Appendix: Efficacy of ADDs – Statistical analysis

This appendix provides a detailed account of the analysis described in section 3 of the main report which was carried out to determine whether the dataset could provide any evidence for the efficacy of ADDs.

1 Methods

1.1 Data preparation

The dataset described in the main report provided records of ADD use from 2014 to 2020, collated across four data sources (see section 3 in the main report). This included data on ADD status (on/off), ADD types, and number of transducers. Additional variables were collated from the same four sources. These included: data on depredation rate, stocking, net material, net weighting, net shape, anti-predator nets, seal-blinds, and whether a site was permitted to use ADDs.

Depredation records were available from the seal licensing surveys and from finfish producers but the temporal resolution varied between data sources. The seal licensing survey data contained records for each month at the lowest scale of temporal resolution, whereas the producers data contained irregular, but often daily records. The seal licensing surveys provided the most comprehensive source of data, therefore monthly was the finest temporal resolution at which the analysis could be carried out. Records from producers were therefore aggregated into a matching monthly format, and combined into a single dataset.

Finfish farms typically have stocking periods, followed by fallow periods during which the site is unused. Dates when sites were stocked and fallowed were required to differentiate between stocked and unstocked periods. The most comprehensive data source relating to aquaculture is the Scottish Government/SEPA data portal[1], which records the total biomass on sites per month, and so these data were included in analysis. Where biomass was greater than zero, farms were considered to be stocked. Some mismatches were found with other data sources; some sites reported stocking information through the seal licencing survey for time periods where no biomass information was recorded, these were considered unstocked (343 records). Time periods where seal depredation was recorded were considered stocked, including records where alternative stocking information was not available (163 records).

“Stocking period” is defined as a set of successive months where the farm was recorded as being stocked, with at least a one-month gap where the farm was unstocked before and after. We defined a “depredation event” as a set of successive months where a stocked farm was recorded as having been depredated by seals, with at least a one-month gap before and after where there was no depredation. For each depredation event we determined the length in months of the event and the number of fish recorded as depredated by seals. We also aggregated the

[1] http://aquaculture.scotland.gov.uk/map/map.aspx

depredation events across stocking periods to determine the number and length of depredation events and total number of fish depredated, per stocking period.

The combined dataset contained 10,125 monthly records where fish were stocked, from 216 farms. However, for 1,481 of these records ADD status was not recorded. Since the focus of this analysis was the relationship between seal depredation and ADD usage on stocked fish farms, we excluded records where ADD usage was unknown, leaving 8,644 monthly records from 209 farms.

ADD type was included in the analysis. In some cases, different types of ADD were used simultaneously (see section 3.3.5 in the main report). This meant that for analysis we could not use a single factor variable for ADD type; instead, we used 8 binary variables, one for each ADD type, and coded these as 1 if the corresponding ADD type was used on a particular farm in a particular month and 0 if it was not.

For the purpose of comparing different management strategies, ADD use was defined as ‘consistent’ if they were used for more than 90% of the time at a given site over the period of analysis. ADD use was defined at ‘inconsistent’ if they were used for less than 90% of the time.

1.2 Research questions

The most appropriate metrics for measuring ADD efficacy were considered; for example, whether ADDs likely to be effective on the scale of months and years, whether ADDs are effective at reducing peak levels of depredation, or the duration of depredation events. A series of research questions were defined to examine the issue using different metrics of depredation and from different levels of aggregation of the data (month, stocking period and depredation event). The data were analysed to address the following questions on the relationship between seal depredation and ADD usage:

At the monthly level:

1. Is the monthly presence or absence of depredation at a finfish farm associated with ADD usage and does any association depend on ADD type?

2. Is the monthly level of depredation (i.e. number of fish killed by seals) at a finfish farm associated with ADD usage and does any association depend on ADD type?

At the level of stocking period:

3. Are the number of depredation events during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

4. Is the total level of depredation during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

5. Is the proportion of months during which depredation events occur during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

At the level of depredation event:

6. Is the total level of depredation at a finfish farm associated with ADD usage and does any association depend on ADD type?

7. Is the length in months of a depredation event at a finfish farm associated with ADD usage and does any association depend on ADD type?

1.2.1 Exploratory analysis

Exploratory analyses were first conducted to address these questions in a simple graphical and tabular way. For example, for question 1 we compared the percentage of months with depredation when ADDs are on versus when they are off. However, this does not account for other factors that affect depredation including, location, season, other anti-predation measures in use. We then constructed a set of statistical models addressing each question that include all other potential explanatory variables available.

In the month-level analyses the full dataset of 8,644 monthly records were used. For the stocking period-level analyses a complete record of ADD usage (on or off) for all months within the stocking period was required. Therefore, stocking periods where there were one or more months with missing ADD information were not included, leaving 7,290 monthly records from 509 stocking periods.

For the depredation event-level analyses, we were only considering data from within depredation events, and could therefore include data from stocking periods where ADD information was missing, so long as it was only missing when depredation was not recorded as occurring. From the original 8,644 monthly records, this left 3,384 records from 458 stocking periods.

1.2.2 Modelling seal depredation

Statistical regression models were constructed with response variables quantifying seal depredation as a function of explanatory variables that could potentially be related to depredation (Table 1). The aim was to account for possible confounding factors that could mask any relationship between seal depredation and ADD usage or type. Generalized Additive Models (GAMs[2]) were used, to allow for smooth relationships between response and explanatory variables (also called covariates). Modelling was performed using the mgcv package within the statistical software R 4.0.2[3]. When smooths were specified on continuous covariates they were thin plate regression splines, except in the case of month when a cyclic cubic regression spline was used (enabling the effect for month 1 and month 12 to join). Smoothness selection used the default methods built into the mgcv package, which are based on minimising generalized cross validation (GCV) or unbiased risk estimator (UBRE)

[2] Wood, S. (2017). Generalized Additive Models: An Introduction with R, Second Edition. Vol. 66.

[3] R Core Team. (2020). *R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.*

scores. Covariate significance in the model was assessed using approximate z- or chi-square tests for parametric and smooth terms, respectively. Overall model goodness of fit was assessed using percentage deviance explained and adjusted R-squared values as well as by inspecting qq-plots of residuals.

Name	Description	Used in analysis?
farmID	Identifier of individual fish farm	Y
region	One of: Highland, Orkney, Shetland, Argyll and Bute, Western Isles	Y
year	Year of record	Y – as a factor variable
month	Month of record	Y – as a numerical variable
Stocked	Whether the farm was stocked with fish on that month or not	N – only used to define stocking periods and subset the data
biomass	Biomass (in kg) of fish at farm	Y
depredation	Number of mortalities due to seal depredation	Y
prodMortsOther	Number of mortalities for reasons other than seal depredation, from fine-scale dataset	N – only used to confirm whether a farm was stocked
prodDepredation	Number of mortalities due to seal depredaton, from fine-scale dataset	N – only used to confirm whether a farm was stocked, and in preference over depredation variable where there was a conflict
ADD_on	Is one or more ADD on	Y
N_devices	How many ADD devices are used	N – too many missing values (almost half of records with ADD on)
Airmar; Ace-RT1; Ace-US3; Terecos; OTAQ; Unknown; GaelForce; MohnAqua	Type of ADD in use that month – 8 binary variables (0 = not used; 1 = used)	Y
ADD_prohibited	Binary variable indicating whether ADD use was prohibited or not	Y
square	Binary variable indicating whether net shape was square or not	Y
APN (Anti-Predator Net)	Binary variable indicating whether anti-predator nets were used or not	Y
Seal_blind	Binary variable indicating whether seal-blinds were used or not	Y
HDPE	Binary variable indicating whether HDPE netting was used or not	N – too many missing values (majority of data)

Table 1 Explanatory variables available and used in the statistical modelling exercise

Separate models were constructed to address each question; these models are detailed in the paragraphs that follow.

Question 1 - Is the monthly presence or absence of depredation at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was presence or absence of depredation at a farm in a month; this was modelled as a Bernoulli random variable (i.e. a binomial random variable with 1 trial), using the default logit link function. The data involve multiple repeat measurements on the same fish farms and hence farm ID was included as a random effect (using the "re" smoother in mgcv); this assumes between-farm differences follow a normal distribution on the logit scale, and this was checked via term plots. Residual autocorrelation was checked using autocorrelation plots (acf_resid function in R package itsadug); where autocorrelation was found the model was refit assuming an AR1 error structure using the observed autocorrelation value; in this case model fitting in R was via the mgcv function bam.

Two models were compared: one using presence or absence of ADDs as a two-level factor covariate, the other using presence or absence of each ADD type as eight two-level factor covariates. The models were compared using a UBRE (for binomial models) or a restricted maximum likelihood criterion (fREML, via the compareML function in the itsadug package) for models that included autocorrelation.

Question 2 - Is the monthly level of depredation (i.e. number of fish killed by seals) at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of fish reported depredated by seals at a farm in a month; this was modelled in four separate models as a Poisson, quasi-Poisson, negative binomial, or Tweedie random variable (in each case using a log link function); the final model was selected by inspecting the estimated over-dispersion (quasi-Poisson) or related parameter (θ for negative binomial, p for Tweedie) and by inspecting residual qq-plots. The same covariates were used as in question 1, including fish farm ID (random effect); autocorrelation was dealt with similarly.

Question 3 - Are the number of depredation events during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of depredation events per stocking period, which was modelled as a Poisson random variable. The number of events were small, and so an over-dispersed distribution such as negative binomial was necessary. Regarding covariates, mean month of the stocking period was used in place of month, and year at the start of the stocking period in place of year; fish farm ID was included as a random effect to allow for dependence between stocking periods within finfish farms. The number of depredation events was expected to increase with the length (in months) of the stocking period so there is an argument to use the log of stocking period length as an offset (log because of the log link function). To give additional flexibility, we used a smooth of log stocking period length. Unlike the month-level analyses where ADD status (on/off and type) was constant for the month in our data, at the stocking level there were some stocking periods where ADDs were used intermittently. Hence all ADD-related variables were coded as numerical covariates, with their value being the proportion of the stocking period the ADD was on. Because the vast majority of values were either 0 (always off) or 1 (always on) there was not enough information to model the response as a smooth function of these covariates, and we assumed a linear relationship (on the scale of the link function). Autocorrelation is at most a minor issue for this question because there are few stocking periods per farm; therefore autocorrelation was not considered in the modelling for this question.

Question 4 - Is the total level of depredation during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of fish reported depredated by seals per stocking period. This was modelled using Poisson, quasi-Poisson, negative binomial and Tweedie random variables (with a log link function) with the distribution selected in the same way as for question 2. The same covariates were modelled as for question 3. As for question 3, autocorrelation is not a concern and was not considered.

Question 5 - Is the proportion of months during which depredation events occur during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of months where depredation was recorded per stocking period. This was modelled as a binomial random variable with the number of trials being the number of months of the stocking period. To accommodate possible overdispersion, the quasi-binomial distribution was also tried, with the decision on which to use being based on the value of the estimated overdispersion parameter as well as examination of residual qq-plots. The same covariates were tried as for question 3. As with question 3, autocorrelation is not a concern and was not considered.

Question 6 - Is the total level of depredation at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of fish reported depredated by seals per depredation event. This was modelled using Poisson, quasi-Poisson, negative binomial and Tweedie random variables (with a log link function) with the distribution selected in the same way is for question 2. Covariates were treated similarly to question 3: log length of depredation event was included as a smooth, month was replaced by mean month of the depredation event, and year by year at the start of the depredation event. Farm ID was included as a random effect. Stocking period within farm as a nested random effect was also explored, but this failed to converge possibly because there were too few stocking periods per farm. The effect on inference of not including stocking period as a second random effect is likely minimal, specifically, variance of estimated terms may be slightly under-estimated. Autocorrelation is at most a minor issue for this question because there are few depredation events per farm, and they are typically separated in time by more than a month; hence autocorrelation was not considered in the modelling.

Question 7 - Is the length in months of a depredation event at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was length of the depredation event; as with question 2 the Poisson, quasi-Poisson, negative binomial and Tweedie response distributions were tried and one was selected based on the estimated overdispersion and examination of qq-plots. Covariates were treated the same as for question 6. As with question 6, autocorrelation is not a concern and was not considered.

2 Results

2.1 Results from exploratory analysis

2.1.1 Month-level results

Of the 8,644 monthly records, 3,384 (39%) had recorded depredation. Table 2 shows these broken down by ADD usage (e.g. ADD on or off). The proportion of months with depredation was higher when ADDs were used (45% of months) than when they were not (32% of months). This seems counter-intuitive at first given that the purpose of ADD use is to deter seals to prevent depredation but this finding could be as a result of ADDs being used more at sites where depredation has been found to be a problem.

Table 2 Number and percentage of months with recorded seal depredation as a function of ADD usage and whether ADD use was permitted

	ADD on	**ADD off**	**ADD not permitted**	**ADD off (permitted)**	**ADD permitted**
No Depredation	2530	2730	823	1907	4437
Depredation	2094	1290	733	557	2651
Total	4624	4020	1556	2464	7088
Percentage (%) with depredation	45%	32%	47%	23%	37%

Dividing the months when ADDs were not used into those when ADD use not permitted versus those when it was allowed but not used, we found depredation rates were higher in the former (47%) than the latter (23%) (Table 2).

If depredation rates at sites where ADD use is not permitted can be taken as representative of background rates throughout Scotland, then this supports the idea that ADDs are used when depredation is expected to be high and not used when it is expected to be low. The argument would be that background predation rate is 47% (from sites where ADD use is not allowed), and the remaining sites can be divided into those where depredation is expected to be high but ADDs are used, giving a 45% depredation rate, and those where depredation rates are expected to be low and ADDs are not considered necessary, giving a 23% depredation rate.

Overall, depredation rates at sites where ADD use is not permitted (47% of months) was higher than the overall rate (combining ADD on and ADD off) at sites where ADD use was permitted (37%), although this could partly be caused by ADD usage reducing depredation. It is important to note that sites where ADD use is not permitted are not necessarily representative of all sites (for example, they may tend to be near protected areas where seal density is higher).

Examining the data by ADD type (Table 3), we found that monthly depredation rates varied by type; being lowest (30%) for the Ace Aquatec US3 and highest (71%) for the Mohn Aqua. However, there were very few records for some types, and similar caveats apply in the interpretation of these results to those given above – for example it could be that use of those devices associated with higher depredation is a result of those types being selectively used when seal depredation is expected to be particularly high.

Table 3 Number and percentage of months with recorded seal depredation as a function of ADD type

	Airmar on	**Ace Aquatec RT1**	**Ace Aquatec US3**	**Terecos**	**OTAQ SealFence**	**GaelForce**	**MohnAqua**	**Unknown**
No Depredation	789	82	602	541	837	25	258	66
Depredation	650	132	257	519	394	60	344	56
Total	1439	214	859	1060	1231	85	602	122
% with depredation	45	62	30	49	32	71	57	46

The level of mortality (i.e. number of fish recorded as depredated by seals) per month and farm had a mean of 199 fish, although it was considerably right-skewed, with 61% of values being zero (corresponding to those months with no depredation), and a small number of very high values (60 records or 5% were more than 1,000 and seven were more than 10,000 over a month).

