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Acoustic seal deterrents in mitigation of human–wildlife conflicts in the whitefish fishery of the River Iijoki in the northern Baltic Sea area

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Abstract

Recovery of many seal populations has intensified seal-fishery conflicts. Acoustic deterrent devices (ADDs), designed to deter seals while minimising collateral harm, provide a potential solution. We investigated feasibility of ADDs to protect a European whitefish (*Coregonus lavaretus*) fishery in the River Iijoki, Finland, which enters the Baltic Sea. A sound barrier produced by a line of ADDs across the river efficiently prevented grey (*Halichoerus grypus*) and ringed (*Pusa hispida*) seals from passing the barrier line, thereby increasing catches, decreasing damage to fishing gear and catch and resulting in fewer seal sightings in the area safeguarded by ADDs. Hence, blocking access of seals to a river or its section by ADDs during a critical fishing period is a promising method for reducing seal-induced catch losses. However, long-term assessments of impacts of ADDs are still needed to verify the overall effectiveness.

KEYWORDS
depredation, deterrent, ethics, management, pinniped, riverine, salmonid

1 | INTRODUCTION

Thriving marine mammal populations are considered a valuable element of healthy ecosystems. Following successful conservation and management, marine mammal, especially seal, populations have recovered quickly in many regions of the world (Lotze et al., 2011; Magera et al., 2013), including the northern Atlantic and the Baltic Sea. Similarly, many fish populations around the globe have been heavily exploited, presumably affecting marine mammal prey density (Hansson et al., 2018; Palomares et al., 2020). Consequently, marine mammals increasingly forage on fishes of commercial interest that are detained by fishing gears, fish ladders and aquaculture pens (Hansson et al., 2018; Schakner & Blumstein, 2013; Tixier et al., 2021). Marine mammal predation has led to a wide-range of intensifying human–wildlife conflicts, the mitigation of which is a major societal and environmental challenge (Morissette et al., 2012; Read, 2008; Waldo et al., 2020). The conflict affects aquaculture, commercial, artisanal and recreational fisheries (Tixier et al., 2021). Socio-economic impacts include catch loss and damage, damage to gear and indirect costs (Kauppinen et al., 2005; Tixier et al., 2021; Vetemaa et al., 2021). In some regions, fishers perceive growing seal populations as a threat to their income and viability of their profession (Arias Schreiber & Gillette, 2021; Blomquist & Waldo, 2021; Suuronen et al., 2023; Waldo et al., 2020).

Hunting seals to mitigate conflicts is commonly considered unfeasible for conservation, ethical, or practical reasons (Jackman et al., 2018; Morissette et al., 2012). Other conflict management efforts include physical barriers, seal-proof gear and chemical, acoustic, visual and tactile deterrents (Schakner & Blumstein, 2013; Tixier et al., 2021). Of these, acoustic deterrent devices (ADDs), sometimes also called acoustic harassment devices, have been used in close proximity to aquaculture pens and fishing gear (Götz & Janik, 2013; Lehtonen et al., 2022; Schakner & Blumstein, 2013). ADDs are designed to create sounds that are painful or distracting enough to deter seals, or other target animals, near the device (Schakner & Blumstein, 2013). ADDs can also be used to deter animals for their own protection, including reduction of by-catch and impacts of offshore pile-driving (Hamilton & Baker, 2019; Voß et al., 2023). ADDs have been considered as a benign way of deterring marine mammals (Götz & Janik, 2013). Most fishes detect sounds no higher than 500 Hz, with a small number of species hearing thresholds of 4000 Hz (Ladich & Fay, 2013; Mann et al., 2007; Popper & Hawkins, 2019), while most ADDs operate at much higher frequencies. Nevertheless, use of ADDs has remained controversial because of the potential to cause pain and damage hearing organs of target and non-target mammals (Findlay et al., 2021; Schaffeld et al., 2020; Todd et al., 2021). Reduced hearing of individuals of target species could compromise effectiveness of devices (Findlay et al., 2022; Götz & Janik, 2013).

Research has generally resulted in mixed evidence of the effectiveness of ADDs, with both high and low long-term deterrence efficiency (Götz & Janik, 2013; Quick et al., 2004). Mixed evidence suggests that ADDs of different manufacturers may differ in performance, and that devices tend to function well only in clearly defined physical settings (Götz & Janik, 2013; Lehtonen et al., 2022). However, ADDs have rarely been used in rivers, despite a high likelihood of human–wildlife conflicts due to confined spatial dimensions and importance of riverine fisheries in many parts of the world (Allan et al., 2005; Graham et al., 2009; Welcomme et al., 2010). Moreover, the scope for negative ecological impacts is limited in rivers, due to a general absence of noise-sensitive non-target species, such as porpoises, even when seals are present.

