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Exploring the potential for observer CPUE for southwest Pacific swordfish (*Xiphias gladius*) and striped marlin (*Kajikia audax*)

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Cover Notes

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EXECUTIVE SUMMARY

This study addressed limitations in previously used CPUE indices for southwest Pacific swordfish and striped marlin stock assessments, which have been questioned on the basis of spatial coverage and potential impacts of gear and operational changes in regional fisheries that may have masked abundance trends. The 2024 striped marlin assessment was rejected due to such concerns, while the swordfish assessment faces similar issues of regional representation. In order to progress towards a potential avenue to resolve these issues, the work outlined in this paper adapted a methodological framework previously used for shark assessments in the WCPFC, applying it to observer data from the longline fleets of New Caledonia, Fiji, Tonga, and French Polynesia. The research aimed to develop potential alternative CPUE indices by standardizing for gear characteristics, vessel effects, and environmental factors like sea surface temperature and the NINA4 index.

For swordfish, standardising for operational fishing parameters altered the CPUE trend. In the western Pacific Island Countries and Territories (PICTs), a model that included variables like bait type and light stick use substantially dampened a prominent CPUE peak from around 2010, suggesting a more continuous decline than seen in an index without operational variables. The use of light sticks was found to be highly effective, increasing the catch rate by up to six times, highlighting how changes in fishing behavior can be mistaken for changes in fish abundance. Furthermore, higher swordfish catch rates were associated with shallower gear (fewer hooks-between-floats) and La Niña-like conditions.

The findings for striped marlin presented a different scenario. In the western PICTs, the standardized CPUE index was characterized by a dramatic and unprecedented surge in recent years, peaking in 2023. Unlike with swordfish, the inclusion of operational variables like bait type had a limited effect on this trend, suggesting the spike was not an artifact of fishing behavior. This recent increase was observed across all western observer programs. The analysis also identified a preference for shallower-set longlines and determined that higher catch rates for striped marlin tended to occur during El Niño-like conditions, the opposite of the environmental correlation found for swordfish.

The analysis also evidenced a stark regional difference in CPUE trends for both species, showing consistent divergent patterns between the western PICTs (Fiji, Tonga, New Caledonia) and French Polynesia. The swordfish trend in French Polynesia was generally flatter and lacked the major peaks seen in the west. The contrast was even more pronounced for striped marlin, where the French Polynesian index showed a slow, prolonged decline, and did not feature the recent sharp increase observed in the western PICTs. Unless these fisheries catch very different sizes of fish, the regional heterogeneity underscores a potential difficulty with using using a single index across the region for

these stocks.

This paper suggests that there is value in using SPC observer data to create regional CPUE indices for billfish in the southern Pacific, while incorporating operational aspects that affect billfish catch-rates.

We recommend that SC21 note:

- The potential of observer data to provide improve longline CPUE abundance indices for billfish.
- The consistent recent strong increase in CPUE of striped marlin for New Caledonia, Tonga and Fiji, but not for French Polynesia.
- The general difference in CPUE patterns for both species between New Caledonia/Fiji/Tonga and French Polynesia.
- The value of the additional covariates available from observer data for CPUE standardisation, particularly for swordfish.
- The abundance indices developed for striped marlin and swordfish in this study can be considered for use in stock assessments.
- Further exploration of links between the NINA4 index and CPUE of swordfish and striped marlin is recommended
- The use of longline observer data could also be considered for development of abundance indices for tuna.

1. INTRODUCTION

Current CPUE indices for Southwest Pacific striped marlin and swordfish potentially suffer from limitations that compromise stock assessment reliability (summarised in Hamer 2025). The 2024 striped marlin assessment was rejected by SC20 due to technical concerns, primarily stemming from conflicts between size composition data and CPUE indices, inadequate spatial coverage where no individual flag or fishery covers the entire stock assessment region, and limited operational covariates in existing distant water fleet indices. Similarly, the swordfish assessment confronts issues with regional representation, where existing indices from New Zealand, Australia and EU fleets only cover subareas within larger model regions, and show CPUE fluctuations that may reflect availability changes rather than actual biomass trends.

This paper investigated the potential to apply standardised CPUE using methods developed for shark stock assessments to derive regional CPUE indices for southwest Pacific swordfish (*Xiphias gladius*) and striped marlin (*Kajikia audax*) for use in the respective 2025 stock assessments. The development of observer-based CPUE indices for shark assessments (Tremblay-Boyer & Neubauer 2019, Hill-Moana et al. 2024) provides an existing methodological framework that can potentially be adapted for billfish applications. This approach incorporates observer data from multiple Pacific Island jurisdictions, and uses spatio-temporal splines, oceanographic predictors (NINA4) and operational covariates including gear characteristics such as hooks-between-floats to standardise CPUE trends in GLMM models. The framework has demonstrated ability to account for spatial and temporal variations in catchability and availability (Neubauer et al. 2024), making it potentially well-suited for addressing some of the current billfish CPUE limitations.

PICTs observer data offers substantial spatial coverage advantages by providing representation across previously underrepresented central Pacific regions, areas between Australian/New Zealand coastal fisheries and distant water fleet operations, and regions where billfish abundance trends may differ from existing indices. Observer data from New Caledonia (NC), Fiji (FJ), Tonga (TO), and French Polynesia (FP/PF) can potentially provide linkages across the assessment region, reducing reliance on extrapolation from geographically restricted indices and potentially enabling development of alternative, possibly more regionally representative abundance trends.

Gear factor investigation through PICTs observer data can potentially address species-specific catchability issues that have compliated existing assessments. For striped marlin, this includes examining hook depth effects given their surface orientation and bait type preferences. For swordfish, observer data may help quantify light stick effects given their nocturnal feeding behavior, and assess bait type influences building on Taiwan observer studies that demonstrated higher swordfish occurrence associated with mackerel bait and spatial differences in effectiveness patterns among bait types (summarised in Hamer 2025).

2. METHODS

2.1 Description of datasets

We used the Pacific Community (SPC) observer dataset for the WCPFC longline fleet for the analysis, focusing on observer data from New Caledonia, Fiji, Tonga, and French Polynesia as these represent a consistent latitudinal band that spans the WCPFC convention area in the south Pacific, and all countries have relatively high observer coverage since the early 2000s (Figures 2–A-2). Records collected by longline observers that are relevant to this assessment are catch and event attributes (including date and time, location), as well as information on gear, such as hooks-between-floats (HBF), total number of hooks fished, use of light-sticks, and bait type.

Not all records have light-sticks and bait type recorded, and recording is highly variable between years, with data availability for selected observer programmes ranging from 34% to 93% (Table 1).

2.2 Standardisation of catch rates from observed sets

Catch rates were standardised using a progression of models aimed at exploring the importance of oceanographic and gear factors on CPUE. Models used a negative-binomial model with over-dispersion adjustment (Tremblay-Boyer & Neubauer 2019), using the number of hooks sampled by observers as an offset. We estimated smooth effects for the number of hooks (effectively allowing for non-linear catch rates with the number of hooks) and hooks between floats (HBF). The NINA4 index was included in two ways (Neubauer et al. 2024) for swordfish and striped marlin models. First, a main effect for the NINA4 index was applied as the mean over the preceding four years. Secondly, an interaction term with observer-program was added, to investigate if region specific trends in catchability (or local abundance) driven by NINA4 could alter the overall index.

For longline, we applied CPUE models to a grid of assumptions for analysis.

1. Using observer data from New Caledonia, Fiji, Tonga, and French Polynesia combined,
2. splitting F from the more western areas (combined TO/FJ/NC vs FP).
3. Using lightstick and bait data; two options – including all data without these variables, only including data with these variables..

This combination results in 6 models per species. As trends were found to differ between FP and more western areas, only the split indices (options 2&3) are reported here. For each combination (regional strata and operational variables or not), a series of models were run, starting with a simple un-standardised model for annual catch rate (i.e. nominal annual CPUE), and sequentially adding effects to the model, with the full model taken as the standardisation model for each analysis, effectively standardising for regional effects of ENSO fluctuations (Figure 1) on availability.

The full longline CPUE model was given by (with light-stick and bait effects applied to models with "operational variables" only):

```
obs_int | hooks ~ (1|yy) +
                  (1|program_code*yy) +
                  (1|vessel_id) +
                  (1|mm) +
                 s(log(hooks)) +
                 s(log(HBF)) +
                 s(lightsticks) +
                  (1|bait_type) +
                 s(SST) +
                   NINA4_MA(4) +
                  (1+NINA4_MA(4)|program_code) +
                t2(lon5,lat5)
```

All variables were added sequentially according to the formula above. All models were fitted with brms using full Bayesian inference from MCMC, with four chains run for 1000 iterations each, discarding 500 iterations as burn-in and retaining 2000 iterations for inference across the four chains.

3. RESULTS

3.1 Swordfish (SWO)

Initial modelling of observer catch-per-unit-effort (CPUE) for both swordfish and striped marlin revealed divergent temporal trends between the observer programmes in the western Pacific (NC, FJ, TO) and the programme in the eastern part of the study area (FP). Consequently, the results presented in the main body of this section focus on the combined dataset for NC, FJ and TO, while the distinct results for the French Polynesian fishery are detailed in Appendix A and used for comparative purposes.

3.1.1 Western PICTs Analysis (Excluding French Polynesia)

The spatial distribution of fishing effort, measured in observed hooks, was concentrated in a latitudinal band between approximately 10°S and 30°S, extending from the waters east of Australia across to the Tonga EEZ (Figure 2). Nominal swordfish catch rates showed considerable spatial variation within this area, with no clear spatial pattern in nominal CPUE (Figure 3).

Model without operational parameters This analysis included all available observer records from 2001–2023, as summarised in Table 2. Due to low levels of available data in 2001, only trends from 2002 are described here.

The standardised annual CPUE index, which accounted for spatio-temporal and environmental effects but not operational details like bait and light-sticks, showed a distinct temporal pattern (Figure 4, top-left panel). The index declined from the early 2000s to 2007, but then increased to a peak around 2010, followed by a rapid decline to a low point between 2016 and 2017. In the most recent years, the index showed a slight recovery and stabilisation but remained below levels seen during the first half of the time-series.

The stepwise inclusion of covariates demonstrated that the inclusion of effort variables, namely number of hooks and hooks-between-floats had the most substantial impact on the year trend, significantly dampening peaks in nominal CPUE in 2010 and 2012 (Figure 5). However, this standardising effect was much stronger for data from Tonga than data from the Fijian observer program (Figure 6). However, despite substantial variability among indices, all showed a pattern of high and fluctuating CPUE before 2015, and low CPUE since 2015, with possible slight increases in recent years. The large inter-annual variability among observer programmes was associated with patterns in data availability from each program. The large peak in CPUE in Fiji around 2010, for example, was associated with relatively low number of records, and may therefore have been due to fishing and reporting patterns as opposed to large changes in local abundance (Figure 7).

Hooks-between-floats had a strong influence on catch rates, with swordfish CPUE peaking at low HBF values (log(HBF) <= 2.3, corresponding to approximately 10 HBF) and declining for deeper gear configurations (Figure 8). HBF patterns were highly variable within the dataset, with few observations of shallow gear configurations that would lead to higher catch rates. Correspondingly, a single year with observations from shallow gear in 2012 led to the downward standardisation of the peak in nominal CPUE in that year.

Swordfish CPUE was negatively correlated with sea surface temperature (SST), with higher catch rates in cooler waters (Figure 9), but this relationship led to little to no standardising effect. The NINA4 environmental index showed a cyclical influence, where higher swordfish availability (positive influence multiplier) was generally associated with negative NINA4 values (La Niña-like conditions) (Figure 10).

Model with operational parameters This analysis was restricted to the subset of data where both bait type and light stick usage were recorded (Table 3), resulting in a substantially smaller dataset, particularly between 2010 and 2014 (Table 1). The inclusion of these operational variables led to a standardised CPUE trend that was markedly different from the previous model (Figure 4, bottom-left panel). The prominent peak in CPUE around 2010 was substantially dampened, and the overall trend was one of a more continuous decline. As a result, the decline from 2014 to 2016 was less pronounced, but the index still fluctuated without a marked trend since 2016 (Figure 11).

This change in the trend was driven by the strong influence of the vessel effect. Hooks-between-floats had a similar effect on CPUE as in the model without operational parameters (Figure 14), leading to a strong standardisation effect for the 2012 year, reducing the peak in the unstandardised CPUE. Despite differences in bait type, the over-all influence on CPUE of bait type was relatively low (Figure 15). The use of light-sticks, on the other hand, had a strong positive effect on swordfish CPUE. The model applied a large positive multiplier (up to 6x) for sets with high numbers of light sticks, confirming their effectiveness in targeting swordfish (Figure 16); however, most effort was reported as fishing without light-sticks, and the standardisation effect was small.

3.1.2 French Polynesia (FP) Analysis and Regional Comparison

The standardised swordfish CPUE trend derived from the French Polynesian observer programme without operational parameters other than HBF was markedly different from that of the western PICTs (Figure 4, right panels). The FP trend was generally flatter, and lacked the pronounced peaks and troughs seen in the west. Instead, it showed a gradual, slight increase over the first half of the time-series, followed by a general downward trend, albeit with large variability (Appendix A, Figure A-3).

The effects of SST and the NINA4 index are weaker and less consistent in the FP fishery compared to the western region (Appendix A, Figures A-5, A-6).

Operational covariate effects were similar to those seen in the more western observer programs, such as the positive influence of HBF and light sticks on catch rates (Appendix A, Figures A-8 – A-10).

3.2 Striped Marlin (MLS)

3.2.1 Western PICTs Analysis (Excluding French Polynesia)

Model without operational parameters The analysis for striped marlin was based on the dataset summarised in Table 4. A notable feature of the raw (nominal) data was the exceptionally high total catch and mean catch per set recorded in 2023. After an initial low period in the early 2000s, the standardised CPUE index was characterised by a period of relative stability or gradual decline from 2002 until approximately 2018. This was followed by a substantial increase, culminating in an unprecedented peak in 2023 (Figure 17, top-left panel). This recent peak remained the dominant feature of the time series even after accounting for spatio-temporal and environmental variability (Figure 18). The peak in CPUE was observed across all regions (Figure 19), and not due to regional influence on CPUE (Figure 20). An intermediate peak in CPUE around 2013 was not consistent across observer programs, but was mainly found in Tonga, and to a lesser extent in Fiji (Figure 19).

Striped marlin catch rates were highest at low HBF values (log(HBF) < 3.0, or <20 HBF), indicating a preference for shallower-set longlines (Figure 21). Catch-rates were highest in subtropical temperatures (log(SST) 3.12 or 22°C; Figure 22), with an influence of the NINA4 index appeared to be opposite to that for swordfish, with higher catch rates tending to occur during positive NINA4 phases (El Niño-like conditions) (Figure 23).

Model with operational parameters The analysis using the subset of data with operational parameters (Table 5) confirmed the primary trend observed in the simpler model. The increase in CPUE from 2019 to 2023 remained the dominant signal in the fully standardised index (Figure 17, bottom-left panel; Figure 24).

Unlike for swordfish, the operational variables examined had a limited effect on the striped marlin CPUE index. No single bait type showed a consistently strong positive influence on catch rates; the effects were variable and the multipliers were generally close to 1.0, suggesting operational factors were not a primary driver of striped marlin catch-rates in this fishery (Figures 27 – 29). In contrast to the model without operational variables, the persistence of the CPUE spike around 2013 in this model was largely due to an absence of data from NC during this time, and driven by the presence of this peak in Tonga and Fiji.

3.2.2 French Polynesia (FP) Analysis and Regional Comparison

Recent striped marlin CPUE trend in French Polynesia did not align with trends observed in the western PICTs. The FP-only index without operational variables showed a slow and prolonged decline over the entire time series, with no evidence of the recent increase observed in the west (Figure 17, right panels; Appendix A, Figure A-15).

Despite the opposing trends, the influence of key covariates on catchability was consistent with the species' biology across regions. In the FP fishery, as in the west, striped marlin catch rates are highest at lower HBF values (Appendix A, Figure A-16), and light sticks had a negative influence (Appendix A, Figure A-18).

4. DISCUSSION

This study explored the utility of observer-based catch-per-unit-effort (CPUE) data to create standardized abundance indices for southwest Pacific swordfish and striped marlin, which aimed to address limitations in existing indices used for stock assessments. Previous indices used in assessments had been challenged on the basis of the spatial coverage, limited operational data, and confounding fluctuations that may have reflected changes in availability rather than true abundance. The application of a methodological framework adapted from shark assessments represented an effort to progress towards meeting these challenges.

A primary finding of this analysis was the pronounced regional heterogeneity in CPUE trends for both species. The temporal trends for swordfish and striped marlin in the western Pacific Island countries and territories (PICTs) of New Caledonia, Fiji, and Tonga were markedly different from those in French Polynesia. For striped marlin, the divergence was particularly stark: the western PICTs index showed a dramatic increase in recent years, culminating in an unprecedented peak in 2023, whereas the French Polynesian index exhibited a prolonged, gradual decline over the same period. Similarly, the swordfish index in the west was characterized by significant peaks and troughs, which were absent from the flatter trend observed in French Polynesia.

The standardization process itself highlighted key drivers of catchability that differed between the two species. For swordfish, the inclusion of operational parameters had a substantial impact on the final index. Specifically, accounting for the number of hooks-between-floats (HBF) and the use of light sticks significantly dampened a large CPUE peak observed around 2010 in the western PICTs. The model confirmed that shallower gear configurations (lower HBF) and, most notably, the use of light sticks—which could increase the catch rate multiplier up to sixfold—were highly effective for targeting swordfish. This demonstrated that shifts in fishing practices could create apparent trends in abundance that were potentially artifacts of targeting behavior. The finding that swordfish CPUE was also correlated with cooler sea surface temperatures and La Niña-like conditions (negative NINA4 values) further illustrated the importance of separating environmental influences on availability from underlying abundance trends.

In contrast, the standardized CPUE trend for striped marlin in the western PICTs was largely insensitive to the inclusion of operational variables like bait type and light sticks. This suggest that the limited availability of these covariates in operational logbook data sets used for CPUE analysis are less of a concern for striped marlin compared to swordfish. The dominant feature—a sharp increase from 2019 to 2023—persisted even in the fully standardized model, suggesting it was not primarily an artifact of the operational factors examined. This recent increase was observed across all three western observer programs. It is also noteworthy that this recent increase is also observed in striped marlin longline and recreational CPUE indices from Australia and New Zealand respectively (Hamer 2025). The model did confirm that striped marlin catch rates were highest with shallower-set longlines (low HBF) and were positively associated with El Niño-like conditions (positive NINA4 values), an opposite environmental correlation to that of swordfish. The relationships between CPUE and the NINA4 index for both species warrant further investigation.

We recommend that SC21 note:

- The potential of observer data to provide improve longline CPUE abundance indices for billfish.
- The consistent recent strong increase in CPUE of striped marlin for New Caledonia, Tonga and Fiji, but not for French Polynesia.
- The general difference in CPUE patterns for both species between New Caledonia/Fiji/Tonga and French Polynesia.
- The value of the additional covariates available from observer data for CPUE standardisation, particularly for swordfish.
- The abundance indices developed for striped marlin and swordfish in this study can be considered for use in stock assessments.
- Further exploration of links between the NINA4 index and CPUE of swordfish and striped marlin is recommended
- The use of longline observer data could also be considered for development of abundance indices for tuna.

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6. REFERENCES

Hamer, P. (2025). *Summary report from the SPC Pre-assessment Workshop – April 2025*. WCPFC-SC21-2025/SA-IP-01 Report to the Western and Central Pacific Fisheries Commission Scientific Committee. Twenty-first Regular Session, 13–21 August 2025, Nuku'alofa, Tonga.

Hill-Moana, T.; Neubauer, P.; Large, K., & Brouwer, S. (2024). *Analysing potential inputs to the 2025 stock assessment of Western and Central Pacific oceanic whitetip shark (*Carcharhinus longimanus*)*. WCPFC-SC20-2024/SA-WP-11-Rev2. Report to the Western and Central Pacific Fisheries Commission Scientific Committee. Twentieth Regular Session,14–21 August 2024, Manila, Philippines. 174 p.

Neubauer, P.; Kim, K.; Large, K., & Brouwer, S. (2024). *Stock assessment of silky shark in the Western and Central Pacific Ocean 2024*. WCPFC-SC20-2024/SA-WP-04-Rev2. Report to the Western and Central Pacific Fisheries Commission Scientific Committee. Twentieth Regular Session,14–21 August 2024, Manila, Philippines. 131 p.

Tremblay-Boyer, L. & Neubauer, P. (2019). *Historical catch reconstruction and CPUE standardization for the stock assessment of oceanic whitetip shark in the Western and Central Pacific Ocean*. WCPFC-SC15-2019/SA-IP-17. Report to the Western and Central Pacific Fisheries Commission Scientific Committee. Fifteenth Regular Session, 12–20 August 2019, Pohnpei, Federated States of Micronesia

TABLES

Table 1: Mean hooks between floats (HBF), proportion of records with light-stick use (LS) and bait type recorded, and the resulting proportion of available records with both LS and Bait recorded.

Year	Mean HBF	LS records	Bait records	Available
1995	9.95	1.00	0.88	0.88
2001	20.95	0.98	0.77	0.74
2002	21.03	0.89	0.83	0.72
2003	21.59	0.89	0.90	0.79
2004	21.84	0.90	0.83	0.73
2005	19.04	0.88	0.86	0.75
2006	20.37	0.91	0.83	0.77
2007	19.36	0.92	0.85	0.77
2008	20.22	0.87	0.90	0.77
2009	21.02	0.82	0.90	0.74
2010	21.70	0.75	0.97	0.74
2011	19.91	0.69	0.94	0.65
2012	19.32	0.67	0.74	0.45
2013	21.48	0.71	0.61	0.34
2014	23.14	0.65	0.71	0.39
2015	23.03	0.49	0.88	0.41
2016	22.95	0.58	0.82	0.45
2017	21.71	0.60	0.95	0.60
2018	21.91	0.56	0.97	0.54
2019	22.17	0.59	0.98	0.57
2020	22.59	0.61	0.99	0.61
2021	22.24	0.67	1.00	0.67
2022	22.73	0.70	1.00	0.69
2023	22.61	0.73	0.99	0.72
2024	22.82	0.61	0.99	0.61

6.1 Swordfish models

6.1.1 No FP; no operational parameters

Table 2: Total number of records, effort (observed hooks), individuals caught and proportion of zero sets by year for the PICTs longline observer dataset for swordfish excluding French Polynesia and operational parameters (light sticks and bait).

Year	Records	Vessels	Effort	Mean catch	Total catch	P Zero
2001	5	2	214	0.00	0	1.00
2002	24	10	1848	0.67	16	0.62
2003	57	21	5813	0.93	53	0.54
2004	74	22	7470	0.96	71	0.55
2005	99	33	12222	0.99	98	0.52
2006	113	33	11976	1.11	125	0.50
2007	78	23	8317	0.56	44	0.59
2008	111	37	15080	1.78	198	0.49
2009	101	26	10536	0.81	82	0.58
2010	93	22	8694	1.84	171	0.59
2011	66	25	5939	1.00	66	0.50
2012	82	22	9298	2.09	171	0.52
2013	167	39	24497	1.58	264	0.46
2014	343	55	50693	1.35	462	0.48
2015	465	63	59420	0.97	450	0.59
2016	620	80	85457	0.75	463	0.60
2017	512	76	74126	0.89	454	0.62
2018	616	83	88850	0.77	477	0.62
2019	598	84	93972	0.89	534	0.57
2020	480	68	72368	1.03	493	0.55
2021	338	54	53642	0.88	297	0.60
2022	437	55	64310	0.91	396	0.60
2023	353	51	60713	0.79	280	0.59

6.1.2 No FP; with operational parameters

Table 3: Total number of records, effort (observed hooks), individuals caught and proportion of zero sets by year for the PICTs longline observer dataset for swordfish excluding French Polynesia and including operational parameters (light sticks and bait).

Year	Records	Vessels	Effort	Mean catch	Total catch	P Zero
2001	5	2	214	0.00	0	1.00
2002	24	10	1848	0.67	16	0.62
2003	57	21	5813	0.93	53	0.54
2004	73	22	7449	0.97	71	0.55
2005	99	33	12222	0.99	98	0.52
2006	113	33	11976	1.11	125	0.50
2007	78	23	8317	0.56	44	0.59
2008	111	37	15080	1.78	198	0.49
2009	94	26	9684	0.74	70	0.62
2010	43	12	3142	0.40	17	0.74
2011	16	8	1388	0.94	15	0.56
2012	14	5	2052	1.36	19	0.57
2013	29	10	4660	1.45	42	0.52
2014	131	29	24469	1.91	250	0.45
2015	397	55	52819	1.03	409	0.56
2016	346	58	50514	0.77	267	0.59
2017	290	58	41322	1.00	291	0.62
2018	343	65	49035	0.85	293	0.61
2019	232	51	32318	0.66	153	0.61
2020	226	47	29189	0.77	174	0.62
2021	170	42	25249	0.99	168	0.55
2022	283	43	39229	1.01	287	0.57
2023	218	39	41797	0.96	210	0.53

6.2 Striped marlin models

6.2.1 No FP; no operational parameters

Table 4: Total number of records, effort (observed hooks), individuals caught and proportion of zero sets by year for the PICTs longline observer dataset for striped marlin excluding French Polynesia and operational parameters (light sticks and bait).