In the 39% of months where some depredation occurred the median number of fish lost was 111 and the mean was 508 fish. Broken down by ADD usage and type (Table 5 and Table 5), similar results to those for depredation rate were found. Mean mortality was higher when ADDs were on than when off, levels of depredation were higher when ADD use is not permitted and there is variation among ADD types in the levels of depredation observed (although with the highest numbers of fish lost attributed to different ADD types than for depredation rate).

Because of the strong skew, we also computed 75th percentile in addition to the mean although these gave the same conclusions.

	ADD on	**ADD off**	**ADD not permitted**	**ADD off permitted**	**ADD permitted**
Mean	236	156	243	102	189
75^{th} percentile	87	18	85	0	43

Table 4 Monthly mean and 75th percentile of number of fish recorded as having been depredated by seals per farm as a function of ADD usage and whether ADD use was permitted

	Airmar on	Ace Aquatec RT1	Ace Aquatec US3	Terecos	OTAQ SealFence	GaelForce	MohnAqua	Unknown
Mean	213	337	170	228	242	130	205	559
75^{th} percentile	72	446	8	132	30	67	99	484

Table 5 Monthly mean and 75th percentile of number of fish recorded as having been depredated by seals per farm as a function of ADD type

2.1.2 Stocking period-level results

Of the 509 stocking periods (from 179 farms) for which complete ADD usage was available, depredation was recorded in 361 (71%) of the periods. The length of a stocking period varied from 1 month to 42 months, with a mean of 14.3 and median of 15 (Figure 1). The short stocking periods tended to come at the beginning or end of the time series and therefore were possibly because stocking was already ongoing when the data collection period started or was ongoing when it ended. The few exceptionally long stocking periods may have been two periods with a gap of less than a month, and so could have been incorrectly coded as a single stocking period.

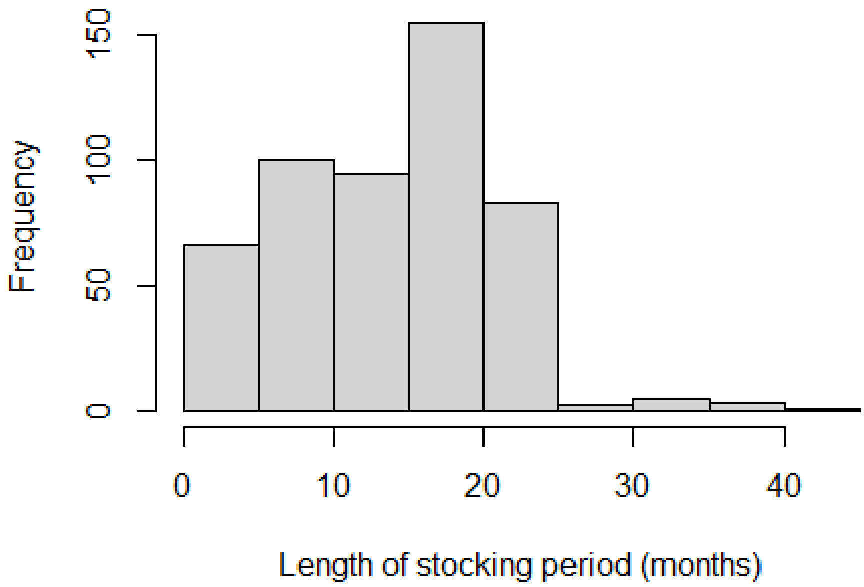


Figure 1 Distribution of stocking period length in months

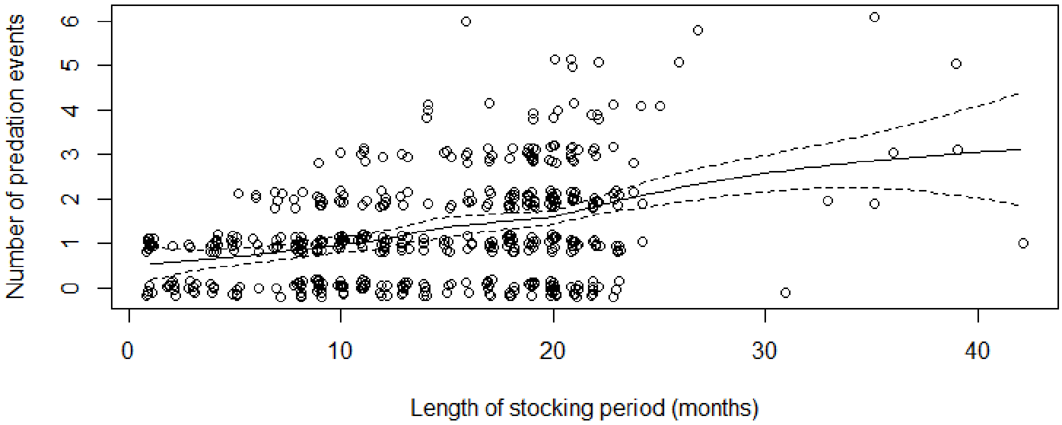


Figure 2 The number of predation events per stocking period against the length in months of the corresponding stocking period; values have been jittered (random noise added to the data) to make them visible. Solid line shows a lowess smooth with dashed lines indicating approximate 95% confidence interval on the smooth

The mean number of depredation events per stocking period was 1.3 and was approximately linearly related to the length of the stocking period (Figure 1 Distribution of stocking period length in months

).

ADDs were typically either “off” for the entire stocking period or “on” for all, or almost all, of the period. Of 509 stocking periods, ADDs were always “off” for 201 (39%), always “on” for 164 (33%) and “on” for more than 90% of the period (but not all of them) for 50 (10%). There were 94 stocking periods (18% of total) where ADDs were on for more than 0% but less than 90% of the months.

Table 6 compares stocking period length and depredation levels between different ADD usages. Comparing stocking periods when ADDs were on consistently (for more than 90% of the time) with those with ADD off, stocking period lengths were similar (14 versus 12.9 months respectively) but the number of depredation events, depredation level and percentage of the stocking period where depredation was recorded was higher. This result mirrors that of the by-month analysis. Also, similarly, stocking periods when ADDs were not permitted had slightly higher number of depredation events, depredation level and percentage of the period where depredation occurred compared with the ‘ADD on’ stocking periods. This last finding excludes the 36 stocking periods where ADDs were not permitted for part of the stocking period (six of which had ADDs on for part of the stocking period, so presumably the restriction on ADD use could had been introduced after ADD use had previously been used).

Looking at stocking periods where ADDs were used ‘inconsistently’ (>0% but <90% of the time), these were on average longer (18.1 months), but had fewer depredation events, lower depredation levels and a smaller percentage of the stocking period where depredation was recorded (Table 6). The last row of Table 6 shows the number of stocking periods in the corresponding category. One explanation for this is that ADDs were used in a responsive manner on these sites, in response to depredation events, and that there were fewer depredation events and lower ADD usage. There is some evidence for this: in 54 of the stocking periods where depredation was recorded, ADD use increased after the first incidence of depredation; ADDs were used in 39% of months before the first recorded depredation and 59% of months after it. ADD usage was also lower in stocking periods where there was no depredation.

	ADD on ≥ 90% of months	**ADD on < 90% of months**	**ADD off**	**ADD not permitted**
Mean length of stocking period (months)	14	18.1	12.9	12.6
Mean number of depredation events	1.40	1.11	1.25	1.61
Mean depredation (i.e. number of depredated fish)	3177	2721	2261	4033
Mean percentage of stocking period where depredation was recorded	48	25	36	54
Number of stocking periods	214	94	201	79

Table 6 Mean length of stocking period, number of depredation events, mortality and proportion of months with depredation per stocking period as a function of ADD usage and whether ADD use was prohibited

Table 7 presents stocking period length and depredation statistics broken down by ADD use, when the corresponding ADD type was on ≥ 90% of months. Only data where the ADD corresponding type was on for ≥ 90% of the stocking period are included; the last row shows the number of stocking periods that meet this criterion. Sample sizes were small in many cases, with only Airmar, Ace Aquatec US3, Terecos and OTAQ used 37 or more stocking periods.

Stocking period lengths were similar among these four ADD types, although there were some differences in depredation statistics, with the Terecos being associated with the highest number of depredation events, largest total depredation and percentage of the stocking period when depredation was recorded. As with previous results, one interpretation of this is that Terecos ADDs were deployed in situations where depredation was expected to be the worst, but additional information would be required to ascribe the underlying cause.

	Airmar on ≥ 90%	Ace Aquatec RT1 on ≥ 90%	Ace Aquatec US3 on ≥ 90%	Terecos on ≥ 90%	OTAQ SealFence on ≥ 90%	GaelForce on ≥ 90%	Mohn Aqua on ≥ 90%	Unknown ≥ 90%
Mean length of stocking period (months)	13.7	20.9	13.1	15.5	17.0	9.4	12.5	12.9
Mean number of depredation events	1.12	2.88	0.85	1.55	0.95	1.60	1.75	1.43
Mean total depredation (i.e. number of depredated fish)	2683	4655	2231	4023	2014	451	2706	7242
Mean percentage of stocking period where depredation was recorded	41	56	39	48	22	91	62	60
Number of stocking periods	69	8	52	55	37	5	28	7

Table 7 Mean length of stocking period, number of depredation events, mortality and proportion of months with depredation per stocking period as a function of ADD type

2.1.3 Depredation event-level results

There were 803 depredation events (from 438 stocking periods and 179 farms) where complete ADD usage was available. Depredation events ranged in length from 1 month to 24 months with a mean of 4.2 (Figure 3); the most common length of a depredation event was 1 month (269 or 33%), followed by 2 months (133 or 17%).

As would be expected from the monthly data, the level of mortality (i.e. number of fish killed per predation event) was strongly right-skewed, with a median of 315 and mean 2139.4 (range 1-49,490). There was a positive, approximately linear relationship between the length of the stocking period and the level of mortality (Figure 4).

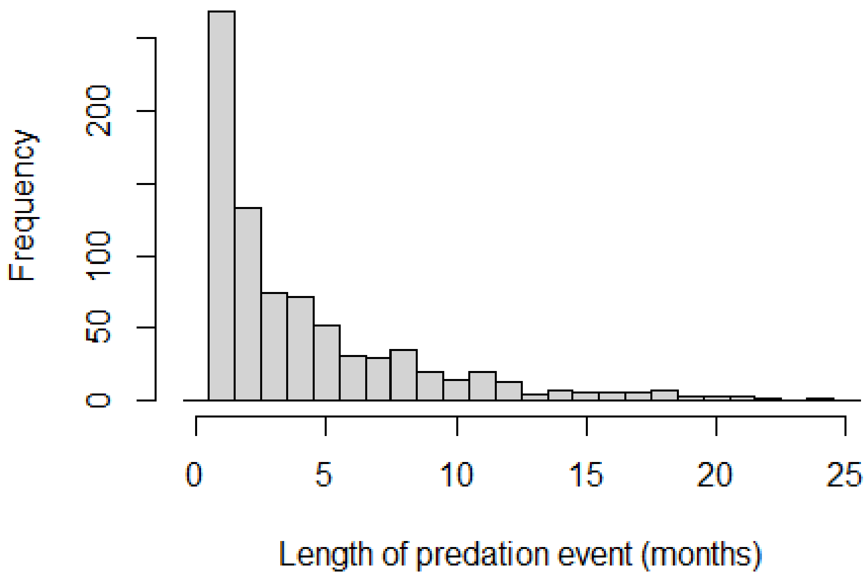
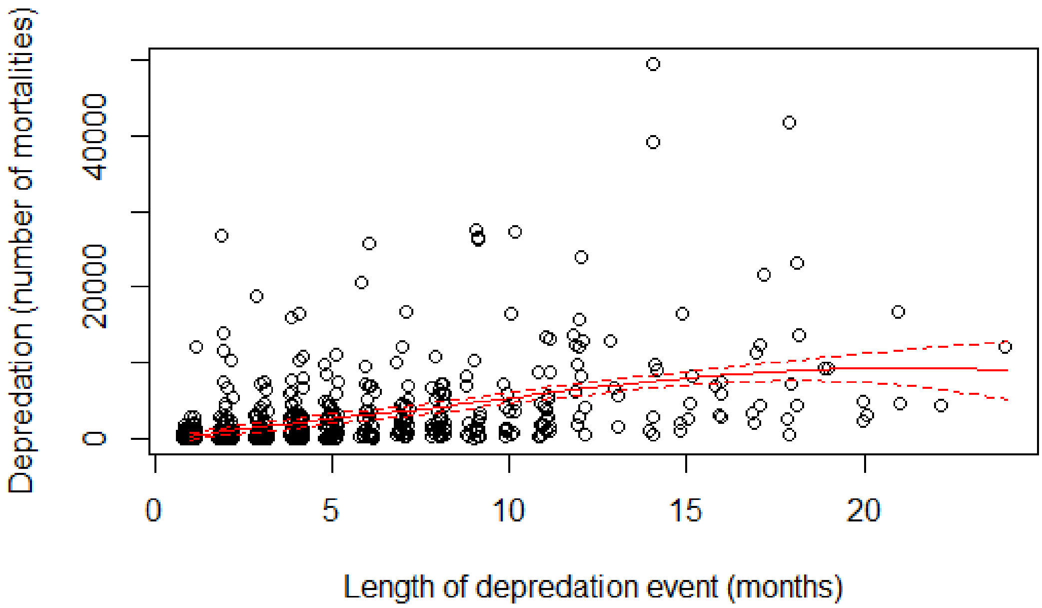


Figure 3 Distribution of depredation event durations in months

(a)



(b)

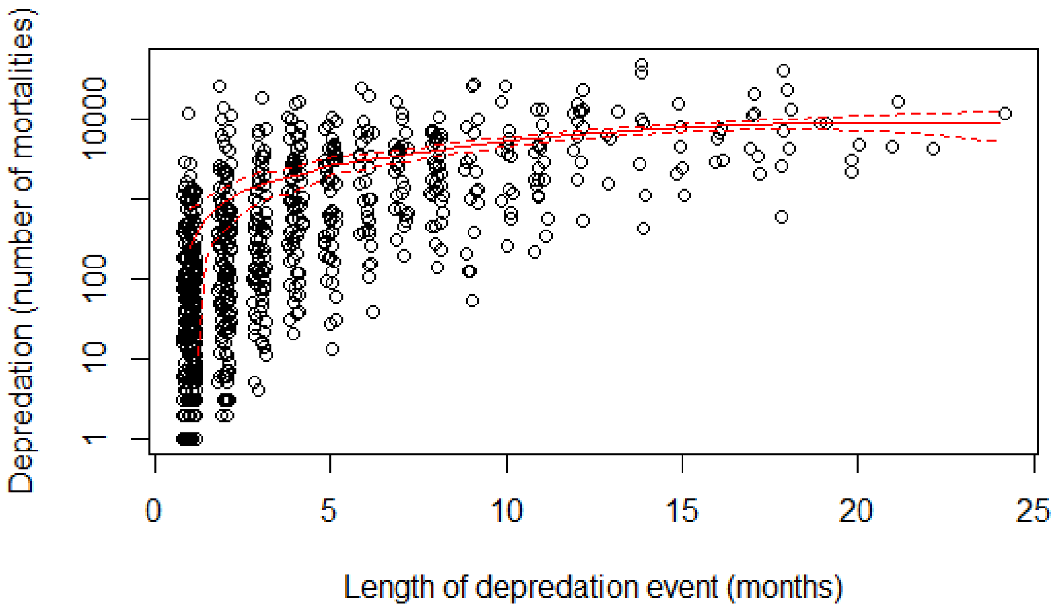


Figure 4 (a) The level of depredation (number of fish killed) per depredation event against the length in months of the depredation event; values on the x-axis have been jittered to make them visible. The solid red line shows a lowess smooth with approximate 95% confidence interval on the smooth indicated by dashed lines. Panel (b) shows the same information, but with the y-axis on the log scale to make the pattern at lower depredation levels more visible.

