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Acoustic receivers detection efficiency: temporal & spatial variations

Juliette Theoleyre

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AGROCAMPUS OUEST

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Acoustic receivers detection efficiency: temporal & spatial variations

Par : Juliette Theoleyre

Soutenu à Rennes
le 07/09/2021

Devant le jury composé de :

Président : Magalie HOUÉE-BIGOT

Autres membres du jury (Nom, Qualité)

Maître de stage : Etienne RIVOT, Céline ARTERO &
Stephen GREGORY

Enseignant référent : Marie PIERRE ETIENNE

Les analyses et les conclusions de ce travail d'étudiant n'engagent que la responsabilité de son auteur et non celle d'AGROCAMPUS OUEST

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CONTEXT

The European Interreg SALmonids MAnagement Round the english CHannel (SAMARCH) project, started in 2017, aims to retrieve new information on salmonids marine phase in order to implement the regulations of both species' Atlantic salmon (*Salmo salar*) and sea trout (*Salmo trutta*) in the English Channel area.

As part of SAMARCH, a smolt tracking project has been realised on Atlantic salmon and sea trout smolts to study their mortality during their first downstream migration through estuarine environments toward the sea. It took place in 2018-2019 in four estuaries: Tamar and Frome (UK), Bresle and Scorff (France).

INTRODUCTION

Aquatic species, as terrestrial species, are impacted by climate change and human activities [Dudgeon 2019]. To preserve aquatic biodiversity, we need to understand its ecology, especially for migrating species that use several environments and therefore are susceptible to be more impacted by human activities (including pollution, dragging, fishing; [Kessel et al. 2014]). Salmon and sea trout are anadromous species and spend the first part of their lives at sea, returning to fresh water to spawn. Even though the freshwater phase of the salmonids is well known, there is still very little knowledge on their marine phase, including their migration routes and behaviour at sea [Klemetsen et al., 2003]. An increase in the fish marine mortality was noticed in the late 80's and early 90's, as counter data showed that returning fish became fewer. Most Northern Europe surveyed salmonid populations declined over decades [ICES 2019]. Currently, it is thought that this early marine phase is critical to individual smolt survival and might therefore underpin these observed salmonid population declines [Thorstad et al., 2012].

Technology and miniaturisation advances are enabling the tracking of increasingly smaller aquatic animals in fresh waters, but also more distant marine waters [Rechisky et al., 2020]. One of these tracking methods is passive acoustic telemetry that is an important and worldwide monitoring tool used to study the spatial ecology and behaviour of aquatic species [Weinz et al., 2021]. Studied individuals are transplanted with an acoustic transmitter (hereafter tag) that emits unique coded ultrasonic signals at a specific frequency. This signal can be recognised by submerged hydrophones coupled with receivers (hereafter receivers) usually deployed at fixed locations along the fish migration path. When a tag is within the detection range of a receiver, its unique identity (ID) is recorded, along with a date-time stamp. The acknowledgment of a signal by a receiver will then be referred to as a detection [Winter et al., 2021; Weinz et al., 2021].

Acoustic tags transmit their ID using a “train” of pulses (or pings). The ID is encoded in the time intervals between successive pulses (i.e., the *relative positions* of pulses in a train; [Johnson et al., 2019a]). A synchronised (sync) interval is the first interval in this series of pulses required for the successful detection of a transmitter. The sync code followed by its pings has its own rhythmicity, providing a unique signal for each tagged individual, which constitutes the ID of the tag [Vemco 2015]. This set of pulses lasts few milliseconds and is randomly repeated at a frequency chosen by the user, usually several seconds to avoid tag collisions, which can occur when several tagged fish are swimming through the receiver detection range at the same time [Simpfendorfer et al., 2008]. All pulses must be heard to be interpreted as a detection. In the Vemco VR2W receivers, data summary statistics are recorded every 24 hours at midnight UTC and when data are downloaded [Vemco 2015]. Those summaries include receiver recorded data on the numbers of tag sync codes and pulses received daily. Thanks to those summaries, one can calculate metrics of receiver performance, such as the “noise quotient”. Among the commonly used receiver performance metrics, noise quotient is considered to capture the ambient noise better than the alternatives [Simpfendorfer et al. 2008].

With passive acoustic telemetry, the exact location of the tagged fish is unknown. The only information recorded is the presence of a tagged fish with a certain level of confidence, usually measured as detection efficiency; a lack of detection can be due either to the absence of a tagged fish or the inability of the receiver to detect a signal even if the fish was within the receiver detection range [Kessel et al., 2014]. Therefore, inference from passive acoustic telemetry must account for detection efficiency to minimise the potential bias from interpreting missed detections as a non-detection due, e.g., to fish mortality [Johnson et al., 2019b ; Rechisky et al., 2020]. Proper knowledge over the detection range and efficiency of the receivers would

increase the confidence of statements relative to the absence of a tagged animal, essential information for study relative to survival rates in order to correctly assess the mortality rate based on detections [Winter et al., 2021].

Detection efficiency (DE) can be calculated as the proportion of known tag transmission that are detected by a receiver in a given period of time. Theoretically, DE shows a decreasing sigmoidal relationship with increasing distance between the tag and the receiver: DE would be 100% at 0 m decreasing to 0% and longer distances, depending on the frequency and the power of the acoustic material used [Kessel et al., 2014 ; Rechisky et al., 2020]. The standard way to measure DE is to perform range tests, which involves emitting tag transmissions (usually from a boat) at different distances from the receiver and measuring the proportion that are detected successfully [Winter et al., 2021]. In reality, DE can be impacted by different variables that can vary temporally and/or spatially. Hence, DE is not always as expected and may present spatial and temporal variations [Heupel et al., 2008; Kessel et al., 2014; Winter et al., 2021].

Environmental variables vary through time and space at the various locations where receivers are deployed. Some of them might create “environmental noise” that could block or interfere with the detection of a complete tag ID (sync code + pulse chain) [Winter et al., 2021]. Thus, they could be the cause of these spatial and temporal variations in DE by disturbing the tag detection [Table 1]. Examples of environmental variables include the physical and chemical properties of water, such as water temperature and water turbidity, which can influence the propagation of the sound in the water column and thus interfere with the tag signal detection [Weinz et al., 2021; Heupel et al., 2008]. Environmental noise can be caused by other subaquatic species (including animals and plants), human activities or by other processes, such as waves created by the wind, all of which can impact the DE if occurring at the same frequency as the tag transmissions [Gjelland and Hedger., 2013; Kessel et al., 2014; Winter et al., 2021]. Physical obstructions, such as topography, submerged aquatic vegetation (SAV) or biofouling covering the head of the receiver can block or deflect the tag detections [Heupel et al., 2008; Gjelland and Hedger., 2013; Weinz et al., 2021].

Range tests are both time-consuming and financially costly, as they necessitate long days of fieldwork, many man hours and boat time [Kessel et al., 2014]. For example, testing the DE of a single receiver every 25m from 0 to 200m in which each test takes 2 minutes will take approximately 45 minutes. These tests must be done for each receiver and the total time taken must then also include the time taken for boat travel between receivers [Kessel et al., 2014]. Ideally, range tests should be performed for several minutes, rather than 2 minutes, to get more accurate data [Johnson et al., 2019b]. Measurements of the environmental parameters related to noise to explain spatial and temporal variations in detection efficiency will add more time to these range tests and are often difficult from a boat, introduce several potential biases (sampling method, device, observatory, etc.) [Weinz et al., 2021]. Furthermore, range tests tend only to be possible under favourable sea conditions, i.e., calm conditions when some environmental noises are minimal [Kessel et al., 2014]. And even when all constraints are met and the range tests can be done, there is always a possibility of logistic difficulties, such as an engine breakdown. In summary, doing range tests and measuring potentially noisy environmental parameters to estimate detection efficiency is time consuming, labour intensive, weather dependent and subject to unforeseen logistical problems.

Despite the difficulties in measuring DE, an understanding of which environmental factors affect it, and whether they affect it positively or negatively, could allow us to predict the DE around the receiver at a given distance. Subsequently, we could deduce the probability that a non-detection is due to a missed detection due to imperfect detection or a lack of detection because there was no tag to be detected, i.e., the fish had died. This information is essential when using passive acoustic telemetry data to make inferences about the mortality of salmonid

smolts through estuaries [Johnson et al., 2019b; Rechisky et al., 2020]. Noise quotient aims to capture a measure of environmental noise around the receiver and can be calculated from data recorded by the receiver itself [Simpfendorfer et al. 2008]. So, perhaps a solution to measure environmental noise without having to collect environmental data during fieldwork would be to use noise quotient as a proxy of the effect(s) of environmental noise(s). Indeed, by predicting DE using only noise quotient could negate the need to collect environmental data during fieldwork and yet still allow us to predict DE whenever a fish was around the receiver.