Year	Records	Vessels	Effort	Mean catch	Total catch	P Zero
2001	5	2	214	0.20	1	0.80
2002	24	10	1848	0.96	23	0.58
2003	57	21	5813	0.84	48	0.63
2004	74	22	7470	0.53	39	0.70
2005	99	33	12222	0.54	53	0.75
2006	113	33	11976	0.77	87	0.62
2007	78	23	8317	0.91	71	0.59
2008	111	37	15080	1.35	150	0.54
2009	101	26	10536	1.01	102	0.57
2010	93	22	8694	1.35	126	0.49
2011	66	25	5939	1.09	72	0.62
2012	82	22	9298	1.80	148	0.52
2013	167	39	24497	1.35	225	0.56
2014	343	55	50693	1.45	496	0.60
2015	465	63	59420	0.95	443	0.64
2016	620	80	85457	1.08	670	0.62
2017	512	76	74126	0.90	462	0.65
2018	616	83	88850	0.74	457	0.68
2019	598	84	93972	1.41	841	0.58
2020	480	68	72368	0.93	444	0.58
2021	338	54	53642	1.80	609	0.49
2022	437	55	64310	1.47	643	0.51
2023	353	51	60713	4.17	1473	0.37

6.2.2 No FP; with operational parameters

Table 5: Total number of records, effort (observed hooks), individuals caught and proportion of zero sets by year for the PICTs longline observer dataset for striped marlin excluding French Polynesia and including operational parameters (light sticks and bait).

Year	Records	Vessels	Effort	Mean catch	Total catch	P Zero
2001	5	2	214	0.20	1	0.80
2002	24	10	1848	0.96	23	0.58
2003	57	21	5813	0.84	48	0.63
2004	73	22	7449	0.49	36	0.71
2005	99	33	12222	0.54	53	0.75
2006	113	33	11976	0.77	87	0.62
2007	78	23	8317	0.91	71	0.59
2008	111	37	15080	1.35	150	0.54
2009	94	26	9684	1.06	100	0.56
2010	43	12	3142	0.81	35	0.56
2011	16	8	1388	0.75	12	0.62
2012	14	5	2052	0.71	10	0.57
2013	29	10	4660	0.62	18	0.76
2014	131	29	24469	2.33	305	0.47
2015	397	55	52819	1.00	398	0.63
2016	346	58	50514	1.04	359	0.61
2017	290	58	41322	0.72	209	0.69
2018	343	65	49035	0.60	207	0.71
2019	232	51	32318	1.00	231	0.63
2020	226	47	29189	0.69	156	0.68
2021	170	42	25249	1.44	244	0.56
2022	283	43	39229	1.38	391	0.51
2023	218	39	41797	5.42	1182	0.33

FIGURES

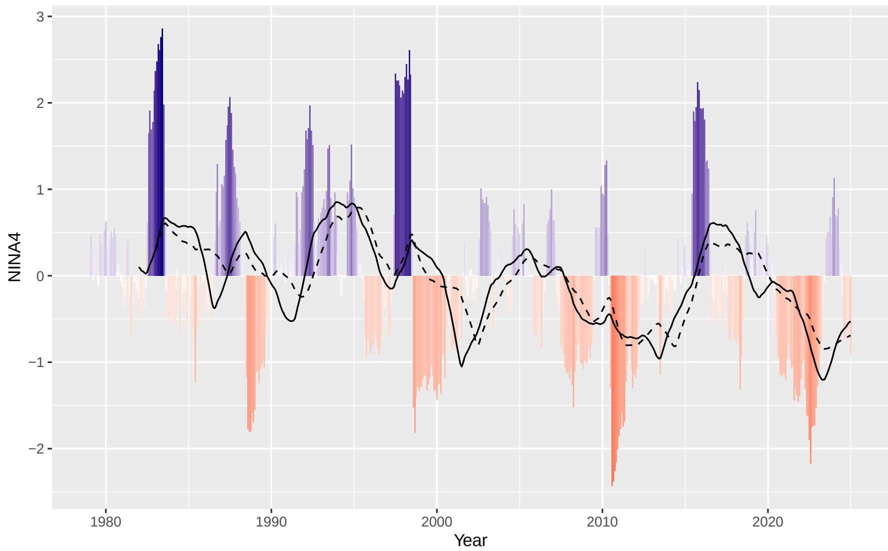

Figure 1: NINA4 index by year-month and 36 month (solid line) and 48 month (dashed line) lagged moving average time-series.

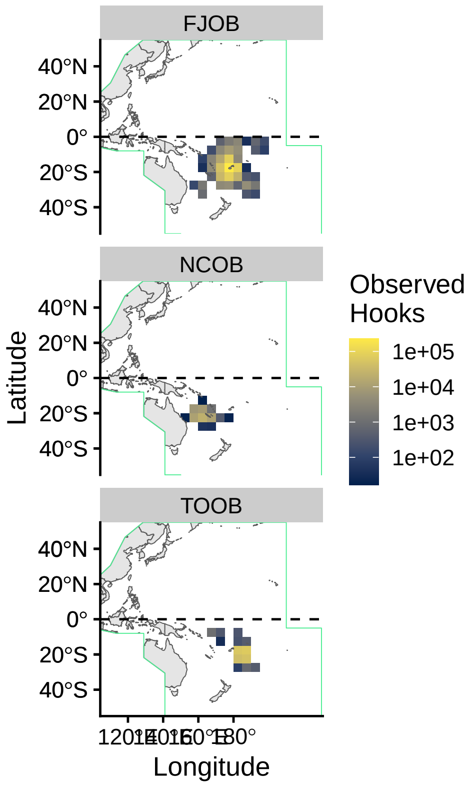

Figure 2: Spatial distribution of observed effort (hooks) for the PICTs longline observer dataset for swordfish excluding French Polynesia.

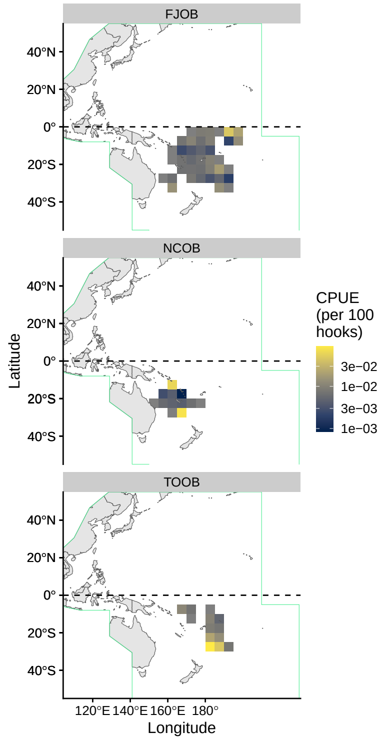

Figure 3: Spatial distribution of observed (nominal) catch-rates for the PICTs longline observer dataset for swordfish excluding French Polynesia.

6.3 Swordfish models

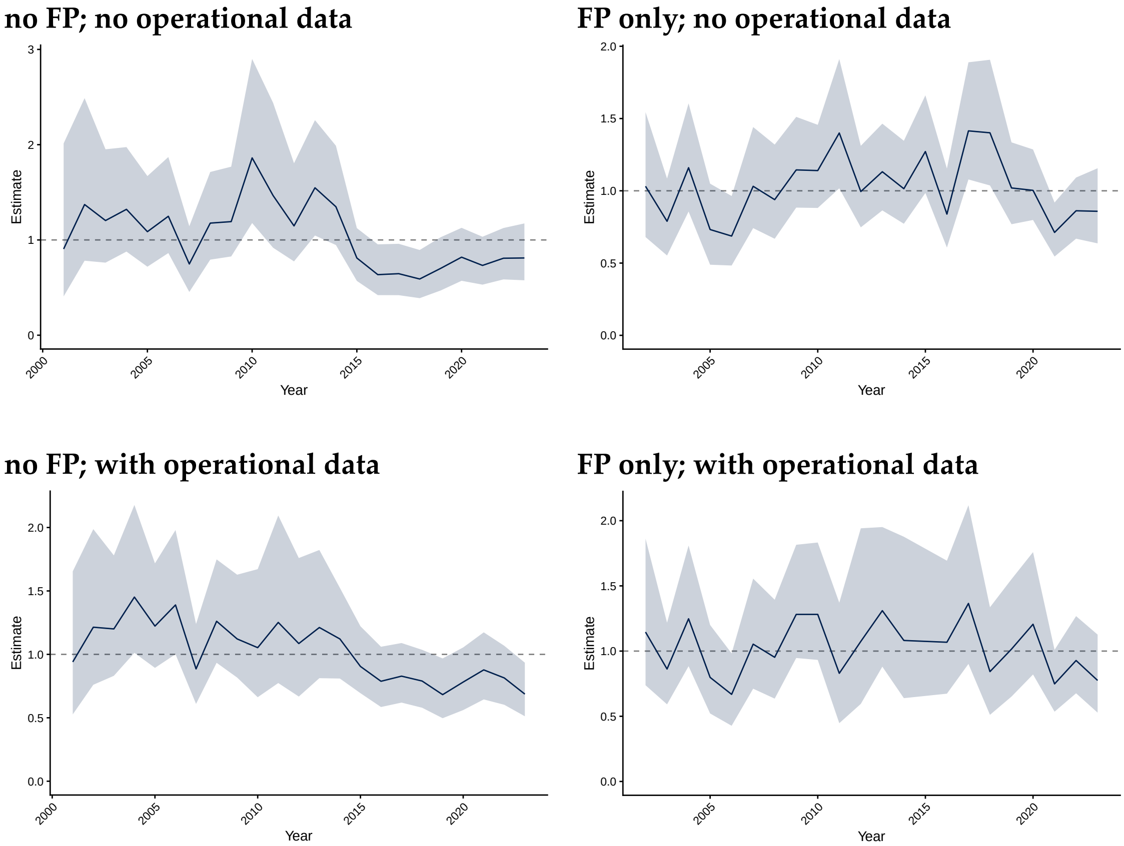

Figure 4: Standardised longline CPUE for swordfish across four distinct data-sets; splitting French Polynesia (FP) observer data from other observer datasets (New Caledonia; Fiji; Tonga), either using operational data or not. Shown is the posterior median and 95% credible interval for the year effect (standardised to a geometric mean of one), standardised for regional trends, operational and environmental variables.

6.3.1 No FP; no operational parameters

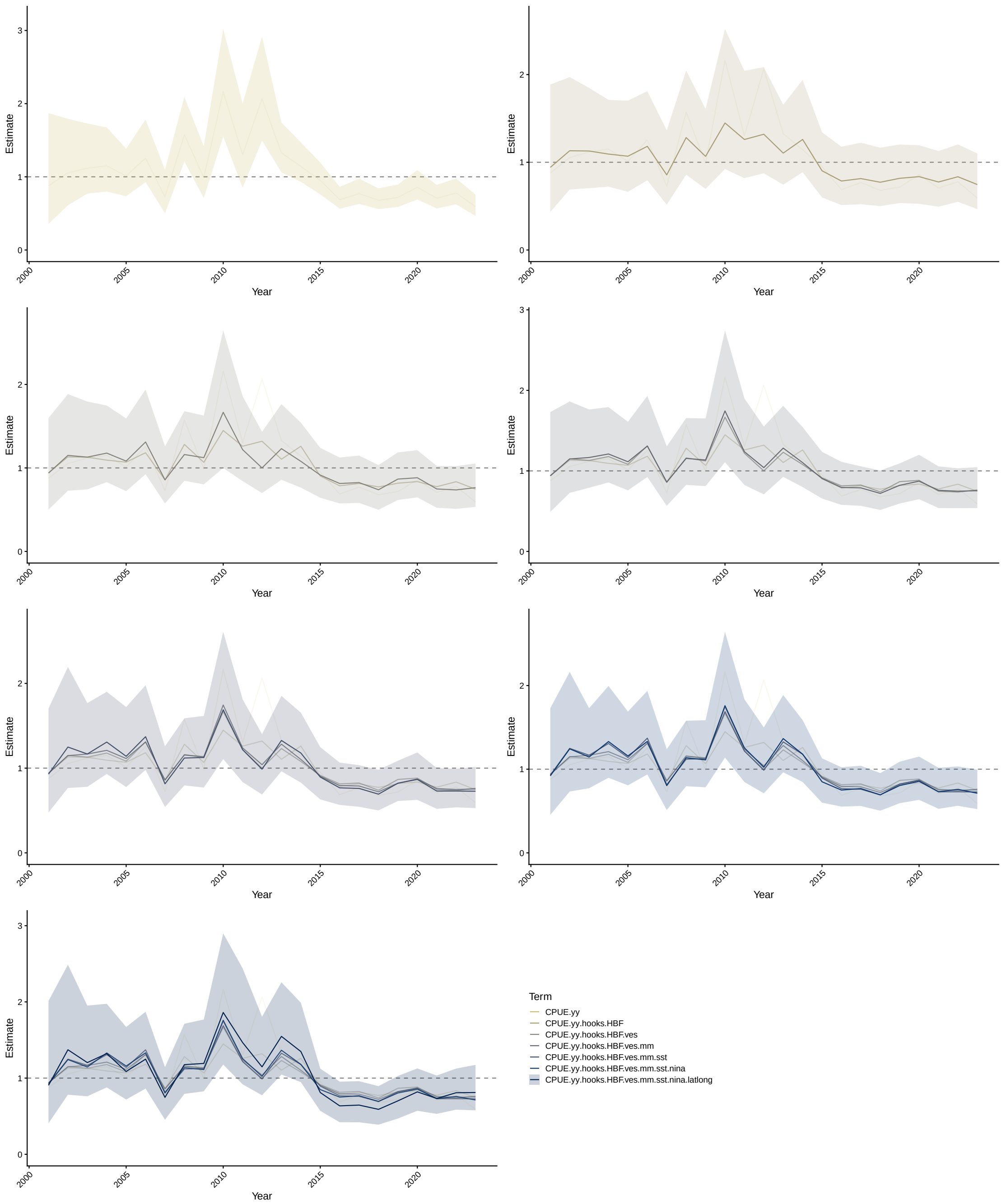

Figure 5: CPUE standardisation effects for the PICTs longline observer dataset for swordfish excluding French Polynesia and excluding operational parameters other than hooks between floats. Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

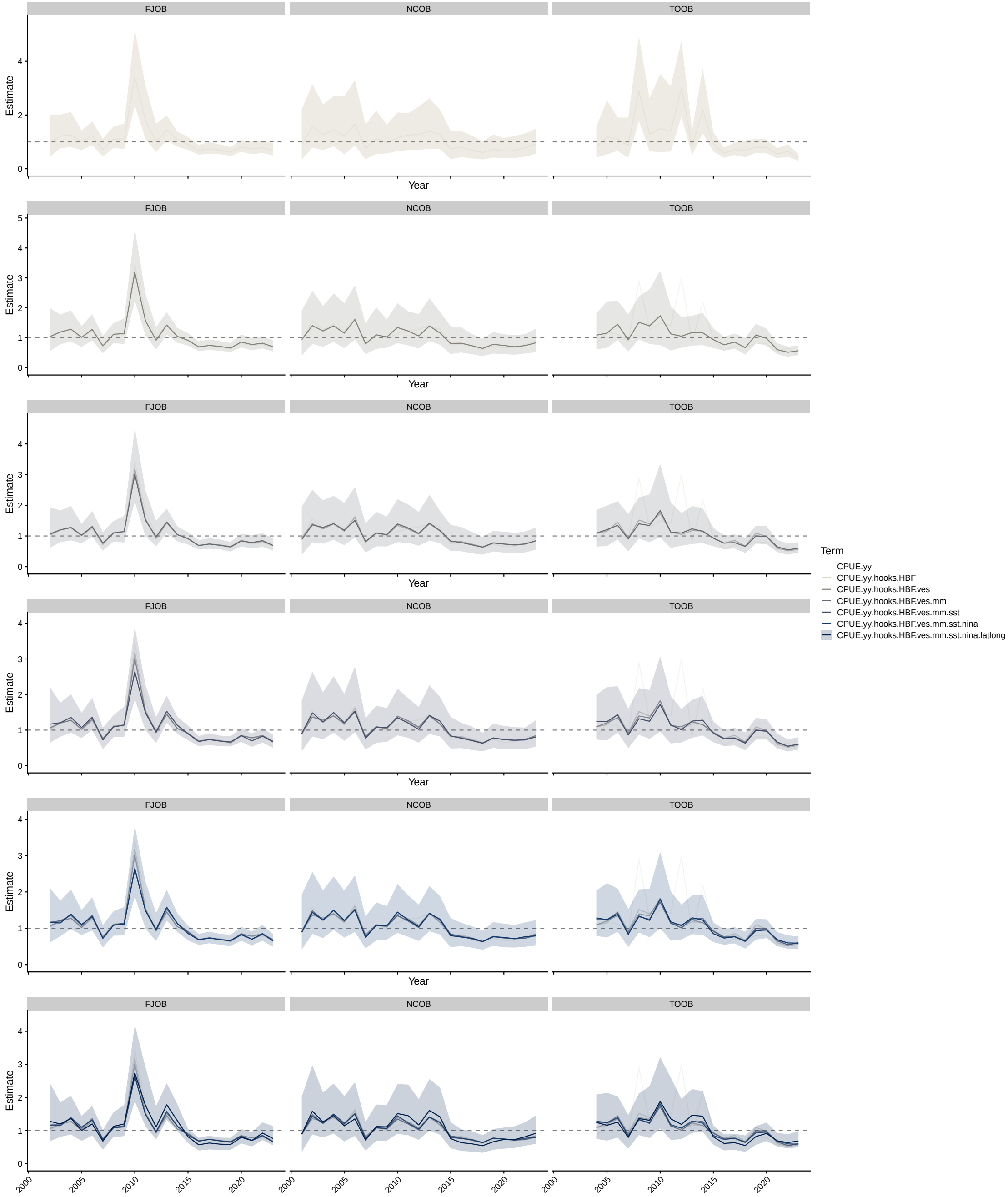

Figure 6: Longline CPUE standardisation effects by observer-prog for the PICTs longline observer dataset for swordfish excluding French Polynesia and excluding operational parameters other than hooks between floats. Each row of plots corresponds to the addition of a variable, starting with a model that includes observer-prog-year catch. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

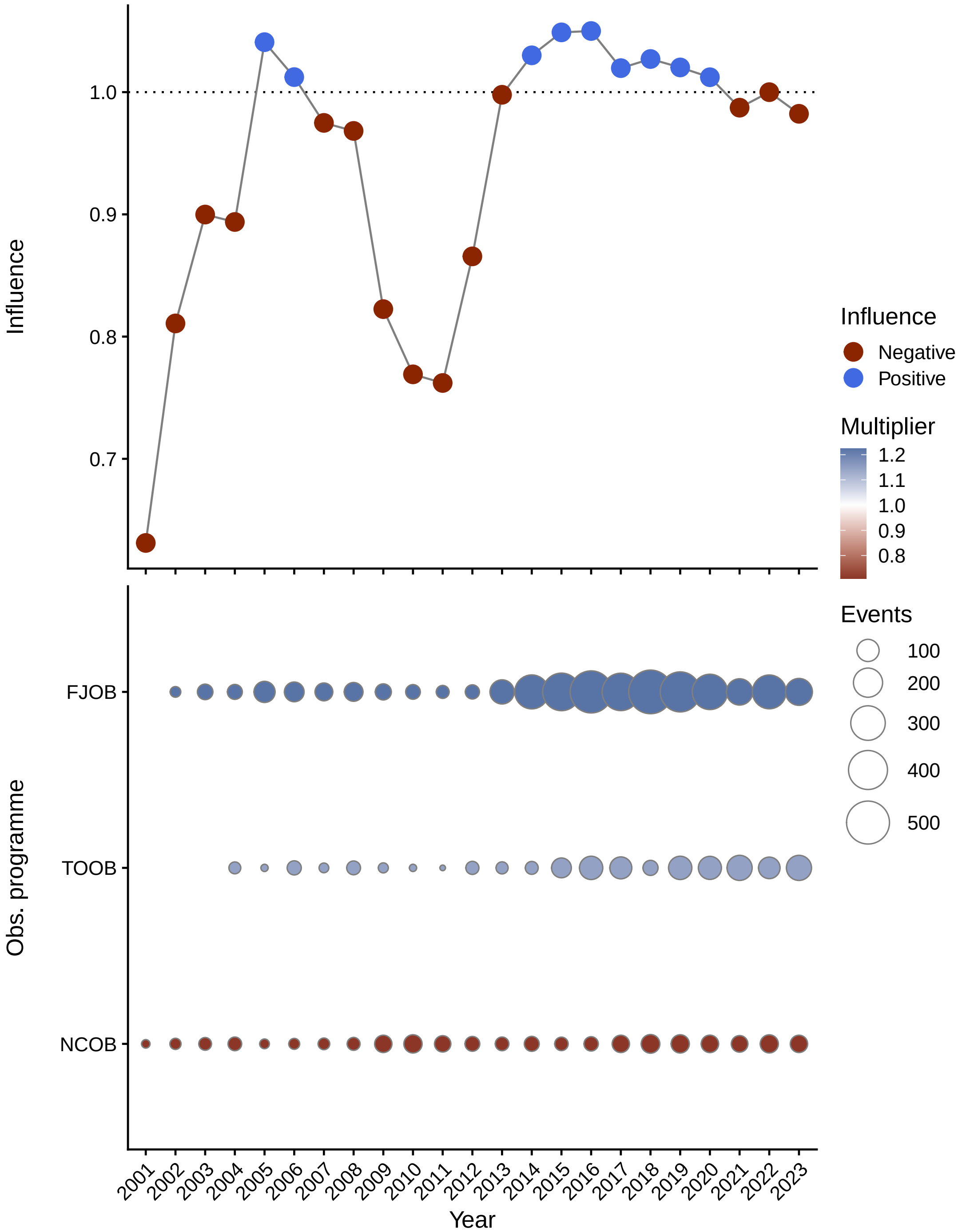

Figure 7: Influence of observer program on catch-rates of swordfish the PICTs longline observer data-set excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

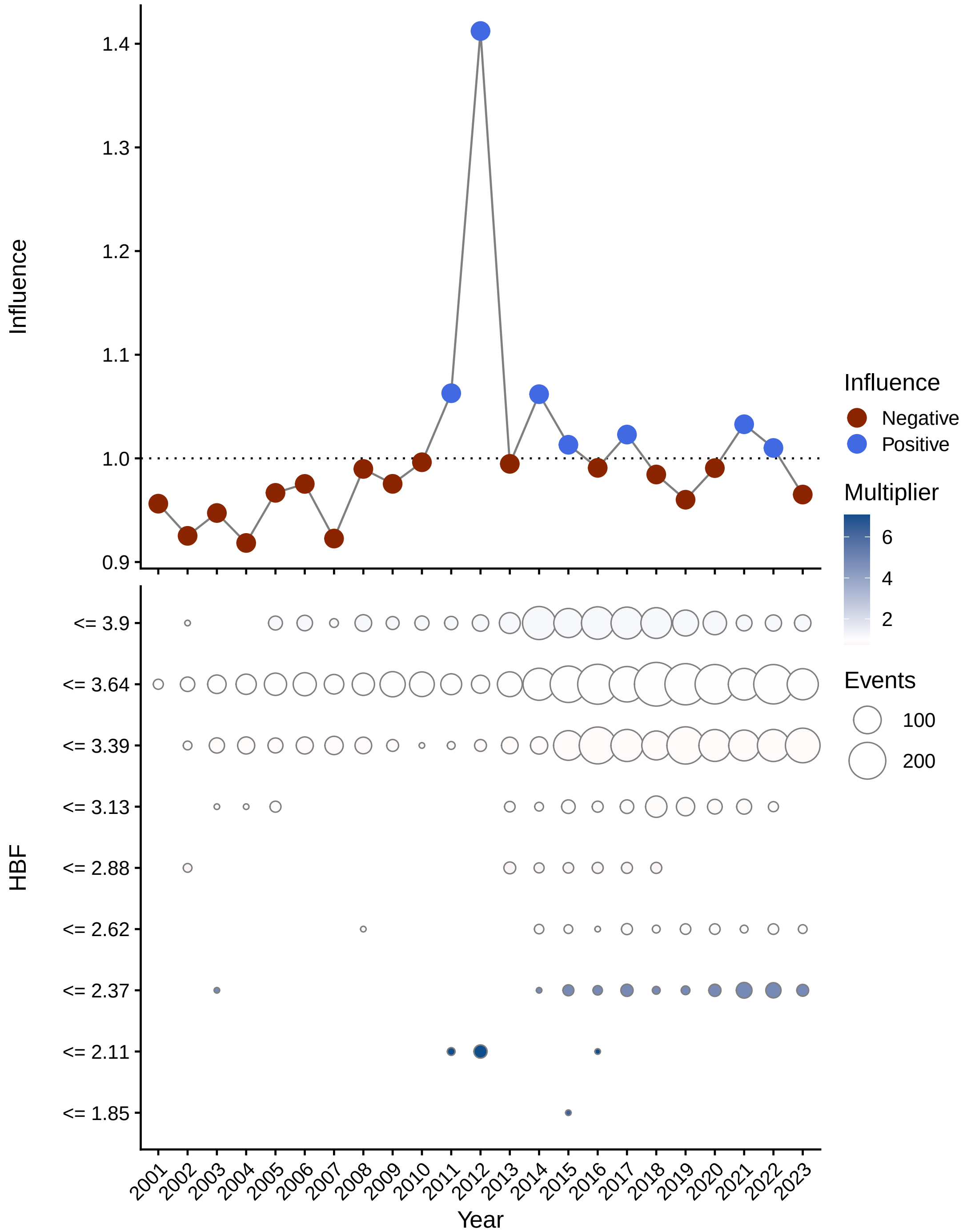

Figure 8: Influence of hooks-between-floats (HBF) on catch-rates of swordfish for the PICTs longline observer dataset excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