Recently, seal-fishery conflicts expanded into some rivers that enter the Baltic Sea, including the River Iijoki, Finland, where seals are causing increasing difficulties for a fishery for anadromous European whitefish (*Coregonus lavaretus*). Therefore, we investigated the efficacy of ADDs in the River Iijoki, to determine whether ADDs would prevent grey seals (*Halichoerus grypus*) and ringed seals (*Pusa hispida*) from entering the section of the river where the whitefish fishery operated during the autumn spawning season. We compared catches, gear damage, catch damage and seal sightings inside and outside of the river section where ADDs were deployed, to complement earlier findings that suggested ADDs could be used to restrict seal movements (Graham et al., 2009) and decrease mortality of free-ranging young salmonids (Yurk & Trites, 2000) in river environments.

2 | METHODS

2.1 | Focal species

Under natural conditions, larvae of anadromous European whitefish (whitefish) end up in the sea within weeks after hatching in a river (Lehtonen et al., 1992). After the sea phase, sometimes foraging hundreds of kilometres from their natal river, they mature and return to spawn, usually in the same river, 4–5 years later (at the length of ≥35 cm) (Veneranta et al., 2021). In most rivers running into the northern Baltic Sea, the upstream spawning migration is blocked or shortened by hydroelectric dams, which has decimated natural reproduction. Therefore, the whitefish lifecycle is supported by stocking (e.g. Jokikokko et al., 2018; Jokikokko & Huhmarniemi, 2014), based on river-specific catches of parental fish (e.g. from the river Iijoki fishery). Eggs are reared in hatcheries and larvae are stocked back into the river the next spring. Therefore, successful catches of brood fish from rivers are necessary for maintaining the life cycle under current conditions.

Grey and ringed seals feed on fish, including salmonids, such as whitefish (Lundström et al., 2007; Tverin et al., 2019). Following bans on multiple harmful chemicals and successful conservation and management measures, seal populations in the Baltic Sea have recovered quickly for decades (Harding & Härkönen, 1999; Kauhala et al., 2019), more than doubling over the past 20 years (Suuronen et al., 2023). Increasing seal abundance has intensified conflicts with fisheries (Suuronen et al., 2023).

2.2 | River Iijoki and whitefish fishery

The main channel of River Iijoki (Finland, 65°19′N, 25°20′E) is ~370 km long with a catchment area of >14,000 km^2 (Saarinen et al., 2010). However, the lowest hydroelectric dam that blocks upward migrations of anadromous fish is located only 7 km upstream of the estuary. Large numbers grey and ringed seals in that section of the river have been sighted in late summer and autumn since 2017. Seals have presumably been attracted by anadromous salmonids, sea trout (*Salmo trutta*), Atlantic salmon (*Salmo salar*), whitefish and the fishery for whitefish. Whitefish are caught by gillnets (bar mesh size = 45–50 mm) with rigid fencing leads. Whitefish are used for human consumption and eggs to support subsequent stocking.

Fish caught in gillnets are easy targets for seals. Until 2017, 400–600 L of whitefish roe was collected each season, whereas between 2017 and 2021, roe harvest ranged 100–300 L after the marked increase of seal sightings in the river (Figure 1). During the same period, fishing effort to gather roe was much higher than earlier (oral communication with Risto Tolonen, local fisheries association, 2022, based on roe hatchery records). Local fishers believe that the river fishery has been harmed by seals.

2.3 | The ADD setup

ADDs were deployed to establish an acoustic barrier deterrent line that would prevent upstream movement of seals. If seals were successfully excluded from the area upstream from the ADDs, we expected seal-induced damage to the whitefish fishery to be significantly reduced. ADDs were deployed in a narrow section of the river, ~3 km upstream from the estuary (Figures 2 and 3). This location was

