



## Fine-scale spatio-temporal catch trends of blue sharks in southern bluefin target sets in the surface longline fishery

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## EXECUTIVE SUMMARY

### **Large, K. (2015). Fine-scale spatio-temporal catch trends of blue sharks in southern bluefin target sets in the surface longline fishery.**

*New Zealand Fisheries Assessment Report 2015/32. 59 p.*

Data from the surface long-line fishery were explored to determine whether catch rates of blue sharks declined in an area as vessels targeting southern bluefin tuna moved in and began fishing, and whether environmental factors (such as sea surface temperature) can be used as predictors of high blue shark catch rates.

Fine-scale position data for catches of blue shark individuals were not available from observer data because more than one third of blue sharks were recorded as tallies at the set (rather than the individual hook) level. Commercial catch-effort data, with complete coverage of the fishery, were used in preference to observer data, to allow exploration of spatio-temporal effects. The fact that some vessels recorded zero blue shark catch for all sets within an area, at times when all other vessels recorded some blue shark catches, may indicate systematic non-reporting which could bias reported results. The only data available to investigate environmental effects on blue shark catch rates were the sea surface temperatures recorded by the vessels at each set.

Vessel groupings within a Fishery Management Area (FMA) and fishing year were arbitrarily determined over scales of space and time that varied from 0.5 to 2 degrees in latitude and longitude, and from several days to several weeks in time. Within a spatio-temporal vessel grouping the blue shark catch rate sometimes showed an overall decline. And, while all vessels within the group may also show a decline in blue shark catch rate, for some groups one or several vessels may show an increasing catch rate. In other examples, at varying spatio-temporal scales, the catch rate of blue sharks did not decline. The number of vessels within a spatio-temporal group varied, as did the length of time different vessels remained in an area while other vessels were fishing. Also, the scale and magnitude of the number of blue sharks caught varied among different spatio-temporal groupings of vessels.

Blue sharks were caught at all the temperatures in which the surface longline fishery operated, but catch rates tended to be higher at lower temperatures and higher in sets that targeted southern bluefin tuna.

This preliminary work suggests that there is some evidence of a vessel group effect on blue shark catch rates. However, further study (along with appropriate environmental data) is required to model these catch rate trends, to test the sensitivity of any trend to varying spatio-temporal scales, and to determine if environmental effects can be used as predictors of declining blue shark catch rates at fine spatio-temporal scales.

## 1. INTRODUCTION

The National Fisheries Plan for Highly Migratory Species (Ministry of Fisheries 2010) has identified the importance of using an ecosystem approach to fisheries management, with Objective 7 specifying an approach that aims to maintain food chain relationships and conserve trophic linkages. In addition, the National Plan of Action for the Conservation and Management of Sharks 2013 (Ministry for Primary Industries 2013) aims to ensure that any utilisation of shark is sustainable and is effectively managed in the fisheries that catch them.

Three species of highly migratory elasmobranchs (blue, porbeagle and mako sharks) are common bycatch in tuna longline fisheries around New Zealand (Francis et al. 2000, 2001, Ayers et al. 2004, Francis et al. 2004, Griggs et al. 2007, 2008). These three shark species have comprised 37% by number of the fish observed aboard tuna longline vessels since 1988–89, and they are numerically more important in the catches than the target tunas and swordfish (29% combined) (Griggs & Baird 2013). The sharks are generally processed for their fins and sometimes their meat, although a significant proportion are discarded (Francis et al. 2000, 2004, Griggs et al. 2006, 2007). Since these three species were introduced into the Quota Management System (QMS) in 2004, discard of live sharks has been permitted under Schedule 6 of the Fisheries Act 1996.

Research project POS2013-01 “Indicator based analysis of the status of New Zealand HMS Sharks”, was completed by Francis et al. (2014), with the analyses performed on blue, porbeagle and mako sharks. The overall research objective of that study was to monitor trends in the stock status of selected HMS sharks in New Zealand using indicator analysis.

This document reports on Objective 1 of Project SEA2013-11 “Additional work for POS2013-01”, with the same overall research objective. The specific project objective was:

1. Assess the fine scale set by set and spatio-temporal trends in catch rates of blue sharks (BWS) in southern bluefin tuna (STN) target sets, to assess areas and physical conditions that aggregate sharks. This objective also includes an assessment of how catch rates decline in an area as it is fished by the fleet, by assessing individual vessels’ daily catch as the fleet arrives in an area and begins fishing.

The aim of this study is to investigate trends of blue shark (BWS) bycatch in the surface longline fishery targeting southern bluefin tuna (STN), as highlighted by fishers and, in particular, to answer these questions (S. Brouwer, MPI, personal communication, 2014):

- Do blue shark catch rates decline in an area after it has been fished for a few days?
- Can that change (if detected) be attributed to reductions in blue shark numbers in the immediate vicinity through either catch, or some environmental factor?
- Further, if some environmental factor affects local abundance of blue sharks, can that be used as a predictor of potentially high blue shark catch rates (in space and time) which could be avoided by fishers?

## 2. METHODS

### 2.1 Fishery data

Data collected by observers on surface longline (SLL) vessels are stored in the centralised observer database (*cod*) administered by NIWA for the Ministry for Primary Industries (MPI). Sampling of individual surface longline sets involves the observers identifying and counting all catch taken on board during the time that they are observing. Information recorded by fishers on the Tuna Longline Catch Effort Return (TLCER) forms is stored on the Catch-Effort database (*warehou*) administered by MPI. The datasets used in POS2013-01 from both *cod* and *warehou* were made available for this project.

A decision about which data would be most appropriate for this analysis was based on defining “fine-scale” as posed in the objective and considering any limitations of scale imposed by the data. A definition of “fleet” was also required.

With observer data, assuming that each BWS caught could be allocated to a hook, their capture position would be able to be estimated to within a few kilometres (km). However the positions with TLCER data would only be estimated to within up to 70 km of the capture position (Japanese longlines can stretch to 140 km). Observer data were therefore considered to be finer in spatial scale, and have a longer time series, but with poor coverage (less than 10%) of the domestic fleet. TLCER data (which accounts for most of the reported effort (Griggs & Baird, 2013)), can only be used from 2004, when BWS was introduced into the QMS and began to be reported moderately reliably.

However, in practice, due to the limited time available for observers to record every fish that comes on board, tallying of BWS catches is prevalent in the observer data. The percentage of tallied blue sharks is 35% and tallying occur on 45.5% of the observed trips (M. Francis, NIWA, personal communication, 2014). ‘Tallied’ sharks are those that are bundled together and counted at the end of the set; they have no accurate position data, but can be used for calculating the total set catch. Tallied sharks have no recorded time of landing, so they cannot be allocated to a hook and their position cannot be estimated. Thus, the finest spatial resolution of BWS data, in both observer and TLCER datasets, is the set.

Poor coverage of the domestic fleet by observers would also make it difficult to investigate trends in catch rates as the fleet arrives in an area and begins fishing. A group of vessels has to stay in close proximity for at least a few contiguous days to allow estimation of rate of decline (if any) of catch rates. To consider fleet dynamics at as fine a space/time scale as possible the data coverage of the fleet needs to be extensive and this is only available with the TLCER data.

For these reasons, the *warehou* TLCER data were used in preference to the observer data from *cod*. For comparison, parallel analysis of data from both sources would be ideal, but this was not possible due to time constraints. The data available from *warehou* for this analysis comprised information from 24 687 surface longline sets from 1 October 2004 to 22 December 2014.

## 2.2 Data summary

For each set, the available data included the date, location (at the start of the set, to the nearest 0.1 degree of latitude and longitude), Fishery Management Area, vessel identifier, number of hooks, target species and number of BWS and STN caught (Table 1). The number of each species caught was derived from the numbers recorded as processed plus the numbers recorded as discarded. Given that it is believed that fishers often derive estimated weights from tallies of BWS caught, numbers were used in preference to weights as the measure of abundance.

**Table 1: Data used for these analyses, with description of variable names.**

Data	Variable	Description
Fishing	Tlset_key	Unique identifier for each set
	Vessel_ID	Unique identifier for individual vessels
	No_Hooks	Number of hooks deployed in each set
Location	Latitude_Start	Latitude at start of set
	Longitude_Start	Longitude at start of set
	FMA	Fishery Management Area
Date	Set_Year	Year in which set started
	Set_Month	Month in which set started
	Set_Day	Day of month in which set started
	Fish.year	Fishing year in which set started (e.g. 01 Oct 04 to 30 Sep 05 is fishing year 2005)
Environment	SST	Sea surface temperature (°C)
Catch by species		<i>Number of this species caught on this longline set</i>
	BWS	Blue shark
	STN	Southern bluefin tuna

Grooming conducted on the TLCER data in the parent project POS2013-01, removed the following sets prior to analysis:

- 93 sets from 2014 fishing year;
- 94 sets with Australian fleet nationality;
- 131 sets outside New Zealand's exclusive economic zone (EEZ);
- 11 sets missing location data for start and end of set; and
- 17 sets with unusually high or NA processed weight recorded for BWS.

A total of 346 (1.4%) of the 24 687 records were removed, leaving 24 341 records (sets) for analysis.

In most fishing years from 2005 to 2013, around half of all hooks set targeted STN (Table 2). In a clear seasonal trend, targeting of STN (the number of hooks and the percentage of all hooks) peaked in the months May, June and July, with few or no hooks targeting STN from October through to February.

Of all the BWS caught in SLL sets from fishing years 2005 to 2013, over 75% was caught in sets targeting STN, with this figure at 86% and 90% respectively for the 2012 and 2013 fishing years (Table 3).

Constraining further analysis to only include sets that targeted STN, restricted the dataset to 9696 records (Table 4).

**Table 2: Effort (number of hooks in all sets) by month in the surface longline fishery for fishing years 2005 to 2013, and effort that only targeted southern bluefin tuna (number of hooks in STN target sets).**

Fishing year	Total	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
<b>2005</b>													
No. hooks in all sets	3 662 645	38 050	56 080	37 530	122 715	183 020	290 991	493 431	616 425	567 725	679 598	376 550	200 530
No. hooks in STN target sets	1 727 219	3 550	0	0	0	22 900	27 570	167 520	305 453	458 725	604 591	126 910	10 000
% of all hooks in STN target sets	47%	9%	0%	0%	0%	13%	9%	34%	50%	81%	89%	34%	5%
<b>2006</b>													
No. hooks in all sets	3 664 419	85 860	79 410	94 980	132 230	215 660	280 476	484 945	666 905	620 000	566 758	299 590	137 605
No. hooks in STN target sets	1 531 003	400	5 800	0	6 400	3 215	11 160	107 580	305 320	503 770	454 868	123 490	9 000
% of all hooks in STN target sets	42%	0%	7%	0%	5%	1%	4%	22%	46%	81%	80%	41%	7%
<b>2007</b>													
No. hooks in all sets	3 655 197	69 793	60 764	90 509	160 954	166 592	309 073	531 145	679 466	490 890	668 248	303 552	124 211
No. hooks in STN target sets	1 979 841	0	0	0	0	11 385	79 210	250 700	458 095	452 040	643 488	84 923	0
% of all hooks in STN target sets	54%	0%	0%	0%	0%	7%	26%	47%	67%	92%	96%	28%	0%
<b>2008</b>													
No. hooks in all sets	2 235 983	40 282	60 290	80 320	107 730	146 565	192 315	284 060	577 300	249 462	247 577	203 332	46 750
No. hooks in STN target sets	1 140 074	0	0	0	0	1 900	26 605	144 070	455 730	190 272	219 867	101 630	0
% of all hooks in STN target sets	51%	0%	0%	0%	0%	1%	14%	51%	79%	76%	89%	50%	0%
<b>2009</b>													
No. hooks in all sets	3 113 583	38 200	89 900	76 150	101 810	165 307	282 568	282 660	637 275	714 250	410 008	218 990	96 465
No. hooks in STN target sets	1 498 666	0	0	0	0	1 990	17 588	18 970	434 780	653 005	313 083	59 250	0
% of all hooks in STN target sets	48%	0%	0%	0%	0%	1%	6%	7%	68%	91%	76%	27%	0%
<b>2010</b>													
No. hooks in all sets	2 988 545	56 090	121 460	119 200	134 445	203 435	334 418	307 860	698 183	406 455	369 048	192 231	45 720
No. hooks in STN target sets	1 581 508	0	0	0	0	0	19 150	33 810	607 163	397 575	339 398	156 712	27 700
% of all hooks in STN target sets	53%	0%	0%	0%	0%	0%	6%	11%	87%	98%	92%	82%	61%
<b>2011</b>													
No. hooks in all sets	3 186 019	45 130	113 750	134 425	179 675	281 313	307 248	351 198	751 595	433 575	231 036	251 994	105 080
No. hooks in STN target sets	1 351 405	12 730	1 150	6 130	19 940	26 430	8 550	46 000	589 225	406 745	136 426	94 779	3 300
% of all hooks in STN target sets	42%	28%	1%	5%	11%	9%	3%	13%	78%	94%	59%	38%	3%
<b>2012</b>													
No. hooks in all sets	3 101 192	51 070	93 640	109 880	168 390	243 110	309 905	316 688	763 064	452 010	309 705	223 250	60 480
No. hooks in STN target sets	1 611 669	0	0	0	65	3 750	78 730	201 110	709 639	409 380	154 365	43 100	11 530
% of all hooks in STN target sets	52%	0%	0%	0%	0%	2%	25%	64%	93%	91%	50%	19%	19%
<b>2013</b>													
No. hooks in all sets	2 658 742	34 560	95 360	87 965	122 760	183 065	424 385	201 510	600 819	442 239	303 997	134 566	27 516
No. hooks in STN target sets	1 472 033	1 000	0	0	2 000	13 950	113 040	90 414	547 176	336 339	255 337	101 236	11 541
% of all hooks in STN target sets	55%	3%	0%	0%	2%	8%	27%	45%	91%	76%	84%	75%	42%

**Table 3: Catch (numbers) by month in the surface longline fishery for fishing years 2005 to 2013 for blue shark (BWS) from all sets and STN target sets) and for southern bluefin tuna (from STN target sets).**

Fishing year	Total	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
<b>2005</b>													
BWS catch (nos) from all sets	13 539	7	85	94	120	57	212	872	1 564	4 318	3 933	1 873	404
BWS catch (nos) from STN target sets	11 018	0	-	-	-	0	0	571	1 279	4 119	3 783	1 265	1
STN catch (nos) from STN target sets	2 682	0	-	-	-	0	0	161	441	487	1 536	56	1
% of all BWS catch that is caught in STN sets	81%	0%	-	-	-	0%	0%	65%	82%	95%	96%	68%	0%
Ratio of BWS catch to STN catch in STN sets	4.11	no STN	-	-	-	no STN	no STN	3.55	2.90	8.46	2.46	22.59	1.00
<b>2006</b>													
BWS catch (nos) from all sets	19 168	73	86	314	240	306	232	514	2 696	4 694	5 502	3 268	1 243
BWS catch (nos) from STN target sets	15 161	0	0	-	42	0	7	350	2 145	4 122	4 987	3 089	419
STN catch (nos) from STN target sets	2 452	0	0	-	0	0	1	204	520	731	862	134	0
% of all BWS catch that is caught in STN sets	79%	0%	0%	-	18%	0%	3%	68%	80%	88%	91%	95%	34%
Ratio of BWS catch to STN catch in STN sets	6.18	0	0	-	0	0	7.00	1.72	4.13	5.64	5.79	23.05	-
<b>2007</b>													
BWS catch (nos) from all sets	23 679	68	351	107	390	585	482	983	5 447	4 922	8 259	1 710	375
BWS catch (nos) from STN target sets	17 917	-	-	-	-	107	98	486	3 291	4 644	8 186	1 105	0
STN catch (nos) from STN target sets	3 975	-	-	-	-	0	31	274	877	854	1 774	165	0
% of all BWS catch that is caught in STN sets	76%	-	-	-	-	18%	20%	49%	60%	94%	99%	65%	0%
Ratio of BWS catch to STN catch in STN sets	4.51	-	-	-	-	no STN	3.16	1.77	3.75	5.44	4.61	6.70	-
<b>2008</b>													
BWS catch (nos) from all sets	19 598	28	35	122	123	343	301	1 335	4 988	6 003	4 411	1 651	258
BWS catch (nos) from STN target sets	16 827	-	-	-	-	0	5	958	4 775	5 903	4 115	1 071	0
STN catch (nos) from STN target sets	4 192	-	-	-	-	0	0	617	2 356	762	386	71	0
% of all BWS catch that is caught in STN sets	86%	-	-	-	-	0%	2%	72%	96%	98%	93%	65%	0%
Ratio of BWS catch to STN catch in STN sets	4.01	-	-	-	-	-	no STN	1.55	2.03	7.75	10.66	15.08	-
<b>2009</b>													
BWS catch (nos) from all sets	25 075	59	117	164	116	233	258	827	4 623	7 751	7 690	2 916	321
BWS catch (nos) from STN target sets	20 646	-	-	-	-	0	29	198	3 593	7 228	7 254	2 344	0
STN catch (nos) from STN target sets	6 251	-	-	-	-	0	26	112	1 894	2 697	1 417	105	0
% of all BWS catch that is caught in STN sets	82%	-	-	-	-	0%	11%	24%	78%	93%	94%	80%	0%
Ratio of BWS catch to STN catch in STN sets	3.30	-	-	-	-	-	1.12	1.77	1.90	2.68	5.12	22.32	-
<b>2010</b>													
BWS catch (nos) from all sets	35 634	216	203	258	281	291	372	968	6 869	10 190	10 958	4 694	334
BWS catch (nos) from STN target sets	31 996	-	-	-	-	-	20	400	6 422	10 051	10 474	4 328	301
STN catch (nos) from STN target sets	8 259	-	-	-	-	-	0	64	3 646	1 906	2 086	514	43
% of all BWS catch that is caught in STN sets	90%	-	-	-	-	-	5%	41%	93%	99%	96%	92%	90%
Ratio of BWS catch to STN catch in STN sets	3.87	-	-	-	-	-	no STN	6.25	1.76	5.27	5.02	8.42	7.00
<b>2011</b>													
BWS catch (nos) from all sets	31 117	390	320	358	314	508	379	1 476	8 689	9 892	5 073	3 262	456
BWS catch (nos) from STN target sets	24 302	150	22	63	141	171	13	362	6 720	9 807	4 510	2 257	86
STN catch (nos) from STN target sets	8 708	5	2	0	1	3	0	117	3 596	3 485	1 134	358	7
% of all BWS catch that is caught in STN sets	78%	38%	7%	18%	45%	34%	3%	25%	77%	99%	89%	69%	19%
Ratio of BWS catch to STN catch in STN sets	2.79	30.00	11.00	no STN	141.00	57.00	no STN	3.09	1.87	2.81	3.98	6.30	12.29
<b>2012</b>													
BWS catch (nos) from all sets	53 731	234	241	261	415	288	1 397	5 017	17 593	14 990	9 539	3 196	560
BWS catch (nos) from STN target sets	46 232	-	-	-	9	18	849	3 697	17 095	14 595	8 107	1 691	171
STN catch (nos) from STN target sets	12 912	-	-	-	0	14	664	1 977	4 840	3 516	1 536	333	32
% of all BWS catch that is caught in STN sets	86%	-	-	-	2%	6%	61%	74%	97%	97%	85%	53%	31%
Ratio of BWS catch to STN catch in STN sets	3.58	-	-	-	no STN	1.29	1.28	1.87	3.53	4.15	5.28	5.08	5.34
<b>2013</b>													
BWS catch (nos) from all sets	62 745	130	299	133	166	689	3 112	2 769	15 041	13 550	18 936	6 073	1 847
BWS catch (nos) from STN target sets	56 375	8	-	-	11	163	1 966	1 916	14 170	12 623	18 228	5 692	1 598
STN catch (nos) from STN target sets	11 481	0	-	-	2	24	682	894	3 321	3 153	2 476	924	5
% of all BWS catch that is caught in STN sets	90%	6%	-	-	7%	24%	63%	69%	94%	93%	96%	94%	87%
Ratio of BWS catch to STN catch in STN sets	4.91	no STN	-	-	5.50	6.79	2.88	2.14	4.27	4.00	7.36	6.16	319.60