Our study aimed to explore whether noise quotient could be used to represent environmental noise, which could thereby be used to explain spatial and temporal variation in detection efficiency. To address this aim, we studied the following three specific objectives: (1) to establish spatial and temporal variations in detection efficiency measured during range tests on the River Frome in 2021 and describe them using measured environmental variables; (2) to explore the relationship between these measured environmental variables and noise quotient for receivers in the River Frome in 2021; and (3) to use this relationship, together with other possible variables representing time and space, to describe detection efficiency during range tests on rivers Bresle, Scorff and Tamar in 2018 – 2021.

Table 1 Hypothesis table of the parameters identified in the literature that have an influence over acoustic detection efficiency where “Collection method” along with “Device” refer to the way data were collected ; “Hypothetic effect” state the hypothetic influence of the parameter (“+” positive or “-” negative) over detection efficiency ; “Observed effect” the effect observed after analysis of the data and “Selection” the reason why the parameter was or wasn’t selected.

Predictor	Definition	Unit	Range / Levels	Collection method	Device	Hypothetic effect	Observed effect	Selection	Reference
Distance	Distance of the tag from the ‘targeted’ receiver	m	[0 ; + ∞]	Fieldwork	GPS & Waypoint	-	-	Structural variable	Winter et al. (2021)
Month	Month during which the tests were performed	/	[1;12]	Fieldwork	Laptop	Winter > Summer	-	Fieldwork collected	Kendall et al. (2021) Weinz et al. (2021)
Water temperature	Temperature of the water	°C	[-∞ ; + ∞]	Fieldwork	HOBO	-	-	Insufficient data	Kessel et al. (2014) Gjelland and Hedger (2013) Heupel et al. (2008) Winter et al. (2021)
Visibility	Maximum distance of visibility in the water column	m	[0 ; + ∞]	Fieldwork	Disk of secchi	+	-	Collinear with <i>Bathymetry</i> & Indufficient data	Kendall et al. (2021). Winter et al. (2021)
Wind speed	Hourly average wind speed	Knots/h	[0 ; + ∞]	Online	Weather Station : windfinder.com	-	-	Fieldwork collected	Kessel et al. (2014) Gjelland and Hedger (2013) Winter et al. (2021)
Wave height	Hourly average wind speed	m	[0 ; + ∞]	Online	Weather Station : windfinder.com	-	-	Redundant with <i>Sea state</i> & Insufficient data	Kessel et al. (2014)
Sea-state	The ‘degree of turbulence of the sea’, generally measured on a scale of 0 to 9 according to average wave height.	/	0 : Mirror 1 : Ripples 2 : Small wavelets	Fieldwork	Qualitative observation	-	-	Fieldwork collected	Kessel et al. (2014)
Tide coefficient	Amplitude of the tide forecast (difference in height between the consecutive high tides and low tides in any given area).	/	[0 ; + ∞]	Online	Weather Station : tides4fishing.com	-	Null	Neutral effect	Kessel et al. (2014) Rechisky et al. (2020)
Tide type	States whether the tide is High/Low/Rising/Decreasing : Hourly measure.	/	Decreasing Low Rising High	Online	Weather Station : windfinder.com	Low < High	Null	Insufficient data	Kessel et al. (2014) Rechisky et al. (2020)
Noise Estimate	Global noise estimation per receiver.	/	Low Medium High	Fieldwork	Qualitative observation	Low > Medium > High	Low > Medium	Collinear with <i>Substrate</i>	Kendall et al. (2021). Winter et al. (2021)

Noise Nuisance	Underwater noise around the receiver	dB	$[-\infty ; +\infty]$	Fieldwork	Hydrophone	-	Null	Insufficient data	Winter et al. (2021)
Noise Quotient	Is the difference between the number of detected pulses among all the pulse trains in the period (i.e., valid pulses) and the total number of available pulses given the number of sync signals (i.e., product of sync signals and constant number of pulses(8 in our study))	/	$[-\infty ; +\infty]$	Calculation	Receiver summary data	-	-	Performance metric	Heupel et al. (2008) Simpfendorfer et al. (2008)
Environment	Refer to the 'environment'/location of the receiver (River, Estuary, Marine).	/	River Estuary Marine	Fieldwork	Map	River > Estuary > Marine	None	Collinear to <i>Substrate</i>	Kendall et al. (2021). Winter et al. (2021)
Bathymetry	Bathymetry at the receiver location.	m	$[-\infty ; +\infty]$	Fieldwork	Bathymetry map	+	-	Previous assessment	Kessel et al. (2021) Gjelland and Hedger (2013) Winter et al. (2021)
Substrate	Substrate at the receiver location (Muddy, Sandy, Coarse substrate).	/	Muddy Sandy Coarse substrate	Fieldwork	Map	Muddy > Sandy > Coarse substrate	+	Previous assessment	Kendall et al. (2021) Winter et al. (2021)
Width	Width of the estuary at the 'targeted' receiver location	m	$[0 ; +\infty]$	Fieldwork	Map	+	+	Redundant with <i>Distance to shore</i>	Winter et al. (2021)
Distance to shore	Minimum distance from the 'targeted' receiver to the coast	m	$[-\infty ; +\infty]$	Fieldwork	Map	+	+	Previous assessment	Winter et al. (2021)
Submerged Aquatic Vegetation (SAV)	Aquatic vegetation attached to the receivers' buoy	/	Absent Small Medium High	Fieldwork	Qualitative observation	-	-	Fieldwork collected	Weinz et al. (2021)

MATERIEL AND METHOD

Study areas and environmental parameters

Both sea trout and Atlantic salmon smolts were tagged and tracked during their first downstream migration in four estuaries discharging into the English Channel: two in southern England (rivers Frome and Tamar) and two in northern France (rivers Bresle and Scorff) [Fig. 1].

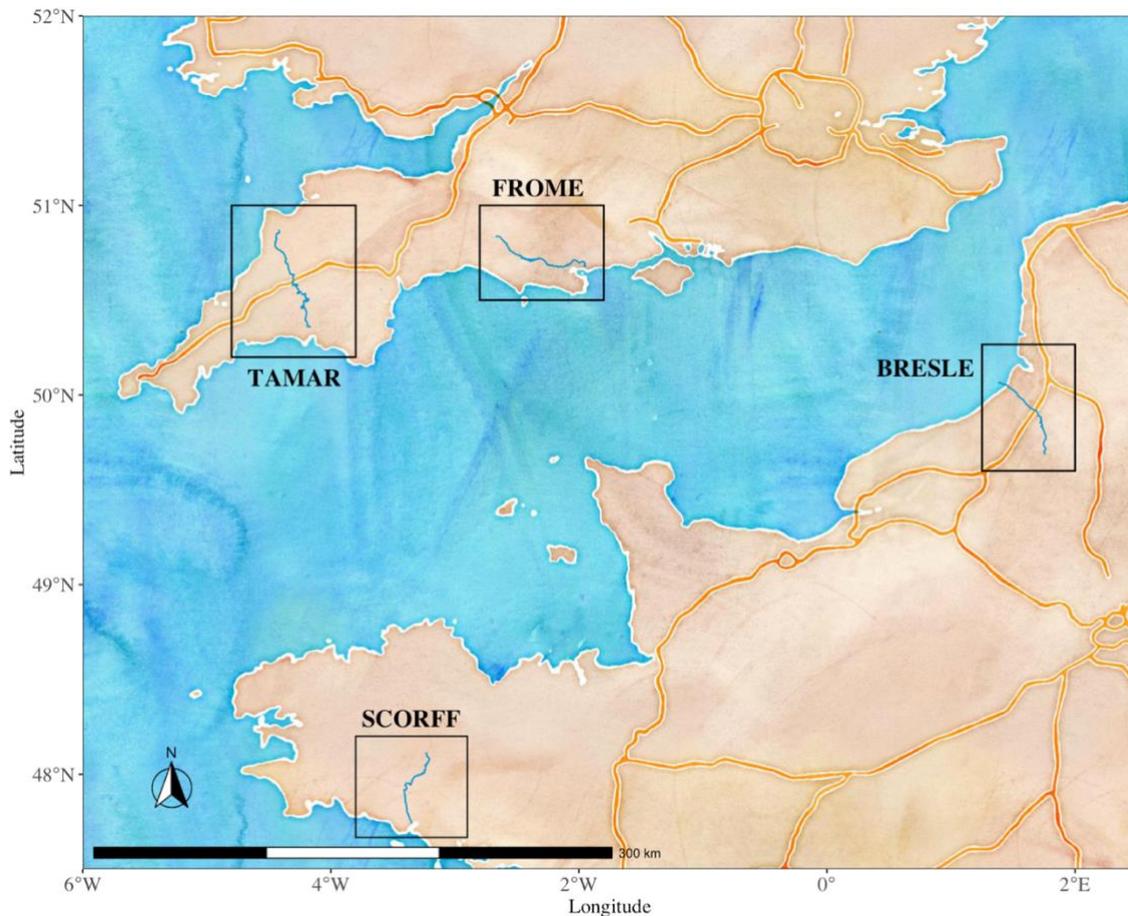


Figure 1 Map of the studied river sites during the project.