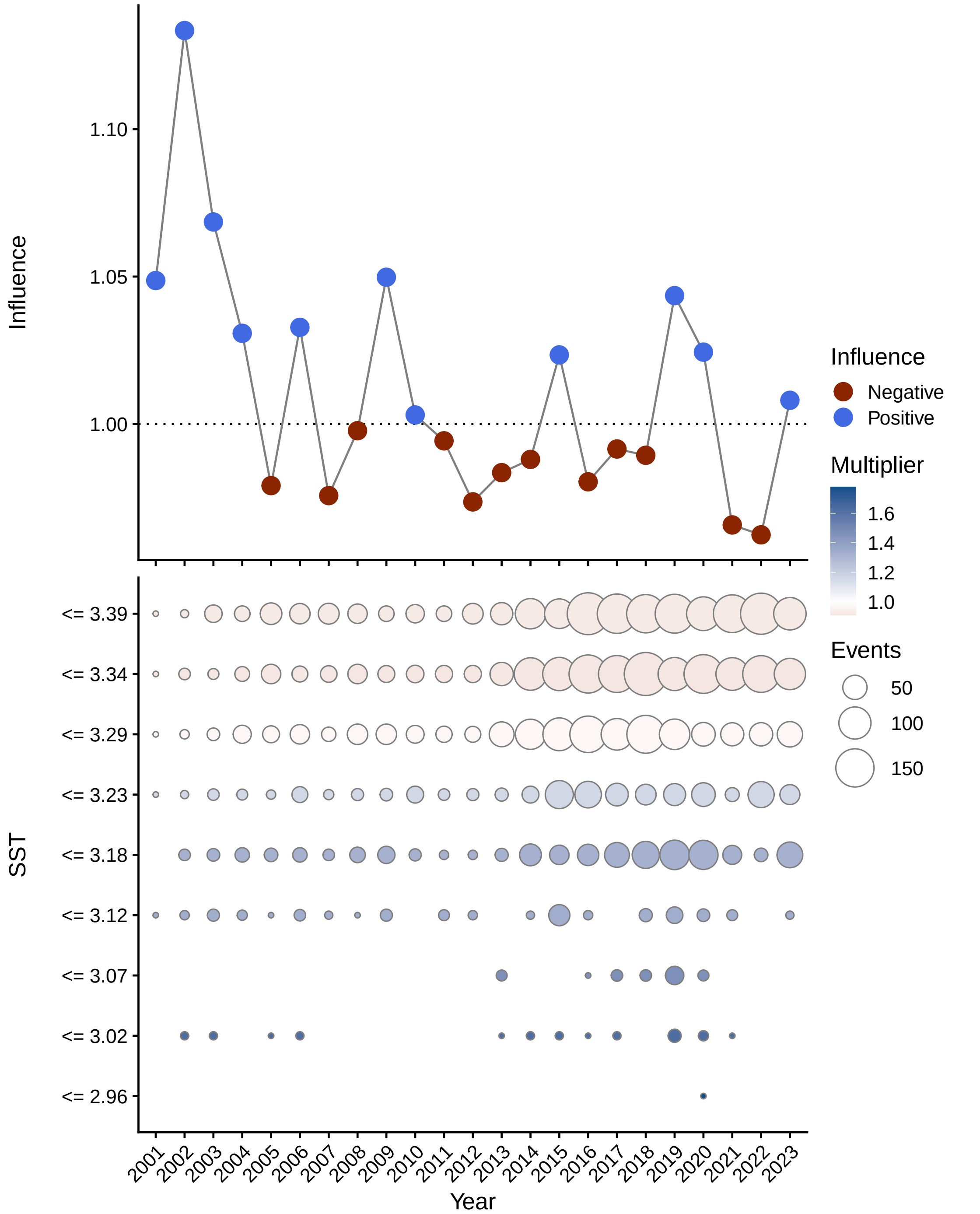

Figure 9: Influence of (log-transformed) SST on catch-rates of swordfish for the PICTs longline observer dataset excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

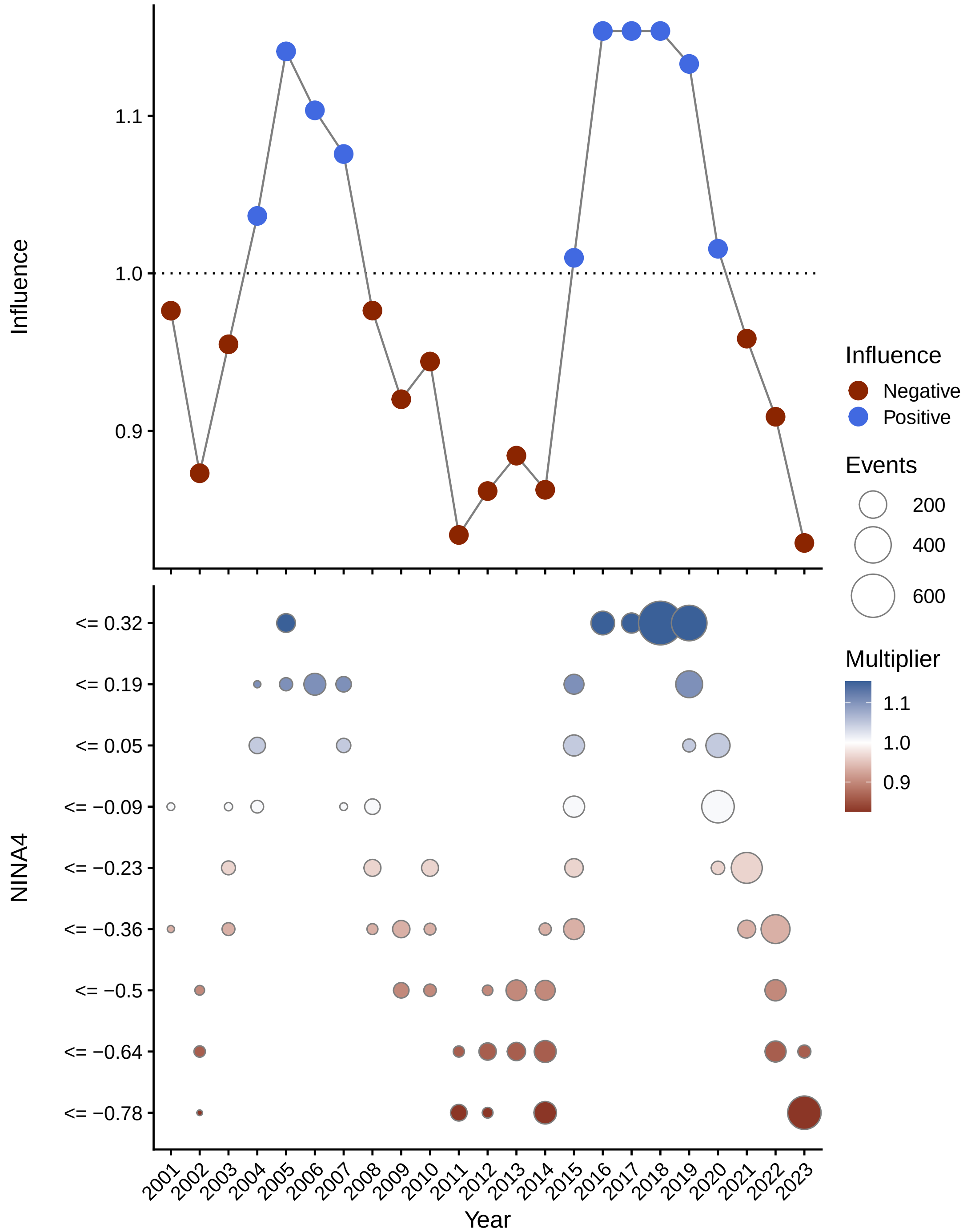

Figure 10: Influence of NINA4 index on catch - rates of swordfish for the PICTs longline observer data - set excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over - all catch - rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

6.3.2 No FP; with operational parameters

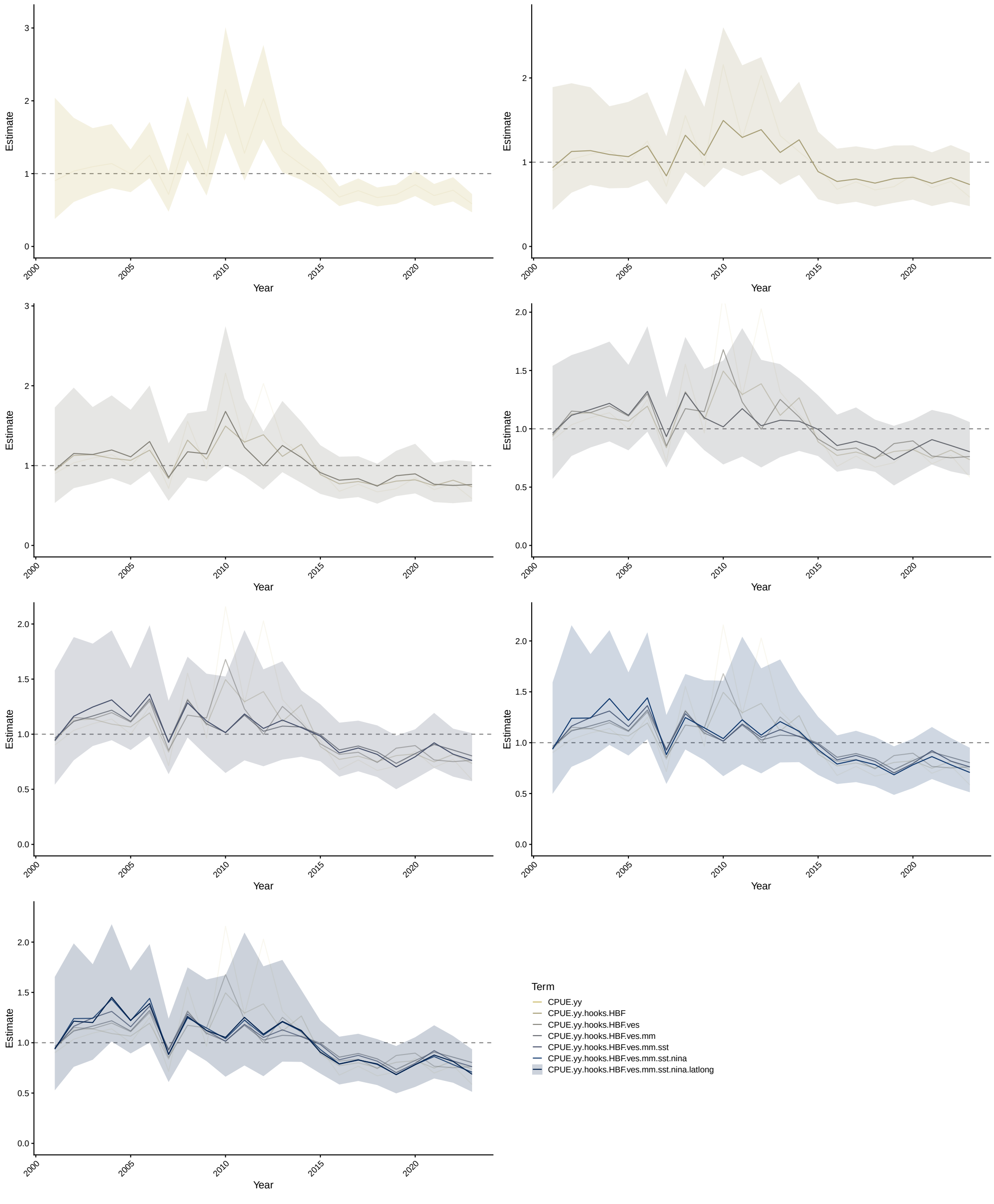

Figure 11: CPUE standardisation effects for the PICTs longline observer dataset for swordfish excluding French Polynesia and including light sticks and bait in addition to hooks between floats (HBF; added with HBF in the corresponding step). Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

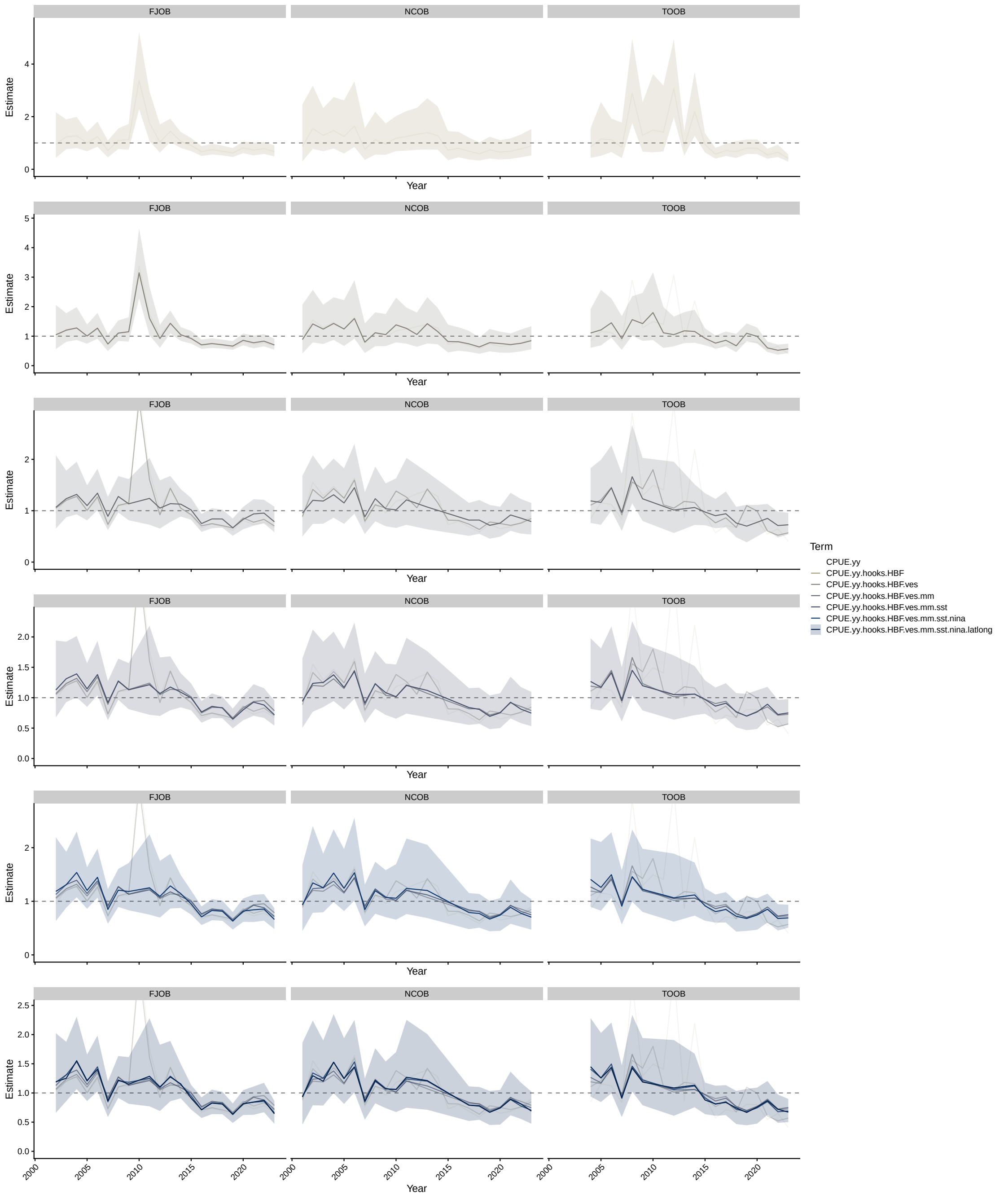

Figure 12: Longline CPUE standardisation effects by observer-prog for the PICTs longline observer dataset for swordfish excluding French Polynesia and including light sticks and bait in addition to hooks between floats (HBF; added with HBF in the corresponding step). Each row of plots corresponds to the addition of a variable, starting with a model that includes observer-prog-year catch. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

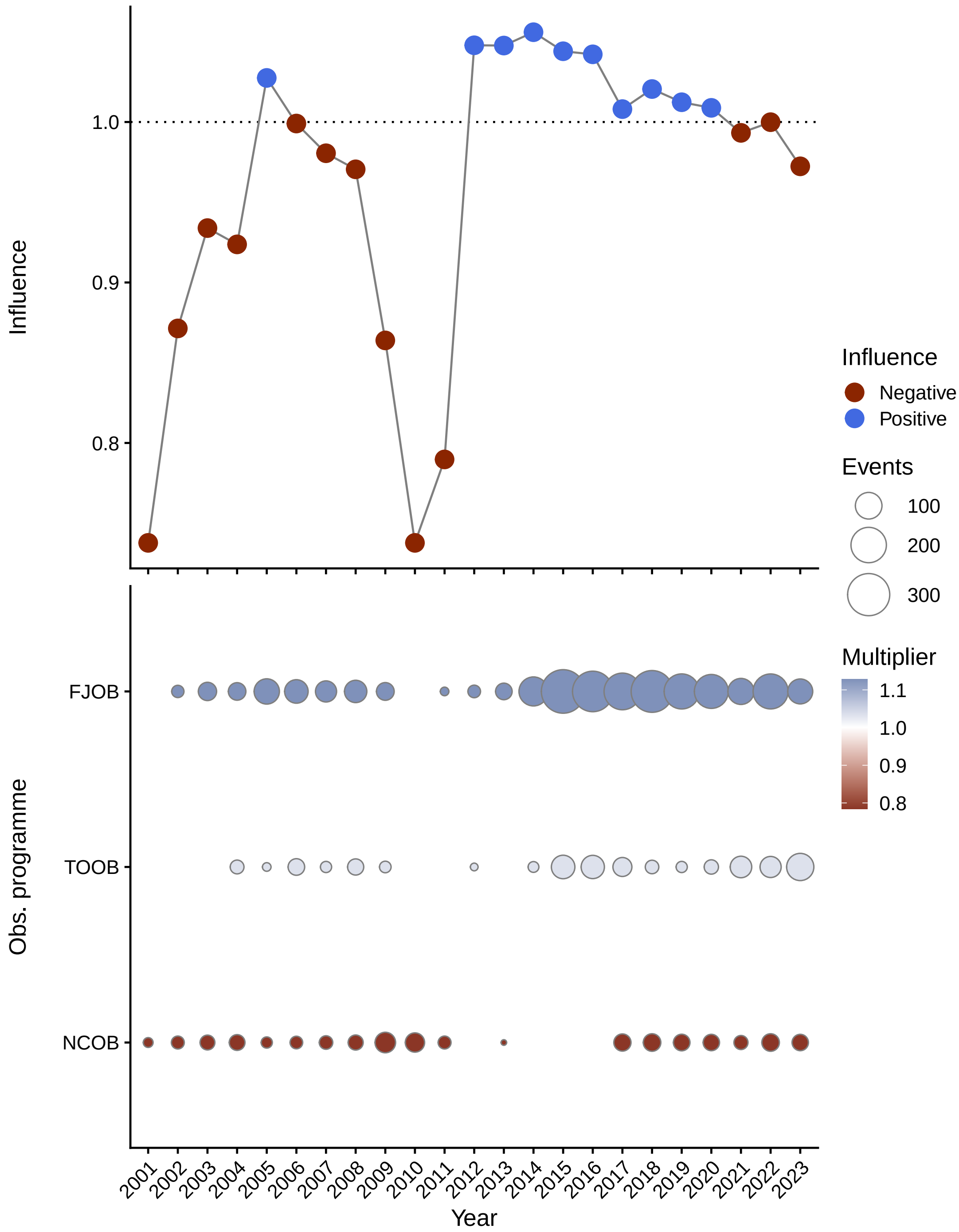

Figure 13: Influence of observer program on catch-rates of swordfish the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

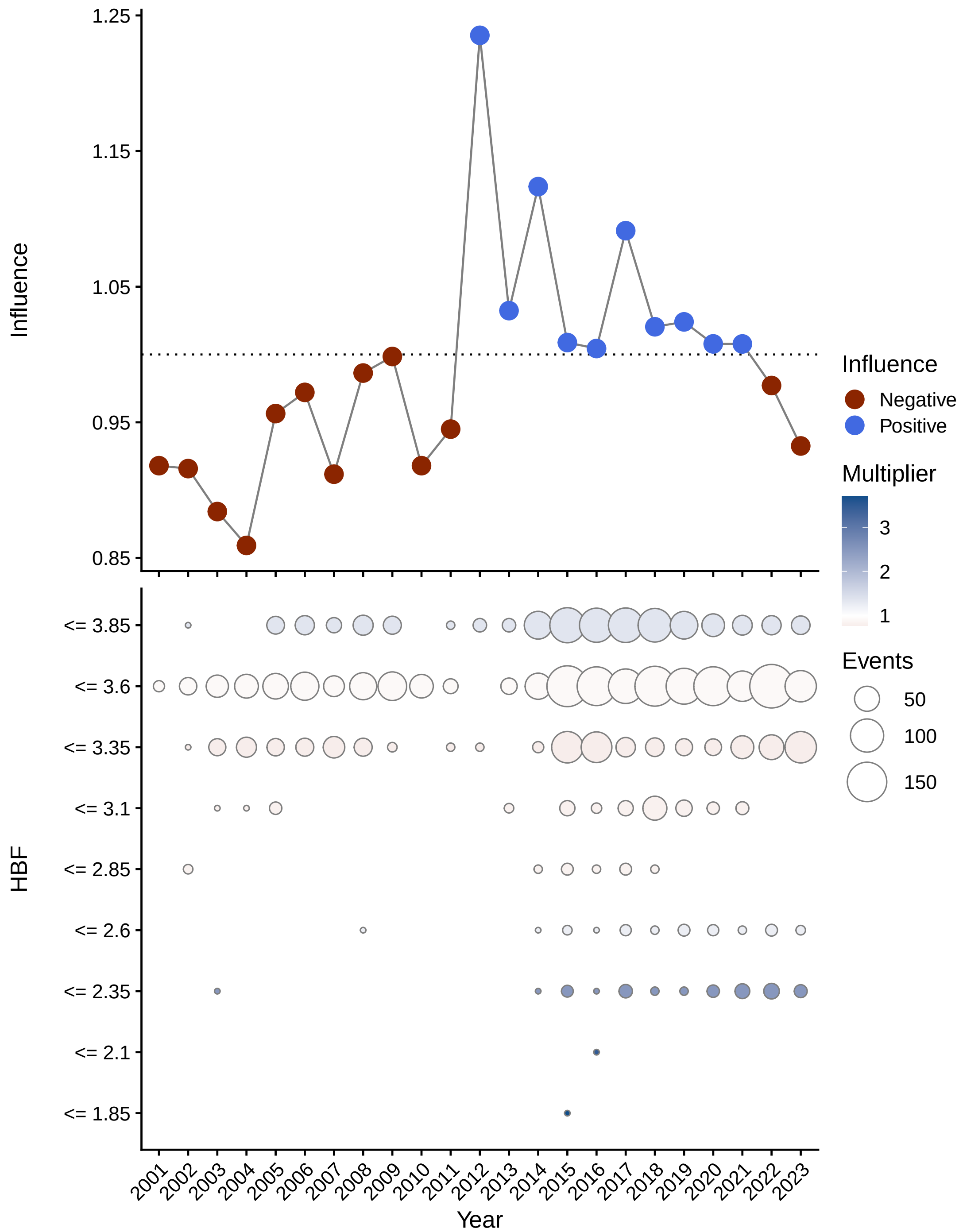

Figure 14: Influence of hooks-between-floats (HBF) on catch-rates of swordfish for the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