**Table 4: Number of records (sets) in the surface longline dataset for fishing years 2005 to 2013, and number of records where the target species was STN.**

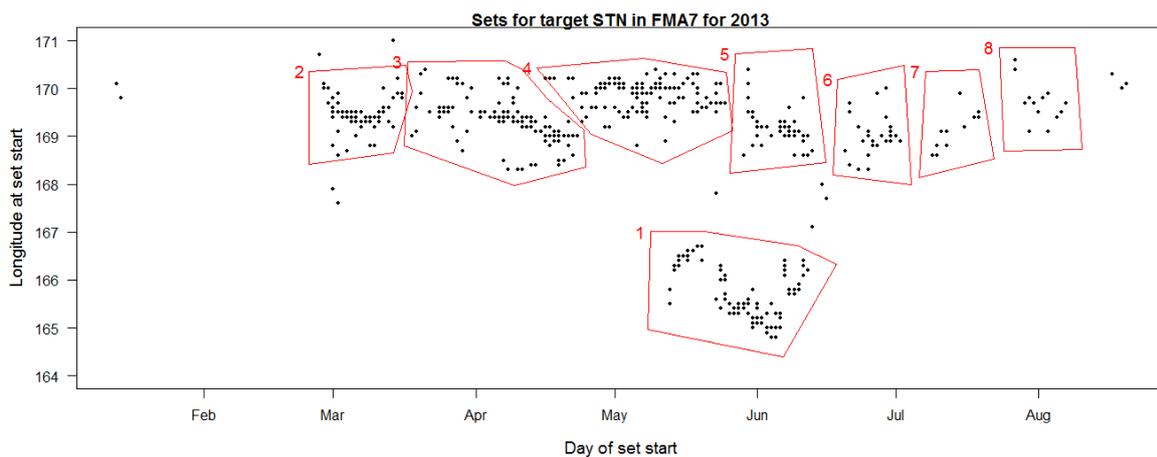
Fishing year	All sets	Sets targeting STN	Sets targeting STN as a % of all sets
2005	2 989	1 160	38.8%
2006	3 030	1 023	33.8%
2007	2 664	992	37.2%
2008	1 932	750	38.8%
2009	2 628	940	35.8%
2010	2 834	1 300	45.9%
2011	2 885	1 014	35.1%
2012	2 784	1 242	44.6%
2013	2 595	1 275	49.1%
Total	24 341	9 696	39.8%

## 2.4 Data analyses

- **In surface longline sets targeting southern bluefin tuna, do blue shark catch rates decline in an area after it has been fished for a few days?**

Exploratory analysis of the data was conducted on sets targeting STN in FMAs 1, 2, 5, and 7.

Scatterplots of start date versus latitude (or longitude) at the start of the set for all the STN targeted sets in each FMA for each fishing year were constructed. This allowed for a manual search of groups of sets that appear to be clustered in space and time (e.g. Figure 1).



**Figure 1: Scatterplot of SLL sets in fishing year 2013 and FMA 7 by day and longitude at the start of the set. Numbered polygons are groups of sets selected and analysed separately.**

For each group of sets, plots of localised catch rates by vessel and accumulated catches by day for BWS and STN were produced. For example, plots of Group 1 from Figure 1 are shown in Figure 2. There were 97 selected sets, from four vessels on 29 days of sets, covering the period 13 May to 12 June 2013, and a spatial polygon that roughly extends over 2.1 and 1.9 degrees latitude and longitude. Species catch rates (numbers per 1000 hooks) for each set are plotted by day, and colour coded by vessel (although each vessel is not uniquely identified).

A least squares regression line was fitted to the catch rates for each vessel (coloured lines). No line was fitted if a vessel was represented by a single set. A least squares regression line (in black) was also fitted to the catch rates for all the sets. These regression lines were fitted to the data automatically using the `geom-smooth` option in the R package `ggplot2`, assuming that the data were independent and identically distributed. These assumptions were not tested for each fit, and some correlation of set characteristics within and between vessels is likely considering individual and combined fisher behaviour may be contributing to some group effect on catch rates. The uncertainty associated with the regression fits is not reported. These lines are used to indicate (rather than evaluate) any trend in catch rates for each vessel in the group of selected sets, as well as any trend in catch rate for all vessels in the selected spatio-temporal combination.

Where more than 5 or 6 vessels are included over longer time periods (more than about 10 days), it becomes difficult to differentiate between vessels in the plots, and colours will be repeated and may not be unique for all the vessels, although the regression lines will still be unique for each vessel. Plots of accumulated catch by day for BWS and STN are included as an indication of the overall numbers caught in each spatio-temporal block. Be aware of differences in y-axis scales when comparing plots.

The number of plots included in this report is limited to those that illustrate the range of patterns observed.

2013 FMA7 -44.2 to -42.1 164.8 to 166.7

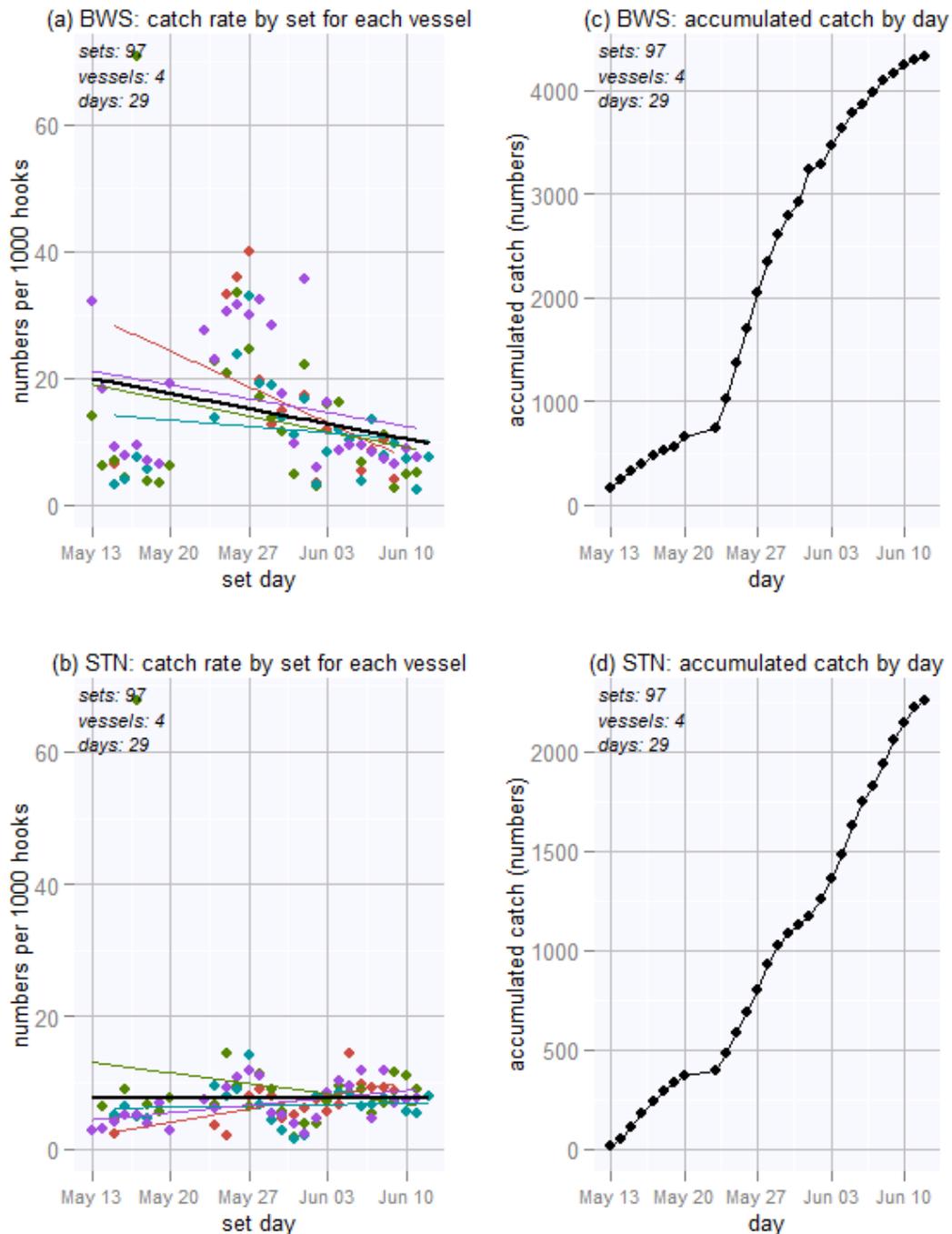


Figure 2: SLL sets targeting STN in FMA7 where set was started in the time period May 13<sup>th</sup> 2013 to 12<sup>th</sup> June 2013 within the spatial limits -44.2 to -42.1 latitude and 164.8 to 166.7 longitude (includes 97 sets, from four vessels, on 29 days). Individual plots are: catch rate (numbers per 1000 hooks) by set for each vessel with regression lines by vessel (coloured) and for all sets (black) for BWS (a) and STN (b); and accumulated catch (numbers) by day for BWS (c) and STN (d) .

- **Environmental factors affecting the decline in blue shark catch rates.**

Distribution maps by month (in Appendices) were constructed for each fishing year:

Effort as the number of hooks set by the surface longline fishery targeting STN in 0.5 degree latitude/longitude rectangles;

BWS catches as the number of blue sharks caught by the surface longline fishery targeting STN in 0.5 degree latitude/longitude rectangles;

BWS catch rates as numbers of blue sharks caught per 1000 hooks set by the surface longline fishery targeting STN, with total catch divided by total effort in 0.5 degree latitude/longitude rectangles; and

Mean sea surface temperature (SST) for sets targeting STN in the surface longline fishery targeting STN in 0.5 degree latitude/longitude rectangles.

Three dimensional views of effort, catch rate for STN and catch rate for BWS (in Results) were constructed for all sets in the surface longline fishery and for sets that target STN in relation to: time and sea surface temperature.

### 3. RESULTS

#### 3.1 Localised decline in BWS catch rates

Patterns of localised decline in blue shark catch rates were evident in each of the four FMAs in all fishing years. Examples from the Japanese charter fleet in FMAs 5 and 7 serve to highlight the general patterns found throughout the data set. Examples from the domestic fleet are also presented.

##### Charter fleet examples

In FMA 5, the Japanese charter vessel sets were straightforward to identify as a group as they were the only vessels in the area targeting STN. In Figure 3, all sets for each of four fishing years (2010 – 2013) are shown. Most (but not all) vessels show an overall declining BWS catch rate, with the catch rate over all sets in each fishing year showing a decline in BWS catch rate. While the spatial scale is similar over the four years, the temporal scale is not, with fewer set days (16 and 18 days) for 2012 and 2013 occurring over a shorter time period, compared to 37 and 27 set days for 2010 and 2011 over a longer time period. While effort occurs, generally, on a daily basis in these groups, there are distinct breaks of a couple of days (e.g. late-May 2011, mid-May 2013), and for over a week in mid-May 2012. Patterns of decline may differ depending on how sets are grouped over time.

Localised patterns of decline in BWS catch rates may also differ depending on how sets are grouped spatially. Looking once again at the Japanese charter fleet, this time in FMA 7, Figure 4 (1a) includes all sets in fishing year 2013 and shows a decline in catch rate for all four vessels. These 97 sets occur within the spatial limits -44.2 to -42.1° latitude and 165.8 to 166.7° longitude. However, the rates of decline and the numbers of BWS being caught are different for two subgroups. When the fleet began fishing in the area, the first eight days of sets were within the latitudes -44.2 to -43.9°, with catch rates for the first sets at just over 30 per 1000 hooks, declining to less than 20 per 1000 hooks, and the accumulated catch at the end of this period was less than 700. The fleet then extended its effort spatially for the next 24 days of sets, with catch rates at the beginning of this period at 20 – 40 per 1000 hooks, declining to less than 10 per 1000 hooks at the end of the period. The accumulated catch for this second group was nearly 4000 (Figure 4–1c).

In another example, again with the Japanese fleet in FMA 7, Figure 5 (1a) includes all sets in fishing year 2012 and once again we see the pattern of declining BWS catch rates over all the sets as the fleet arrived in the area and continued fishing for a month from mid-May to mid-June. However, for the first

13 days of this period the fleet is concentrated spatially further south-east than the later fishing effort. Catch rates during the first period show a definite decline for all vessels (Figure 5-2a). However, during the second period, two of the four vessels show an increase in catch rate, and over all sets the catch rate increases. The accumulated catch in each time period is similar at approximately 2500 (Figure 5-2c).

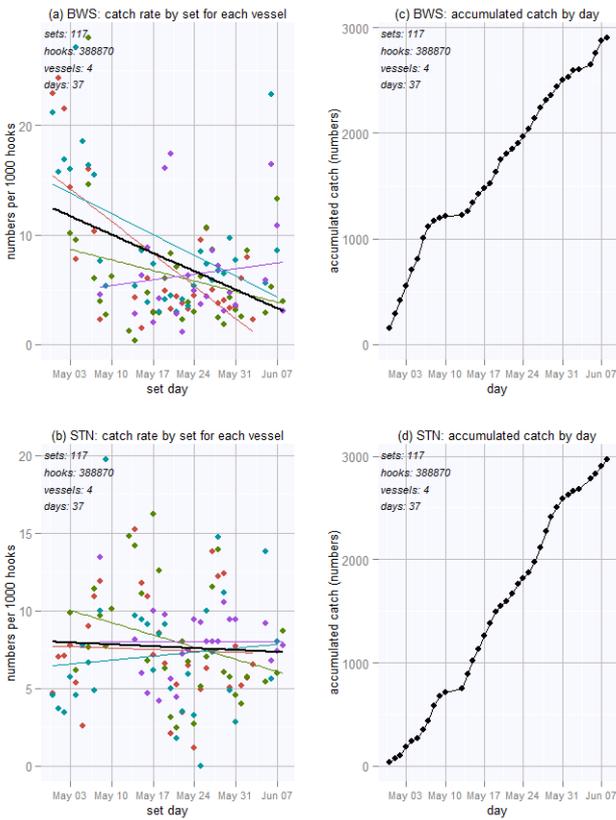
### Domestic fleet examples

Exploring catch rate trends for groups of domestic sets in FMA 7 for the fishing year 2012 further highlights the issue of determining over what spatio-temporal scale these rates are considered meaningful. The four plots in Figure 6 illustrate the catch rates for sets within similar spatial limits but for increasing time periods from when vessels arrive in the area, i.e. from 8 March 2012: to 2 April (Figure 6-1a); to 10 April (Figure 6-2a); to 26 April (Figure 6-3a); and to 9 May (Figure 6-4a). Four vessels were fishing during March, with one vessel experiencing a decline in BWS catch rate. A further four vessels came into the area in late March and early April. Catch rates declined for two of these vessels, one vessel reported zero BWS catches, and over all sets BWS catch rate declined. The three other catch rate plots show the number of vessels in the area increasing from 8 to 11, 16 and then 18 as time extends from the start of fishing in this area. BWS catch rates for some vessels decline depending on the time frame, and increase for others. Over all sets the BWS catch rate stays in decline until the time period extends into the third month.

