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Full Length Article

The use of acoustic deterrent devices to mitigate fishery-seal conflict at the scale of an entire coastal bay

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A R T I C L E I N F O

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A B S T R A C T

Recovering seal populations are increasingly in conflict with aquaculture and fisheries. One potential approach to mitigate these conflicts is the use of seal deterrents, such as acoustic deterrent devices (ADDs). These devices are typically deployed near aquaculture pens or fishing gear where seal foraging is considered problematic. In the current multiyear study, we assessed the feasibility of creating a larger seal-restricted area by installing ADDs in narrow straits leading to a large (~40 km^2) coastal bay. We found that fishers' gillnets were subject to lower levels of seal-induced damage during years when ADDs were in use. However, seal-induced damage and seal sightings remained common within the bay even when the devices were operated. Catches of secondary target species seemed to respond positively to ADD deployment, whereas those of the main target species, the pikeperch (*Sander lucioperca*), did not significantly increase, suggesting a limited effect on the catches. Fishers' perceptions of the use of ADDs varied but were generally positive. Overall, the results indicate that the tested approach provided only modest measurable benefits to the fishery within a large bay. One potential explanation to this finding is that the number of ADDs deployed may have been insufficient to more substantially limit seal movements into the area. The study also highlights the influence of local environmental conditions and other context-dependent factors on ADD effectiveness and the need for further research into the performance of different ADD configurations.

1. Introduction

Ringed seal (*Pusa hispida*) and grey seal (*Halichoerus grypus*) populations in the Baltic Sea have in recent decades quickly strengthened in response to reductions in hunting and certain environmental pollutants (Magera et al., 2013; Suuronen et al., 2023; Lehtonen and Suuronen, 2025). Their recovery is considered a significant management and conservation success (Hammerschlag et al., 2019; Nelms et al., 2021). However, especially grey seals often interact with coastal aquaculture and fisheries (Oksanen et al., 2014; Suuronen et al., 2023; Lehtonen and Suuronen, 2025). Consequently, the quick population recoveries especially since the 1990s (Harding and Härkönen, 1999; Harding et al., 2007; Suuronen et al., 2023) have intensified conflicts between coastal fish-related livelihoods and seals in the region (Waldo et al., 2020; Blomquist and Waldo, 2021; Suuronen et al., 2023), similarly to many other coastal areas around the globe where seal populations have markedly recovered (Butler et al., 2008; Cronin et al., 2014; Vincent et al., 2016; Tixier et al., 2021; Lehtonen and Suuronen, 2025).

Such interactions between seals (or marine mammals in general) and human livelihoods are often complex, controversial and difficult to resolve. Attempted solutions include fishing gear and aquaculture facility modifications that decrease economic losses and seal fatalities, physical barriers and lethal (or non-lethal) removal of seals (Suuronen et al., 2006; Hemmingsson et al., 2008; Bowen and Lidgard, 2013; Hamilton and Baker, 2019). Another emerging approach has been the use of acoustic deterrent devices (ADDs) that produce intense underwater sounds that deter seals (Shivik et al., 2003; Fjälling et al., 2006; Götz and Janik, 2013; Schakner and Blumstein, 2013; Lehtonen and Suuronen, 2025). The devices usually emit sounds at frequencies (>5 kHz) that are, at a high sound pressure, painful and/or frightening to seals (Schakner and Blumstein, 2013; Lehtonen and Suuronen, 2025), while the frequencies are high enough not to be sensed by fish (Popper and Hawkins, 2019). Originally, the main application of seal deterrents was in aquaculture, especially at salmon farms (Quick et al., 2004; Götz and Janik, 2013). Another emerging application is to employ ADDs to safeguard fishing gear from foraging seals, and seals from entanglement

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and drowning, especially in the context of small-scale fisheries that use gillnets or trap-nets (Fjälling et al., 2006; Harris et al., 2014; Lehtonen et al., 2022). ADDs have also been trialled for preventing seals from entering into, or foraging at, a specific site, such as a section of a coastal river (Graham et al., 2009; McKeegan et al., 2024; Veneranta et al., 2024). Finally, they may have potential for reducing seal disturbance to fish reproduction or migration (Yurk and Trites, 2000; Schakner and Blumstein, 2013; Lehtonen et al., 2023a). One challenge faced by the site-specific ADD applications is that the devices are expensive, while the effective range of a single device is typically clearly less than 50 m (Veneranta et al., 2024; Lehtonen and Suuronen, 2025), meaning that the ratio of the costs to the potential benefits may not be favourable under a wide range of circumstances. Moreover, the underwater noise generated by multiple ADDs has raised animal welfare concerns (Findlay et al., 2021, 2024; Lehtonen and Suuronen, 2025).

Accordingly, researchers have suggested that, at some localities, coastal geography may provide opportunities to use ADDs in a more efficient manner (Lehtonen et al., 2023a), so that only a few devices would be needed to prevent seals entering a larger area of high importance to fishery, aquaculture or fish reproduction. Here, we provide the first test of the feasibility of such a setup in a multiyear assessment. Over a development and optimisation process of multiple years, we used various configurations of ADDs with the intention of keeping seals away from Naantalinaukko (Fig. 1), a large bay on the southwestern cost of Finland. The area is important for small-scale pikeperch (*Sander lucioperca*) gillnet fishery and as a reproduction site of the species (Veneranta et al., 2011; Kallasvuo et al., 2017; HELCOM, 2021). The pikeperch (also known as the zander) is the most important target species of many commercial and recreational fishers in the region (Olin et al., 2023). The commercial small-scale fishers targeting the species receive additional income from gillnet catches of other species that are common in the area, especially the northern pike (*Esox lucius*), European whitefish (*Coregonus maraena*, also known as *C. lavaretus*) and European perch (*Perca fluviatilis*). The most important fishing periods in the area are the spring after the end of icing conditions (April and May) and then again after a summer break, from September (or early October) until the onset of winter conditions, usually in early to mid December. The commercial fishers use gillnets and to a lesser extent fyke traps, both of which are commonly visited by foraging seals (Lehtonen et al., 2022; Suuronen et al., 2023), resulting in gear and catch damage (i.e. economical losses) and increasing stress to the fishers. Recreational fishery is also common in the area but, with regard to active recreational fishing methods, not directly affected by seals to the same extent as the commercial fishery. We hypothesised that the placement of ADDs into narrow straits that connect the bay, Naantalinaukko, with the surrounding waters would improve the conditions for the commercial small-scale fishers, by decreasing damages to their fishing gear and catch and by improving their catches.