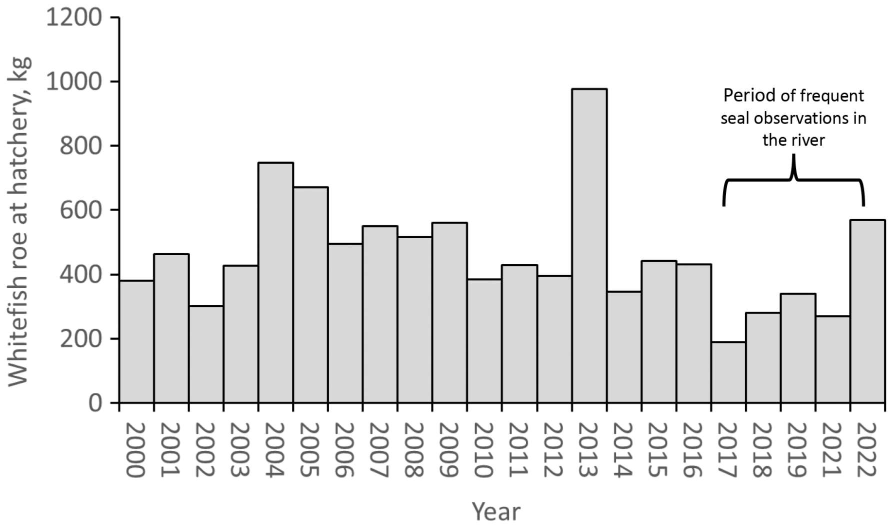

FIGURE 1 The total weight of roe collected from European whitefish (*Coregonus lavaretus*) caught in the River Iijoki and delivered to a hatchery during 2000–2022. Seals were sighted mostly only in the estuary before 2017, but were more frequently sighted in the entire river up to the lowest dam thereafter. ADDs were deployed in 2022. (Based on the data by Risto Tolonen, local fisheries association).

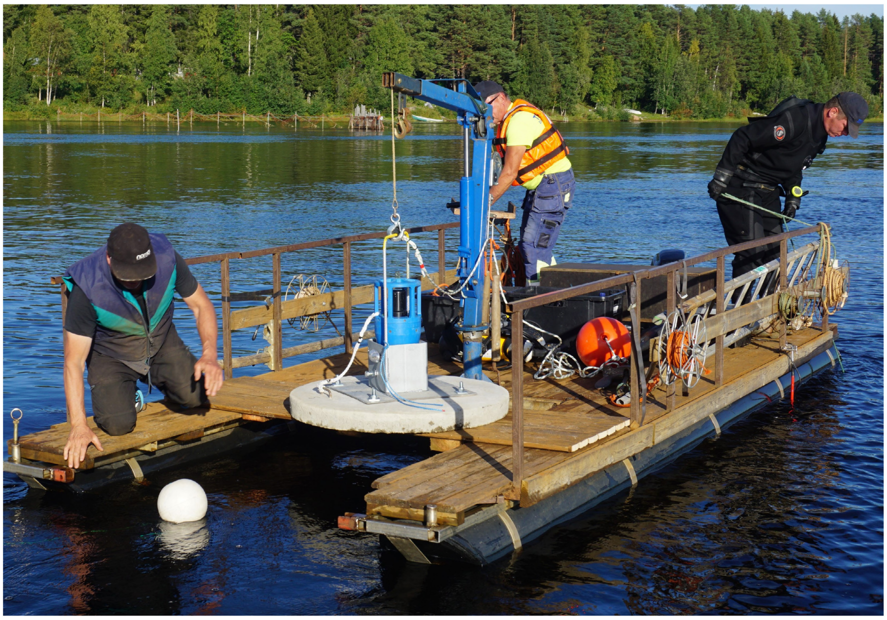

FIGURE 2 Deployment of an ADD (Model ASR-US3), attached to a concrete weight, in the River Iijoki, Finland 26th August 2022.

selected based on the river-depth profile and availability of electricity to power the devices through electric cables on the riverbed from on shore.

Six ADDs were installed in a line across the river, including five in the ~200-m-wide main channel and one in a narrower ~50-m-wide side channel, with ~35 m between devices (Figure 3). Devices were installed on the riverbed, to allow boat traffic in the area while reducing the potential for damage by floating objects, such as logs. The study was initiated by switching devices on at the end of August in 2022 and data were collected until late October, for 66 days in total (41–66 per station). Five collaborating, economically compensated, local fishers kept logbooks while operating at their own fishing stations. Two stations were on the estuary side, one was in the immediate vicinity, and two were upstream of the deterrent line (Figure 3). Fishers used gillnets of varying heights (3–5 m) and lengths (12–30 m), depending on water depth at their station. Gillnet length and fishing effort (840–1551 h per station) variation were accounted for in statistical analysis. Fishing effort included 769 net deployments, each lasting 8.1 h on average. Each fisher recorded the date and duration of fishing effort, the number of whitefish caught, if any fish were damaged by seals, and if any gear was damaged. Badly damaged gillnets were replaced. Fishers also reported seal sightings. Seals were not always identified to species (grey or ringed seal), with all seals being lumped together for analysis as a seal. After initiating the study, one grey seal was observed 3 km upstream of the deterrent line, which might explain some subsequent seal damage in that section. However, after 2 weeks, fishers no longer observed the animal.