At the other end of the season, seven domestic vessels are fishing in FMA 7. Figure 7 (1a) includes all sets by these vessels from 19 June 2012 to 16 August 2012. Two of the vessels show an appreciable decline in BWS catch rate, but over all sets there is a minimal decline in catch rate. By restricting the temporal scale for these sets, we see different catch rate patterns. From 19–25 June 2012 (Figure 7-2a), three of six vessels show a declining catch rate, but over all sets the catch rate increases. After this period, from 29 June to 22 July 2012 (Figure 7-3a), two vessels show declining catch rates (the third vessel makes only one set). If this period is extended to the end of the season, 29 June to 16 August 2012 (Figure 7-4a), one of the vessels remained in the area and the set catch rates increased from the end of the period prior, before decreasing again. Examples of BWS catch rates in FMAs 1 and 2 exhibit varying trends. In 2012 fishing year from late-June to mid-July most of the 14 vessels show an increase in catch rate, with several vessels recording zero BWS catches for all their sets (Figure 8-1a). In 2013, from mid-June to late-July, there was a mix of increasing and declining catch rates by vessel, with several vessels recording zero BWS catches for all sets (Figure 8-2a). Similar patterns of catch rates and zero catches are found in the data for FMA 2 in fishing years 2012 and 2013 (Figure 8-3a and 8-4a).

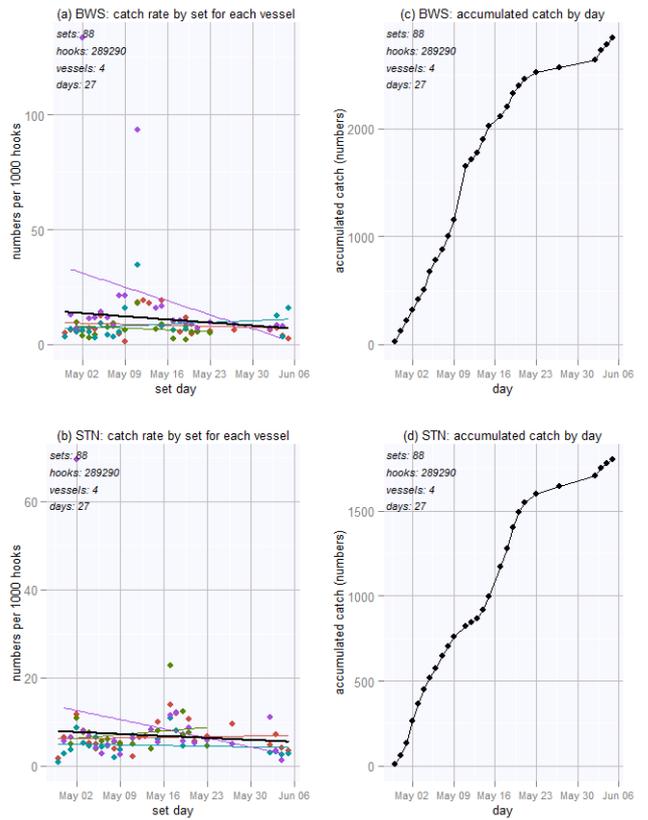
(1)

2010 FMA5 -45.4 to -44.3 164.3 to 166.1



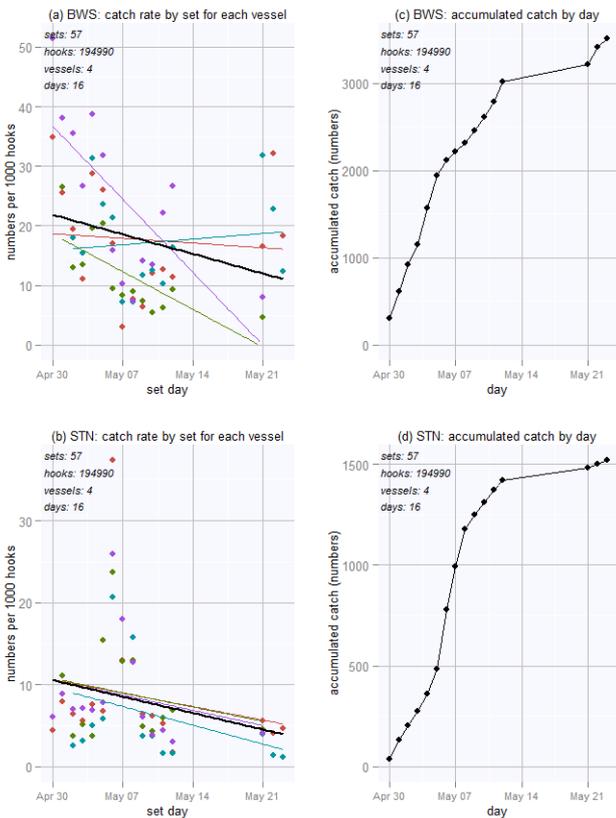
(2)

2011 FMA5 -45.6 to -44.3 164.4 to 165.9



(3)

2012 FMA5 -45.2 to -44.3 164.8 to 165.8



(4)

2013 FMA5 -46 to -44.3 164.6 to 166.8

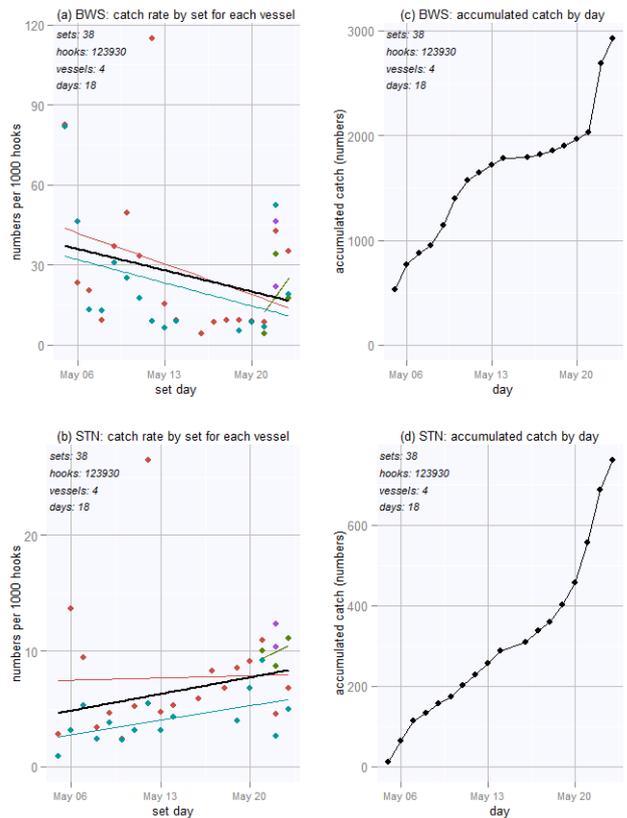
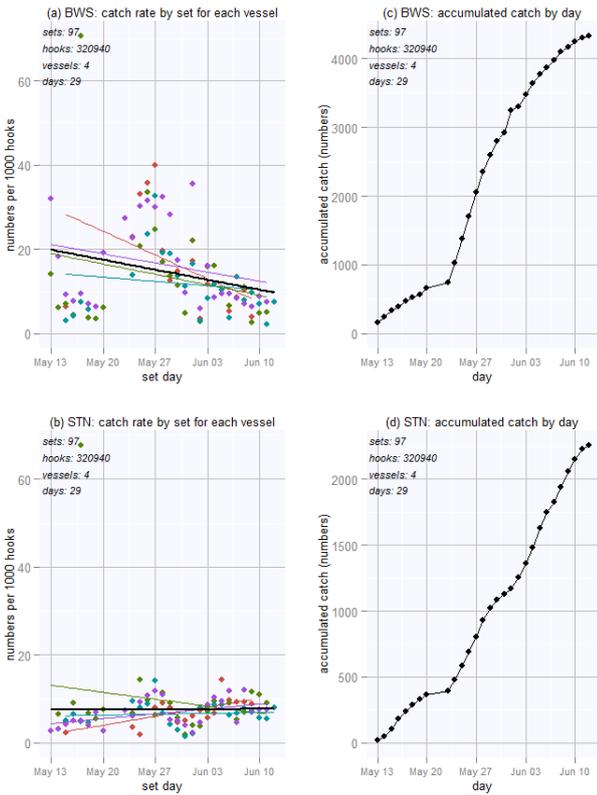


Figure 3: Catch rate plots for groups of sets selected from FMA 5 for fishing years 2010 (1), 2011 (2), 2012 (3), and 2013 (4).

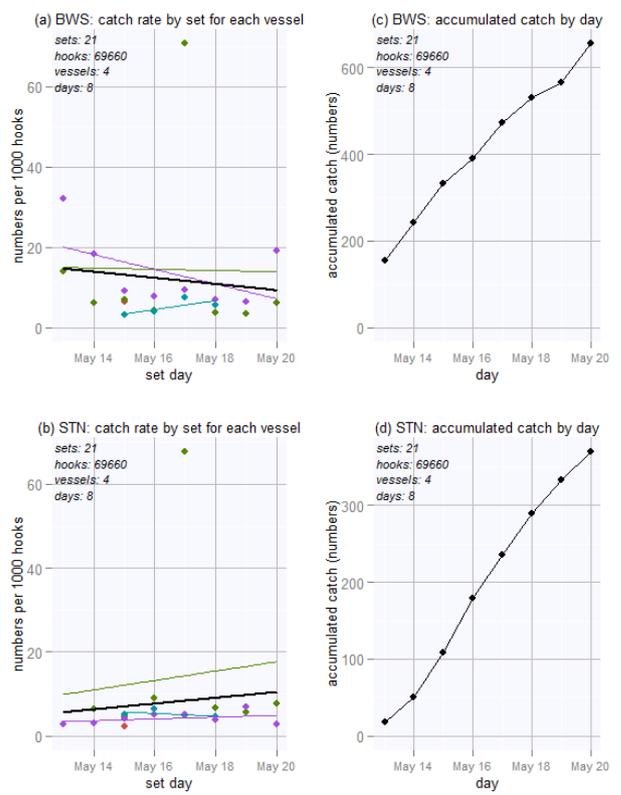
(1)

2013 FMA7 -44.2 to -42.1 164.8 to 166.7



(2)

2013 FMA7 -44.2 to -43.9 165.5 to 166.7



(3)

2013 FMA7 -44.2 to -42.1 164.8 to 166.4

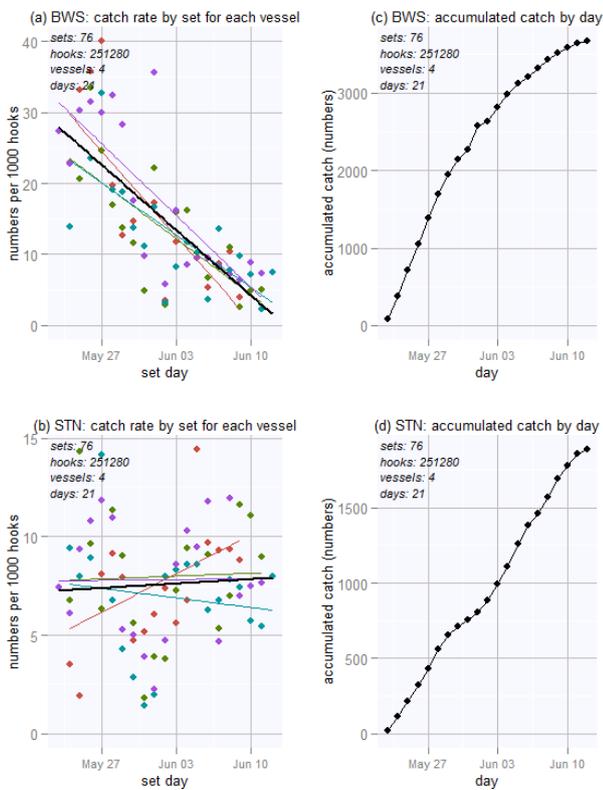
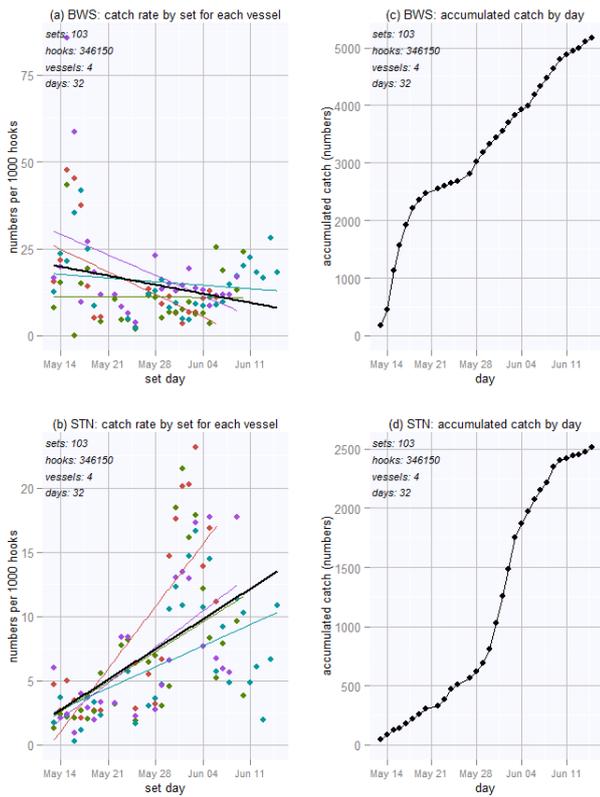


Figure 4: Catch rate plots for groups of sets selected from FMA 7 in 2013 fishing year with (1) all sets for Japanese charter vessels; (2) early sets for Japanese charter vessels; and (3) later sets for Japanese charter vessels.

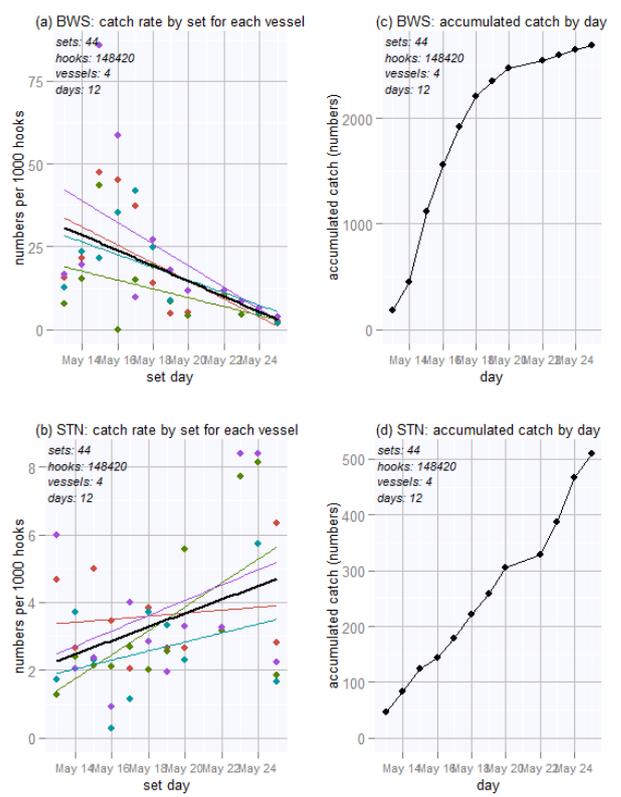
(1)

2012 FMA7 -44.2 to -41.9 164.2 to 167.6



(2)

2012 FMA7 -44.2 to -43.2 164.2 to 166.3



(3)

2012 FMA7 -43.3 to -41.9 165.6 to 167.6

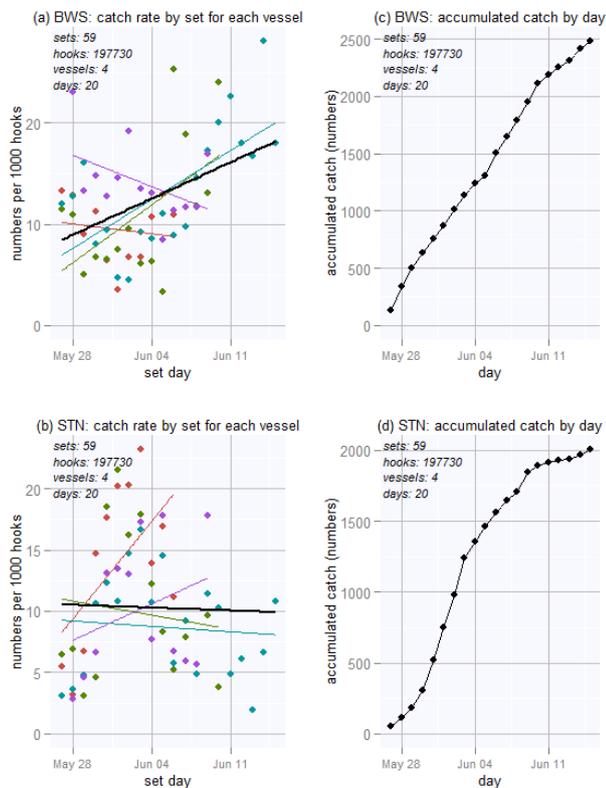
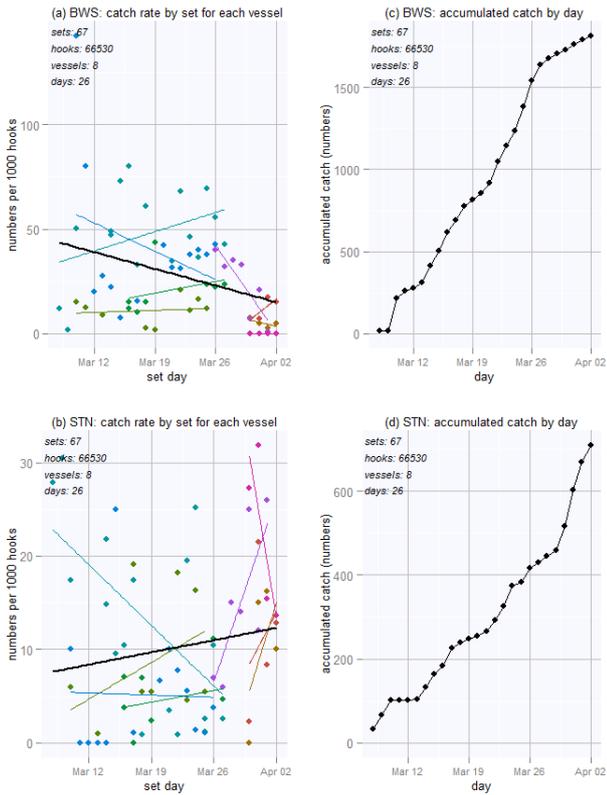


Figure 5: Catch rate plots for groups of sets selected from FMA 7 in 2012 fishing year with (1) all sets for Japanese charter vessels; (2) early sets for Japanese charter vessels; and (3) later sets for Japanese charter vessels.