2. Methods

2.1. Study site and general study design

The study was conducted at a bay, hereafter referred to by its local name, Naantalinaukko (60.49°N, 21.96°E), next to the city of Naantali, on Finland's southwestern cost (Fig. 1). The elongated bay has the maximum dimension (length) of ~10 km and area of ~40 km^2 (Fig. 1). It was chosen for the study because it is connected to the surrounding coastal archipelago by only three narrow straits (Fig. 1). Such a setting, previously detailed (but not tested) by Lehtonen et al. (2023a), allows an attempt to close an area from seals by using ADDs at critical locations, so that the seals would not enter the area (for a similar approach applied for a section of a river, see Veneranta et al., 2024).

The first ADDs were brought to the straits of Naantalinaukko in 2018.

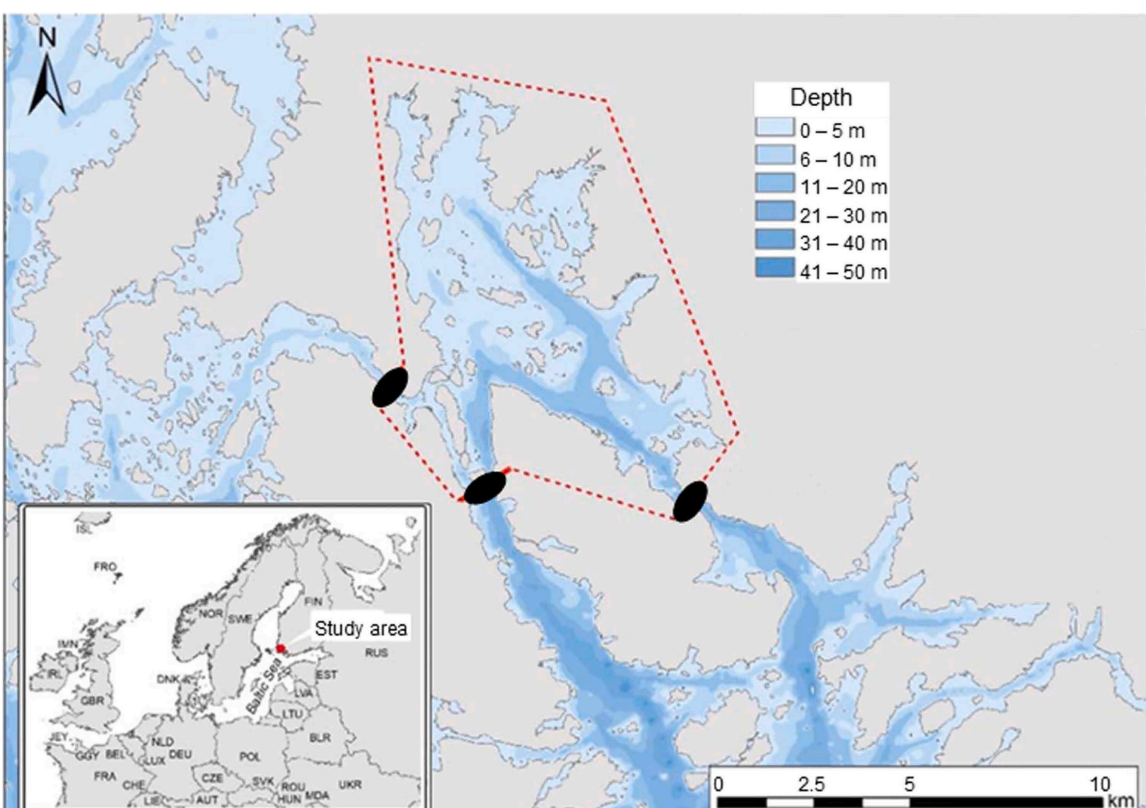

Fig. 1. The study area in the Turku archipelago, southwestern coast of Finland, Baltic Sea. The black balloons indicate the sites of ADDs and the red dotted line shows the area, Naantalinaukko, that was intended to be restricted from seals.

To account for variation in natural conditions and the details of the ADD setup, we ran the study over multiple years. As far as we are aware, our study has the largest scale of any studies of this type to date. Because of the method-development aspect of the underlying project, the details of the ADD configuration were not constant (Table 1). In data analyses (see below), we combined the various ADD deployment configurations into a single 'ADD use period', spanning September 2018 to December 2023. In addition, the study included a pre-ADD period (for catch data: January 2015–August 2018), and a post-ADD period (January 2024–December 2025). Our analyses compared periods and areas with and without ADD deployment regarding the following indicators of seal impacts on the local fishery.

2.2. Catches in relation to the use of ADDs

In this section, we compared fish catches from the Naantalinaukko bay and the surrounding waters during periods when ADDs were deployed in Naantalinaukko and when they were not. Across the coastal region, Archipelago Sea, commercial pikeperch unit catches have shown moderate interannual variation over the past two decades, with no clear long-term trend (Olin et al., 2023; Jakubavičiūtė et al., 2024). Similarly, absolute pikeperch catches in the region remained relatively stable throughout the study period (2015–2025), although with a slight decline around the time ADDs were operated in Naantalinaukko (Fig. 2).

The data for this section were collected as part of official fisheries surveys, conducted independently of the present study. The data were provided by the Natural Resources Institute Finland from Official Statistics of Finland (OSF) and consisted of monthly catches by commercial small-scale fishers from ICES statistical rectangles (Lehtonen et al., 2023b) 49H1, 49H2 and 50H1 (Olin et al., 2023). The Naantalinaukko bay study area is located at the intersection of these three rectangles. To ensure comparability between catches from Naantalinaukko and the surrounding waters, we restricted the analyses to fishers whose primary target species was the pikeperch, as determined by the typical composition of their monthly catches. In addition, we included only fishers who had reported gillnet catches both during the ADD deployment period (September 2018–December 2023) and during at least one of the two periods without ADDs (January 2015–August 2018 and January 2024–December 2025). This dataset included monthly catches by species to the nearest kilogram, accompanied by information on the number of nets and the number of fishing days. It covered the years 2015–2025 and included seven small-scale commercial fishers operating within Naantalinaukko and 52 fishers targeting pikeperch in the surrounding waters, yielding a total of 2619 monthly catch entries.