The six ADDs used in the study were the AceAquatec US3 (ASR-US3) model. This deterrent device emitted short, randomised sound pulses, which the manufacturer claimed to decrease the scope for habituation or hearing injury by seals. Therefore, these devices were technically different from many other ADDs that emit monotonic sound pulses. The ASR-US3 was designed to create a

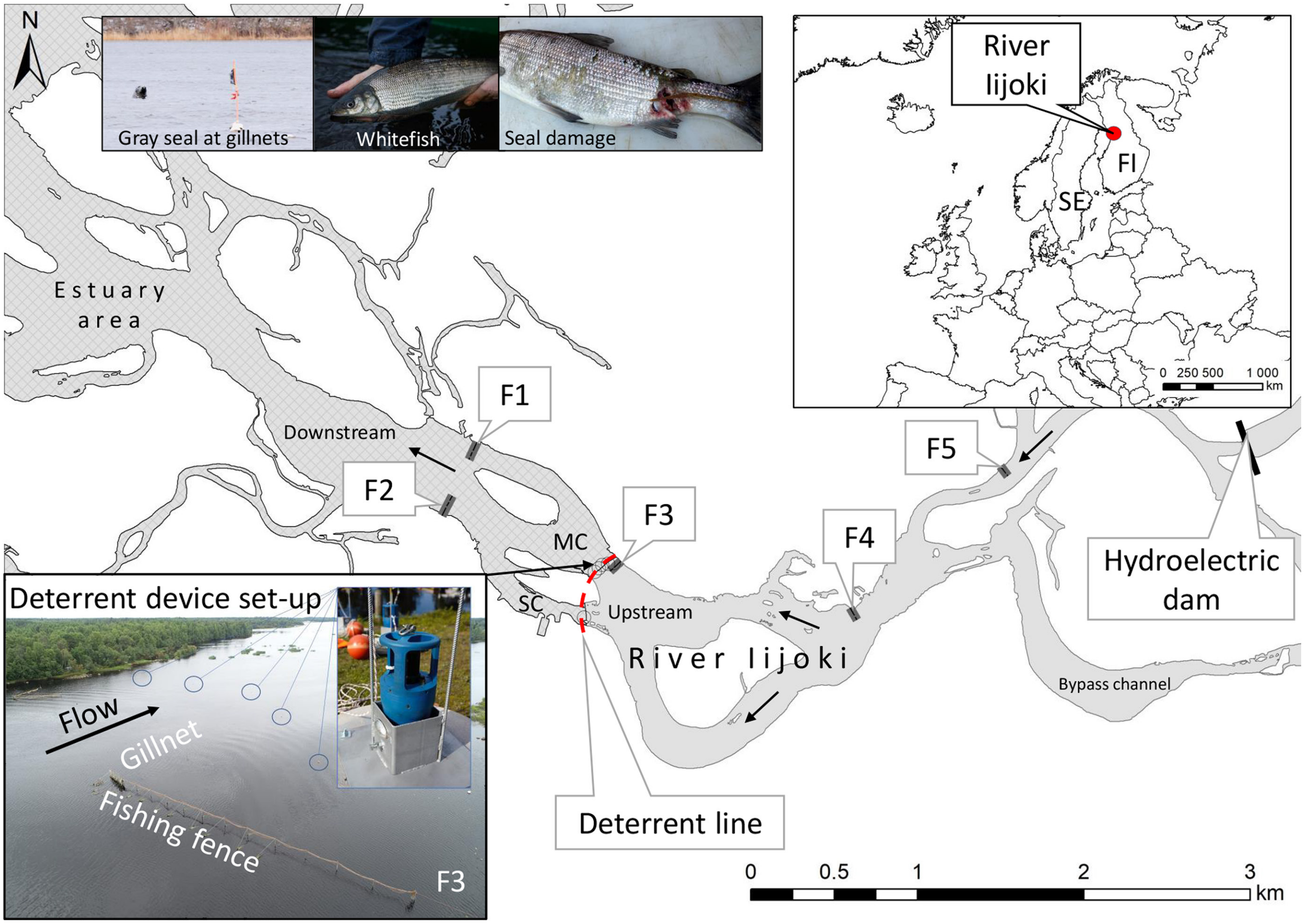

FIGURE 3 Locations of an ADDs line and five fishing stations (F1–F5) in the River Iijoki, Finland, from late August to late October, 2022. The river mouth is at the upper left, ~3 km downstream from the ADD line. Main (MC) and side (SD) channels of the river are marked. The first hydroelectric dam that blocks upstream movement of seals and fish is marked. Whitefish cannot access the bypass channel due to low flow and a submerged dam.