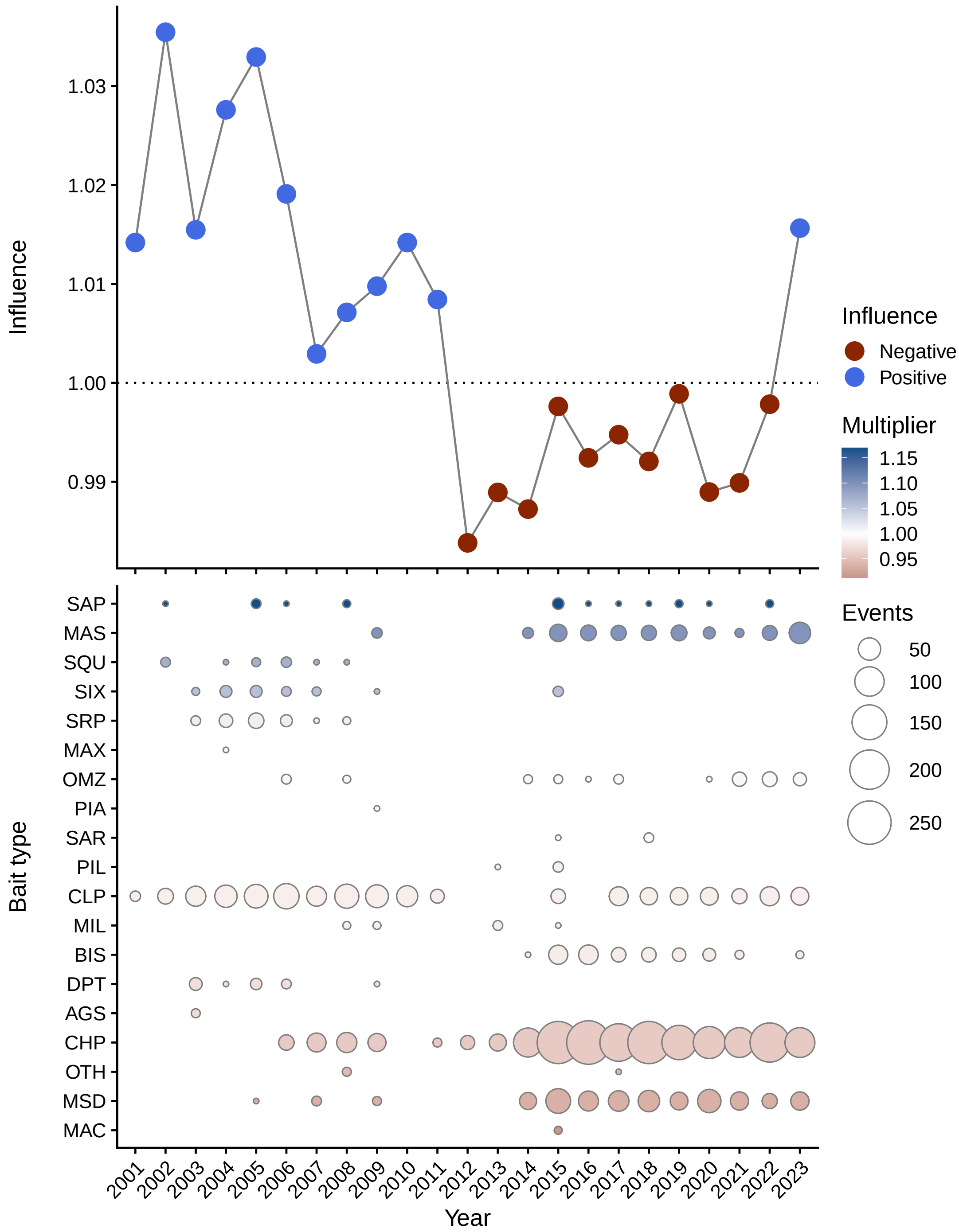

Figure 15: Influence of bait types on catch-rates of swordfish for the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

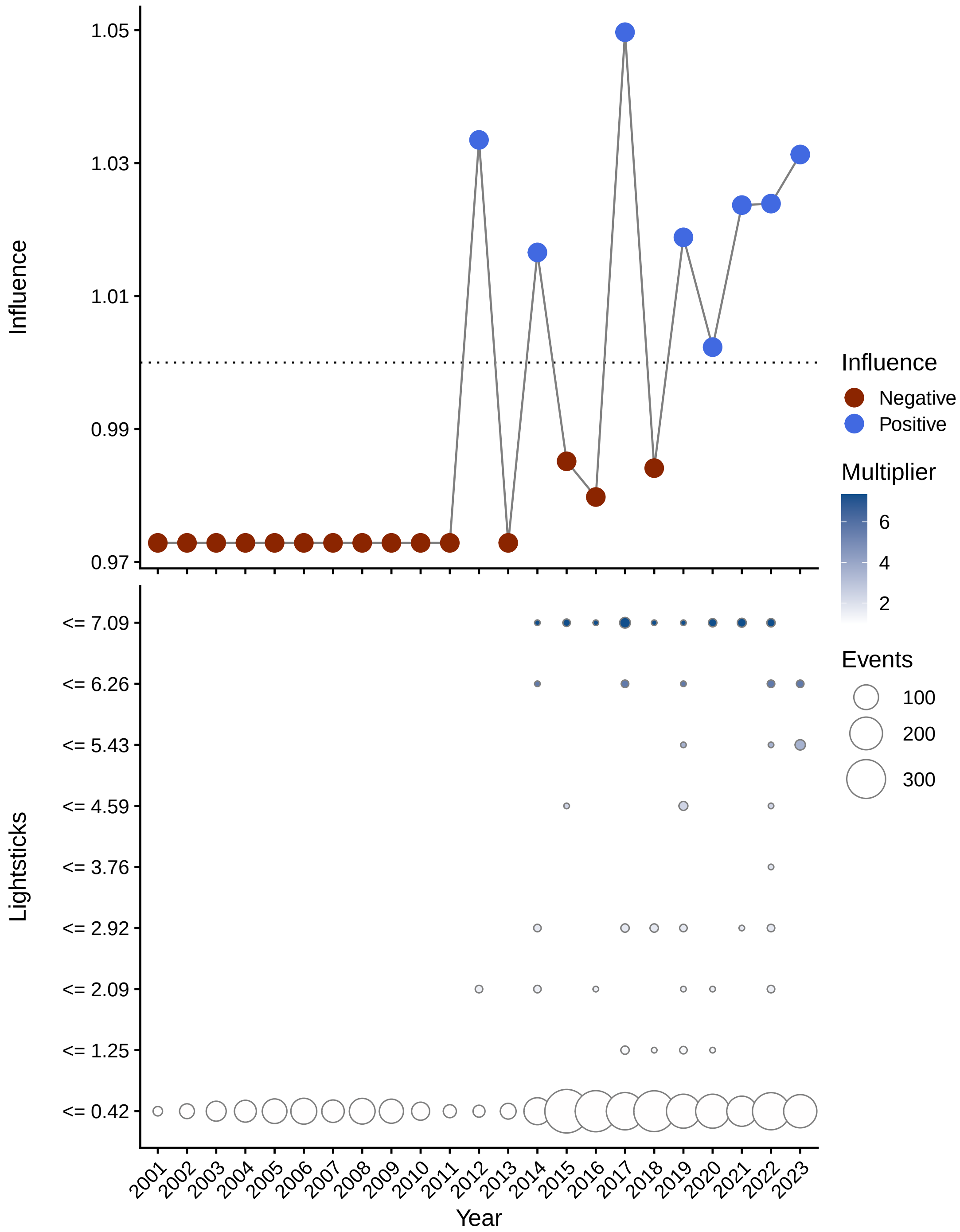

Figure 16: Influence of light sticks on catch - rates of swordfish for the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over - all catch - rate in the model was standardised downward by the corresponding amount to account for influencesof covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

6.4 Striped marlin models

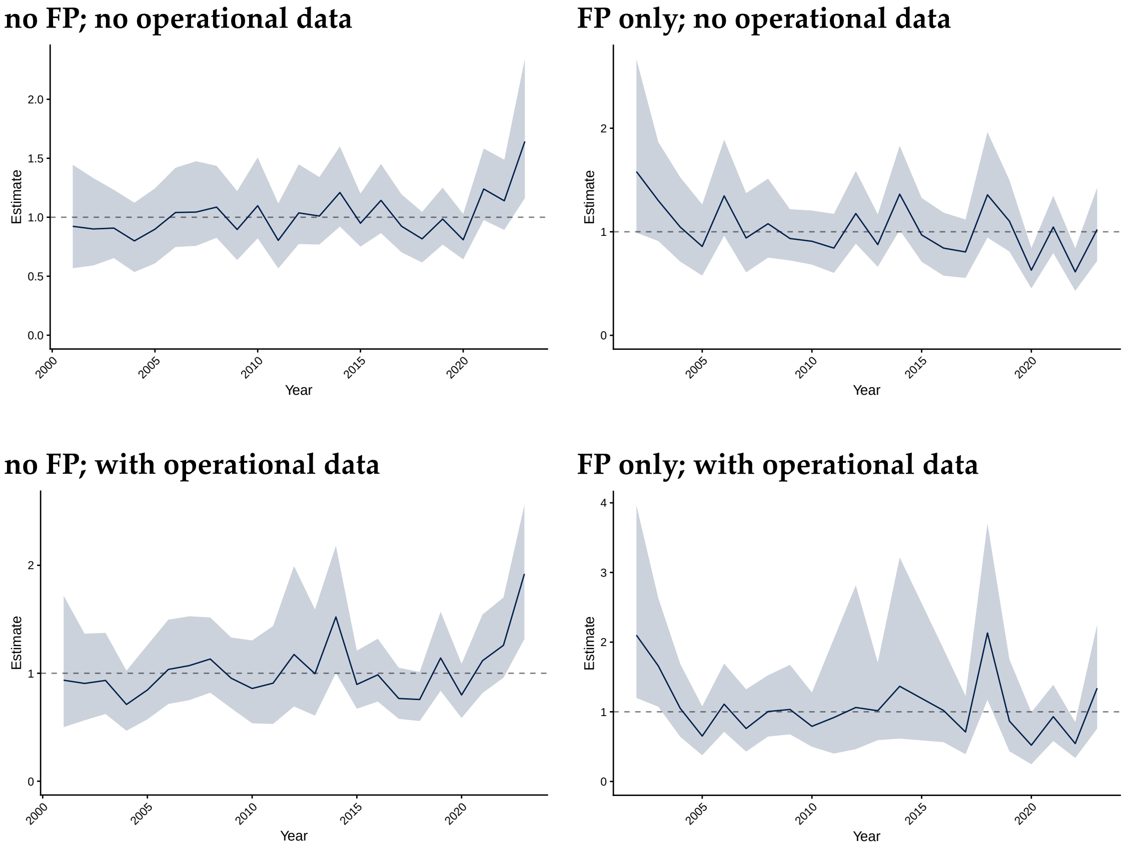

Figure 17: Longline CPUE for striped marlin across four distinct data-sets; splitting French Polynesia (FP) observer data from other observer datasets (New Caledonia; Fiji; Tonga), either using operational data or not. Shown is the posterior median and 95% credible interval for the year effect, standardised for regional trends, operational and environmental variables.

6.4.1 No FP; no operational parameters

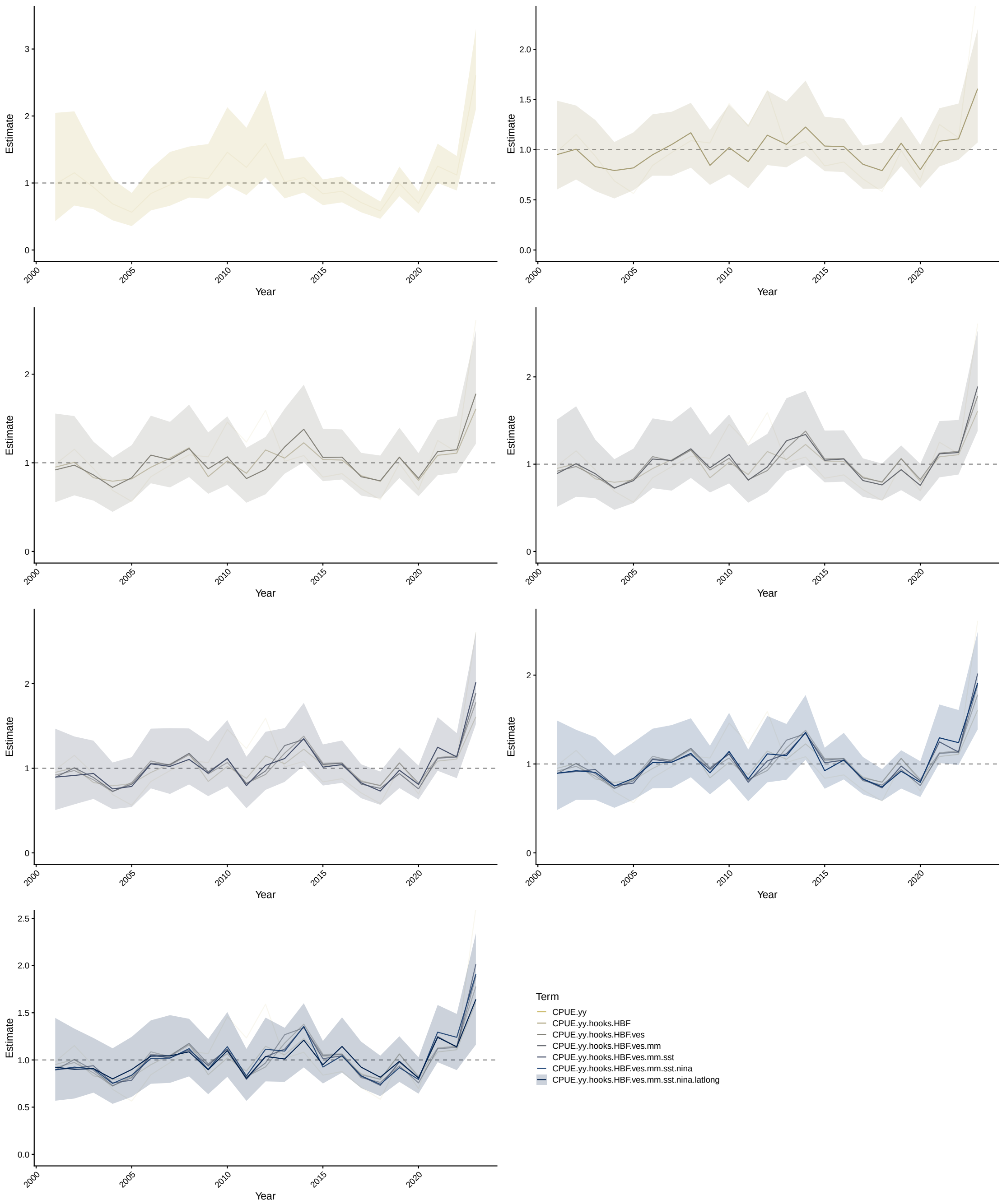

Figure 18: CPUE standardisation effects for the PICTs longline observer dataset for striped marlin excluding French Polynesia and excluding operational parameters other than hooks between floats. Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

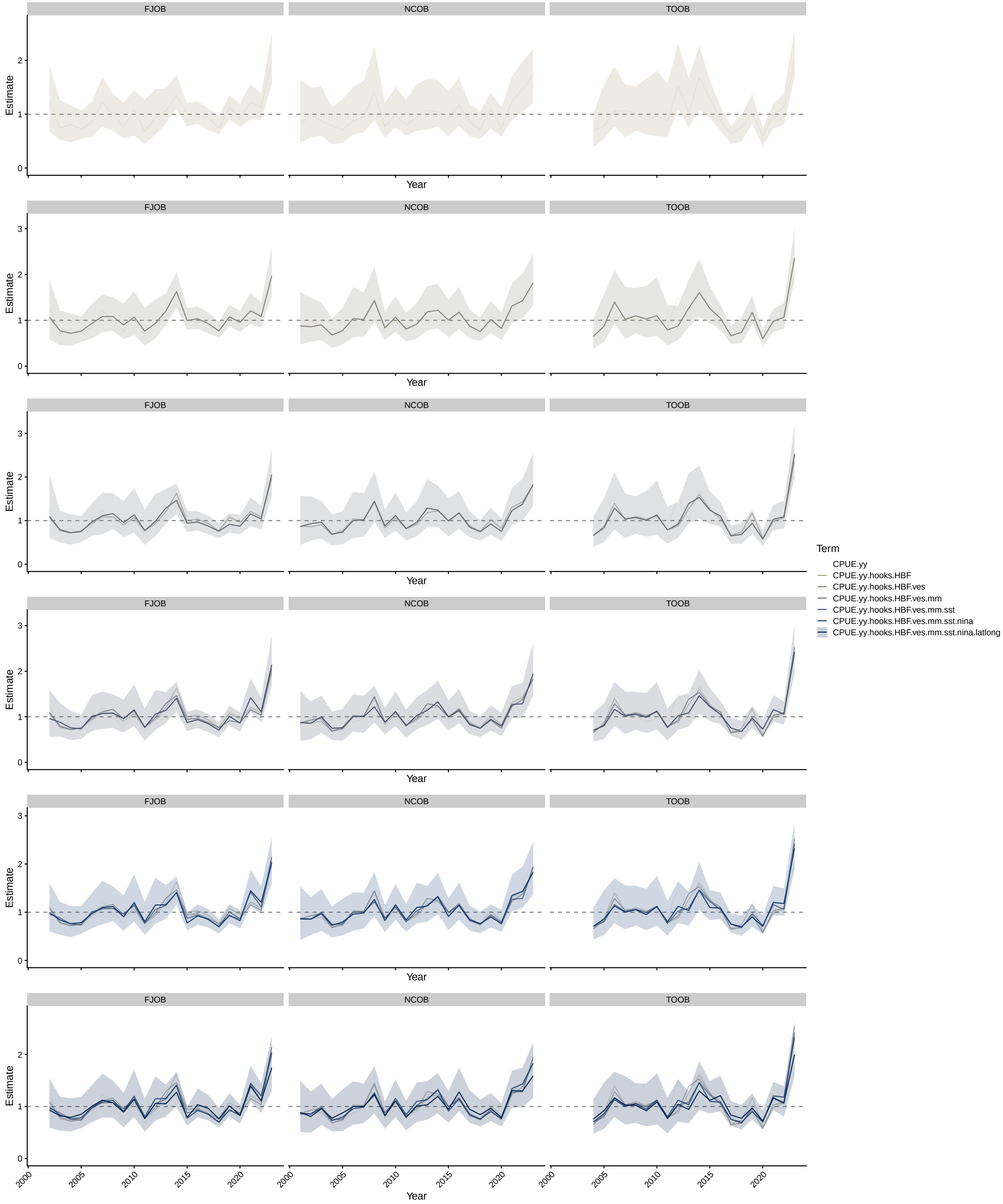

Figure 19: Longline CPUE standardisation effects by observer-prog for the PICTs longline observer dataset for striped marlin excluding French Polynesia and excluding operational parameters other than hooks between floats. Each row of plots corresponds to the addition of a variable, starting with a model that includes observer-prog-year catch. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

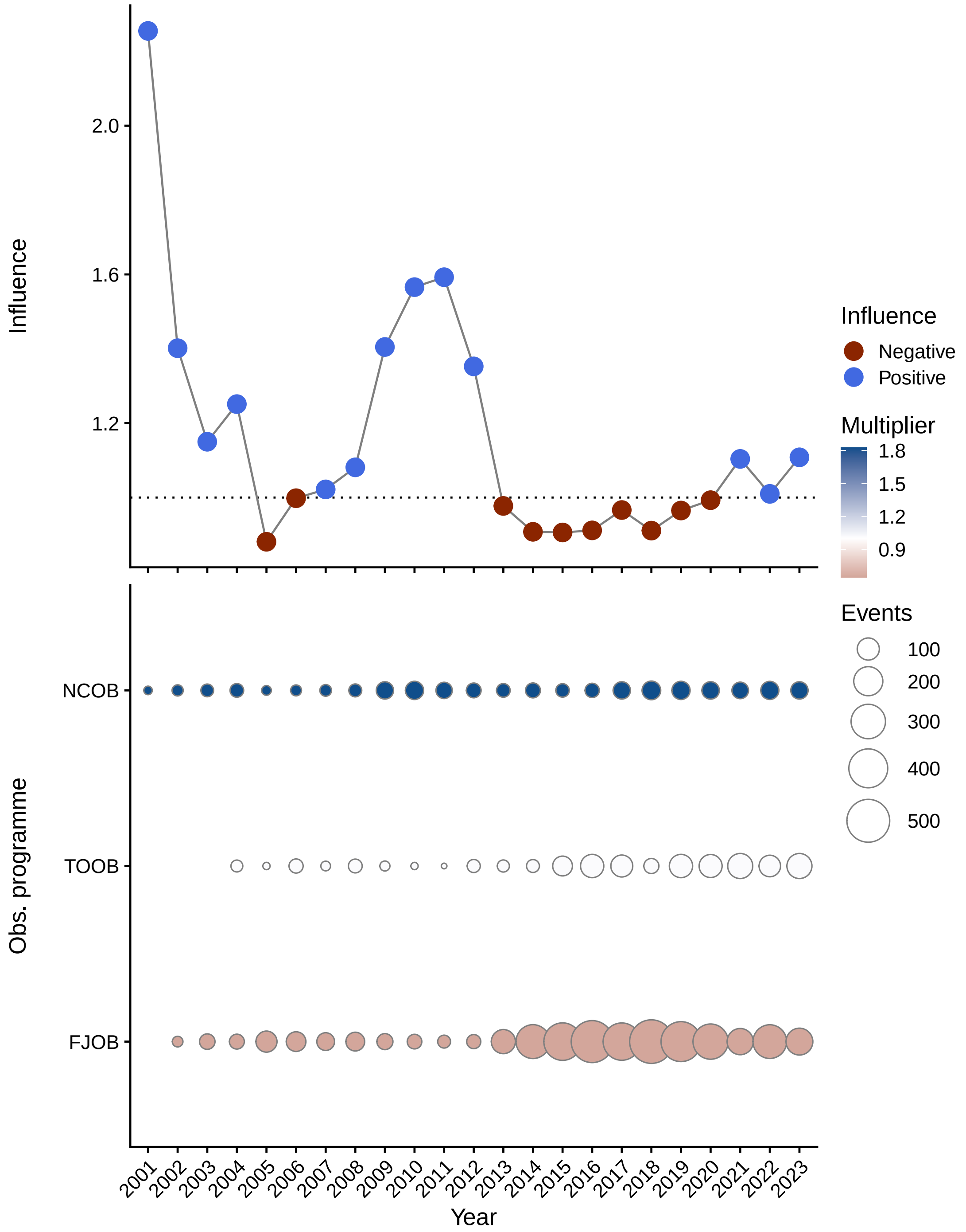

Figure 20: Influence of observer program on catch-rates of striped marlin the PICTs longline observer dataset excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

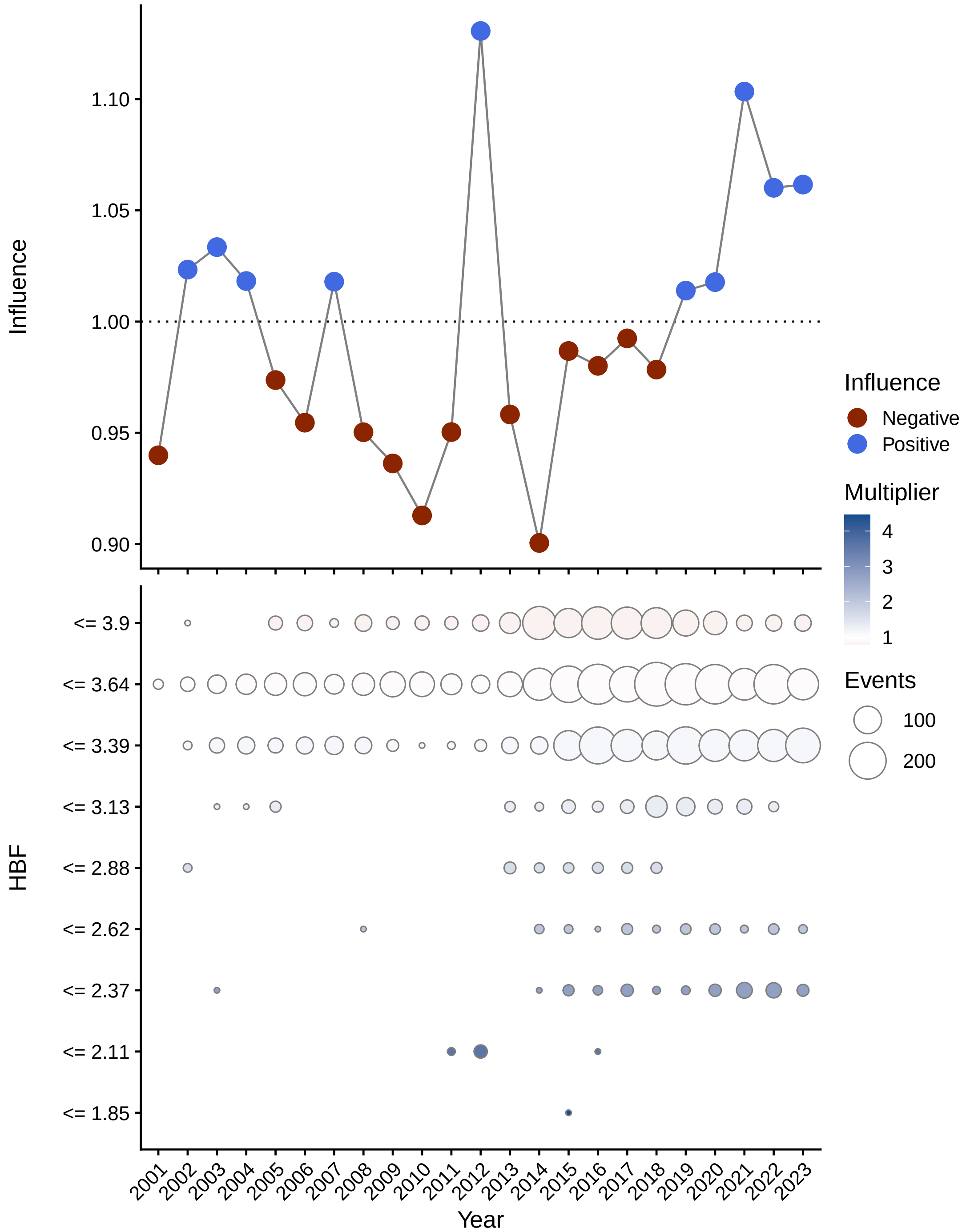

Figure 21: Influence of hooks-between-floats (HBF) on catch-rates of striped marlin for the PICTs longline observer dataset excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