Of the 803 depredation events, ADDs were “off” for 344 (43%), consistently “on” for 420 (52%) and inconsistently “on” for 39 (5%).

Table 8 and Table 9 show the length of the depredation event and depredation levels as a function of ADD usage and type, excluding the 39 events where ADD usage changed during the event. Table 8 only includes depredation events where ADDs were either on or off for the whole event; the last row shows number of depredation events in the corresponding category. Table 9 only includes data where the ADD type was on throughout the depredation event; the last row indicates the number of depredation events that meet this criterion.

The patterns seen broadly follow the monthly and stocking period results with higher depredation associated with ADDs on compared with off, higher depredation when ADDs were not permitted (for the whole depredation event) compared with off, and variation among ADD types in the amount of depredation.

	ADD on	ADD off	ADD not permitted
Mean length of depredation (months)	4.5 (0.22)	3.4 (0.18)	3.8 (0.27)
Mean depredation (i.e. number of depredated fish)	2300 (250)	1638 (194)	2015 (319)
Number of depredation events	420	344	184

Table 8 Mean length of depredation period and depredation level per depredation event as a function of ADD usage and whether ADD use was permitted (excludes depredation events with a mixture of ADD on and ADD off). Standard errors of the means are shown in brackets.

	Type 1 on	Type 2 on	Type 3 on	Type 4 on	Type 5 on	Type 6 on	Type 8 on	Type 9 on
Mean length of depredation event (months)	4.6 (0.41)	5.8 (1.4)	4.1 (0.45)	4.8 (0.48)	4.4 (0.49)	7.0 (1.8)	4.3 (1.5)	4.4 (0.55)
Mean total depredation (i.e. number of depredated fish)	2236 (376)	3246 (903)	2261 (618)	2231 (486)	3423 (896)	6329 (2609)	849 (558)	1745 (539)
Number of depredation events	122	18	55	95	82	8	13	65

Table 9 Mean length of depredation period and depredation level per depredation event as a function of ADD type (only includes periods where ADD was on throughout). Standard errors of the means are shown in brackets.

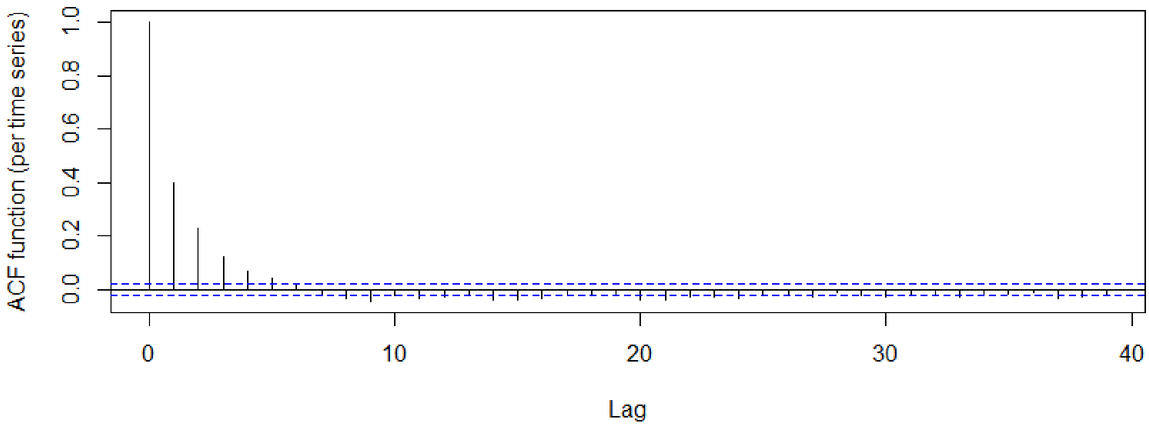
2.2 Results from statistical models of seal depredation

2.2.1 Month-level results

Question 1. Is the monthly presence or absence of depredation at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable for this model was presence or absence of depredation at a farm in a month. The initial models showed evidence of autocorrelation (Figure 5) which appeared to decline in an exponential manner and so would be well modelled as an autoregressive process of order 1 (AR1). The estimated lag-1 autocorrelation was 0.40 (the value was nearly identical for a model using ADD type as factor covariates). Models were therefore fit assuming this level of AR1 correlation within farms, using the bam function in mgcv. Comparing the model with ADD on or off as a covariate versus that with a set of factor covariates for each ADD type, the former had a lower REML score and lower degrees of freedom, so was the preferred model. Estimated coefficients from the ADD on/off model are shown in Table 10 and smooths depicted (on the logit link scale) in Figure 6. The residual qq-plot is shown in Figure 7; there were no problems indicated based on visual interpretation of these plots. Percentage deviance explained by the model was 36.7%.

(a)



(b)

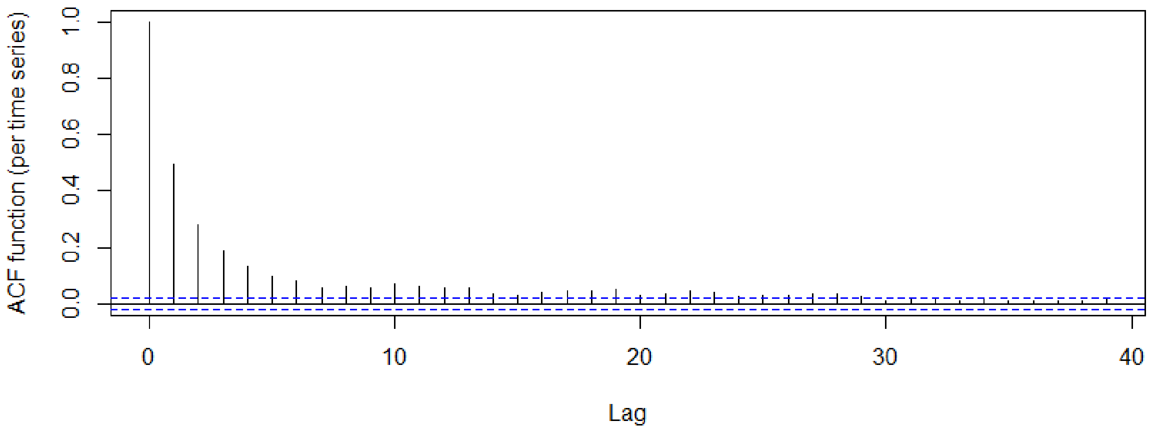


Figure 5 Autocorrelation plot from initial month-level models with ADD on or off and other covariates. Models with ADD type as a series of factor covariates showed near-identical patterns. Response is (a) presence/absence of depredation (Q1); (b) level of predation (Q2).

```
## Parametric coefficients:
##                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)            -1.23234    0.41457  -2.973  0.00295 **
## add_onTRUE              0.80899    0.12258   6.600 4.12e-11 ***
## add_prohibitedTRUE     -0.14544    0.17333  -0.839  0.40141
## fyear2015              -0.32322    0.17988  -1.797  0.07236 .
## fyear2016              -0.30584    0.19265  -1.588  0.11238
## fyear2017              -0.23720    0.19376  -1.224  0.22088
## fyear2018               0.03487    0.19484   0.179  0.85797
## fyear2019              -0.20837    0.20294  -1.027  0.30454
## fregionOrkney           1.35568    0.45510   2.979  0.00289 **
## fregionShetland        -0.55015    0.36942  -1.489  0.13643
## fregionArgyllandBute -0.38733    0.35461  -1.092  0.27472
## fregionWestern Isles -1.22751    0.38609  -3.179  0.00148 **
## squareTRUE              0.79064    0.31862   2.481  0.01308 *
## APNTRUE                 0.50998    0.12382   4.119 3.81e-05 ***
## seal_blindTRUE          0.31550    0.12535   2.517  0.01184 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                      edf  Ref.df Chi.sq p-value
## s(month)           3.370   8.000  32.45  <2e-16 ***
## s(biomass)         5.415   6.534  58.65  <2e-16 ***
## s(stock_month)     6.652   7.410 135.87  <2e-16 ***
## s(ffarmID)       166.279 205.000 869.48  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## R-sq.(adj) =  0.409   Deviance explained = 36.7%
## fREML =  11238  Scale est. = 1         n = 8644
```

Table 10 Estimated model coefficients and associated statistical significance from the model of monthly presence or absence of depredation (associated with question 1), with ADD on (TRUE) or off (FALSE) as a factor covariate.

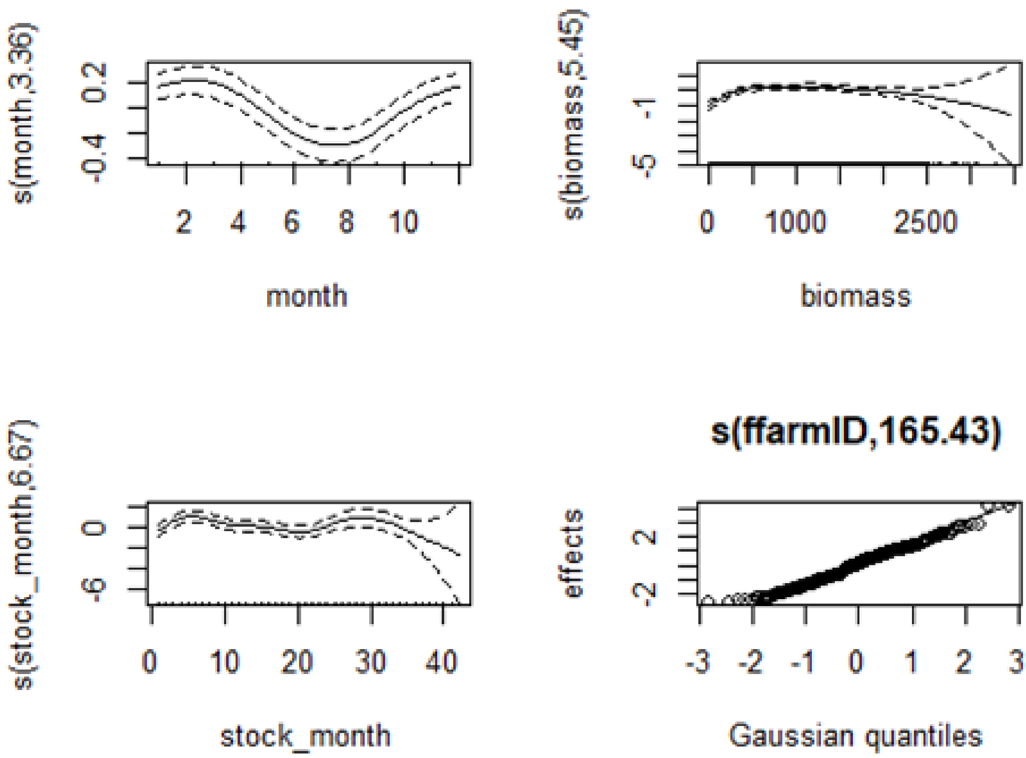


Figure 6 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the model of monthly presence or absence of depredation (associated with question 1), with ADD on (TRUE) or off (FALSE) as a factor covariate.

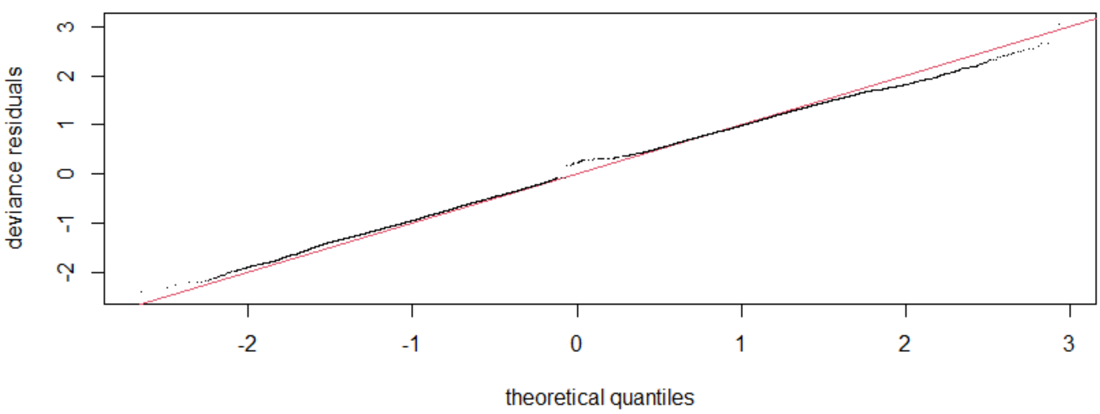


Figure 7 Quantile-quantile plot from the model of monthly presence or absence of depredation (associated with question 1), with ADD on (TRUE) or off (FALSE) as a factor covariate.

The estimated coefficients are each associated with an (approximate) test of statistical significance, and those significant at $p \leq 0.05$ were:

- the factor covariates: ADD on, region (Orkney and Western Isles), use of a square net, use of APN and use of seal blind
- the numeric covariates modelled as smooths: month, biomass, length of stocking period (coded as stock month)
- farm ID as a random effect.

The factor covariates ADD not permitted and year were not statistically significant.

The coefficient for ADD on the logit link scale is 0.81 (SE 0.12). Interpretation of this value is difficult because of the logit link function, but broadly speaking the positive value means that ADD on is associated with an increase in probability of depredation, after accounting for the effect of all other covariates in the model. To get a more refined interpretation, note that the coefficient in a logit model corresponds to the change in log odds, so exponentiating the value gives the change in the odds ratio. Odds are the probability of an event occurring divided by the probability of it not occurring, i.e. in this context the probability of depredation divided the probability of no depredation – an odds of 1 corresponds to equal chance of depredation versus no depredation. An odds ratio is the ratio of two odds – in this case the odds when ADD is on versus the odds when ADD is not on. So, given that exp(0.81) is 2.2, the interpretation is that the odds of depredation in a particular month at a particular farm increased by a factor of 2.2 when ADDs were on versus when they were off. This is similar to the finding in the exploratory data analysis, which was that ADD use was associated with a higher percentage of monthly depredation; the conclusion is therefore robust and persists when a broad range of explanatory variables are accounted for.

For factor covariates with multiple levels, the significance and coefficient are reported in comparison to the ‘baseline’ level – i.e. the first level of the factor – for the covariate ‘region’, the region Highland was the baseline level against the other levels were compared. The coefficient for the Orkney region was positive (1.36) and for Western Isles is negative (-1.23) meaning that, once the effect of other covariates was accounted for, depredation probability was higher in Orkney and lower in the Western Isles than in the baseline region (Highland).