While the four rivers are 70 km long on average, each one of the estuaries has its own configuration [Fig. 2A-D]. Specifically: (1) the river Tamar estuary is 68 m wide and 2 m deep around its entry and gradually widens before narrowing to a width of 318 m and 28 m depth at its exit. After the exit, the estuary opens into Plymouth Sound which is nearly 6 km wide with depth varying between 5 and 11 m; (2) the river Frome estuary “entry” is 31 m wide and 1 m deep. It leads up to a large harbour connected to the sea by a 315 m wide opening of 9.5 m deep. With its total of 36 km², it’s the biggest estuary of Europe; (3) the river Scorff estuary is at the tidal limit and is 39 m wide and 1 m deep it then gradually expands before narrowing to a width of 600 m width and 21 m depth at the exit; and (4) the river Bresle estuary is a rather unusual as the river splits into two arms at the downstream end: one entering a commercial harbour (120 m x 500 m, 4.5 m deep) and the other a recreational harbour (60 m x 450 m, 4.5 m deep).

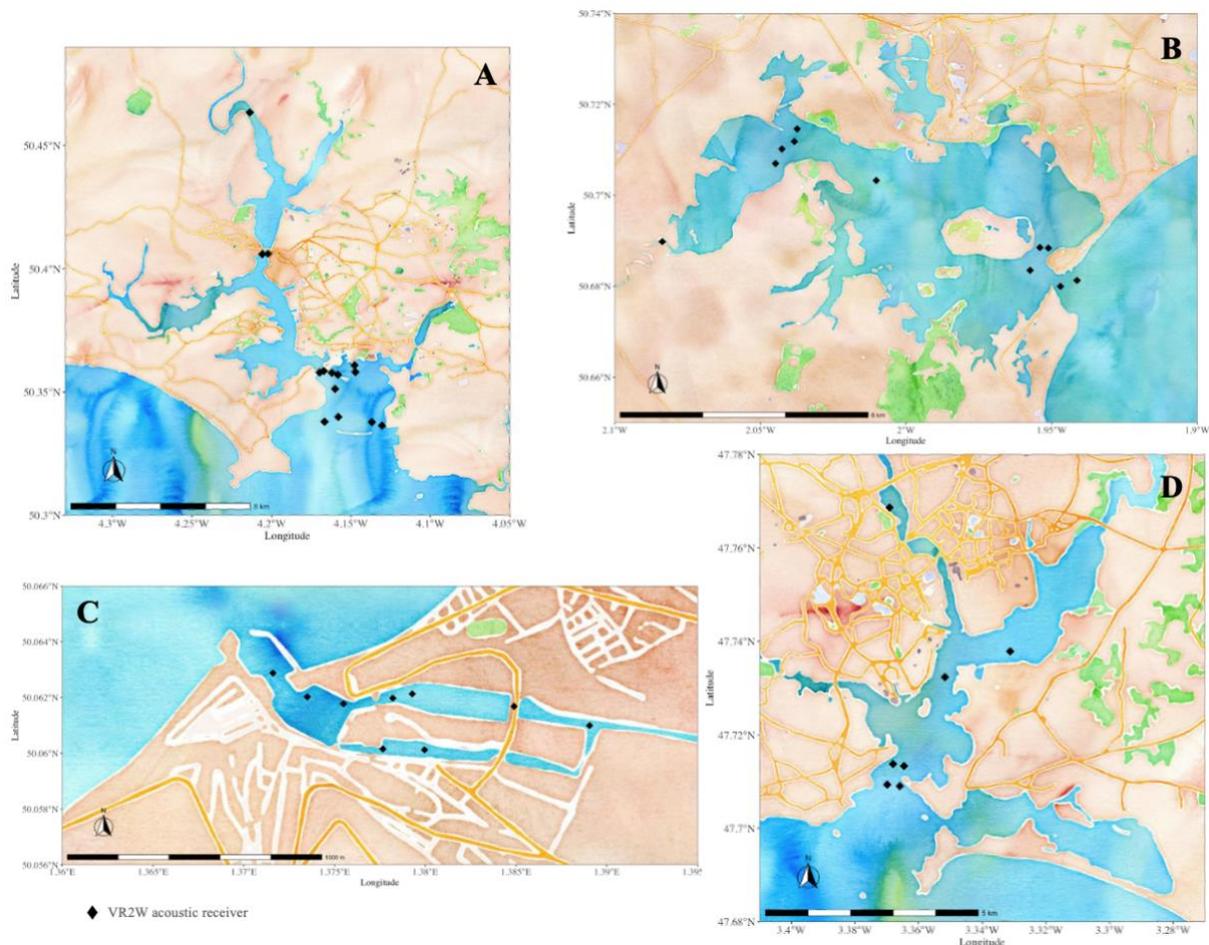


Figure 2 Map showing the locations (diamond) of the acoustic receivers deployed in each sites of the study: (A) Tamar, (B) Frome, (C) Bresle, and (D) Scorff.

Between 10 and 15 VR2W 180 kHz acoustic receivers (Vemco, Halifax, Nova Scotia, Canada) were deployed in each site, along estuaries as well as on their tributaries [Fig. 2A-D]. One or two receivers were deployed in a location to cover the width of the site.

Various environmental parameters could produce environmental noise that affects receiver DE [Kendall et al. 2021; Winter et al., 2021]. To assess their impact on the receiver's performance, we collect those measurements either on the field, online or from previous assessment of their habitat [Table 1]. Though the salmonid smolt tracking project took place on all four estuaries, fieldwork in 2021 was focused on the river Frome only. Therefore, some environmental parameters collected were available only for the river Frome during the year 2021.

Range tests

To assess the DE of the receivers in these estuaries, two different types of acoustic boat range tests were performed with a V9 tag (180 kHz) beeping every 10 seconds: (1) stationary and (2) drift range tests.

Stationary tests

Stationary boat range tests were performed with the engine and sounder off to avoid acoustic interference. The test tag was lowered from a stationary boat, anchored to the bottom of the

estuary, at distance intervals of 25 m from the receiver between 0 and 200 m. The tag was held underwater for 2 minutes at 1 m below the water surface. Acoustic tests were carried out after cleaning the receiver and always in the same direction. Distances were estimated from GPS positions of the receivers.

Drift tests

Range tests prior to 2021 were done without an anchor, when the boat was drifting. Depending on the sea state, the boat would not stay at a precise location, but would move with the prevailing conditions, including current, wind, etc. Thus, range tests were performed while drifting from one location to another along the direction of drifting. Other than that, they were performed the same way.

Statistical analysis

Parameter exploration & preparation

Data were collected to test hypotheses about the effects of environmental variables on DE [Table 1]. When there are 2 or more explanatory variables in the model, they should not be strongly correlated, i.e., they should not be collinear [Dormann et al 2013]. The presence of collinearity among explanatory variables will inflate the standard errors of the estimated model coefficients and can produce unreliable results. Examining a correlation matrix between the continuous parameters along with a contingency table analysis (Pearson's Chi-squared test) for the categorical predictors will indicate if there are correlations between predictors [Dormann et al 2013]. For continuous explanatory variables, collinearity was tested via Pearson's correlation whereby an absolute correlation coefficient greater than 0.7 indicates a dependence between two variables [Dormann et al 2013]. For categorical explanatory variable, pairs of variables were analysed using contingency tables. Where explanatory variables were judged to be collinear, only one could be included in the model and which one was included was decided based on its perceived effect on DE.

Continuous variables were standardised (zero mean and unit standard deviation) to allow comparison within and between models. Standardized coefficients are coefficients adjusted so that they may be interpreted as having the same, standardized scale and the magnitude of the coefficients can be directly compared (ranked). Standardized coefficients represent the mean change in the response given a one standard deviation change in the explanatory variable. Taking the absolute value of the standardized coefficients enables them to be ranked from highest to lowest, in order of strength of association with the response variable.

