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RESEARCH NOTE

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The impact of boat activities associated with an acoustic fish telemetry study on waterbird populations in a Special Protection Area

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Abstract

It is widely recognized that the research techniques used to monitor and study wildlife have the potential to disturb and alter the behavior of the study species. However, other impacts on sensitive, non-target, species are rarely investigated. Here, we assessed the disturbance of waterbirds in relation to the boating activities associated with an acoustic telemetry study on European eel (*Anguilla anguilla*) in a UK water storage reservoir designated a Special Protection Area (SPA) for waterbirds. Counts of 11 species of waterbirds were surveyed pre-, during-, and post-activity. Boating activities had no impact on waterbird counts, but counts were correlated with cloud cover, air temperature, and wind speed; results may also reflect seasonal differences in bird numbers at this site. Our results indicate that the deployment of acoustic telemetry receivers and netting for studying fish, when applied with appropriate well-informed mitigation measures, can be undertaken without causing significant disturbance to waterbird species, including those that are threatened or sensitive to disturbance.

KEYWORDS

boat, conservation, disturbance, lake, management, migration, reservoir, Special Protection Area, telemetry, waterbird

1 | INTRODUCTION

Increasingly it is recognized that research techniques used to monitor and study wildlife, to aid their conservation and management, may also disturb and alter their behavior (Brogi et al., 2019; Bullock et al., 2015; Hedger et al., 2017; Mayer et al., 2021; Vandenabeele et al., 2011; Williamson et al., 2016). The impact of such activities, including live capture, boat use, tagging, and drone use, on the behavior, physiology, and welfare of study animals is consequently a burgeoning area of research. As well as direct impacts on the study animals or populations, research techniques may have indirect effects on other non-target species that co-inhabit ecosystems where research or management is

TABLE 1 Latin and common names of 18 waterbird species surveyed, including their IUCN Regional Red List assessment of extinction risk for Great Britain (GB IUCN Red List) status (Stanbury et al., 2021) and their designation as cited species within the SPA, Ramsar, or Site of Special Scientific Interest (SSSI) at Abberton Reservoir.

Latin name	Common name	GB IUCN Red List status	Cited in SPA, Ramsar, or SSSI
Alopochen aegyptiaca	Egyptian goose	Least Concern	NA
Anas acuta	Pintail	Critically Endangered	NA
Anas clypeata	Northern shoveler	Least Concern	SPA, Ramsar, SSI
Anas crecca	Eurasian teal	Least Concern	SPA, Ramsar
Anas platyrhynchos	Mallard	Vulnerable	NA
Ardea cinerea	Grey heron	Vulnerable	NA
Aythya ferina	Common pochard	Endangered	SPA, Ramsar, SSSI
Aythya fuligula	Tufted duck	Vulnerable	SPA, Ramsar, SSSI
Bucephala clangula	Common goldeneye	Vulnerable	SPA, Ramsar, SSSI
Cygnus olor	Mute swan	Least Concern	SPA, Ramsar, SSI
Fulica atra	Common coot	Vulnerable	SPA, Ramsar, SSSI
Limosa limosa	Black-tailed godwit	Endangered	Ramsar
Mareca penelope	Eurasian wigeon	Vulnerable	SPA, Ramsar, SSSI
Mareca strepera	Gadwall	Least Concern	SPA, Ramsar, SSSI
Mergus merganser	Goosander	Least Concern	SSSI
Phalacrocorax carbo	Great cormorant	Near Threatened	SPA, Ramsar, SSSI
Podiceps cristatus	Great crested grebe	Least Concern	SPA
Vanellus vanellus	Lapwing	Vulnerable	SSI

undertaken (Norvell et al., 2014; Reed & Bonter, 2018). Hence, research and management techniques should be evaluated not only for their impact on target or study species, but also for any potential effects on the behavior and welfare of other non-target species, particularly if these species are sensitive or threatened.