To complement the pikeperch catch assessment, we also analysed the same fishers' combined catches of three other common and commercially important species in the region: the northern pike, European perch, and European whitefish. Northern pike and European perch were present in the catches of nearly all fishers, and European whitefish catches were common.

Table 1
Outline of the use and configuration of ADDs in the Naantalinaukko bay.

Year	Details of the ADD setup and use
Before 2018	No ADDs were deployed prior to September 2018. In early September, one ADD (brand: Otaq Sealfence) was installed in each of the three narrow straits connecting Naantalinaukko to the surrounding waters (Fig. 1). Each device was attached to a floating platform. Water depth at these sites was 7–12.5 m, and the deterrent noise transmitter of the ADD was positioned at a depth of 3.5–7 m. The ADDs were removed at the end of December for the winter period.
2019	A fourth ADD, similarly mounted on a floating platform, was added to the setup, resulting in two ADDs being deployed in the widest strait. In April, all four ADDs were activated. Between mid-June and early September, the devices were serviced and their power systems upgraded. The ADDs remained operational throughout the winter season.
2020	In early June, all four ADDs were removed for servicing. At the beginning of September, the ADDs were reinstalled and reactivated. They remained operational throughout the winter season.
2021	In early June, the four ADDs were switched off for the summer break. In early September, the serviced devices were brought back, reinstalled and reactivated. One ADD was inoperative for seven days in mid-November due to a power issue. The ADDs were again removed in mid-December for the winter season in mid December.
2022	After winter, the four ADDs were reinstalled and reactivated between late March and early April. In mid-June, they were switched off for the summer break. In early August, two additional ADDs (Ace Aquatec US3) were installed on the seafloor in the widest strait (middle one, Fig. 1) and one addition ADD (Ace Aquatec US3) in the easternmost strait (Fig. 1), bringing the total number of activated devices to seven. In mid-December all ADDs were switched off for the winter season.
2023	The use of ADDs commenced in April, following the melting of sea ice. All four Otaq ADDs were switched off at the end of May, and the three Ace Aquatec ADDs were switched off in early June. In early September, two additional Ace Aquatec US3 ADDs were installed on the seafloor in the widest strait, bringing the total number of devices to nine. All nine ADDs were activated. In late December, four of the ADDs were switched off and removed.
2024 onward	The remaining five ADDs were switched off in early January 2024. No ADDs have been in use in the area since that time.

2.3. Gillnet damage, catch damage and seal sightings

Here, we used fishers' written records of gillnet damage, catch damage and seal sightings to compare the intensity of fisher–seal conflict during the period when ADDs were deployed in the straits leading to Naantalinaukko (September 2018–December 2023) and the period after it, i.e. without ADDs (January 2024–December 2025). Most commercial operators fishing in Naantalinaukko participated in the data collection. While seven fishers contributed data, one did so only during the post-ADD period, one only during the ADD use period and two operated most of the time jointly. Consequently, the analyses of this section were based on four independent fishers or fishing units (of a pair of fishers operating together). The participating fishers' fishing sites remained largely unchanged between years. Data collection began when the ADDs were first deployed in September 2018 (see Section 2.5 for details) and continued until the end of 2025. For each day of fishing, fishers reported whether they saw a seal, whether their gillnets had sustained new, presumably seal-induced, damage (typically large holes), and whether any fish in the nets showed evidence of seal-induced damage (Fig. 3). To support these records, fishers also photographed damaged fish and fishing gear.

2.4. Fisher perception of efficacy of the ADDs

In March 2025, we distributed a multiple-choice questionnaire to the seven collaborating fishers. It asked the fishers to subjectively compare gillnet damage, catch damage, fish catches and seal sightings between the following periods (1) before ADD deployment (pre September 2018) and the deployment period (September 2018–December 2023), (2) trends during the ADD deployment period, and (3) ADD deployment period and the subsequent fishing season after ADD deployment (January–December 2024). Consequently, the first section of the questionnaire included 4×3 multiple choice questions. In addition, the questionnaire included a multi-choice question about the fisher's opinions on the effects of ADDs (if any) on seal movements, and another one about the effects on fish movements. Finally, the questionnaire asked for any additional thoughts that the fisher might have about the use of ADDs in the area. We received 4–6 answers per question, with two of the fishers not having fished in the area over the entire study period (and were therefore not able to reply to some of the questions) and one fisher choosing not to answer any questions. We did not subject the questionnaire responses to formal statistical analysis. Instead, we compiled and presented the results graphically to provide additional context and information on the topic.

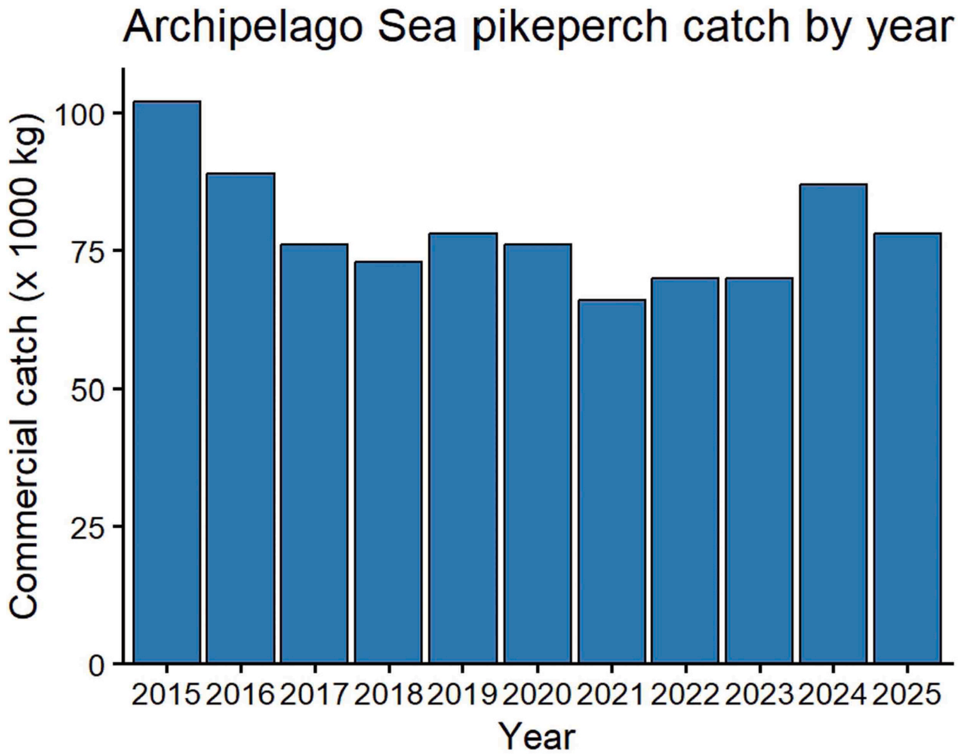

Fig. 2. Commercial pikeperch catches in the Finnish waters of the Archipelago Sea in the northern Baltic Sea in 2015–2025. Data source: Natural Resources Institute Finland, Statistics database, Commercial marine fishery.