The coefficients for square net (0.79), APN (0.51) and seal blind (0.32) were all positive, meaning that their use is associated with increased depredation probability. As with the use of ADDs, it may be that these other anti-predator devices tend to be employed when seal depredation is expected to be higher.

Examining the smooth fits (Figure 6), it appears that probability of depredation was lower in summer than winter, was lower at small stocking biomass (the decline with larger biomass was accompanied by very wide confidence intervals indicating considerable uncertainty at high biomass where there are few data) and lower for the first few months of a stocking period (again the values at very high stocking period lengths were uncertain). The between-farm random effect, which is assumed to be normally distributed on the logit scale, appeared to fit the data well (Figure 6 bottom right plot: points lie well on the diagonal straight line).

Although the analysis with ADD type was not preferred by the model selection criterion (it has a higher REML score), it is of interest to see the coefficients for ADD type, as they address the question of whether the probability of depredation varies by ADD type once other variables are accounted for. The estimated coefficients from this model are shown in Table 10. All were positive, indicating that use of each ADD type was associated with an increased probability of depredation, but the effects for the Ace Aquatec RT1 and the category unknown ADD type were not statistically significant at the 5% level. The coefficient for the GaelForce was the largest (1.24), meaning that the probability of depredation increased slightly when this device was used, compared to when it was not used, but it was not the most statistically significant.

Given the above, our conclusion regarding question 1 is that ADD usage is associated with increased monthly presence of depredation (increasing the odds of depredation by a factor of 2.2) once other available variables were accounted for, and that there is some evidence that this varied for certain ADD types.

Question 2. Is the monthly level of depredation (i.e. number of fish killed by seals) at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable for this model was the number of fish depredated at a farm in a month (i.e. depredation level). Of the four distributions tried (Poisson, quasi-Poisson, negative binomial and Tweedie), the negative binomial showed the best fit in terms of qq-plot closest to a straight diagonal line, and was used in subsequent modelling. The estimated overdispersion parameter of the negative binomial was θ = 0.102 – in this parameterization of the negative binomial, the variance is equal to mean + mean$^2/\theta$. Evidence of autocorrelation was found (Figure 5 bottom panel), and an AR1 model was used with autocorrelation of 0.49 (ADD on/off model). Comparing the model with ADD on or off as a covariate versus that with a set of factor covariates for each ADD type, the former had a lower REML score and lower degrees of freedom. Estimated coefficients for the ADD on/off model are shown in Table 11 and smooths depicted (on the log link scale) in Figure 8. The residual qq-plot is shown in Figure 9, there were a large values of depredation for which the residuals are somewhat larger than predicted (right hand dots above the red line in Figure 9). The percentage of deviance explained by the model was 34.7%.

The estimated coefficients that were significant at $p \leq 0.05$ were:

- the factor covariates: ADD on, ADD prohibited, year (years 2015, 2017 and 2019), region (Orkney), use of APN and use of seal blind
- the numeric covariates modelled as smooths: month, biomass, length of stocking period (coded as stock month)
- farm ID as a random effect.

The factor covariate square net was not statistically significant.

The coefficient for ADD on the log link scale was 0.95 (SE 0.15). Back transforming from the scale of the log link function, this means that the number of fish depredated per month was estimated to be 2.58 times greater when ADDs were on versus when off.

Depredation level was estimated to be exp(0.52) = 1.7 times higher in sites/months where ADD use was permitted than where it was not permitted. The level of depredation was estimated to vary by year, with 2015, 2017 and 2019 all lower than the baseline year (2014) by factors of 0.61, 0.57, and 0.55, respectively. Depredation level was estimated to be seven times higher in Orkney than the baseline Highland region. APN and use of seal blinds were associated with increases in predation levels of 1.9 and 2.4 times, respectively.

Examining the smooth fits (Figure 8), depredation level was lower in the summer, lower at low fish stocking biomass and in the initial months of stocking (although it was also estimated to decrease in later months of stocking for long stocking periods). The between-farm random effect did not completely follow the assumed normal distribution (Figure 8 bottom right plot), with more farms having low levels of predation than expected (dots below line on left hand side of the plot). This was likely because many farms had zero predation, and the normal effect did not accurately capture this.

The model with ADD types as individual factor covariates (Table 12) showed a positive association between depredation level and ADD on for all ADD types, although only the Terecos (type 4) and OTAQ Seal Fence (type 5) were statistically significant, with depredation level being 2.9 times higher when the Terecos was used, and 4.1 times higher when the OTAQ SealFence was used.

Our overall conclusion regarding question 2 is that ADD usage is associated with increased monthly level of depredation (1.7 times higher with ADD on versus off) once other available variables were accounted for, and that there is some evidence that this varied by ADD type.

```
## Parametric coefficients:
##                        Estimate Std. Error t value Pr(>|t|)
## (Intercept)              1.5909     0.5835   2.727 0.006410 **
## add_onTRUE               0.9488     0.1527   6.212 5.49e-10 ***
## add_prohibitedTRUE       0.5205     0.2412   2.159 0.030916 *
## fyear2015               -0.4982     0.2273  -2.192 0.028423 *
## fyear2016               -0.4493     0.2493  -1.802 0.071578 .
## fyear2017               -0.5718     0.2529  -2.261 0.023803 *
## fyear2018               -0.1027     0.2560  -0.401 0.688378
## fyear2019               -0.6024     0.2680  -2.248 0.024627 *
## fregionOrkney            1.9602     0.7568   2.590 0.009614 **
## fregionShetland         -0.7279     0.6029  -1.207 0.227387
## fregionArgyllandBute    -0.9626     0.5927  -1.624 0.104406
## fregionWestern Isles    -0.5561     0.6333  -0.878 0.379882
## squareTRUE               0.8009     0.4774   1.678 0.093450 .
```

```
## APNTRUE                       0.6481     0.1767   3.667 0.000247 ***
## seal_blindTRUE                0.8805     0.1675   5.256 1.51e-07 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                     edf  Ref.df      F p-value
## s(month)          6.846   8.000 17.467  <2e-16 ***
## s(biomass)        7.370   8.072 17.321  <2e-16 ***
## s(stock_month)    6.909   7.718 20.871  <2e-16 ***
## s(ffarmID)      180.863 204.000  7.779  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 11 Estimated model coefficients and associated statistical significance from the model of monthly level of depredation (associated with question 2), with ADD on (TRUE) or off (FALSE) as a factor covariate.

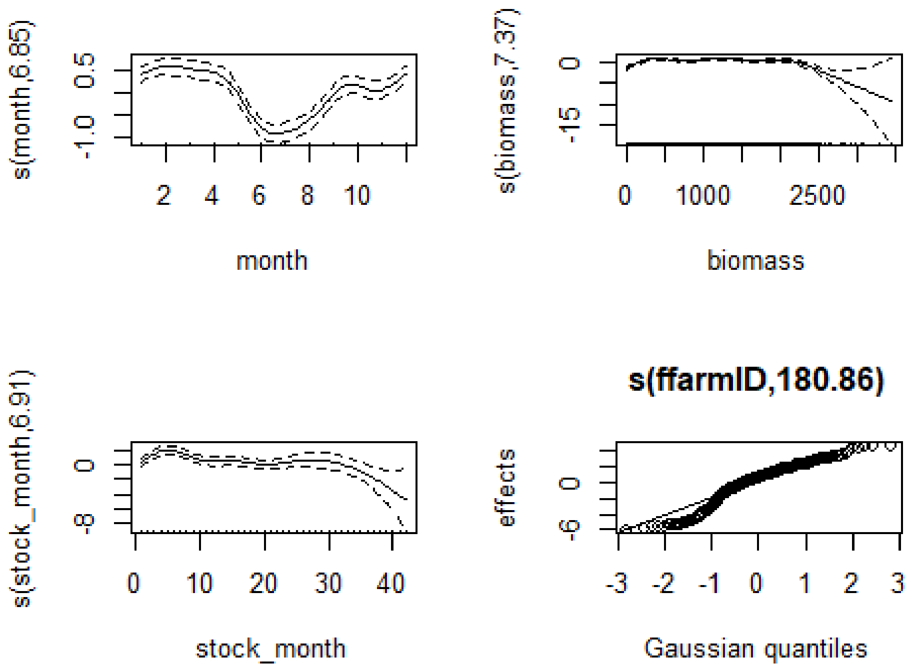


Figure 8 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the model of monthly level of depredation (associated with question 2), with ADD on (TRUE) or off (FALSE) as a factor covariate.

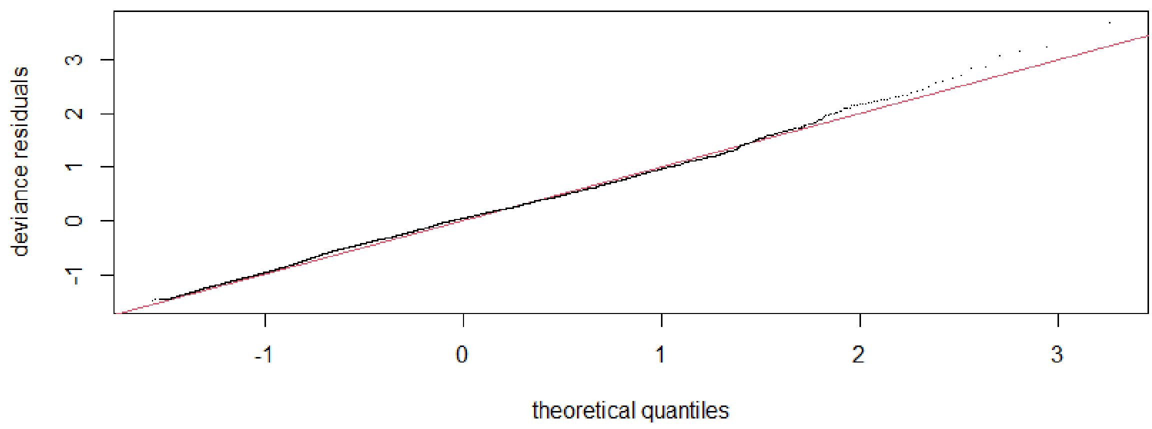


Figure 9 Quantile-quantile plot from the model of monthly level of depredation (associated with question 2), with ADD on (TRUE) or off (FALSE) as a factor covariate.

```
## Parametric coefficients:
##                      Estimate Std. Error t value Pr(>|t|)    
## (Intercept)            1.7940     0.6174   2.906 0.003675 ** 
## add_type1TRUE          0.6100     0.3166   1.927 0.054059 .  
## add_type2TRUE          0.5399     0.4091   1.320 0.186976    
## add_type3TRUE          0.3968     0.3427   1.158 0.246901    
## add_type4TRUE          1.0956     0.3171   3.455 0.000553 ***
## add_type5TRUE          1.3990     0.3130   4.469 7.94e-06 ***
## add_type6TRUE          0.4929     0.5273   0.935 0.349926    
## add_type8TRUE          0.9361     0.7625   1.228 0.219615    
## add_type9TRUE          0.4888     0.3838   1.273 0.202883    
## add_prohibitedTRUE     0.5306     0.2484   2.136 0.032707 *  
## fyear2015             -0.5062     0.2276  -2.224 0.026166 *  
## fyear2016             -0.4997     0.2508  -1.993 0.046347 *  
## fyear2017             -0.6727     0.2583  -2.604 0.009235 ** 
## fyear2018             -0.2301     0.2648  -0.869 0.384754    
## fyear2019             -0.7029     0.2782  -2.527 0.011538 *  
## fregionOrkney          1.8909     0.7704   2.454 0.014132 *  
## fregionShetland       -0.6322     0.6184  -1.022 0.306693    
## fregionArgyllandBute  -0.9787     0.5953  -1.644 0.100190    
## fregionWestern Isles  -0.6373     0.6377  -0.999 0.317596    
## squareTRUE             0.8393     0.4867   1.725 0.084646 .  
## APNTRUE                0.5346     0.1883   2.839 0.004541 ** 
## seal_blindTRUE         0.6240     0.1821   3.426 0.000614 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
```

```
## Approximate significance of smooth terms:
##                      edf  Ref.df      F p-value    
## s(month)           6.827   8.000 18.362  <2e-16 ***
## s(biomass)         7.367   8.083 17.440  <2e-16 ***
## s(stock_month)     6.928   7.740 22.663  <2e-16 ***
## s(ffarmID)       180.472 204.000  7.369  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```
Table 12 Estimated model coefficients and associated statistical significance from the model of monthly level of depredation (associated with question 2), with ADD type as a set of factor covariates.

2.2.2 Stocking period-level results

Question 3. Are the number of depredation events during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable for this model was the number of depredation events per stocking period, modelled as a Poisson distribution. Comparing the ADD on/off model with the ADD type model, the latter had a slightly lower UBRE score (-0.015 for on/off versus -0.022 for type) and so is preferred. The estimated coefficients are shown for the ADD type model in Table **13** and the smooths in Figure 10. The residual qq-plot is shown in Figure 11, which indicates that the residuals are under-dispersed relative to their predicted distribution; therefore, caution should be exercised in interpreting the model selection statistics and statistical significance of model coefficients. Percentage deviance explained by the model was 39%.

The estimated coefficients that were significant at $p \leq 0.05$ were:

- Factor covariates: ADD type (types 2 (Ace Aquatec RT1), 4 (Terecos), and 9 (MohnAqua)), ADD prohibited, year that stocking started (2015), region (Orkney), use of square nets
- The smooth of the log of stocking length (stock_month in Table 13).