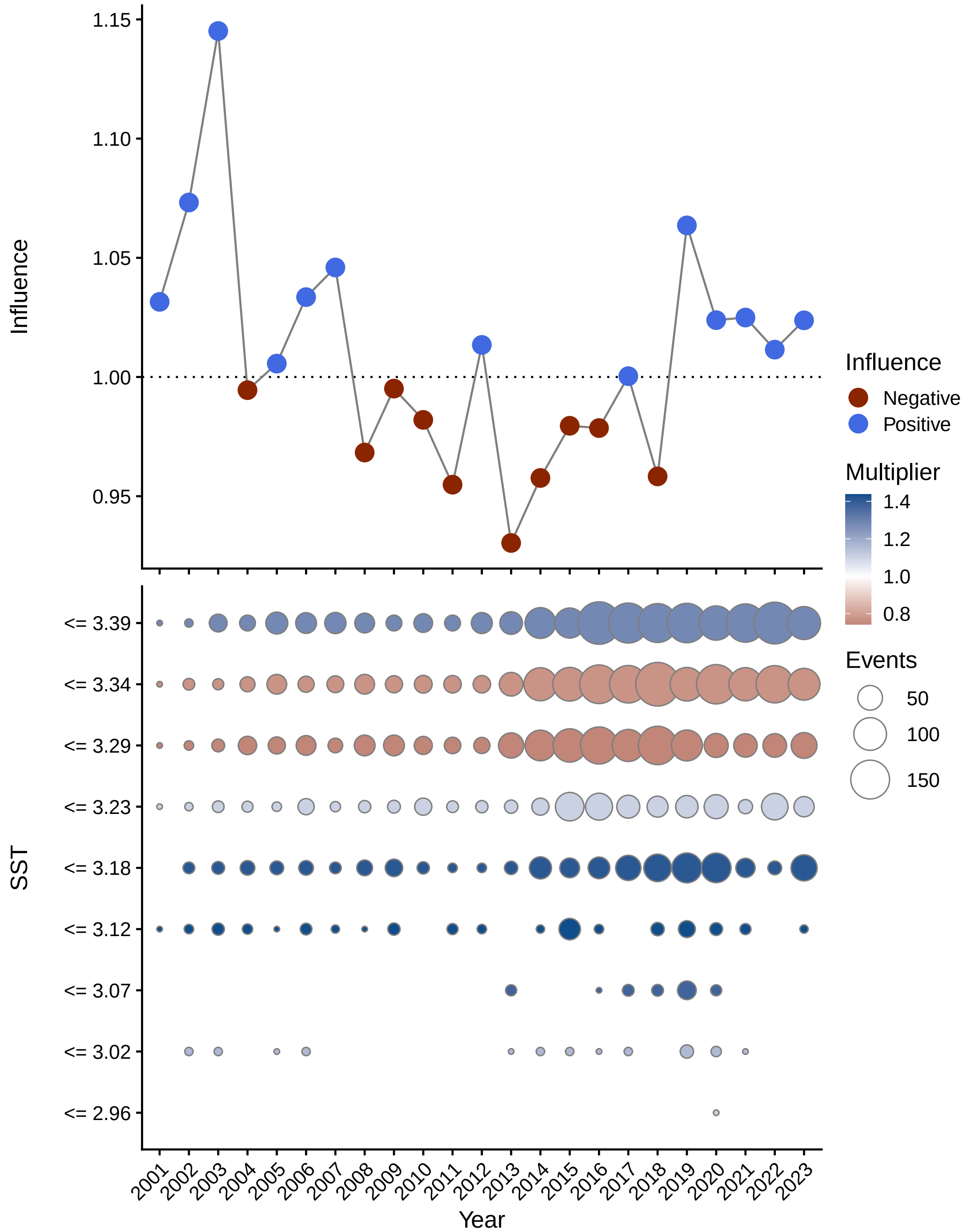

Figure 22: Influence of SST on catch-rates of striped marlin for the PICTs longline observer dataset excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

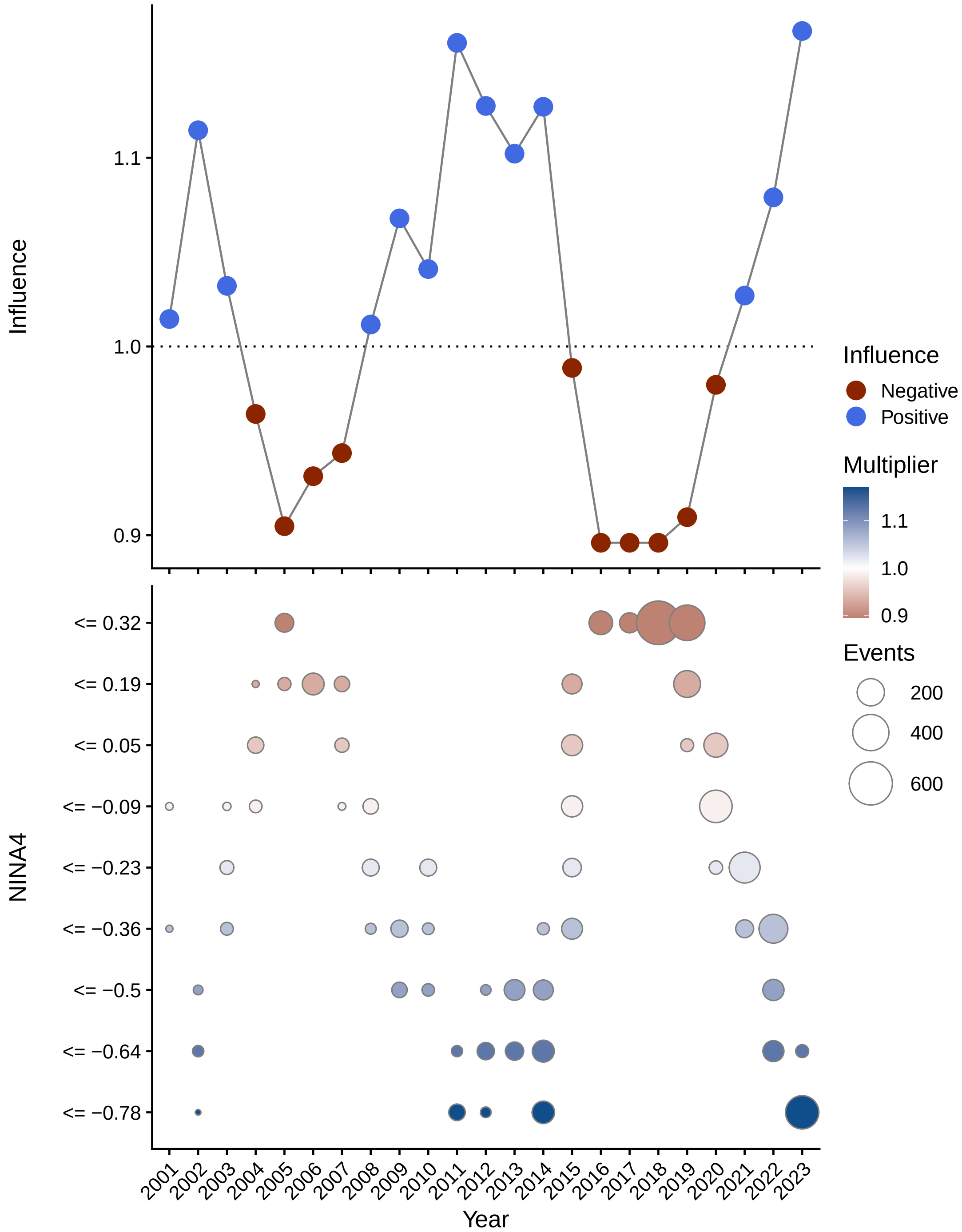

Figure 23: Influence of NINA4 index on catch-rates of striped marlin for the PICTs longline observer dataset excluding French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standard-ised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

6.4.2 No FP; with operational parameters

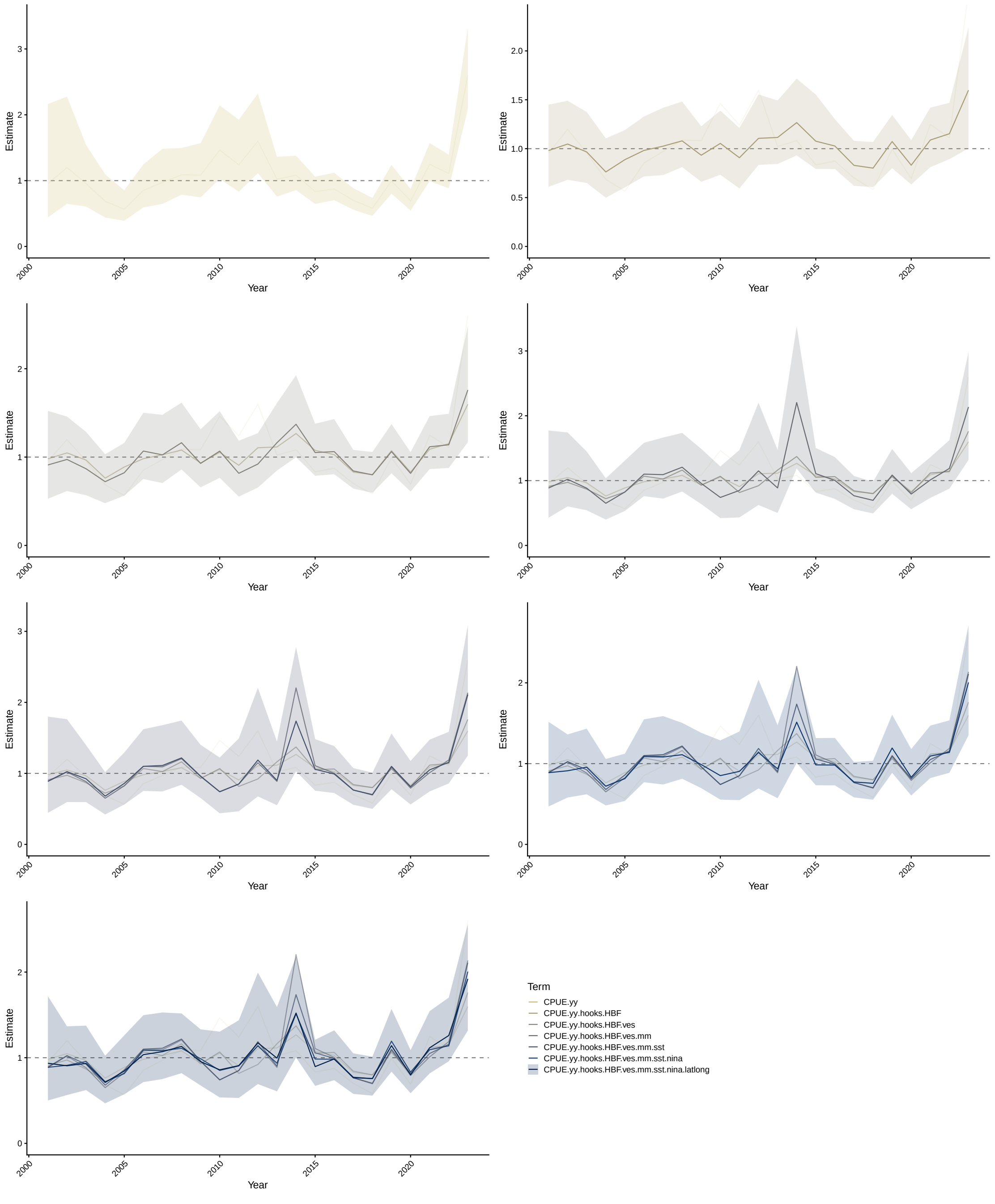

Figure 24: CPUE standardisation effects for the PICTs longline observer dataset for striped marlin excluding French Polynesia and including light sticks and bait in addition to hooks between floats (HBF; added with HBF in the corresponding step). Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

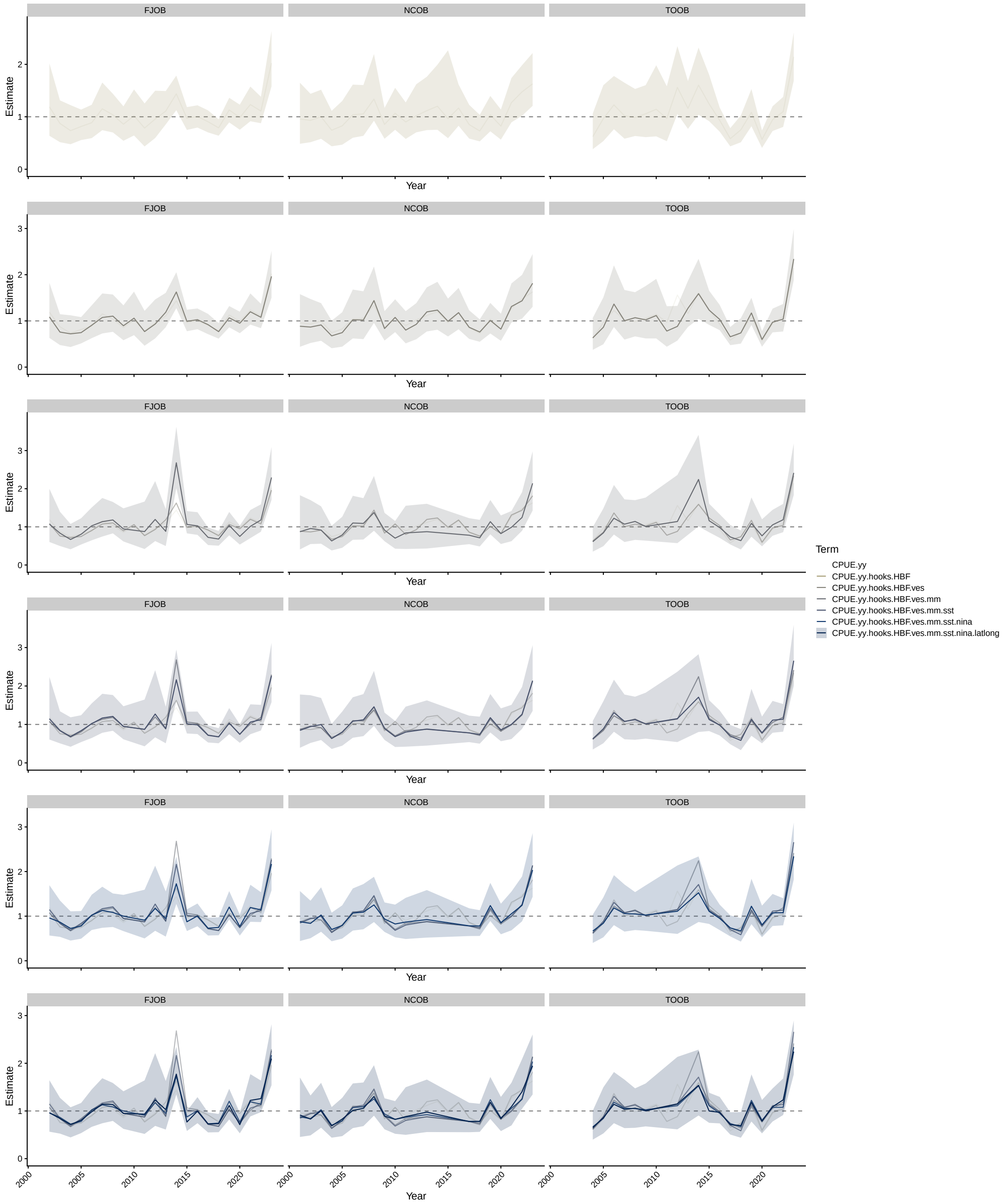

Figure 25: Longline CPUE standardisation effects by observer-prog for the PICTs longline observer dataset for striped marlin excluding French Polynesia and including light sticks and bait in addition to hooks between floats (HBF; added with HBF in the corresponding step). Each row of plots corresponds to the addition of a variable, starting with a model that includes observer-prog-year catch. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

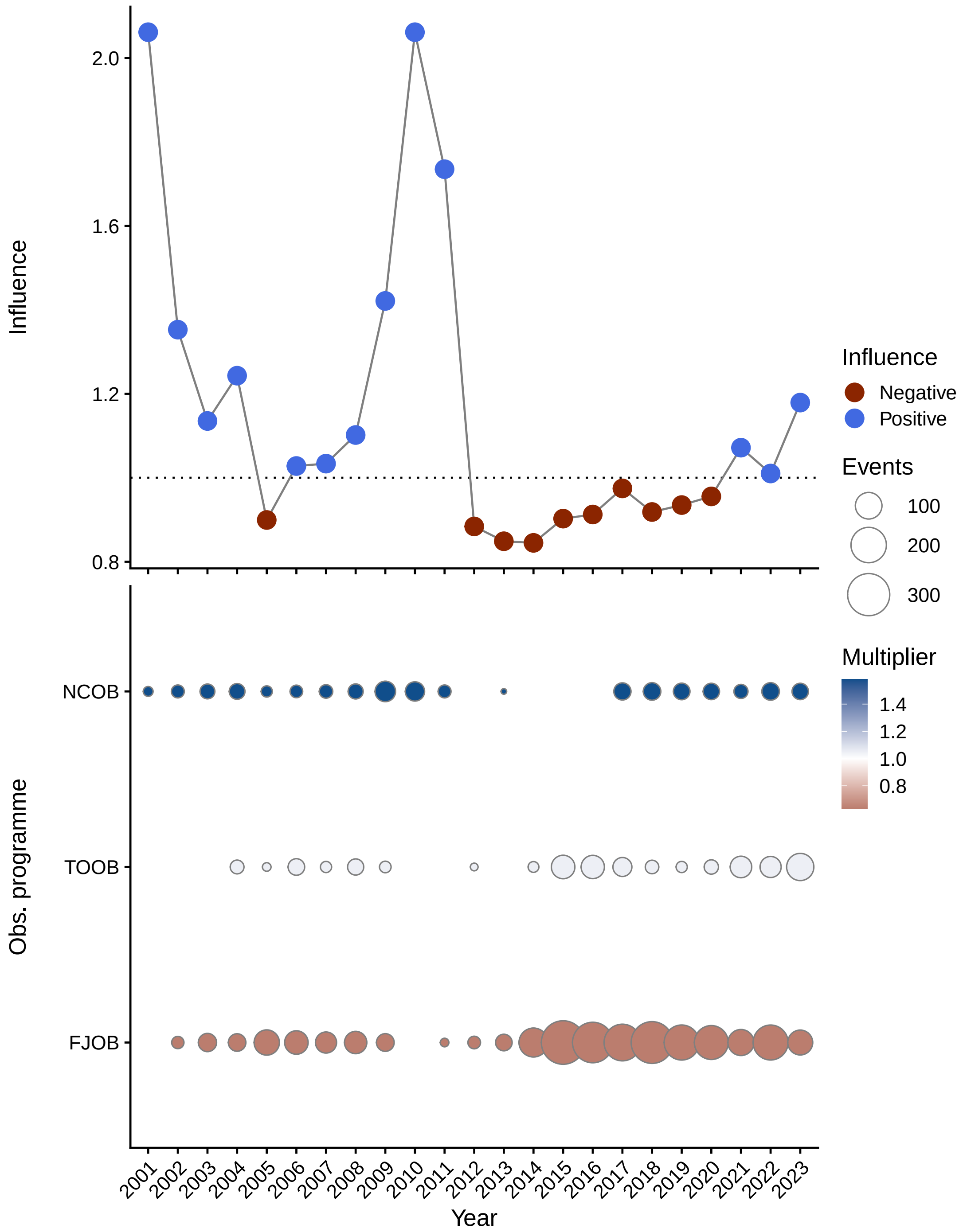

Figure 26: Influence of observer program on catch - rates of striped marlin the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over - all catch - rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

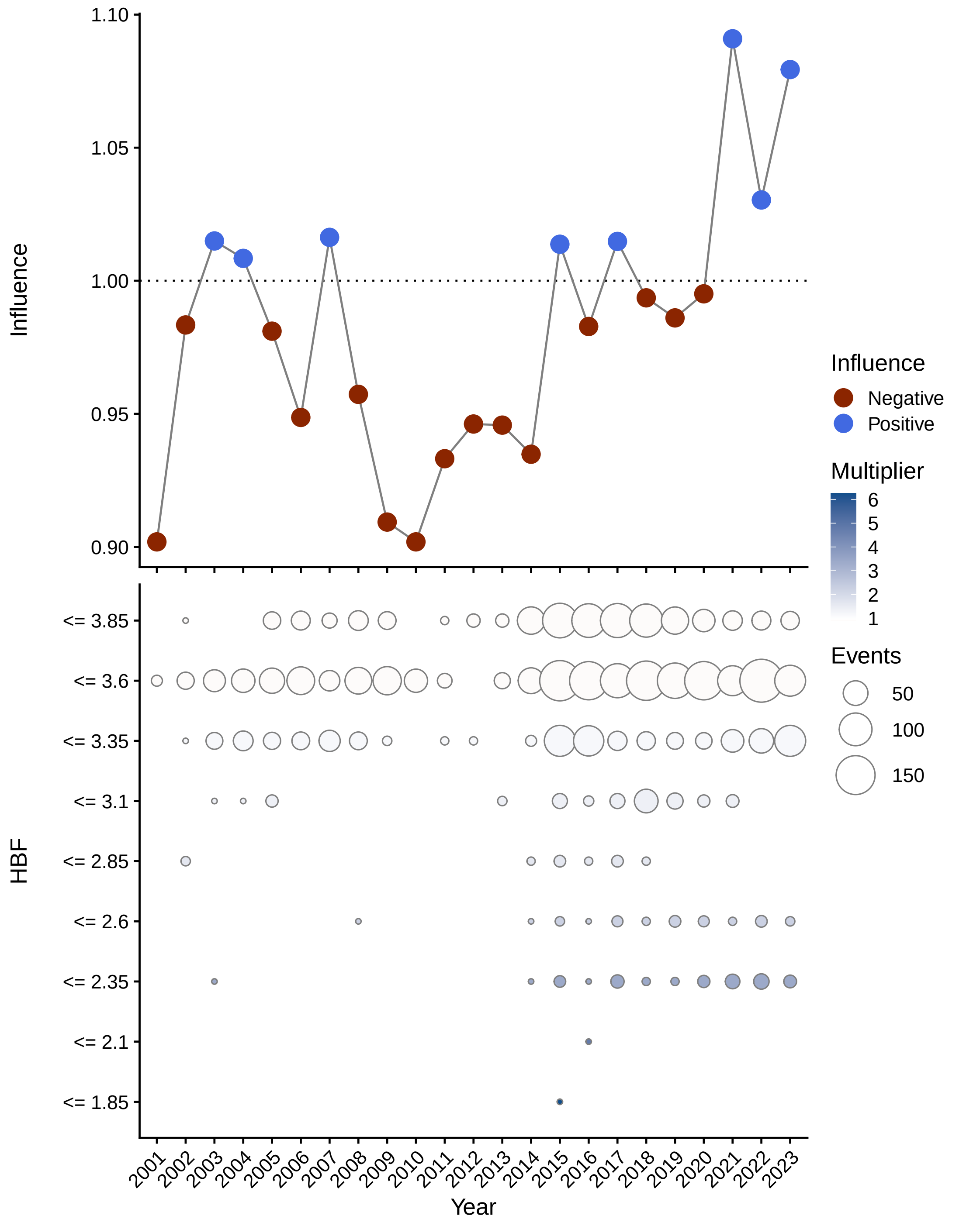

Figure 27: Influence of hooks - between - floats (HBF) on catch - rates of striped marlin for the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over - all catch - rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