Model fitting and selection

Recorded range test data were downloaded and treated with the VUE software (Vemco, Halifax, Nova Scotia, Canada). The resulting data were used to calculate counts of detections for model fitting: the number of successful detections ($N_{recorded\ detection}$) and the number of transmissions available to be detected ($N_{expected\ or\ theoretical\ detection}$). To visually explore DE, we calculated it directly and for each range test (i.e., at each receiver on each occasion) as $DE = (N_{recorded\ detection} / N_{expected\ or\ theoretical\ detection}) \times 100$ and used this for plotting, etc. To test the effect of environmental variables on DE we modelled $N_{recorded\ detection}$ as a proportion of $N_{expected\ or\ theoretical\ detection}$ in a binomial GLMM where the proportion p was estimated as a function of the environmental variables. The environmental variables used in each GLMM varied according to the specific objective. We will refer to 3 main categories of environmental variables: (1) fieldwork collected, (2) inherent and (3) noise quotient, identified in the Selection column of [Table 1]. The GLMM also included a random effect of receiver

location to account for variation in receiver DE due to unmeasured variables. This random effect allows the receiver to have different intercepts to take account of the spatial variation within the sampling, as well as accounting for repeated measures. *Distance* from the receiver was considered as a structural parameter and was included in all models. Prior to analysis, observations with any missing data were excluded. GLMMs were fit using R (v.4.0.3; R Core Team 2020) via RStudio (v. 1.3.1093).

Where appropriate, models were compared to exclude environmental variables that explained negligible amounts of variation in DE. This was done using model comparison. To compare the fits of two models, we used the `anova()` function to test whether the more complex model was significantly better at explaining the variation in DE than the simpler model. It performs a Chi-square test to compare models (i.e., it tests whether reduction in the residual sum of squares are statistically significant or not). If the resulting p-value was sufficiently low (i.e., $p < 0.05$), we concluded that the more complex model was significantly better than the simpler model, and thus favoured the more complex model. If the p-value was not sufficiently low (i.e., $p > 0.05$), we favoured the simpler model.

The variance explained by the GLMM was calculated as the marginal R-squared (fixed effects only) and conditional R² (fixed and random effects) using the `r2()` function from the ‘performance’ package. [Weinz et al., 2021]. The marginal R-squared indicated how much of the variance is explained by the model was explained by the fixed effect part only, while the conditional R-squared indicated how much variance was explained by the “full” model. Deviance measured the unexplained variation of a model and therefore measures its goodness of fit. Subtracting the deviance of the “full” model to the deviance of the structural model, we obtained the variation explained by the environmental variables.

Model prediction

The noise quotient was calculated from summary data stored by the receivers and is considered to represent a measure of environment noise [Simpfendorfer et al. (2008)]. The number of sync codes (N_{sync}) and pulses (N_{pulses}) were used to calculate noise quotient following:

$$Noise\ quotient = N_{pulses} - (N_{sync} \times 8)$$

In perfect conditions where there is no environmental noise, noise quotient is 0 because there are 8 pulses in a tag transmission. Excessive syncs or pulses suggests that there are a large number of transmission collisions, echoes or noise in the vicinity of the receiver. Negative values would indicate tag collisions occurrence while positive values would be interpreted as ambient/ anthropogenic/ biotic noise [Simpfendorfer et al. (2008)]. Using a Linear Mixed Model (LMM), we established the relationships between environmental variables (fieldwork collected and inherent) and noise quotient for receivers in the River Frome in 2021 to assess whether noise quotient could be used as a proxy variable for those environmental variables. Hence, the LMM response variable would be the noise quotient and the environmental variables the explanatory variables.

RESULTS

Spatial and temporal variation of the detection efficiency

Range tests were performed at different locations and at different times allowing the assessment of spatial and temporal variation. Spatial variation was observed between receivers of the same river and among the different rivers of the study. For example, detection efficiency for each River Frome receiver was highly variable and ranged from 0 to 100% and their mean detection efficiency (over all range tests) decreased with distance from the saline limit, with higher DE at the upstream saline limit and lower DE when close to the estuary exit [Fig. 3A]. Overall mean detection efficiency (over all receivers and range tests) also varied between rivers, with French estuaries having lower detection efficiency [Fig. 3B].

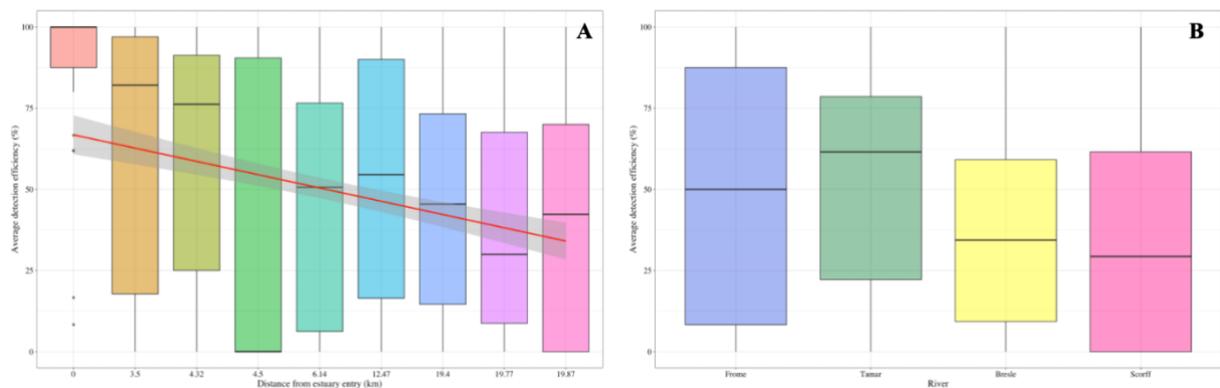


Figure 3 Spatial variation of the detection efficiency: (A) within the receivers deployed in the River Frome estuary and (B) among the different rivers of the study.

Detection efficiency also varied temporally, both between individual range tests [Fig. 3A], but also depending on the month. For example, detection efficiency among range tests at the River Frome receivers in 2021 appeared higher during late winter and early spring (March) and to deteriorate in subsequent months (April-August), although the trend was weak and the within-month variability was high [Fig. 4].

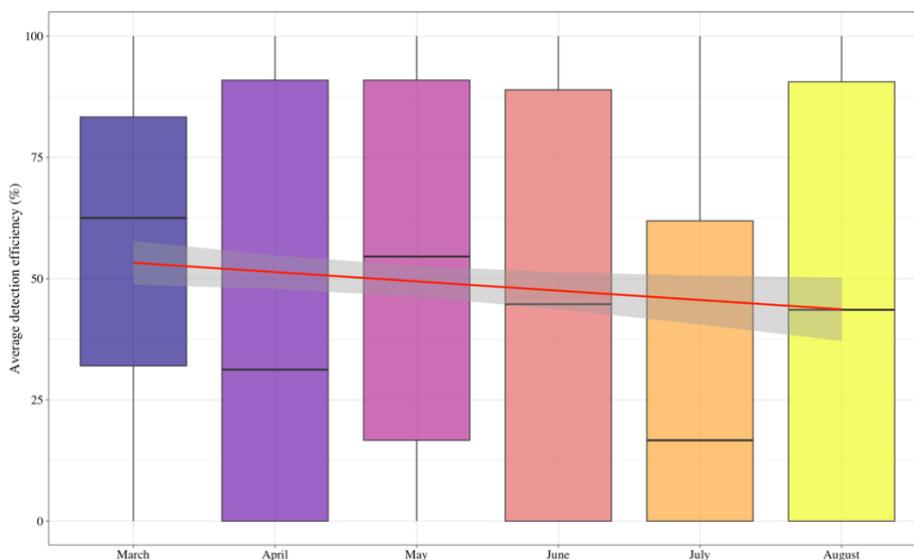


Figure 4 Temporal variation of the detection efficiency of the River Frome receivers during 2021.

Environment parameters influence on detection efficiency

Based on exploration of collinearity among explanatory variables, some were excluded from the study because they were redundant or had insufficient data to be useful [Table 1].

Using GLMM to describe detection efficiency from fieldwork collected and inherent environmental variables as explanatory variables, we tested our hypotheses about the influence of environmental parameters on the DE of receivers measured in the River Frome in 2021. A summary of the model is presented in [Table 2] and plots of the different effects, showing their directions and strengths, are shown in [Fig. 5].

Tableau 2 : Summary of the Generalized Linear Mixed Model (GLMM) describing detection efficiency based on environmental variables from the River Frome collected in 2021.