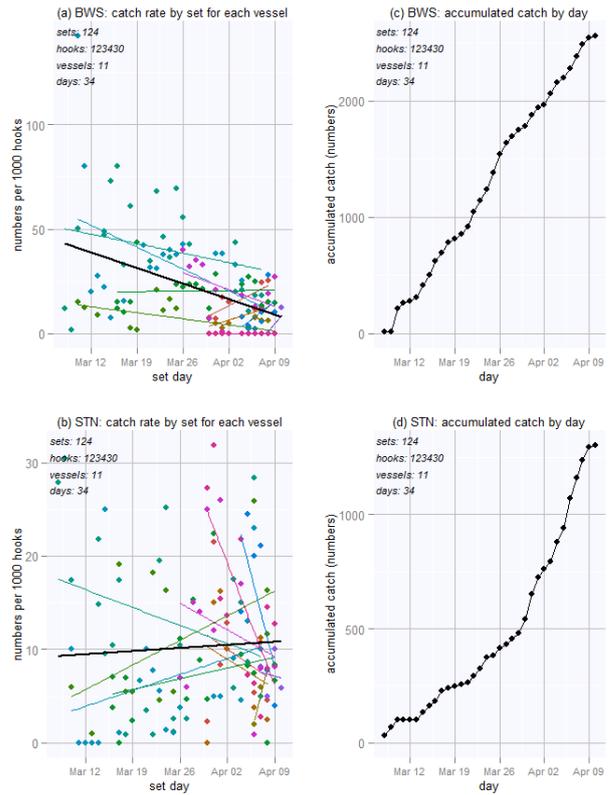
(1)

2012 FMA7 -42.5 to -40.7 167.9 to 171



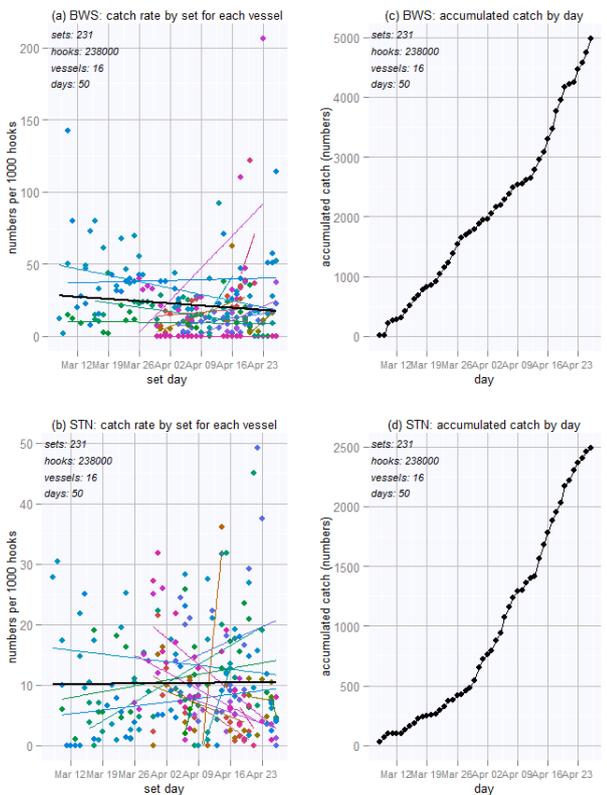
(2)

2012 FMA7 -42.9 to -40.5 167.9 to 171



(3)

2012 FMA7 -42.9 to -40 167.9 to 171.2



(4)

2012 FMA7 -42.9 to -39.9 167.9 to 171.2

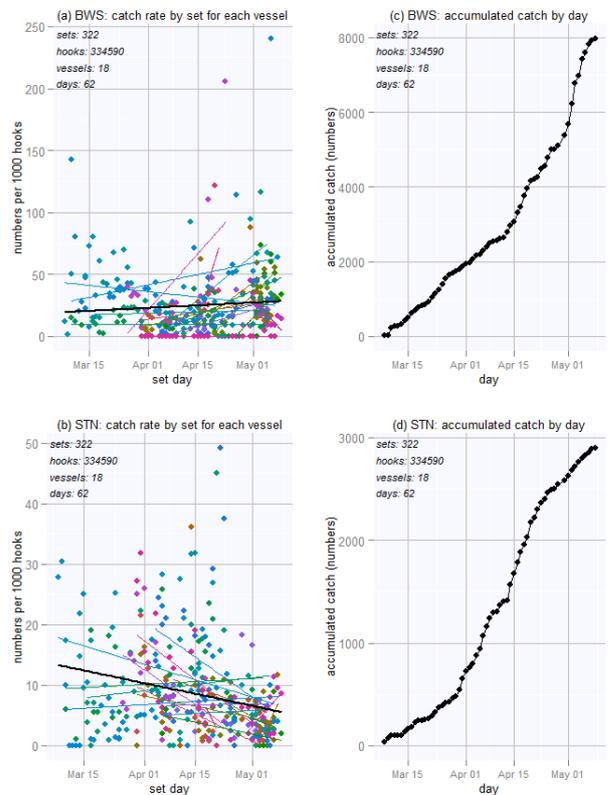
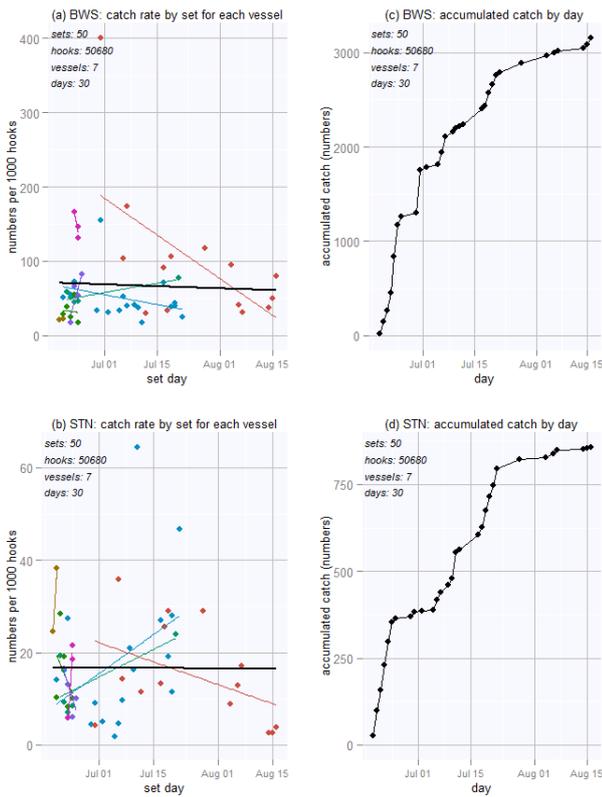


Figure 6: Catch rate plots for groups of sets by domestic vessels selected from FMA 7 in 2012 fishing for time periods extending from the start of fishing on 8 March 2012 to: 2 April (1); 10 April (2); 26 April (3); and 9 May (4).

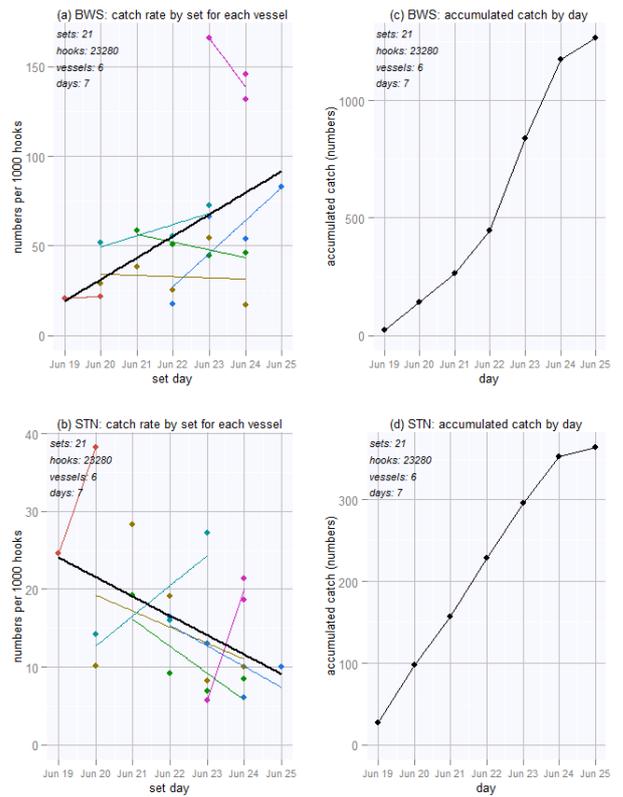
(1)

2012 FMA7 -42.4 to -41.4 168.6 to 170



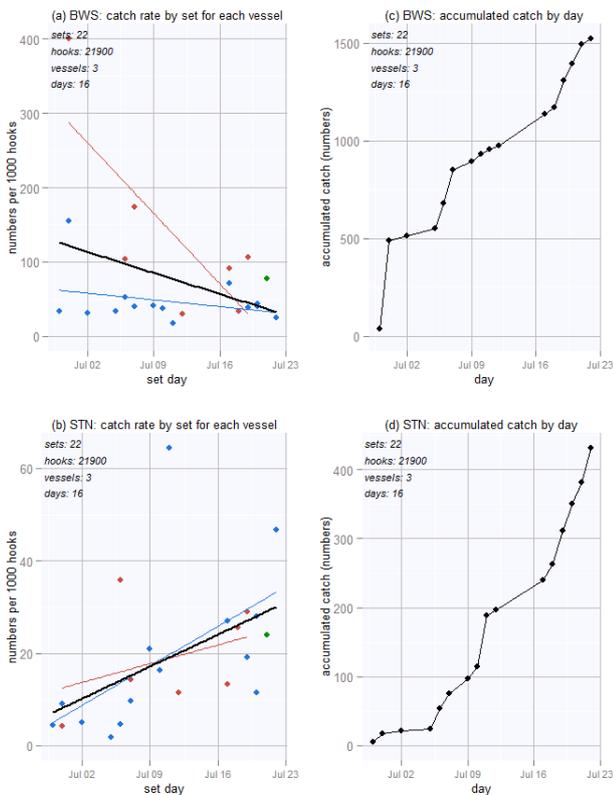
(2)

2012 FMA7 -42.4 to -41.5 168.6 to 169.6



(3)

2012 FMA7 -42.4 to -41.9 169 to 170



(4)

2012 FMA7 -42.4 to -41.4 168.9 to 170

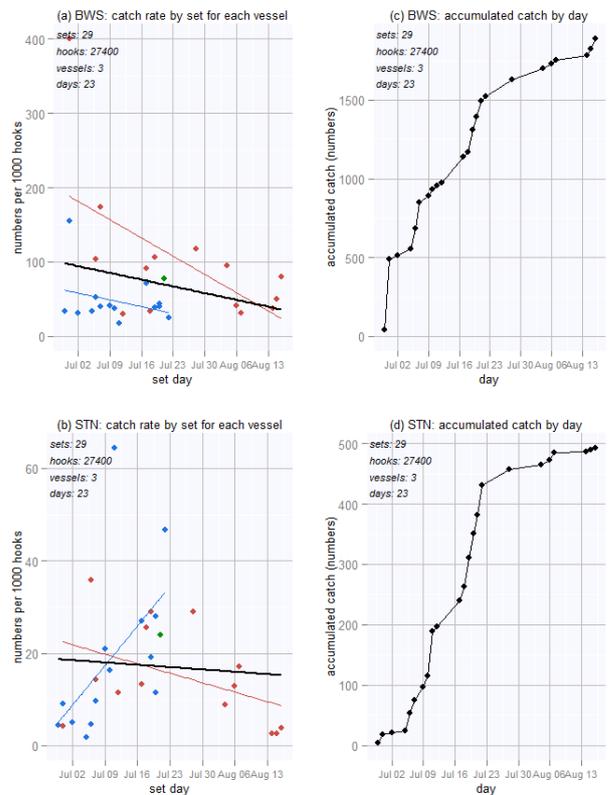
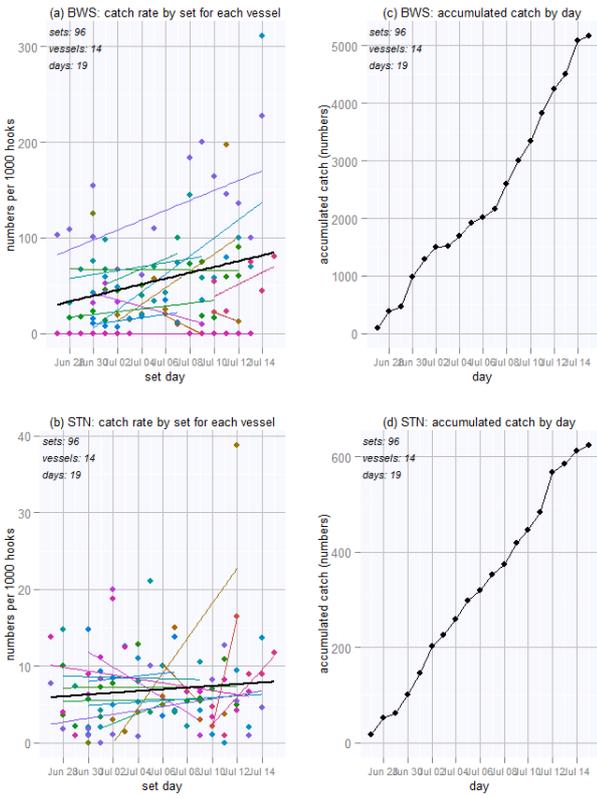


Figure 7 Catch rate plots for groups of sets by domestic vessels selected from FMA 7 in four time periods in the second half of the 2012 fishing year.