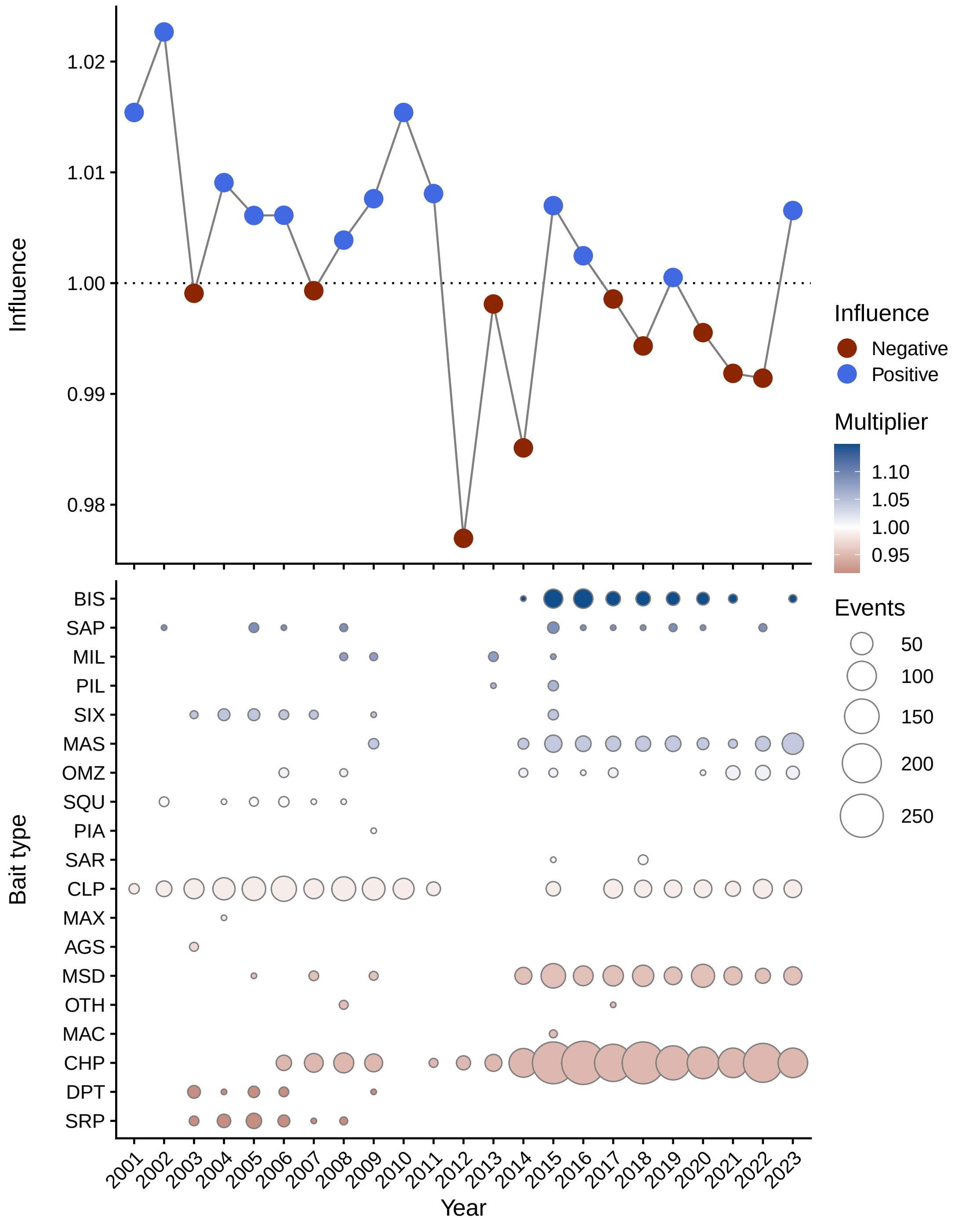

Figure 28: Influence of bait types on catch-rates of striped marlin for the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

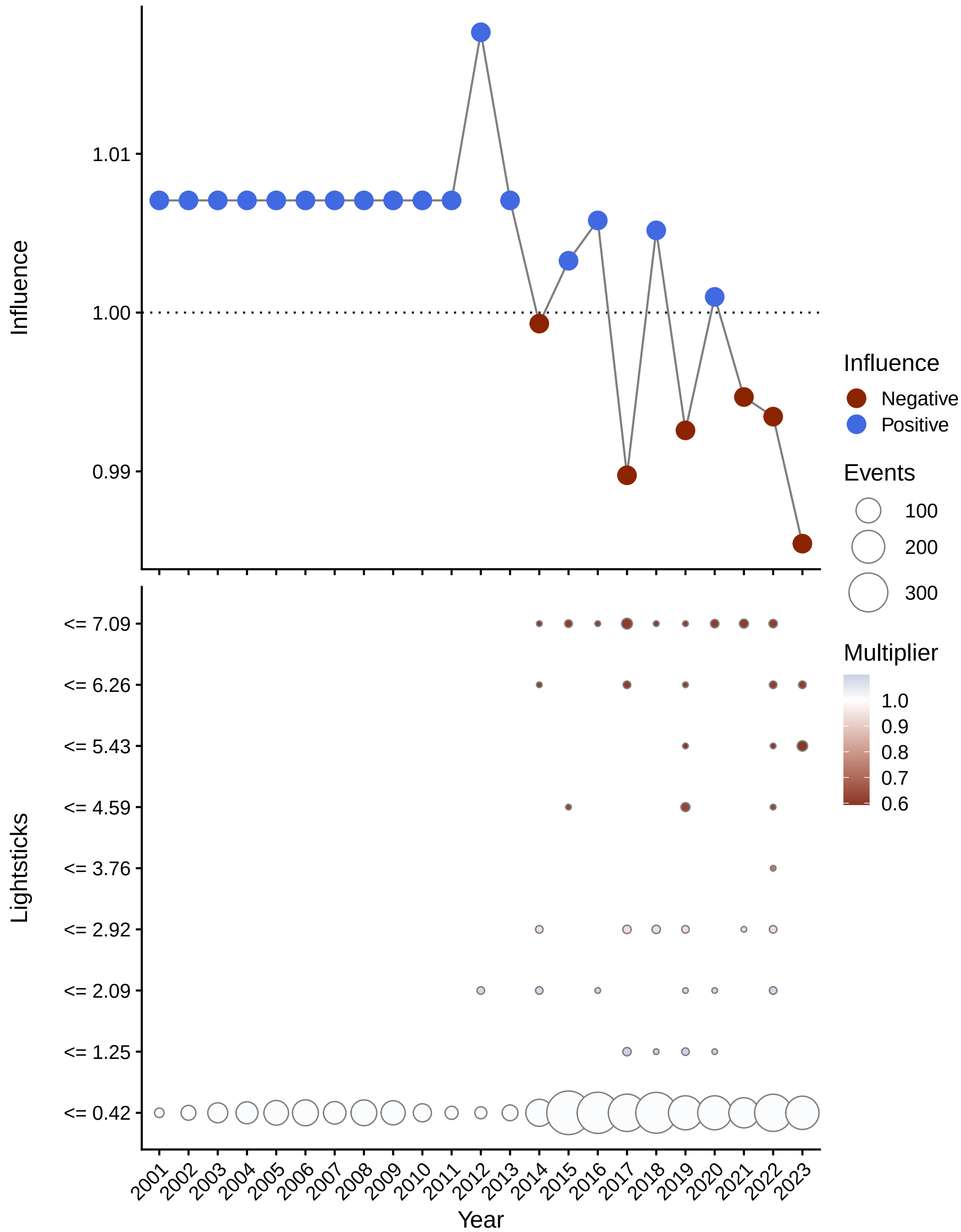

Figure 29: Influence of light sticks on catch-rates of striped marlin for the PICTs longline observer dataset excluding French Polynesia and including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

APPENDIX A MODELS FOR FRENCH POLYNESIA ONLY

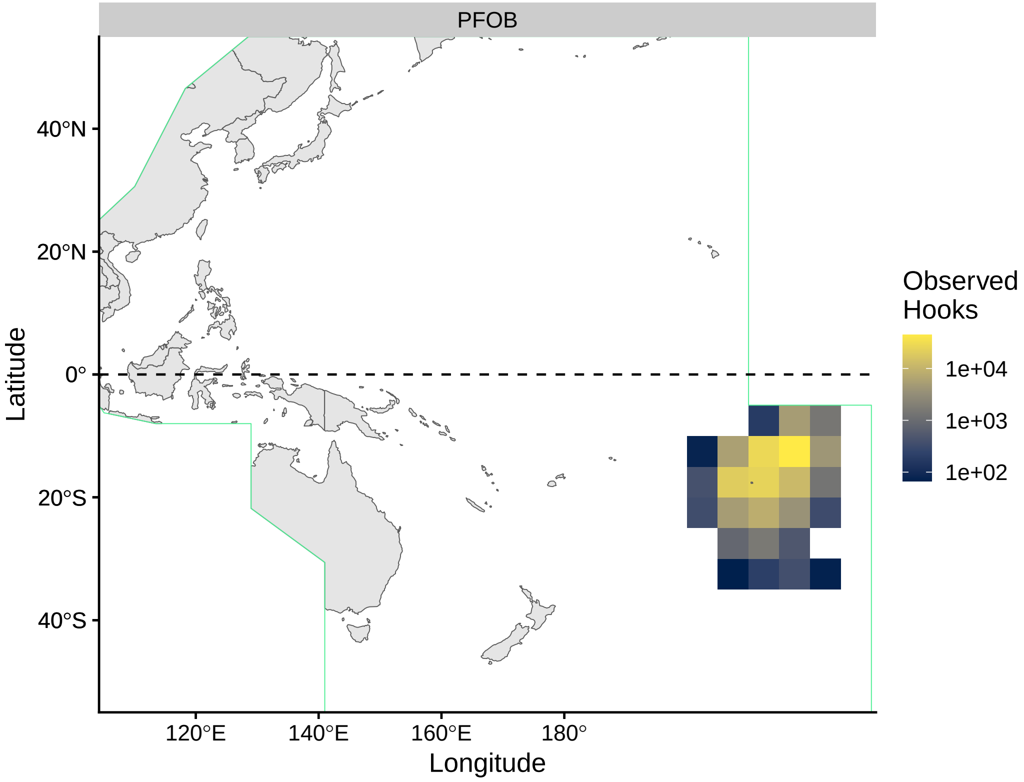

Figure A-1: Spatial distribution of observed effort (hooks) for the longline observer dataset for French Polynesia.

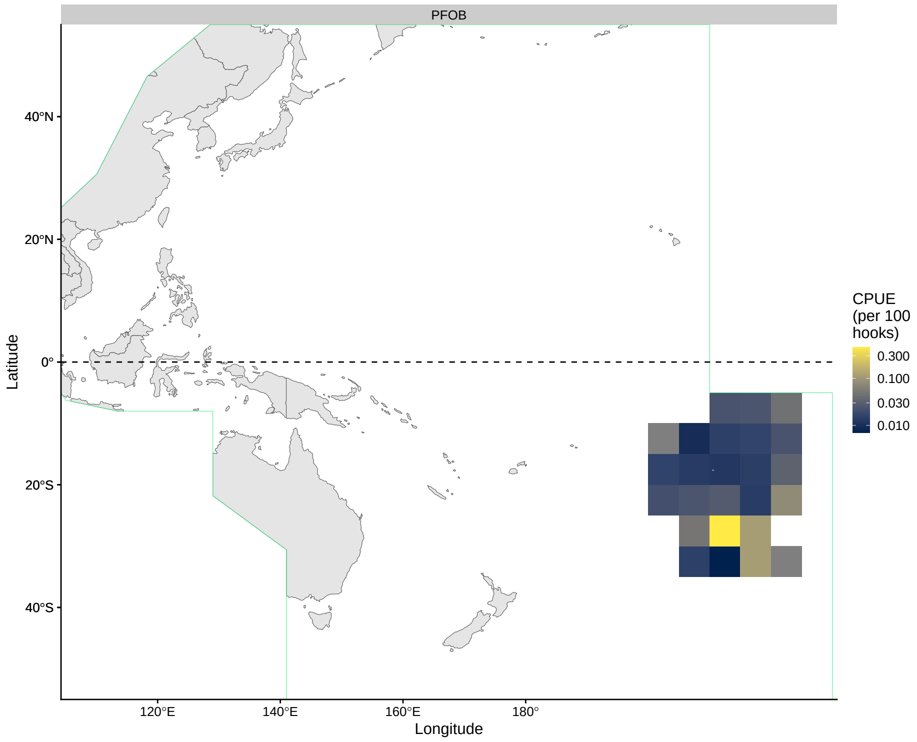

Figure A-2: Spatial distribution of observed catch-rates for the longline observer dataset for French Polynesia.

A.1 Swordfish models

A.1.1 FP only; no operational parameters

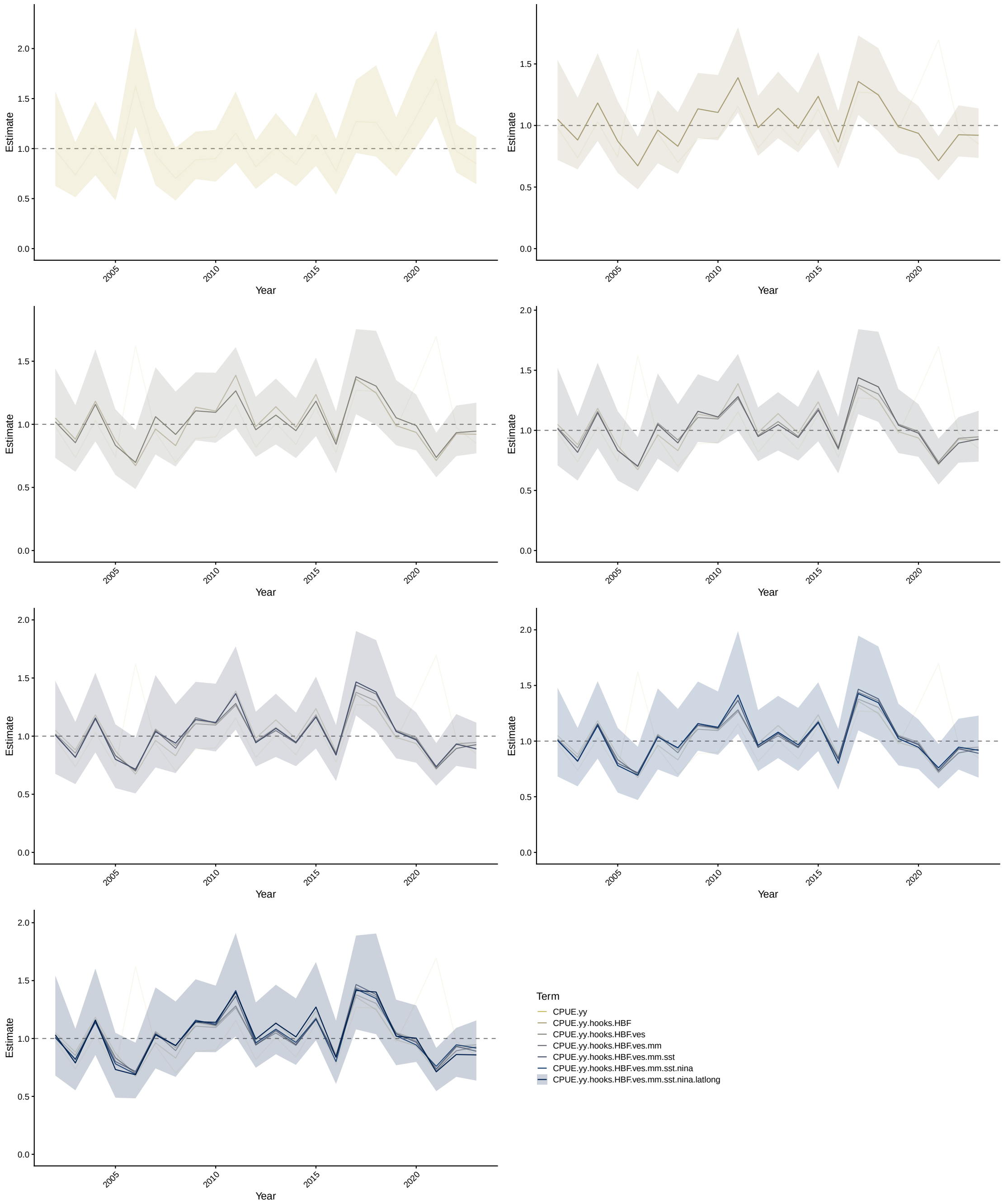

Figure A-3: CPUE standardisation effects for the longline observer dataset for French Polynesia, excluding operational parameters other than hooks between floats. Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

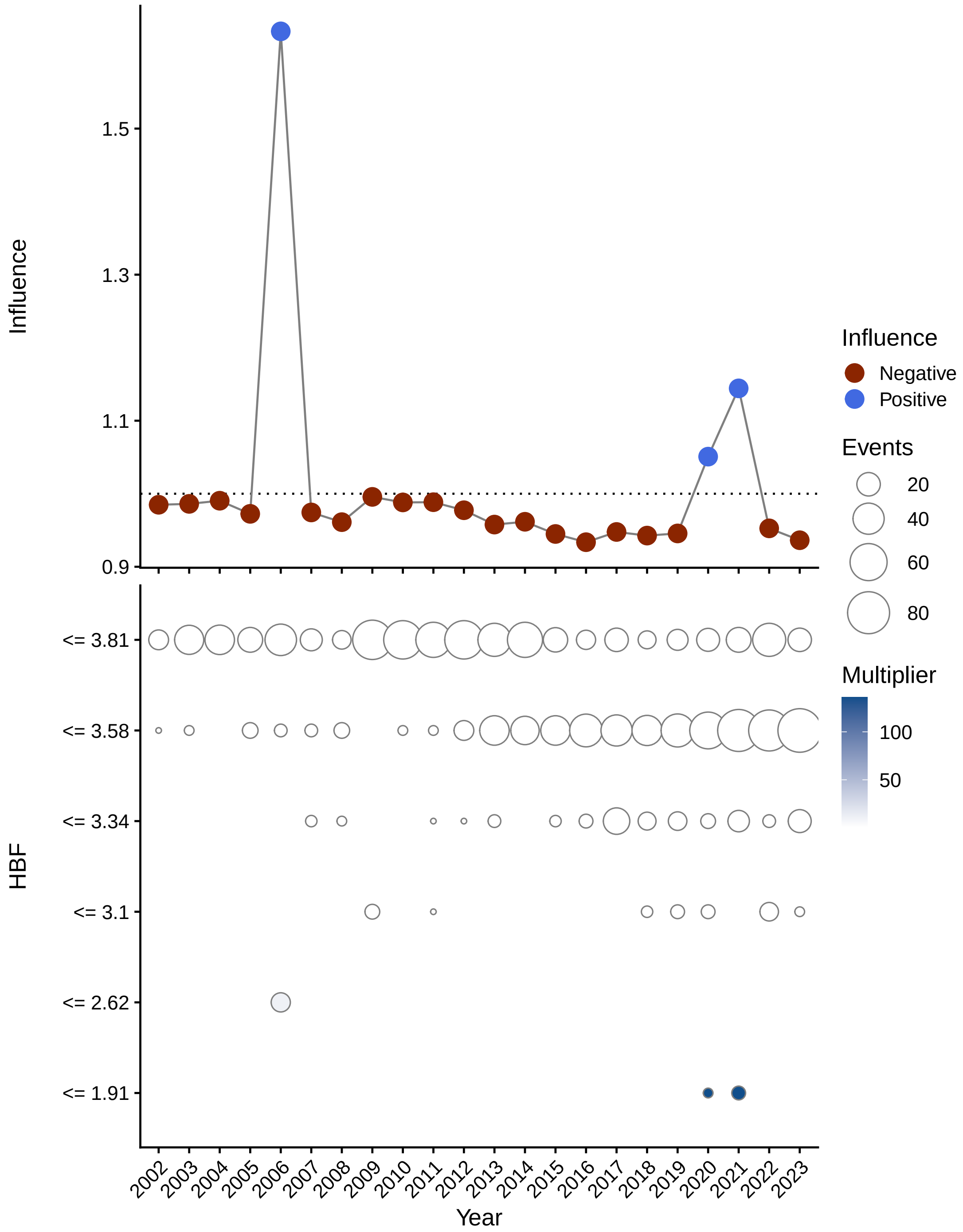

Figure A-4: Influence of hooks-between-floats (HBF) on catch-rates of swordfish for the longline observer dataset for French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

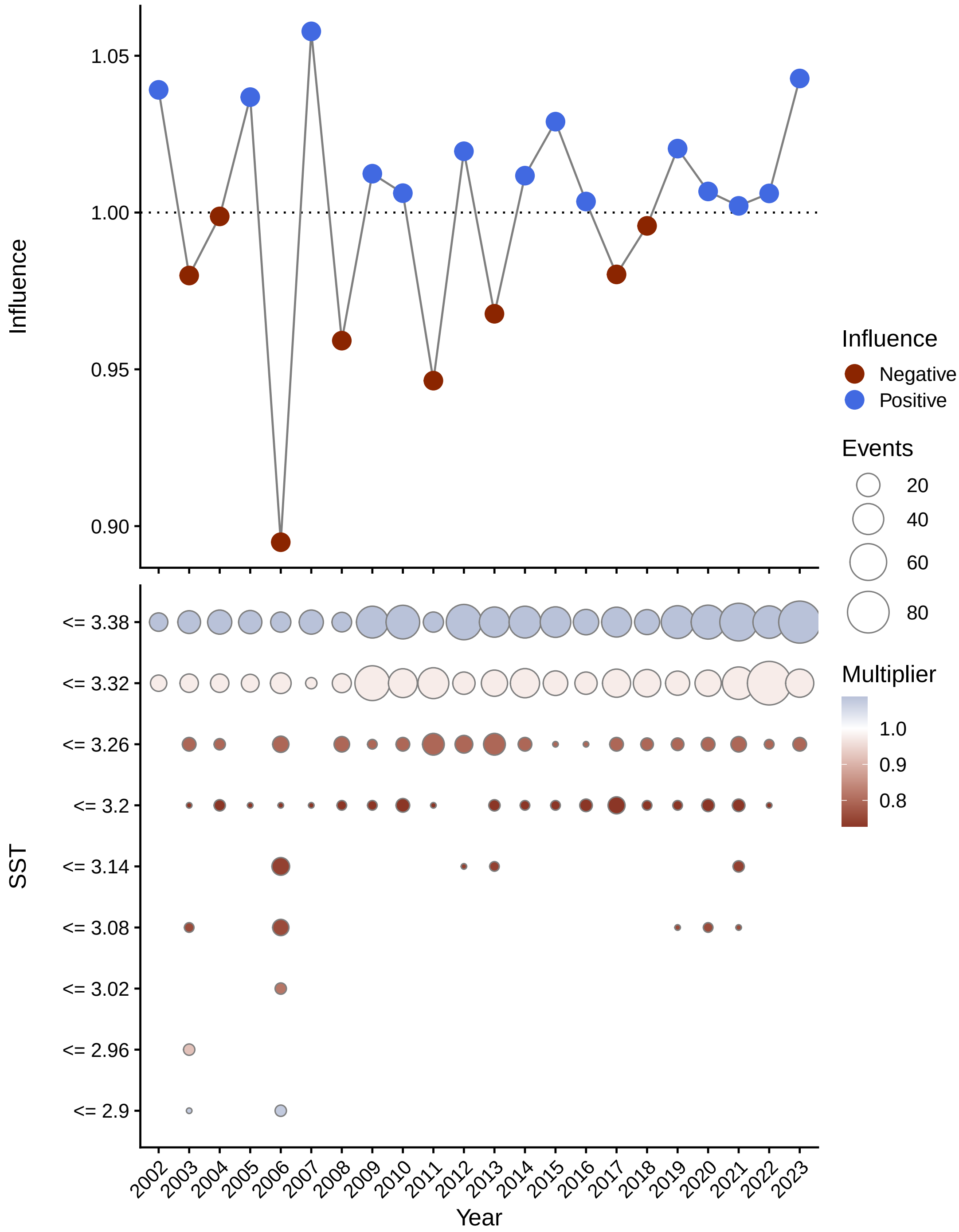

Figure A-5: Influence of SST on catch-rates of swordfish for the PICTs longline observer dataset for French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