All significant ADD type coefficients were positive, indicating that these ADD types were associated with a greater number of depredation events. For example, the largest, the MohnAqua device, had a coefficient of 0.73 on the log link scale, which corresponds to there being exp(0.73) = 2.1 times more depredation events when that ADD type was on versus when it was off. ADDs not being permitted were associated with more depredation events; the year 2015 was associated with fewer depredation events than the baseline year (2014); the Orkney region was associated with more depredation events than the baseline region (Highland); square nets were associated with more depredation events; the number of depredation events increased almost linearly with the length of the stocking period variable (Figure 10). The random effect of farm ID was significant (Table 13) and fitted the assumed normal distribution well, except at the extremes (Figure 10).

```
## Parametric coefficients:
##                        Estimate Std. Error z value Pr(>|z|)
## (Intercept)           -0.243214   0.199589  -1.219 0.223007
## add_type1              0.245550   0.174800   1.405 0.160096
## add_type2              0.694075   0.239419   2.899 0.003744 **
## add_type3             -0.015773   0.203263  -0.078 0.938148
## add_type4              0.501617   0.182559   2.748 0.006001 **
## add_type5             -0.002075   0.218797  -0.009 0.992433
## add_type6              0.157127   0.336026   0.468 0.640069
## add_type8              0.548404   0.406012   1.351 0.176788
## add_type9              0.733932   0.191309   3.836 0.000125 ***
## add_prohibited         0.364886   0.158982   2.295 0.021725 *
## fstart_year2015       -0.270849   0.132887  -2.038 0.041531 *
```

```
## fstart_year2016      -0.013607   0.118963  -0.114 0.908933
## fstart_year2017       0.111518   0.128128   0.870 0.384099
## fstart_year2018      -0.046285   0.176550  -0.262 0.793196
## fstart_year2019       0.071659   0.530111   0.135 0.892471
## fregionOrkney         0.634955   0.194492   3.265 0.001096 **
## fregionShetland       0.132612   0.162609   0.816 0.414771
## fregionArgyllandBute -0.070666   0.142801  -0.495 0.620699
## fregionWestern Isles -0.133763   0.161093  -0.830 0.406342
## square                0.328140   0.142458   2.303 0.021256 *
## APN                   0.049272   0.111788   0.441 0.659382
## seal_blind            0.014312   0.124347   0.115 0.908369
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                         edf  Ref.df Chi.sq p-value
## s(log(stock_month))  2.641   3.261 49.068  <2e-16 ***
## s(mean_month)        2.647   3.411  1.494  0.6410
## s(mean_biomass)      1.000   1.000  0.612  0.4340
## s(ffarmID)          26.652 190.000 31.072  0.0713 .
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 13 Estimated model coefficients and associated statistical significance from the model of the number of depredation events per stocking period (associated with question 3), with each ADD type as a covariate.

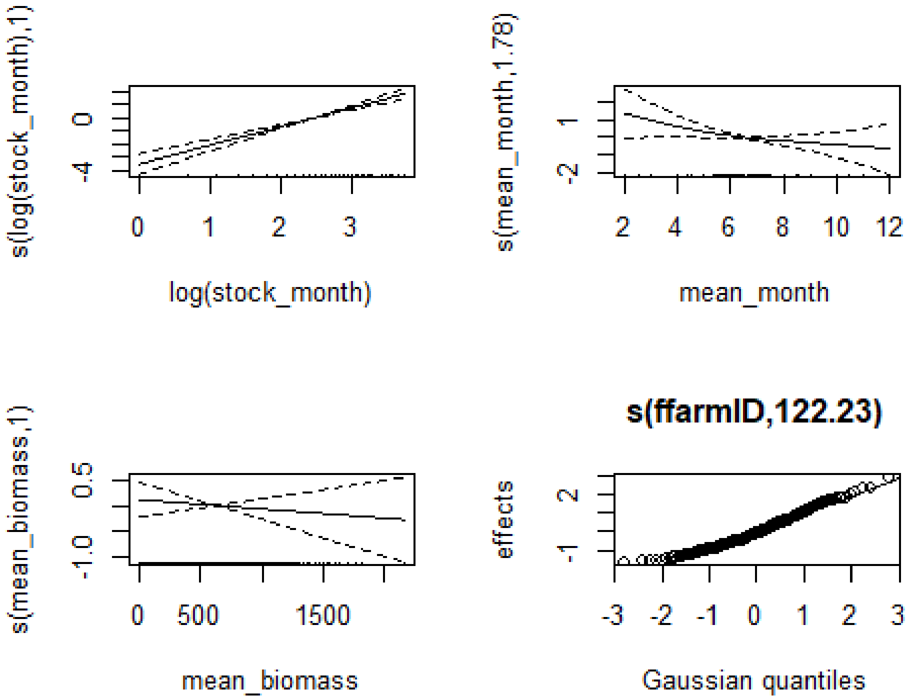


Figure 10 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the model of the number of depredation events per stocking period (associated with question 3) with each ADD type as a covariate.

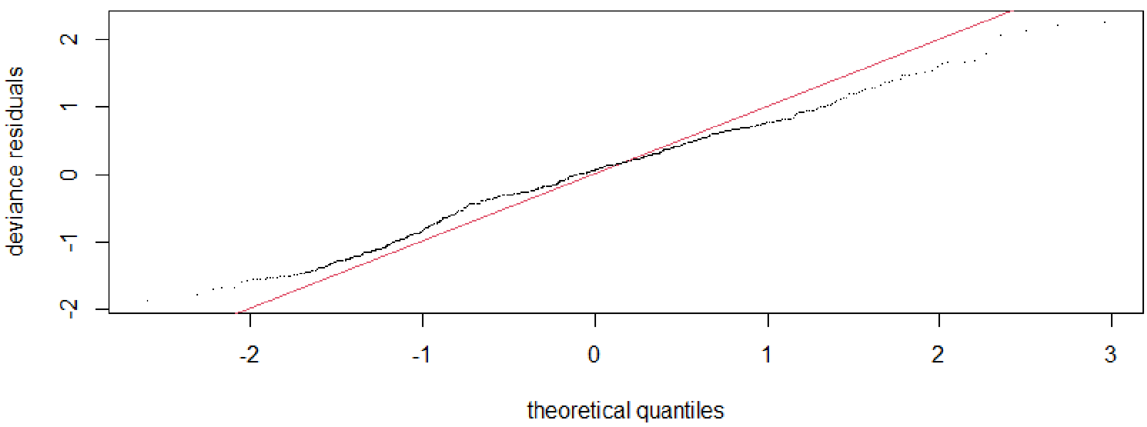


Figure 11 Quantile-quantile plot from the model of the number of depredation events per stocking period (associated with question 3) with each ADD type as a covariate.

Coefficients of the ADD on/off model is also of interest and are shown in Table 14. The overall effect of ADD on was significant, with a coefficient of 0.42, meaning that the number of depredation events was expected to be exp(0.42) = 1.5 times greater when ADDs were on for the entire stocking period versus when they were off for the entire duration of stocking.

The overall conclusion is that ADD usage is associated with an increased number of depredation events per stocking period (1.5 times more when ADDs are on for the whole stocking period) once other variables were accounted for, and that there is good evidence that this varied by ADD type.

```
## Parametric coefficients:
##                         Estimate Std. Error z value Pr(>|z|)
## (Intercept)             -0.28119    0.19017  -1.479  0.13925
## add_on                   0.42130    0.14576   2.890  0.00385 **
## add_prohibited           0.38839    0.16217   2.395  0.01662 *
## fstart_year2015         -0.26885    0.13397  -2.007  0.04477 *
## fstart_year2016         -0.04024    0.11704  -0.344  0.73096
## fstart_year2017          0.02611    0.12286   0.213  0.83170
## fstart_year2018         -0.12954    0.17131  -0.756  0.44953
## fstart_year2019         -0.01031    0.53512  -0.019  0.98463
## fregionOrkney            0.65618    0.20028   3.276  0.00105 **
## fregionShetland          0.18020    0.16316   1.104  0.26941
## fregionArgyllandBute -0.14044    0.14780  -0.950  0.34202
## fregionWestern Isles -0.21643    0.16305  -1.327  0.18439
## square                   0.37199    0.15145   2.456  0.01404 *
## APN                      0.05522    0.11146   0.495  0.62028
## seal_blind               0.11991    0.11304   1.061  0.28879
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                          edf  Ref.df Chi.sq p-value
## s(log(stock_month))  2.638   3.238 49.787 < 2e-16 ***
## s(mean_month)        2.975   3.790  3.893 0.49185
## s(mean_biomass)      1.000   1.000  0.437 0.50863
## s(ffarmID)          43.272 190.000 55.740 0.00711 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 14 Estimated model coefficients and associated statistical significance from the model of the number of depredation events per stocking period (associated with question 3), with proportion of time ADD on (0 = never on; 1 = always on) as a covariate.

Question 4. Is the total level of depredation during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable for this model was the number of fish reported depredated by seals per stocking period. Of the four response variable distributions tried (Poisson, quasi-Poisson, negative binomial and Tweedie), the quasi-Poisson showed the best fit in terms of qq-plot closest to a straight diagonal line, and was used in subsequent modelling. The estimated overdispersion parameter of the quasi-Poisson was 2,148 (this gives the ratio of variance to mean in the quasi-Poisson). Comparing the ADD on/off model with the ADD type model, the latter had a lower GCV score (2860 versus 2832) and so is preferred. The estimated coefficients are shown for the ADD type model in Table 15 and the smooths in Figure 12. The residual qq-plot is shown in Figure 13, which indicates that there is minor deviation from the desired straight line (which indicates no systematic variance in residuals). Percentage deviance explained by the model was 79%.

```
## Parametric coefficients:
##                          Estimate Std. Error t value Pr(>|t|)
## (Intercept)              5.584586   0.381295  14.646  < 2e-16 ***
## add_type1                1.101456   0.280154   3.932 0.000102 ***
## add_type2               -0.002006   0.307869  -0.007 0.994806
## add_type3                1.518279   0.325527   4.664 4.44e-06 ***
## add_type4                1.553238   0.280288   5.542 5.97e-08 ***
## add_type5                1.206236   0.336659   3.583 0.000389 ***
## add_type6                1.246834   0.327038   3.813 0.000163 ***
## add_type8               -0.523539   1.198711  -0.437 0.662565
## add_type9                0.972930   0.310424   3.134 0.001871 **
## add_prohibited           1.371840   0.265894   5.159 4.19e-07 ***
## fstart_year2015         -0.447224   0.171476  -2.608 0.009501 **
## fstart_year2016         -0.241010   0.144965  -1.663 0.097316 .
## fstart_year2017         -0.125395   0.164264  -0.763 0.445762
## fstart_year2018          0.228075   0.203299   1.122 0.262700
## fstart_year2019          1.587739   0.949816   1.672 0.095506 .
## fregionOrkney            1.251745   0.483427   2.589 0.010025 *
## fregionShetland          0.434877   0.395072   1.101 0.271773
## fregionArgyllandBute    -0.524055   0.365354  -1.434 0.152372
## fregionWestern Isles    -0.211883   0.387066  -0.547 0.584452
## square                   0.776182   0.350052   2.217 0.027253 *
## APN                      0.244415   0.162561   1.504 0.133619
## seal_blind               0.289786   0.177556   1.632 0.103576
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                            edf  Ref.df      F p-value
```

```
## s(log(stock_month))    1.000   1.000 87.003  <2e-16 ***
## s(mean_month)          5.573   6.516  1.729   0.121
## s(mean_biomass)        6.662   7.692  1.129   0.398
## s(ffarmID)           129.452 190.000  2.983  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 15 Estimated model coefficients and associated statistical significance from the model of the level of depredation per stocking period (associated with question 4), with each ADD type as a covariate.

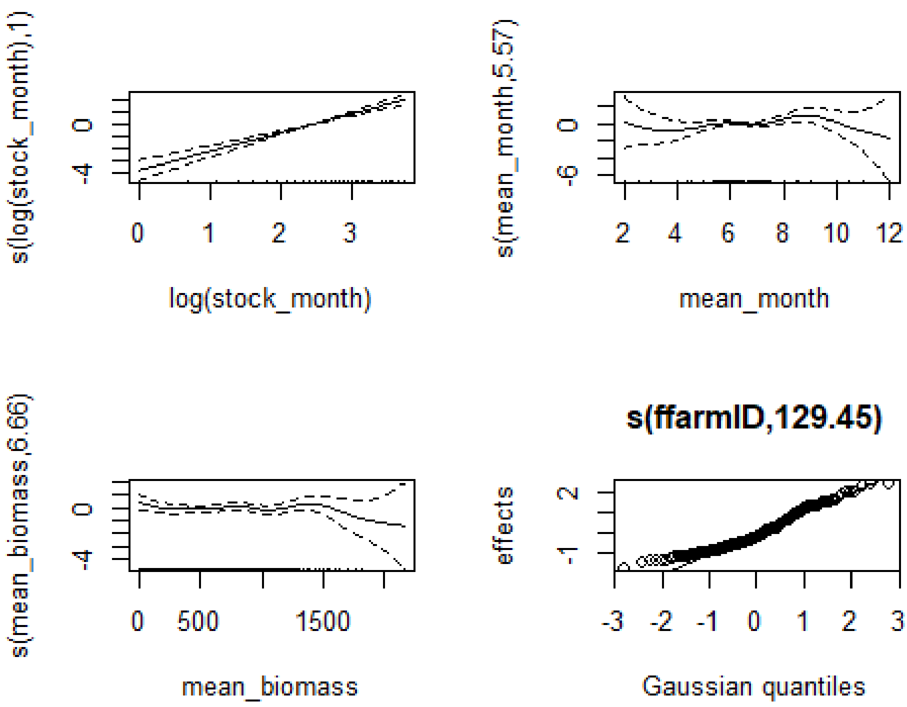


Figure 12 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the model of the level of depredation per stocking period (associated with question 4) with each ADD type as a covariate.

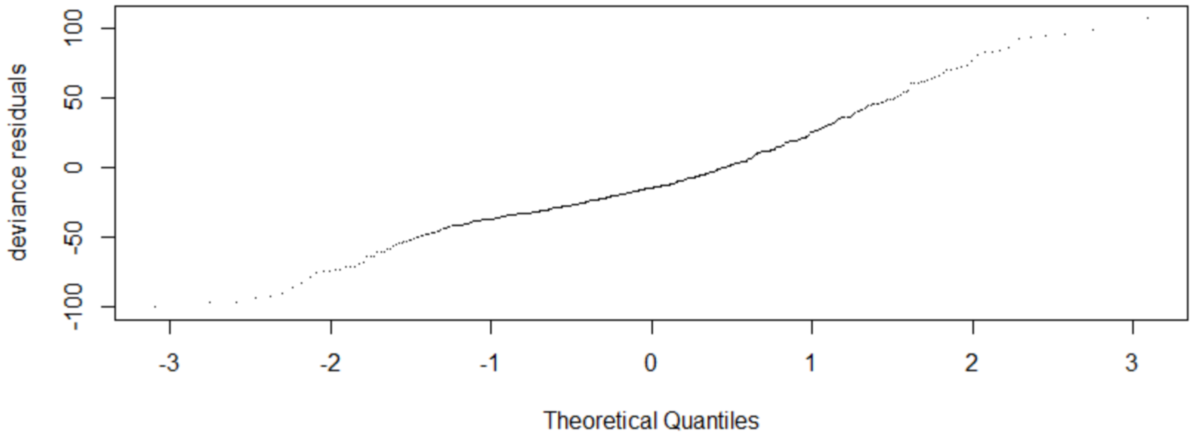


Figure 13 Quantile-quantile plot from the model of the level of depredation per stocking period (associated with question 4) with each ADD type as a covariate. (No guide line is provided for quasi-Poisson models.)

The estimated coefficients that were significant at p ≤ 0.05 were:

- Factor covariates: ADD type (types 1 (Airmar), 3 (Ace Aquatec US3), 4 (Terecos), 5 (OTAQ SealFence), 6 (Unknown) and 9 (MohnAqua), ADD prohibited, year that stocking started (2015), region (Orkney), use of square nets
- The smooth of the log of stocking length.

These are very similar to those from the analyses in question 3. Again, all significant ADD type coefficients were positive, indicating that these ADD types were associated with greater depredation level. ADD not permitted was associated with higher depredation level; the year 2015 was associated with a lower depredation level than the baseline year (2014); the region Orkney was associated with a higher depredation level than the baseline region (Highland); square nets were associated with a higher depredation level; the level of depredation increased linearly with the length of the stocking period (Figure 12). The random effect of farm ID was significant (Table 15); it fitted the assumed normal distribution well, except at the lower extreme where the between-farm variation was less than that assumed by a normal distribution (Figure 12, indicated by dots above the line).

The coefficients of the ADD on/off model are also of interest and are shown in Table 16. The overall effect of ADD on was significant, with a coefficient of 1.4, meaning that the level of depredation was expected to be exp(1.4) = 4 times greater when ADDs were on for the entire stocking period compared with when they were off for the entire duration of stocking.

The overall conclusion regarding question 4 is that ADD usage is associated with an increased level of depredation per stocking period (4 times higher when ADDs on for the whole stocking period) once other variables were accounted for, and that there is good evidence that this varied by ADD type.

