Testing the effectiveness of an acoustic deterrent device for excluding seals from Atlantic salmon rivers in Scotland

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In Scotland, there is frequent conflict between salmon rod fisheries and seals, which is often managed by the shooting of seals in rivers, with potential negative impacts on protected populations of seals. Non-lethal devices have not been tested extensively in rivers as an alternative to shooting. Trials were carried out between January and May 2006 on the River North Esk and between October 2007 and February 2008 on the River Conon in northeast Scotland to examine the effectiveness of an acoustic deterrent device (ADD) at deterring seals from a specific area of river and as a barrier to the upstream movement of seals. The ADD was switched on and off alternately for periods of several days, and surveys were carried out to estimate the number of seals present within each river. The ADD had no significant effect on the absolute abundance of seals in the survey area in either river, but it did reduce seal movement upstream significantly, by ~50% in both rivers. This reduction was constant over the 4-month period of both trials. The results suggest that ADDs might be a useful conservation tool in the management of seal–salmon conflicts, particularly in estuaries and rivers where the potential for adversely impacting cetaceans is limited.

Keywords: acoustic deterrent, conflict, grey seal, harbour seal, marine mammal–fisheries interactions, salmon.

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Introduction

Interactions between seals and salmon fisheries epitomize the widespread and contentious nature of conflicts between marine mammals and fisheries. For example, predation by sea lions on Pacific salmon (*Oncorhynchus* spp.) and by seals on both Pacific and Atlantic salmon (*Salmo salar*) in estuaries and rivers is a source of concern throughout the Pacific Northwest in both the United States and Canada (Fraker and Mate, 1999), as well in the UK (Carter *et al*., 2001; Middlemas *et al*., 2006; Butler *et al*., 2008).

In the UK, seals interact with salmon farms, coastal net fisheries, and rod-and-line fisheries for wild salmon. The continued growth of the grey seal (*Halichoerus grypus*) population and declining salmon abundance in the 1990s intensified the problem, and the implementation of the EU Habitats Directive led statutory authorities to review their approach to managing seals and salmon (Butler *et al*., 2008). The first attempt in the UK to balance the potentially conflicting interests of seal and salmon conservation with fisheries and wildlife tourism was introduced in April 2005 in the form of the Moray Firth Seal Management Plan (MFSMP; Butler *et al*., 2008). The MFSMP permits the lethal removal of perceived individual "problem" animals from important salmon rivers within strict annual limits, as described by Wade (1998). The recent decline in most of the large harbour seal (*Phoca vitulina*) populations around Britain, however, highlights the need to investigate, thoroughly, alternative non-lethal conservation tools to manage seal–salmon interactions, although the ultimate causes of the decline are currently unknown (Lonergan *et al*., 2007).

One of the few alternative methods for the non-lethal removal of seals is underwater acoustic devices, which produce loud sounds with the aim of deterring seals from the vicinity of the device, typically at marine aquaculture sites. These devices are known as acoustic deterrent devices (ADDs), acoustic harassment devices (AHDs), or seal scarers. Although the terms AHD and ADD are sometimes used to indicate the devices with a higher or lower power output, respectively, they are often taken to be synonymous. Here, we refer to all such devices as ADDs, irrespective of their power. ADDs have been used as anti-predator controls at marine salmon farms since the 1980s, but views on their effectiveness are equivocal (Quick *et al*., 2004; Sepulveda and Oliva, 2005), perhaps reflecting the vastly different source levels, frequencies, and sound patterns deployed by various ADDs. The results of field studies on the effectiveness of ADDs at deterring seals and reducing seal interactions are similarly equivocal, possibly also the consequence of the wide variety of situations and devices used. Some studies have found ADDs to be effective at deterring seals in some circumstances, although not necessarily completely effective (Yurk and Trites, 2000; Fjälling *et al*., 2006), whereas others reported no effect (Olesiuk *et al*., 1996; Jacobs and Terhune, 2002). Although ADDs may be effective in the short term, evidence suggests that their effectiveness in the longer term appears to decline (Jefferson and Curry, 1996; but see Fjälling *et al*., 2006, for a notable exception).