Predictor	Range / Level	Estimate \pm s.e.	Z-value	Pr(> z)
(Intercept)	—	1.035 \pm 0.714	1.448	0.148
Distance	[- 1.485 ; 1.686]	-1.332 \pm 0.030	-42.988	< 2e-16
Month	[-0.970 ; 1.881]	-0.472 \pm 0.035	-13.558	< 2e-16
Bathymetry	[- 1.381; 1.831]	-0.108 \pm 0.301	-0.359	0.720
Distance to shore	[- 1.797 ; 1.749]	-0.415 \pm 0.260	-1.598	0.110
Wind speed	[- 1.397 ; 2.787]	-0.060 \pm 0.035	-1.700	< 0.1
Substrate	Muddy	Reference level	—	—
	Sandy	0.368 \pm 0.815	0.451	0.652
	Coarse substrate	0.283 \pm 1.025	0.276	0.783
Sea state	0 : Mirror	Reference level	—	—
	1 : Ripples	-0.466 \pm 0.096	-4.871	< 1e-06
	2 : Small wavelets	-0.830 \pm 0.134	-6.207	< 5e-10
SAV	Absent	Reference level	—	—
	Small	-0.880 \pm 0.143	-6.135	< 8e-10
	Medium	-1.140 \pm 0.193	-5.874	< 4e-09
	High	-1.150 \pm 0.227	-6.559	< 4e-11
Random effect	Variance	Standard deviance		
Receiver location				
(Intercept)	0.486	0.697		

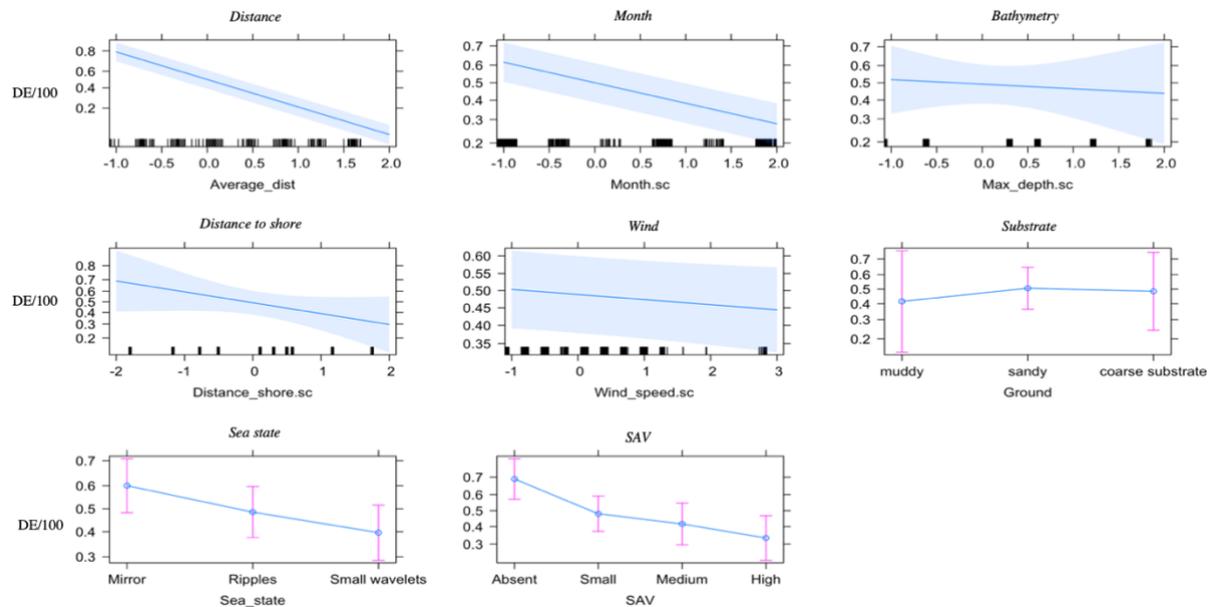


Figure 5 Plots showing the directions and strengths of the effects of environmental variables hypothesised to influence detection efficiency of acoustic receivers.

Based on our GLMM model output, *Distance*, *Month*, *Sea state* and *SAV* all had a significant effect on DE ($p < 0.05$) [Table 2]. Estimated coefficients representing the effects of each environmental variable, alongside plots of their marginal effects (the effect of each environmental variable while holding the effects of others constant at their mean value), allowed us to evaluate the influence of each environmental variable on DE. Concerning the continuous variables, all our hypotheses were confirmed except for *Distance to shore*: they all had a negative impact over DE [Table 1]. The strengths of their negative effects was not always statistically significant, suggesting that their effects were negligible, but p-values do not necessarily identify ecologically important effect sizes and so we cannot state they had no effect upon DE. Among *Substrate* types, both sandy and coarse substrate coefficients were positive compared to muddy and the sandy substrate was estimated to have the largest effect on DE, suggesting that a sandy substrate was associated with higher DE than coarse substrate, which itself was associated with higher DE than muddy substrate. As the severity of *Sea-state* and *SAV* increased, so their negative effects on DE also increase, as was hypothesised. Ranking the absolute values of the continuous standardized estimate coefficient, environmental variables would have been ranked by order of importance as: *Distance* > *Month* > *Distance to shore* > *Bathymetry* > *Wind*.

The marginal R² of the model (explanatory variables only) was 0.402 and conditional R² (explanatory variables and random effects) was 0.406. Results show that the selected environmental variables explained 18.5% of the detection efficiency variation. Thus, variation in detection efficiency in time and space can be explained – in part – by environmental variables.

Relationship between noise quotient and the environmental variables

As *noise quotient* is considered to represent a measure of acoustic noise in the environment, we explored the relationship between noise quotient and the fieldwork collected and inherent environmental variables [Table 1]. As for the GLMM models, the structure parameter *Distance* from the receiver, as well as a random effect of the receiver location, were included in the LMM.

Table 3 Summary of the Linear Mixed Model (LMM) describing the noise quotient based on environmental variables from the River Frome collected in 2021.

Predictor	Range / Level	Estimate \pm s.e.	t-value	Pr(> t)
(Intercept)	—	- 4.614 \pm 235.583	- 0.020	0.985
Distance	[- 1.485 ; 1.686]	80.431 \pm 34.400	2.325	< 0.05
Month	[-0.970 ; 1.881]	- 73.964 \pm 37.767	-1.958	< 0.1
Bathymetry	[- 1.381; 1.831]	221.536 \pm 80.093	2.766	< 0.05
Distance to shore	[- 1.797 ; 1.749]	- 53.535 \pm 65.378	- 0.819	0.446
Wind speed	[- 1.397 ; 2.787]	70.175 \pm 46.922	1.496	0.135
Substrate	Muddy	Reference level	—	—
	Sandy	109.927 \pm 217.310	0.506	0.628
	Coarse substrate	0.432 \pm 283.055	0.002	0.999
Sea state	0 : Mirror	Reference level	—	—
	1 : Ripples	268.050 \pm 117.154	2.288	< 0.05
	2 : Small wavelets	483.450 \pm 162.960	2.967	< 0.001
SAV	Absent	Reference level	—	—
	Small	- 74.314 \pm 141.839	- 0.524	0.600
	Medium	- 153.809 \pm 212.560	- 0.723	0.470
	High	- 636.538 \pm 239.364	- 2.659	< 0.001
Random effect	Variance	Standard deviance		
Receiver location				
(Intercept)	15464	124.4		
Residuals	534332	731.0		