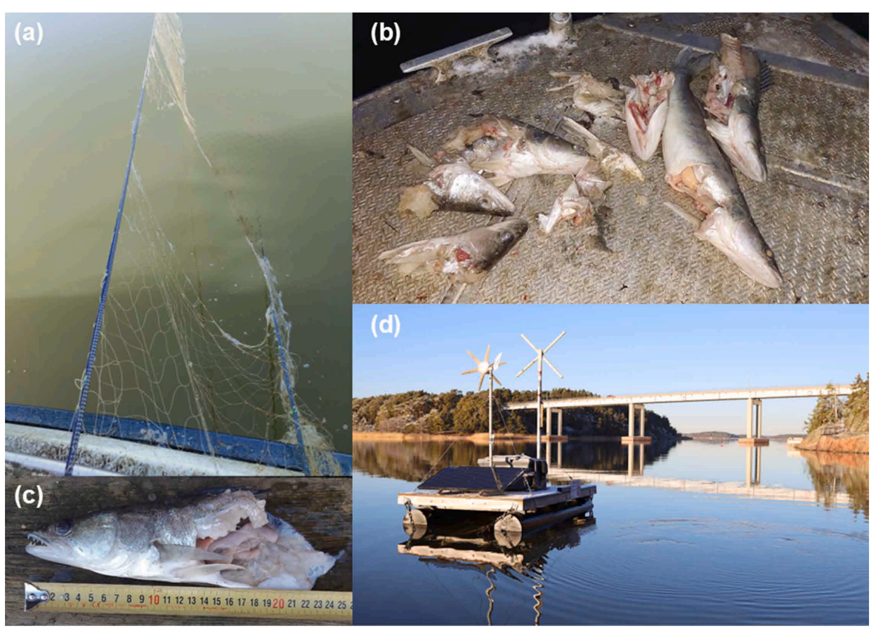

Fig. 3. (a) A gillnet damaged by a seal. (b, c) Seal-damaged pikeperch. (d) Floating platform for one of the ADDs at a strait connecting the Naantalinaukko bay to the surrounding waters. Photo credits: (a) Jan Kallonen, (b) Rauno Tähtinen, (c) Janne Aaltonen, (d) Esa Lehtonen.

2.5. ADD setup timeline

Due to the method-development nature of the project, the experimental setup was progressively refined over time, particularly to incorporate technical features and resources that became available during the study (Table 1). As part of this optimisation, we gradually increased the number of ADDs installed in the widest of the straits (width: ~150 m) that connect Naantalinaukko to surrounding waters (Fig. 1; Table 1). Additional considerations regarding ADD placement, including power supply arrangements, are described in detail by Lehtonen et al. (2023a) and Lehtonen and Suuronen (2025).

Generally, ADDs were switched off during the summer season (June–August), allowing for maintenance and system upgrades (Table 1). This period coincides with a local seasonal pause in commercial pikeperch fishing. The fishery in Naantalinaukko takes a summer break because catches often decline, potentially due to fish moving elsewhere beyond fishers' reach, and because fish caught in nets are more likely to die quickly during the warm-water period, posing practical and economic challenges for the fishery. Most seals are also assumed to move away from the bay during summer. Similarly, during mid-winters, when the bay was ice-covered, pikeperch fishing activity was low, and seals presumably left the area, allowing ADDs to be removed for winter maintenance in some years during the deployment (Table 1).

2.6. Statistical methods

We ran all analyses using the R 4.2.2 software.

To assess pikeperch catches in Naantalinaukko and its surrounding waters (within rectangles 49H1, 49H2 and 50H1), we fitted a generalized linear mixed model (hereafter GLMM) with a negative binomial distribution, as appropriate for our over-dispersed data consisting of integers (catches in full kilogrammes of fish). The response variable was the pikeperch catch each fisher had caught in each month, and we fitted the following explanatory variables: the ADD deployment period (ADDs in use: September 2018–December 2023 versus ADDs not in use: pre September 2018 and January2024–December2025), area with respect to ADDs (Naantalinaukko bay versus the surrounding waters), the interaction between period and area, the season (spring: March–May versus summer: June–August versus autumn: September–November versus winter: December–February), the number of days fished in that month, and the number of gillnets in use. The last two variables were added to account for the fishing effort. In addition, we accounted for variation related to the fishers and their fishing sites by adding fisher ID as a random effect. In this analysis, a significant interaction between ADD use period and area would indicate that changes associated with the ADD deployment period differed between the area where ADDs were used and where they were not. Thus, the interaction term was used to assess whether, and to what extent, the ADD deployment affected catches.

In separate binomial GLMMs, we assessed the three fisher-provided proxies of seal impact on the fishery: the proportion of days with seal-induced gillnet damage, seal-damaged fish in the catch and seal sightings within the bay. Regarding the proportion of sea-induced gillnet damage, we first formed a compound response variable (using the 'cbind' command in R) by binding the number of days each month when at least one new seal-induced damage (Fig. 3) appeared in the fisher's nets with the number of days that month when no seal-induced gillnet damage was observed. Hence, the model assessed the proportion of days with gillnet damage while retaining the information about the absolute numbers of observation days. We fitted the ADD deployment period (during ADDs: September 2018–December 2023 versus after ADDs: January 2024–December 2025) and the season (spring versus autumn versus winter) as explanatory variables. In addition, we denoted fisher ID as a random effect (to account for variation due to the observers and their fishing sites). Regarding the other two similar models assessing the occurrence of fisher-reported seal-damaged catch (Fig. 3) and seal sightings, we formed the response variables the same fashion as with gillnet damage, above, and used the same explanatory variables and the random effect.

