Fisheries New Zealand
Tini a Tangaroa

Factors influencing snapper recreational fishing effort and catch in FMA 1

New Zealand Fisheries Assessment Report 2026/40

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ISSN 1179-5352 (online)
ISBN 978-1-997391-09-8 (online)

October 2026



New Zealand Government

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Please cite this report as:

McKenzie J.R.; Maggs, J.; Bian, R. (2026). Factors influencing snapper recreational fishing effort and catch in FMA 1. *New Zealand Fisheries Assessment Report 2026/40.*54 p.

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PLAIN LANGUAGE SUMMARY

This study investigated the main factors affecting recreational fishing activity and snapper catches in Fisheries Management Area 1 (FMA 1) between January 2003 and September 2025. Statistical models were used to examine the effects of weather, time of year and day, fishing location, tides, snapper abundance, fishing regulations, economic conditions, phases of the moon, and large-scale climate conditions. The results showed that the number of recreational fishing boats was mainly influenced by the type of day, the boat ramp used, wind speed and direction, and time of day. Other factors had much smaller effects.

The amount of snapper caught per fishing boat was mainly influenced by the boat ramp, month of the year, and time of day. The strong seasonal and daily patterns in catches were consistent with what is known about snapper behaviour, including their seasonal movements for spawning and increased feeding activity around dawn and dusk. Overall, the results indicate that when, where, and under what weather conditions people go fishing are the most important factors determining recreational fishing activity and snapper catches in FMA 1.

EXECUTIVE SUMMARY

McKenzie J.R.; Maggs, J.; Bian, R. (2026). Factors influencing snapper recreational fishing effort and catch in FMA 1. ***New Zealand Fisheries Assessment Report 2026/40*****. 54 p.**

The purpose of this report was to identify the main factors influencing both recreational fishing effort and recreational snapper catch in FMA 1.

Generalised Additive Models (GAMs) were used to assess the relative explanatory power of various factors on the number of recreational fishing vessels observed per hour at FMA 1 boat ramps between January 2003 and September 2025 (excluding COVID months). The same GAM modelling approaches were also used to investigate explanatory drivers on FMA 1 recreational snapper catch over the same period.

Covariate terms offered to the recreational boat number and snapper-catch GAM predictive models were ramp, month, day-type, hour, wind speed, wind direction, tide-state, snapper regulation change, SST-monthly anomaly, annual quarter relative petrol price change, annual quarter relative CPI index change, snapper annual relative abundance, lunar phase, and the SOI index.

Factors that consistently accounted for the highest individual Root Mean Square Error (RMSE) improvement in the various FMA 1 GAM model recreational boat number predictions were: day-type, ramp, wind speed, wind direction, and hour. All other covariate terms, although statistically significant in the boat-number GAMs, consistently ranked well below the four main terms in explanatory power.

Factors that consistently accounted for the highest individual Root Mean Square Error (RMSE) improvement in the various FMA 1 GAM model recreational snapper-catch per boat predictions were: “ramp”, “month” and “hour”. GAM model partial plots for “month” and “hour” were consistent with known FMA 1 snapper spawning migrations and crepuscular feeding behaviours.

1. INTRODUCTION

Understanding the level and composition of recreational harvest is a key aspect of managing shared fisheries. It informs total removals in stock assessments, guides the allocation of catch limits, and supports the management of allowances. To estimate harvest in New Zealand's substantive recreational fisheries, Fisheries New Zealand has previously conducted a National Panel Survey (NPS) every 5 or 6 years (Heinemann & Gray 2024), complemented by year-round national boat ramp monitoring to track trends between surveys (Maggs et al. 2024a, b).

The continuous monitoring of the fishery conducted under the national boat ramp survey produces a relative harvest index, which is scaled to the NPS absolute harvest estimates to estimate long-term harvest indices. However, this work has shown that recreational harvest varies considerably between years, and this variability is not solely driven by changes in fish abundance or human population growth. Understanding the drivers behind this variability, particularly in effort is essential for explaining observed patterns, improving harvest estimation, predicting future levels of recreational fishing intensity, and informing decisions about appropriate survey frequency.

As a first step towards unravelling this uncertainty, Watson & Hartill (2005) used a hierarchical Bayesian approach to model boat ramp traffic per unit population as a proxy for fisher effort. They reported that despite population growth, there had been declines in the per capita tendency to go fishing. Bian & Hartill (2015) repeated this work with a longer time-series, and incorporated web camera counts of boat traffic, but the research was still limited to fishing effort in FMA 1. Like the previous study, Bian & Hartill (2015) also reported declines in the per capita tendency to go fishing. Both studies incorporated an exploratory component, where they evaluated the influence of different (mostly environmental) covariates on fishing effort. Since then, over a decade of additional data has become available for FMA 1 and there is an understanding that other socio-economic factors may influence levels of fishing effort and harvest.

This project builds upon the previous recreational fishing effort studies, and seeks to understand recent drivers of, predominantly, snapper recreational line-boat fishing effort in the Fisheries Management Area 1 (FMA 1; Figure 1). This study makes use of FMA 1 recreational boat ramp interview data collected between January 2003 and September 2025 as described in Maggs et al. (2024b) (Figure 1). The study was funded by Fisheries New Zealand under project MAF2025-01 the stated objective being:

"To explore environmental covariates and other external factors affecting snapper recreational fishing effort and harvest in FMA 1."

Two analytical investigations were undertaken in the study:

1. An investigation of factors influencing recreational line "effort" defined as the number of observed recreational fishing boats returning per hour at FMA 1 boat ramps.

2. An investigation of factors influencing recreational "catch" defined as number of snapper landed per interviewed boat at FMA 1 boat ramps.

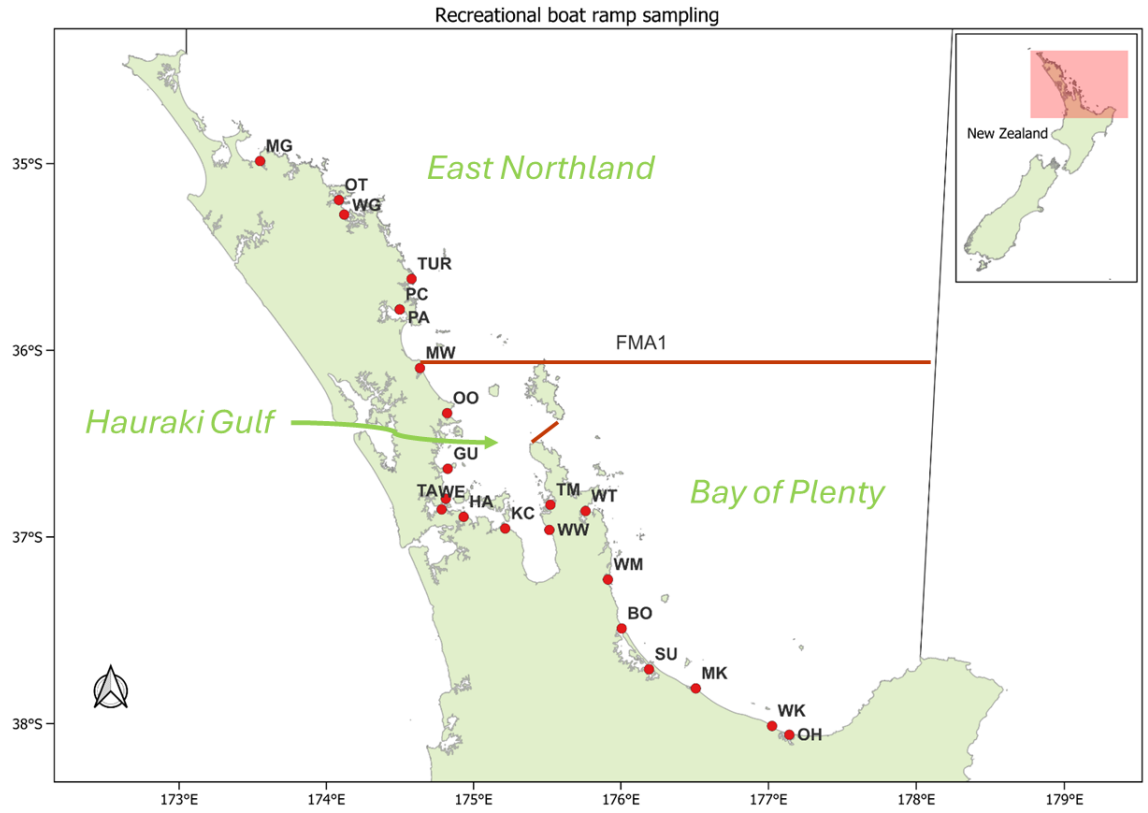


Figure 1: Locations of boat ramps where ramp interviews and digital camera monitoring was conducted in FMA 1 from January 2003 to September 2025. East Northland (MG, Mangonui; OT, Kerikeri; PA & PC, Parua Bay; TUR, Tutukaka; WG, Waitangi); Hauraki Gulf (MW, Mangawai; OO, Omaha; GU, Gulf Harbour; HA, Half Moon Bay; KC, Okahu Bay; TA, Takapuna; TM, Te Kouma; WE, Westhaven; WW, Waikawau); Bay of Plenty (WT, Whitianga; WM, Whangamata; BO, Bowentown; SU, Sulphur Point; MK, Maketu; WK, Whakatane; OH, Ohope).

2. METHODS

2.1 FMA 1 ramp interview data

The FMA 1 ramp interval series used in the analysis covered the period January 2003 through to September 2025[1]. The total number of recreational boats landing per-hour (observed fishing effort) during an "observed" interview day was derived from the FMA 1 ramp camera footage (Maggs et al. 2024a). The proportion of these boats deemed to have been fishing was "imputed" from the subset of boats interviewed during the given hour. Note: oats recorded by the ramp cameras outside the times when interviewers were present at the ramps were not included in the count data.

The factors affecting recreational catch analysis was based on the same FMA 1 ramp interview dataset. The unit of record observation being number of snapper landed per interviewed boat meant that no interpolation was required to non-interviewed boat totals.

[1] Data from the Auckland COVID lockdown months March–May 2020 and August–December 2021 were excluded from the analyses.

2.2 GAM Modelling methods

Generalised Additive Modelling (GAM) approaches (Wood 2011) were used to identify factors having high "explanatory" power for FMA 1 recreational "fishing effort" and "snapper catch" datasets (Equation 1). The use of GAM models in preference to Generalised Linear Modelling (GLM) methods enabled fitting of continuous covariate terms with complex smoothers (Equation 1). The associated GAM model diagnostics provided by the R (R Core Team 2026) package *mgcv* (Wood 2017) also provided greater insight as to the explanatory power of covariate terms and the nature of their relationship with the model response variable, i.e., recreational effort or catch (see Wood 2017).

Equation 1: $$g(\mu_i) = \alpha + f_1(x_{1i}) + f_2(x_{2i}) + f_3(x_{3i}) + \ldots + f_n(x_{ni}) + \varepsilon_i$$

Where:

$g(.)$ is the link function (e.g., log for Poisson, logit for binomial) and $\mu_i = \mathbb{E}(y_i)$;
u_i is the observational response (e.g., number of boats per hour for observation *i*);
xn_i value of covariate n for observation *i*;
α is the model intercept;
$f_n(.)$ are unknown smoother functions estimated from the data (typically represented as penalised regression splines);
ε_i is the model error (unexplained variation) term, assumed distribution as per the chosen link function (e.g., Gaussian, Poisson, etc.)

2.3 Model covariate terms

Four classes of covariate terms were offered in the GAM standardisations:

1. Effort/catch;
2. Spatiotemporal;
3. Environmental;
4. Socioeconomic.

2.3.1 Effort/catch covariates

Regional active-fishers population estimates
This covariate term was derived by multiplying NZ census regional adult (18+) population estimates by estimates of the proportion of the regional population that could be classed as "actively-fishing" in each given year.

Estimates of the proportion of New Zealanders over the age of 18 engaging in recreational fishing within a twelve-month period largely came from Active New Zealand surveys (https://sportnz.org.nz) and National Marine Panel surveys (Heinemann & Gray 2024). These data suggest that annual adult fishing participation between 2003 and 2014 was in the order of 20%. The 2023 Active New Zealand analysis suggested that the active-fisher population proportion had declined to 17% by 2017 and then further declined each year down to 12% in 2023. The 2011–12, 2017–18, and 2022–23 National Marine Panel surveys proportion fishing estimates were 24.6, 20.8, and 17.6% respectively (Heinemann & Gray 2024). Estimates from the two survey sources were amalgamated for the available survey years and interpolated estimates were derived for the non-survey years (Appendix 1). The derived proportions were reviewed and agreed upon by the Fisheries New Zealand Marine Amateur Fisheries Working Group.

The final relative annual indices of regional active-fisher numbers were derived (without an explicit estimate of uncertainty) by multiplying regional NZ census population estimates and the proportion active-fisher estimates (Figure 2).

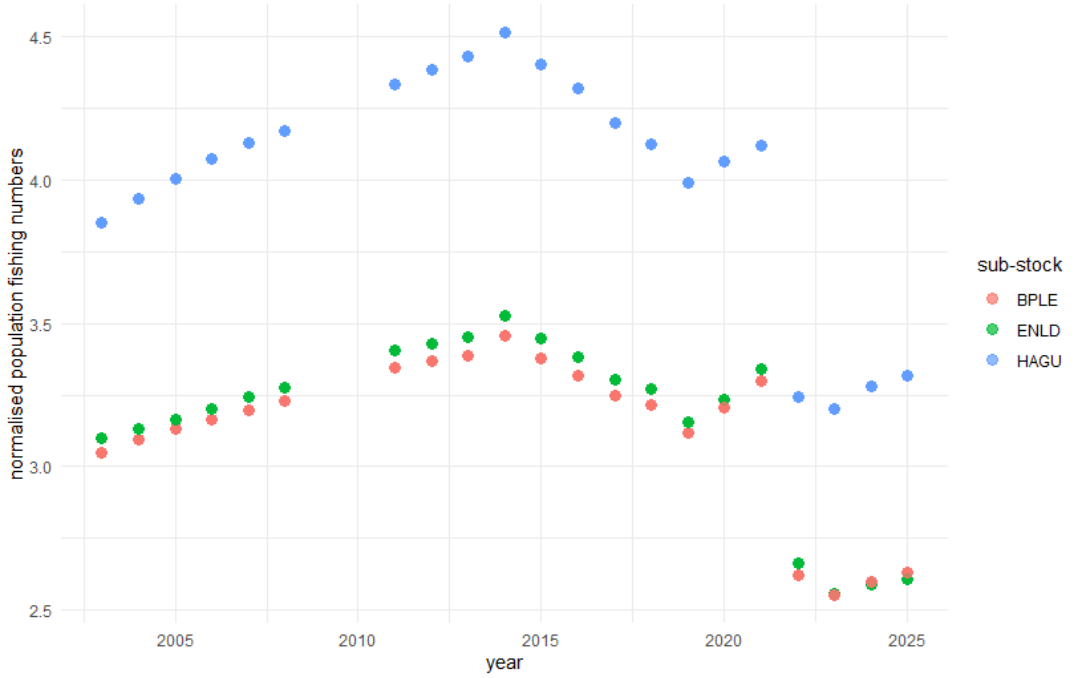


Figure 2: Normalised annual regional number of active-fishers as derived by multiplying regional NZ census population estimates and the proportion active-fisher estimates (ENLD, East Northland; HAGU, Hauraki Gulf; BPLE, Bay of Plenty).

If no other factors were at play, it is "reasonable" to assume that the hourly number of fishing boats observed at FMA 1 boat ramps was proportional to the regional "active-fisher" population numbers. Active-fisher population size was therefore included in the GAM standardisations as a log-offset term thus standardising for a population effect without explicitly estimating its magnitude.

Number-of-fishers-per-boat
In the FMA 1 snapper catch analyses the equivalent primary covariate was "number of fishers per boat". This term was, however, included in the GAM standardisations as a direct effect rather than as a "offset" to better account for potential non-linearity between individual fishers and catch.

2.3.2 Spatiotemporal covariates

The following spatiotemporal covariate terms were offered in both the effort and catch GAM standardisations:

Month
Offered as a pseudo-numeric cyclic term (1–12; January–December),

Day-Type
A two-level factor term distinguishing between "working-day" and "weekends and public holidays".

Hour
Interview hour-of-the-day offered as 14 integer numeric values (07:00–20:00)

Area
Factor representing the three FMA 1 sub-areas (East Northland; Hauraki Gulf; Bay of Plenty) (Figure 1).

Ramp
Factor denoting each of the 22 FMA 1 interview boat-ramps (Figure 1). Fitted in the GAMs as a random effect term.

2.3.3 Environmental covariates

The following environmental covariate terms were offered in effort and catch GAM model standardisations:

Wind direction
A two-level factor term distinguishing between "offshore" and "onshore" wind direction relative to ramp location.

Wind speed
A continuous variable of daily average wind speed in knots as measured at two monitoring stations (Leigh and Whakatane). The Leigh wind measurement data were applied to East Northland and Hauraki Gulf ramp data, the Whakatane wind measurement data were only applied to the Bay of Plenty ramp data.

Tide
Factor representing tide state relative to the hourly time intervals at the ramp the observations took place, these being: High; Incoming; Outgoing; Low (i.e., 3-hour interval classes).

Sea Surface Temperature (SST)
SST records were supplied by the University of Auckland Leigh marine station being a time series of daily (9 am) readings (Figure 3). The Leigh SST data were applied to all the FMA 1 ramp data records (i.e., also east Northland and Bay of Plenty ramp data).

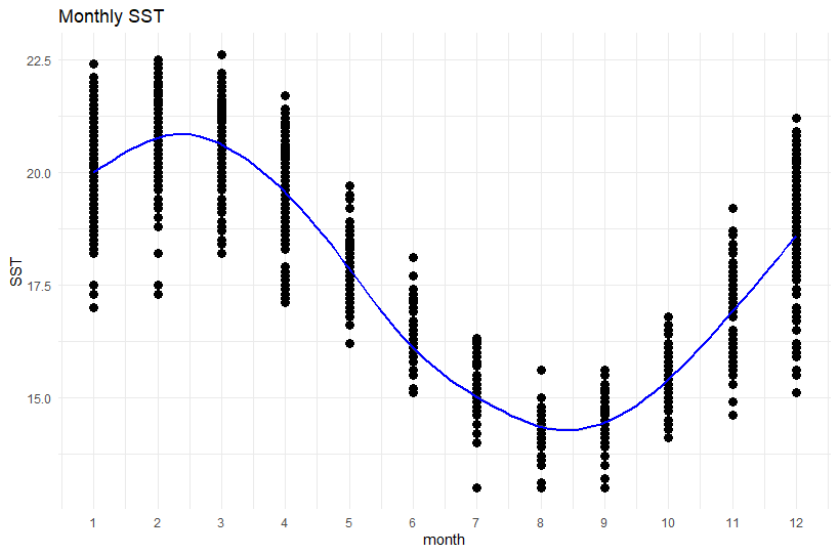


Figure 3: University of Auckland Leigh marine station daily (9 am) SST values (January 2003 through to September 2025) by month. Blue line is a loess smoother spline fit to the data.

SST Anomaly
A strong correlation between SST and month is evident in Figure 3, meaning that SST was unlikely to offer much additional explanatory power over "month" in the GAM standardisations. As an alternative,

SST was instead offered as an anomaly score relative to the expected monthly average as derived from the whole series (Figure 4).

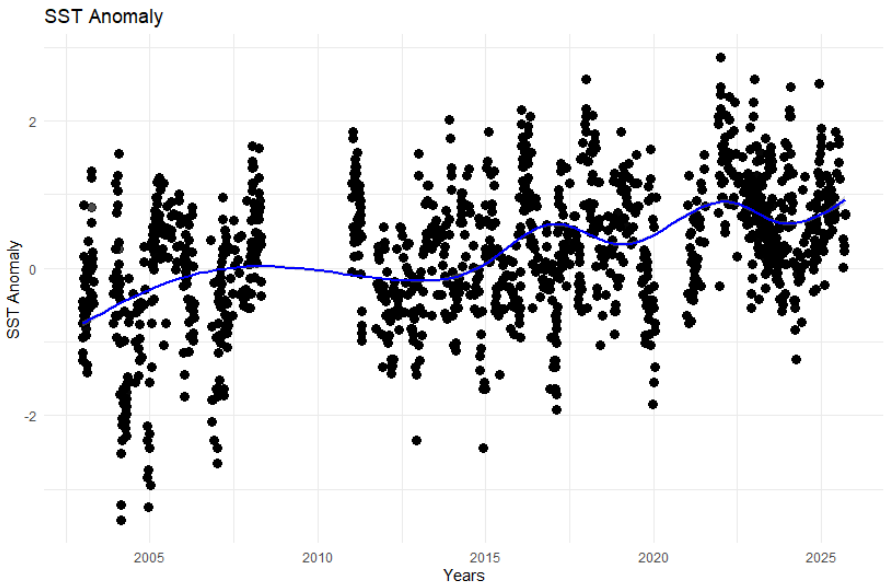


Figure 4: **University of Auckland Leigh marine station daily (9 am) SST anomaly values (January 2003 through September 2025) by month. Values being the difference in observed daily SST from the monthly average over the whole series. Blue line is a loess smoother spline fit to the data.**

Southern Oscillation index (SOI)

The Southern Oscillation Index (SOI) is a measure of the difference in atmospheric pressure between Tahiti and Darwin. It is used as an indicator of large-scale atmospheric circulation in the tropical Pacific and helps predict shifts in global weather and climate patterns (Figure 5).