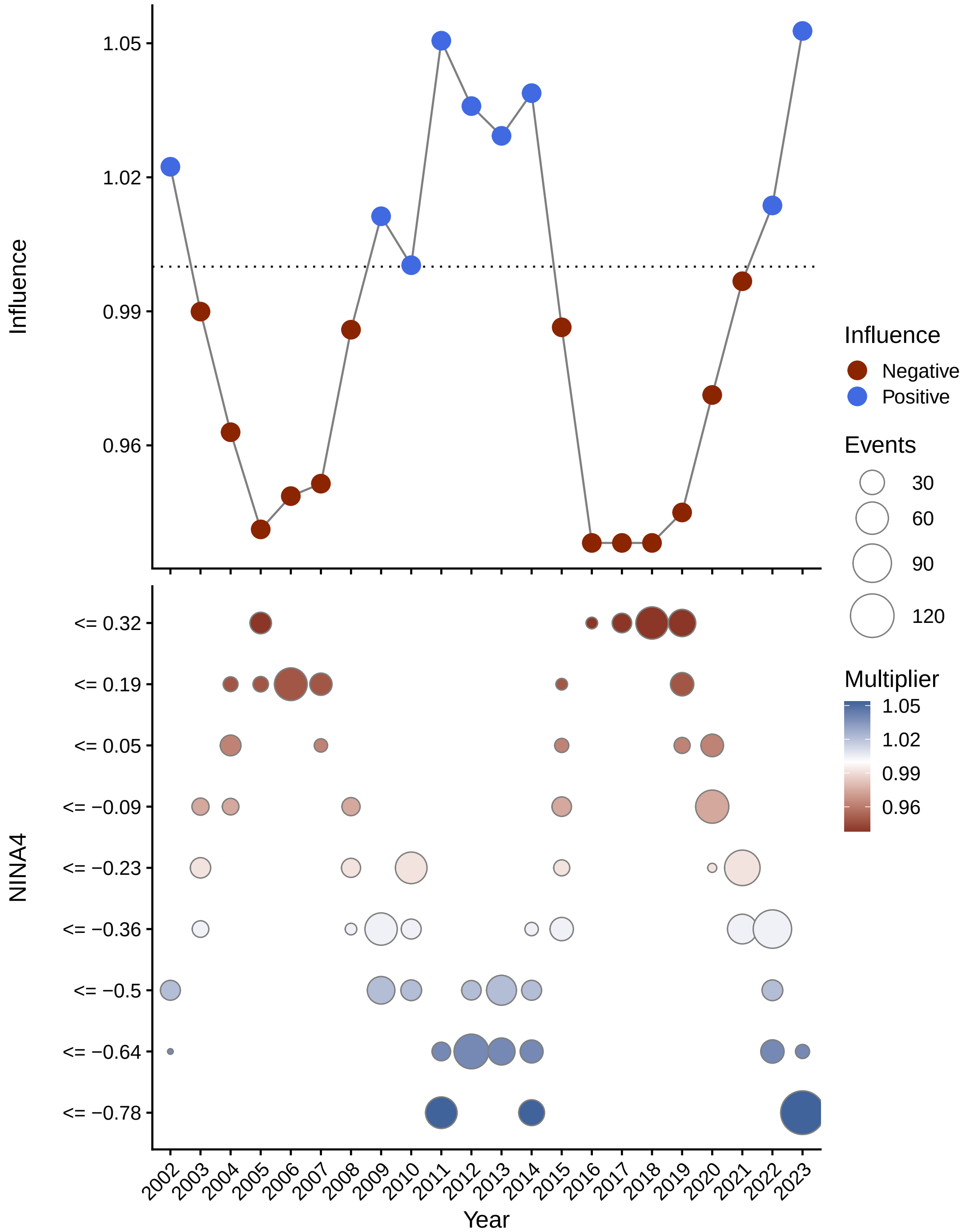

Figure A-6: Influence of NINA4 index on catch-rates of swordfish for the PICTs longline observer dataset for French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

A.1.2 FP only; with operational parameters

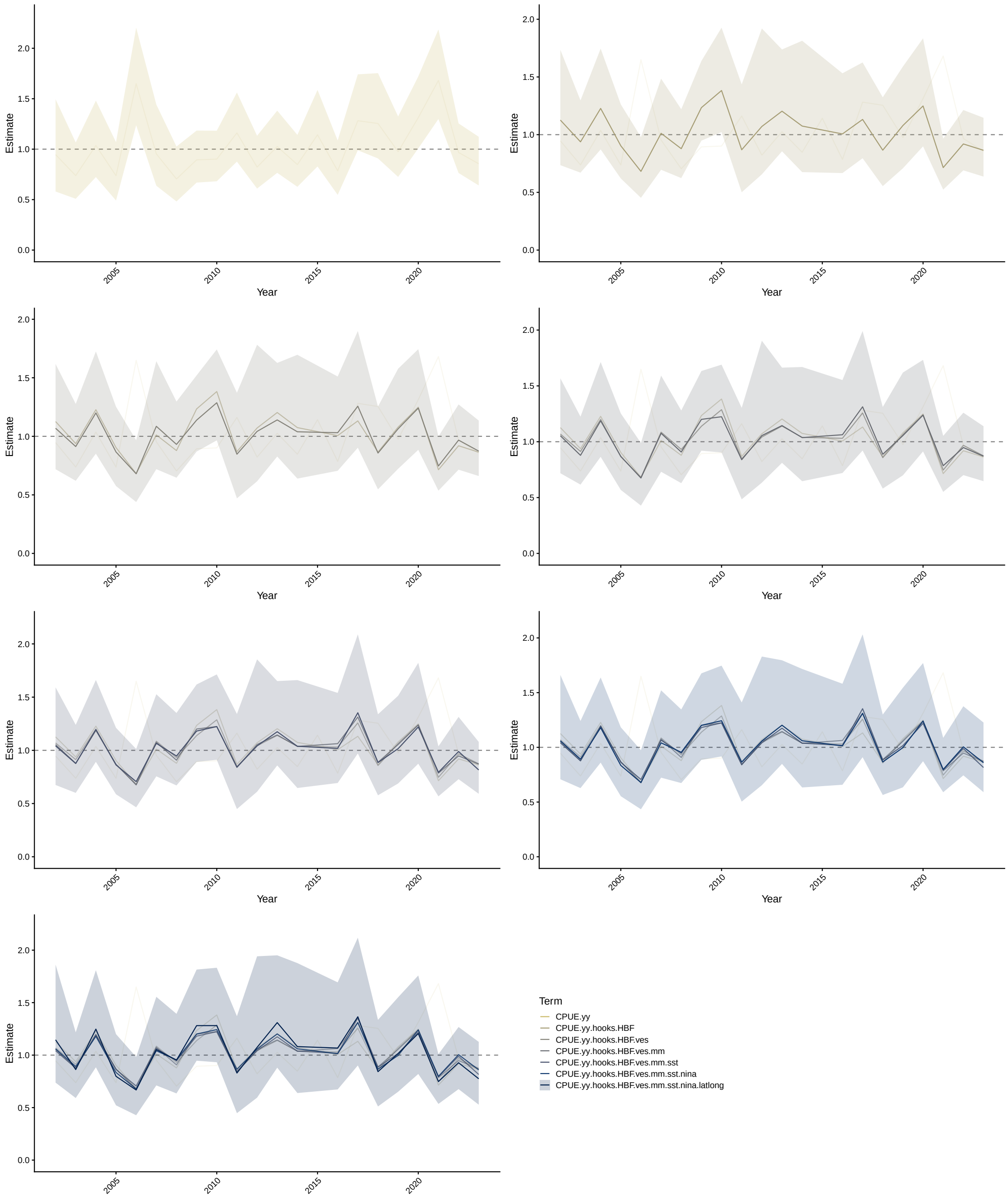

Figure A-7: CPUE standardisation effects for the PICTs longline observer dataset for swordfish for French Polynesia, including light sticks and bait in addition to hooks between floats (HBF; added with HBF in the corresponding step). Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

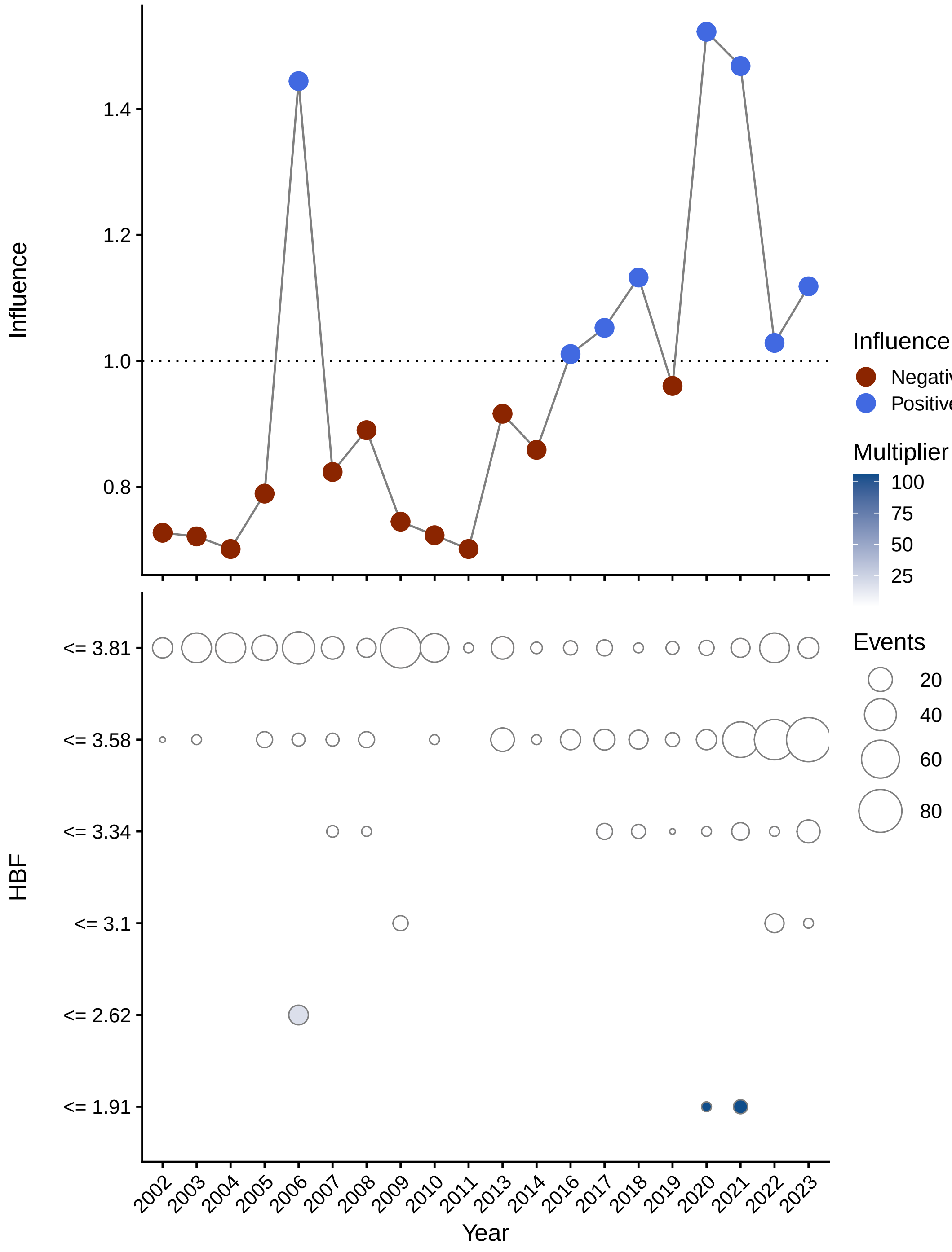

Figure A-8: Influence of hooks-between-floats (HBF) on catch-rates of swordfish for the longline observer dataset for French Polynesia ,including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

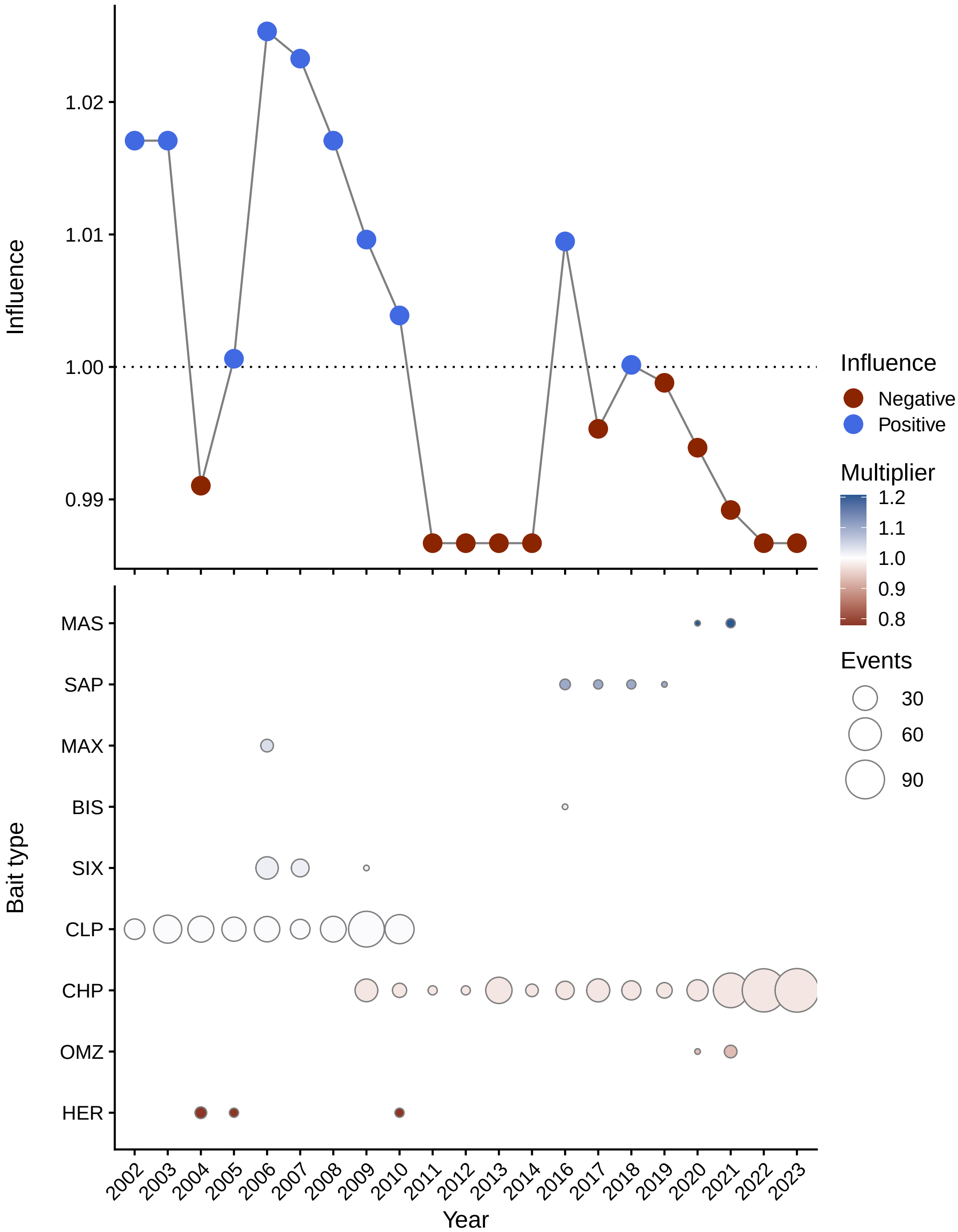

Figure A-9: Influence of bait types on catch-rates of swordfish for the longline observer dataset for French Polynesia ,including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

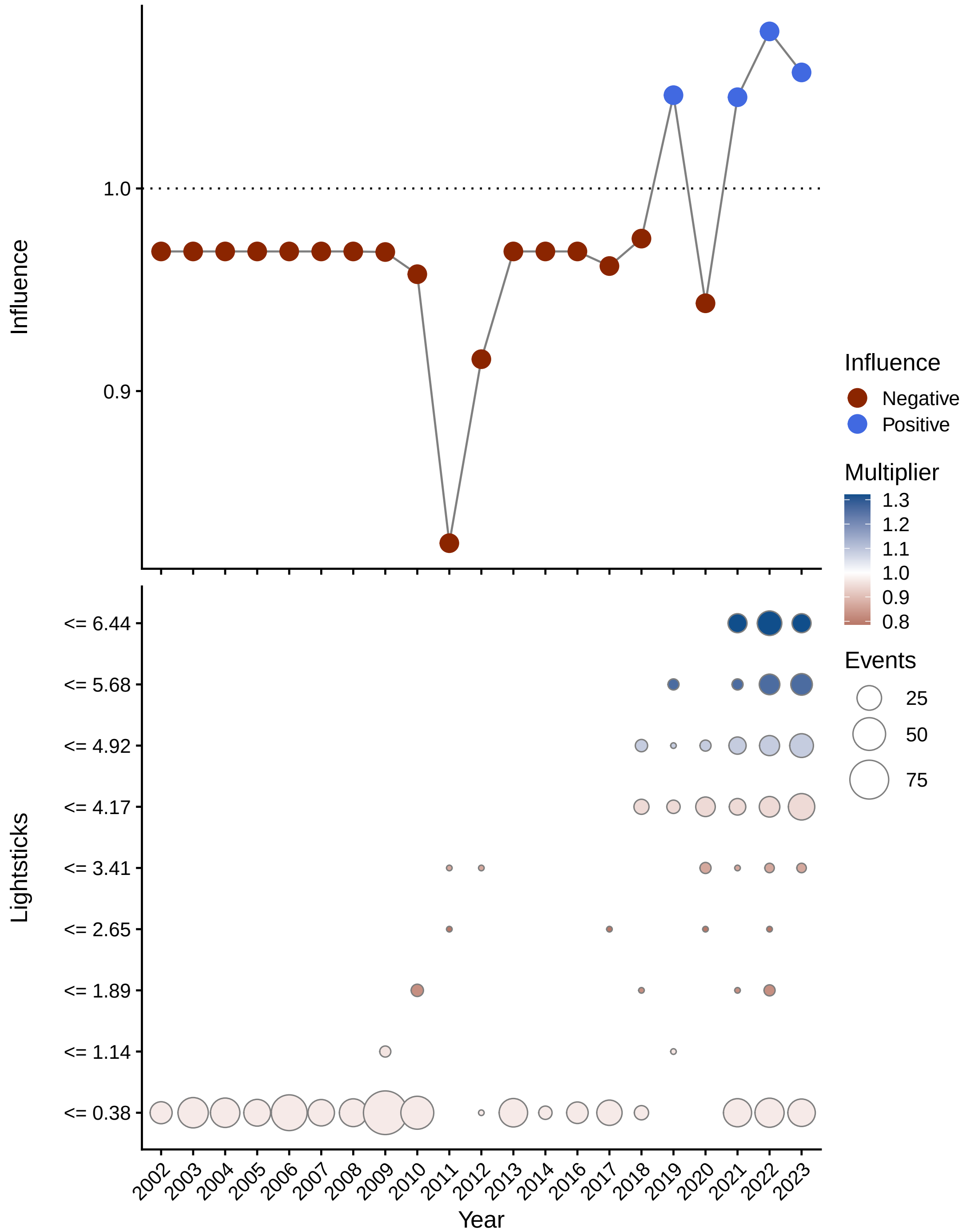

Figure A-10: Influence of light sticks on catch-rates of swordfish for the longline observer dataset for French Polynesia ,including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

A.2 Striped marlin models

A.2.1 FP only; no operational parameters

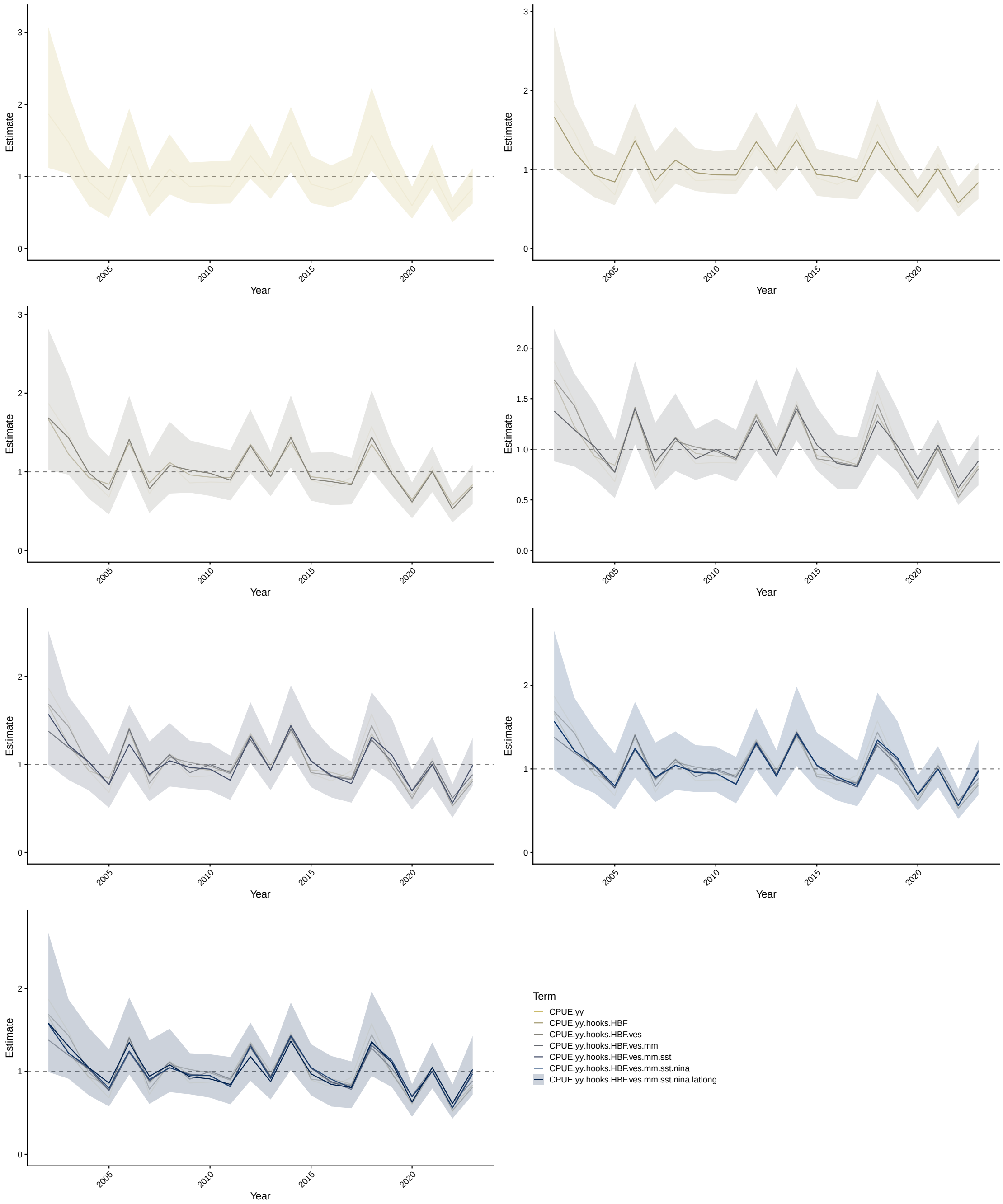

Figure A-11: CPUE standardisation effects for the PICTs longline observer dataset for striped marlin for French Polynesia and excluding operational parameters other than hooks between floats. Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

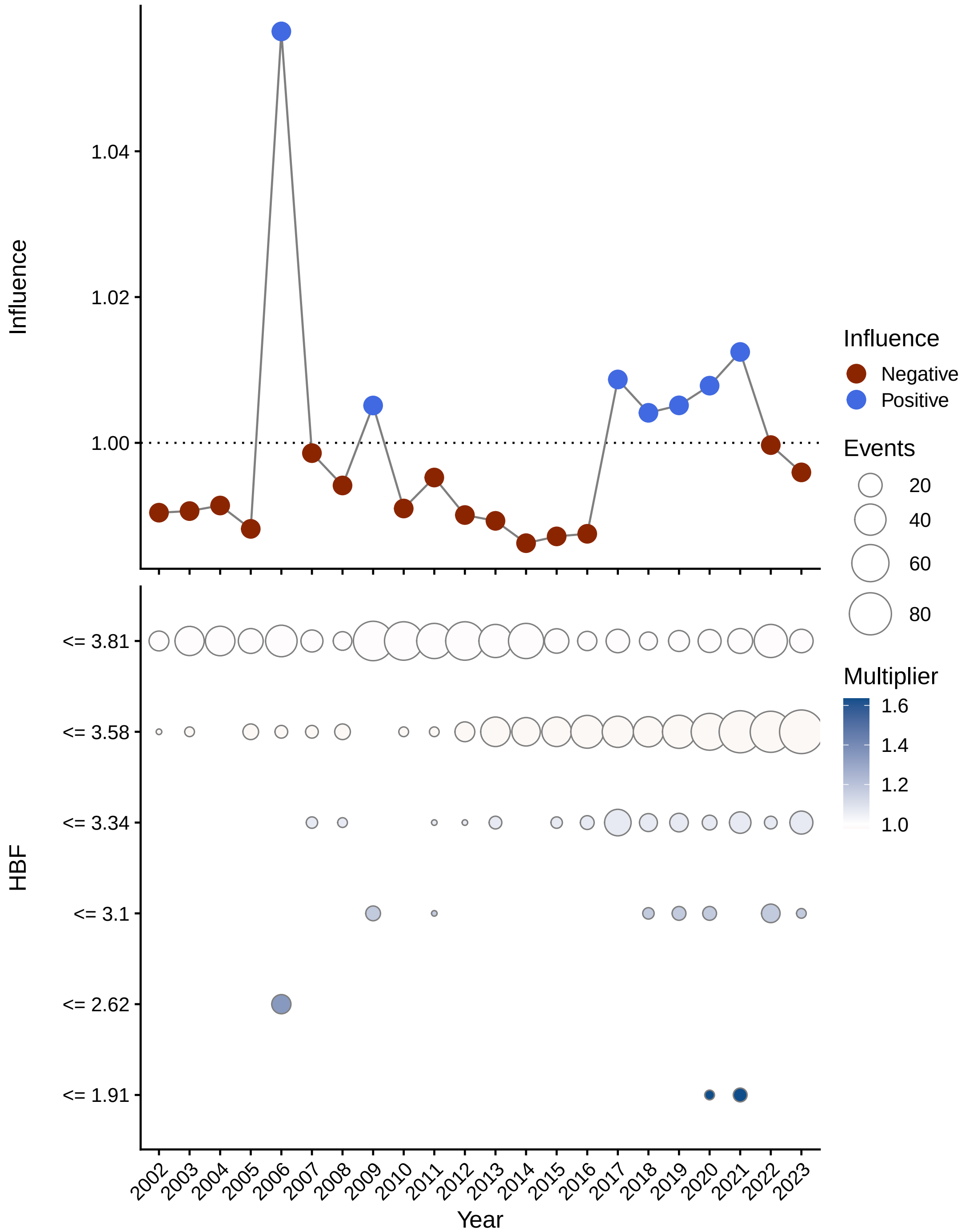

Figure A-12: Influence of hooks-between-floats (HBF) on catch-rates of striped marlin for the longline observer dataset for French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