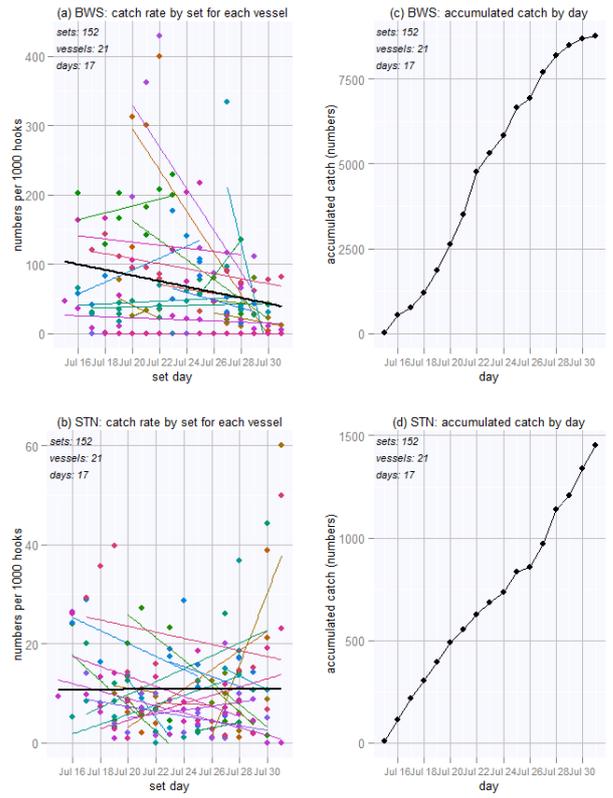
(1)

2012 FMA1 -37 to -35.5 176.4 to 177.9



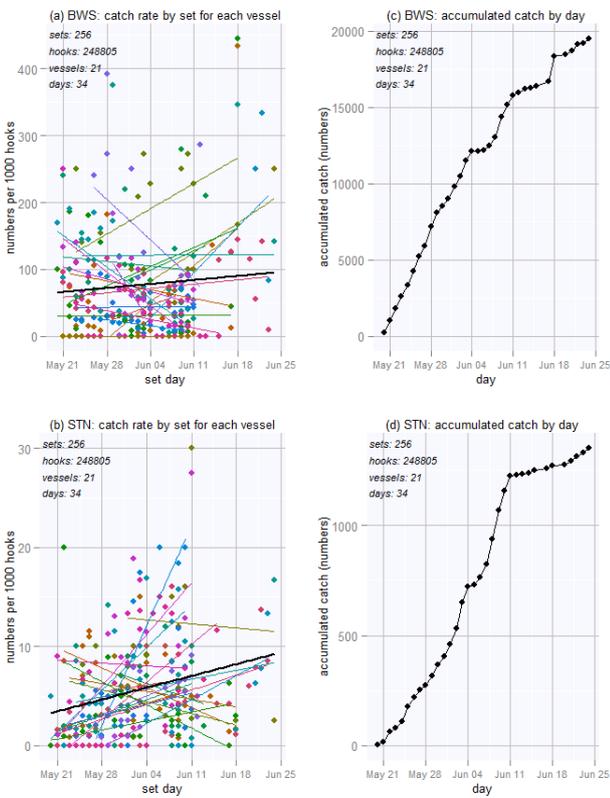
(2)

2013 FMA1 -37.2 to -35.6 176.6 to 177.9



(3)

2012 FMA2 -40.5 to -36.5 177.5 to 179.9



(4)

2013 FMA2 -40.1 to -37.7 178.1 to 179.6

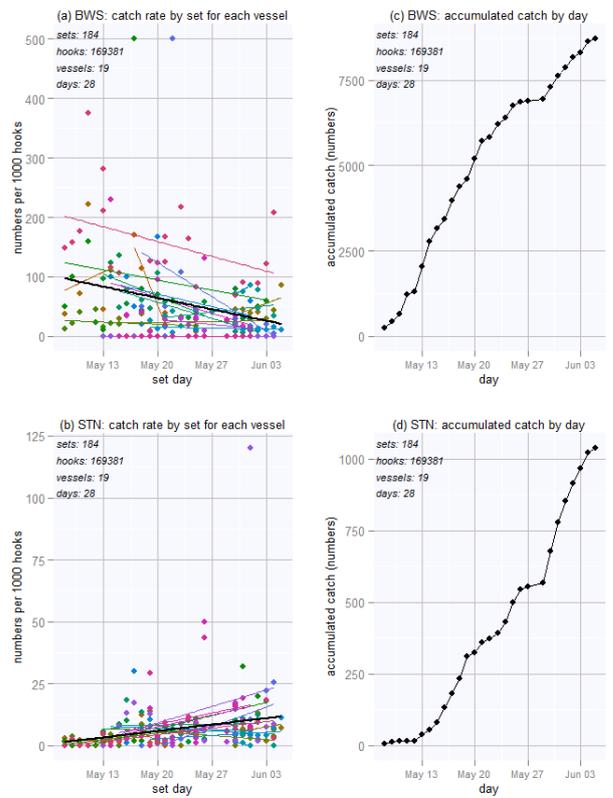


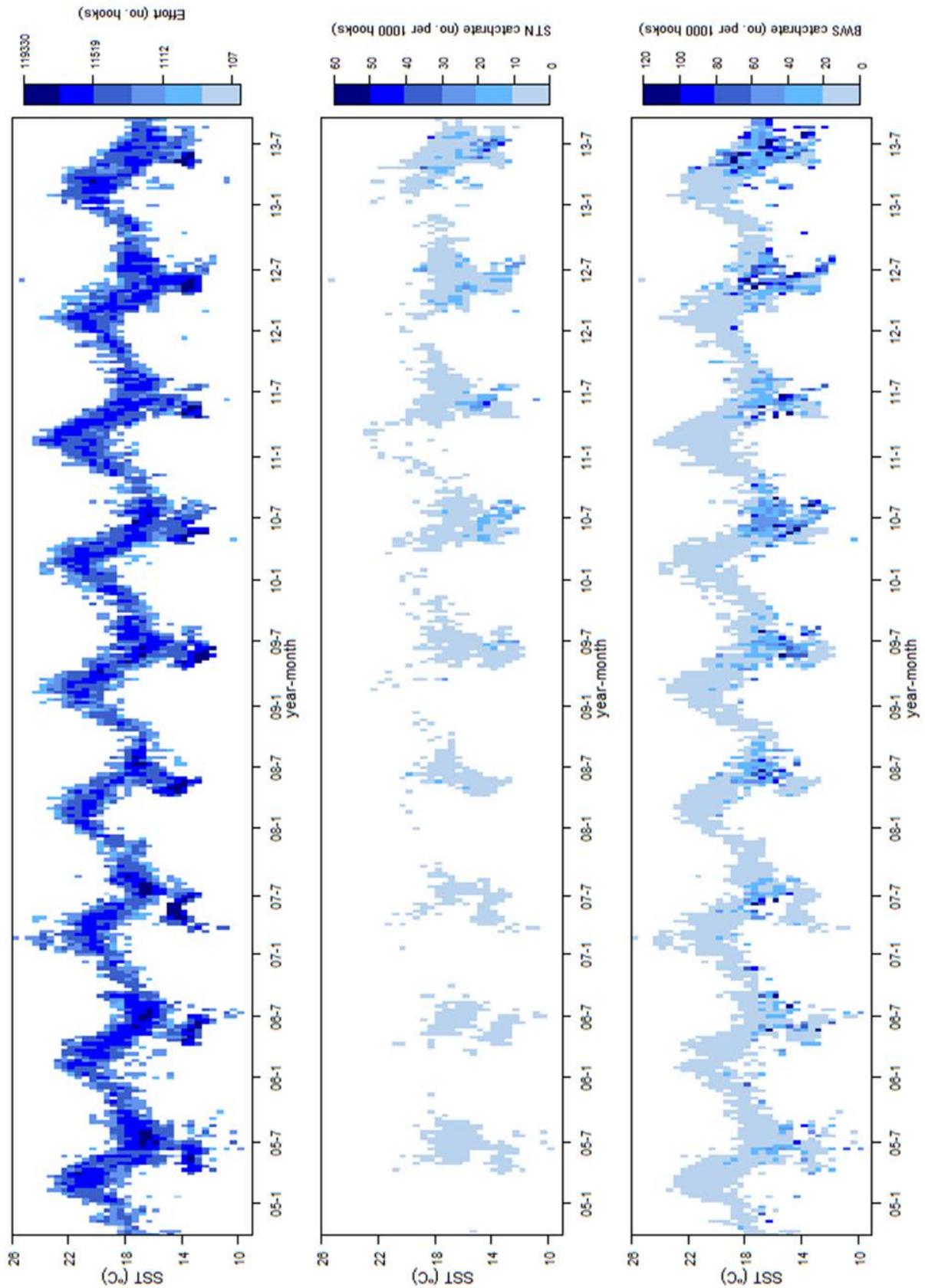
Figure 8: BWS catch rate trends in FMA 1, fishing years 2012 (1), 2013 (2); and in FMA 2, fishing years 2012 (3), 2013 (4)

### **3.2 Distribution of fishing effort and catch rates in relation to sea surface temperature**

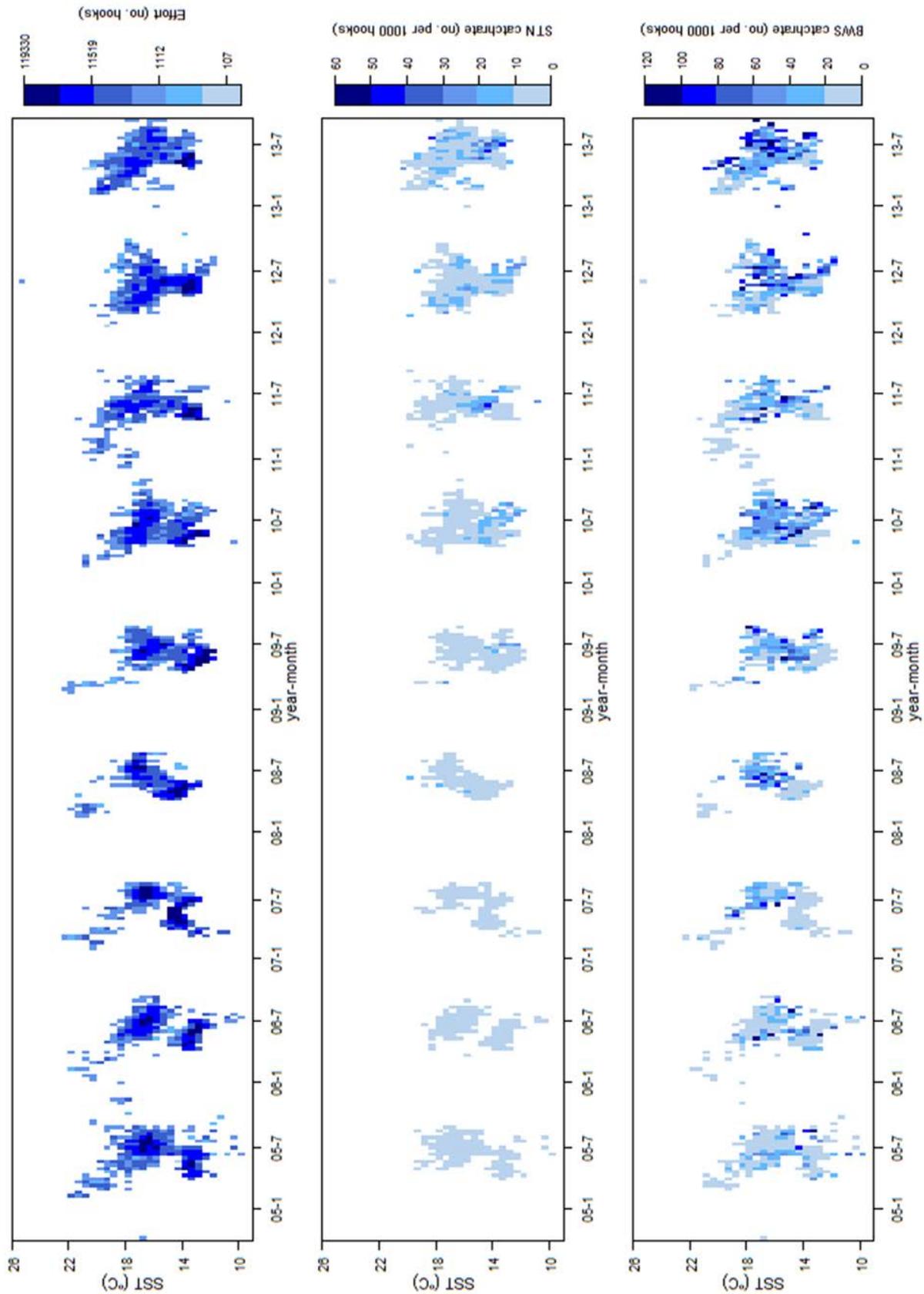
Fishing effort (number of hooks set) targeting STN occurs in most months each fishing year. In general, the main season begins in May in FMAs 5 and 7 (in the Southwest) and FMA 2 in the Northeast, although in some years may be earlier (March or April). In June and July effort moves north in both areas: the Southwest effort is concentrated in FMA 7 and the northeast effort extends into FMA 1. By August, effort is concentrated in FMA 1 and a more restricted area in FMA 7 (see distribution maps in Appendices). This suggests that the fishery starts further south in both the Southwest and Northeast areas, and moves progressively north throughout the winter towards spring.

Blue shark are caught in most sets (Figure 9-right), and in most sets targeting STN (Figure 10-right), whereas STN tend to be caught when they are targeted (Figure 9-middle, Figure 10-middle). The sea surface temperature recorded by vessels follows a seasonal trend of warmer temperatures in summer and cooler in winter, with most effort each year at temperatures below about 20 °C (Figure 9-left), and more intense effort tending to occur at cooler temperatures below 15–16 °C.

Blue sharks are caught at all the temperatures (approx. 12–24 °C) in which the surface longline fishery operates (Figure 9-right), but catch rates tend to be higher at lower temperatures (less than 20 °C) and higher in sets that target STN (Figure 10-right). In sets that target STN, the highest catch rates for STN tend to be at a lower and more restricted SST range of 12–16 °C (Figure 10-middle) than the highest BWS catch rates which are in the SST range 12–20 °C (Figure 10-right).



**Figure 9: Sea Surface Temperature, All Sets.** Three dimensional view of effort (left), STN catch rate (middle) and BWS catch rate (right) for all sets in the surface longline fishery for fishing years 2005 to 2013. Each cell (colour gradient) represents the total effort (number of hooks) or the total catch divided by the total effort (numbers per 1000 hooks) by sea surface temperature at 0.5 °C intervals (y-axis) and by time at 2 week intervals (x-axis).



**Figure 10: Sea Surface Temperature for STN Target Sets. Three dimensional view of effort (left), STN catch rate (middle) and BWS catch rate (right) for sets targeting STN in the surface longline fishery for fishing years 2005 to 2013. Each cell (colour gradient) represents the total effort (number of hooks) or the total catch divided by the total effort (numbers per 1000 hooks) by sea surface temperature at 0.5 °C intervals (y-axis) and by time at 2 week intervals (x-axis).**

## 4. DISCUSSION

Francis, et al. (2014) concluded that there has been no overall decrease of abundance for blue shark in New Zealand in the past decade. This current study explored catch rates of blue shark by vessel on localised spatial and temporal scales within the surface longline fishery. Examples of “fishing down” of blue sharks by individual vessels and groups of vessels as they enter an area and begin to fish, as suggested by fishers, can be found in the data. However, the scale within both space and time over which these examples occur varies, and counter examples (where catch rates increase) can also be found for similar spatio-temporal scales.

In answer to the questions posed by S. Brouwer (page 2), while there is some evidence in the data to suggest that blue shark catch rates decline in a localised area after it has been fished for a few days, this study did not determine whether such changes were attributable to reductions in blue shark numbers in the immediate vicinity through either catch or some environmental factor. Further work is required to model any patterns in localised catch rate depletion of blue sharks and to determine if such a model can be used to predict potentially high blue shark catch rates associated with the Southern bluefin tuna fishery.

One possible approach is to build a predictive model of catch rates of blue sharks and southern bluefin tuna that characterises the movement of the fishery in relation to a spatio-temporal temperature profile (or some other environmental variable). This approach could build on methods currently used to investigate the effect of the environment on blue shark catch rates (e.g. general additive models as used by Bigelow et al. 1999, Mitchell et al. 2014), along with those that incorporate fisher behaviour (e.g. He et al. 1997 used cluster analysis based on catch composition to characterise fishing strategies).

Such models may also need to account for, simplify and make assumptions about: how the various migratory species move within the fishery throughout the year, various prey relationships, and how different metrics (e.g. SST, chlorophyll-a) may be indicative of (or proxies for) key features of blue shark ecology. Future work could build on recent studies by McGregor & Horn (2015) where SST and latitude were found to be influential contributors in modelling catch rates of highly migratory species in New Zealand waters, and by Horn et al. (2013) where the diets of highly migratory species in New Zealand waters were evaluated.

## 5. ACKNOWLEDGMENTS

I thank Ian Doonan for discussions and guidance on the analysis methodology. Malcolm Francis provided a valuable review of this document. The work was funded by the Ministry for Primary Industries under project SEA2013-11.