3. Results

3.1. Catches in relation to the use of ADDs

Regarding pikeperch catches (standardised for the effort), there was no significant interaction between ADD use period and ADD area (Fig. 4; Table 2), indicating that we did not detect a significant effect of ADD use on the catch. Pikeperch catches tended to be higher in the Naantalinaukko bay than in the surrounding waters (Fig. 4; Table 2). In the

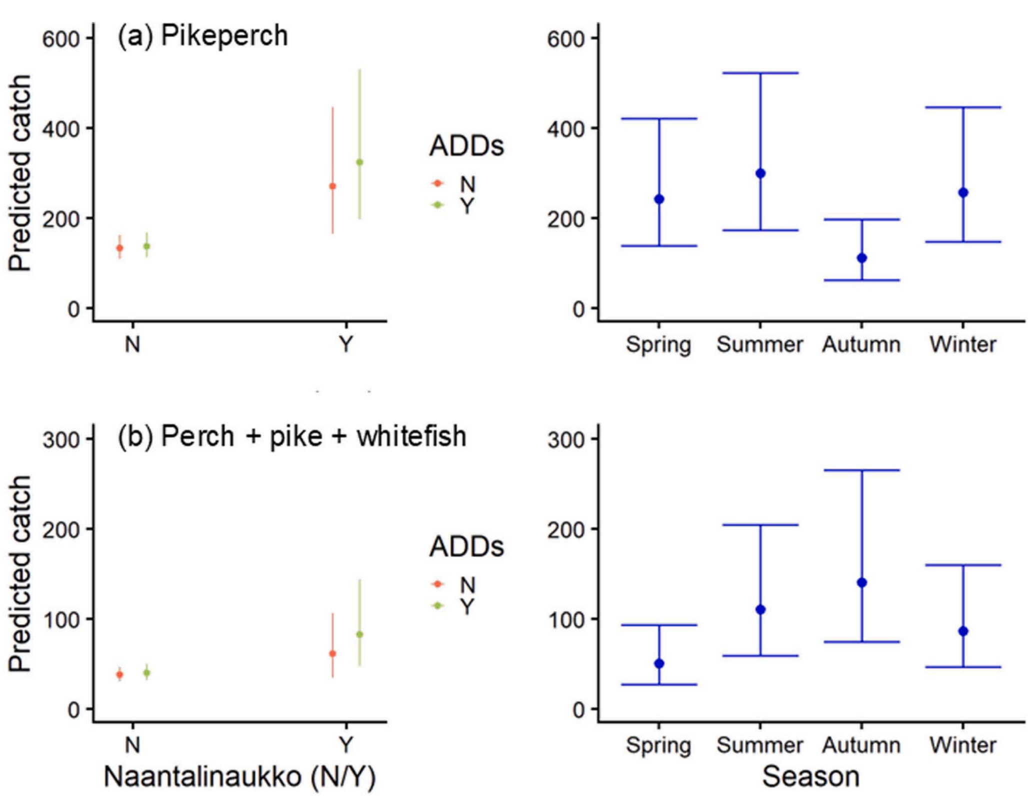

Fig. 4. The modelled interactive effect between the experimental period (ADDs in Naantalinaukko: September 2018–December 2023 versus no ADDs anywhere: January2024–December 2015) and the area of ADD use (the ADD deployment area of Naantalinaukko versus surrounding waters), and the modelled effect of season on (a) monthly pikeperch catch (standardised for catching effort) and (b) monthly combined gillnet catch of three other commercially important species in the area. The whiskers indicate 95% confidence intervals.

Table 2
The results of the GLMMs that assessed the effects of the ADD use area (Naantalinaukko bay versus surrounding waters), the ADD use period (ADDs: September 2018–December 2023 versus no ADDs: January 2015–August 2018 & January 2024–December 2025), the interaction between the two effects (as indicative of area-specific effects of ADD use period), and the season on the catches of the pikeperch and three other important target fish species.

Effect	Pikeperch catch			Pike, perch & whitefish		
	β±SE	*Z*	*P*	*β±SE*	*Z*	*P*
ADD area	0.7113 ± 0.2831	2.639	0.0083	0.4810 ± 0.2023	1.591	0.11
ADD period	0.0321 ± 0.0406	0.791	0.43	0.0592 ± 0.0420	1.409	0.16
ADD area × ADD period	0.1464 ± 0.0941	1.555	0.12	0.2452 ± 0.0967	2.535	0.011
Spring vs. summer	0.2170 ± 0.0482	4.50	< 0.0001	0.7827 ± 0.0495	15.82	< 0.0001
Spring vs. autumn	-0.7763 ± 0.0900	-8.626	< 0.0001	1.025 ± 0.089	11.51	< 0.0001
Spring vs. winter	0.0617 ± 0.0491	1.256	0.21	0.5382 ± 0.0511	10.52	< 0.0001
Summer vs. autumn	-0.9933 ± 0.0876	-11.33	< 0.0001	0.2424 ± 0.0870	2.786	0.0053
Summer vs. winter	-0.1552 ± 0.0462	-3.358	0.0008	-0.2445 ± 0.0471	-5.195	< 0.0001
Autumn vs. winter	0.8380 ± 0.0881	9.512	< 0.0001	-0.4870 ± 0.0849	-5.738	< 0.0001
Days of fishing	0.0506 ± 0.0024	20.88	< 0.0001	0.0476 ± 0.0025	19.24	< 0.0001
Number of nets	0.0163 ± 0.0010	16.19	< 0.0001	0.0109 ± 0.0010	11.03	< 0.0001

region overall, the catches were the highest during the summer season and lowest during autumn.