Movement data are increasingly recognized as being vital to the conservation and management strategies for threatened species (Allen & Singh, 2016; Fraser et al., 2018; Martin et al., 2007). Acoustic telemetry is one of the primary research methodologies used to collect such data in aquatic environments (Donaldson et al., 2014; Hussey et al., 2015; Matley et al., 2022), and typically requires the use of boats to deploy arrays of listening receivers (Hellström et al., 2022; Kessel et al., 2014; Matley et al., 2022). However, boat traffic can cause behavioral disturbance to a range of aquatic species including marine mammals (Pellegrini et al., 2021; Sprogis et al., 2020; Tripovich et al., 2012), elasmobranchs (Berthe & Lecchini, 2016; Pierce et al., 2010), teleost fish (Graham & Cooke, 2008; Holles et al., 2013), crocodilians (Choudhary et al., 2017; Webb & Messel, 1979), and bird species (Bellefleur et al., 2009; Chatwin et al., 2013; Dehnhard et al., 2019; Peters & Otis, 2006; Ronconi & Clair, 2002). In order to limit disturbance on non-target species, assessments on the impact of boat use during acoustic telemetry deployments should be undertaken, especially if non-target populations are threatened or in vulnerable life stages.

The European eel (*Anguilla anguilla*) is a critically endangered species of teleost fish (Drouineau et al., 2018; Jacoby et al., 2015), threatened by a variety of factors including habitat destruction and fragmentation, mortality in hydropower turbines, fisheries impacts, and climate change (Castonguay & Durif, 2015; Jacoby et al., 2015). Information on movement ecology is considered vital to inform conservation and management plans for this species (Piper et al., 2017; Walker et al., 2014; Williamson et al., 2023). Beginning in October 2022, an extensive acoustic telemetry array (151 receivers) for monitoring the fine-scale movements of eel was deployed at Abberton Reservoir, Essex, UK. As part of the network of protected Natura 2000 sites, Abberton Reservoir is a Ramsar wetland,[1] Site of Special Scientific Interest (SSSI),[2] and Special Protection Area (SPA)[3] for wintering and molting waterbirds, with some of the species inhabiting the site designated in threat categories by the IUCN Regional Red List assessment of extinction risk for Great Britain (Stanbury et al., 2021) (Table 1). These waterbird species are a primary conservation focus of the Natura 2000 designation, which can create potential conflicts when management actions to support the conservation of European eels, such as survey netting and boat activities, trade off

