952) and steel panels from *Buoy II* (Nordergründe) owing to different environmental conditions.

System B can be easily adapted to deeper waters (e. g. girder and cable length) potentially fitting it with more than two position locks. Sledges could be equipped with other kinds of carrying units, test bodies or data loggers, such as units made of Polyethylene being sufficiently robust, but lighter and potentially cheaper than stainless-steel. Overall, this device is considered cost-effective considering that it is installed once and can be used for different approaches dealing with research in sheltered marine environments. At least in the present case, it does not need substantial maintenance efforts or maintenance costs, which might be slightly different in other geographical areas with higher corrosion (tropic environment).

Apart of the potential modifications in *System B* to be applicable for other research approaches such as material testing or ecological studies, the next potential approach could be the installation of this device in a harsher environment (e.g. wall outside harbours). In this case, it is exposed to stronger wave and currents to assess which components should be shored up to withstand stronger forces but maintaining the overall functionality and easy handling. Up to a certain extent, this paves the way for its further modification and use even in more exposed offshore areas probably also on swimming structures (e.g. pontons moored or fixed to gas-/oil-/wind-/supply- platforms).

As impacts of corrosion and hydrodynamic loads on artificial structures are suggested to be greatest in the upper water layer, where biofouling growth is also strong (Edyvean, 1987), during the here conducted field studies the upper 1–5 m of water depth were important to obtain biofouling communities. *System A* provides a convincing device to obtain living naturally attached and heterogenous fouling assemblages for SWWC-flume experiments as samples can be taken by means of a ship crane less depending on sea conditions than dive operations. Further, it means lower risk compared to also more costly dive operations, especially in areas of high current speeds. Additionally, this applies also to sheltered areas where *System B* renders dive operations and the accompanying securing of the working area unnecessary. This is important with respect to avoid the disruption of operational processes (boat traffic) in harbours, also regarding costs. In regular sampling surveys for the biological monitoring of the present communities scrape samples or images can be difficult to obtain in a quantitative, reproducible manner owing to water visibility (e.g. plankton, sediment) or practical constraints (Caspers, 1952; De Mesel et al., 2015). This may even occur in surface waters, due to the wave movement and, like in Nordergründe, great sediment load in the water column. Consequently, for the biological monitoring test bodies, such as small panels, are considered as appropriate instrument for the sound analysis of fouling development as well as the use of test stations for a standardized sampling of those test bodies (e.g. Perkol-Finkel et al., 2008; Wahl et al., 2011; Menchaca et al., 2014; Beermann, 2013).

5. Conclusions

The here developed *System A* and *B* provide a sound basis for biofouling research. They provide heterogenous, naturally attached biofouling material taken in a standardized manner to conduct subsequent measurement trials in a SWWC-flume and monitoring studies, respectively.

Considering the objectives of the present study:

1 Both systems were sufficiently robust to cope with rough weather conditions and severe sea states maintaining their functionality in the exposed and sheltered site, respectively.

2 Both systems can be easily handled, maintained, processed, and sampled. After some practice the TBF-subunits of *System A* exhibited a straightforward handling and provided the possibility to remove and re-insert several test bodies at once in the MSFs. Nevertheless, owing to the fixation at the buoy, the work with *System A* is restricted to a certain range of ocean currents and wave heights. From the start *System B* revealed to be highly reliable in its functionality and

straightforward handling, providing samplings regardless of weather and tidal conditions.

3 The TBF-carrier unit provided a protected removal of the test bodies, and the mounting ensures the preparation for the potential transport of the test bodies. Owing to results from *Buoy II* it is suggested that biofouling can settle and grow unhindered on test bodies of *System A*. In contrast to *System A, System B* could provide test bodies overgrown by biofouling from the tidal and the permanent immersion zone. The easy removal of the test bodies ensured the biological monitoring over the year.

Both systems are applicable in almost all geographic areas. In respect to biofouling research, this could be highly useful for the cataloguing of the geographical distribution of biofouling taxa and the characterisation of their communities, which is of important role in the risk management of marine sectors.

Furthermore, both systems offer standardized samplings for reproducible data collection. They provide a margin for modifications to be applied in other different research approaches such as testing of different materials, moveable parts used in marine environments, surface quality testing, antifouling coating test surveys, but also for studies in marine ecology concerning microplastic or invasive species.

CRediT authorship contribution statement

W. Isbert: Methodology, Project administration, Investigation, Writing – original draft. **C. Lindemann:** Investigation, Writing – original draft. **J. Lemburg:** Methodology, Writing – review & editing. **M. Littmann:** Methodology, Writing – review & editing. **K. Tegethoff:** Methodology, Investigation, Writing – review & editing. **N. Goseberg:** Conceptualization, Writing – review & editing, Funding acquisition. **S. Durst:** Methodology, Investigation, Writing – review & editing. **D. Schürenkamp:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **B.H. Buck:** Conceptualization, Methodology, Writing – original draft, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.apor.2023.103572.

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