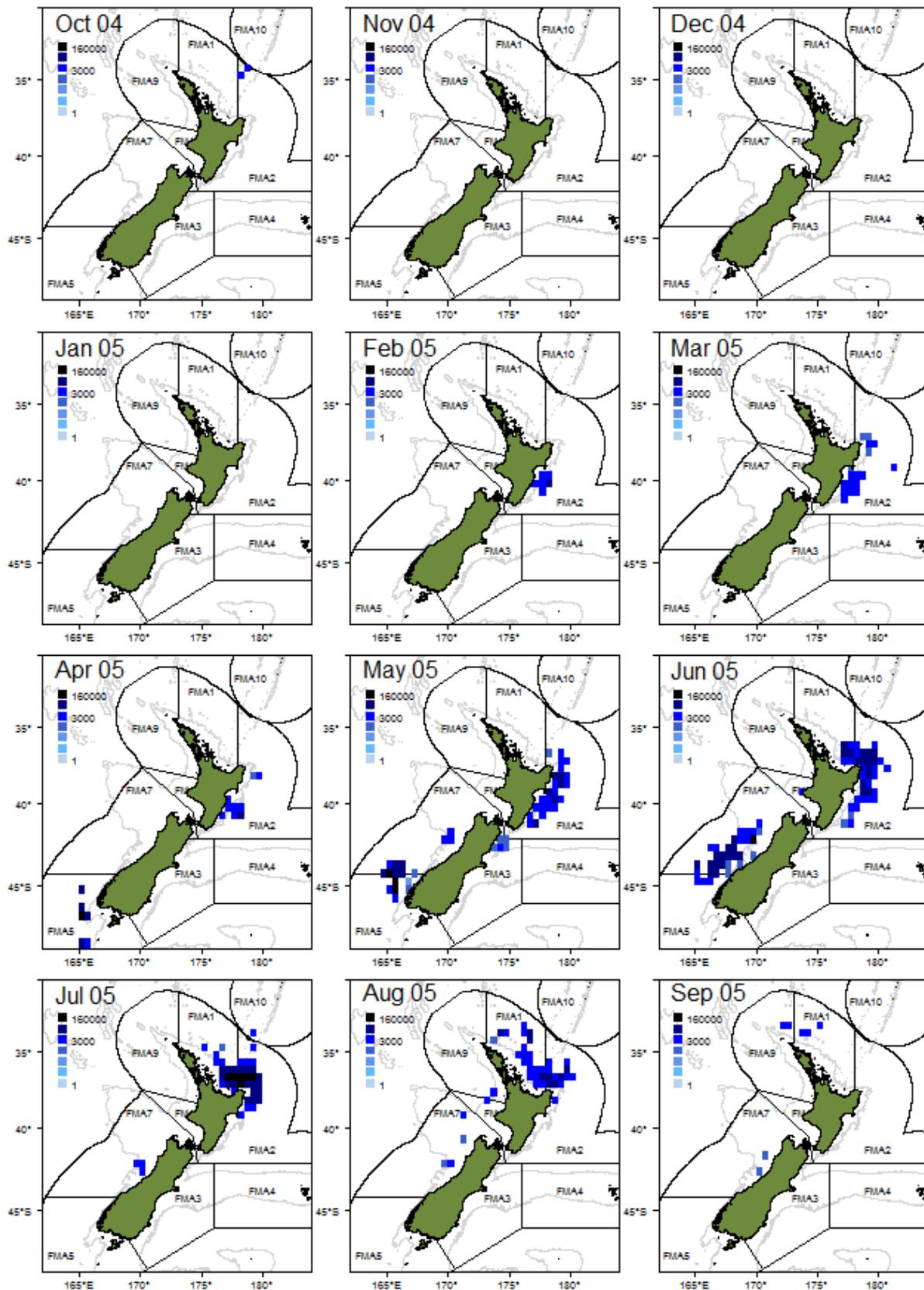
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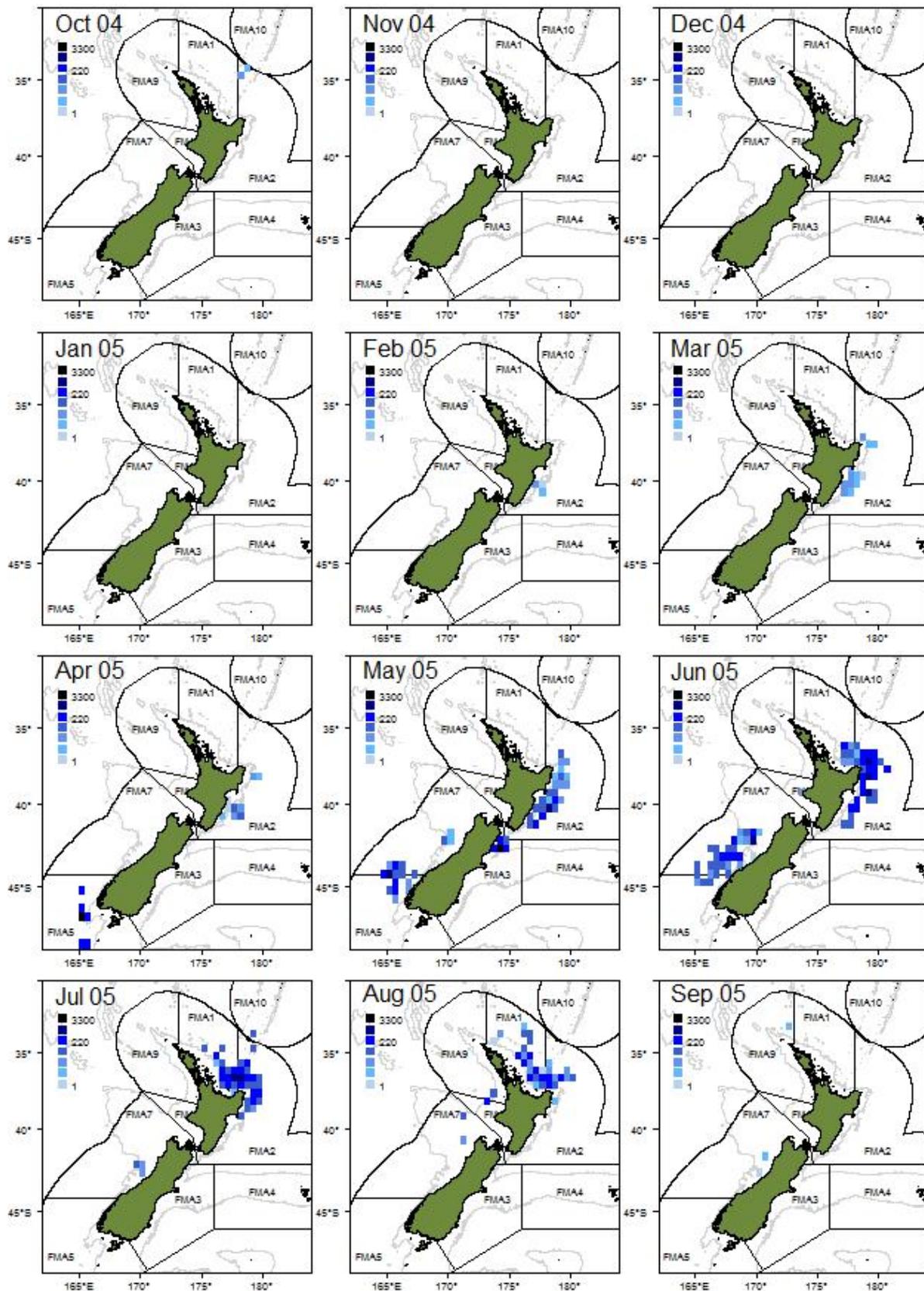


## APPENDICES

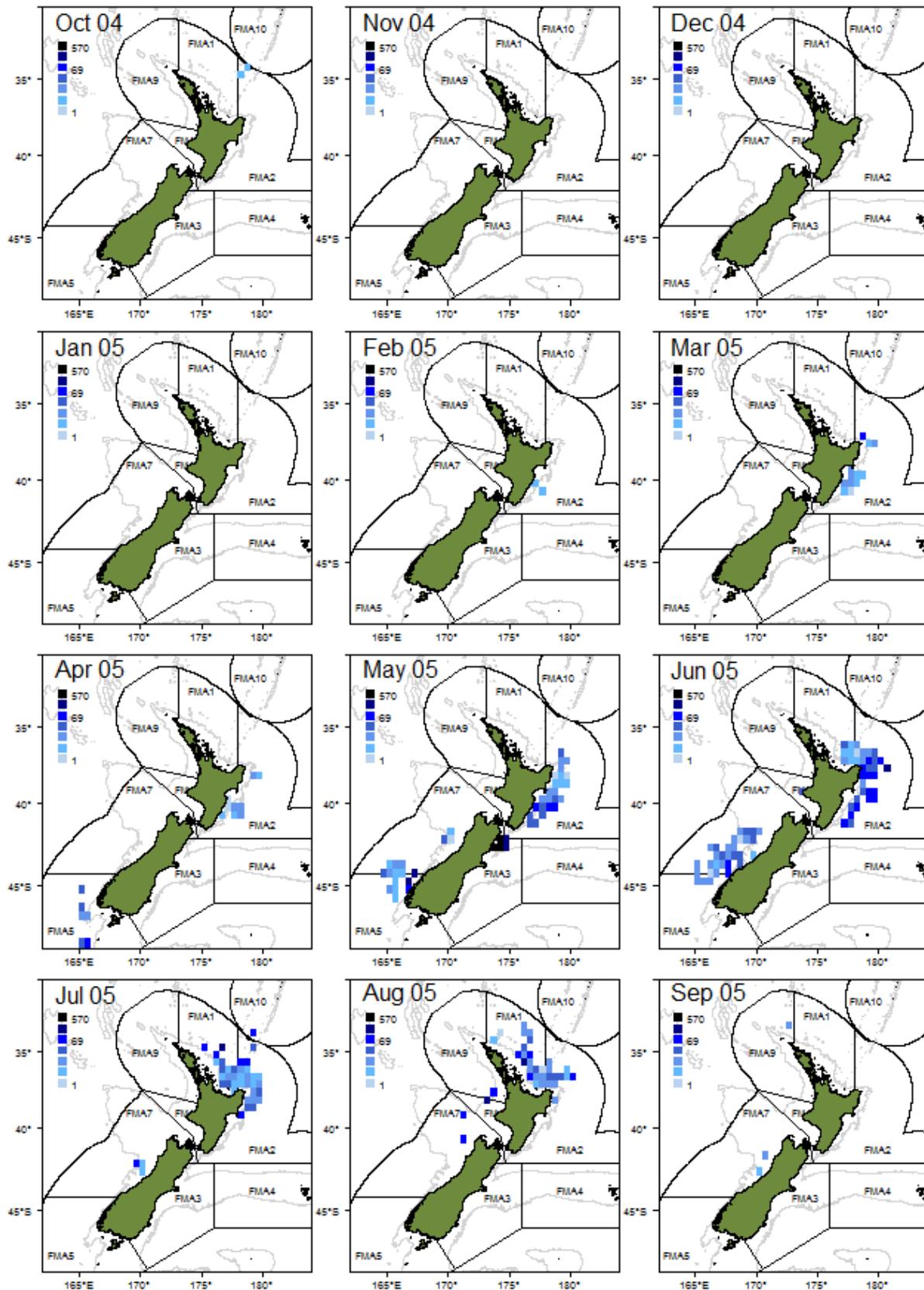
Appendix 1: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2005. (Log scale used for colour palette. Depth contour at 1000 m.)



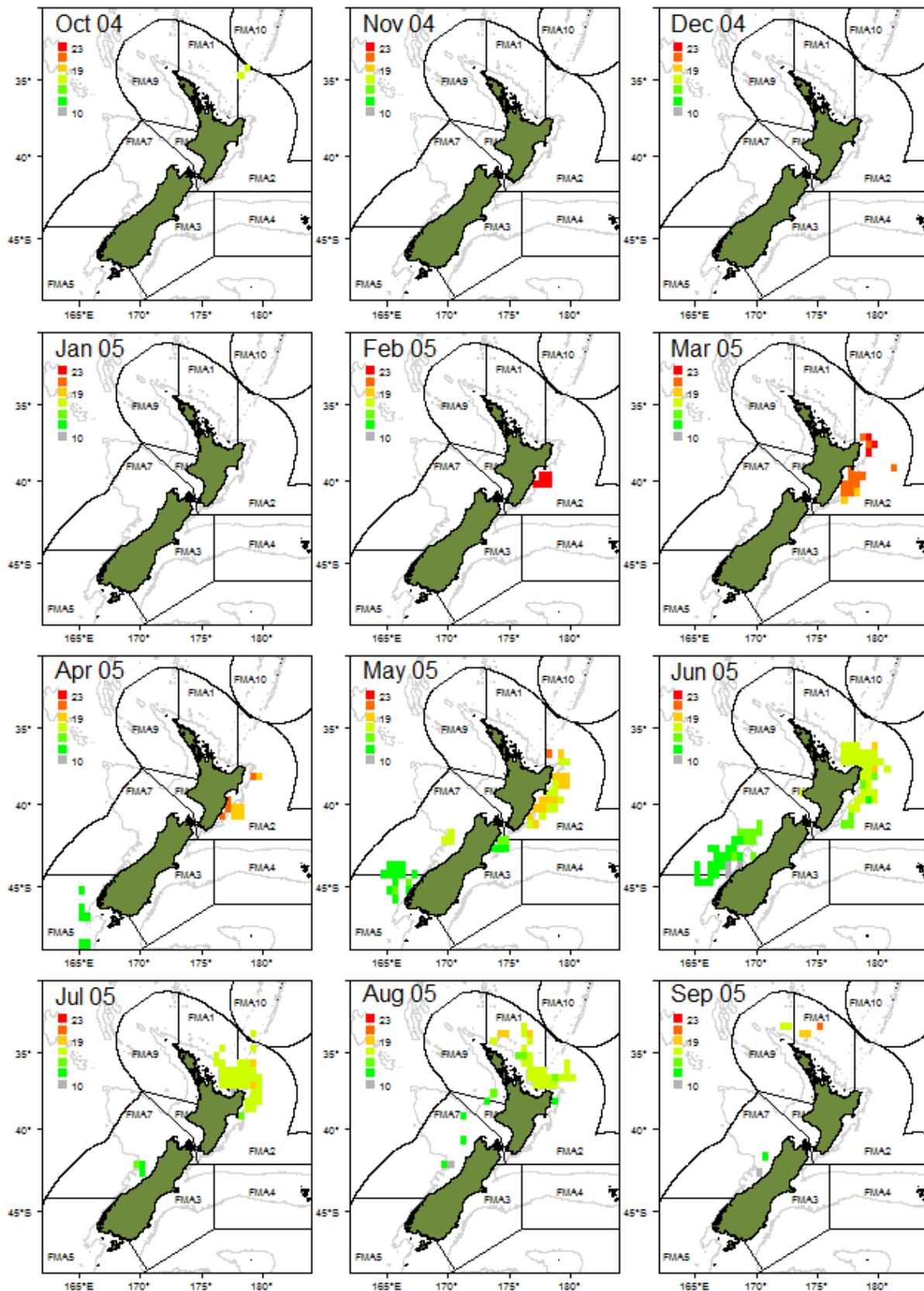
**Appendix 2: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2005. (Log scale used for colour palette. Depth contour at 1000 m.)**



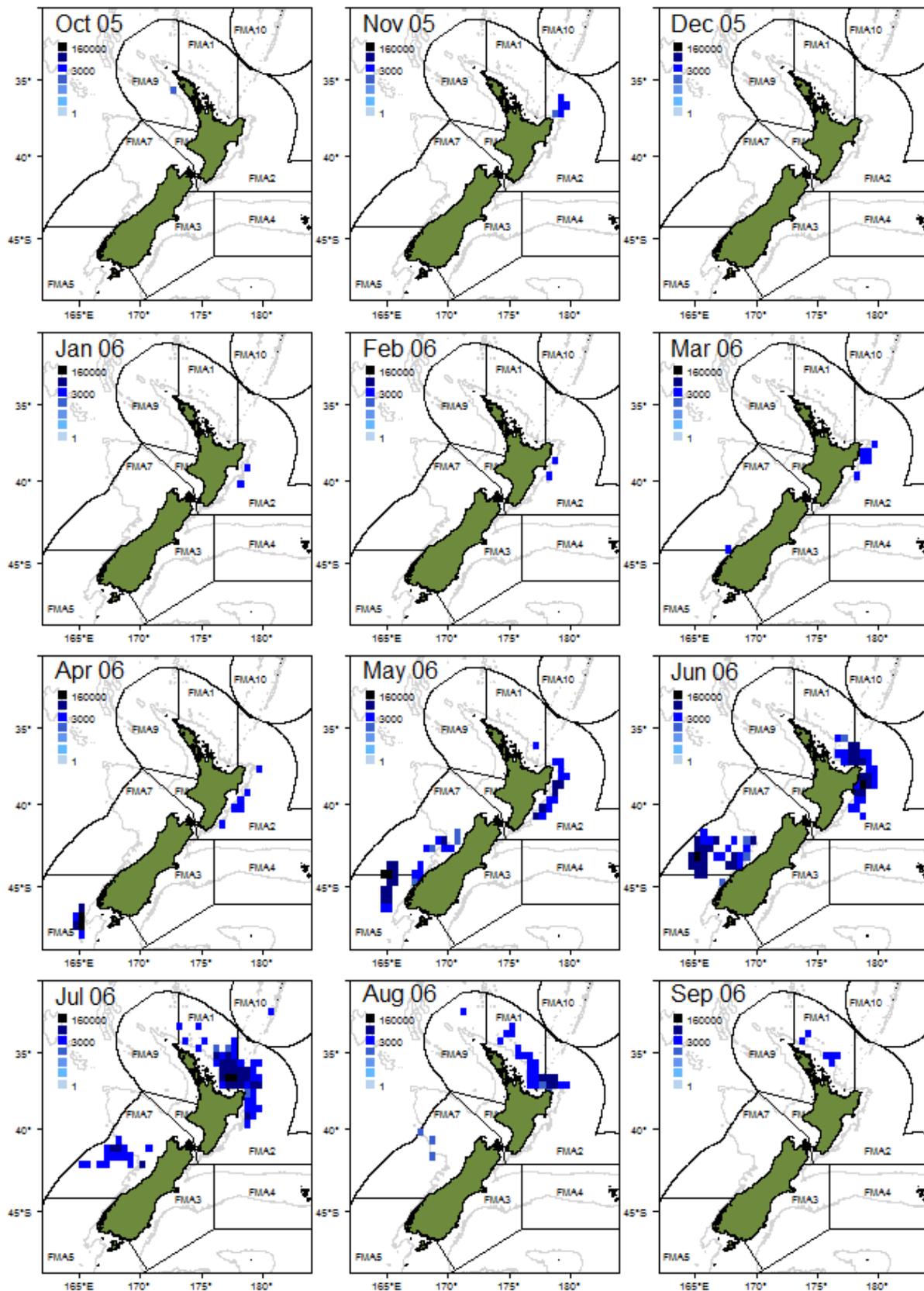
**Appendix 3: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2005. (Log scale used for colour palette. Depth contour at 1000 m.)**