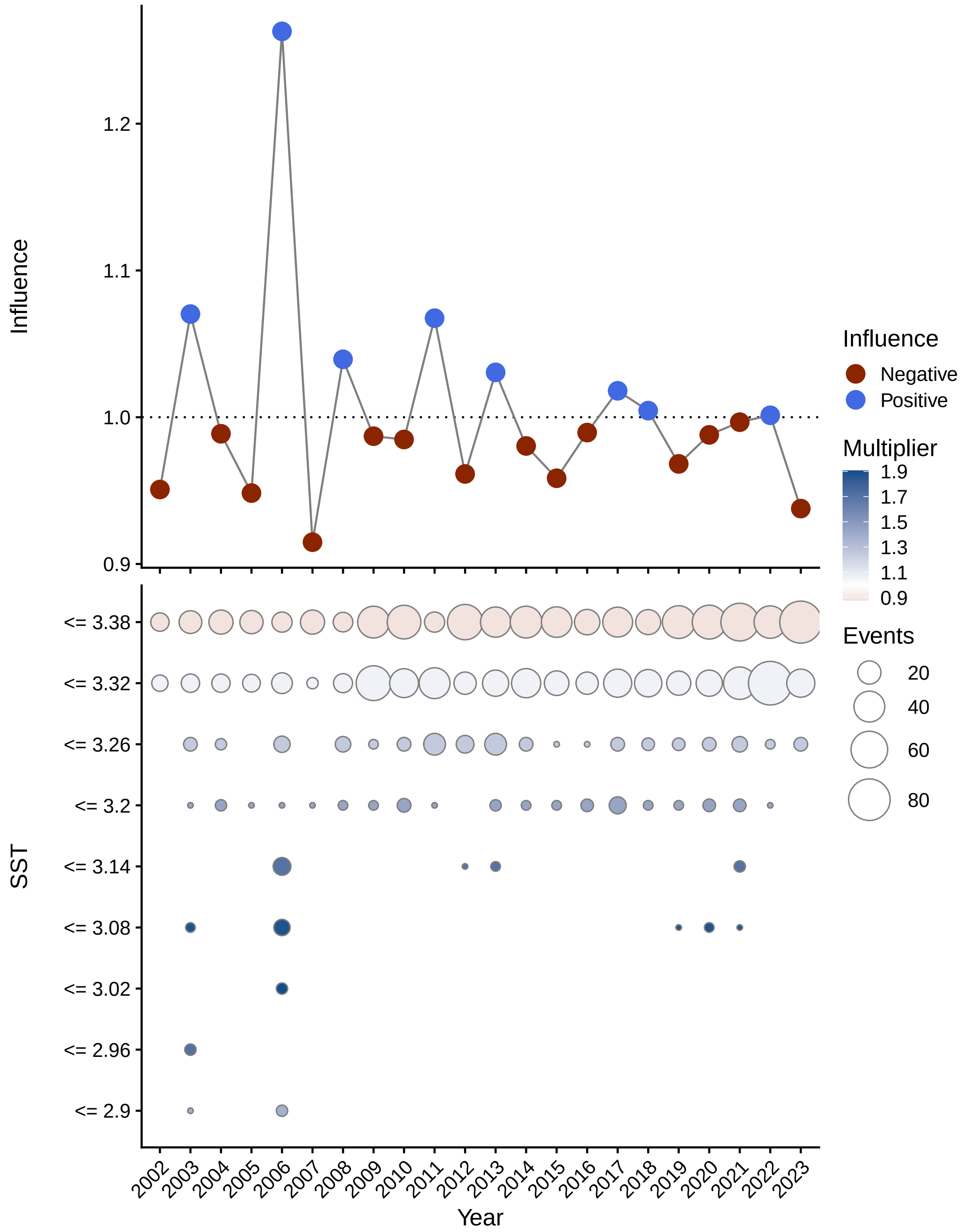

Figure A-13: Influence of SST on catch-rates of striped marlin for the PICTs longline observer dataset for French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

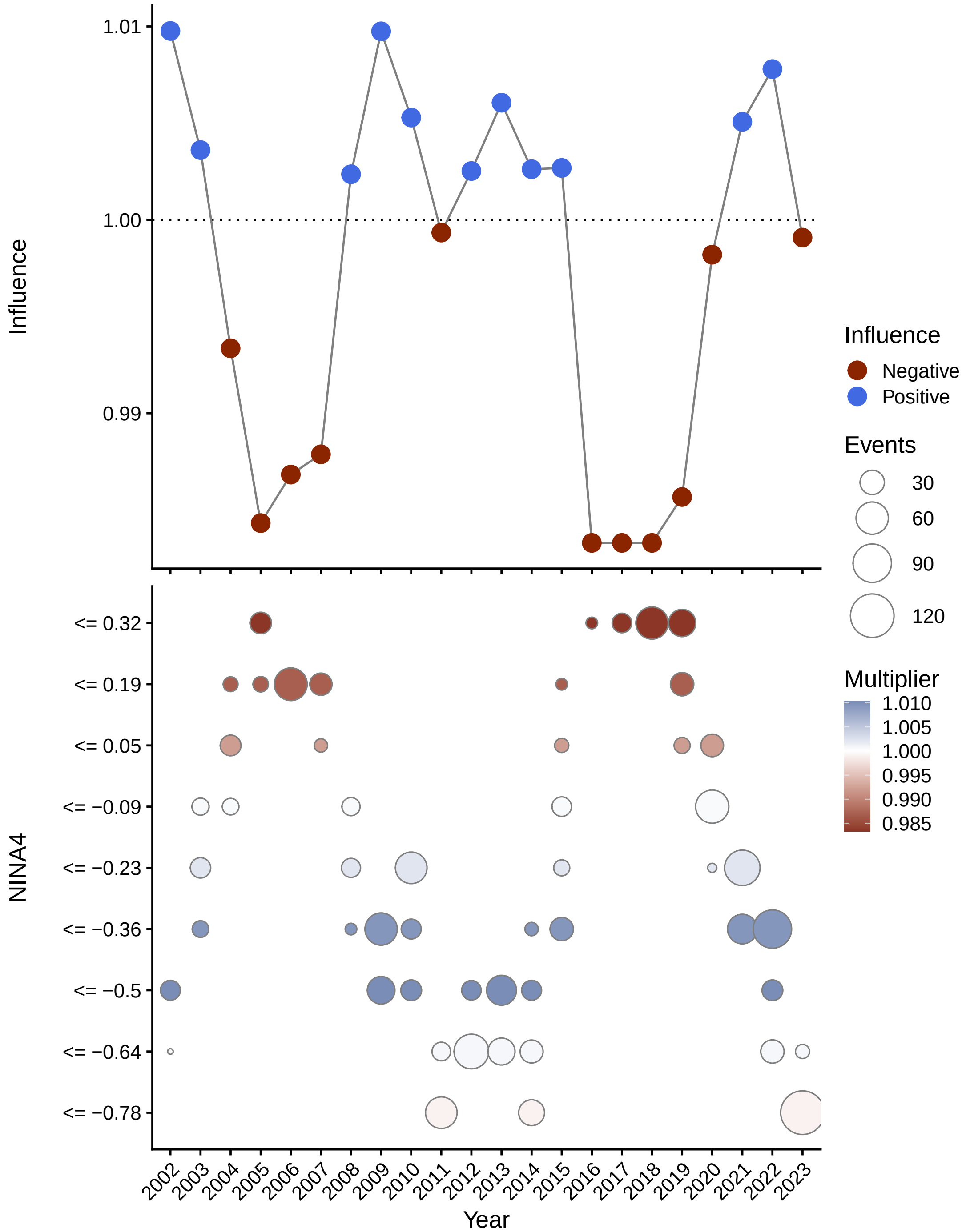

Figure A-14: Influence of NINA4 index on catch-rates of striped marlin for the PICTs longline observer dataset for French Polynesia and excluding operational parameters other than hooks between floats, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

A.2.2 FP only; with operational parameters

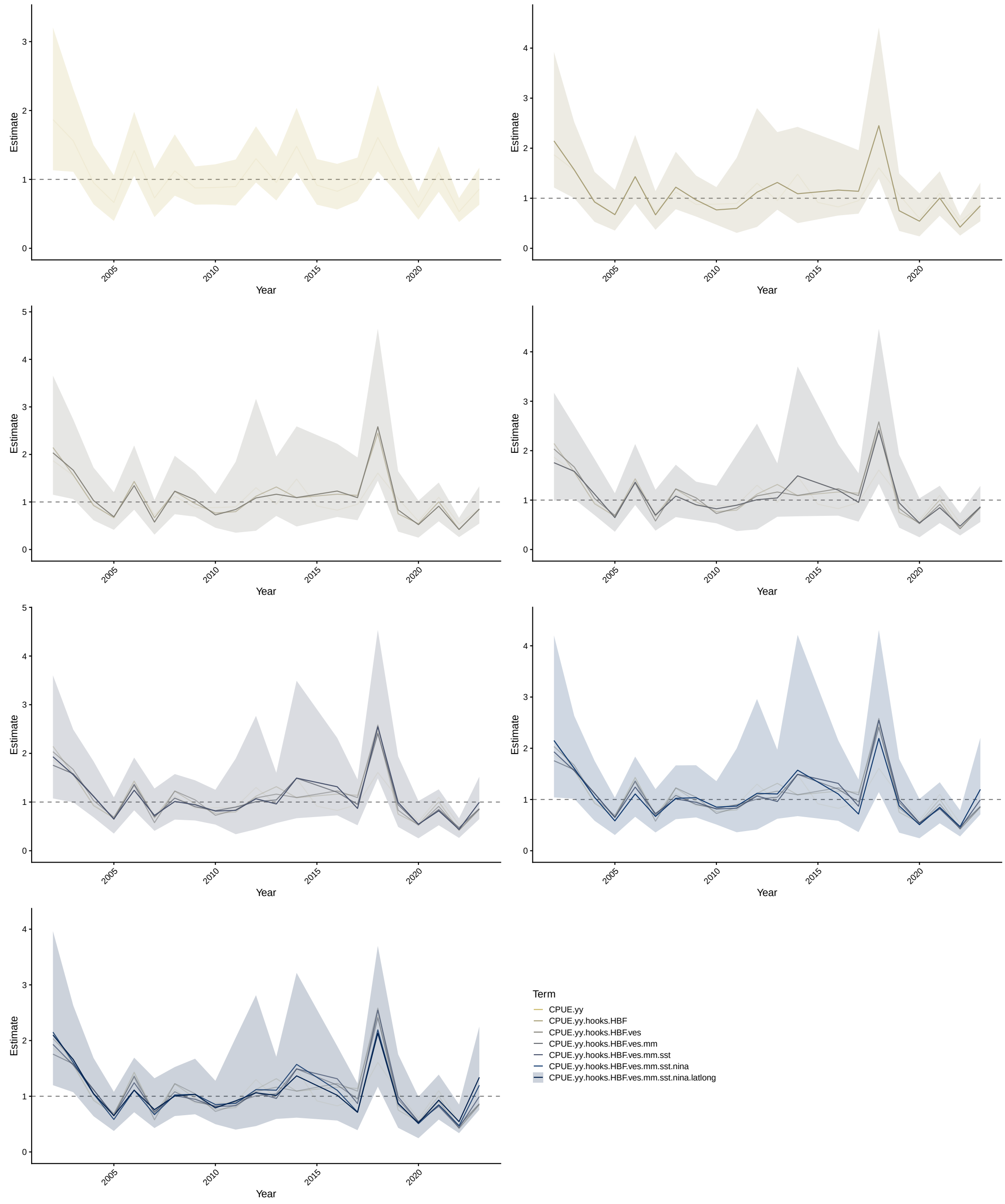

Figure A-15: CPUE standardisation effects for the longline observer dataset for striped marlin for French Polynesia, including light sticks and bait in addition to hooks between floats (HBF; added with HBF in the corresponding step). Each row of plots corresponds to the addition of a variable. In each row, the posterior median and credible interval is shown for the updated model, posterior medians for the year effect from sub-models are shown for comparison. (Note the different scales on the y-axes)

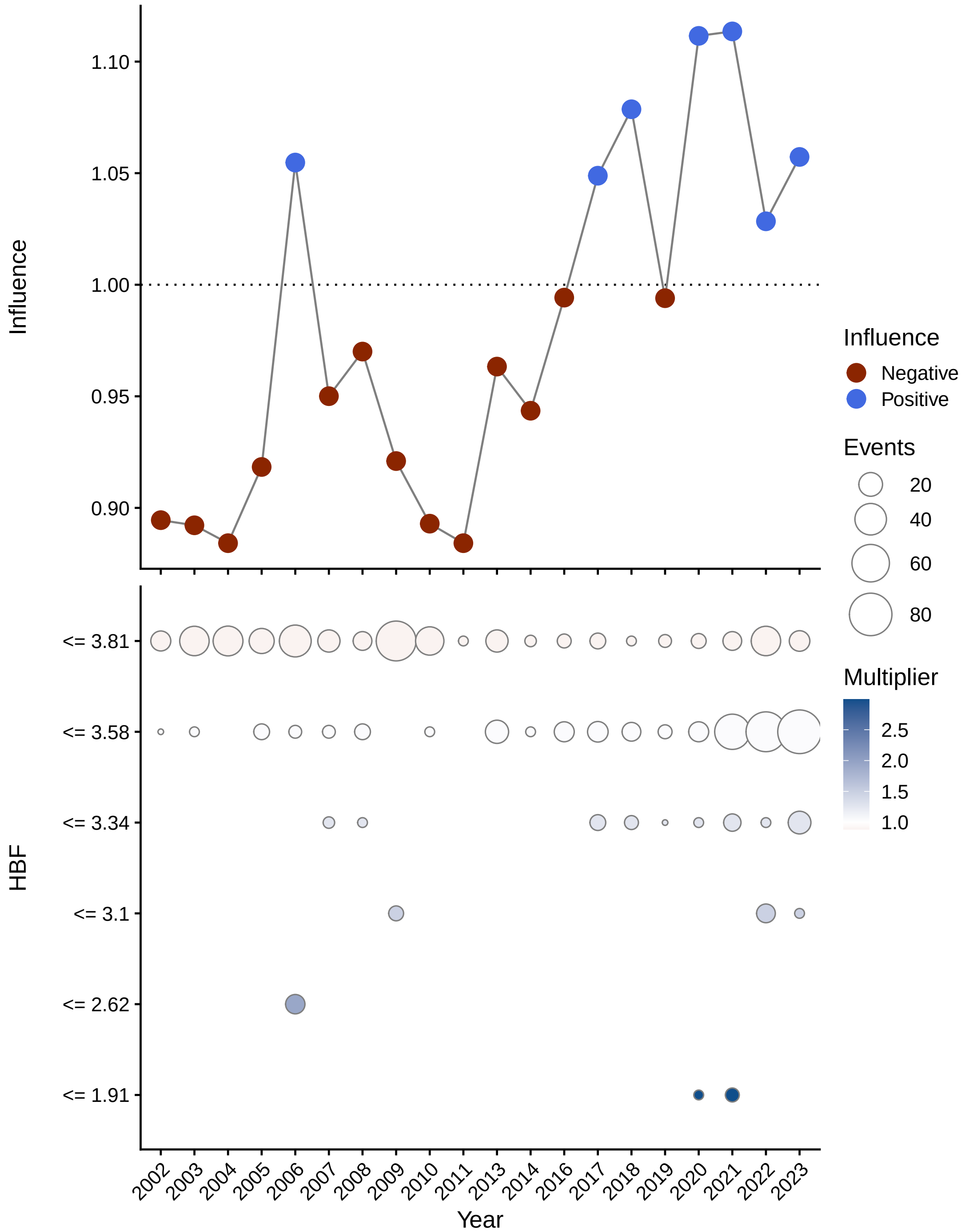

Figure A-16: Influence of hooks-between-floats (HBF) on catch-rates of striped marlin for the longline observer dataset for French Polynesia, including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

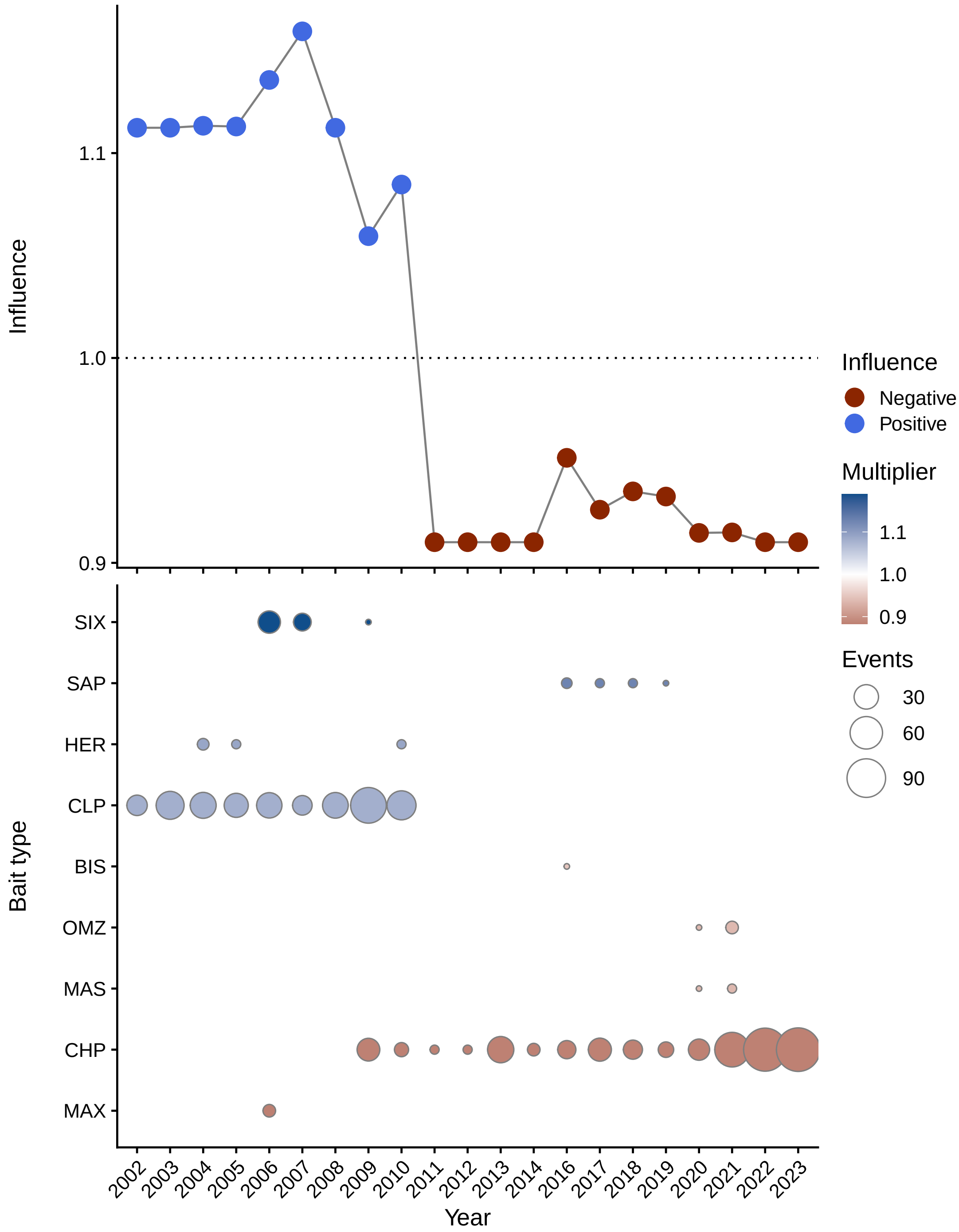

Figure A-17: Influence of bait types on catch-rates of striped marlin for the longline observer dataset for French Polynesia ,including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.

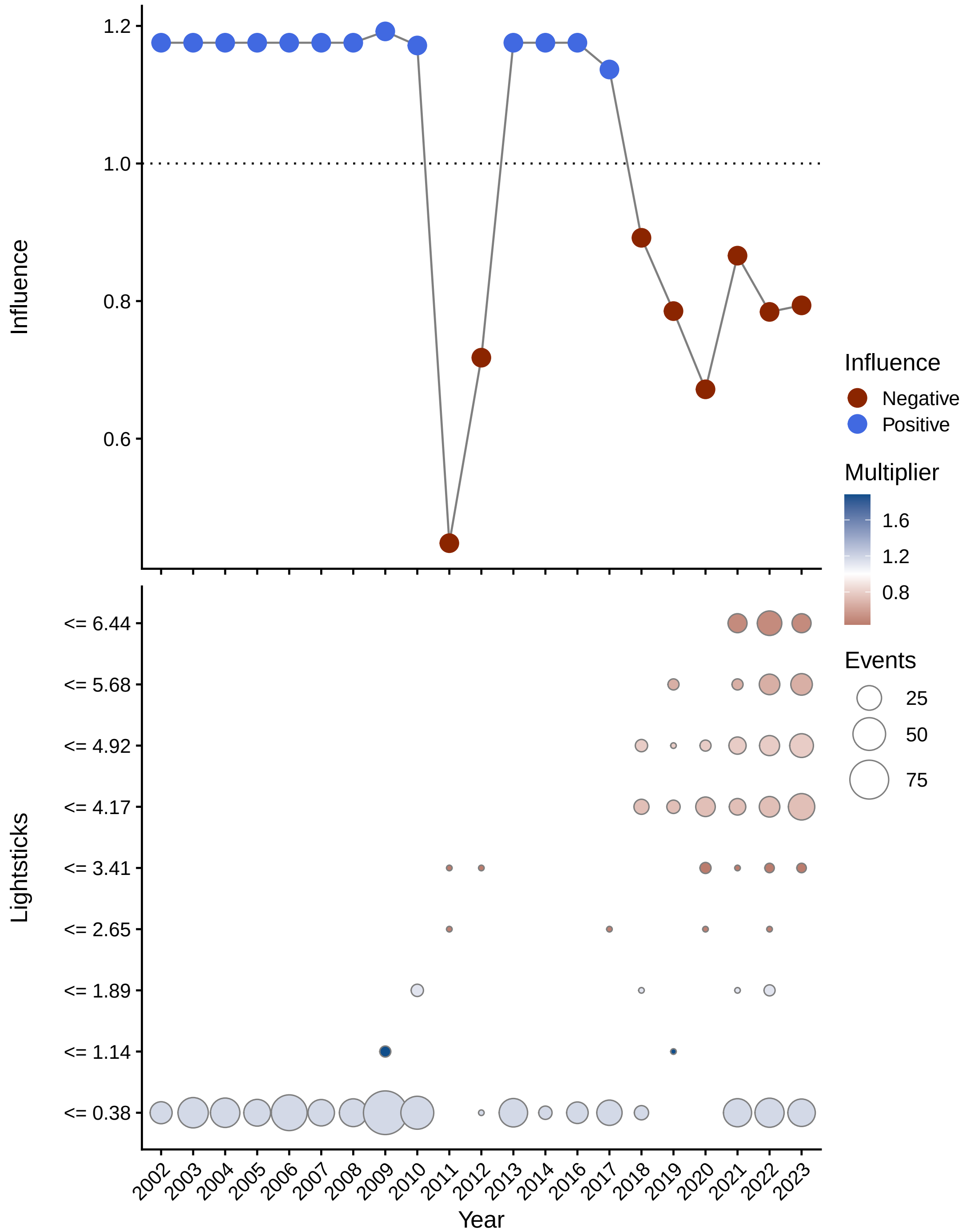

Figure A-18: Influence of light sticks on catch-rates of striped marlin for the longline observer dataset for French Polynesia ,including light sticks and bait, with positive influence showing years where the over-all catch-rate in the model was standardised downward by the corresponding amount to account for the influence of covariates. Influence is shown in colour as a multiplier on average catch rates, with circle size corresponding to the amount of effort entering the model.