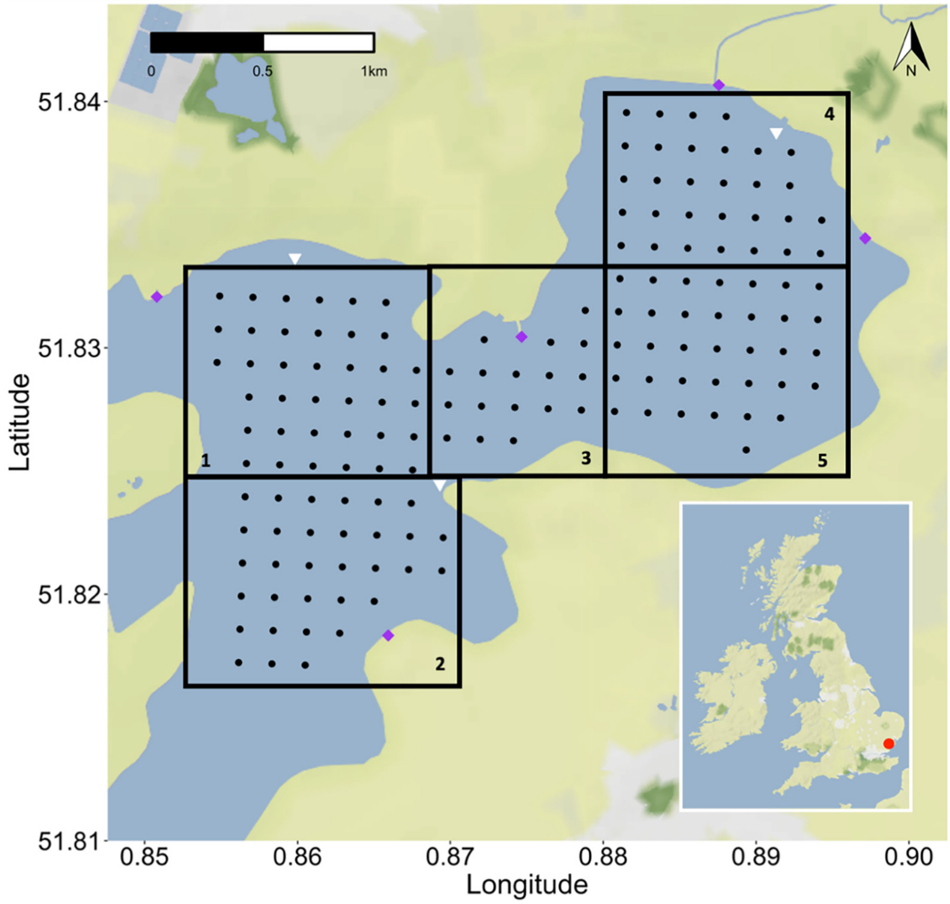

FIGURE 1 Location of Abberton Reservoir, Essex, UK. Acoustic telemetry array highlighted by filled black circles. Netting locations by white triangles. Waterbird survey locations by purple diamonds. Boating activity areas (1–5) denoted by black rectangles. Abberton reservoir position in the UK (red circle) included as insert in bottom right corner.

against the protections afforded to waterbird species. During molting, many species of waterbirds lose all their flight feathers (Jenni & Winkler, 2020; Kjellén, 1994) and are therefore particularly vulnerable to disturbance impacts because with their flying abilities limited, escape behaviors are restricted (Dehnhard et al., 2019). Currently, the impact of deploying acoustic telemetry receiver systems on surrounding wildlife is unknown. Assessing changes in numbers of bird populations is a common method to assess disturbance (Hill et al., 1997; Johnson, 2008; Palacios et al., 2022; Wallis et al., 2019). In this study, we investigated the effect of deploying an array of acoustic receivers on the counts of threatened waterbirds during sensitive stop over periods at Abberton Reservoir, a UK SPA and SSSI.

2 | METHODS

2.1 | Study site

Abberton Reservoir is a large artificial raw water storage reservoir (4.75 km^2) managed by Northumbrian Water Group located in Essex, UK (Figure 1). It supports wintering populations of more than 20,000 internationally and nationally important waterbirds and as such, is categorized as a SPA under UK legislation (previously under the European Union Directive on the Conservation of Wild Birds) (Engelen et al., 2008; Kirby et al., 1996).

2.2 | Boating activities

The deployment of the acoustic telemetry array and netting for European eel to capture and tagging occurred within three distinct activity phases. Given that establishing the detection range of acoustic receivers is critical for interpreting acoustic telemetry data (Kessel et al., 2014), range testing experiments were first undertaken in the northeastern section of the reservoir between 18th and 27th October 2022. Second, between February 28, 2023 and March 6, 2023 the full array of 151 receivers (Model HR2, Innovasea, Nova Scotia, Canada) was deployed across the entire reservoir (Figure 1). Third, between September 3, 2023 and September 14, 2023 all the receivers were retrieved, batteries replaced, and redeployed. Netting for eel, using double-ended fyke nets, was conducted throughout these three periods. All these activities required the use of a small boat (rigid open workboat, 5 m in length with 60 hp. 4-stroke outboard). Given that boating activities can disturb waterbirds (Blight et al., 2023; Mayer et al., 2019; McFadden et al., 2017; Mori et al., 2001; Rodgers Jr. & Schwikert, 2002; Scarton, 2018), the consents for site access required that boating activities be limited to specific regions (Figure 1). Further, following guidelines from the literature, boat speed was kept below 5 knots and a buffer zone of 250 m (conservative mean flight distance plus standard deviation of most sensitive species) was maintained around waterbird rafts to help mitigate impacts (Mayer et al., 2019; McFadden et al., 2017; Mori et al., 2001; Wallis et al., 2019).

2.3 | Waterbird surveys

Visual bird surveys were conducted on a total of 10 days coinciding with research boating activities, spread across the three activity phases (Table S1, Supporting Information). Each day, surveys were undertaken approximately hourly, covering periods pre-, during-, and post-boating activities (minimum 6 and maximum 11 surveys per day), yielding a total of 84 surveys. During each survey, individuals of all waterbird species, aside from members of the subfamily Larinae (gulls), occurring within the survey area were identified and counted using 10× magnification binoculars (Swarovski EL 10×40) and x30-x60 magnification telescope (Kowa TSN883 Prominar 20-60x). Numbers of all species were recorded. Numbers and species of Larinae were not recorded, as they are not a focus, or cited, in the SPA, SSSI or Ramsar designations at Abberton. The survey area extended to a 1 km buffer around the predetermined areas where boat work was to be undertaken during the day (Figure 1), including any areas the boat passed through to get to the working areas. As such, the approximate survey area was 5 km^2. Bird counts were plotted directly onto an Ordnance Survey (OS) base map of the reservoir, overlain with a 50 m × 50 m grid to aid accurate spatial positioning, on a handheld computer (Microsoft Surface) with ArcGIS software. In addition, environmental data including mean wind speed (mph), wind direction, maximum wind gust (mph), mean air temperature (°C), cloud cover (%), presence of rain (presence or absence), relative humidity (%), and visibility (very good, good, moderate, poor) were taken at reservoir-scale resolution for each survey. Wind, temperature, and relative humidity data were extracted from the Met Office website (https://www.metoffice.gov.uk/). Cloud cover, rain presence, and visibility were taken from visual assessment.