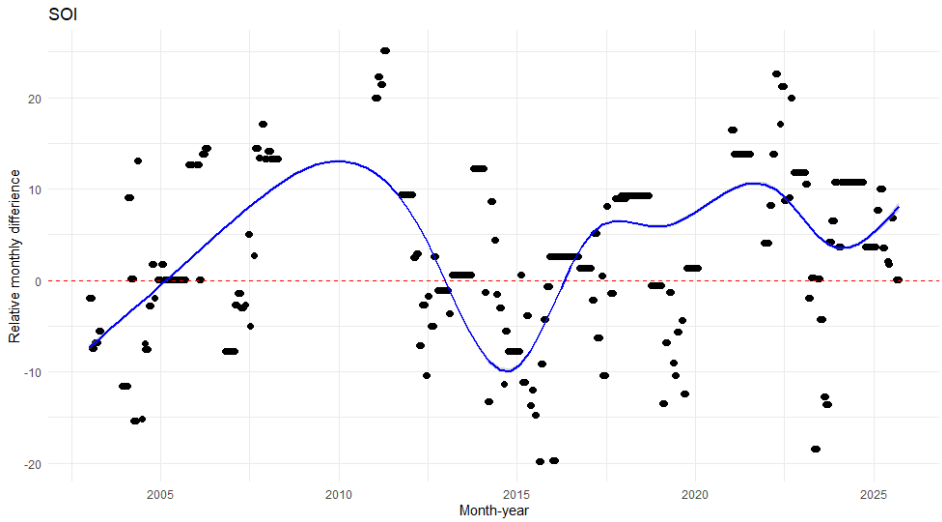


Figure 5: **Monthly Southern Oscillation Index (SOI) over the survey period being the measure of the difference in atmospheric pressure between Tahiti and Darwin. Blue line is a loess smoother spline fit to the data.**

Lunar cycle
Numeric cyclic variable representing moon-phase (Figure 6).

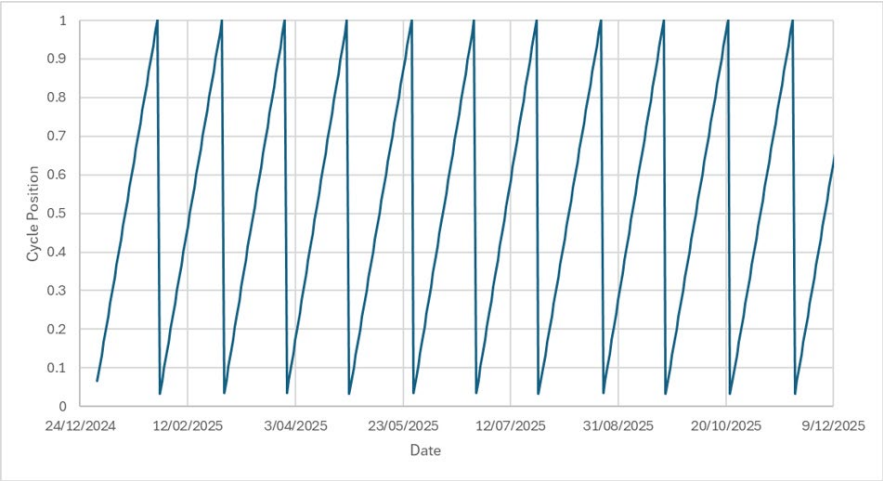


Figure 6: Lunar cycle position values for a subset interval of the data.

SNA 1 regional relative abundance (SSBs from 2024 SNA 1 assessment base-case model)
Estimates of FMA 1 regional relative snapper spawning stock biomass (SSB) as derived from the 2024 SNA 1 base-case assessment model (McKenzie et al. 2024) were offered in the GAM standardisations as annual continuous values (Figure 7).

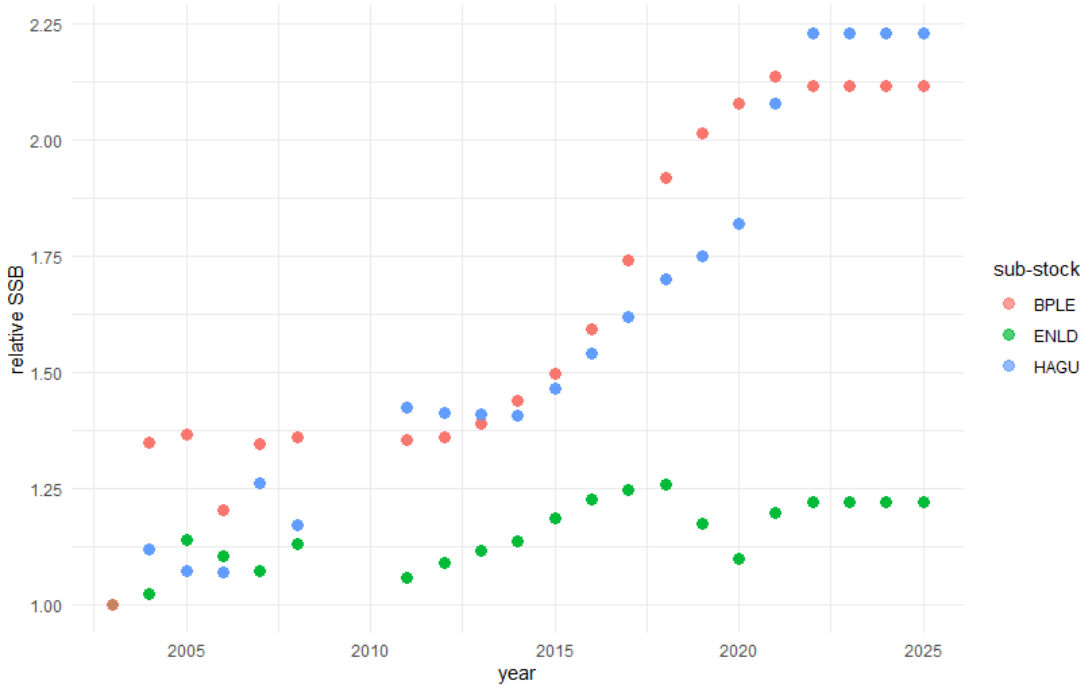


Figure 7: Relative regional change in FMA 1 snapper Spawning Stock Biomass (SSB) change as predicted by the 2023 SNA 1 base-case assessment model (McKenzie et al. 2024). Note: Spawning Stock Biomass (SSB) differences are shown relative to regional 2004 predicted SSBs.

2.3.4 Socio-economic covariates

The following socioeconomic covariate terms were offered in effort and catch GAM model standardisations:

Quarterly relative petrol price difference
Quarterly mean current petrol-price values spanning the study period were sourced from Statistics New Zealand. From these, a relative petrol-price change series was derived, calculated as the ratio of the mean petrol-price in each ramp survey observation's quarter to the mean petrol-price in the preceding quarter (Figure 8). Fitting petrol price variation in the GAMs in this way negated the need to inflation-adjust the raw petrol price values.

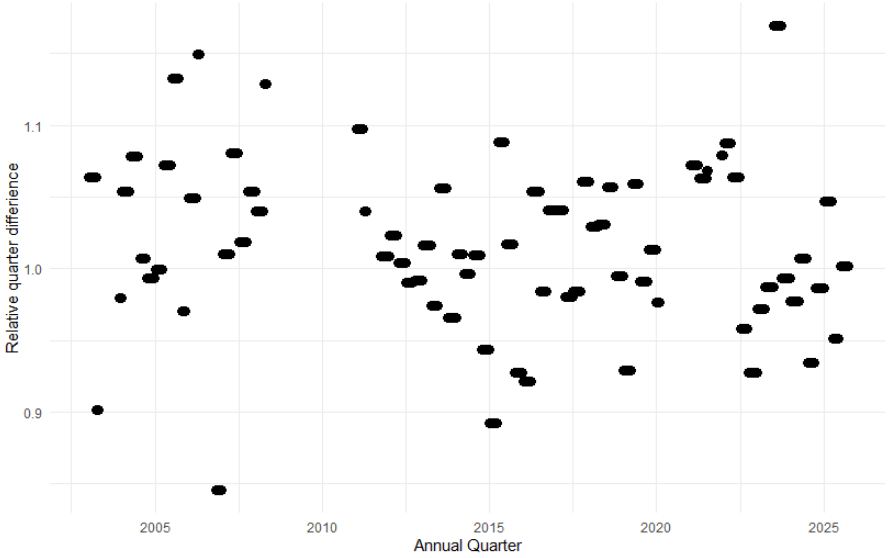


Figure 8: Relative petrol-price change being the ratio between a given ramp survey observation annual-quarter price and the previous annual-quarter price.

Quarterly relative Consumer Price Index difference
Quarterly Consumer Price Index (CPI) values spanning the study period were sourced from Statistics New Zealand. From these, a relative CPI change series was derived, calculated as the ratio of the CPI in each ramp survey observation's quarter to the CPI in the preceding quarter (Figure 9).

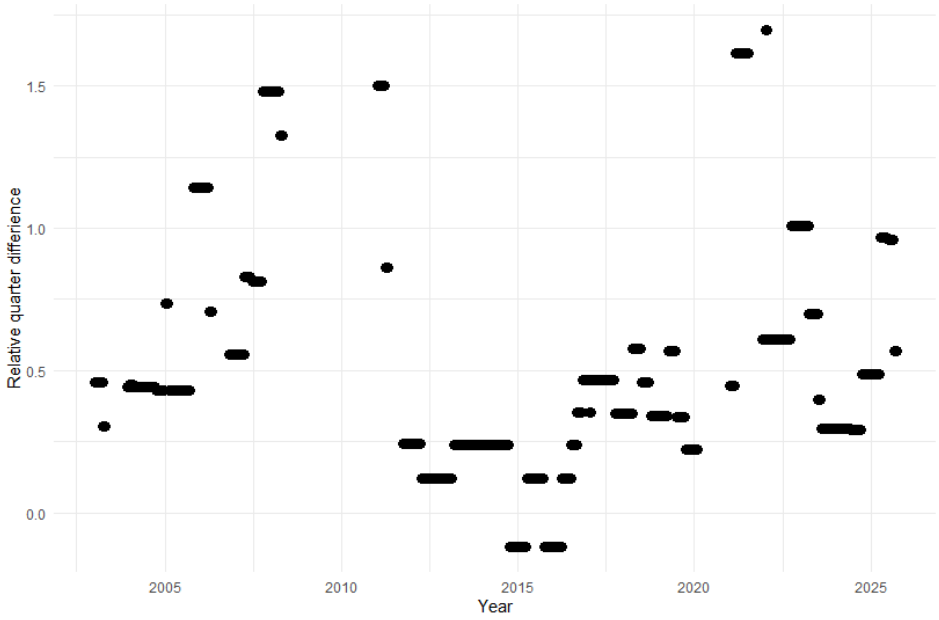


Figure 9: Relative CPI change being the ratio between a given ramp survey observation annual-quarter price and the previous annual-quarter price.

FMA 1 snapper recreational catch regulation change
Two-level factor representing the April 1st, 2014, change in FMA 1 recreational limits for snapper (pre_change; post_change).

Under the 2014 April 1st FMA 1 snapper recreational rule change, the minimum legal size was increased from 27 cm to 30 cm and the individual bag limit reduced from nine to seven.

2.4 Model fitting and diagnostics

GAM standardisation was conducted using the R *mgcv* package (Wood 2017), with additional diagnostics via DHARMa (Hartig 2024).

2.4.1 Choice of model link function family

The appropriate GAM link function family (Poisson, Zero-inflated Poisson, Negative Binomial, Zero-inflated Negative Binomial, or Tweedie) was selected by fitting null models (i.e., models without covariate terms) and then comparing fitted results using QQ-norm residual plots, Kolmogorov–Smirnov tests, dispersion and zero-inflation test scores, and Akaike Information Criterion (AIC) scores.

2.4.2 RMSE stepwise selection of model explanatory covariate terms

Unlike GLMs, residual deviance or R^2 is not a reliable forward selection improvement criterion for GAMs because the effective degrees of freedom (eDF) of spline terms depend nonlinearly on the estimated smoothing parameter and are therefore not fixed. Consequently, deviance reduction per degree of freedom is not directly comparable across candidate GAMs. Instead, explanatory covariates were selected based on improvements in predictive accuracy, measured as Root Mean Square Error (RMSE). To avoid optimistic bias, models were trained using a random 80% subsample of the data and evaluated by predicting against the remaining 20% of the data. This process was repeated five times for each candidate covariate, and the final RMSE was calculated as the mean across the five validation runs.

RMSE comparative statistics derived were:

- Percentage RMSE improvement of the full-model (all terms) over the null-model (no covariate terms except for the "offset" parameter term where applicable). Equates to the maximum RMSE model improvement possible (i.e., no-terms vs all terms included).
- *RMSE.improvement*: Percentage RMSE improvement for each successive covariate term added relative to the RMSE of the model comprising all previously selected covariate terms.
- *RMSE.full.model:* Remaining Percentage RMSE after the addition of each successive covariate term.

The stepwise selection process stopped when best *RMSE.improvement* score for the best-performing remaining terms fell below 0.3%.

3. RESULTS

3.1 Factors affecting recreational effort

3.1.1 GAM link function family selection

The FMA 1 recreational effort ramp interview data contained a high number of zero boats-per-hour observations. Conversely, observations of >25 boats-per-hour were rare in the ramp interview datasets (Figure 10).

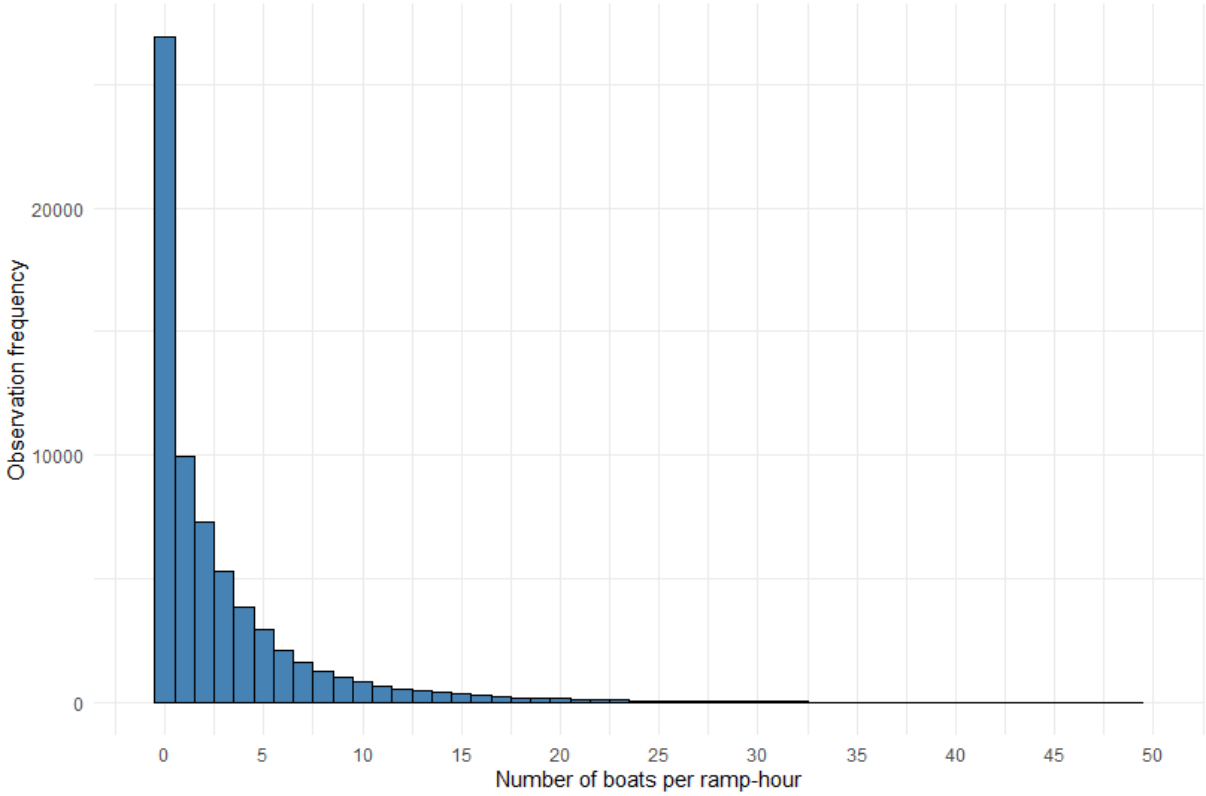


Figure 10: Frequency of number-of-boats-per-hour observations in the FMA 1 recreational fishing effort dataset.

The "zero-inflated negative binomial" (ZINB) and "Tweedie" link functions produced the best GAM fits to the raw boat-count observational data (null_model[2]; Table 1). The ZINB link model gave the best AIC result; the Tweedie had marginally better residual diagnostic performance (Table 1).

QQ-norm plots for both link function models were virtually identical indicating that either link model would be an appropriate choice (Figure 11). The "Tweedie" link function model subsequently proved to have fewer convergence issues and so was chosen for the final analysis, largely for pragmatic reasons.

Table 1: GAM link family residual diagnostic null_model test results.

Model	KS_D	Normal residual probability	Dispers-ion	Null dispersion probability	Zero inflation ratio	Null zero inflation probability	AIC	Conclusion
ZI-NegBinomial	0.0115	< 0.0001	1.0296	0.046	1.0087	0.054	282 542	*Best AIC*
NegBinomial	0.0626	< 0.0001	1.389	< 0.0001	0.9825	0.002	282 589	
Tweedie	0.0075	< 0.0001	1.0642	< 0.0001	1.0001	0.994	290 308	*Best residual diagnistics*
ZI-Poisson	0.1587	< 0.0001	2.4576	< 0.0001	1.0002	0.988	356 853	
Poisson	0.3366	< 0.0001	6.8883	< 0.0001	6.3202	< 0.0001	457 094	

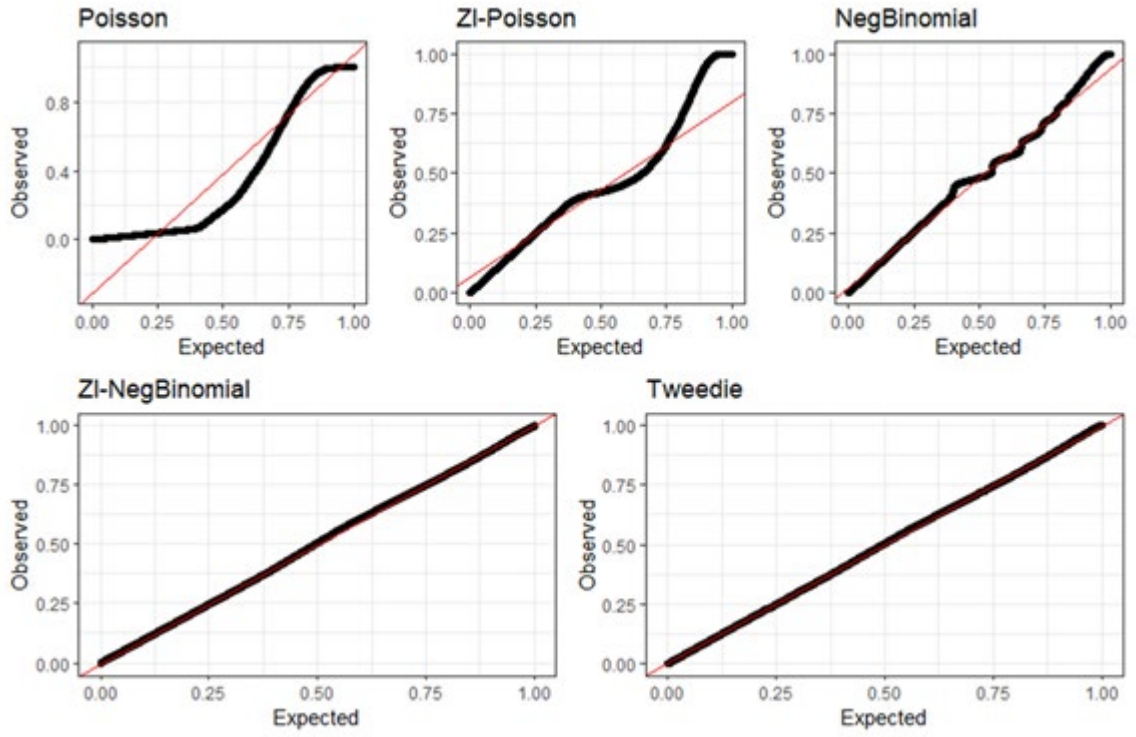


Figure 11: QQ-norm residual plots for various GAM link function fits to hourly boat count data.