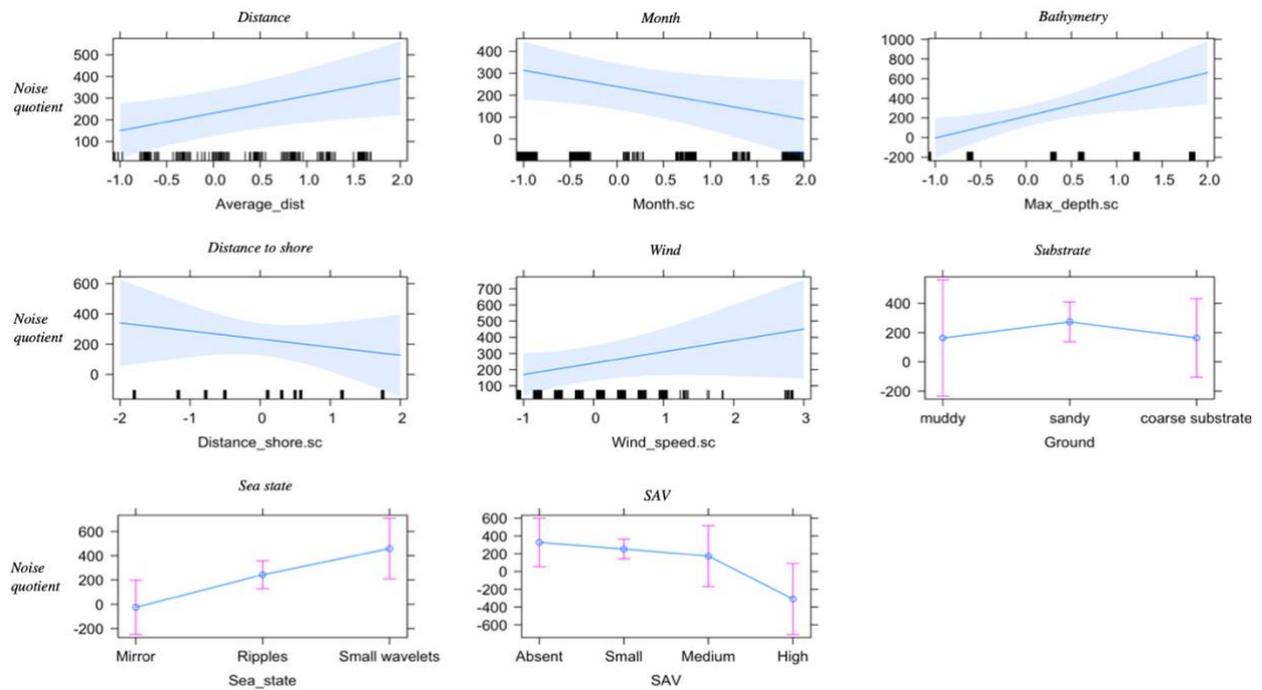


Figure 6 Plots showing the directions and strengths of the effects of environmental variables hypothesised to influence detection efficiency of acoustic receivers.

Based on the LMM output, *Distance*, *Bathymetry*, *Sea state* and *SAV* had a significant effect on DE ($p < 0.05$) [Table 3]. Estimated coefficients representing the effects of each environmental variable, alongside plots of their marginal effects (the effect of each environmental variable while holding the effects of others constant at their mean value), allowed us to evaluate the influence of each environmental variable on DE. Concerning the continuous variables, *Month* and *Distance to shore* confirmed our hypotheses and had a negative effect on *Noise quotient*. The effects of the other continuous variables were positive and contrary to our hypotheses, although *Wind speed* was not statistically significant. Regarding the categorical variables, *Substrate* and *Sea state* had positive effects on *Noise quotient* and *SAV* had a negative effect on *Noise quotient*. The *Substrate* and *Sea state* results were as hypothesised, although the positive effect of coarse substrate on noise quotient was expected to be higher than that of sandy. The *SAV* result was contrary to our hypothesis and suggested that high levels of *SAV* were associated with lower noise quotient.

The marginal R² of the model (explanatory variables only) was 0.118 and conditional R² (explanatory variables and random effects) was 0.143.

In parallel to this model, 2 other models were studied: one LMM with noise quotient as the response variable and only fieldwork collected environmental variables as explanatory variables, the other with only inherent environmental parameters as explanatory variables. Calculations of the variation explained by each of those groups of environmental variables revealed that only 1.1% of noise quotient was explained by the fieldwork collected variables against only 0.7% for the inherent variables. Comparison of these models with the complete LMM that included both groups of environmental variables suggested that the one considering only the fieldwork collected variables was a better fit than the one only considering the inherent variables.

Noise quotient as a proxy variable

Data collected during the previous years of the project (2019-2020) did not include the fieldwork variables [Table 1] and so we wanted to explore whether noise quotient, which can be calculated for all receivers without the need to measure additional environmental variables, was a sufficient descriptor of DE or whether additional environmental variables were still needed. To do this, we compared three GLMM differing by the explanatory variables that were used to describe detection efficiency. The models differed in their complexity, i.e., the number of independent variables they use, yet all of them still included *Distance* as a structural parameter and the location of the receiver as a random effect. As previously stated, detection efficiency varies between the different rivers of the study. Hence, we added a new structural parameter: *River*, to the model.

Table 4 Summary of the Generalized Linear Mixed Model (GLMM) predicting the detection efficiency with (a) Noise quotient, (b) inherent environmental parameters, (c) Noise quotient and inherent environmental parameters as explanatory variables, based on data from the 4 rivers of the study (Tamar, Frome, Bresle and Scorff) collected since 2018.

Predictor	Range / Level	Estimate \pm s.e.	Z-value	Pr(> z)
(a)				
(Intercept)	—	-0.126 \pm 0.363	-0.348	0.728
Distance	[- 1770 ; 1.651]	- 1.102 \pm 0.021	- 52.727	< 2e-16
River	Frome	Reference level	—	—
	Tamar	0.595 \pm 0.516	1.153	0.249
	Bresle	- 0.523 \pm 0.573	- 0.912	0.362
	Scorff	- 3.097 \pm 0.531	- 5.835	< 5e-09
Noise quotient	[- 3.498 ; 8.556]	- 0.083 \pm 0.028	-2.980	< 0.001
(b)				
(Intercept)	—	0.261 \pm 0.606	0.430	0.667
Distance	[- 1.485 ; 1.686]	- 1.122 \pm 0.021	-53.082	< 2e-16
River	Frome	Reference level	—	—
	Tamar	1.153 \pm 0.728	1.158	0.113
	Bresle	- 1.043 \pm 0.697	- 1.498	0.134
	Scorff	- 3.174 \pm 0.628	- 5.057	< 4e-07
Month	[- 1.010 ; 1.719]	- 0.290 \pm 0.025	-11.670	< 2e-16
Distance to shore	[- 1.471 ; 2.126]	0.068 \pm 0.248	0.277	0.782
Bathymetry	[- 2.675 ; 1.938]	- 0.337 \pm 0.217	- 1.557	0.119
Substrate	Muddy	Reference level	—	—
	Sandy	- 0.745 \pm 0.649	- 1.147	0.251
	Coarse substrate	- 0.534 \pm 1.001	- 0.529	0.597
	Rocky	- 0.439 \pm 0.552	- 0.795	0.427
(c)				
(Intercept)	—	0.331 \pm 0.623	0.532	0.595
Distance	[- 1.485 ; 1.686]	- 1.122 \pm 0.021	-53.059	< 2e-16
River	Frome	Reference level	—	—
	Tamar	1.129 \pm 0.747	1.511	0.131
	Bresle	- 1.048 \pm 0.714	- 1.467	0.142
	Scorff	- 3.290 \pm 0.644	- 5.108	< 3e-07
Month	[- 1.010 ; 1.719]	- 0.296 \pm 0.025	- 11.906	< 2e-16
Distance to shore	[- 1.471 ; 2.126]	0.092 \pm 0.254	0.364	0.716
Bathymetry	[- 2.675 ; 1.938]	- 0.334 \pm 0.222	- 1.506	0.132
Substrate	Muddy	Reference level	—	—
	Sandy	- 0.852 \pm 0.666	- 1.279	0.201
	Coarse substrate	- 0.580 \pm 1.037	- 0.559	0.576
	Rocky	- 0.492 \pm 0.565	- 0.872	0.382
Noise quotient	[- 3.498 ; 8.556]	- 0.108 \pm 0.028	- 3.795	< 1e-03
Random effect		Variance	Standard deviance	
Receiver location				
Intercept (a)		0.486		0.697
Intercept (b)		1.026		1.013
Intercept (c)		1.082		1.040

In general terms, the results from the three different models confirmed the results from the GLMM fit to the River Frome DE data collected in 2021. Explanatory variables *Distance*, *River* and *Noise quotient* had significant effects on DE ($p < 0.05$) where they were included [Table 4]. Of particular interest was the effect of *Noise quotient* on DE that was negative, suggesting that the noisier the environment the lower the DE. Of the *River* output, we noticed the same result as in the previous model and [Fig. 3B]: the River Scorff had the lowest overall DE, while the River Tamar had the highest. Of the other variables explored, the effect of *Month* was significant and negative, as was expected, and the effects of *Bathymetry* and *Substrate* were negligible contrary to our expectations.

Comparisons among these three models (a, b & c) suggested that noise quotient was a useful explanatory variable of DE, but that the addition of the environmental variables significantly improved fit over the model omitting them. The marginal R² of the model c that included both noise quotient and environmental variables (explanatory variables only) was 0.468 and conditional R² (explanatory variables and random effects) was 0.478.