```
## Parametric coefficients:
##                      Estimate Std. Error t value Pr(>|t|)
## (Intercept)           5.73634    0.38388  14.943  < 2e-16 ***
## add_on                1.39826    0.27294   5.123 4.97e-07 ***
## add_prohibited        1.27841    0.27684   4.618 5.45e-06 ***
## fstart_year2015      -0.30658    0.17521  -1.750   0.0810 .
## fstart_year2016      -0.17250    0.14591  -1.182   0.2379
## fstart_year2017      -0.15157    0.16315  -0.929   0.3535
## fstart_year2018       0.06842    0.20009   0.342   0.7326
## fstart_year2019       0.50591    0.91213   0.555   0.5795
## fregionOrkney         1.24793    0.49349   2.529   0.0119 *
## fregionShetland       0.32571    0.40426   0.806   0.4210
## fregionArgyllandBute -0.55637    0.37297  -1.492   0.1367
## fregionWestern Isles -0.28476    0.39118  -0.728   0.4671
## square                0.55499    0.35975   1.543   0.1238
## APN                   0.07894    0.15610   0.506   0.6134
## seal_blind            0.33491    0.16627   2.014   0.0447 *
## ---
```

```
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                            edf  Ref.df      F p-value
## s(log(stock_month))   1.000   1.000 89.454  <2e-16 ***
## s(mean_month)         6.040   6.977  1.745  0.0947 .
## s(mean_biomass)       8.019   8.666  2.267  0.0299 *
## s(ffarmID)          127.948 190.000  2.893  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 16 Estimated model coefficients and associated statistical significance from the model of the level of depredation per stocking period (associated with question 4), with proportion of time ADD on (0 = never on; 1 = always on) as a covariate.

Question 5. Is the proportion of months during which depredation events occur during a stocking period at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of months in a stocking period where depredation was recorded, modelled as a binomial or quasibinomial random variable with the number of trials being the length of stocking period (in months). Of the two distributions, the quasi-binomial gave a qq-plot closest to a straight diagonal line, and was used in subsequent modelling. The estimated overdispersion parameter of the quasi-binomial was 8.0 (this is a multiplier on the variance relative to expectation under the binomial). Comparing the ADD on/off model with the ADD type model, the former had a lower GCV score (4.23 vs 4.40) and so was preferred. The estimated coefficients are shown for the ADD on/off model in Table 17 and the smooths in Figure 14. The residual qq-plot is shown in Figure 15 – this shows no major issues. Percentage deviance explained by the model was 79%.

The only estimated coefficient that was significant at $p \le 0.05$ was ADD on.

The estimated coefficient value of 1.53 can be interpreted as meaning that the odds of a particular month within a stocking period containing a depredation event increased by a factor of exp(1.53) = 4.6 when ADDs were on for the entire stocking period compared with when they were off for the entire duration of stocking. Although the other coefficients were somewhat comparable with the similar analysis undertaken for question 1, the estimated uncertainty on the coefficients were larger.

```
## Parametric coefficients:
##                        Estimate Std. Error t value Pr(>|t|)
## (Intercept)            -1.92503    0.84185  -2.287  0.02286 *
## add_on                  1.53114    0.47941   3.194  0.00154 **
## add_prohibited          0.73666    0.54705   1.347  0.17904
## fstart_year2015        -0.61352    0.37054  -1.656  0.09873 .
## fstart_year2016        -0.30029    0.28259  -1.063  0.28874
## fstart_year2017        -0.14164    0.34569  -0.410  0.68228
## fstart_year2018        -0.22576    0.43529  -0.519  0.60436
## fstart_year2019         2.13813    1.76447   1.212  0.22648
```

```
## fregionOrkney          1.80543    1.20217   1.502  0.13412
## fregionShetland        0.08866    0.98923   0.090  0.92864
## fregionArgyllandBute -0.36021    0.93016  -0.387  0.69882
## fregionWestern Isles -1.11364    1.00645  -1.107  0.26933
## square                 1.54910    0.86167   1.798  0.07314 .
## APN                    0.09881    0.35942   0.275  0.78354
## seal_blind             0.16103    0.36016   0.447  0.65510
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                     edf  Ref.df     F p-value
## s(mean_month)     6.985   7.891 0.470   0.876
## s(mean_biomass)   1.000   1.000 0.118   0.731
## s(stock_month)    1.000   1.001 0.795   0.373
## s(ffarmID)      159.565 190.000 0.930   0.207
```

Table 17 Estimated model coefficients and associated statistical significance from the model of the proportion of depredation months per stocking period (associated with question 5) with proportion of time ADD on as a covariate.

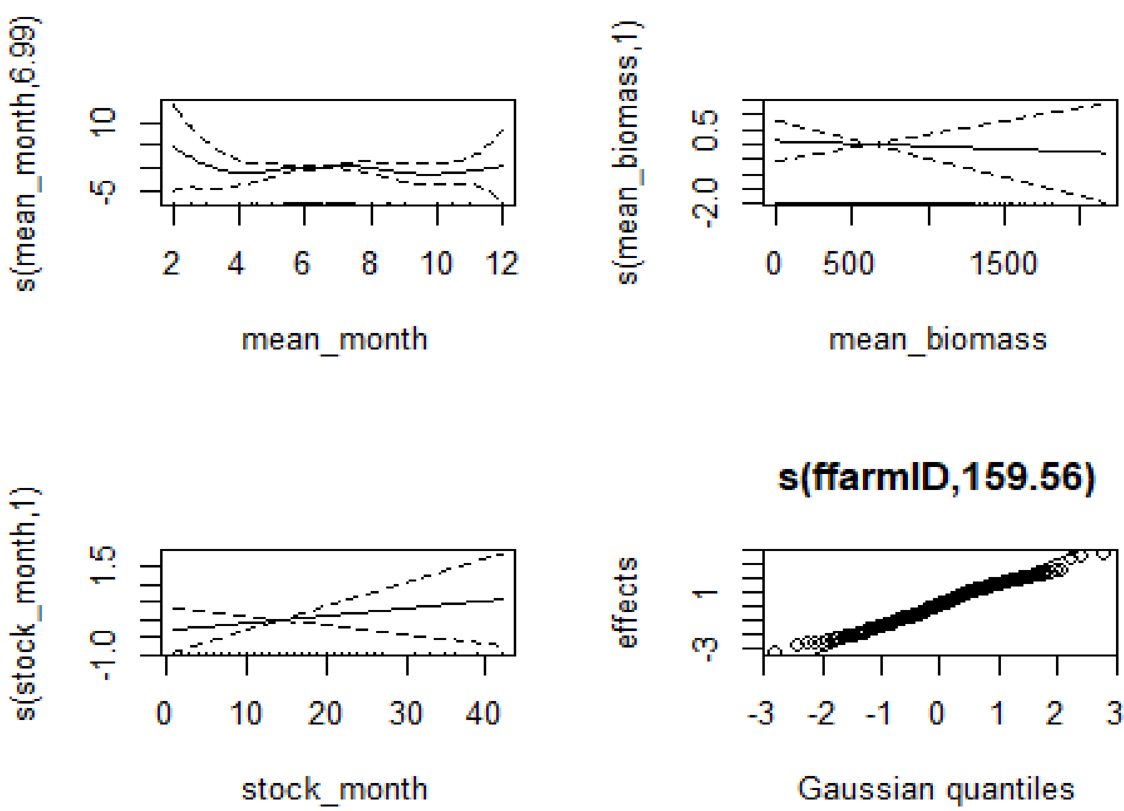


Figure 14 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the

model of the proportion of depredation months per stocking period (associated with question 5) with proportion of time ADD on as a covariate.

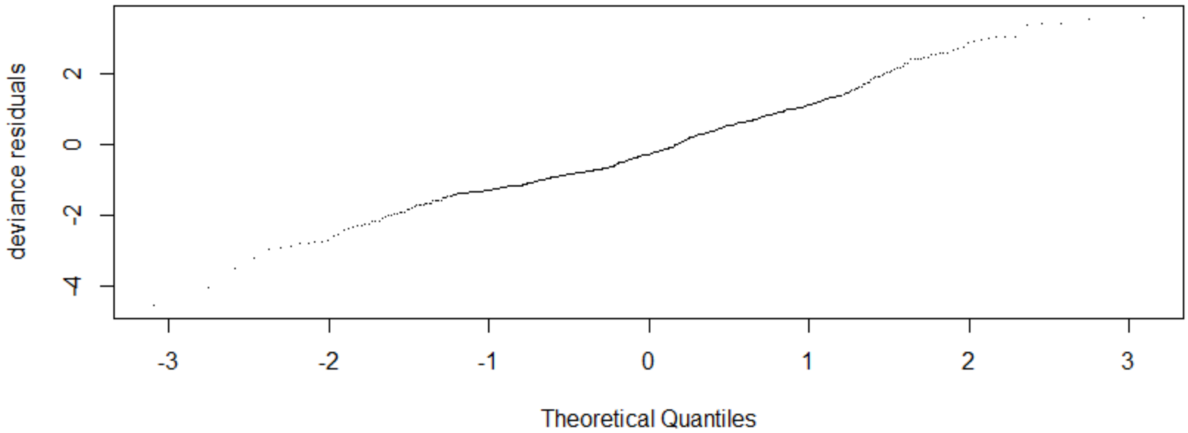


Figure 15 Quantile-quantile plot from the model of the proportion of depredation months per stocking period (associated with question 5) with proportion of time ADD on as a covariate. (No guideline is provided for quasi-binomial models.)

Coefficients for the ADD type model are shown in Table 18. ADD type, specifically type 1 (Airmar), 3 (Ace Aquatec US3) and 9 (MohnAqua) were statistically significant at p ≤ 0.05, and the estimated coefficients were positive in all three cases, indicating an association with increased proportion of depredation months per stocking period.

```
## Parametric coefficients:
##                        Estimate Std. Error t value Pr(>|t|)
## (Intercept)            -2.12573    0.86906  -2.446   0.0150 *
## add_type1               1.34146    0.59946   2.238   0.0259 *
## add_type2               0.22445    0.81106   0.277   0.7822
## add_type3               1.33927    0.66714   2.007   0.0455 *
## add_type4               1.11852    0.57173   1.956   0.0513 .
## add_type5               0.56401    0.66386   0.850   0.3962
## add_type6               1.02508    0.84373   1.215   0.2253
## add_type8               2.58877    1.66620   1.554   0.1212
## add_type9               1.48847    0.67874   2.193   0.0290 *
## add_prohibited          0.72008    0.55124   1.306   0.1924
## fstart_year2015        -0.70487    0.37314  -1.889   0.0598 .
## fstart_year2016        -0.25756    0.28436  -0.906   0.3657
## fstart_year2017         0.03712    0.35908   0.103   0.9177
## fstart_year2018         0.04210    0.44561   0.094   0.9248
## fstart_year2019         2.53636    1.77219   1.431   0.1534
## fregionOrkney           1.94743    1.18494   1.643   0.1013
## fregionShetland         0.11461    0.97586   0.117   0.9066
## fregionArgyllandBute -0.16335    0.90994  -0.180   0.8576
## fregionWestern Isles -0.92466    0.99135  -0.933   0.3517
## square                  1.63262    0.85398   1.912   0.0568 .
## APN                     0.26873    0.37799   0.711   0.4776
```

```
## seal_blind            0.32592    0.39507   0.825   0.4100
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                     edf  Ref.df     F p-value
## s(mean_month)     7.032   7.926 0.555   0.815
## s(mean_biomass)   1.000   1.000 0.018   0.893
## s(stock_month)    1.000   1.001 0.611   0.435
## s(ffarmID)      158.811 190.000 0.929   0.200
```

Table 18 Estimated model coefficients and associated statistical significance from the model of the proportion of depredation months per stocking period (associated with question 5) with each type of ADD as a covariate.

The overall conclusion regarding question 5 is that ADD usage is associated with an increased proportion of months with depredation per stocking period (odds of predation 4.6 times higher when ADDs are on for the whole period) once other variables were accounted for, and that there is good evidence that this varied by ADD type.