[2] `formula_null<- n_boats ~ 1 + offset(log(pop_fishing_area))`

3.1.2 Level of cross-correlation in model covariate terms

Catch (number of snapper landed per hour) was highly correlated (0.7) with the effort response (boats per hour) (Figure 12). The possibility that catch also influences effort is only likely to apply in the context of "expected fishing success" (refer Appendix 2). However, expected fishing success is likely to be more directly determined by snapper stock abundance (SNA_abundance) than "catch" per se, hence snapper abundance was chosen as a preferable covariate proxy to "catch" in the model investigations (refer Appendix 2). The fact that snapper abundance altered annually (Figure 7) also explains the high correlation with fishing year (fyear_n; Figure 12), thus fyear_n was also deemed to be redundant to the model investigations.

Month and SST were, understandably, also strongly correlated (0.7; Figure 12). SST was dropped from the analyses in favour of retaining month, as SST was still considered as an anomaly measure relative to overall monthly averages.

Correlation was also present between the "CPI_shift" and SOI covariate terms (Figure 12) although there is unlikely to be any causality explanation to this.

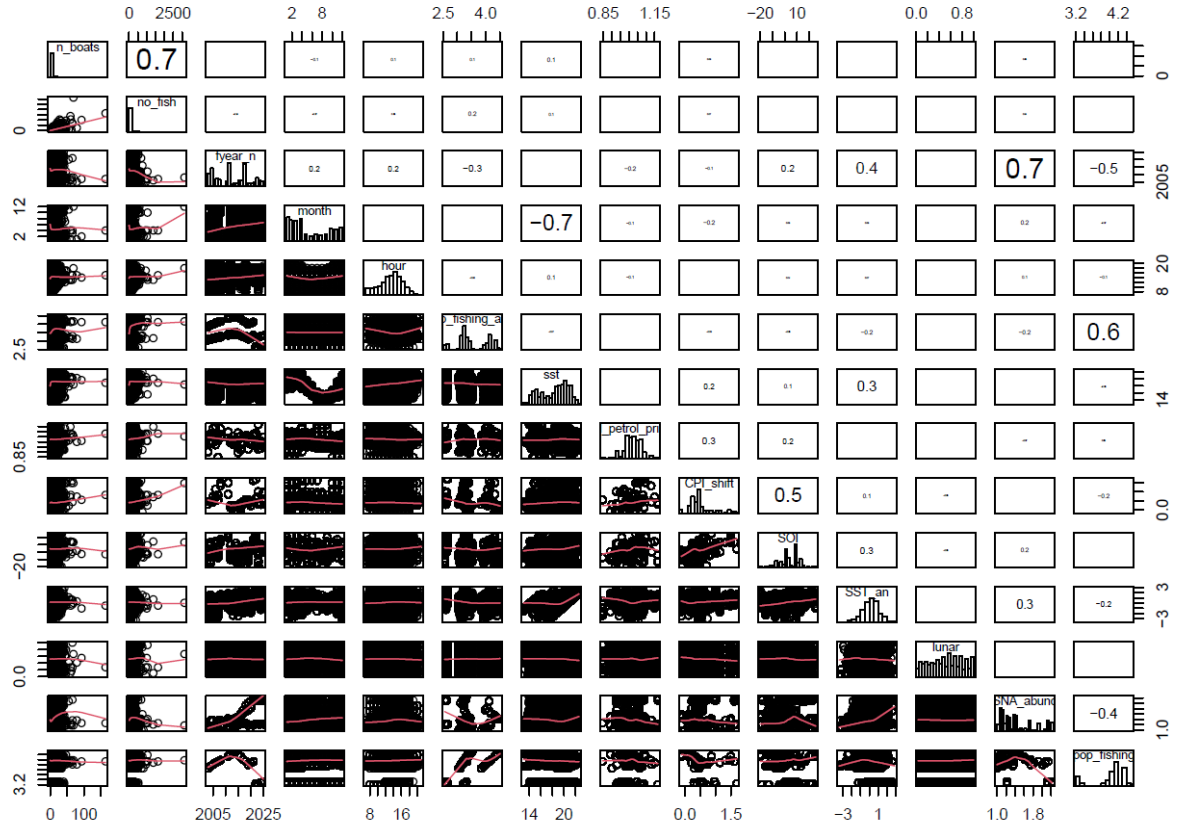


Figure 12: Model effort and covariate term Pearson correlation plots.

3.1.3 Fishing effort GAM covariate term selection all FMA 1 areas combined dataset

The all FMA 1 areas effort full GAM model comprised 13 covariate terms in addition to the log fishing area fishing population term (Table 2).

All covariate terms, except for the "SOI" smoother term, had significant explanatory power in the full-effort-model (Appendix 3). The "SOI" term was therefore dropped from the full-effort-model covariate space.

A concurvity test on the revised full-effort-model smoother terms produced "moderate" to "high" concurvity scores for "rel_petrol_price", "CPI_shift" and "SNA_abundance", the interpretation being that the additional variation in the data these terms accounted for was minimal (TableAppendix 2; Appendix 4).

The partial predictive relationships between the model smoother terms and the effort response were predominantly non-linear (Figure 13). The partial predictive relationship with "month" shows a strong negative effect with the winter period (Figure 13). A negative relationship with "windspeed" is also evident being slightly more pronounced if the wind was onshore (Figure 13). The partial "hour" plot indicates lower effort before 10 am (Figure 13).

Table 2: Full-effort-model (*R mgcv* syntax) smoother and factor covariate terms.

GAM formula term	Description
`formula_full <- n_boats ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund,by=area,bs="cs",k=5) +`	as cubic spline smoother term crossed with area
`s(CPI_shift,bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term
`offset(log(pop_fishing_area))`	offset

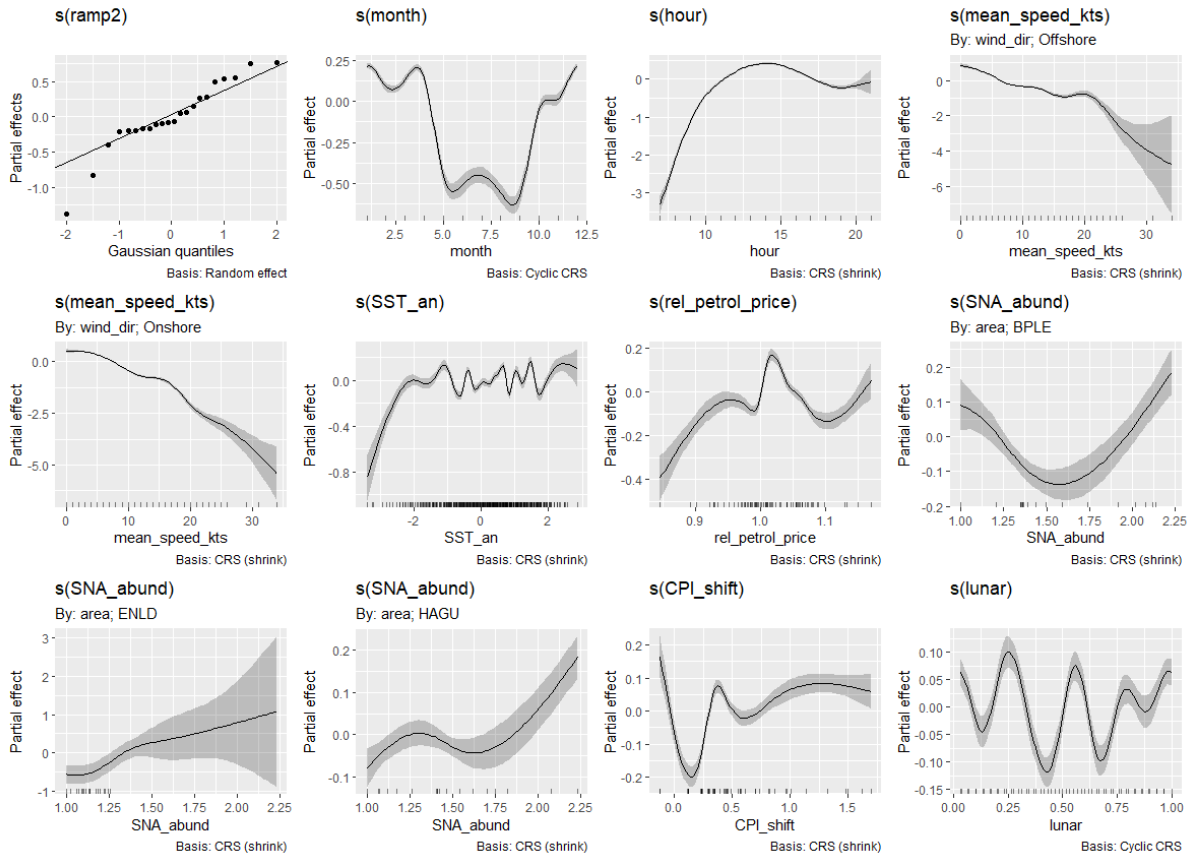


Figure 13: Partial effect plots of the all-areas-combined full-effort-model significant terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 25.70% (Table 3). The random effect of "ramp" contributed highly to RMSE, as did "day-type" and "hour". Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 5).

Table 3: Decreasing stepwise RMSE improvement in model fishing-effort prediction by the successive addition of 'explanatory' covariate terms; all areas combined.

Predictor	eDf	Deviance explained	R.sqr	AIC	RMSE improvement	CV RMSE full par	CV RMSE full model	CV
Null model	1	0%	1.25	231 073	0%	NA	25.70%	0.026
s(ramp2, bs = "re")	21.90	9.64%	9.72	224 738	4.44%	0.033	20.35%	0.026
day_type_m	22.92	21.24%	19.78	216 519	6.03%	0.027	13.50%	0.027
s(mean_speed_kts, by = wind_dir, bs = "cs", k = 8)	35.46	29.94%	26.89	209 709	4.75%	0.043	8.35%	0.023
s(hour, bs = "cs", k = 14)	45.47	38.06%	34.35	202 765	5.46%	0.032	2.75%	0.037
s(month, bs = "cc", k = 12)	55.12	40.84%	36.51	200 206	1.55%	0.025	1.18%	0.089
s(SNA_abund, by = area, bs = "cs", k = 5)	64.11	41.09%	37.05	200 007	0.41%	0.12	0.76%	0.124
s(lunar, bs = "cc")	71.89	41.33%	37.47	199 806	0.36%	0.112	0.40%	0.199

3.1.4 Fishing effort GAM covariate term selection East Northland area dataset

The East Northland effort full GAM model comprised 13 covariate terms in addition to the population offset term (Table 4).

Table 4: East Northland effort-model (R *mgcv* syntax) smoother and factor covariate terms.

GAM formula term	Description
`formula_full <- n_boats ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund, bs="cs",k=5) +`	as cubic spline smoother term
`s(CPI_shift, bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term
`offset(log(pop_fishing_area))`	offset

All covariate terms, except for the "tide_state" factor, had significant explanatory power in the full-effort-model (Appendix 6). The "tide_state" term was therefore dropped from the full-effort-model covariate space.

A concurvity test on the revised full-effort-model smoother terms produced "moderate to "high" concurvity scores for "rel_petrol_price", "CPI_shift", "SOI", and "SNA_abundance", the interpretation being that the additional data variation accounted by these terms was minimal (TableAppendix 3; Appendix 4).

Except for "SNA_abundance", the partial predictive relationships between the model smoother terms and the effort response were predominantly non-linear (Figure 14). "Windspeed" again generally shows a negative relationship with effort, the anomalous positive uptick in the "offshore" windspeed partial plot greater than 20 knots is largely due to a paucity of observational data in this range as denoted by the wide error bounds (Figure 14).

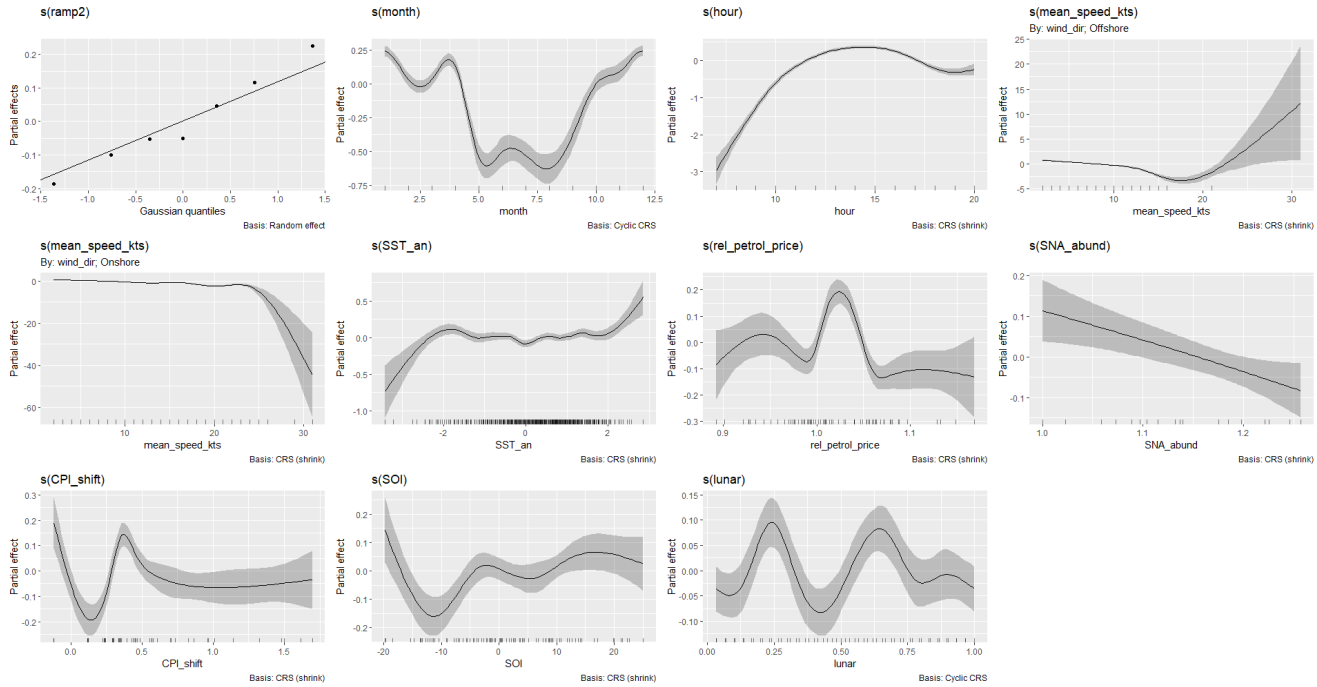


Figure 14: Partial effect plots of the East Northland full effort GAM model significant smoother terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 19.46% (Table 5). The terms "day_type", "wind_speed and direction", and "hour" contributed highly to RMSE explanatory power (Table 5). The random effort "ramp" term had less explanatory power than for the all-areas model (Table 5). Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 9).

Table 5: Decreasing stepwise RMSE improvement in model fishing-effort prediction by the successive addition of 'explanatory' covariate terms; East Northland.

Predictor	eDf	Deviance explained	R.sqr	AIC	RMSE improvement	CV par	full model RMSE	CV
Null model	1	0%	0.27	62 927	0%	NA	19.46%	0.011
day_type_m	2	9.89%	8.34	60 750	4.36%	0.052	14.48%	0.008
s(mean_speed_kts, by = wind_dir, bs = "cs", k = 8)	13.61	20.04%	16.62	58 410	4.89%	0.027	9.14%	0.016
s(hour, bs = "cs", k = 14)	23.07	28.35%	24.35	75 961	4.89%	0.024	4.05%	0.048
s(month, bs = "cc", k = 12)	30.94	31.31%	26.74	73 129	1.57%	0.103	2.44%	0.062
s(ramp2, bs = "re")	36.26	32.41%	28.35	72 108	1.22%	0.09	1.25%	0.181
s(SST_an, bs = "cs", k = 19)	46.76	32.75%	28.71	71 659	0.49%	0.295	0.85%	0.186
s(rel_petrol_price, bs = "cs", k = 9)	55.07	33.22%	29.25	71 125	0.59%	0.151	0.56%	0.216

3.1.5 Fishing effort GAM covariate term selection Hauraki Gulf area dataset

The Hauraki Gulf effort full GAM model comprised 13 covariate terms in addition to the population offset term (Table 6).

Table 6: Hauraki Gulf effort-model (R *mgcv* syntax) smoother and factor covariate terms.

GAM formula term	Description
`formula_full <- n_boats ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund, bs="cs",k=5) +`	as cubic spline smoother term
`s(CPI_shift, bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term
`offset(log(pop_fishing_area))`	offset

All covariate terms, except for the "SOI" smoother term, had significant explanatory power in the full-effort-model (Appendix 8). The "SOI" term was therefore dropped from the full-effort-model covariate space.

A concurvity test on the revised full-effort-model smoother terms produced "moderate" to "high" concurvity scores for "rel_petrol_price", "CPI_shift" and "SNA_abundance", the interpretation being that the additional variation in the data these terms accounted for was minimal (TableAppendix 4; Appendix 4).

The partial predictive relationships between the model smoother terms and the effort response were predominantly non-linear, notable relationships with "month", "windspeed", "wind-direction", and "hour" like those of the full model (Figure 15).

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 28.40% (Table 7). The terms "day_type", "wind_speed and direction", "ramp", and "hour" contributed highly to RMSE explanatory power (Table 7). Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 7).

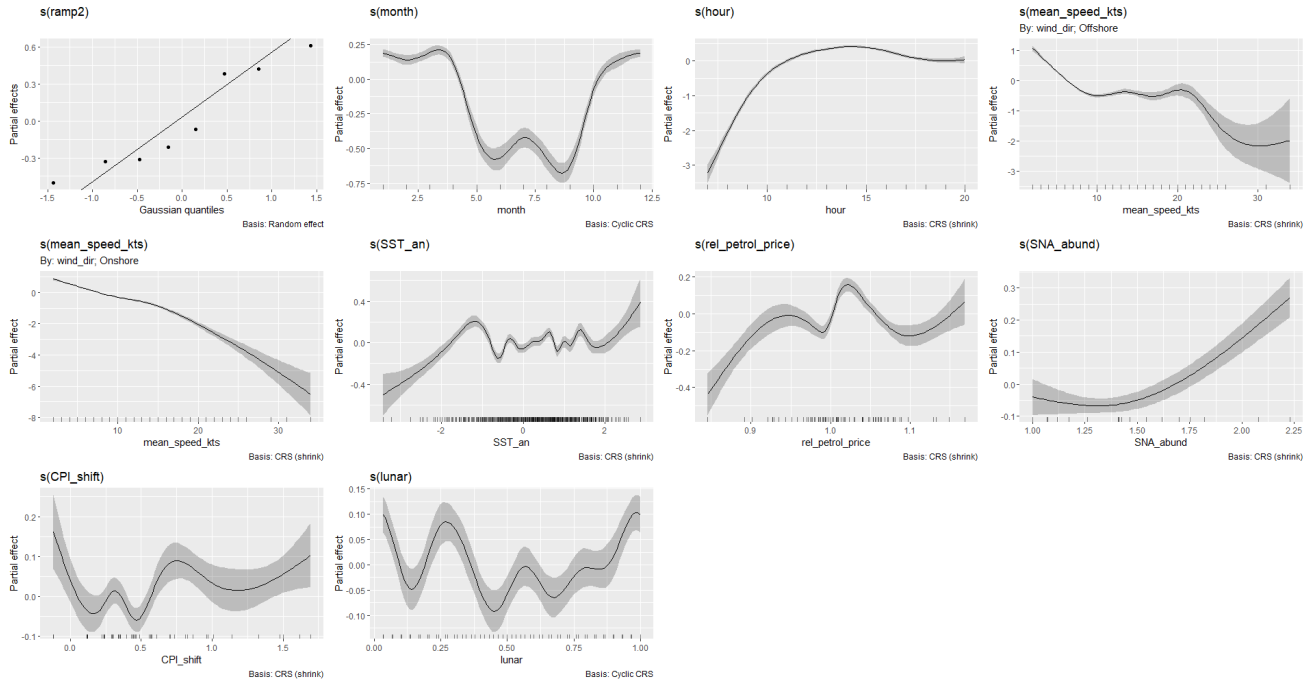


Figure 15: Partial effect plots of the Hauraki Gulf full effort GAM model significant smoother terms.