Discussion

Spatial & Temporal variation of detection efficiency

Spatial variation of detection efficiency was observed among receivers in the same estuary, as well as between the different estuaries of the study. Detection efficiency depends on the location of the receiver. What differs within and between estuaries are the environmental variables. For example, at the beginning of the River Frome estuary the water is quieter, as the location is better protected from the wind, while around the exit the water is choppy. Moreover, the River Frome estuary exit is also the busiest in terms of human activities, with shuttle boats taking tourists from Poole to the Brownsea Island on an hourly basis and a chain ferry that crosses the entrance to Poole Harbour between Sandbanks and Shell Bay. Among the observations of average DE in the River Frome estuary is that the values at 4.5 km from the saline limit appears very low. This could be explained by an environmental variable that was not measured sufficiently regularly: *Visibility*. We recommend that future models to predict detection efficiency should include visibility that might explain some of the lower observations of DE [Winter et al. 2021]. Moreover, at this specific location the receiver could have been lying on the bottom of the sea, which could have impacted its performance during range testing [Heupel et al., 2008].

Detection efficiency was – on average – lower in the French rivers compared to the English rivers. This might be related to the way the sampling was executed. Indeed, the River Frome was the river where the most range tests were performed, and consequently the higher chance of better (and worse) DE during the test. Moreover, range tests on the French rivers were not conducted under 25 m, yet it is around 0 m that DE should be highest. Values for the UK estuaries might have been boosted by those 0 m tests.

Temporal variability in detection efficiency may be due to seasonal or ephemeral variables. For example, environmental noise in the River Frome estuary could be linked with the intensification of anthropogenic activities at the beginning of the sunny days that increase with progression through the months: the harbour could get busier in summer as it is used not only as a crossing point, but also for leisure [Winter et al., 2021]. Another explanation might be that with warmer temperature, the growing of vegetation around the receivers (biofouling growth begins around June), as well as the accumulation of phyto/zooplankton in the water column,

could negatively impact DE [Weinz et al. 2021]. The existence of a seasonal bias could also be due to an important number of transient species that create environmental noise [Rechisky et al. 2020]. Finally, the low DE in July could be explained by the fact that only the 3 receivers nearest to the saline limit were tested (with – on average – the worst DE) because of an engine breakdown.

Even though we have highlighted several important biases in our sampling protocol, we reiterate the fact that collecting of data during fieldwork is tricky, and even when done as best as possible, is still complicated by weather conditions and logistical complexities, including available man-power and financial support. Nevertheless, even some measurements of environmental variables thought to affect detection efficiency can be used to correct those biases [Kessel et al., 2014].

Environment parameters influence on detection efficiency

Almost all the environmental variables hypothesised to affect detection efficiency were confirmed to influence DE, although with varying strengths and sometimes contrary expectations. Most of our hypotheses were confirmed [Table 1]. The probability to detect a tag decreased with increasing *Distance* from the receiver. *Wind*, however, did not have an impact as strong as the one demonstrated in Gjelland and Hedger (2013), although its effect on DE was negative as hypothesised. The *SAV* had negative influence over DE, as it will obstruct the path between the tag and the receiver and perhaps such vegetation produces oxygen via photosynthesis that attenuates the acoustic signal [Weinz et al. (2021)]. Regarding the *Sea state*, we confirmed that the choppiest the water – the worse the detection. Nevertheless, we must also acknowledge that range tests could only be done under favourable sea state conditions [Kessel et al., 2014]. Viewed differently, we can state that even despite a minimal variation in sea state, the impact of this variable was already statistically significant, highlighting its importance. For this variable, the best option would be to use a sentinel tag with enough battery to do a continuous range test, including sea state conditions when the boat range testing would be impossible [Winter et al., 2021]. Concerning those environmental variables that had effects contrary to our expectations, *Distance to shore* was expected to have a negative effect because noise created by the waves against the shore would be higher at shorter distances, but perhaps this effect was insignificant compared to the effect of noise produced against the buoy where the receiver is attached. Moreover, the water near the coast is shallower, leading to fewer boat crossings. Thus, receivers close to the coast might be less impacted by boat traffic. The negative effect of *Month* could be argued the same way it was concerning temporal variation of DE – that boat traffic or phytoplankton or biofouling increases with progression through the year towards warmer summer months. DE was lowest when the *Substrate* was muddy perhaps related to the fact that coarse substrates were only surveyed at deep locations, with less chance of creating echoes which would disturb the tag detection [Simpfendorfer et al., 2008]. Another lead would be that, with a muddy substrate, the light and small particles of its composition would blur the water more easily, decreasing the visibility which would certainly decrease DE [Winter et al. 2021].

Relationship between noise quotient and the environmental variables

Even though the accuracy of the model exploring the relationship between noise quotient and the fieldwork collected and inherent environmental variables was not high, we still managed to establish relationships confirming that noise quotient could be representative of acoustic noise in the environment. It appears that our previous assumption that DE is lower during summer months might not be linked with changes in environmental noise. We expect the estuary to get

busier and thus noisier during summer. Nevertheless, we demonstrate here a negative effect of *Month* on *noise quotient*, suggesting that environmental noise might not increase with *Month*. Concerning the *Distance to shore*, once again we can draw the same conclusion as before, namely, the noise created on the shore is insignificant compared to the noise created in the proximity of the receiver. We hypothesised a strong effect of *Wind* on environmental noise. That we found it to be a weak effect might be linked to the fact that that data was collected from a weather forecasting station, located at an average of 1 to 5 km away from the receivers. Moreover, Gjelland and Hedger (2013) demonstrates that wind impact on acoustic receiver efficiencies was not due to an increase in ambient noise directly, but rather through the entrainment of air bubbles in the littoral zone. Although not statistically significant, the effect of *Wind* on noise quotient was nevertheless positive, confirming the direction of our hypothesis: the stronger the wind – the noisier the environment. *Bathymetry* had a positive effect on noise quotient. To interpret this result, we need to consider the fact that the deeper environments in the River Frome estuary correspond to the marine environment, which is a noisier environment than the shallower areas closer to the saline limit at the beginning of the estuary. Higher *SAV* decreased the noise quotient and thus the ambient noise around the receiver, suggesting that with large amounts of *SAV* could protect the receiver from other sources of environmental noise [Weinz et al. 2021]. This hypothesis is consistent with the fact that *SAV* can block detection, just as it might block other environmental noise. Moreover, higher levels of *SAV* were associated with negative noise quotient values that are synonymous with tag collisions [Simpfendorfer et al., 2008]. Thus, higher *SAV* could lead to more tag collisions. Concerning *Sea state*, the choppiest the water, the noisier the environment around the receiver. We note when the sea state was mirror-like, i.e., no wavelets, noise quotient values were near 0, which characterises a perfect environment for tag detection.

Noise quotient as a proxy variable

Noise quotient had a negative effect on DE suggesting that the noisier the environment the lower the DE. Yet, *noise quotient* is considered to represent a measure of acoustic noise in the environment. Together, these findings suggest that noise might interfere with the detection of tags by blocking or deflecting the detection [Simpfendorfer et al. 2008]. Even though considering noise quotient as the only explanatory variable (except the structural ones) delivered an accurate prediction of detection efficiency, inclusion of some of the environmental variables significantly improved model over omitting them. Thus, by capturing the noise produced by the environmental variables that had not been measured during the fieldwork prior to 2021, the calculated value of *noise quotient* improved our predictions of DE.

Ideally, fixed distance sentinel tags (i.e. acoustic tags attached to each receiver – or at a given distance from the receiver – beeping continuously) could be deployed to measure the detection efficiency of each receiver over time. With this continuous stream of data, we could perform a temporal follow-up of the efficiency of the receiver. Results from [Winter et al. (2021)] indicate that sentinel tag data, if available, can provide equally valuable information on acoustic receiver performance than active range testing. Though this method would be costly, it would be an alternative to the hard work of range testing and with fewer, possibly different, biases. Provided the interval of transmission was set long enough to avoid tag collision with tagged animals, it might be an easier and more accurate method to access noise quotient and produce better predictions of DE.

Conclusion

Spatial and temporal variation in detection efficiency was observed within and among receivers in the same estuary and between different estuaries. Those variations can be explained – in part – by environmental variables such as *Sea state* or *SAV*. Knowledge over such environmental variables allowed us to describe the detection efficiency of our receivers. Nevertheless, collection of some of those environmental variables is one hard and onerous task. Measurements of some simple environmental variables, such as sea bed substrate and month or range test, can be included in models to describe detection efficiency. Noise quotient, a receiver performance metric that can be calculated from receiver-recorded data, should not be used to replace measurements of all environment variables, but its inclusion alongside some environmental variables can improve the model fit. Thus, noise quotient can be used to represent environmental noise created by some environmental variables collected on the fieldwork, especially those that vary temporally. As those variables are part of the cause of spatial and temporal variation in detection efficiency, noise quotient would add essential information to predict this DE. This essential information would be used in the interpretation of acoustic detection data to estimate the mortality of salmonid smolts through estuaries: it could help us deduce the probability that undetected fish were present or not.