It has been proposed that ADDs be used to assist in the management of seal–salmon conflicts in rod-and-line fisheries by excluding seals from rivers to protect vulnerable stocks or substocks running at certain times of the year (Butler *et al*., 2006). The objectives of this study were to (i) assess, from a management perspective, whether or not seals could be effectively deterred from a specific area of river using an ADD, and (ii) test the efficiency of the ADD as a barrier to the upstream movement of seals.

Material and methods

The ADDs used in the trials were Lofitech Seal Scarers (Lofitech AS, Leknes, Norway) that generate ~500-ms pulses of ca. 15 kHz (Fjälling *et al*., 2006). The pulse emission patterns were randomized, with a source level of ca. 189 dB re 1 μPa at 1 m (Lofitech AS; http://www.lofitech.no). Measurements made after the trials confirmed these parameter values, but also noted the presence of harmonics of varying degrees in almost all pulses. The second harmonic at ca. 30 kHz was 15–40 dB lower than the fundamental, and the third harmonic at ca. 45 kHz was 20–50 dB lower than the fundamental. There was no energy below 5 kHz. The randomization of the pulse emission pattern was investigated by a 15-min recording: 213 pulses were emitted with a mean interval of ca. 5 s between pulses; intervals between pulses did not exceed 60 s.

The study was carried out in the Rivers North Esk and Conon in northeast Scotland. Both rivers support important Atlantic salmon stocks and fisheries. The River Conon runs into the Moray Firth, which contains Special Areas of Conservation for Atlantic salmon and harbour seals designated under the EU Habitats Directive. Management of seals and salmon in the Moray Firth region is coordinated under the MFSMP (Butler *et al*., 2008).

The North Esk trial

The ADD was installed at Kinnaber Fishings on the North Esk on 4 February 2006 by Kinnaber Fishery and the manufacturers of the ADD (Lofitech AS). The River North Esk is ~38 m wide at the site of the ADD installation. River depth fluctuates with rainfall and tidal state, but is generally <2.5 m, and in cross section is deepest near the bank where the ADD was positioned and gradually becomes shallower to the opposite bank. The ADD sound head was situated ~3 m into the river from the bank in water ~2 m deep and was fixed 1 m above the riverbed. The riverbed substratum consists mainly of smooth pebbles and stones. During normal river levels, the flow appears to be laminar, with no opportunity for the formation of air bubbles. The site is surrounded by a mixture of farmland and woodland and is relatively undisturbed by people.

To distribute experimental and control periods throughout the 5-month trial, the ADD was systematically switched on and off alternately for periods of 3–8 consecutive days in February and March 2006. The ADD was then switched on for the entire month of April and switched off for the entire month of May 2006. Surveys were carried out within 2 h of high tide (Middlemas *et al*., 2006) from a fixed location on the north bank of the river at Kinnaber Fishings, between January and May 2006. The area of river visible to the observer was searched systematically using binoculars; whenever a seal was observed at the surface during the survey, the species, time, and approximate location were recorded. The number of seals observed was estimated at the end of each survey based on the occurrence of coincident observations and the position and timing of each observation, which allowed possible swimming trajectories of individual seals to be followed.

The River Conon trial

The ADD in this river was installed on the bank opposite Garrie Island at the beginning of November 2007. At the site of the ADD installation, the river is ca. 45 m wide and is steep-sided in cross section, with depth increasing rapidly to 2 m from either bank. The ADD sound head was situated 2 m from one bank in water ~2 m deep. The gradient then eases, with the river reaching a depth of <3.5 m near the centre. The ADD was situated in a relatively deep, slow-moving pool, with faster-flowing water both upstream and downstream. The pool extends ca. 50 m downstream and 10 m upstream from the ADD. Downstream of the pool, the river widens and shallows to a depth of 1 m, with a deeper channel running down one bank. The riverbed substratum is generally clay overlaid with small, smooth pebbles and stones. Both banks are wooded, and walkers occasionally visit the area.