startle response. The five devices in the main channel resulted in overall sound output that varied unpredictably, with at least one of the ADDs emitting a sound pulse most of the time, whereas sounds were more intermittent from the single device in the side channel. An information sheet by the manufacturer suggested an operational range of 50 m, nominal sound emission frequency of 8–11 kHz, sound pressure of 181 dB re 1 μPa at 1 m, and randomised sound pulses emitted during 0.9%–10% of total operation time. Transmission frequency of sound pulses (scram rate) were set to a maximum value of 108 pulses per hour. Devices were connected to the Internet, and their operation was monitored through a separate web-application.

To investigate the range of ADD sound in the river, an external contractor (JM Pajala Oy) measured sound intensity at 26 points at varying distances from the ADDs in late September 2022. Two Ocean Instruments SoundTrap 300 digital sound recorders were used at two different frequency ranges, SPL 1/3 OB 20 kHz and SPL 5–50 kHz. The former was the optimal hearing range of grey and ringed seals. Hydrophone sensitivity was 176 dB re 1 μPa at a recording rate of 96 kHz. During measurements, air temperature was 8–10°C, water temperature was 7.3°C, water depth was 1.2–4.0 m and the river flow rate was 38–264 m^3/s. To assess effects of flow rate variation, ADDs' sounds were monitored continuously during 1 day, when flow rate varied greatly, at 47 m downstream from main channel ADDs. Results of this check indicated that variation in flow rate did not noticeably affect sound intensity.

2.4 | Statistical analyses

R 4.2.2 software (https://www.r-project.org/) was used for statistical analyses. To estimate weakening of ADD sounds with distance, a linear model (or 'regression'; the lm function in R) was fitted for frequency-specific sound intensity (SPL 1/3 OB 20 kHz) in relation to distance. To assess the effectiveness of ADDs for deterring seals, four generalised linear mixed models (GLMMs) were fitted using the GLMMTMB function. The fishing station near the deterrent line yielded very similar results to two upstream stations (Figure 3), these three stations were combined into a single group as the area safeguarded by ADDs.

Whitefish catches on both sides, downstream and upstream, of the deterrent line were compared in a GLMM with a negative binomial distribution (appropriate for over-dispersed count data). The response variable was the number of whitefish each fisher caught each day. Explanatory variables were the section of river in relation to the deterrent line (upstream or downstream of the ADD, or safeguarded versus not guarded), duration of fishing effort each day (hours) and gillnet length (metres). Variation related to each fishing station and catch date were fitted as random effects.

To evaluate the likelihood of gillnet damage, presumably caused by seals, a GLMM was fitted with a binomial distribution with a binary response variable (seal damage present or seal damage absent). A binary response was used because fishers differed in how they reported damage. Most fishers reported damage as the number of new holes in gillnet each day, with was rarely higher than one. Explanatory variables included the section of river in relation to the deterrent line (upstream or downstream), duration of fishing effort each day (hours), length of gillnet used each day (metres) and numbers of fish caught in gillnets each day. Variation due to each fishing station and date were treated as random effects.

To investigate the probability of catch damage, a GLMM was fitted with a binomial distribution, using the occurrence of catch damage as the response variable (damaged whitefish present or not present) and explanatory variables, river section in relation to the deterrent line (upstream or downstream), duration of fishing effort each day (hours), and number of whitefish caught each day. Absent versus present response variables were used because of the low number of damaged whitefish per net (median: 1, range: 1–4). The same random effects were used as above.

Although fishers likely differed in attentiveness and eyesight, seal sightings were also investigated a GLMM with the response variable, if the fisher had seen a seal at least once while fishing (yes or no). Explanatory factors included river section in relation to the deterrent line (upstream or downstream) and the number of times a fisher visited their fishing station each day. The same random effects were used as above.

3 | RESULTS

Fishers caught more whitefish (per day) upstream than downstream of the deterrent line ($\beta=0.4700$; SD $=0.1312$; $z=3.58$; $p<0.001$; Figure 4a; Table 1). Small differences in fishing effort per day did not significantly affect whitefish catch ($\beta=0.0168$; SD $=0.0145$; $z=1.157$; $p=0.25$). Whitefish catch was higher in shorter gillnets ($\beta=-0.0350$; SD $=0.0072$; $z=-4.82$; $p<0.001$). Catch increased during the study, with 68% of 2539 whitefish caught in the last 16 days.