REFERENCES

- Dormann, C. F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carre, G., Garcia Marquez, J. R., Gruber, B., Lafourcade, B., Leitao, P. J., Munkemuller, T., McClean, C., Osborne, P. E., Reineking, B., Schroder, B., Skidmore, A. K., Zurell, D., & Lautenbach, S. 2013. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, 36: 27–46.
- Dudgeon, D. (2019). Multiple threats imperil freshwater biodiversity in the Anthropocene. *Current Biology* 29(19), R960--R967.
- Heupel, Michelle R., Katie L. Reiss, Beau G. Yeiser, and Colin A. Simpfendorfer. 'Effects of Biofouling on Performance of Moored Data Logging Acoustic Receivers: Effects of Biofouling on Acoustic Receivers'. *Limnology and Oceanography: Methods* 6, no. 7 (July 2008): 327–35. <https://doi.org/10.4319/lom.2008.6.327>.
- ICES. "Baltic Salmon and Trout Assessment Working Group". en. In: (2019). Publisher: ICES. doi:10.17895/ICES.PUB.4979.url:http://www.ices.dk/sites/pub/Publication%20Reports/Forms/DispForm.aspx?ID=35435
- JONHSON Sam, WEBBER Dale, SMEBDOL Stephanie and MOWAT Ryan, 2019. Aquatic Acoustic Telemetry Data Analysis : (a) Introduction to Acoustic Telemetry and Study Design. VEMCO (intern document). 184 p.
- JONHSON Sam, WEBBER Dale, SMEBDOL Stephanie and MOWAT Ryan, 2019. Aquatic Acoustic Telemetry Data Analysis : (b) Deployment and testing. VEMCO (intern document). 149 p.
- Kendall, M.S., B.L. Williams, R.D. Ellis, K.E. Flaherty-Walia, A.B. Collins, and K.W. Roberson. 'Measuring and Understanding Receiver Efficiency in Your Acoustic Telemetry Array'. *Fisheries Research* 234 (February 2021): 105802. <https://doi.org/10.1016/j.fishres.2020.105802>.
- Kessel, S. T., S. J. Cooke, M. R. Heupel, N. E. Hussey, C. A. Simpfendorfer, S. Vagle, and A. T. Fisk. 'A Review of Detection Range Testing in Aquatic Passive Acoustic Telemetry Studies'. *Reviews in Fish Biology and Fisheries* 24, no. 1 (March 2014): 199–218. <https://doi.org/10.1007/s11160-013-9328-4>.
- Klemetsen, A., Amundsen, P.-A., Dempson, J. B., Jonsson, B., Jonsson, N., O'Connell, M. F., & Mortensen, E. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish*, 12: 1–59.
- Rechisky, Erin L., Aswea D. Porter, Paul M. Winchell, and David W. Welch. 'Performance of a High-Frequency (180 KHz) Acoustic Array for Tracking Juvenile Pacific Salmon in the Coastal Ocean'. *Animal Biotelemetry* 8, no. 1 (December 2020): 19. <https://doi.org/10.1186/s40317-020-00205-z>.
- Simpfendorfer, Colin Ashley, Michelle RaNae Heupel, and Angela B Collins. 'Variation in the Performance of Acoustic Receivers and Its Implication for Positioning Algorithms in a Riverine Setting'. *Canadian Journal of Fisheries and Aquatic Sciences* 65, no. 3 (1 March 2008): 482–92. <https://doi.org/10.1139/f07-180>.

Thorstad, E. B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A. H., & Finstad, B. 2012. A critical life stage of the Atlantic salmon *Salmo salar*: behaviour and survival during the smolt and initial post-smolt migration. *Journal of Fish Biology*, 81: 500–542.

VEMCO. Vue Software Manual, AMIRIX Systems Inc, 2015. 75p : DOC-4399-24

Weinz, Amy A., Jordan K. Matley, Natalie V. Klinard, Aaron T. Fisk, and Scott F. Colborne. ‘Performance of Acoustic Telemetry in Relation to Submerged Aquatic Vegetation in a Nearshore Freshwater Habitat’. *Marine and Freshwater Research*, 2021. <https://doi.org/10.1071/MF20245>.

Winter, Emily R., Andrew M. Hinds, Steve Lane, and J. Robert Britton. ‘Detection Range and Efficiency of Acoustic Telemetry Receivers in a Connected Wetland System’. *Hydrobiologia* 848, no. 8 (May 2021): 1825–36. <https://doi.org/10.1007/s10750-021-04556-3>.

Fiche résumé = quatrième de couverture du mémoire*

 	Diplôme : Ingénieur Spécialité : Agronome Spécialisation / option : Science des données Enseignant référent : Marie Pierre Etienne
Auteur(s) : Juliette Theoleyre Date de naissance* : 28/09/1997	Organisme d'accueil : Game and Wildlife Conservation Trust (GWCT) Adresse : River Laboratory, East Stoke, Wareham BH20 6BB, United Kingdom
Nb pages : 21 Annexe(s) : /	Maîtres de stage : Etienne Rivot, Céline Artero & Stephen Gregory
Année de soutenance : 2021	
Titre français : Variation spatio-temporelle de l'efficacité de détection acoustique Titre anglais : Acoustic receivers detection efficiency : temporal and spatial variations	
Résumé (1600 caractères maximum) : 1598 La télémétrie acoustique passive est un outil important pour l'étude de l'écologie spatial et du comportement des organismes des écosystèmes marins et d'eau douce. Or, la compréhension l'efficacité de détection (DE) des récepteurs acoustiques est primordiale pour l'interprétation des données acoustiques afin d'estimer le taux de mortalité des saumoneaux à travers l'estuaire. Les variation spatiaux-temporelles de DE ont été observée à la fois au sein d'un même estuaire ainsi qu'entre les estuaires de l'étude. Ces variations peuvent – en partie – s'expliquer par des variables environnementales tel que les conditions de mer et la SAV. Connaissant ces paramètres, il serait possible de prédire la DE, seulement, la collecte de ces données est fastidieuse. La mesure de paramètres environnementaux simple comme la nature du fond ou le mois de l'année peuvent être inclus dans un modèle afin de décrire la DE. Le noise quotient, une métrique de performance calculée directement à partir des données enregistrées sur le récepteur, ne devrait pas être utilisée pour remplacer les variables environnementales disponibles mais sa prise en compte permet une amélioration de la performance du modèle. Ainsi, le noise quotient peut être utilisé comme représentant du bruit ambiant généré par les variables environnementales collectées sur le terrain, notamment celles qui varient temporellement. Le noise quotient apporterait une information supplémentaire essentielle à la prédiction de la DE. Cette information aiderait à déterminer la probabilité du statut présent ou absent d'un poisson non-détecté.	

Abstract (1600 caractères maximum) : 1516

Passive acoustic telemetry provides an important tool to study the spatial ecology and behaviour of organisms in marine and freshwater systems. Understanding the detection efficiency of acoustic receivers is therefore critical for interpreting acoustic data and to estimate mortality of salmonid smolts through estuaries. Spatial and temporal variation in detection efficiency was observed within and among receivers in the same estuary and between different estuaries. Those variations can be explained – in part – by environmental variables such as *Sea state* or *SAV*. Knowledge over such environmental variables allowed us to describe the detection efficiency of our receivers. Nevertheless, collection of some of those environmental variables is one hard and onerous task. Measurements of some simple environmental variables, such as sea bed substrate and month, can be included in models to describe detection efficiency. Noise quotient, a receiver performance metric that can be calculated from receiver-recorded data, should not be used to replace measurements of all environment variables, but its inclusion alongside some environmental variables can improve the model fit. Thus, noise quotient can be used to represent environmental noise created by some environmental variables collected on the fieldwork, especially those that vary temporally. Noise quotient would add essential information to predict this DE. This information would help us deduce the probability that undetected fish were present or not.

Mots-clés : Télémétrie acoustique passive, Efficacité de détection, « Range test », « Noise quotient », Variabilité spatio-temporelle, Variables environnementales

Key Words: Passive acoustic telemetry, Detection efficiency, Range test, Noise quotient, Spatial and temporal variation, Environment variables

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