2.2.3 Depredation event-level results.

Question 6. Is the total level of depredation at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was the number of fish reported depredated by seals per depredation event. Of the four response variable distributions tried (Poisson, quasi-Poisson, negative binomial and Tweedie), the negative binomial had a slightly better fit than the Tweedie; both were better than quasi-Poisson or Poisson. Negative binomial, with an estimated overdispersion parameter of $\theta = 0.73$ was used in subsequent modelling. Comparing the ADD on/off model with the ADD type model, the former had a lower AIC (calculated using the compareML function; ΔAIC 3.72) and so was preferred. The estimated coefficients are shown for the ADD on/off model in Table 19 and the smooths in Figure 16. The residual qq-plot is shown in Figure 17 – low values are slightly under-predicted. Percentage deviance explained by the model was 67%.

```
## Parametric coefficients:
##                      Estimate Std. Error z value Pr(>|z|)
## (Intercept)           6.57168    0.31076  21.147  < 2e-16 ***
## add_on                0.03440    0.17737   0.194 0.846211
## add_prohibited       -0.01495    0.19269  -0.078 0.938149
## fstart_year2015      -0.48423    0.18202  -2.660 0.007806 **
## fstart_year2016      -0.29044    0.18270  -1.590 0.111899
## fstart_year2017      -0.46073    0.18219  -2.529 0.011447 *
## fstart_year2018      -0.47041    0.17952  -2.620 0.008783 **
## fstart_year2019      -0.70428    0.20833  -3.381 0.000723 ***
## fregionOrkney         0.18402    0.36891   0.499 0.617908
## fregionShetland       0.45468    0.31050   1.464 0.143105
```

```
## fregionArgyllandBute -0.60316    0.28591  -2.110 0.034894 *
## fregionWestern Isles  0.90930    0.31122   2.922 0.003481 **
## square               -0.30222    0.26575  -1.137 0.255442
## APN                   0.16260    0.13685   1.188 0.234761
## seal_blind            0.10805    0.14700   0.735 0.462298
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                 edf  Ref.df  Chi.sq p-value
## s(log(depredation_month))    2.446   2.984 830.759  <2e-16 ***
## s(mean_month)                6.892   7.903  42.054  <2e-16 ***
## s(mean_biomass)              1.008   1.016   2.934  0.0882 .
## s(ffarmID)                 125.905 174.000 612.154  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```
Table 19 Estimated model coefficients and associated statistical significance from the model of the level of depredation per depredation event (associated with question 6) with proportion of time ADD on as a covariate.

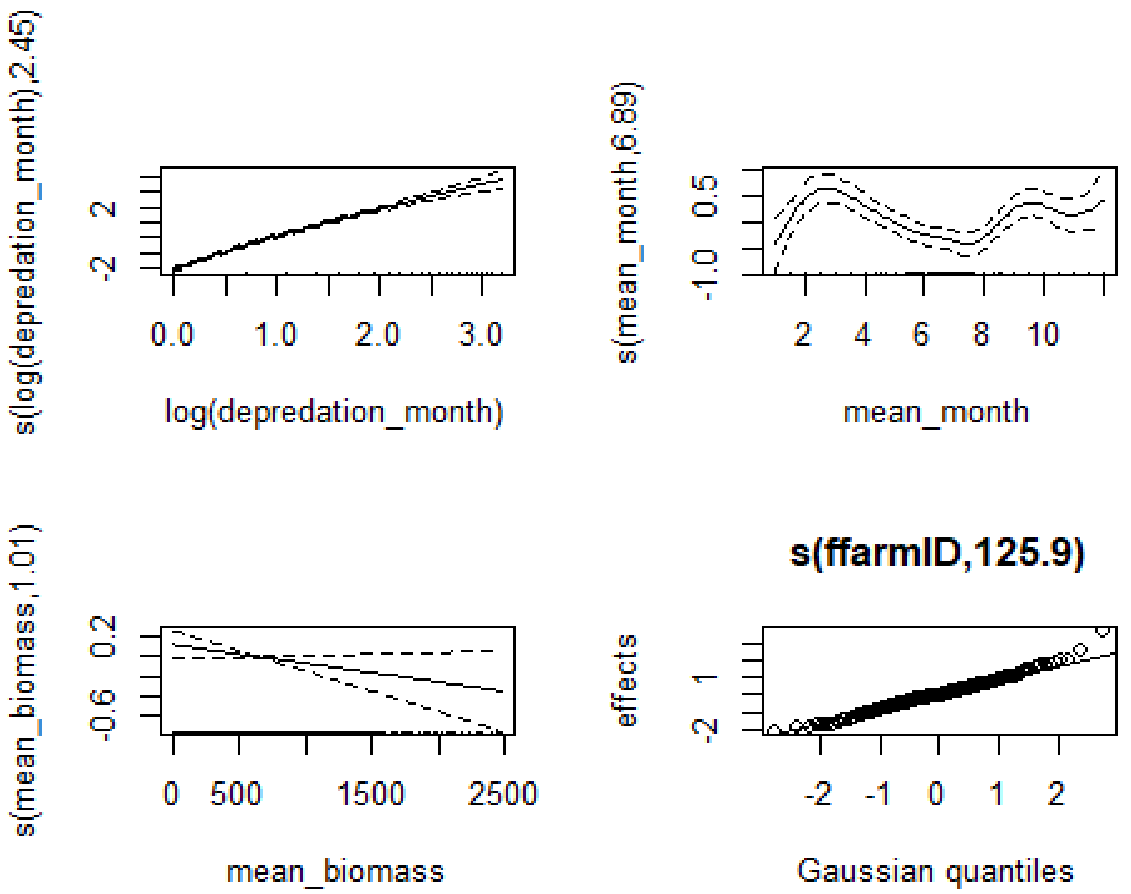


Figure 16 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the

model of the level of depredation per depredation event (associated with question 6) with proportion of time ADD on as a covariate.

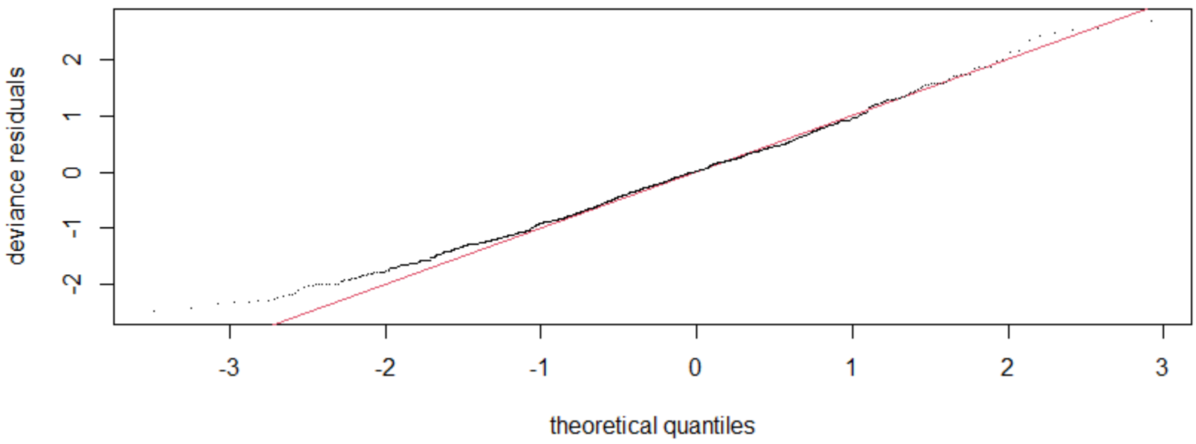


Figure 17 Quantile-quantile plot from the model of the level of depredation per depredation event (associated with question 6) with proportion of time ADD on as a covariate.

The estimated coefficients that were significant at $p \leq 0.05$ were:

- factor covariates: year that the depredation event started (2015, 2017, 2018 and 2019), region (Argyll and Bute and Western Isles)
- smooth of the log of depredation event length and smooth of mean month of the year of the depredation event.

Unlike the previous analyses, ADD on/off was not statistically significant (and indeed the estimated coefficient size was close to zero). Depredation level was negatively associated with the years 2015, 2017, 2018 and 2019 and with the Argyll and Bute region, positively associated with the Western Isles region and increased linearly with the length of the depredation event (Table 20).

Coefficients for the ADD type model are shown in Table 20. ADD type 8 (the GaelForce) had the only statistically significant (at $p \leq 0.05$) coefficient relating to ADD usage and is negatively associated with predation level.

```
## Parametric coefficients:
##                         Estimate Std. Error z value Pr(>|z|)
## (Intercept)              6.63100    0.30987  21.399  < 2e-16 ***
## add_type1                0.02026    0.21638   0.094 0.925401
## add_type2                0.44692    0.35413   1.262 0.206949
## add_type3                0.26802    0.26952   0.994 0.320021
## add_type4               -0.01321    0.23272  -0.057 0.954734
## add_type5                0.23182    0.24638   0.941 0.346744
## add_type6                0.82334    0.46724   1.762 0.078048 .
## add_type8               -1.19742    0.49338  -2.427 0.015226 *
## add_type9               -0.38444    0.25144  -1.529 0.126272
## add_prohibited           0.03451    0.19115   0.181 0.856741
```

```
## fstart_year2015      -0.46644    0.18207  -2.562 0.010410 *
## fstart_year2016      -0.27445    0.18401  -1.492 0.135827
## fstart_year2017      -0.52402    0.18615  -2.815 0.004878 **
## fstart_year2018      -0.51772    0.18637  -2.778 0.005470 **
## fstart_year2019      -0.74989    0.21712  -3.454 0.000553 ***
## fregionOrkney         0.09635    0.36451   0.264 0.791536
## fregionShetland       0.41527    0.31091   1.336 0.181658
## fregionArgyllandBute -0.61433    0.28350  -2.167 0.030239 *
## fregionWestern Isles  0.88191    0.31133   2.833 0.004616 **
## square               -0.20657    0.26577  -0.777 0.436998
## APN                   0.11153    0.14022   0.795 0.426412
## seal_blind            0.06663    0.15452   0.431 0.666310
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                                edf  Ref.df  Chi.sq p-value
## s(log(depredation_month))    2.520   3.071 787.979  <2e-16 ***
## s(mean_month)                6.811   7.833  38.137  <2e-16 ***
## s(mean_biomass)              1.005   1.010   3.345  0.0683 .
## s(ffarmID)                 123.505 174.000 573.258  <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 20 Estimated model coefficients and associated statistical significance from the model of the proportion of depredation months per stocking period (associated with question 5) with each type of ADD as a covariate.

The fact that ADD on/off is not significant is, at first sight, surprising given previous results. However, it is consistent with the finding from question 3 that the number of depredation events per stocking period is positively associated with ADD use: that ADD use is positively associated with the number of depredation events, but not necessarily with the amount of depredation per event. This may also explain the negative association between depredation level and GaelForce usage, although this ADD type was in use during only 14 depredation events so sample size is small.

The overall conclusion regarding question 6 is that there is no statistically significant association between ADD use and depredation level per depredation event, although there was a negative association between the GaelForce usage and depredation level when ADD types were modelled as separate factor covariates.

Question 7. Is the length in months of a depredation event at a finfish farm associated with ADD usage and does any association depend on ADD type?

The response variable was length of the depredation event in months. Of the four response variable distributions tried, the quasi-Poisson showed the best fit in terms of qq-plot closest to a straight diagonal line, and was used in subsequent modelling. The estimated overdispersion parameter of the quasi-Poisson was 1.07. Comparing the ADD on/off model with the ADD type model, the latter had a lower GCV score, although they were close (1.52 for ADD on/off versus 1.50 for ADD type). The estimated coefficients are shown for the ADD type model in Table 21 and the smooths in Figure 18. The residual qq-plot is shown in Figure 19 – this indicates no noticeable deviation from the desired straight line. Percentage deviance explained by the model was 75%.

```
## Parametric coefficients:
##                         Estimate Std. Error t value Pr(>|t|)
## (Intercept)              1.44403    0.11834  12.202  < 2e-16 ***
## add_type1                0.28401    0.08998   3.156 0.001677 **
## add_type2                0.38218    0.15034   2.542 0.011269 *
## add_type3                0.09352    0.10812   0.865 0.387390
## add_type4                0.30510    0.10065   3.031 0.002539 **
## add_type5                0.40593    0.10935   3.712 0.000225 ***
## add_type6                0.77126    0.18451   4.180 3.35e-05 ***
## add_type8                0.37847    0.21315   1.776 0.076310 .
## add_type9                0.20626    0.10896   1.893 0.058835 .
## add_prohibited           0.21188    0.08655   2.448 0.014651 *
## fstart_year2015         -0.21178    0.08107  -2.612 0.009218 **
## fstart_year2016         -0.15016    0.08625  -1.741 0.082195 .
## fstart_year2017         -0.19851    0.08941  -2.220 0.026782 *
## fstart_year2018         -0.29198    0.09039  -3.230 0.001304 **
## fstart_year2019         -0.80863    0.10867  -7.441 3.50e-13 ***
## fregionOrkney           -0.18637    0.10878  -1.713 0.087190 .
## fregionShetland         -0.20681    0.09613  -2.151 0.031854 *
## fregionArgyllandBute -0.05760    0.07750  -0.743 0.457614
## fregionWestern Isles -0.32283    0.09526  -3.389 0.000748 ***
## square                   0.01961    0.07917   0.248 0.804460
## APN                      0.07324    0.06464   1.133 0.257626
## seal_blind              -0.15246    0.07027  -2.170 0.030428 *
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                        edf  Ref.df      F  p-value
## s(mean_month)        5.304   6.268 75.162  < 2e-16 ***
## s(mean_biomass)      3.120   3.773  7.195 2.76e-05 ***
## s(fstock_n)        174.257 453.000  0.832  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 21 Estimated model coefficients and associated statistical significance from the model of the length of the depredation event (associated with question 7) with each type of ADD as a covariate.

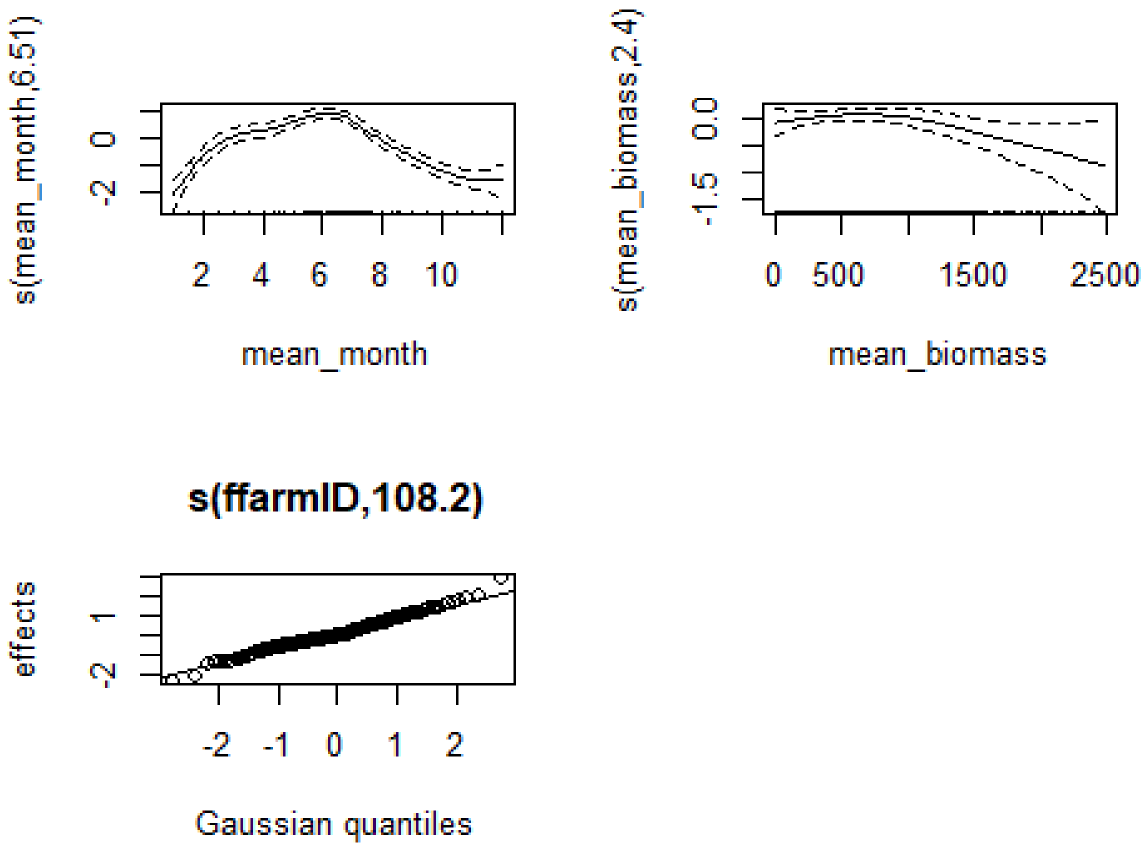


Figure 18 Estimated smooth coefficients (approximate 95% confidence intervals shown as dashed lines) and quantile-quantile plot for the random effect from the model of the length of the depredation event (associated with question 7) with each type of ADD as a covariate.

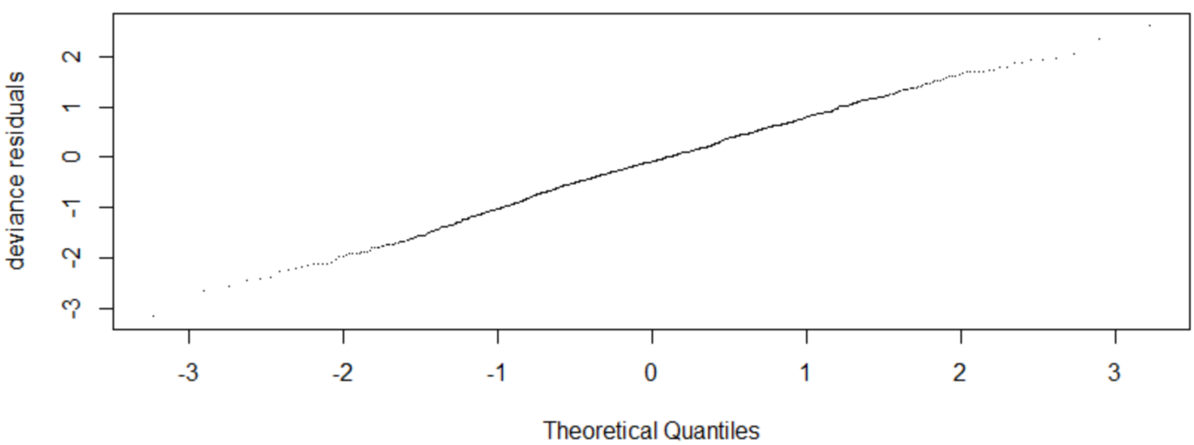


Figure 19 Quantile-quantile plot from the model of the level of depredation per depredation event (associated with question 6) each type of ADD as a covariate.

The estimated coefficients that were significant at $p \leq 0.05$ were:

- factor covariates: ADD type (types 1 (Airmar), 2 (Ace Aquatec RT1), 4 (Terecos), 5 (OTAQ SealFence) and 6 (Unknown), ADD not permitted, year that depredation event started (2015, 2017, 2018, 2019), region (Shetland and Western isles), use of seal blinds
- smooths of mean month and stocking biomass

All ADD type coefficients were positive, as was ADD not permitted; those associated with region and seal blind had a negative relationship (i.e. reduced depredation). For the smooths, the depredation events with mean month in summer tended to be longer, as did those with intermediate or higher levels of stocking biomass. Looking at coefficients of the ADD on/off model, which had a very similar GCV score, the ADD on coefficient was significant at $p \leq 0.05$, and had a coefficient of 0.23 (Table 22). Hence, under this model, depredation events where ADDs were on throughout were estimated to be exp(0.23) = 1.26 times longer than those with ADDs off.

The overall conclusion regarding question 7 is that ADD usage is associated with slightly longer depredation events, that this is the case for most ADD types but that there is variation among types.