To distribute experimental and control periods throughout the 5-month trial, the ADD was systematically switched on and off alternately for periods of 1–4 and 3–13 consecutive days, respectively, from November 2007 to February 2008. Surveys were carried out within 2.5 h of high tide (Middlemas *et al*., 2006) from the river bank over a standard 1.5-km transect. The ADD was situated roughly one-third of the way downstream from the top of the transect. The same observational and data-recording procedures employed at the River North Esk site were also used here.

Data analysis

All statistical analyses were carried out using R 2.6.2 (R Development Core Team, 2008). Models were selected using AIC scores, with the aim of minimizing this measure (Crawley, 2005). The significance of variables was assessed from the change in deviance caused by removing or adding that term to the selected model, assuming a chi-squared distribution. The effect of the ADD was tested on (i) the number of seals within the survey area, and (ii) seal presence upstream of the ADD using generalized linear models or generalized additive models when one or more of the terms were non-linear. To test for any change in the effect of the ADD over time, the number of days from the first day that the ADD was switched on at each site was modelled as a covariate. The results of both trials were combined, and study site was modelled as a fixed effect because the sample size was insufficient to include site as a random effect.

The effect of the ADD on the number of seals observed within the survey area was modelled with a Poisson error distribution. As the time taken to carry out surveys was variable, the log of the survey time was used as an offset in the analysis of the number of seals observed. Previous work has shown that seal abundance in rivers varies seasonally (Carter *et al*., 2001; Butler *et al*., 2006; Middlemas *et al*., 2006). Therefore, where there was a seasonal trend in the number of seals observed, the effect of the ADD was tested using models incorporating this trend. The generalized additive modelling function of the mgcv library (version 1.3-29) in R was used to describe the underlying seasonal pattern in seal abundance (Thompson *et al*., 2005) by fitting a smoothing spline to the “day of winter”, defined as the number of days from 30 September (Wood and Augustin, 2002).

The effect of the ADD on seal presence upstream of the device was modelled with a binomial error distribution. To preclude the need to model seasonal trends in seal presence, only those surveys during which seals were present were used in the analysis. To standardize survey effort for the logistic regression analysis, only 1 h per survey was considered for surveys on the North Esk and only 1.5 h per survey for surveys on the River Conon. This was taken to be the last 1–1.5 h of the survey for surveys ending before or <30 min after high tide, or the hour of the survey centred on high tide, for some surveys on the North Esk. This excluded two surveys with <1 h of observation within an hour of high tide on the North Esk.

Results

Seals were seen in 20 of the 57 surveys carried out on the North Esk between January and May 2006 and in 37 of the 62 surveys carried out on the River Conon between October 2007 and February 2008 (Table 1). The average number of seals observed per survey (±1 s.e.) was 0.46 ± 0.09 on the North Esk (range = 0–3) and 0.90 ± 0.12 on the River Conon (range = 0–4). Both species of seal, harbour and grey, were observed in both rivers, although grey seals were more prevalent than harbour seals in the River Conon during the study (average numbers of grey seals observed per survey: North Esk = 0.14 ± 0.06, River Conon = 0.87 ± 0.12; average numbers of harbour seals observed per survey: North Esk = 0.30 ± 0.06, River Conon = 0.03 ± 0.02).

Seals were present in 55% of the surveys when the ADD was switched off compared with 39% of surveys when it was switched on (for both sites and all months; Table 1). The number of seals counted during surveys varied from October to May ($\chi^2 = 64.46$, d.f. = 12.4, $p < 0.001$). When this trend in seal abundance was controlled for, the effect of the ADD on seal abundance within the survey area was not significant ($\chi^2 = 0.34$, d.f. = 0.94, $p = 0.53$). There was no difference in this result between the North Esk and the River Conon ($\chi^2 = 1.98$, d.f. = 1.03, $p = 0.16$), and there was no change in the effect of the ADD with time, either linear or non-linear [ADD*day, $\chi^2 = 1.31$, d.f. = 0.66, $p = 0.16$; s (day, by = ADD), $\chi^2 = 1.11$, d.f. = 0.69, $p = 0.20$]. Examination of the approximate surfacing locations using identifiable landmarks demonstrated that on all six occasions when the ADD was operating at the North Esk and seals were present, they were observed within 350 m of the ADD, and on four of the six occasions, seals were observed either upstream or within 100 m of the ADD. Similarly on 11 of the 15 surveys during which seals were present when the ADD was operating at the River Conon, they were observed within 200 m of the ADD.