Table 7: Decreasing stepwise RMSE improvement in model fishing-effort prediction by the successive addition of 'explanatory' covariate terms; Hauraki Gulf.

Predictor	eDf	Deviance explained	R.sqr	AIC	RMSE improvement	CV par	RMSE Full model	CV
Null model	1	0%	-0.31	103 174	0%	NA	28.40%	0.032
day_type_m	2	12.71%	8.93	99 623	4.92%	0.045	22.38%	0.029
s(mean_speed_kts, by = wind_dir, bs = "cs", k = 8)	13.76	23.84%	18.02	96 298	5.29%	0.042	16.22%	0.032
s(ramp2, bs = "re")	20.72	32.40%	27.38	93 405	5.84%	0.029	9.81%	0.043
s(hour, bs = "cs", k = 14)	31.02	41.64%	35.97	90 077	6.70%	0.037	2.91%	0.068
s(month, bs = "cc", k = 12)	39.76	44.59%	38.37	88 896	1.74%	0.102	1.14%	0.173
s(SST_an, bs = "cs", k = 19)	56.61	45.31%	39.07	88 593	0.49%	0.187	0.64%	0.299
s(SNA_abund, bs = "cs", k = 3)	58.23	45.39%	39.29	88 561	0.24%	0.199	0.38%	0.499

3.1.6 Fishing effort GAM covariate term selection Bay of Plenty area dataset

The Bay of Plenty effort full GAM model comprised 13 covariate terms covariate terms in addition to the population offset term (Table 8).

A concurvity test on the revised full-effort-model smoother terms produced "moderate" to "high" concurvity scores for "rel_petrol_price", "SOI", "CPI_shift" and "SNA_abundance", the interpretation being that the additional variation in the data these terms accounted for was minimal (TableAppendix 5; Appendix 4).

The partial predictive relationships between the model smoother terms and the effort response were predominantly non-linear, notable relationships with "month", "windspeed", "wind-direction", and "hour" (Figure 16).

Table 8: Bay of Plenty effort-model (R *mgcv* syntax) smoother and factor covariate terms

GAM formula term	Description
`formula_full <- n_boats ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund, bs="cs",k=5) +`	as cubic spline smoother term
`s(CPI_shift, bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term
`offset(log(pop_fishing_area))`	offset

All covariate terms had significant explanatory power in the full-effort-model (Appendix 10).

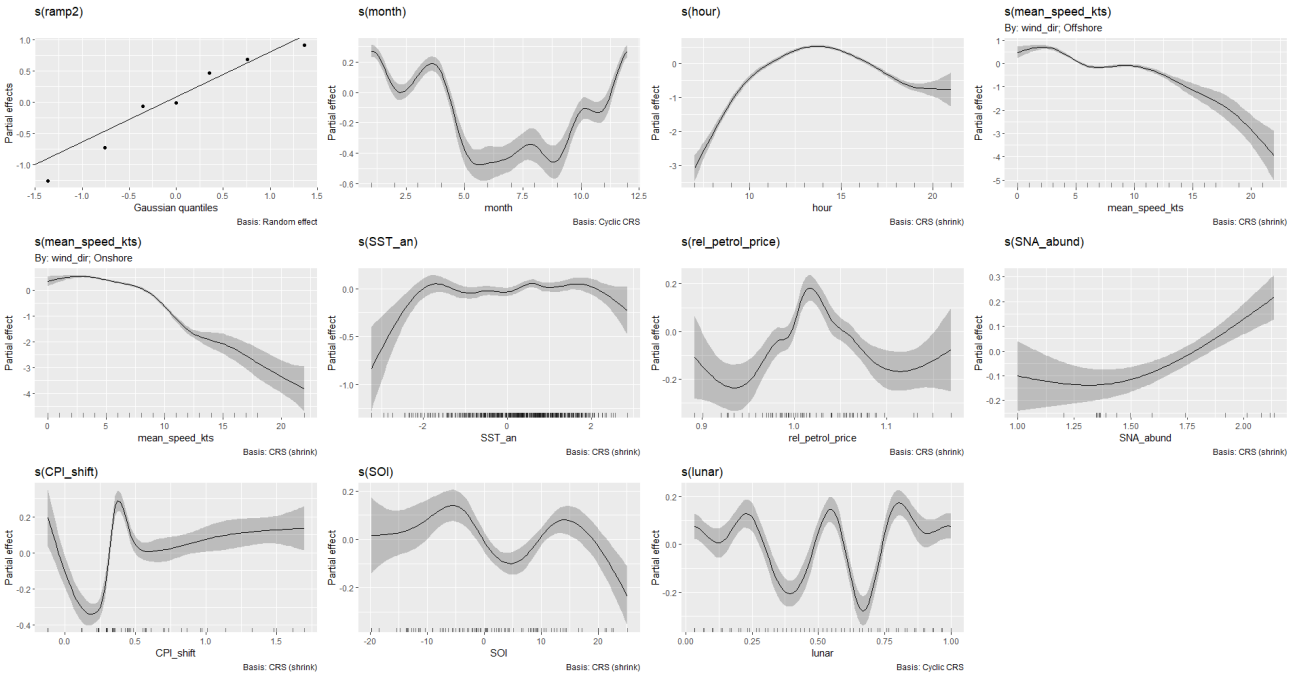


Figure 16: Partial effect plots of the Bay of Plenty effort GAM model significant smoother terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 25.57% (Table 9). The terms "ramp", "day_type", "hour", and the "wind_speed

and direction" interaction term contributed highly to RMSE explanatory power (Table 9). Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 11).

Table 9: Decreasing stepwise RMSE improvement in model fishing-effort prediction by the successive addition of 'explanatory' covariate terms; Bay of Plenty.

Predictor	eDf	Deviance explained	R.sqr	AIC	RMSE improvement	CV par	RMSE full model	CV
Null model	1	0%	0.44	61 440	0%	NA	25.57%	0.023
s(ramp2, bs = "re")	6.97	12.62%	9.67	59 333	5.00%	0.051	19.57%	0.033
day_type_m	7.98	22.87%	19.13	57 450	6.13%	0.022	12.85%	0.043
s(hour, bs = "cs", k = 14)	15.71	31.66%	27.11	55 697	5.50%	0.049	6.98%	0.105
s(mean_speed_kts, by = wind_dir, bs = "cs", k = 8)	27.15	37.94%	31.94	54 297	3.45%	0.114	3.41%	0.121
s(month, bs = "cc", k = 12)	36.74	40.41%	34.01	53 746	1.67%	0.083	1.72%	0.218
s(lunar, bs = "cc")	44.31	41.06%	35.1	53 620	0.86%	0.141	0.85%	0.310

3.2 Factors affecting recreational snapper catch

3.2.1 GAM link function family selection

The FMA 1 recreational snapper catch ramp interview data contained a high number of zero snapper-per-boat observations. Conversely, observations of >30 snapper per interviewed boat were rare in the ramp interview data (Figure 17).

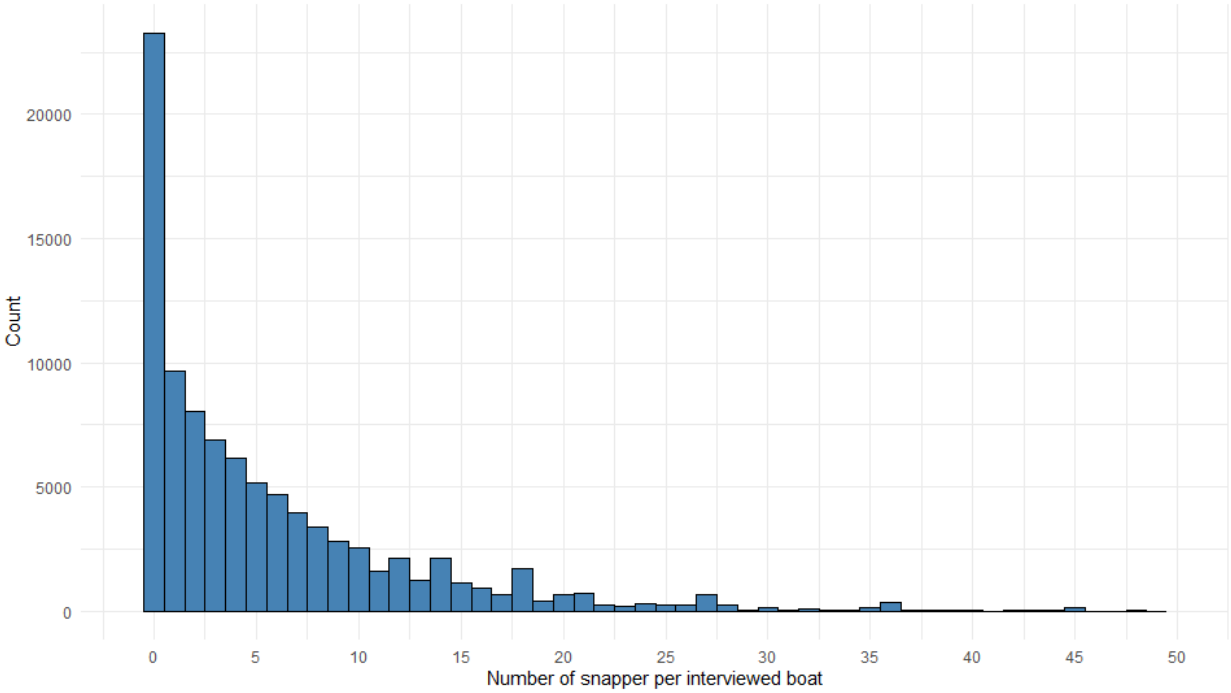


Figure 17: Frequency of number-of-snapper-per-boat observations in the FMA 1 recreational fishing effort dataset.

The "zero-inflated negative binomial" (ZINB) and "Tweedie" link functions produced the best GAM fits to the raw snapper catch observational data (null_model[3]; Table 10). The ZINB link model gave the best AIC result, the Tweedie had marginally better residual diagnostic performance (Table 10).

QQ-norm plots for both link function models were virtually identical indicating that either link model would be an appropriate choice (Figure 18). The "Tweedie" link function model subsequently proved to have fewer convergence issues and so was chosen for the final analysis, largely for pragmatic reasons.

Table 10: GAM link family residual diagnostic null_model test results

Model	KS_D	Normal residual probability	Dispers-ion	Null dispersion probability	Zero inflation ratio	Null zero inflation probability	AIC	Conclusion
ZI-NegBinomial	0.0239	<0.0001	0.9818	0.106	1.0732	<0.0001	524 130.6	Best AIC
NegBinomial	0.0396	<0.0001	1.3253	<0.0001	0.9518	<0.0001	525 099.2	
Tweedie	0.0061	0.001929	1.089	<0.0001	1.0002	0.982	532 825.3	Best residual diagnostics
ZI-Poisson	0.2399	<0.0001	3.4606	<0.0001	1.0002	0.928	783 570.1	
Poisson	0.366	<0.0001	10.1345	<0.0001	85.4217	<0.0001	990 979.3	

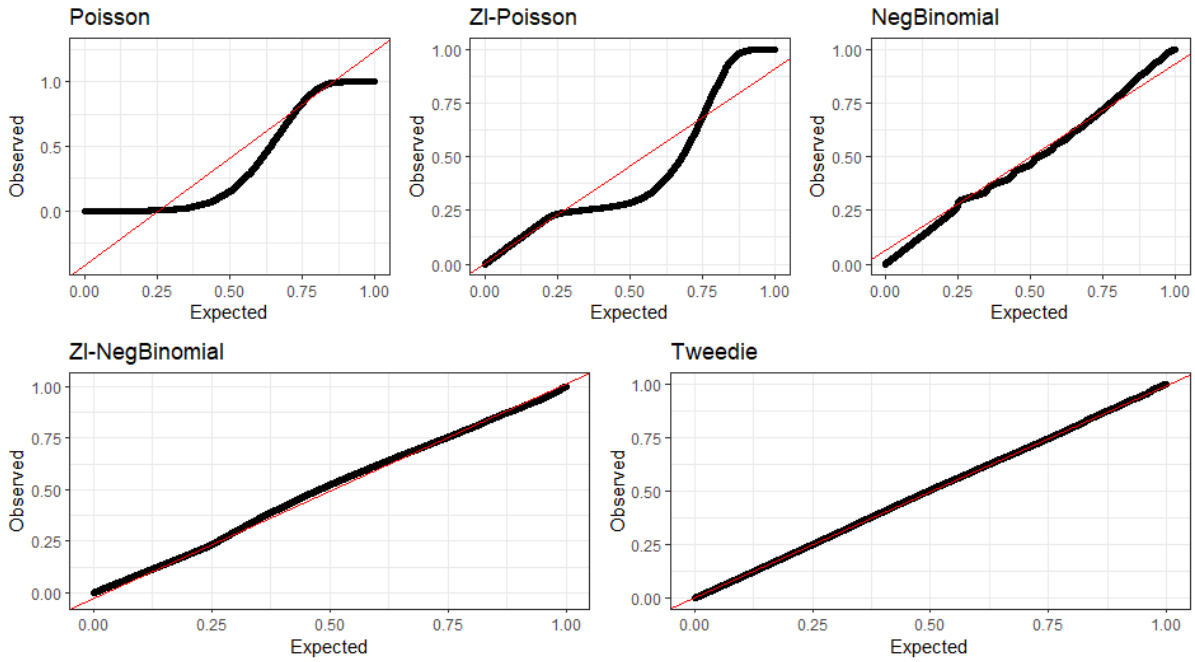


Figure 18: QQ-norm residual plots for various GAM link function fits to snapper count data.

3.2.2 Level of cross-correlation in model covariate terms

An expected correlation between the response variable snapper-catch and the "number of fishers per boat" covariate is evident in the Pearson cross-correlations (Figure 19). Marked correlation (0.5) is also seen between the "CPI_shift" and SOI covariate terms.

[3] `formula_null<- SNA_catch ~ 1`

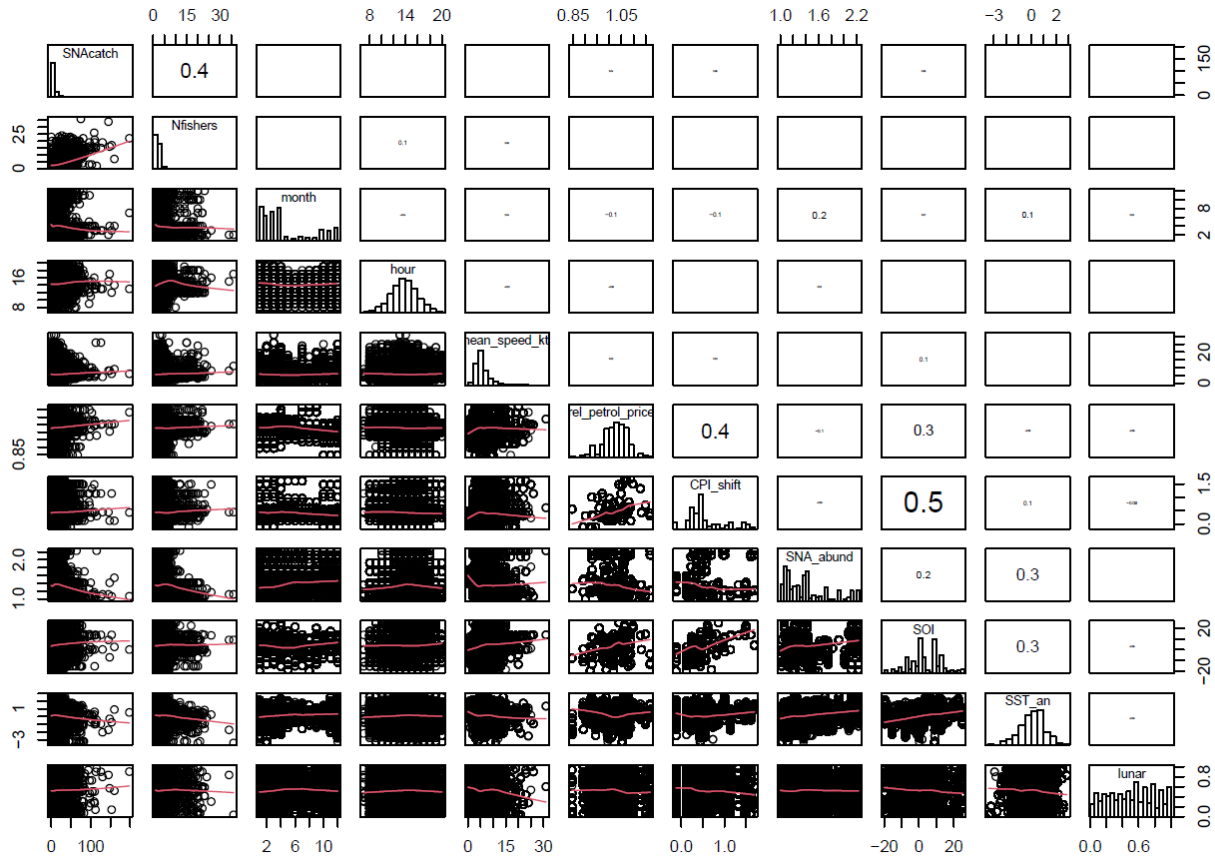


Figure 19: **Model catch and covariate term Pearson correlation plots.**

3.2.3 Snapper catch GAM covariate term selection all FMA 1 areas combined dataset

The all-areas-combined snapper-catch GAM model comprised 14 covariate terms (Table 11).

Table 11: **Full-catch-model (*R mgcv* syntax) smoother and factor covariate terms.**

GAM formula term	Description
`formula_full <- SNA_catch ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(Nfishers, bs = "cs", k=10)+`	as cubic spline smoother term
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund,by=area,bs="cs",k=5) +`	as cubic spline smoother term crossed with area
`s(CPI_shift,bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term

The "tide-state" term was only marginally significant and therefore dropped from the full model space (Appendix 12). All remaining covariate terms had significant explanatory power and were retained in the full-model (Appendix 12).

A concurvity test on the revised full-effort-model smoother terms produced "moderate" to "high" concurvity scores for "SOI", "rel_petrol_price", "CPI_shift", and "SNA_abund", the interpretation being that the additional variation accounted for by these terms in the data was minimal (TableAppendix 6; Appendix 4).

The partial predictive relationships between the model smoother terms and the effort response were predominantly non-linear (Figure 20). The partial plot of month with the catch response variable appears consistent with known winter/summer snapper feeding and spawning behaviour, specifically snapper catch rates are known to increase after late winter, peaking during the spawning months (October and November) after which catch rates typically decline, increasing again from late January until autumn (Figure 20). Also evident in the partial plots is the typical crepuscular nature of snapper feeding behaviour, catch rates being typically higher during morning and dusk hours (Figure 20).