The combined secondary target catches of northern pike, European perch and European whitefish revealed a significant interaction between

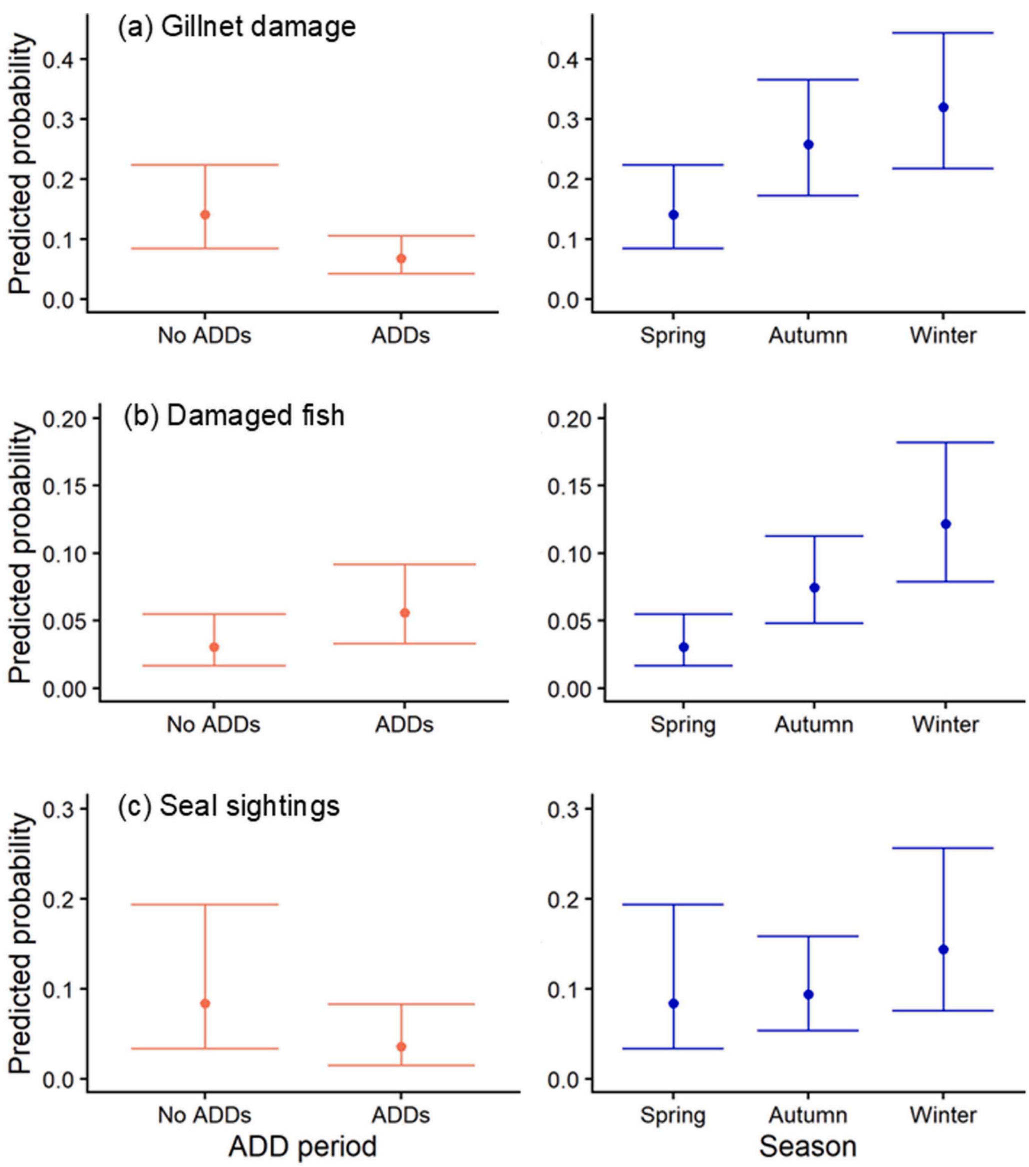

Fig. 5. The modelled effects of the experimental period (ADDs: September 2018–December 2023 versus no ADDs: January 2024–December 2015) and season on the proportion of fisher-reported (a) gear damage presumably caused by seals, (b) damaged catch and (c) seal sightings in the ADD deployment area (Naantalinaukko, southwestern coast of Finland). Note that the pikeperch fishers in Naantalinaukko took fishing breaks from the onset of winter conditions until mid-spring and again for the summer period, resulting in the lack of summer month observations. The whiskers indicate 95% confidence intervals.

ADD use period and ADD area (Table 2), indicating that these catches significantly deviated from the predicted (were higher) in Naantalinaukko when ADDs were in use (Fig. 4). Effort-standardised catches of these species in the region were highest in autumn and lowest in spring (Fig. 4; Table 2).

3.2. Gillnet damage, catch damage and seal sightings

The fishers reported seal-induced damages in their nets markedly more frequently without ADDs (in 2024 and 2025) than during the period of ADD deployment (September 2018–December2023) (Fig. 5; Table 3). In addition, the frequency of seal-induced net damage increased from spring towards winter (Fig. 5; Table 3). In contrast, the fishers reported less catch damage after the ADD deployment period (2024 and 2025) than during it (Fig. 5; Table 3), with an increasing trend from spring to winter (Fig. 5; Table 3). Finally, seal sightings were more frequent after the ADD deployment period than during it (Fig. 5; Table 3), with no significant seasonal trend in the sightings (Fig. 5; Table 3).

3.3. Fisher perception of efficacy of the ADDs

Most fishers perceived that, in relation to seals, the prerequisites for fishing were better during the period with ADDs (September 2018–December2023) than before ADDs (Fig. 6). Similarly, most fishers perceived that, during the time ADDs were used, prerequisites for fishing improved over time (Fig. 6). Finally, a majority of them also perceived that fishing conditions were better during the ADD deployment period than after it (Fig. 6). The positive effect was perceived to be the clearest in relation to gillnet damage (Fig. 6). Overall, however, fishers' perceptions were variable, with a minority of them perceiving no differences between the periods or even their catches to be higher after the ADD deployment period than during it (Fig. 6).

4. Discussion

The results suggest that seals damaged the gillnets of small-scale commercial fishers less frequently when ADDs were deployed in Naantalinaukko (September 2018–December2023) than when the devices were no longer operational (2024–2025). In addition, the combined catches of the three important secondary catch species were relatively higher within the bay than in surrounding waters during the ADD use period. In contrast, we did not detect a corresponding effect for pikeperch catches, which were high within the bay throughout the study, including the periods when ADDs were not in use. Taken together, these findings suggest that using ADDs can have demonstrable, but relatively limited, success in decreasing seal-induced losses to a commercial fishery within a larger area, such as the Naantalinaukko bay (Fig. 1).