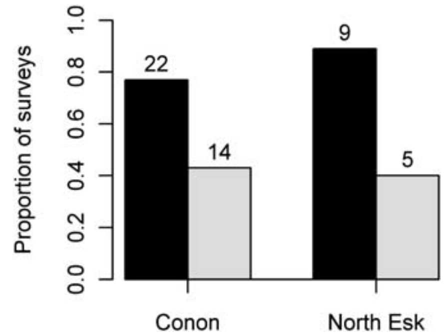

Figure 1. The proportion of surveys (when seals were present) in which a seal was seen upstream of the ADD with the ADD turned on (white bars) or off (black bars). Numbers above the bars indicate the number of surveys.

Seals were observed upstream of the ADD in fewer surveys when the ADD was switched on than when it was switched off (for both sites and all months, 15 vs. 40%; Table 1). When seals were present during the surveys, they were detected upstream of the ADD in fewer surveys when the ADD was switched on than when it was switched off ($\chi^2 = 7.78$, d.f. = 1, $p = 0.005$; Figure 1). The ADD reduced the probability of a seal being sighted upstream of the ADD by roughly one-half, i.e. from 81 to 42%. There was no difference between the North Esk and the Conon in this result ($\chi^2 = 0.22$, d.f. = 1, $p = 0.64$), and there was no change in this effect with time, either linear or non-linear [ADD*day, $\chi^2 = 0.69$, d.f. = 1, $p = 0.41$; s (day, by = ADD), $\chi^2 = 0.28$, d.f. = 1.08, $p = 0.63$].

Discussion

Our results suggest that the ADD was partially effective as a barrier to seal movements upstream, reducing the probability of a seal

Table 1. Monthly breakdown of the number of surveys carried out, the number of surveys in which seals were present, and the number of surveys in which seals were observed upstream of the ADD with the ADD turned on and off.

	ADD off			ADD on		
Month	Surveys	Seals present	Seal upstream of ADD	Surveys	Seals present	Seal upstream of ADD
North Esk, 2006						
January	6	4	–	0	–	–
February	9	6	5	11	3	1
March	10	4	4	11	1	0
April	0	–	–	6	2	1
May	4	0	0	0	–	–
Total	29	14	9	28	6	2
Conon, 2007/2008						
October	5	4	3	0	–	–
November	8	5	4	8	1	0
December	5	5	4	7	7	3
January	9	6	6	5	5	2
February	9	2	0	6	2	1
Total	36	22	17	26	15	6

–, no data.

being sighted upstream of the ADD by roughly 50%. However, the ADD had no significant effect on overall seal abundance within the survey area, in either river.

Although seals were detected upstream of the ADD on fewer surveys when the ADD was switched on, the ADD was not 100% effective as a barrier. This could have been due partly to occasional lapses in the power supply to the ADD as a result of unexpectedly rapid voltage drops in the batteries caused by low air temperatures. On-site measurements of the output from the ADD would be required to assess the extent of any reduction in performance. However, difficulties with the maintenance and operation of an ADD are likely to be experienced when using an ADD for routine management purposes.