2.4 | Data analysis

All analyses were conducted in R version 4.4.2 (R Core Team, 2024). First, data were filtered to retain only those species cited in the SPA designation (Table 1, $n = 11$). To assess if boating activities impacted bird numbers, count data for the 11 species were predicted in a single Generalized Linear Mixed Model (Harrison et al., 2018) with a negative binomial distribution to account for overdispersion (family = nbinom1, link = logit) with the "glmmTMB" function from the *glmmTMB* package (Brooks et al., 2017). Survey period (pre-, during-, post-) was included as an explanatory variable, with the "pre" period considered unaffected data and used as the intercept group. A group of a priori selected explanatory environmental variables was also included: mean wind speed (mph), wind direction, maximum wind gust (mph), mean air temperature (°C), cloud cover (%), presence of rain (presence or absence), relative humidity (%), and visibility. In addition, to assess the impact of the varying environmental conditions that can occur between different months, activity phase was also included as a fixed effect. Explanatory variables with continuous distributions were rescaled using the "scale" function from the *base* package (R Core Team, 2024) to aid model fitting and interpretation. To prevent pseudoreplication, both unique survey ID and species were included as independent random factors. Analysis was undertaken using multimodel inference (Burnham & Anderson, 2002; Grueber et al., 2011). Full details of this methodology can be found in Appendix S1. Following the All Species modeling, the process above was used to separately model the counts of three species (teal, tufted duck, and wigeon) previously identified as particularly sensitive to disturbance at this site (Wallis et al., 2019), but excluding species as a random effect in the models.

3 | RESULTS

A total of 18 species were surveyed through the activities (Table 1). A total of 1620 counts were obtained for the 18 species. Total bird numbers for pre-, during-, and post-boating activities were 27,884 (median = 1545, range = 393–8368), 50,294 (median = 4004, range = 345–12,195), 17,933 (median = 1089, range = 204–5590), respectively. Summary statistics of count data can be found in Table 2. Significant collinearity was found between the fixed effects. The resulting global model contained the fixed effects of mean wind speed, mean temperature, rain presence, and cloud percentage, all with VIF values under the critical threshold of 5 (McGowan et al., 2012; Welzel & Deutsch, 2011) along with unique survey ID as a random

TABLE 2 Summary table of counts per species at Abberton reservoir during three activity phases.

Activity phase	Species name	Period	*n*	Median count	Range
October 2022	Black-tailed godwit	Pre	10	0	0–12
		During	25	0	0–0
		Post	5	0	0–0
	Common coot	Pre	10	0.5	0–131
		During	25	25	0–60
		Post	5	0	0–26
	Great cormorant	Pre	10	0.5	0–11
		During	25	0	0–1
		Post	5	0	0–0
	Egyptian goose	Pre	10	0	0–2
		During	25	0	0–2
		Post	5	0	0–0
	Gadwall	Pre	10	0	0–8
		During	25	0	0–0
		Post	5	0	0–0
	Common goldeneye	Pre	10	0	0–2
		During	25	0	0–2
		Post	5	0	0–0
	Goosander	Pre	10	0	0–6
		During	25	0	0–5
		Post	5	0	0–0
	Great crested grebe	Pre	10	5	0–11
		During	25	5	0–12
		Post	5	0	0–10
	Grey heron	Pre	10	0	0–2
		During	25	0	0–0
		Post	5	0	0–0
	Lapwing	Pre	10	17.5	0–26
		During	25	0	0–28
		Post	5	0	0–0
	Mallard	Pre	10	108	45–217
		During	25	64	14–124
		Post	5	51	18–96
	Mute swan	Pre	10	11.5	8–16
		During	25	8	6–15
		Post	5	8	8–15
	Pintail	Pre	10	6	0–96
		During	25	12	0–78
		Post	5	0	0–36
	Common pochard	Pre	10	2	0–26
		During	25	4	0–12
		Post	5	0	0–4