The magnitude, and even direction, of the observed effects varied among response variables, suggesting that the effectiveness of this approach is context-dependent. While the daily probabilities of seal sightings and gear damage within the bay were lower during the ADD deployment period, both continued to occur at notable rates even when ADDs were in operation, indicating that seals regularly entered the area throughout the study period. Moreover, the rate of reporting seal-damaged catch was significantly higher during the ADD deployment period than after it. It is important to note, however, that the catch damage was not directly matched with the size of the catch, and the absolute numbers of damaged fish remained relatively low throughout the study period, possibly due to seals not always leaving visible evidence from eating fish from the nets (Königson et al., 2007; Königson et al., 2009).

Multiple factors may explain the limited and context-dependent effectiveness of the ADD deployment in reducing seal-induced losses to the small-scale commercial fishery within the bay. First, the deterrent effect of the ADDs may simply have been insufficient. Previous studies (Lehtonen et al., 2022, 2023a; Veneranta et al., 2024) and fishers' experiences indicate that the specific device models used in the present study can effectively deter seals at a short range. However, their effective range may not have been sufficient in the Naantalinaukko setting. Even in a spatially confined river environment, some seals were able to bypass a line of ADDs deployed across the river, resulting in only a partial protection of catches and fishing gear in upstream areas (Veneranta et al., 2024). Physical characteristics of the environment, such as bottom topography and water depth, are also likely to influence deterrent sound propagation and may create areas where the deterrent effect is reduced to the extent that seals can enter the area (Lehtonen and Suuronen, 2025). Seals that managed to enter the bay may also have been less likely to leave it due to the ADDs, if the devices succeeded in restricting their movement through the straits connecting bay to the surrounding waters. In addition, the ADDs were not operating during the maintenance periods in summer and mid-winter, when commercial fishing activity was minimal or absent. However, although seals could enter the bay during such periods, fishers' observations suggest that they are unlikely to remain in the bay at these times, despite relatively high seal activity preceding the winter break, as shown by the present results. The periods without deterrent noise could have the benefit of reducing the likelihood of seals habituating to the sound or learning to exploit areas with weaker deterrent noise coverage (Lehtonen and Suuronen, 2025). Finally, it should be noted that local hunters removed some seals from the area during both the ADD deployment and non-deployment periods, which may have locally influenced seals' activity and the observed levels of fishery damage. We had no control over these hunting activities and have no reason to believe that they were associated with ADD use.

Another factor that complicates the application and assessment of different ADD configurations is spatial and temporal environmental variation (Lehtonen and Suuronen, 2025). Local characteristics, together with seasonal cycles and more irregular fluctuations in weather and temperature, can influence the behaviour and spatial distribution of both fish and seals, as well as fishing conditions, independent of the use of ADDs. For example, while our data indicate that pikeperch catch rates in the region are highest during the summer months, fishers in Naantalinaukko typically suspend gillnet fishing during this period because high water temperatures cause fish to die quickly in the nets, increasing both catch losses and workload. Seal behaviour also varies spatially and seasonally, for instance regarding their selection of foraging areas at both regional and local scales. Consequently, fishers operating within the bay reported highly variable experiences regarding seal interactions. We accounted for some of this variation by conducting a multiyear study

Table 3
The results of the three GLMMs that assessed the time period (with ADDs: September 2018–December 2023 versus without ADDs: January 2024–December 2025) and seasonal differences in fisher-reported proxies of seal impact on the fishery in the study area (Naantalinaukko, southwestern coast of Finland).

Effect	Gillnet damage			Catch damage			Seal sightings		
	$\beta \pm SE$	Z	P	$\beta \pm SE$	Z	P	$\beta \pm SE$	Z	P
ADD period	-0.8184 ± 0.1410	-5.803	< 0.0001	0.6228 ± 0.1835	3.394	0.0011	-0.9001 ± 0.2895	-3.109	0.0019
Spring vs. autumn	0.7538 ± 0.1531	4.925	< 0.0001	0.9303 ± 0.2229	4.173	< 0.0001	0.1183 ± 0.4052	0.292	0.77
Spring vs. winter	1.056 ± 0.1858	5.683	< 0.0001	1.474 ± 0.245	6.016	< 0.0001	0.6047 ± 0.4439	1.362	0.17
Autumn vs. winter	0.3022 ± 0.1504	2.009	0.045	0.5436 ± 0.1633	3.329	0.0009	0.4865 ± 0.3206	1.517	0.13

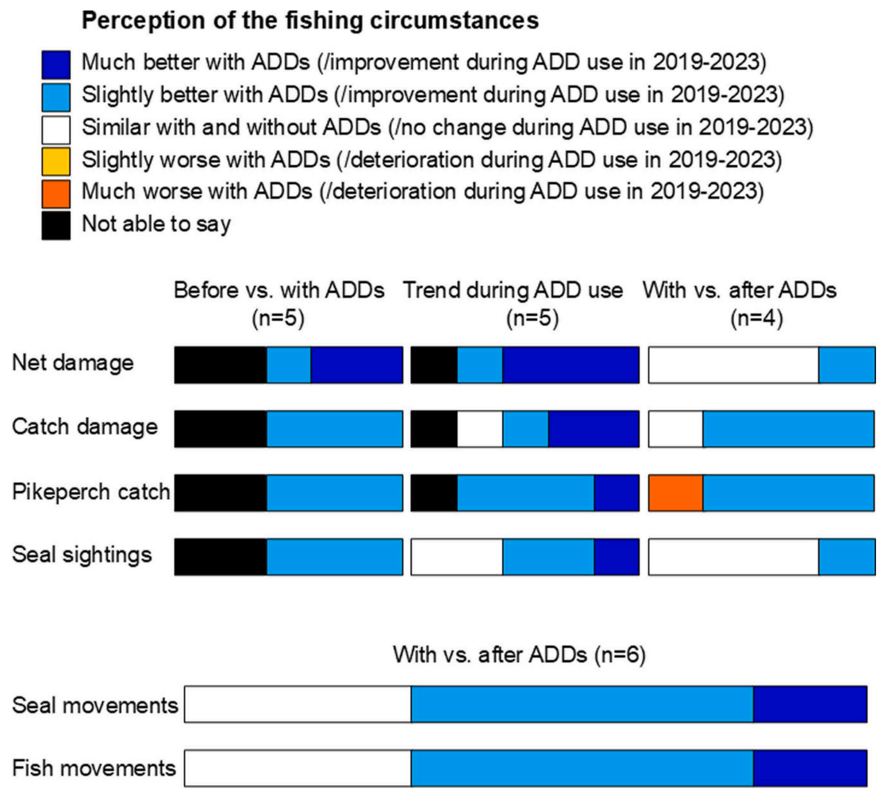

Fig. 6. The results of a questionnaire to fishers. Lower levels of net damage, catch damage and seal sightings, as well as higher pikeperch catches were defined to be better for the fisher. The numbers of answers are given in the parenthesis.

and by including fisher identity as a random effect in the statistical analyses. Nevertheless, the post-ADD period (2024–2025), may have been atypical in terms of climatic conditions. Fishers reported unusually warm autumn water temperatures during both years, and the seasonal movements of fish and seals into the bay appeared to occur later than what they have typically observed.