The probability of a seal-damaged gillnet was lower upstream than downstream of the deterrent line ($\beta=-2.195$; SD $=0.560$; $z=-3.92$; $p<0.001$; Figure 4b; Table 1), but not to net length ($\beta=0.0026$; SD $=0.0481$; $z=0.054$; $p=0.96$) or the number of fish caught ($\beta=-0.0025$; SD $=0.0168$; $z=-0.146$; $p=0.88$). The probability of a seal-damaged gillnet increased with the length of time the net was in the water during the day ($\beta=0.1062$; SD $=0.0432$; $z=2.46$; $p=0.014$). Overall, 83 gillnets were damaged by seals, with 35 nets damaged beyond repair.

The probability of catching a seal-damaged whitefish increased with the total number of whitefish caught ($\beta=0.0488$; SD $=0.0144$;

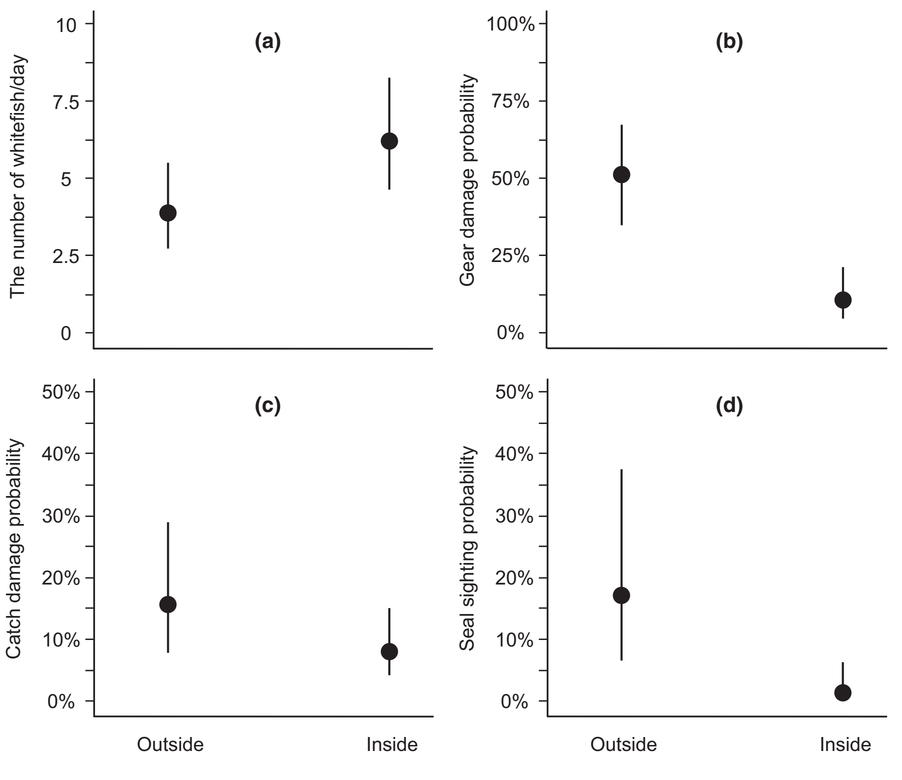

FIGURE 4 Model-predicted daily number of whitefish caught (a), probability of gillnet damage (b), probability of catching a whitefish with seal-induced damage (c) and probability of observing a seal (d) at fishing stations downstream (outside) and upstream (inside) of an ADDs line in the River Iijoki, Finland from late August to late October, 2022. Vertical lines show 95% confidence intervals.

$z = 3.39$; $p < 0.001$) but did not differ significantly upstream and downstream of the deterrent line ($\beta = -0.7569$; SD = 0.4432; $z = -1.71$; $p = 0.088$; Figure 4c; Table 1). Differences in fishing effort per day did not significantly affect the probability of catching a seal-damaged whitefish ($\beta = -0.0164$; SD = 0.0463; $z = -0.353$; $p = 0.72$). Overall, 57 whitefish were damaged by seals.