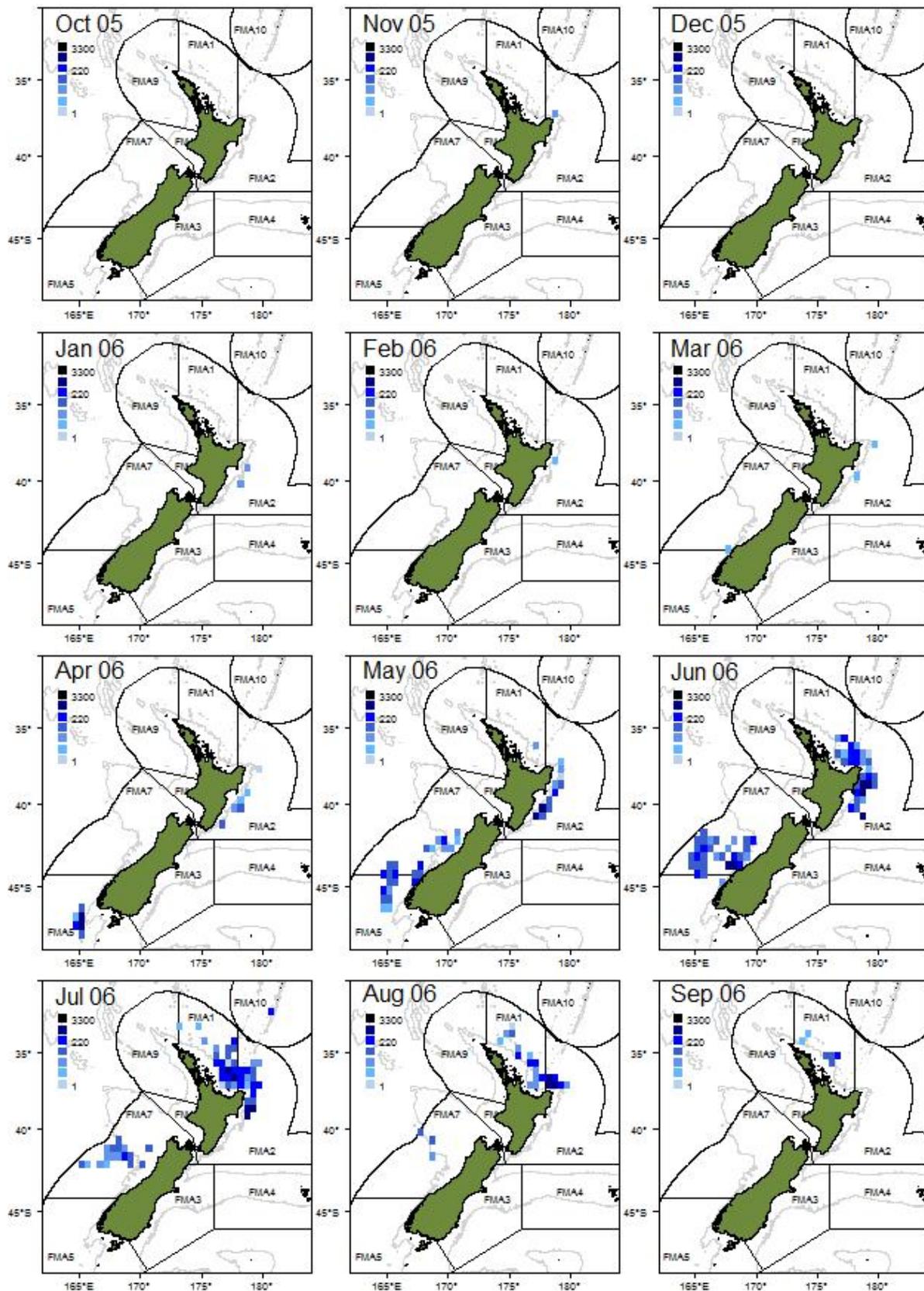
**Appendix 4: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2005.**



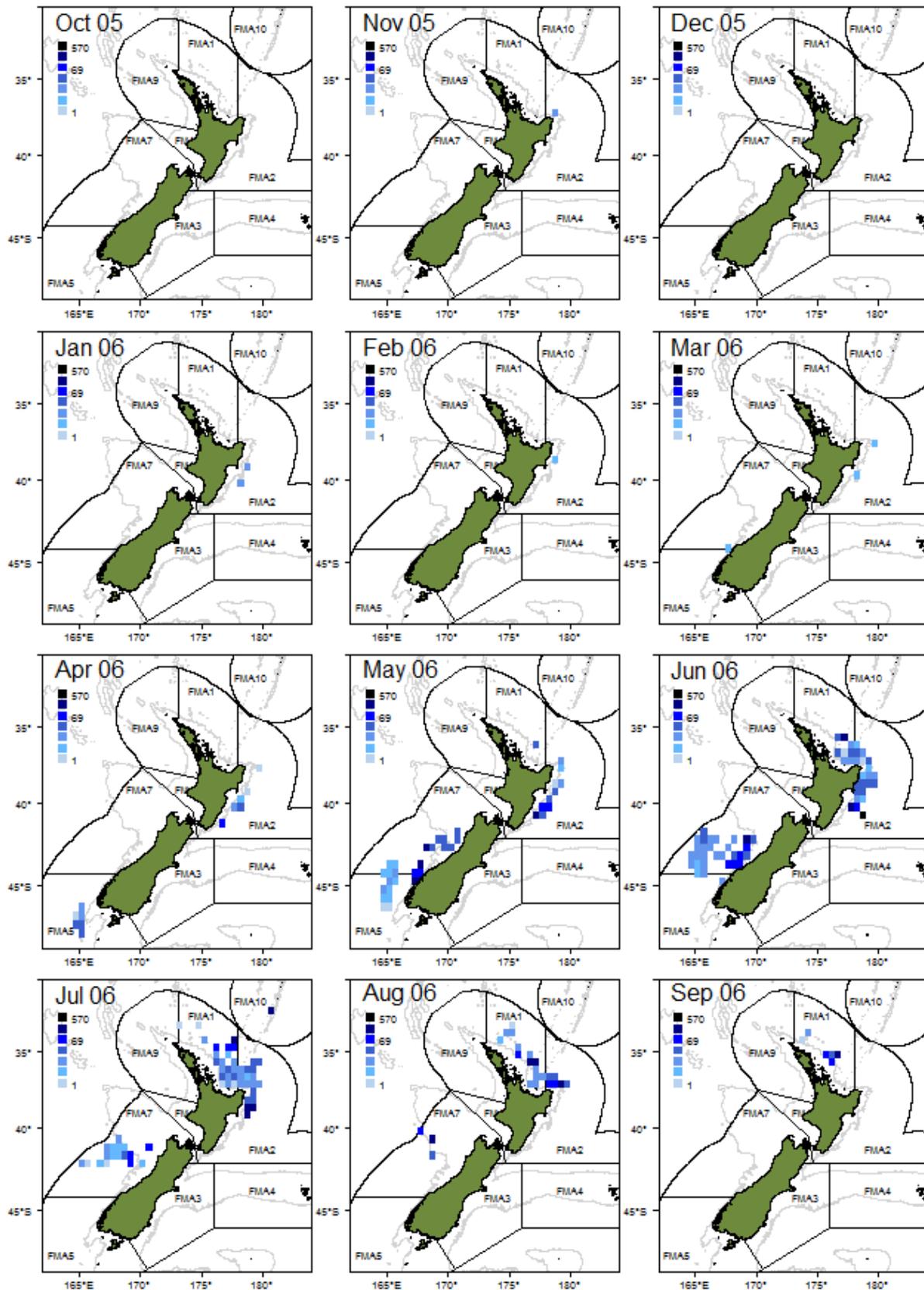
**Appendix 5: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2006. (Log scale used for colour palette. Depth contour at 1000 m.)**



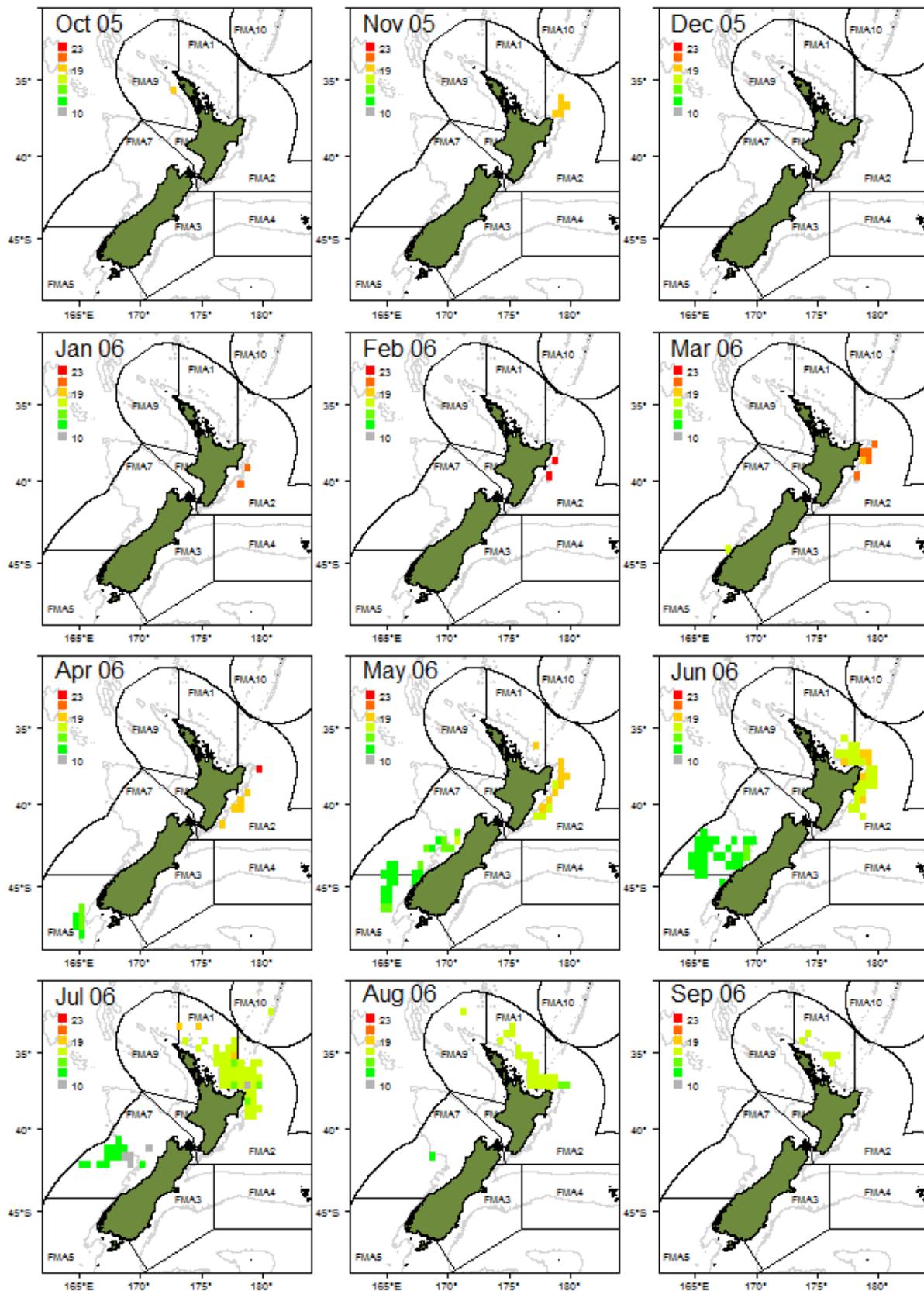
**Appendix 6: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2006. (Log scale used for colour palette. Depth contour at 1000 m.)**



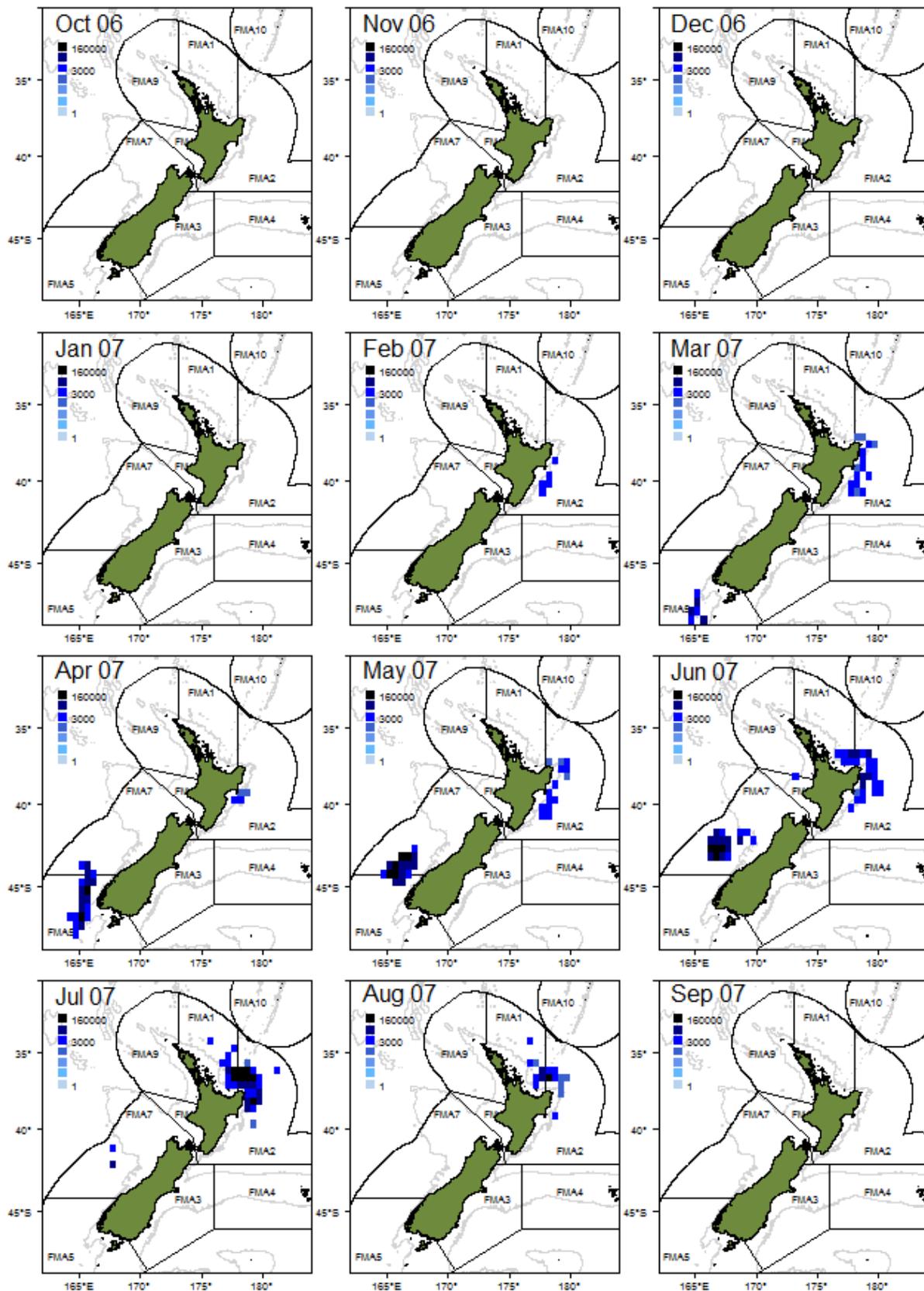
**Appendix 7: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2006. (Log scale used for colour palette. Depth contour at 1000 m.)**