A similar attempt to prevent seals moving upriver in the Puntledge River by deploying an ADD as an acoustic barrier was unsuccessful (Olesiuk *et al.*, 1996). In that river, harbour seals intercept out-migrating fry and smolts at a well-lit bridge, with up to 25 harbour seals feeding at the bridge at the same time on certain nights (Olesiuk *et al.*, 1996). There was therefore strong motivation for seals to pass the acoustic barrier, which was situated downstream of the main foraging site. In our study, the ADD was situated relatively close to the top of the tidal stretches of both rivers and only ca. 250 m downstream of a weir in the North Esk that forms an obstacle to upstream seal movement. The apparent inconsistency with the findings of Olesiuk *et al.* (1996) might be explained by a lack of motivation for seals to travel upstream past the ADD in both rivers. In locating an ADD closer to the mouth of a river, however, any potential gain must be weighed against the possibility of displacing cetacean species from the vicinity of the river mouth (Johnston, 2002; Morton and Symonds, 2002).

The ADD did not reduce seal abundance within the survey area. Previous studies with ADDs in rivers have also produced mixed results in terms of their effectiveness (Olesiuk *et al.*, 1996; Yurk and Trites, 2000). Seals were visible to the observers up to 800 m downstream of the ADD at the North Esk and up to 500 m downstream of the ADD at the River Conon. The effective range of the ADD, according to the manufacturer, is reported to be ca. 300 m, but it is likely that there will be a significant decrease in the sound level over a relatively short distance from the source (of ca. 30 dB over the first 30 m). In addition, the effective range will be considerably less in a noisy river environment where the shallow-water depth and bottom profile will affect sound transmission. It is possible, therefore, that seals present "in the survey area" when the ADD was operative may have simply remained outside the effective range of the ADD, although during 67% or more of surveys at both sites when seals were present and the ADD was operating, seals were observed within 200 m of the ADD.

This suggests that the ADD was not particularly effective at deterring seals from its vicinity and is consistent with a study carried out in the Bay of Fundy, Canada, in which some seals came within 45 m of an active ADD (Jacobs and Terhune, 2002). These findings are, however, apparently inconsistent with the results of the experiment by Yurk and Trites (2000), also carried out in the Puntledge River, that differed from the experiment of Olesiuk *et al.* (1996) in that they deployed the ADD from the actual bridge at which seals were accustomed to forage rather than downstream of it. On most nights when the ADD was deployed from the bridge, no seals fed within a 50-m radius of the bridge compared with a mean of eight animals feeding in the absence of the ADD. Similarly, Fjälling *et al.* (2006) found that ADDs had a positive effect by reducing damage to catch and gear and increasing the landed intact catch size when deployed in the salmon-trap, net fishery in the Baltic Sea. However, it may be that seals are prepared to swim past an operative ADD when the motivation exists to do so, e.g. to reach a foraging or haul-out site, but are less prepared to approach and remain within the vicinity of an operative ADD to forage.

It should also be noted that Yurk and Trites (2000) deployed their ADD for only seven nights in total, so reducing the potential for habituation (Anderson and Hawkins, 1978; Jefferson and Curry, 1996). In this study, the reduction in the probability of sighting a seal upstream of the operational ADD was stable over a period of four months at both sites, showing no evidence of habituation. Anderson and Hawkins (1978) reported that habituation was rapid. Therefore, our trials should be sufficient to demonstrate a lack of habituation, although longer-term trials may be required to further assess the degree of habituation that might occur between years in both rivers, potentially reducing the long-term efficacy of ADDs.

There was no information available on seal foraging behaviour or the normal seasonal variation in seal presence and abundance in the North Esk before the trial. Fitting seasonal trends to the data should have corrected for the presence of any existing patterns, although the possibility that the ADD caused the observed trends cannot be excluded. Studies in the Rivers Dee, Don, and Spey and our own work in the Rivers Conon, Kyle of Sutherland, and Ness, however, found a similar decline in seal abundance from winter to early summer (Carter *et al.*, 2001; Butler *et al.*, 2006).

Management implications

The results of the trial suggest that ADDs would be useful in the management of seal–salmon conflicts, if they are sited appropriately. The ADD reduced the movement of seals upstream, and this effect was consistent over a period of 4 months in two different rivers. Although only partially effective as a barrier, using ADDs in combination with other techniques, using new sound patterns, or using additional devices to reduce the possibility of seals moving around the extremities of the sound field may result in a practical solution to the problem.

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