The probability of observing a seal during a day was significantly lower upstream than downstream of the repellent line ($\beta = -2.697$ SD = 0.738; $z = -3.66$; $p < 0.001$; Figure 4d; Table 1). In contrast, the probability of observing a seal during a day was not significantly related to the number of times a fisher visited a fishing station each day ($\beta = 0.2200$; SD = 0.2161; $z = 1.02$; $p = 0.31$). The frequency of seal observations varied during the study and was highest in October, when 19 of 31 seals were sighted.

ADD noise linearly dampened 1 dB re 1 µPa over every 17.7 m (Figure 5). ADD sounds became indistinguishable from ambient river noises at a level of 83 dB re 1 µPa, at a distance of 933 m (Figure 5). ADDs produced sounds within a frequency range (5–40 kHz) that exceeded the range specified in the manufacturer information sheet. The highest sound pressure was 149.7 dB re 1 µPa at an SPL 1/3 OB 20 kHz range (or 155 dB re 1 µPa at SPL 5–50 kHz), at a distance of 7 m from the nearest device.

4 | DISCUSSION

We found that the 'sound wall' produced by a line of ADDs reduced seal access to upstream sections of the river Iijoki. Fishers caught more whitefish, suffered less gear damage, saw fewer seals and caught fewer seal-damaged whitefish at fishing stations upstream than downstream of the deterrent line. Hence, blocking seal access to a river or river section by ADDs at a critical fishing period is a promising method for mitigating seal damage in fisheries in riverine environments.

Although the seal movement restriction by ADDs was incomplete, similar to previous studies in river environments (Graham et al., 2009; Yurk & Trites, 2000), our results imply that ADDs could be effective in rivers. Notably, ADD sounds became indistinguishable from background noise in a relatively fast flowing river (Iijoki) at several hundred metres from the source (Figure 5), with river characteristics affecting attenuation range. Within an estimated effective range of 50 m, sound pressure was ~135 dB re 1 µPa or more at SPL 1/3 OB 20 kHz. Given concerns of widespread noise pollution by ADDs in certain coastal environments (Findlay et al., 2021, 2022), this limited range could be an advantage in similar rivers.

TABLE 1 Fishing stations downstream (not guarded) and upstream (ADD guarded) of acoustic deterrent devices (ADD), numbers of European whitefish (Coregonus lavaretus) caught (daily mean with range), percentage of seal-damaged whitefish, and percentage of days when a seal was sighted on the River Iijoki, Finland, from late August to late October, 2022.

Station	Treatment	Days fished/ netting hours	Number of whitefish caught/day	Damaged whitefish proportion (%)	Daily net damage probability (%)	% of days with a seal sighting
1	Not guarded	41/840	3 (0–16)	3.9	46	17
2	Not guarded	50/1008	6 (0–28)	4.2	40	34
3	ADD guarded	59/1284	12 (0–43)	2.5	19	8
4	ADD guarded	58/1372	15 (0–71)	1.7	9	2
5	ADD guarded	62/1470	8 (0–36)	1.2	5	0

Fishing stations downstream (not guarded) and upstream (ADD guarded) of acoustic deterrent devices (ADD), numbers of European whitefish (Coregonus lavaretus) caught (daily mean with range), percentage of seal-damaged whitefish, and percentage of days when a seal was sighted on the River Iijoki, Finland, from late August to late October, 2022.