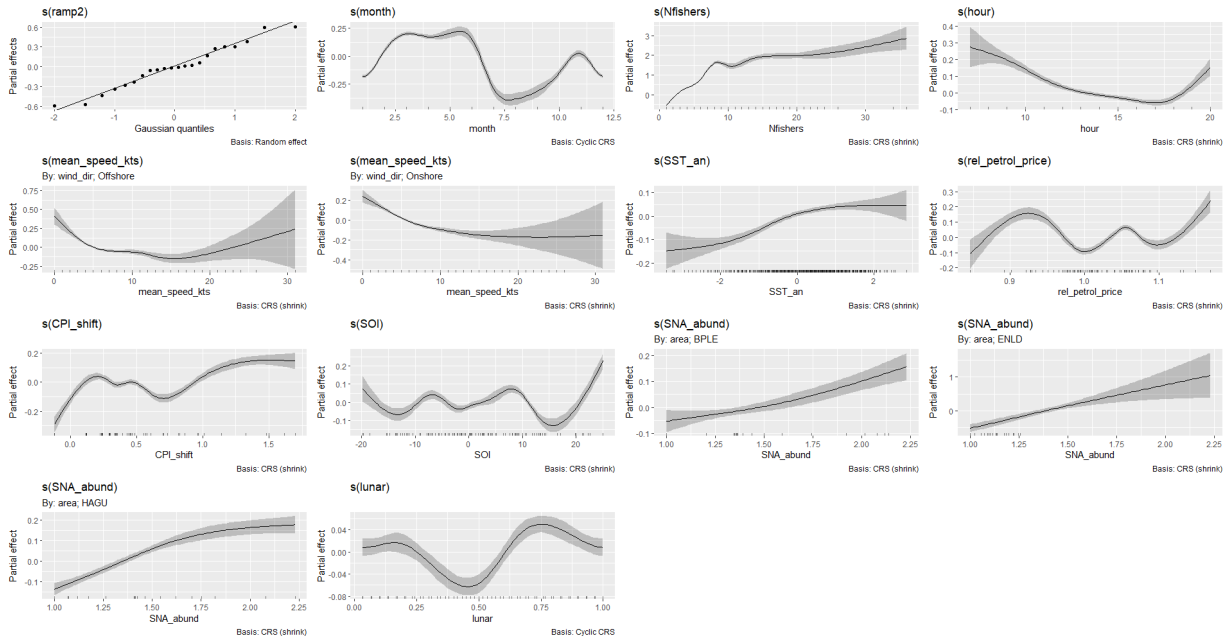


Figure 20: Partial effect plots of the all-areas-combined full-catch-model significant terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 16.95% (Table 12). The effort term "Nfishers" contributed highly to RMSE as "day-type" and "hour". Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 13).

Table 12: Decreasing stepwise RMSE improvement in model snapper-catch prediction by the successive addition of 'explanatory' covariate terms; all areas combined.

Predictor	eDf	Deviance explained	R sqr	AIC	RMSE improvement	CV par	RMSE full model	CV
Null model	1	0%	0	426 305	0.00%	NA	16.95%	0.02
s(Nfishers, bs = "cs", k = 10)	9.26	10%	15.1	416 944	7.74%	0.028	8.55%	0.019
s(ramp2, bs = "re")	30.21	17%	24.01	408 908	5.76%	0.025	2.64%	0.078
s(month, bs = "cc", k = 12)	39.70	19%	25.78	406 879	1.24%	0.075	1.38%	0.124
s(CPI_shift, bs = "cs", k = 8)	45.60	20%	26.45	406 308	0.40%	0.167	0.98%	0.118
s(SOI, bs = "cs", k = 9)	53.58	20%	26.72	406 063	0.17%	0.242	0.81%	0.125
s(hour, bs = "cs", k = 7)	58.48	20%	26.99	405 878	0.15%	0.142	0.65%	0.154
day_type_m	59.61	20%	27.2	405 667	0.17%	0.258	0.48%	0.166
s(rel_petrol_price, bs = "cs", k = 9)	66.84	21%	27.43	405 539	0.14%	0.067	0.34%	0.229

3.2.4 Snapper catch GAM covariate term selection East Northland dataset

The East Northland snapper-catch full GAM model comprised 14 covariates terms (Table 13).

Table 13: East Northland catch model (*R mgcv* syntax) smoother and factor covariate terms.

GAM formula term	Description
`formula_full <- SNA_catch ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(Nfishers, bs = "cs", k=10)+`	as cubic spline smoother term
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund,bs="cs",k=5) +`	as cubic spline smoother term
`s(CPI_shift,bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term

Covariate terms "tide-state", "SNA_abundance", "CPI_shift" and "lunar cycle" were not significant and so were dropped from the full GAM model (Appendix 14).

The concurvity scores on all the remaining smoother terms in the revised full-effort-model were low, the implication being that the variation each of these terms accounted for in the model was relatively unique (TableAppendix 7; Appendix 4).

Except for the "SST_anomaly", the model smoother term partial predictive relationships were non-linear (Figure 21). Monthly catch patterns were similar to the FMA 1 analysis model, catch rates are also higher in the morning hours although a dusk hour increase was not evident (Figure 21).

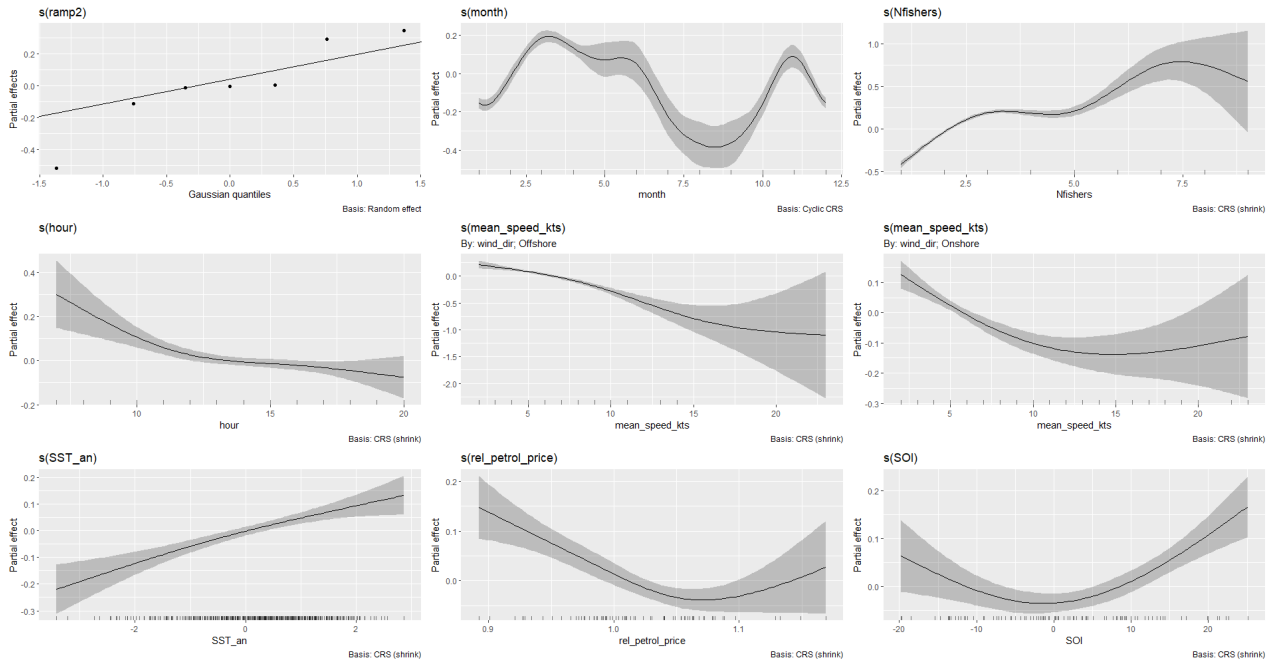


Figure 21: Partial effect plots of the East Northland snapper-catch model smoother terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was only 4.07% (Table 14). The effort term "ramp" and "Nfishers" contributed most to RMSE. Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 15).

Table 14: Decreasing stepwise RMSE improvement in model snapper-catch prediction by the successive addition of 'explanatory' covariate terms; East Northland.

Predictor	eDf	Deviance explained	R sqr	AIC	RMSE improvement	CV par	RMSE full model	CV
Null model	1	0%	0	90 857	0.00%	NA	4.07%	0.066
s(ramp2, bs = "re")	6.95	3%	3.28	90 098	1.69%	0.096	2.35%	0.07
s(Nfishers, bs = "cs", k = 5)	10.61	5%	5.2	89 598	1.17%	0.043	1.29%	0.083
s(month, bs = "cc", k = 12)	18.88	7%	6.82	89 234	0.84%	0.076	0.47%	0.161
s(mean_speed_kts, by = wind_dir, bs = "cs", k = 4)	22.52	7%	7.22	89 111	0.22%	0.07	0.30%	0.286

3.2.5 Snapper catch GAM covariate term selection Hauraki Gulf dataset

The Hauraki gulf snapper-catch full GAM model comprised 14 covariate terms (Table 15).

Covariate terms “tide-state”, “SOI” were not highly significant and so were dropped from the full GAM model (Appendix 16).

A concurvity test on the revised full-effort-model smoother terms produced “moderate” concurvity scores for “rel_petrol_price”, “CPI_shift”, and “SNA_abund”, the interpretation being that the additional variation in the data these terms accounted for was minimal (TableAppendix 8; Appendix 4).

The partial predictive relationships between the model smoother terms and the effort response were predominantly non-linear (Figure 22). Monthly and hourly catch patterns (Figure 22) were similar to the full area analysis model.

Table 15: Hauraki Gulf catch -model (*R mgcv* syntax) smoother and factor covariate terms.

GAM formula term	Description
`formula_full <- SNA_catch ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(Nfishers, bs = "cs", k=10)+`	as cubic spline smoother term
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund,bs="cs",k=5) +`	as cubic spline smoother term
`s(CPI_shift,bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term

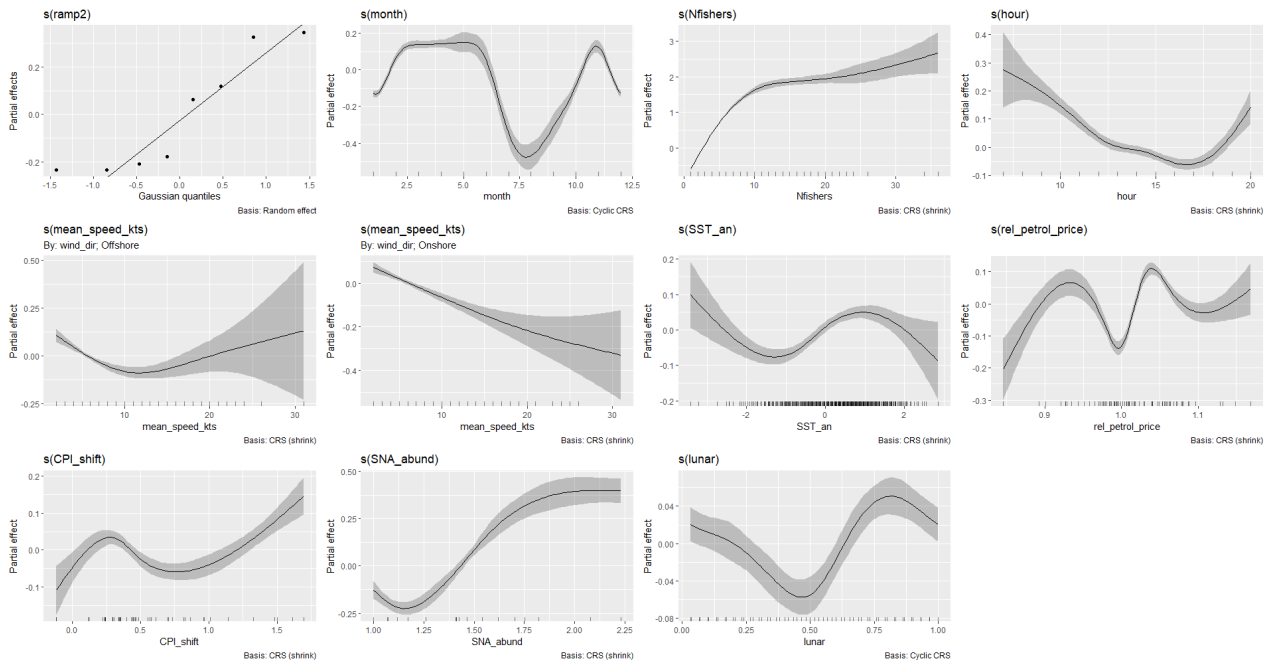


Figure 22: Partial effect plots of the Hauraki Gulf snapper-catch model smoother terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 19.71% (Table 16). The effort term "Nfishers" and "ramp" contributed the most RMSE improvement (Table 16). Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 17).

Table 16: Decreasing stepwise RMSE improvement in model snapper-catch prediction by the successive addition of 'explanatory' covariate terms; Hauraki Gulf.

Predictor	eDf	Deviance explained	R sqr	AIC	RMSE improvement	CV par	RMSE full model	CV
Null model	1	0%	0	228 058	0.00%	NA	19.71%	0.04
s(Nfishers, bs = "cs", k = 8)	6.48	14%	21.08	221 146	13.74%	0.042	5.24%	0.046
s(ramp2, bs = "re")	13.41	18%	24.58	219 331	2.25%	0.092	2.92%	0.047
s(month, bs = "cc", k = 12)	22.53	20%	26.31	218 425	1.01%	0.171	1.90%	0.031
s(CPI_shift, bs = "cs", k = 6)	27.28	21%	27.24	217 944	0.55%	0.116	1.34%	0.059
s(hour, bs = "cs", k = 8)	32.06	21%	27.57	217 830	0.27%	0.136	1.07%	0.099
s(rel_petrol_price, bs = "cs", k = 6)	37.04	21%	27.8	217 740	0.22%	0.213	0.84%	0.126
day_type_m	38.08	21%	28.05	217 589	0.17%	0.196	0.67%	0.133
s(SNA_abund, bs = "cs", k = 7)	43.45	22%	28.3	217 491	0.21%	0.153	0.46%	0.175
reg_change	43.29	22%	28.51	217 397	0.15%	0.275	0.31%	0.255

3.2.6 Snapper catch GAM covariate term selection Bay of Plenty dataset

The Bay of Plenty snapper-catch full GAM model comprised 14 covariates terms (Table 17).

Table 17: Bay of Plenty catch-model (*R mgcv* syntax) smoother and factor covariate terms.

GAM formula term	Description
`formula_full <- SNA_catch ~`	response
`s(ramp2,bs="re") +`	pseudo smooth term as random effect
`s(month,bs="cc",k=12) +`	as a pseudo cyclic smoother term
`day_type_m +`	as factor
`s(Nfishers, bs = "cs", k=10)+`	as cubic spline smoother term
`s(hour,bs="cs",k=7) +`	as cubic spline smoother term
`s(mean_speed_kts, by =wind_dir, bs ="cs", k =6) +`	as cubic spline smoother term crossed with wind_dir
`tide_state +`	as factor
`regulation_change +`	as factor
`s(SST_an,bs = "cs", k= 8)`	as cubic spline smoother term
`s(rel_petrol_price,bs="cs",k=9) +`	as cubic spline smoother term
`s(SNA_abund,bs="cs",k=5) +`	as cubic spline smoother term
`s(CPI_shift,bs = "cs", k=6) +`	as cubic spline smoother term
`s(lunar, bs = "cc") +`	simple cyclic term
`s(SOI,bs = "cs", k=7) +`	as cubic spline smoother term

Covariate terms "tide-state", "SNA_abaundance" were not highly significant and so were dropped from the full GAM model (Appendix 18).

A concurvity test on the revised full-effort-model smoother terms produced "moderate" concurvity scores for "ramp", "relative_petrol_price", and "CPI_shift", the interpretation being that the additional variation in the data these terms accounted for was minimal (TableAppendix 9; Appendix 4).

The partial predictive relationships between the model smoother terms and the effort were approximately linear (edf ≈ 1.0; Appendix 18) for "relative_petrol_price" and "SOI" (Figure 23). The lack of a significant relationship between offshore windspeed and snapper catch (Appendix 18) is also seen in the partial plots (Figure 23).

The partial plot of "month" with the catch response variable (Figure 23) differed from the pattern evident in the comparable East Northland and Hauraki Gulf model partial plots (Figure 21, Figure 22) being consistent with known spring summer spawning migrations from the Bay of Plenty to the Hauraki Gulf and autumn return migration (McKenzie et al. 2024).

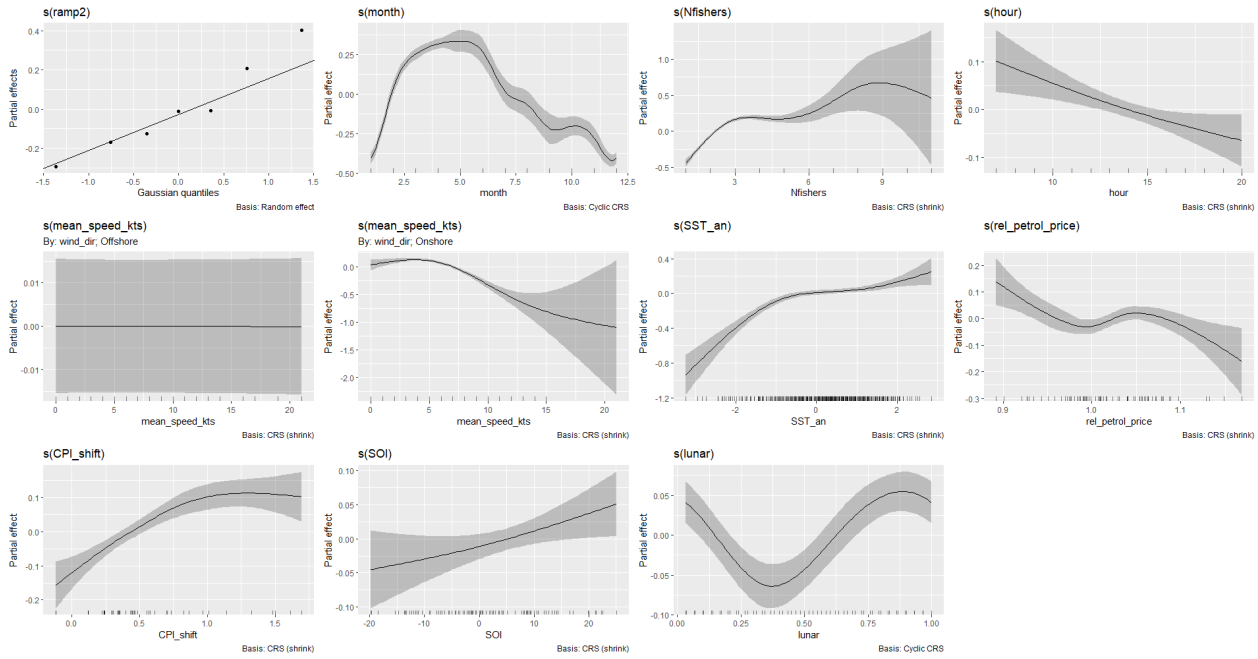


Figure 23: Partial effect plots of the Bay of Plenty snapper-catch model smoother terms.

The maximum average RMSE improvement over the Null model (no terms fitted) from the full model (all terms fitted) was 19.43% (Table 18). The effort term "Nfishers" contributed most to RMSE followed by "ramp" and "month" (Table 18). Despite failure of the DHARMa uniformity (KS), and outlier tests (these tests tend to be overly sensitive with large data sets), the residual plots do not show any extreme levels of misfit and can be regarded as "acceptable" (Appendix 19).

Table 18: Decreasing stepwise RMSE improvement in model snapper-catch prediction by the successive addition of 'explanatory' covariate terms; Bay of Plenty.

Predictor	eDf	Deviance explained	R.sqr	AIC	RMSE improvement	CV par	RMSE.full.model	CV
Null model	1	0%	0	228 058	0.00%	NA	19.43%	0.040
0s(Nfishers, bs = "cs", k = 6)	5.63	14%	21.12	221 151	13.73%	0.040	5.01%	0.044
s(ramp2, bs = "re")	12.58	18%	24.59	219 332	2.24%	0.096	2.71%	0.053
s(month, bs = "cc", k = 12)	21.70	20%	26.29	218 426	1.00%	0.168	1.70%	0.026
s(CPI_shift, bs = "cs", k = 6)	26.45	21%	27.24	217 945	0.57%	0.110	1.13%	0.073
s(hour, bs = "cs", k = 3)	28.44	21%	27.51	217 837	0.23%	0.152	0.90%	0.105
s(rel_petrol_price, bs = "cs", k = 6)	33.40	21%	27.74	217 747	0.23%	0.219	0.67%	0.114
day_type_m	34.38	21%	27.99	217 601	0.16%	0.246	0.51%	0.118
reg_change	35.37	21%	28.23	217 544	0.19%	0.237	0.32%	0.209

4. DISCUSSION

The purpose this report was to identify the main factors influencing both recreational fishing effort and recreational snapper catch in FMA 1. It is important to understand that the results from these investigations have different management interpretations depending upon whether the focus is on understanding drivers of "effort" or drivers of "catch". This is because "catch" is highly determined by "effort", e.g., zero "effort" means zero "catch", increasing "effort" means increasing "catch". However, "effort" is typically only indirectly affected by "catch" in that higher "catch" per-unit "effort" (e.g. because of higher abundance) may encourage greater participation in fishing.

By investigating drivers of recreational fishing effort, we are specifically trying to understand what factors determine people's willingness/ability to participate in fishing; less understanding is gained into underlying stock abundance.