```
## Parametric coefficients:
##                        Estimate Std. Error t value Pr(>|t|)
## (Intercept)             1.45099    0.11959  12.133  < 2e-16 ***
## add_on                  0.23083    0.07675   3.008  0.00274 **
## add_prohibited          0.16635    0.08720   1.908  0.05691 .
## fstart_year2015        -0.20657    0.08179  -2.526  0.01180 *
## fstart_year2016        -0.11350    0.08667  -1.310  0.19081
## fstart_year2017        -0.16114    0.08816  -1.828  0.06809 .
## fstart_year2018        -0.24456    0.08714  -2.807  0.00517 **
## fstart_year2019        -0.75391    0.10527  -7.162 2.33e-12 ***
## fregionOrkney          -0.19371    0.10894  -1.778  0.07589 .
## fregionShetland        -0.22659    0.09340  -2.426  0.01556 *
## fregionArgyllandBute -0.06600    0.07695  -0.858  0.39138
## fregionWestern Isles -0.29209    0.09263  -3.153  0.00169 **
## square                  0.04428    0.07848   0.564  0.57279
## APN                     0.09383    0.06452   1.454  0.14639
## seal_blind             -0.10578    0.06745  -1.568  0.11734
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Approximate significance of smooth terms:
##                     edf  Ref.df      F  p-value
## s(mean_month)     5.232   6.193 75.566  < 2e-16 ***
## s(mean_biomass)   3.174   3.833  9.396 1.01e-06 ***
## s(fstock_n)     176.659 453.000  0.835  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 22 Estimated model coefficients and associated statistical significance from the model of the proportion of depredation months per stocking period (associated with question 5) with proportion of time ADD on as a covariate.

For the depredation event-level models, it may have been a better reflection of dependencies in the data to use a hierarchical random effects model with stocking period within fish farm – but there were too few stocking periods per farm and this model did not converge. Models fit using the bam function within the mgcv package in R use a discrete approximation to represent continuous covariate effects, although the approximation is very close.

3 Power analysis

To illustrate the strength of an experimental approach to measuring ADD efficacy we undertook a simple prospective power analysis using a simulation approach.

A range of effect sizes were tested to illustrate the effect of sample size on statistical power. We used data from stocking periods where ADD use was not permitted and assumed these to be representative of “background” levels of seal depredation. These data were available at the monthly level, so for convenience we assumed the experimental manipulation (ADD on/off) occurs at the level of month (working at the level of a week may be possible in practice, and would be preferable as described above). We assumed that the experiment would involve selecting a sample of experimental stocking periods, and then in each stocking period randomly allocating half of the months to ADD on and half to ADD off. (In practice the length of a stocking period may not be known in advance and a different randomization scheme would likely be used.)

The question was defined as whether ADD use reduced the proportion of months in which depredation occurred (other questions could, and likely would, be asked in addition, for example relating to the amount of depredation). Post-experimental analysis would be conducted via a one-sample t-test on the mean difference per stocking period in the proportion of months with depredation when ADDs are off minus the proportion of months with depredation when ADDs are on (i.e. the difference in frequency of depredation; stocking period is the sample unit in this analysis).

Using a simulation approach, we examined the statistical power (probability of a significant result) of this design to detect the effect of ADD usage over a range of sample sizes (number of stocking periods) and effect sizes (proportional reduction in depredation frequency due to ADD usage – e.g. 0.1 means that depredation is 10% less likely when ADD is on than under baseline). For each specified combination of sample size and effect size we repeated the following 10,000 times. We sampled the specified stocking periods and their associated depredation history at random with replacement from the pool of those in the dataset where ADD use was not permitted for the entire stocking period and the stocking period lasted four months or longer. Within each stocking period, we randomly assigned half of the months to treatment and half to control. (Where there were an odd number of months, then one additional month was in the ADD off category.) For months that were assigned to ADD on and where depredation occurred, we randomly removed the depredation with probability equal to one minus effect size. After doing this for all stocking periods in the sample, we performed a one-sample t-test on the difference in mean depredation rate between ADD on and ADD off, using stocking period as the sample unit, and recorded the test as being statistically significant if the p-value was less than or equal to 0.05. To increase power, a one-way test was used, which looks for a decrease in depredation associated with ADD usage and not an increase. The rationale for ADD use relies on a decreasing relationship between ADD use and depredation, so an increasing relationship is not relevant to the question of ADD efficacy. The proportion of the 10,000 simulations where the test was significant was taken as an estimate of the statistical power of that scenario. We repeated this procedure for effect sizes of 0.1, 0.2, 0.3 and 0.4 and sample sizes of 10, 15, 20, 25, 30, 35 and 40.

One way that the above simulation is unrealistic is that it assumes the expected reduction in depredation is the same for all stocking periods, where in reality this may vary due to variation in usage, local conditions, seal behaviour, etc. To get some insight into this, we ran a second set of simulations where for each sampled stocking period, we randomly (with probability 0.5) either made all ADD usage completely ineffective (i.e. we just used the baseline depredation rates) or we made it twice as effective (i.e. we doubled the effect size). This "inconsistent ADD effect" scenario does not change overall effect size, but increases variability in effect over the sample units (stocking periods).

Results are shown in

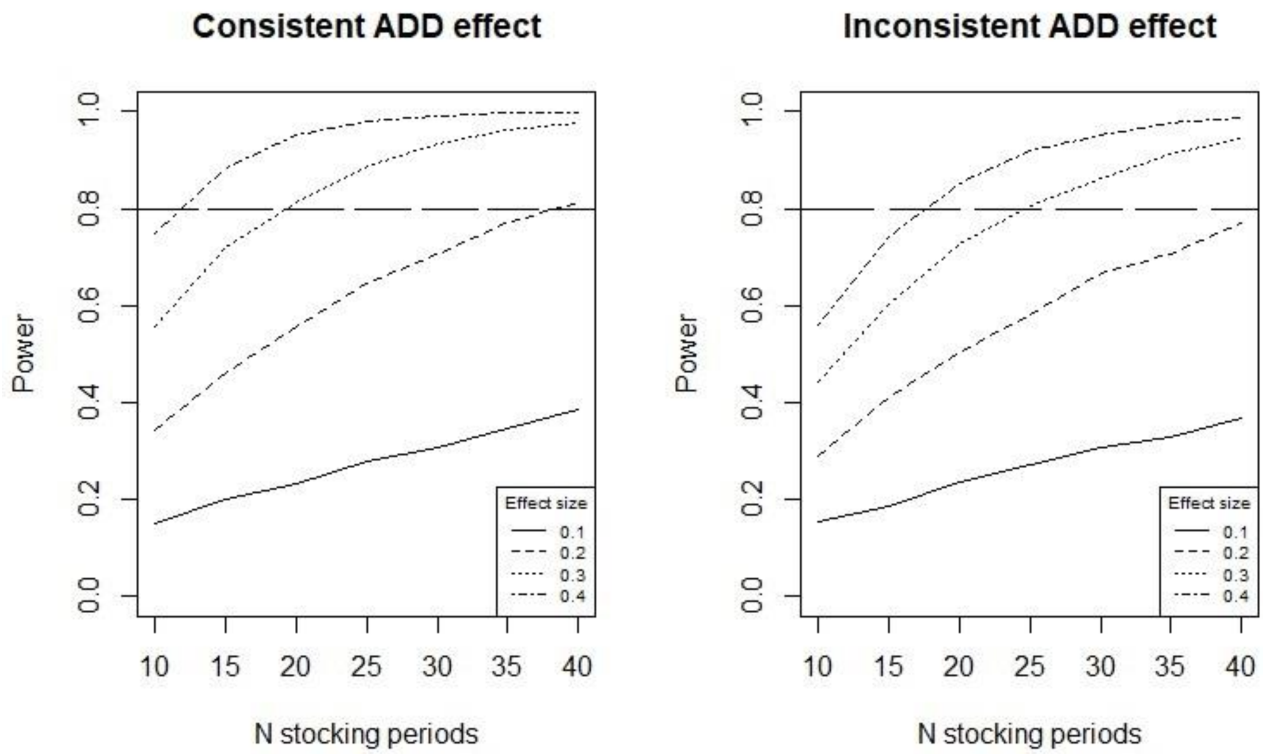


Figure 20. The left panel is for a scenario where ADD effectiveness is consistent across all stocking periods, and the right is where ADD effectiveness varies across stocking periods (being completely ineffective at half of them and twice as effective as the baseline effect size at the others). Statistical power of 0.8 is often taken as a benchmark. Using this measure, statistical power is obtained with a sample size of 15 stocking periods when ADDs consistently cause a 40% reduction in frequency of depredation (effect size 0.4). Smaller effect sizes required larger sample sizes to achieve a power of 0.8: 20 stocking periods were required to produce a reduction in depredation of 30% and 40 stocking periods to produce a reduction of 20%. Statistical power was not achieved in this simulation given the smallest effect size of a 10% decrease in depredation. Inconsistent ADD effect increased the sample size

requirement, for example, at the large effect size of 40%, required sample size for a power of 0.8 went from 15 to 20 stocking periods. (Note that sample size scenarios were run in discrete increments of 5.)

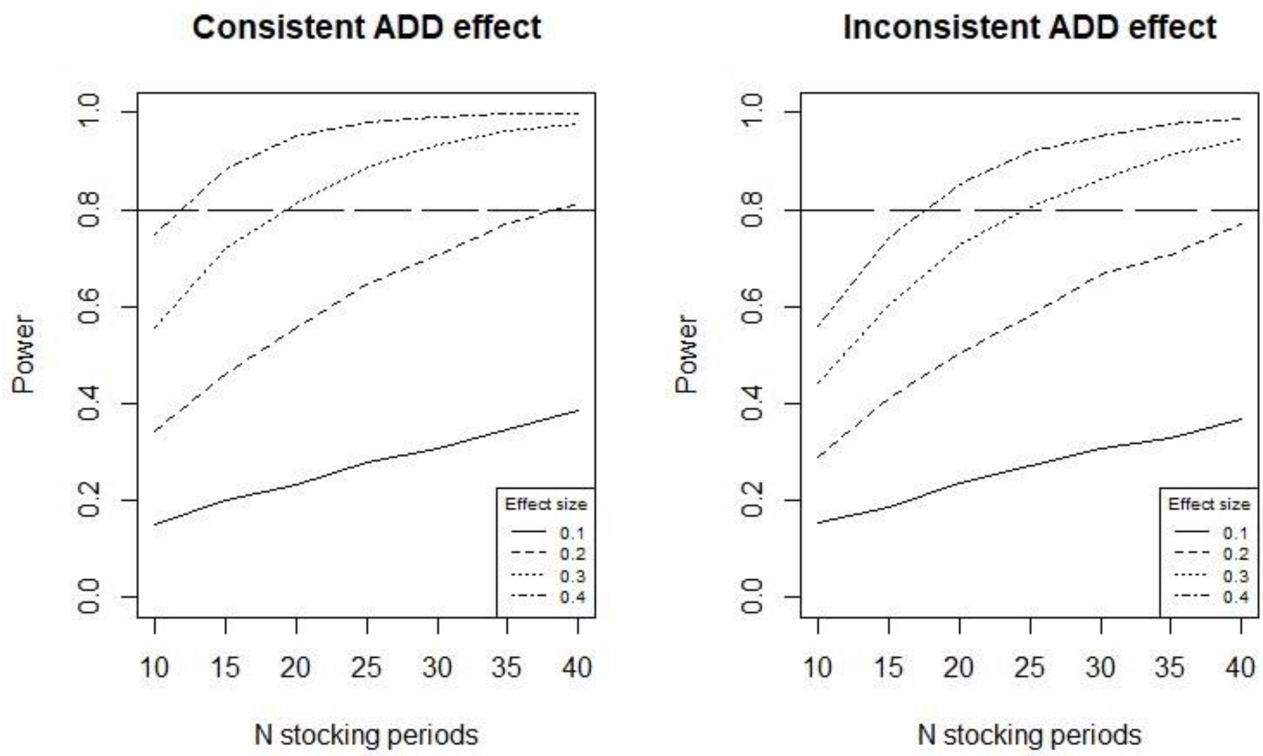


Figure 20 Statistical power of an experiment to evaluate ADD effectiveness over a range of effect sizes (proportional decrease in depredation frequency) and sample sizes (number of stocking periods)

The power analysis reported above uses a coarse temporal scale, which could be made improved in several ways. With more fine-scale background data, a weekly schedule could be used. Assumptions about correlation in response across weeks (for example caused by individual seals becoming habituated) could be built in. A more powerful design and analysis would use a hierarchical framework and consider paired weeks of ADD-on, ADD-off as a sample unit nested within a stocking period (akin to a split plot design). Autocorrelation in time between successive weeks would then need to be accounted for. Power could be increased further by accepting a higher false-positive rate ("alpha-level" on the statistical test), for example 0.1 rather than the conventional 0.05.