(Continues)

TABLE 2 (Continued)

Activity phase	Species name	Period	*n*	Median count	Range
	Northern shoveler	Pre	10	0	0–2
		During	25	0	0–2
		Post	5	0	0–2
	Eurasian teal	Pre	10	81.5	28–383
		During	25	64	6–113
		Post	5	41	8–109
	Tufted duck	Pre	10	4	0–163
		During	25	28	0–64
		Post	5	6	0–40
	Wigeon	Pre	10	7.5	0–38
		During	25	4	0–12
		Post	5	0	0–9
March 2023	Black-tailed godwit	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Common coot	Pre	5	344	325–996
		During	11	458	359–1400
		Post	3	420	420–1053
	Great cormorant	Pre	5	0	0–11
		During	11	0	0–6
		Post	3	0	0–0
	Egyptian goose	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Gadwall	Pre	5	180	158–247
		During	11	140	66–181
		Post	3	113	86–134
	Common goldeneye	Pre	5	34	29–115
		During	11	40	12–119
		Post	3	42	40–85
	Goosander	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Great crested grebe	Pre	5	14	6–18
		During	11	17	0–23
		Post	3	17	0–19
	Grey heron	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Lapwing	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0

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TABLE 2 (Continued)

Activity phase	Species name	Period	*n*	Median count	Range
	Mallard	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Mute swan	Pre	5	4	0–16
		During	11	6	2–17
		Post	3	6	4–18
	Pintail	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Common pochard	Pre	5	4	0–109
		During	11	26	0–96
		Post	3	15	0–52
	Northern shoveler	Pre	5	0	0–0
		During	11	0	0–0
		Post	3	0	0–0
	Eurasian teal	Pre	5	202	156–400
		During	11	268	100–397
		Post	3	169	95–387
	Tufted duck	Pre	5	998	85–2116
		During	11	617	109–1651
		Post	3	955	91–1057
	Wigeon	Pre	5	424	399–454
		During	11	349	117–496
		Post	3	296	245–329
September 2023	Black-tailed godwit	Pre	7	0	0–0
		During	16	0	0–0
		Post	8	0	0–0
	Common coot	Pre	7	26	0–1280
		During	16	29.5	0–1274
		Post	8	38.5	0–1285
	Great cormorant	Pre	7	12	4–993
		During	16	431.5	8–651
		Post	8	291.5	0–655
	Egyptian goose	Pre	7	0	0–0
		During	16	0	0–0
		Post	8	0	0–0
	Gadwall	Pre	7	53	12–79
		During	16	32	17–69
		Post	8	31.5	19–68
	Common goldeneye	Pre	7	0	0–0
		During	16	0	0–0
		Post	8	0	0–0

(Continues)

TABLE 2 (Continued)

Activity phase	Species name	Period	n	Median count	Range
	Goosander	Pre	7	0	0–0
		During	16	0	0–0
		Post	8	0	0–0
	Great crested grebe	Pre	7	0	0–6
		During	16	0	0–0
		Post	8	0	0–0
	Grey heron	Pre	7	0	0–0
		During	16	0	0–0
		Post	8	0	0–0
	Lapwing	Pre	7	0	0–0
		During	16	0	0–0
		Post	8	0	0–0
	Mallard	Pre	7	154	40–204
		During	16	103.5	49–172
		Post	8	120	99–150
	Mute swan	Pre	7	75	54–296
		During	16	87	16–196
		Post	8	106	62–281
	Pintail	Pre	7	0	0–96
		During	16	0	0–70
		Post	8	0	0–70
	Common pochard	Pre	7	0	0–685
		During	16	0	0–665
		Post	8	0	0–655
	Northern shoveler	Pre	7	39	0–73
		During	16	25.5	19–50
		Post	8	19	12–47
	Eurasia teal	Pre	7	429	111–586
		During	16	286.5	127–429
		Post	8	228.5	62–311
	Tufted duck	Pre	7	0	0–25
		During	16	0	0–29
		Post	8	0	0–24
	Wigeon	Pre	7	22	10–57
		During	16	18.5	5–25
		Post	8	18	0–37

Note: Number of surveys (n), median count, with count range per boat period, activity phase, and species are presented.

effect. Residuals of the global model were free from heteroscedasticity and temporal autocorrelation (Figure S1). Following the dredge and nesting of the global All Species model, one parsimonious model was found (results presented in Table 3).