A further benefit of identifying factors that correlate strongly with fishing effort is the possibility of using them for prediction. Since the GAM models used in this report are non-linear predictive models, given a relevant set of covariate values, they could potentially provide future-year fishing effort estimates. In years where recreational effort can be predicted, recreational catch can also be predicted provided a relative measure of snapper stock abundance is also known for that year (Appendix 2). However, given that the RMSE predictive improvement of our GAM effort models was in the order of only 25% over the null-models (no covariates), none of these models could be classed as having high fishing-effort predictive power. The effort-driver conclusions provided by these models should, therefore, be viewed "qualitatively".

Our drivers of snapper catch somewhat accounted for effort, being catch per interviewed boat. Consequently, these analyses may provide insight as to the underlying spatiotemporal distribution of the stock (in this case FMA 1 snapper), although they were less capable of providing insight as to human-factor behaviours and constraints affecting catch. The GAM catch model RMSE improvement levels were also low, so the catch-driver predictions should, again, be viewed "qualitatively".

Factors affecting FMA 1 recreational fishing effort

Factors that consistently accounted for the highest individual RMSE improvement in the various FMA 1 GAM models were "day_type", "ramp", "windspeed/direction" interaction term, and "hour_of_day".

The factors "day_type" and "ramp" were simply accounting for differences in boat traffic between ramps and between weekdays and holiday days, and so are arguably of little interest. Possibly of more interest was the consistently high explanatory ranking of "windspeed_direction". Although the effect of windspeed on fishing effort has an obvious causal interpretation, the GAM model partial plots nicely illustrate the non-linear nature of this relationship and the ameliorating effect of wind-direction. Wind speed appears to be less of an effect when the winds were off-shore.

The next consistently high-ranking term was "month". The importance of "month" confirms that there are likely to be important additional seasonal factors at play influencing the likelihood of people going fishing.

All other covariate terms, although statistically significant in effect, consistently ranked well below the four main terms in explanatory power.

The continuous covariate terms "snapper_abundance", "CPI_shift", "petrol_shift" and "SOI" in addition to low relative explanatory importance, produced high concurvity scores in the models meaning Model covariate term Pearson correlation plots hat what little variation they were accounting for in the effort data could equally well be accounted for by other model terms.

In contrast, despite having very low RMSE explanatory power, the GAM concurvity scores for "Lunar_cycles" and "SST_anomaly" were consistently low, meaning that the variation accounted for by these terms was small but unique.

The remaining factors "regulation_change" and "tide_state" were never selected in the stepwise RMSE term selections.

In summary, no socioeconomic factors (i.e., "rel_petrol_price", "CPI_shift", and "regulation_change") were found to strongly influence FMA 1 recreational fishing effort. All the strongest fishing effort influential terms were either spatiotemporal or environmental.

Factors affecting FMA 1 recreational snapper catch

The relative RMSE improvement in the FMA 1 snapper catch GAM models were on average lower than in the fishing effort GAM models (15% cf. 25%), with much of the model RMSE improvement being accounted for by the "number fishers per boat" term ("NFishers"). The explanatory importance of "Nfishers" term on catch is expected and was only included as a main-effects term and as an as offset parameter term to account for potential non-log-linearity in its effect on snapper-catch. The "NFishers" non-log-linearity assumption was subsequently confirmed by the GAM model partial plots and related "effective degrees of freedom" estimates.

The RMSE explanatory power of the remaining snapper catch model terms were low (< 5%). The spatiotemporal terms "ramp" and "month" were consistently the next most explanatory. Despite sometimes meeting the RMSE model selection criteria, high concurvity scores diminish the explanatory importance of "CPI_shift", "snapper_abundance", "rel_petrol_price", and "SOI" in the GAM model snapper-catch fits.

Disregarding "CPI_shift" and "SOI", "hour" was typically the next highest RMSE explanatory variable in the FMA 1 GAM catch models. Encouragingly, the individual area GAM model month and hour partial plots exhibited trends and patterns consistent with known FMA 1 snapper spawning migrations and crepuscular feeding behaviours.

The factor "day_type", which was highly explanatory in the effort models, although statistically significant in all FMA 1 area GAM snapper-catch models, typically had low-ranking RMSE explanatory power. The observed low explanatory importance of this factor is consistent with expectation i.e., snapper fishing success is likely to be independent of "day-of-the-week".

Overall, these investigations indicate that recreational fishing effort and recreational snapper catch in FMA 1 are primarily influenced by different processes and should therefore be interpreted separately. Recreational fishing effort was driven predominantly by environmental and spatiotemporal factors that influence people's opportunity or willingness to fish, whereas socioeconomic variables and management regulation changes contributed little additional explanatory power. Recreational snapper catch, once fishing effort had occurred, was similarly influenced mainly by spatiotemporal factors, with temporal patterns that were consistent with known snapper biology and behaviour. Although the GAM models identified statistically significant relationships and biologically plausible patterns, their relatively modest predictive performance means that the results should be interpreted primarily as qualitative evidence of the relative importance of different drivers rather than as quantitative forecasting tools. Nevertheless, the consistency of the key explanatory variables across models provides useful insight into the dominant factors shaping recreational fishing activity and catch in FMA 1, and offers a sound basis for improving future monitoring, refining predictive models, and informing fisheries management.

5. ACKNOWLEDGEMENTS

This study was funded by the Fisheries New Zealand (project MAF2025-01).

The authors would like to thank Kate Johnson and Ian Blixt for reviewing the final document; and Marianne Vignaux for editing it.

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7. APPENDICES

Appendix 1: Annual population "active-fisher" proportion estimates

TableAppendix 1: Assumed annual active-fisher population proportion fishing as derived from Active NZ and National Panel Survey estimates. Estimates for years where no survey estimates are available are interpolated.

Fishing year	Proportion fishing	Derivation
2003-2014	0.200	pub. estimate
2015	0.191	interpolated
2016	0.183	interpolated
2017	0.174	pub. estimate
2018	0.168	pub. estimate
2019	0.160	pub. estimate
2021	0.163	pub. estimate
2022	0.129	pub. estimate
2023	0.123	pub. estimate
2024	0.123	interpolated
2025	0.123	interpolated

Appendix 2: Understanding the relationship between snapper abundance and recreational catch and effort.

Given the assumption that recreational line effort snapper "catchability" (q) is constant in respect to time (t), recreational catch-per-unit-effort (CPUE) can be assumed to be proportional to snapper abundance (EquationAppendix 1).

EquationAppendix 1: $$q\frac{catch}{effort} = snapper\ abundance$$

From EquationAppendix 1 it also follows that, assuming that effort catchability (q) and snapper population abundance are known, it is possible to derive the expected (E) recreational catch for a given unit of effort (EquationAppendix 2).

EquationAppendix 2: $$effort\frac{snapper\ abundance}{q} = E[catch]$$

It follows from Equations 1 & 2 that snapper abundance and recreational fishing effort are relatively independent, whereas catch expectation (E[catch]) is dependent on the values of both these terms such that catch expectation will change when the level of effort and or snapper-abundance changes.

Appendix 3: All areas combined effort GAM full-model summary diagnostics

```
Family: Tweedie(p=1.225)
Link function: log

Formula:
n_boats ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(hour, bs = "cs", k = 14) + s(mean_speed_kts,
    by = wind_dir, bs = "cs", k = 8) + tide_state + reg_change +
    s(SST_an, bs = "cs", k = 22) + s(rel_petrol_price, bs = "cs",
    k = 9) + s(SNA_abund, by = area, bs = "cs", k = 5) + s(CPI_shift,
    bs = "cs", k = 6) + s(SOI, bs = "cs", k = 7) + s(lunar, bs = "cc") +
    offset(log(pop_fishing_area))

Parametric coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        -0.38509    0.10987  -3.505 0.000457 ***
day_type_m2        -1.02588    0.01119 -91.702  < 2e-16 ***
tide_stateincoming -0.06939    0.01663  -4.172 3.02e-05 ***
tide_statelow_tide -0.13547    0.02128  -6.366 1.95e-10 ***
tide_stateoutgoing -0.04860    0.01636  -2.970 0.002975 **
reg_changeold       0.22859    0.02728   8.378  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                                       edf Ref.df         F p-value
s(ramp2)                            20.078769     21   426.308  <2e-16 ***
s(month)                             9.713706     10   250.442  <2e-16 ***
s(hour)                              9.884272     13   689.534  <2e-16 ***
s(mean_speed_kts):wind_dirOffshore   6.200710      7   509.310  <2e-16 ***
s(mean_speed_kts):wind_dirOnshore    6.456032      7   925.652  <2e-16 ***
s(SST_an)                           19.698856     21    20.278  <2e-16 ***
s(rel_petrol_price)                  7.700688      8    49.216  <2e-16 ***
s(SNA_abund):areaBPLE                2.889631      4    78.654  <2e-16 ***
s(SNA_abund):areaENLD                2.733978      4 12244.926  0.0042 **
s(SNA_abund):areaHAGU                3.026984      4   107.014  <2e-16 ***
s(CPI_shift)                         4.942071      5    59.469  <2e-16 ***
s(SOI)                               0.007562      6     0.001  0.3830
s(lunar)                             7.747818      8    27.001  <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.382   Deviance explained = 42.2%
-REML =  92426  Scale est. = 2.2038    n = 66987
```

The "SOI" term was not significant and therefore dropped from the full model space.

Appendix 4: GAM smoother term concurvity test results

Concurvity tests test if two GAM covariate smooth terms are tracing similar non-linear paths through predictor space, such that their individual contributions become unreliable (the nonlinear equivalent of multicollinearity).

Interpreting concurvity test score values:

Value	Interpretation
0.0 – 0.3	Low concurvity — smooths are largely independent, estimates reliable
0.3 – 0.6	Moderate — worth watching, CIs may be somewhat inflated
0.6 – 0.8	High — smooths are substantially collinear, interpret individual terms cautiously
> 0.8	Very high — serious concurvity, individual smooth estimates and SEs are unreliable

Concurvity scores typically derived in three ways:

Statistic	What it measures
Observed	Measures how much the raw predictor values (before smoothing) overlap with each other.
Estimate*	Concurvity in the model's fitted smooth values
Worst	Computed from the basis function space alone, ignoring the data entirely.

*The estimate score is interpretively the most relevant.

TableAppendix 2: Effort response all-areas-combined GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(hour)	0.174	0.107	0.039
s(mean_speed_kts):wind_dirOnshore	0.171	0.064	0.077
s(mean_speed_kts):wind_dirOffshore	0.112	0.085	0.083
s(lunar)	0.179	0.092	0.094
s(SST_an)	0.321	0.077	0.099
s(ramp2)	1	0.085	0.170
s(month)	0.463	0.336	0.177
s(rel_petrol_price)	0.684	0.412	0.375
s(CPI_shift)	0.674	0.632	0.449
s(SNA_abund):areaHAGU	0.861	0.370	0.536
s(SNA_abund):areaBPLE	0.872	0.529	0.736
s(SNA_abund):areaENLD	1	0.984	0.836

TableAppendix 3: Effort response East Northland GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(hour)	0.182	0.124	0.029
s(lunar)	0.140	0.085	0.091
s(mean_speed_kts):wind_dirOffshore	0.503	0.142	0.111
s(mean_speed_kts):wind_dirOnshore	0.183	0.052	0.120
s(SST_an)	0.414	0.158	0.146
s(ramp2)	1	0.180	0.195
s(month)	0.57	0.382	0.225
s(rel_petrol_price)	0.726	0.481	0.411
s(CPI_shift)	0.739	0.621	0.464
s(SOI)	0.721	0.375	0.504
s(SNA_abund)	0.929	0.904	0.856

TableAppendix 4: Effort response Hauraki Gulf GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(hour)	0.156	0.087	0.024
s(mean_speed_kts):wind_dirOnshore	0.133	0.069	0.074
s(mean_speed_kts):wind_dirOffshore	0.121	0.068	0.084
s(lunar)	0.152	0.083	0.095
s(SST_an)	0.345	0.124	0.123
s(month)	0.444	0.334	0.179
s(ramp2)	1	0.039	0.188
s(rel_petrol_price)	0.685	0.348	0.391
s(CPI_shift)	0.712	0.424	0.444
s(SNA_abund)	0.876	0.753	0.751

TableAppendix 5: Effort response Bay of Plenty GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(hour)	0.228	0.136	0.048
s(lunar)	0.216	0.114	0.121
s(SST_an)	0.410	0.164	0.152
s(mean_speed_kts):wind_dirOffshore	0.333	0.253	0.186
s(mean_speed_kts):wind_dirOnshore	0.411	0.169	0.209
s(ramp2)	1	0.188	0.212
s(month)	0.557	0.388	0.242
s(rel_petrol_price)	0.724	0.654	0.401
s(SOI)	0.668	0.409	0.437
s(CPI_shift)	0.754	0.656	0.465
s(SNA_abund)	0.946	0.935	0.887

TableAppendix 6: Snapper catch response all-areas-combined GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(Nfishers)	0.071	0.069	0.043
s(hour)	0.151	0.119	0.075
s(mean_speed_kts):wind_dirOffshore	0.176	0.159	0.105
s(mean_speed_kts):wind_dirOnshore	0.256	0.167	0.116
s(lunar)	0.286	0.117	0.128
s(SST_an)	0.397	0.346	0.220
s(month)	0.485	0.196	0.223
s(ramp2)	1	0.423	0.225
s(SOI)	0.743	0.446	0.435
s(rel_petrol_price)	0.732	0.597	0.479
s(CPI_shift)	0.784	0.659	0.486
s(SNA_abund):areaHAGU	0.856	0.759	0.583
s(SNA_abund):areaBPLE	0.862	0.788	0.733
s(SNA_abund):areaENLD	1	0.970	0.790

TableAppendix 7: Snapper catch response East Northland GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(Nfishers)	0.059	0.058	0.036
s(mean_speed_kts):wind_dirOnshore	0.070	0.068	0.056
s(hour)	0.098	0.082	0.089
s(mean_speed_kts):wind_dirOffshore	0.330	0.077	0.093
s(month)	0.273	0.098	0.106
s(ramp2)	1	0.029	0.198
s(rel_petrol_price)	0.278	0.234	0.218
s(SST_an)	0.287	0.284	0.241
s(SOI)	0.297	0.196	0.264

TableAppendix 8: Snapper catch response Hauraki Gulf GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(Nfishers)	0.050	0.047	0.041
s(hour)	0.136	0.102	0.054
s(lunar)	0.088	0.078	0.057
s(mean_speed_kts):wind_dirOffshore	0.116	0.082	0.086
s(mean_speed_kts):wind_dirOnshore	0.150	0.141	0.112
s(month)	0.388	0.109	0.155
s(SST_an)	0.358	0.268	0.241
s(ramp2)	1.000	0.094	0.249
s(CPI_shift)	0.748	0.452	0.479
s(rel_petrol_price)	0.639	0.393	0.520
s(SNA_abund)	0.950	0.910	0.563

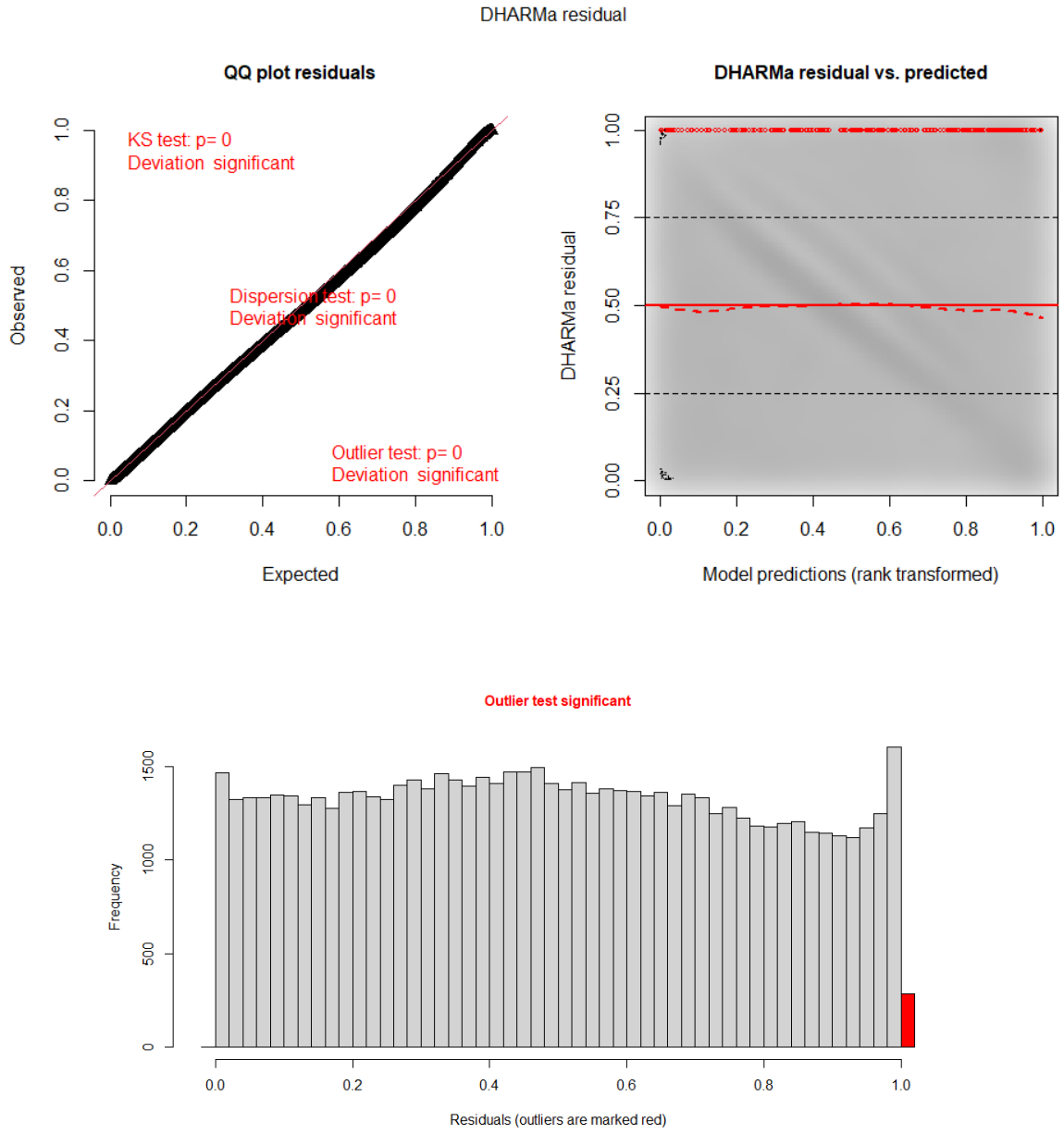
TableAppendix 9: Snapper catch response Bay of Plenty GAM smoother term concurvity scores, shaded values indicate moderate concurvity, green value high concurvity, i.e., low additional variation explained.