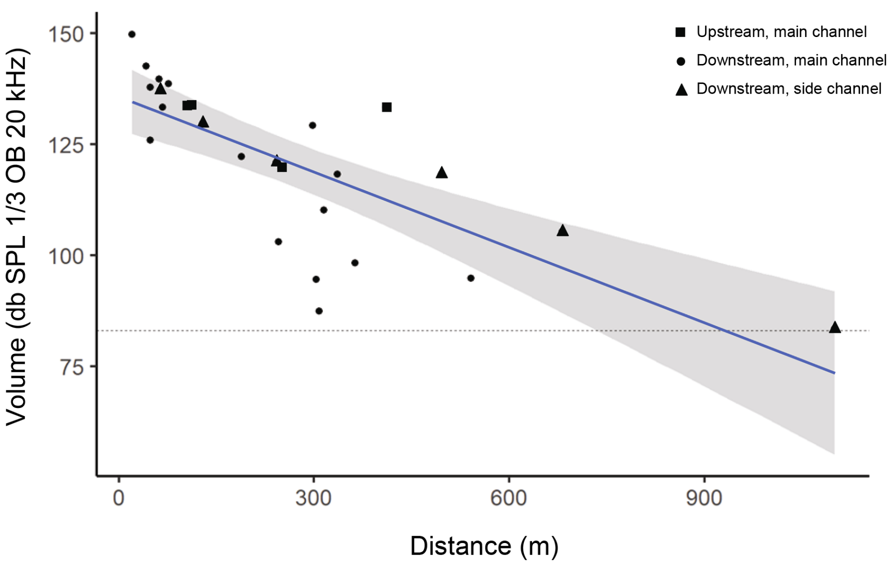

FIGURE 5 Sound intensity as a function of distance from ADDs deployed upstream and downstream in main and side channels of the River Iijoki, Finland, from late August to late October 2022. Orientations of measurement points with regard to ADDs are indicated with the three different point types. The grey shaded area shows 95% confidence intervals. The horizontal dotted line indicates 83 dB re 1 µPa, at which ADD sounds became indistinguishable from ambient river noise.

Feasibility of ADDs in a given setting needs to be balanced against their economic and social viability, thereby highlighting the importance of case-by-case cost–benefit assessments. From an economic point of view, ADDs are relatively expensive (in our study, ~21 k€ per unit, with an expected lifespan of 10+ years declared by the manufacturer) and their installation, operation and care in rivers requires considerable time and resources. In the river Iijoki, although commercial value of whitefish roe is relatively high (current consumer price >100 €/kg in Finland), the immediate economic value of the river fishery is unlikely to exceed costs of ADDs, at least without considerable state subsidies. However, the most valuable function of many whitefish river fisheries in dammed rivers running into the Baltic Sea is that they provide eggs for stocking programs to maintain whitefish stocks, which are otherwise hampered by dams. Stocking programs are essential for sustaining river-specific populations and overall whitefish catches in the sea. Hence, in the absence of successful river catches, whitefish populations would likely decline. Therefore, commercial and recreational harvest of whitefish outside natal rivers provide considerable additional value, the estimation of which is beyond the scope of our study.

Our study design was not optimal for testing ADD effects, partly due to logistic considerations and wishes of collaborating fishers. For example, after the peak of the whitefish upstream spawning run in late October, most whitefish had potentially already passed the downstream section but were still caught in the upper section. Our catch data cannot prove or refute this possibility. Nevertheless, we believe that ADD explained our results more than natural differences between upstream and downstream fishing locations. First, during years prior to our study (2017–2021), seals were commonly observed in both sections of the river. Second, during the study, catches were higher and seal sightings were fewer in the upstream section than what local fishers perceived in the same section during preceding years (2017–2021). Third, whitefish catches over the entire river fishery (from river mouth to the first dam) were higher during the study than without ADDs in 2017–2021.

Future studies should assess the efficiency of ADDs in relation to other mitigation measures and variation in individual animals, target species, ADD models and local conditions. For example, seals may differ in their individual ability to bypass ADDs (e.g., by lifting their head above the water surface; Fjälling et al., 2006), the hearing ability (Sills et al., 2015), or noise tolerance (Kastak et al., 2008). Previous studies suggested that ADDs can restrict movement of harbour seals (*Phoca vitulina*) in rivers (Graham et al., 2009; Yurk & Trites, 2000), but studies in river fisheries have been lacking. Furthermore, ADD technology has developed quickly, which highlights the importance of new assessments of the applicability of deterrents in river environments. Finally, effects of ADDs in river environments over multiple years are needed, because ADDs can lose some or all of their effectiveness in long-term use (Götz & Janik, 2013; Schakner & Blumstein, 2013; Tixier et al., 2021). For example, over time, seals can habituate to noise or learn how to bypass deterrents (Schakner & Blumstein, 2013). In the case of ASR-US3, the manufacturer's information sheet implies that varying tones and sound intensities are used to minimise the scope for habituation.

In conclusion, our findings supported the usefulness of ADDs to protect river fisheries by showing that river areas upstream of an ADD line produced higher catches, less gear damage and fewer damaged fish. ADD sounds were audible underwater at considerable distances from devices, despite a noisy river environment. Our findings agreed with observations of local fishers, who perceived a markedly better fishing after deployment of ADDs. Hence, our findings are promising regarding the applicability of ADDs in riverine environments and particularly for safeguarding stationary fishing gear in relatively small rivers. Further studies are still needed to investigate the importance of differences in individual animals and ADD types, to further address animal welfare and economic feasibility, and to elucidate the long-term efficiency of ADDs in river environments.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The acoustic deterrent devices used in this study were designed by a leading manufacturer not to have negative effects on wildlife. Features such as 'soft start' allowed animals sensitive to the noises (mostly seals) to move away before the full volume was attained. The devices were used in a river environment where animals are free to move and non-target marine mammal species do not occur.

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