Bird counts did not significantly differ in the during and post periods compared to the pre period, indicating minimal impact of boating activities for acoustic telemetry deployment on bird numbers at this site. Cloud percentage and mean wind speed were correlated with bird

TABLE 3 Model results from the All Species model, following model selection and model averaging.

	Estimate	*SE*	*z* value	CI	*p* value
Intercept	3.33	0.37	9.03	2.61, 4.05	<.001
Period					
During	−0.06	0.11	−0.56	−0.27, 0.15	.58
Post	−0.21	0.15	−1.44	−0.51, 0.08	.15
Cloud (%)	0.11	0.05	2.39	0.02, 0.21	.02
Mean wind speed (mph)	−0.13	0.05	−2.81	−0.22, −0.04	<.001

Note: Estimates with unconditional standard error (*SE*), 95% confidence intervals (CI), associated *p* values are presented.

numbers. There was a positive relationship between cloud percentage and bird count, while mean wind speed exhibited a negative relationship. The marginal R^2 (R2m) and conditional R^2 (R2c) of the model were 0.01 and 0.39, respectively.

For the individual species models for teal, tufted duck, and wigeon, following model selection, all models were free from heteroscedasticity and temporal autocorrelation (Figures S2–S4). In common with the All Species model, there was no impact of boat activity on bird counts during and post periods compared to pre among all three species. Further, cloud percentage similarly had positive relationships with counts for all three species (teal, estimate = 0.33, CI = 0.19, 0.47, $p < .001$; tufted duck, estimate = 0.5, CI = 0.17, 0.82, $p = .003$; wigeon, estimate = 0.26, CI = 0.04, 0.48, $p = .02$). When it rained significantly fewer teal (estimate = −0.59, CI = −0.94, −0.23, $p < .001$) and wigeon (estimate = −0.92, CI = −1.38, −0.46, $p < .001$) were observed. Mean temperature had a significantly negative relationship with tufted duck (estimate = −1.53, CI = −1.78, −1.27, $p < .001$) and wigeon (estimate = −1.61, CI = −1.86, −1.37, $p < .001$) counts. Mean wind had a significantly negative relationship with teal (estimate = −0.38, CI = −0.53, −0.23, $p < .001$) and wigeon (estimate = −0.61, CI = −0.86, −0.37, $p < .001$) counts. Marginal R^2 (R2m) and conditional R^2 (R2c) were 0.30 and 0.30, 0.90 and 0.95, and 0.85 and 0.93 for teal, tufted duck, and wigeon, respectively. Full model results can be found in Tables S2–S4.

4 | DISCUSSION

To our knowledge, this is the first study to investigate the impact of boating activities associated with acoustic telemetry studies on waterbird numbers. Although there has been an increasing focus on the impacts of research methodologies on target species, disturbance to non-target species is rarely assessed. At the reservoir level, no disturbance impacts were seen on waterbird numbers. Numbers of survey species were, however, correlated with cloud cover, rain, wind speed, and temperature changes. Further, we found no apparent impact on the counts of three species that are known to be particularly sensitive to disturbance at this site (Wallis et al., 2019).

The key finding that waterbird counts at Abberton were not significantly altered by acoustic telemetry activities is unlikely due to habituation because there is minimal boat disturbance at this site; it is most likely that the boating activities tested were minimally intrusive. Disturbance to birds from boat traffic has been seen extensively (Bellefleur et al., 2009; Carney & Sydeman, 1999; Dehnhard et al., 2019; McFadden et al., 2017) but is often determined by several factors. Previous studies have shown that the speed (Bellefleur et al., 2009; Burger, 1998; Ronconi & Clair, 2002) and frequency of boat encounters (Carney & Sydeman, 1999; McFadden et al., 2017; Schwemmer et al., 2011) are important drivers of disturbance. The minimal impact seen in this study is, therefore, most likely due to the mitigation measures in place during boating activities. These included the application of low boating speeds and conservative buffer zones, as well as the relatively low level of boat activity required for netting and deployment of acoustic telemetry gear, resulting in waterbirds rarely experiencing multiple encounters from boats. However, habitat type may also play a factor as waterbird disturbance to anthropogenic activities in Europe was lowest in lentic waterbodies, such as reservoirs, compared to riverine and coastal areas (Mayer et al., 2019; Robinson & Pollitt, 2002).