Term	Worst	Observed	Estimate
s(Nfishers)	0.062	0.058	0.032
s(lunar)	0.081	0.081	0.065
s(hour)	0.111	0.109	0.107
s(month)	0.467	0.317	0.184
s(mean_speed_kts):wind_dirOffshore	0.258	0.256	0.206
s(SST_an)	0.330	0.245	0.225
s(mean_speed_kts):wind_dirOnshore	0.321	0.194	0.244
s(ramp2)	1.000	0.095	0.301
s(SOI)	0.515	0.513	0.411
s(rel_petrol_price)	0.589	0.370	0.429
s(CPI_shift)	0.620	0.530	0.432

Appendix 5: Final all-areas-combined effort model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
n_boats ~ s(ramp2, bs = "re") + day_type_m + s(mean_speed_kts, by = wind_dir,
          bs = "cs", k = 8) + s(hour, bs = "cs", k = 14) + s(month, bs =
          "cc", k = 12) + s(SNA_abund, by = area, bs = "cs", k = 5) + s(lunar,
          bs = "cc") + offset(log(pop_fishing_area))
```



Appendix 6: East Northland effort GAM full-model summary diagnostics

```
Family: Tweedie(p=1.122)
Link function: log

Formula:
n_boats ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(hour, bs = "cs", k = 14) + s(mean_speed_kts,
    by = wind_dir, bs = "cs", k = 8) + tide_state + reg_change +
    s(SST_an, bs = "cs", k = 19) + s(rel_petrol_price, bs = "cs",
    k = 9) + s(SNA_abund, bs = "cs", k = 3) + s(CPI_shift, bs = "cs",
    k = 8) + s(SOI, bs = "cs", k = 7) + s(lunar, bs = "cc") +
    offset(log(pop_fishing_area))

Parametric coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)        -0.694736   0.057707 -12.039  < 2e-16 ***
day_type_m2        -0.956481   0.020428 -46.821  < 2e-16 ***
tide_stateincoming  0.005994   0.029222   0.205  0.83748
tide_statelow_tide -0.061632   0.036475  -1.690  0.09110 .
tide_stateoutgoing -0.035676   0.028747  -1.241  0.21461
reg_changeold      -0.098390   0.036202  -2.718  0.00658 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                                     edf Ref.df       F  p-value
s(ramp2)                           5.837      6  58.035  < 2e-16 ***
s(month)                           9.252     10  70.620  < 2e-16 ***
s(hour)                            8.738     13 152.473  < 2e-16 ***
s(mean_speed_kts):wind_dirOffshore 4.892      7 112.945  < 2e-16 ***
s(mean_speed_kts):wind_dirOnshore  6.611      7 283.182  < 2e-16 ***
s(SST_an)                         10.181     18   4.291  < 2e-16 ***
s(rel_petrol_price)                7.091      8  19.298  < 2e-16 ***
s(SNA_abund)                       1.328      2   6.088 0.000312 ***
s(CPI_shift)                       6.177      7  14.540  < 2e-16 ***
s(SOI)                             5.145      6   6.291 1.05e-06 ***
s(lunar)                           6.464      8   8.400  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

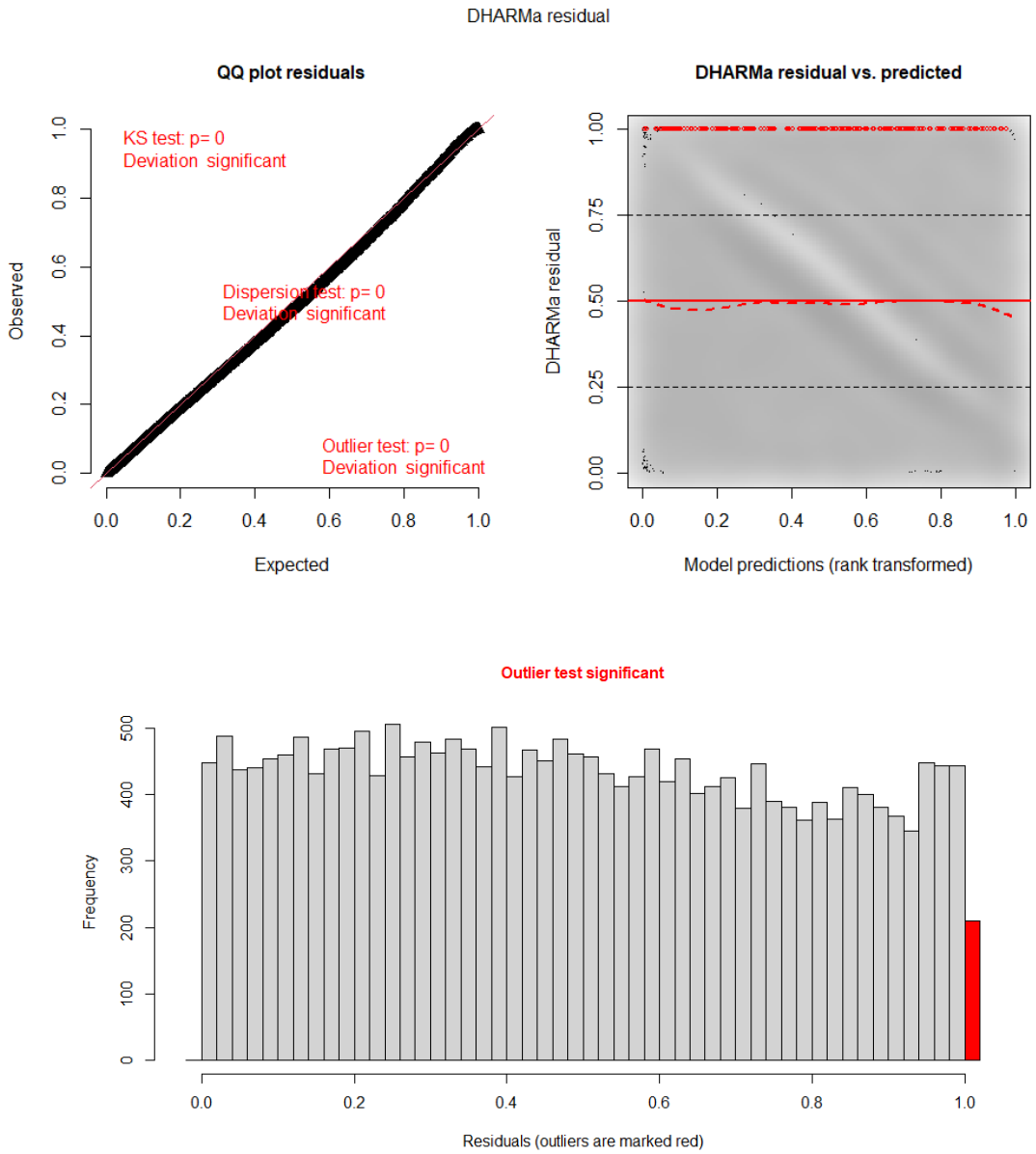
R-sq.(adj) =    0.3   Deviance explained = 33.9%
-REML =  24637  Scale est. = 1.5868    n = 22059
```

The “tide_state” term was not significant and therefore dropped from the full model space.

Appendix 7: Final East Northland effort model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
n_boats ~day_type_m + s(mean_speed_kts, by = wind_dir, bs = "cs", k = 8) +
        s(hour, bs = "cs", k = 14) + s(month, bs = "cc",k = 12) + s(ramp2,
        bs = "re") + s(SST_an, bs = "cs", k = 19) + s(rel_petrol_price, bs
        = "cs", k = 9) + offset(log(pop_fishing_area))
```



Appendix 8: Hauraki Gulf effort GAM full-model summary diagnostics

```
Family: Tweedie(p=1.233)
Link function: log

Formula:
n_boats ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(hour, bs = "cs", k = 14) + s(mean_speed_kts,
    by = wind_dir, bs = "cs", k = 8) + tide_state + reg_change +
    s(SST_an, bs = "cs", k = 19) + s(rel_petrol_price, bs = "cs",
    k = 9) + s(SNA_abund, bs = "cs", k = 3) + s(CPI_shift, bs = "cs",
    k = 8) + s(SOI, bs = "cs", k = 7) + s(lunar, bs = "cc") +
    offset(log(pop_fishing_area))

Parametric coefficients:
                  Estimate Std. Error t value Pr(>|t|)
(Intercept)        -0.36243    0.12851  -2.820   0.0048 **
day_type_m2        -1.15584    0.01636 -70.642  < 2e-16 ***
tide_stateincoming -0.12969    0.02411  -5.378 7.57e-08 ***
tide_statelow_tide -0.17406    0.03092  -5.630 1.82e-08 ***
tide_stateoutgoing -0.05410    0.02371  -2.282   0.0225 *
reg_changeold       0.30108    0.03322   9.064  < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:
                                       edf Ref.df       F p-value
s(ramp2)                          6.980065      7 594.865  <2e-16 ***
s(month)                          9.227644     10 112.814  <2e-16 ***
s(hour)                           9.993306     13 287.301  <2e-16 ***
s(mean_speed_kts):wind_dirOffshore  6.252195      7 301.940  <2e-16 ***
s(mean_speed_kts):wind_dirOnshore   4.762351      7 548.601  <2e-16 ***
s(SST_an)                        15.773024     18  12.869  <2e-16 ***
s(rel_petrol_price)               7.323062      8  26.233  <2e-16 ***
s(SNA_abund)                      1.913773      2 110.758  <2e-16 ***
s(CPI_shift)                      5.738768      7   9.400  <2e-16 ***
s(SOI)                            0.008442      6   0.001    0.48
s(lunar)                          7.177722      8  11.834  <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

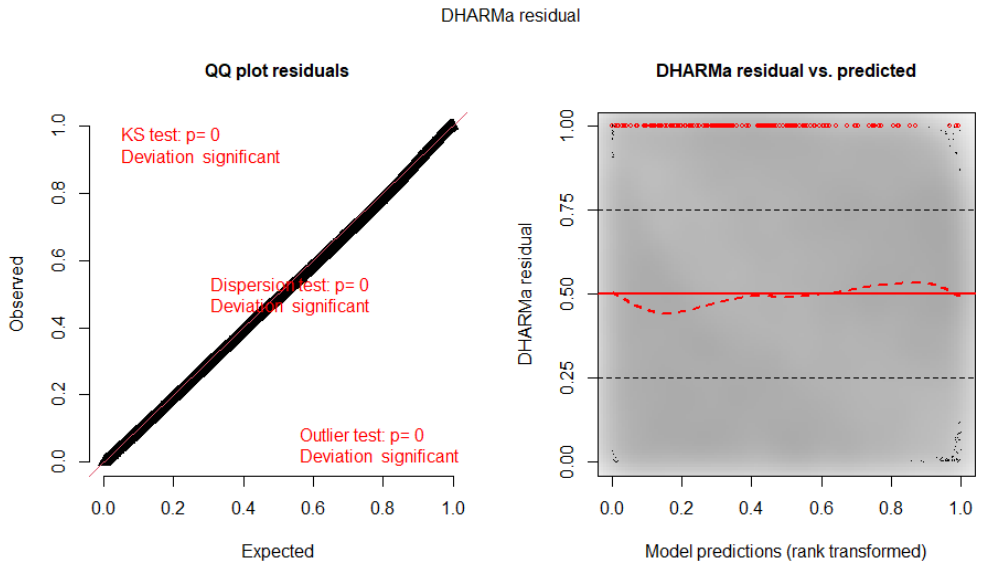
R-sq.(adj) =  0.404   Deviance explained = 46.5%
-REML =  39346  Scale est. = 2.2611    n = 27437
```

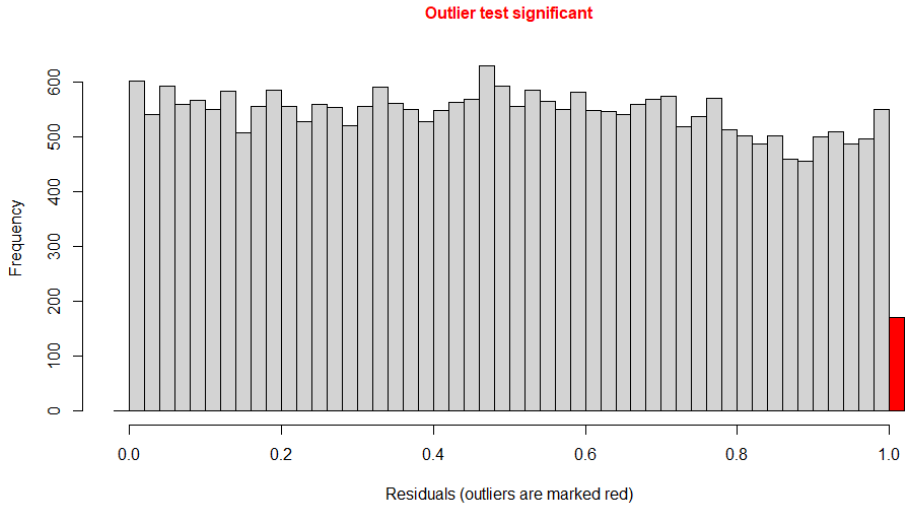
The “SOI” term was not significant and therefore dropped from the full model space.

Appendix 9: Final Hauraki Gulf effort model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
n_boats ~ day_type_m + s(mean_speed_kts, by = wind_dir, bs = "cs",k = 8) + s(ramp2,
          bs = "re") + s(hour, bs = "cs", k = 14) + s(month, bs = "cc", k = 12) +
          s(SST_an, bs = "cs", k = 19) + s(SNA_abund, bs = "cs", k = 3) +
          offset(log(pop_fishing_area))
```





Appendix 10: Bay of Plenty effort GAM full-model summary diagnostics

```
Family: Tweedie(p=1.275)
Link function: log

Formula:
n_boats ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(hour, bs = "cs", k = 14) + s(mean_speed_kts,
    by = wind_dir, bs = "cs", k = 8) + tide_state + reg_change +
    s(SST_an, bs = "cs", k = 19) + s(rel_petrol_price, bs = "cs",
    k = 9) + s(SNA_abund, bs = "cs", k = 3) + s(CPI_shift, bs = "cs",
    k = 8) + s(SOI, bs = "cs", k = 7) + s(lunar, bs = "cc") +
    offset(log(pop_fishing_area))

Parametric coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)        -0.74189    0.25403  -2.920  0.00350 **
day_type_m2        -0.90544    0.02265 -39.976  < 2e-16 ***
tide_stateincoming -0.02108    0.03497  -0.603  0.54657
tide_statelow_tide -0.11755    0.04538  -2.590  0.00959 **
tide_stateoutgoing -0.04461    0.03444  -1.295  0.19525
reg_changeold       0.44724    0.06496   6.885 5.98e-12 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

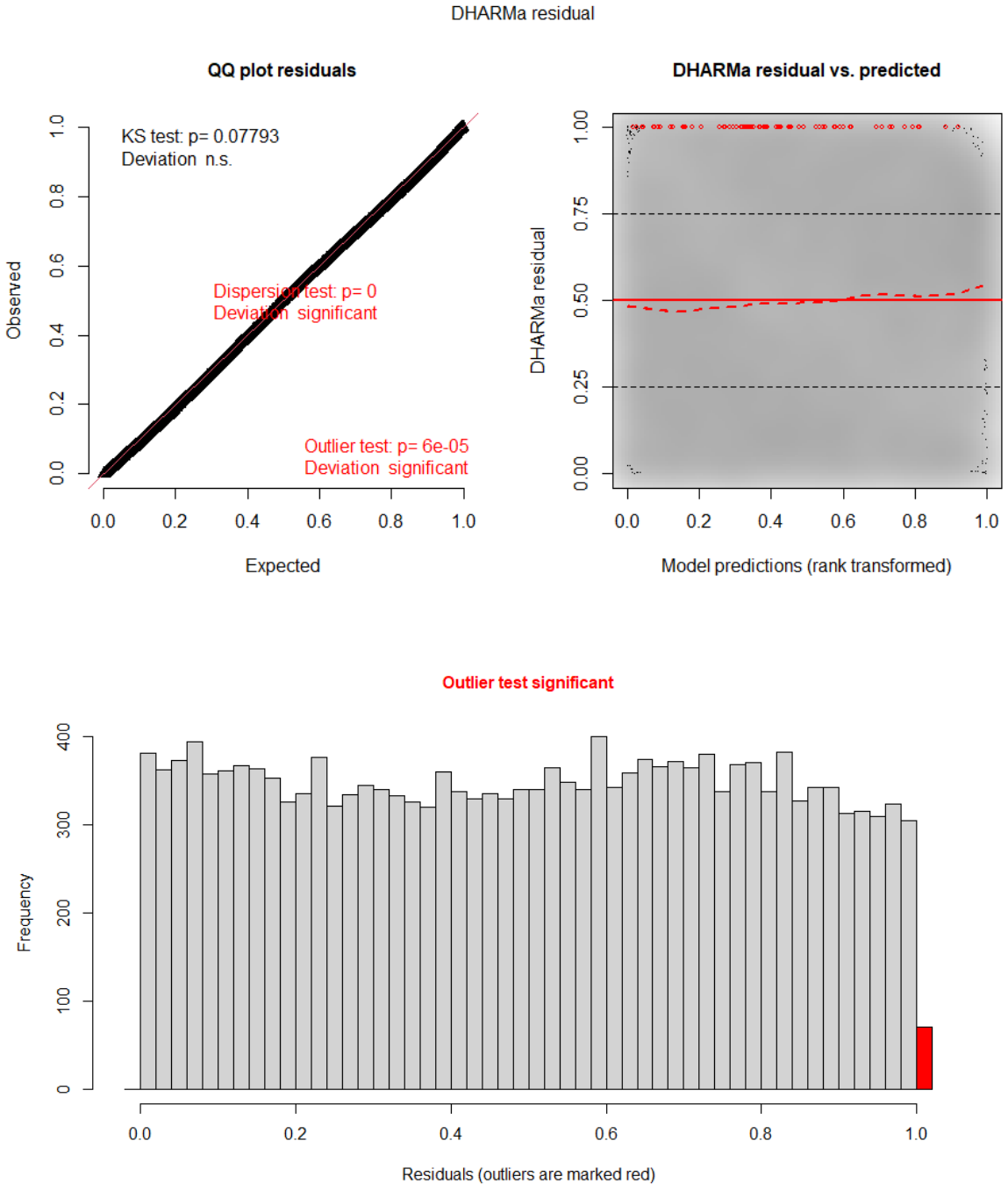
Approximate significance of smooth terms:
                                   edf Ref.df       F p-value
s(ramp2)                         5.984      6 576.866 < 2e-16 ***
s(month)                         9.190     10  50.821 < 2e-16 ***
s(hour)                          7.955     13 181.844 < 2e-16 ***
s(mean_speed_kts):wind_dirOffshore 5.729      7  57.508 < 2e-16 ***
s(mean_speed_kts):wind_dirOnshore  5.684      7 182.638 < 2e-16 ***
s(SST_an)                        7.677     18   1.898 1.2e-05 ***
s(rel_petrol_price)              6.832      8  10.458 < 2e-16 ***
s(SNA_abund)                     1.749      2  17.978 < 2e-16 ***
s(CPI_shift)                     6.772      7  47.309 < 2e-16 ***
s(SOI)                           5.121      6  10.136 < 2e-16 ***
s(lunar)                         7.676      8  25.987 < 2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) =  0.369   Deviance explained = 42.7%
-REML =  23918  Scale est. = 2.5946    n = 17491
```

Appendix 11: Bay of Plenty effort model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
n_boats ~ s(ramp2, bs = "re") + day_type_m + s(hour, bs = "cs",
          k = 14) + s(mean_speed_kts, by = wind_dir, bs = "cs", k = 8) + s(month, bs
          = "cc", k = 12) + s(lunar, bs = "cc") + offset(log(pop_fishing_area))
```