The ADD configuration also changed over time as part of the project's adaptive, method-development approach. Consequently, the estimated ADD treatment effect represents an average across multiple deployment configurations that may have differed in their deterrence effectiveness. For example, the seafloor-mounted ADDs used in the widest strait during 2022–2023 may have produced different deterrence effects than the ADDs attached to floating platforms. The total number of active ADDs was also greater in 2022–2023 than during previous years. Further research is needed to determine how deployment characteristics, such as device placement, mounting method, and the number of units used, affect the efficacy of ADDs under different environmental conditions (Lehtonen and Suuronen, 2025).

From an economic perspective, ADDs remain a relatively costly management tool. Although their expected lifespan is approximately ten years, their purchase, installation, operation, and maintenance require substantial financial and time investments. In our analyses, the increase in pikeperch catches within the bay during the ADD deployment period (as indicated by the ADD area × ADD use period interaction) was not statistically significant, while, based on both fisher reports and questionnaire responses, the most notable benefit of ADD deployment was a reduction in gear damage. The rate of seal-induced gillnet damage, primarily new holes in the nets, was approximately twice as high after the ADD deployment period than during it. Moreover, the catch of secondary target species was modestly higher during the ADD deployment in an analysis that accounted for the catch trends in the surrounding waters. However, for such benefits to outweigh in economical terms the purchase and maintenance costs of multiple ADD units, fishing activity within the ADD-protected area would need to be substantially greater than that currently occurring in Naantalinaukko. Moreover, given their generally low profit margins, individual small-scale fishers may be unable to investment in ADDs, even if their use would generate an economic net return.

A detailed cost–benefit analysis is beyond the scope of the present study, partly because several costs and benefits associated with ADD deployment are difficult to quantify. For example, although device operation and maintenance require a substantial time investment, reduced gear damage may offset time costs by decreasing the need for net repair and replacement. Long-term assessments are further complicated by the possibility that ADD efficacy may decline when devices are used over multiple years at the same location (Lehtonen and Suuronen, 2025). In addition to material factors, several fishers reported a subjective sense of relief from seal interactions while ADDs were in use. Overall, local fishers' perceptions of ADDs were variable but predominantly positive, with most participants deeming that ADDs reduced the negative effects of seals on their fishing activities. Their views were consistent with previous assessments indicating that commercial and recreational fishers commonly support the use of ADDs when their deployment does not interfere with fishing activities (Suuronen et al., 2025). Indeed, any reduction of seal activity within ADD-protected areas could also benefit recreational fishers, but potentially at the expense of opportunities for recreational seal observation. It is also worth noting that the bay is an important spawning and nursery area for pikeperch (Veneranta et al., 2011; Kallasvuo et al., 2017; HELCOM, 2021), yet little is known about the potential effects of seal predation or disturbance on pikeperch reproductive success. Conversely, the potential impacts of ADDs on non-target species are of concern, particularly in waters where cetaceans occur (Mikkelsen et al., 2017; Findlay et al., 2021, 2024; Lehtonen and Suuronen, 2025). Although cetaceans do not occur in Naantalinaukko, these examples illustrate the complexity of factors that may need to be considered from multiple perspectives when assessing the feasibility of ADD deployment, while also highlighting priorities for future research.

In conclusion, the results of the present study suggest that, although ADDs may reduce seal-induced damage to fishing gear and modestly improve catches when used to create seal-restricted coastal areas, the overall effectiveness of this approach remains context-dependent and limited. Achieving a more notable exclusion of seals from a coastal area may require a large number of ADDs, indicating that these devices may be better suited for smaller-scale applications, such as protecting individual fishing gears or aquaculture pens. In the Naantalinaukko bay, modelled gillnet damage was clearly lower during the ADD deployment period than after it (Fig. 4), and seal sightings also tended to increase once ADD use ended. Nevertheless, none of the ADD configurations tested in this study (Table 1) completely prevented seals from entering the area. Fishers continued to report relatively frequent gear damage and seal sightings throughout the study period. Furthermore, fish catch trends within the bay generally mirrored those observed in surrounding areas where ADDs were not used. In this respect, while catches of secondary target species within the bay responded significantly to the ADD deployment period, catches of the primary target species, pikeperch, did not. Many previous studies evaluating ADDs for the protection of individual fishing gears or aquaculture pens have reported more evident positive outcomes (Harris et al., 2014; Vetemaa et al., 2021; Lehtonen et al., 2022; Veneranta et al., 2024; Lehtonen and Suuronen, 2025), while some other ADD applications had a poor efficiency or their efficiency was found to decrease over time (Jacobs and Terhune, 2002; Sepúlveda and Oliva, 2005; Nelson et al., 2006; Lehtonen and Suuronen, 2025). These factors highlight the importance of carefully considering ADD use on a case-by-case basis and across different deployment configurations. Such assessments would benefit from further research into the ecological, social, ethical and economic factors that determine the success or failure of ADDs in mitigating conflicts between fishers and seals.

CRediT authorship contribution statement

Topi K. Lehtonen: Writing – review & editing, Writing – original draft, Visualization, Project administration, Formal analysis, Data curation. **Esa Lehtonen:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization. **Roope Lehmonen:** Writing – review & editing, Investigation, Data curation.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Esa Lehtonen reports financial support by European Maritime and Fisheries Fund. The following companies, including seal deterrent manufacturers, provided collaborative, non-financial support during the study (primarily to E.L.): TR Marine Diving and Marine Service Ltd, the Water and Marine Group Ltd, JS Merityö Ltd, Powerduo Ltd, Arwell-Tekniikka Ltd, Scandi Net Ltd, Mapon Finland Ltd, JMPAJALA Ltd and Ace Aquatec Ltd. Other authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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