Environmental variables, including cloud cover, mean temperature, presence of rain, and mean wind speed were correlated with bird counts. Although environmental conditions can be correlated with numbers and abundance in waterbirds (Brandolin & Blendinger, 2016; Li et al., 2021; McConkey & Bell, 2005; Tavares et al., 2015), the relationships found between bird numbers and the environmental parameters seen here may reflect changes in bird numbers associated with seasonal change in weather. As with other large, lentic waterbodies across the UK (Ellis & Cameron, 2022; Pavón-Jordán et al., 2019; Woodward et al., 2021) waterbirds are typically more common in winter months at this site (Wallis et al., 2019). However, negative relationships between air temperature, rainfall, and high wind speeds and bird counts have previously been observed at this site with long-term, monthly datasets (Wallis et al., 2019) and were previously attributed to high wind speeds and rainfall disrupting zooplankton distribution. Due to survey design, surveys pre-, during-, and post-boating activities were conducted on the same day. Therefore, time of day could be confounded with period in the study. However, several studies have shown no or minimal link between survey time and wetland bird numbers (Christopher et al., 2008; Harms & Dinsmore, 2014; Huang et al., 2024; Kissling, 2004; Naugle et al., 2000; Rawal et al., 2021; Tozer et al., 2016), suggesting that it is unlikely that this is a dominant factor in our study.

The lack of change in bird numbers at the site due to research-related boating activities is a good indication that birds show little evidence of leaving localized areas, or the SPA, during this work. However, birds may remain at this site, despite disturbance, because it is the only appropriate habitat in the area. Monitoring behavior of waterbirds may provide additional information on the impacts of disturbance. For example, alterations in resting, feeding, and fleeing behaviors of individuals following disturbance could alter the energy budgets of species, and greatly impact their migratory success, and lead to negative impacts on population sizes (Donaldson et al., 2007; Marasinghe et al., 2022; Platteeuw & Henkens, 1997). Therefore, future studies combining count data with behavioral data may offer further insights into more nuanced impacts potentially arising from research-related boating activities.

Research methodologies have the potential to cause disturbance to both target and non-target species. Our results indicate that the deployment of acoustic telemetry receivers and netting for study fish, when applied with appropriate well-informed mitigation measures, can be undertaken both during sensitive time periods and in sensitive locations, without causing significant disturbance to waterbird species, including those that are threatened or particularly sensitive to disturbance. Research on movement ecology is vital for informing conservation and management of threatened species. However, such knowledge should not be acquired at the expense of increased stress and disturbance of other species. Hence, in areas where target species share important habitat with other species, particularly those that are threatened or when research is being carried out during sensitive life stages, the potential impacts of research techniques should be evaluated.

AUTHOR CONTRIBUTIONS

Michael J. Williamson: Conceptualization (equal); investigation (equal); formal analysis (supporting); data curation (supporting); visualization (equal); writing – original draft (lead); writing – review and editing (lead); project administration (support). **Joseph Williamson**: Methodology (equal); formal analysis (leading); data curation (supporting); visualization (equal); writing – review and editing (supporting). **Darren Frost**: Investigation (equal); data curation (lead); writing – review and editing (supporting). **Kim Wallis**: Conceptualization (equal); methodology (supporting); writing – review and editing (supporting). **Rosalind M. Wright**: Funding acquisition (equal); project administration (support); writing – review and editing (supporting). **Adam T. Piper**: Conceptualization (equal); investigation (equal); methodology (supporting); writing – review and editing (supporting); supervision (equal); project administration (lead); funding acquisition (equal).

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Raw data supporting the results, and the final code for analysis, are available from the Zenondo Digital Repository: https://zenodo.org/records/17091825.

ETHICS STATEMENT

This study did not involve human or animal subjects and needed no institutional approval.

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ENDNOTES

[1] https://jncc.gov.uk/jncc-assets/RIS/uk11001.pdf.

[2] https://designatedsites.naturalengland.org.uk/SiteDetail.aspx?SiteCode=s1001904.

[3] https://jncc.gov.uk/jncc-assets/SPA-N2K/UK9009141.pdf.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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