Appendix 12: All areas combined snapper catch GAM full-model summary diagnostics

```
Family: Negative Binomial(0.826)
Link function: log

Formula:
SNAcatch ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(Nfishers, bs = "cs", k = 10) + tide_state +
    s(hour, bs = "cs", k = 7) + s(mean_speed_kts, by = wind_dir,
    bs = "cs", k = 8) + s(SST_an, bs = "cs", k = 8) + s(rel_petrol_price,
    bs = "cs", k = 9) + s(CPI_shift, bs = "cs", k = 8) + s(SOI,
    bs = "cs", k = 9) + s(SNA_abund, by = area, bs = "cs", k = 5) +
    s(lunar, bs = "cc", k = 7) + reg_change

Parametric coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)         1.42244    0.06573  21.640   <2e-16 ***
day_type_m2         0.16035    0.01080  14.851   <2e-16 ***
tide_stateincoming  0.01317    0.01611   0.817   0.4137
tide_statelow_tide  0.02446    0.02061   1.187   0.2353
tide_stateoutgoing -0.03570    0.01589  -2.247   0.0246 *
reg_changeold       0.29853    0.02142  13.938   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                                    edf Ref.df       F  p-value
s(ramp2)                         20.567     21  231.58  < 2e-16 ***
s(month)                          9.395     10  225.33  < 2e-16 ***
s(Nfishers)                       7.623      9 1234.90  < 2e-16 ***
s(hour)                           4.596      6   51.74  < 2e-16 ***
s(mean_speed_kts):wind_dirOffshore  3.561      7   25.68  < 2e-16 ***
s(mean_speed_kts):wind_dirOnshore   2.826      7   36.67  < 2e-16 ***
s(SST_an)                         3.148      7   18.35  < 2e-16 ***
s(rel_petrol_price)               6.818      8   21.43  < 2e-16 ***
s(CPI_shift)                      5.917      7   33.92  < 2e-16 ***
s(SOI)                            7.286      8   28.82  < 2e-16 ***
s(SNA_abund):areaBPLE             1.225      4   19.57 5.87e-06 ***
s(SNA_abund):areaENLD             1.368      4 6284.94  < 2e-16 ***
s(SNA_abund):areaHAGU             2.343      4   68.61  < 2e-16 ***
s(lunar)                          3.924      5   14.72  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

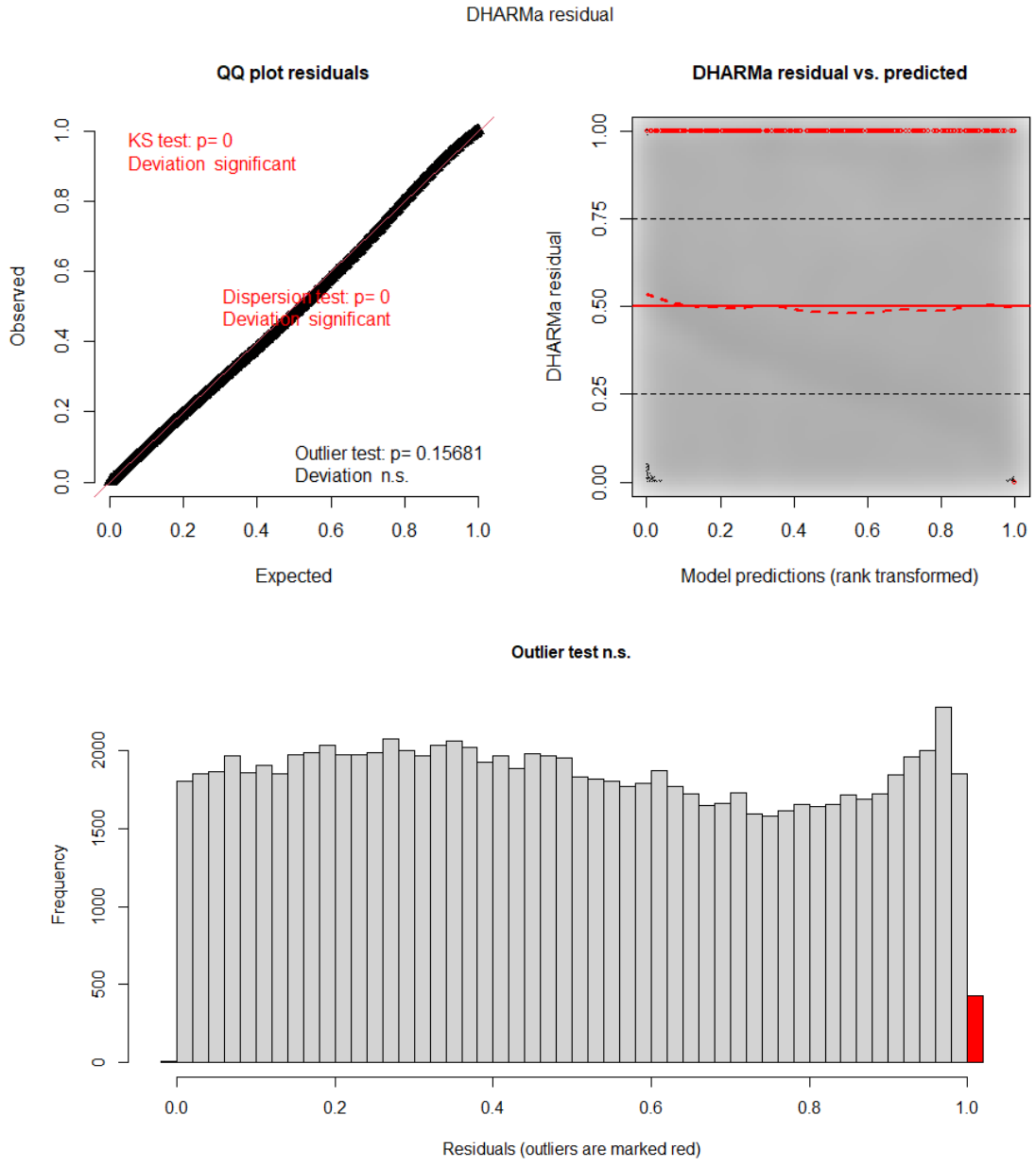
R-sq.(adj) =  0.275   Deviance explained = 16.6%
-REML =  91214  Scale est. = 1         n = 93555
```

The "tide-state" term was only marginally significant and therefore dropped from the full model space.

Appendix 13: All areas combined snapper-catch model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
SNAcatch ~ s(Nfishers, bs = "cs", k = 10) + s(ramp2, bs = "re") + s(month, bs = "cc",
          k = 12) + s(CPI_shift, bs = "cs", k = 8)
```



Appendix 14: East Northland combined snapper catch GAM full-model summary diagnostics

```
Family: Tweedie(p=1.324)
Link function: log

Formula:
SNAcatch ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(Nfishers, bs = "cs", k = 5) + tide_state +
    s(hour, bs = "cs", k = 4) + s(mean_speed_kts, by = wind_dir,
    bs = "cs", k = 4) + s(SST_an, bs = "cs", k = 4) + s(rel_petrol_price,
    bs = "cs", k = 4) + s(CPI_shift, bs = "cs", k = 4) + s(SOI,
    bs = "cs", k = 4) + s(SNA_abund, bs = "cs", k = 3) + s(lunar,
    bs = "cc", k = 4) + reg_change

Parametric coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)         1.14845    0.09544  12.033  < 2e-16 ***
day_type_m2         0.11905    0.02048   5.814 6.19e-09 ***
tide_stateincoming  0.01087    0.02910   0.373   0.7088
tide_statelow_tide  0.01903    0.03615   0.526   0.5985
tide_stateoutgoing -0.01804    0.02898  -0.623   0.5334
reg_changeold       0.06674    0.02637   2.531   0.0114 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                                      edf Ref.df       F  p-value
s(ramp2)                          5.95088      6 156.931  < 2e-16 ***
s(month)                          8.28668     10  45.118  < 2e-16 ***
s(Nfishers)                       3.66614      4 275.083  < 2e-16 ***
s(hour)                           2.43657      3  14.900 1.12e-06 ***
s(mean_speed_kts):wind_dirOffshore 1.88358      3  34.784  < 2e-16 ***
s(mean_speed_kts):wind_dirOnshore  1.81534      3  16.645  < 2e-16 ***
s(SST_an)                         1.48268      3  15.049  < 2e-16 ***
s(rel_petrol_price)               2.31815      3  16.114  < 2e-16 ***
s(CPI_shift)                      0.68372      3   0.845   0.0627 .
s(SOI)                            2.22743      3  10.050  < 2e-16 ***
s(SNA_abund)                      0.61853      2   1.057   0.0719 .
s(lunar)                          0.04253      2   0.023   0.3313
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

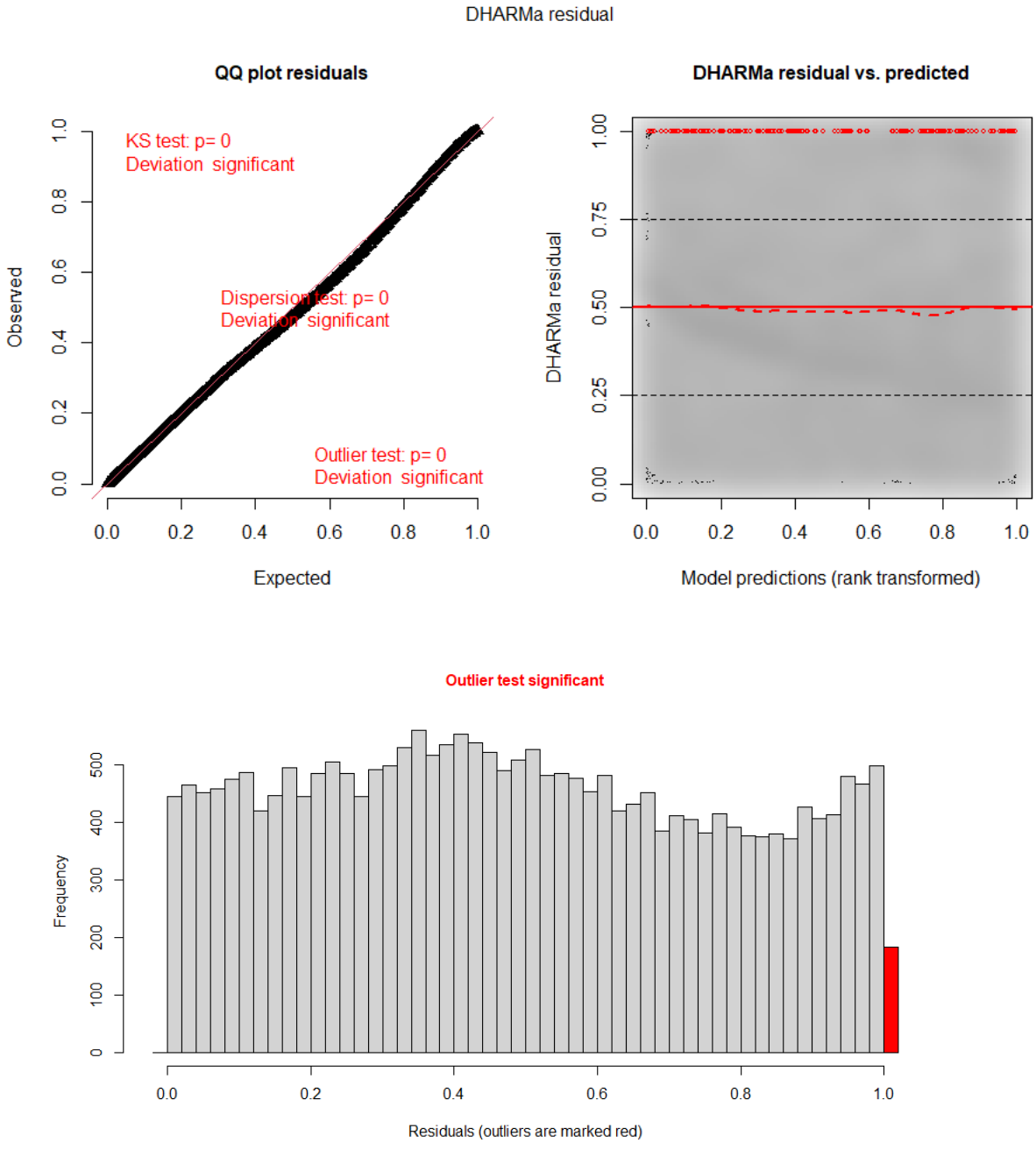
R-sq.(adj) =  0.0808   Deviance explained = 8.02%
-REML =  34029  Scale est. = 2.8362    n = 23208
```

Covariate terms "tide-state", "SNA_abundance", "CPI_shift" and "lunar cycle" were not highly significant and were dropped from the full GAM model.

Appendix 15: East Northland snapper-catch model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
SNAcatch ~ s(ramp2, bs = "re") + s(Nfishers, bs = "cs", k = 5) +  s(month, bs = "cc",
          k = 12) + s(mean_speed_kts, by = wind_dir, bs = "cs", k = 4)
```



Appendix 16: Hauraki Gulf combined snapper catch GAM full-model summary diagnostics

```
Family: Tweedie(p=1.367)
Link function: log

Formula:
SNAcatch ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(Nfishers, bs = "cs", k = 8) + tide_state +
    s(hour, bs = "cs", k = 8) + s(mean_speed_kts, by = wind_dir,
    bs = "cs", k = 4) + s(SST_an, bs = "cs", k = 6) + s(rel_petrol_price,
    bs = "cs", k = 6) + s(CPI_shift, bs = "cs", k = 6) + s(SOI,
    bs = "cs", k = 3) + s(SNA_abund, bs = "cs", k = 7) + s(lunar,
    bs = "cc", k = 7) + reg_change

Parametric coefficients:
                   Estimate Std. Error t value Pr(>|t|)
(Intercept)         1.49846    0.08100  18.499   <2e-16 ***
day_type_m2         0.14991    0.01187  12.630   <2e-16 ***
tide_stateincoming  0.02713    0.01790   1.516   0.1296
tide_statelow_tide  0.03635    0.02277   1.597   0.1104
tide_stateoutgoing -0.03230    0.01764  -1.831   0.0671 .
reg_changeold       0.57532    0.04104  14.020   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                                       edf Ref.df       F p-value
s(ramp2)                         6.9577294      7  270.45 < 2e-16 ***
s(month)                         9.2701532     10  105.50 < 2e-16 ***
s(Nfishers)                      5.5091187      7 3542.42 < 2e-16 ***
s(hour)                          4.9366735      7   41.13 < 2e-16 ***
s(mean_speed_kts):wind_dirOffshore 2.2210223      3   20.60 7.7e-07 ***
s(mean_speed_kts):wind_dirOnshore  1.4355551      3   28.72 < 2e-16 ***
s(SST_an)                        3.9080706      5   17.08 < 2e-16 ***
s(rel_petrol_price)              4.9440773      5   48.85 < 2e-16 ***
s(CPI_shift)                     3.9309082      5   15.07 < 2e-16 ***
s(SOI)                           0.0001037      2    0.00   0.657
s(SNA_abund)                     4.6925717      6   85.79 < 2e-16 ***
s(lunar)                         4.1498435      5   17.55 < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

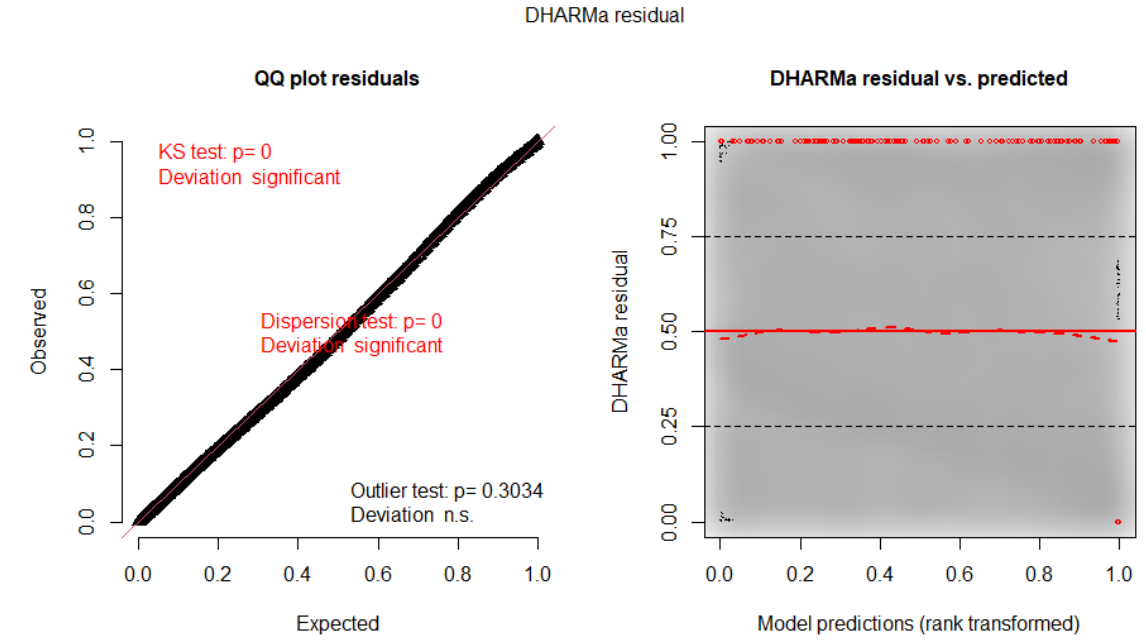
R-sq.(adj) =   0.29   Deviance explained = 22.3%
fREML =  64795  Scale est. = 2.9845    n = 45414
```

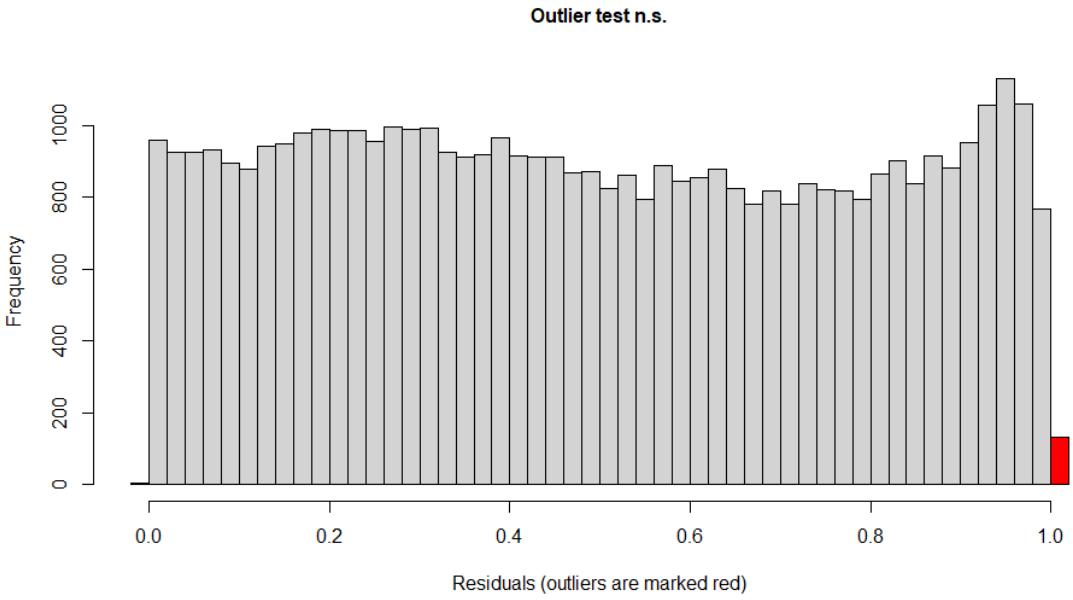
Covariate terms "tide-state", "SOI" were not highly significant and were dropped from the full GAM model.

Appendix 17: Hauraki Gulf snapper-catch model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
SNAcatch ~ s(Nfishers, bs = "cs", k = 8) + s(ramp2, bs = "re") +  s(month, bs = "cc",
           k = 12) + s(CPI_shift, bs = "cs", k = 6) + s(hour, bs = "cs", k = 8) +
           s(rel_petrol_price, bs = "cs", k = 6) + day_type_m + s(SNA_abund, bs =
           "cs", k = 7) + reg_change
```





Appendix 18: Bay of Plenty combined snapper catch GAM full-model summary diagnostics

```
Family: Tweedie(p=1.351)
Link function: log

Formula:
SNAcatch ~ s(ramp2, bs = "re") + s(month, bs = "cc", k = 12) +
    day_type_m + s(Nfishers, bs = "cs", k = 6) + tide_state +
    s(hour, bs = "cs", k = 3) + s(mean_speed_kts, by = wind_dir,
    bs = "cs", k = 4) + s(SST_an, bs = "cs", k = 6) + s(rel_petrol_price,
    bs = "cs", k = 6) + s(CPI_shift, bs = "cs", k = 6) + s(SOI,
    bs = "cs", k = 3) + s(SNA_abund, bs = "cs", k = 3) + s(lunar,
    bs = "cc", k = 4) + reg_change

Parametric coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)         1.264509   0.081995  15.422   <2e-16 ***
day_type_m2         0.175787   0.019137   9.186   <2e-16 ***
tide_stateincoming -0.014924   0.028730  -0.519   0.6034
tide_statelow_tide -0.006345   0.037567  -0.169   0.8659
tide_stateoutgoing -0.050635   0.028531  -1.775   0.0759 .
reg_changeold       0.182245   0.018268   9.976   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
                                       edf Ref.df       F  p-value
s(ramp2)                          5.871e+00      6 147.233  < 2e-16 ***
s(month)                          8.453e+00     10 143.656  < 2e-16 ***
s(Nfishers)                       3.799e+00      5 150.935  < 2e-16 ***
s(hour)                           1.077e+00      2   9.456 0.000267 ***
s(mean_speed_kts):wind_dirOffshore 1.994e-03      3   0.001 0.327191
s(mean_speed_kts):wind_dirOnshore  2.250e+00      3  45.144  < 2e-16 ***
s(SST_an)                         3.773e+00      5  27.583  < 2e-16 ***
s(rel_petrol_price)               3.423e+00      5   5.034 2.88e-05 ***
s(CPI_shift)                      2.375e+00      5  13.107  < 2e-16 ***
s(SOI)                            9.058e-01      2   2.917 0.010449 *
s(SNA_abund)                      5.843e-05      2   0.000 0.228308
s(lunar)                          1.841e+00      2  16.299  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.128   Deviance explained = 11.9%
fREML =  37435  Scale est. = 3.496     n = 24933
```

Covariate terms "tide-state", "SNA_abundance" were not highly significant and were dropped from the full GAM model.

Appendix 19: Bay of Plenty snapper-catch model DHARMa residual diagnostic plots.

Final RMSE selected model formula:

```
SNAcatch ~ s(Nfishers, bs = "cs", k = 6) + s(ramp2, bs = "re") + s(month, bs = "cc",
           k = 12) + s(CPI_shift, bs = "cs", k = 6) + s(hour, bs = "cs", k = 3) +
           s(rel_petrol_price, bs = "cs", k = 6) + day_type_m + reg_change
```