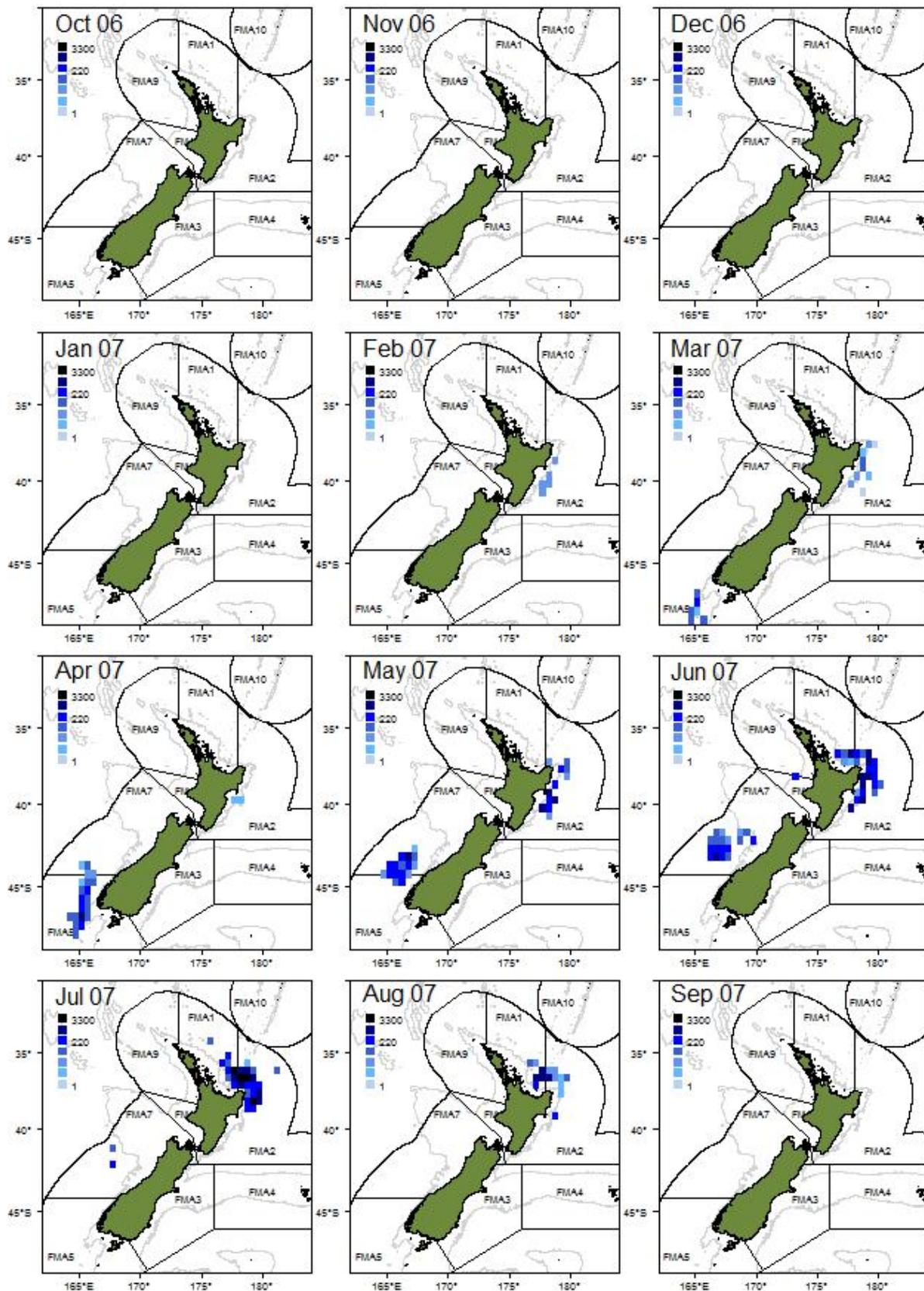
**Appendix 8: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2006.**



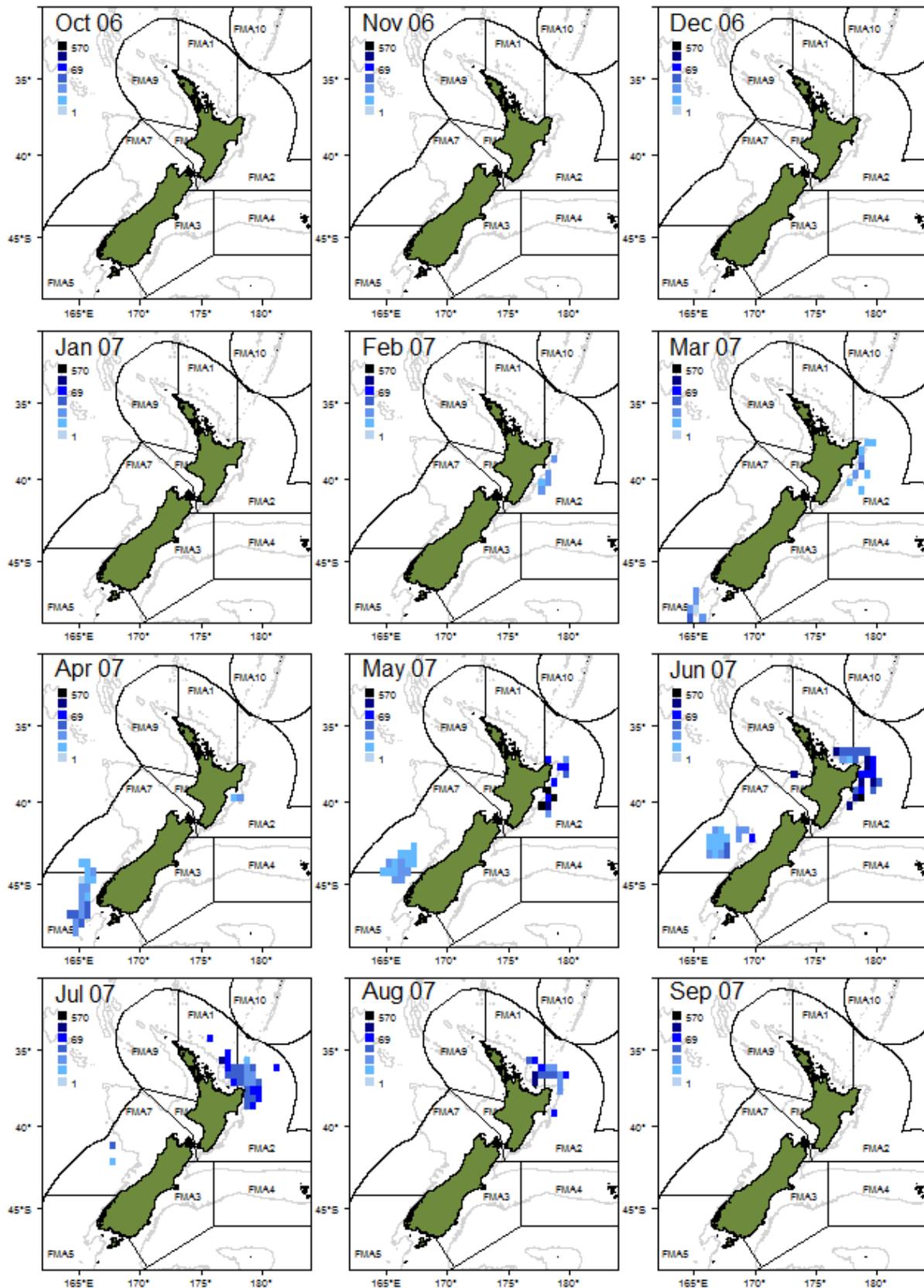
**Appendix 9: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2007. (Log scale used for colour palette. Depth contour at 1000 m.)**



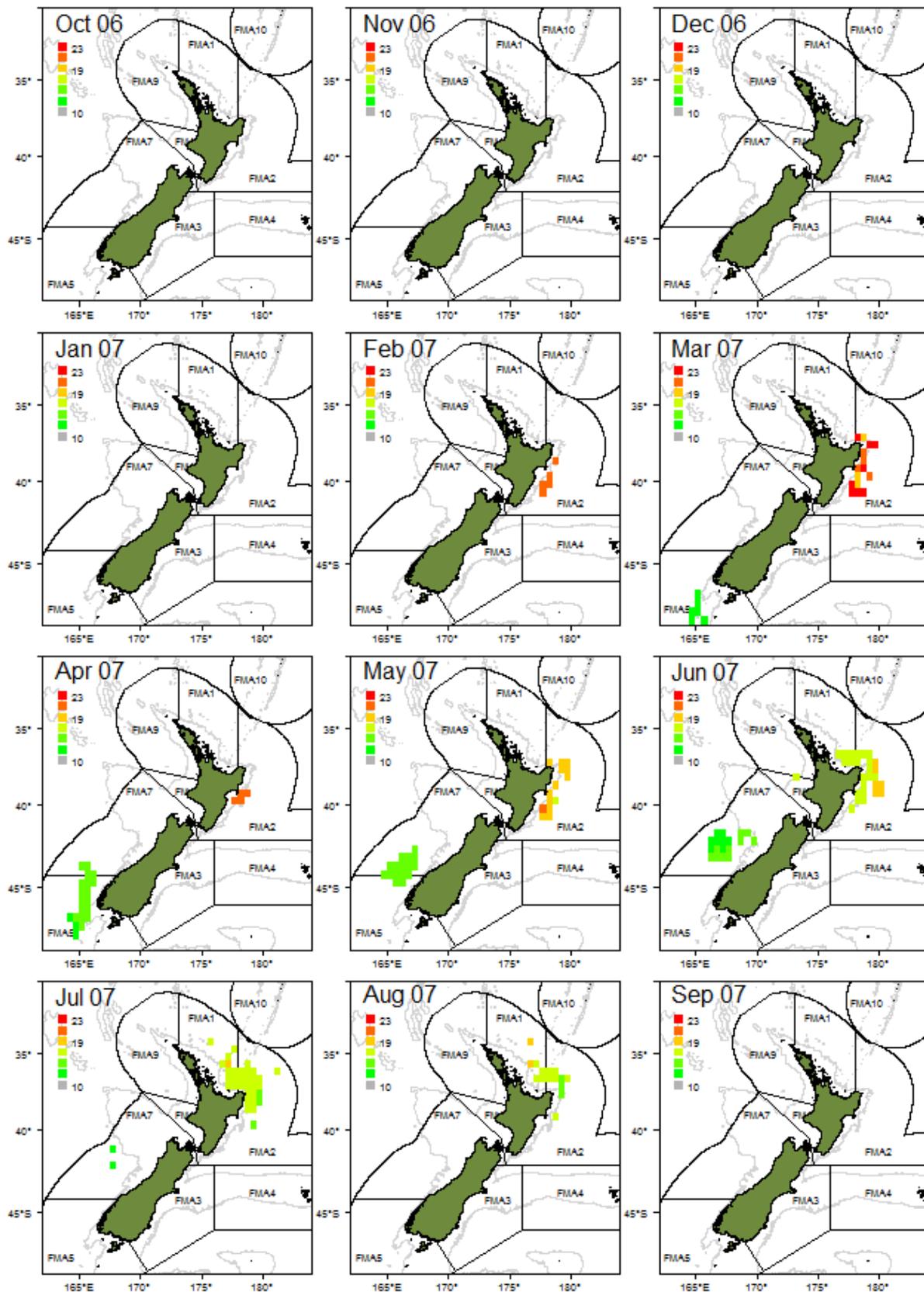
**Appendix 10: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2007. (Log scale used for colour palette. Depth contour at 1000 m.)**



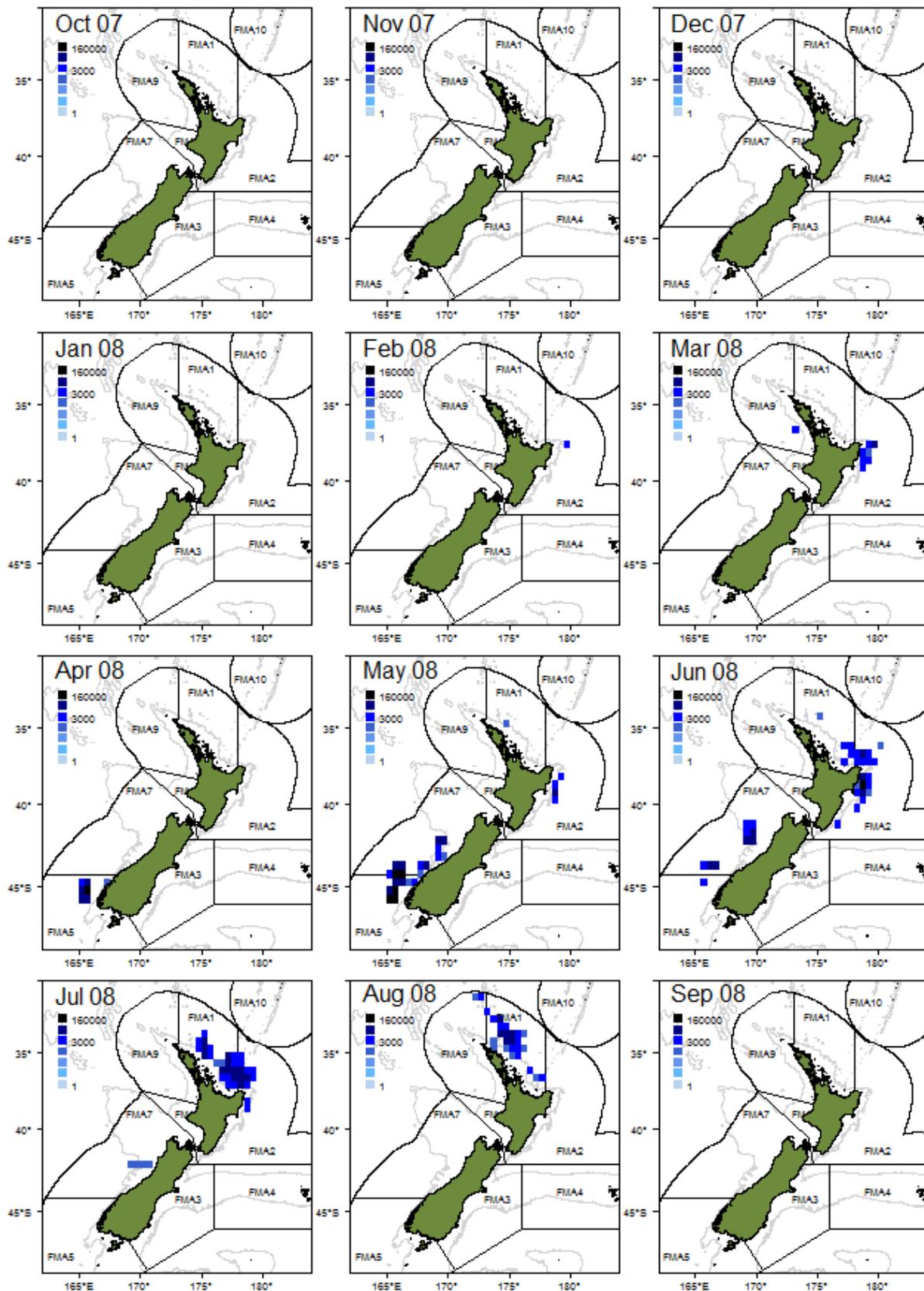
**Appendix 11: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2007. (Log scale used for colour palette. Depth contour at 1000 m.)**



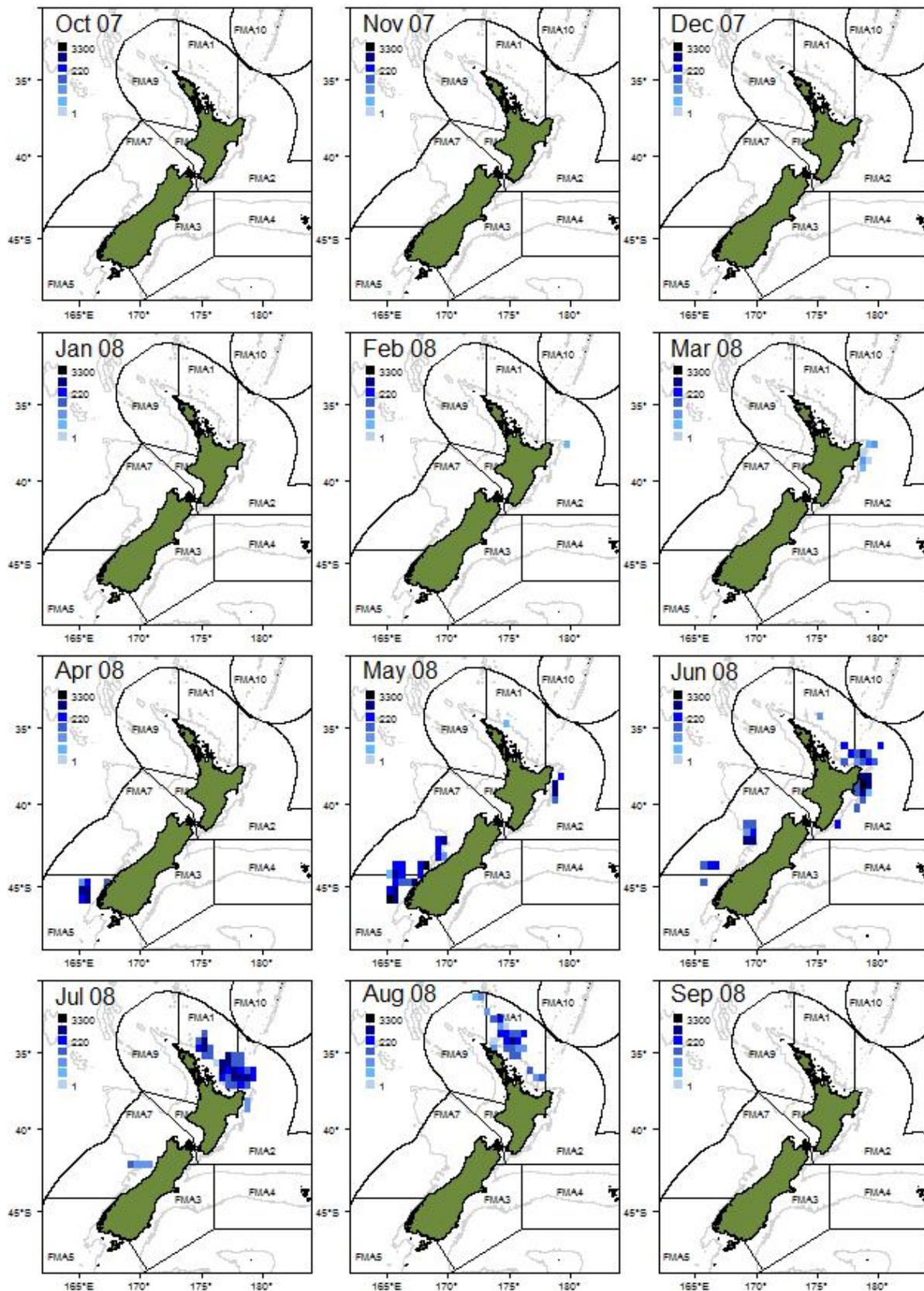
**Appendix 12: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2007.**



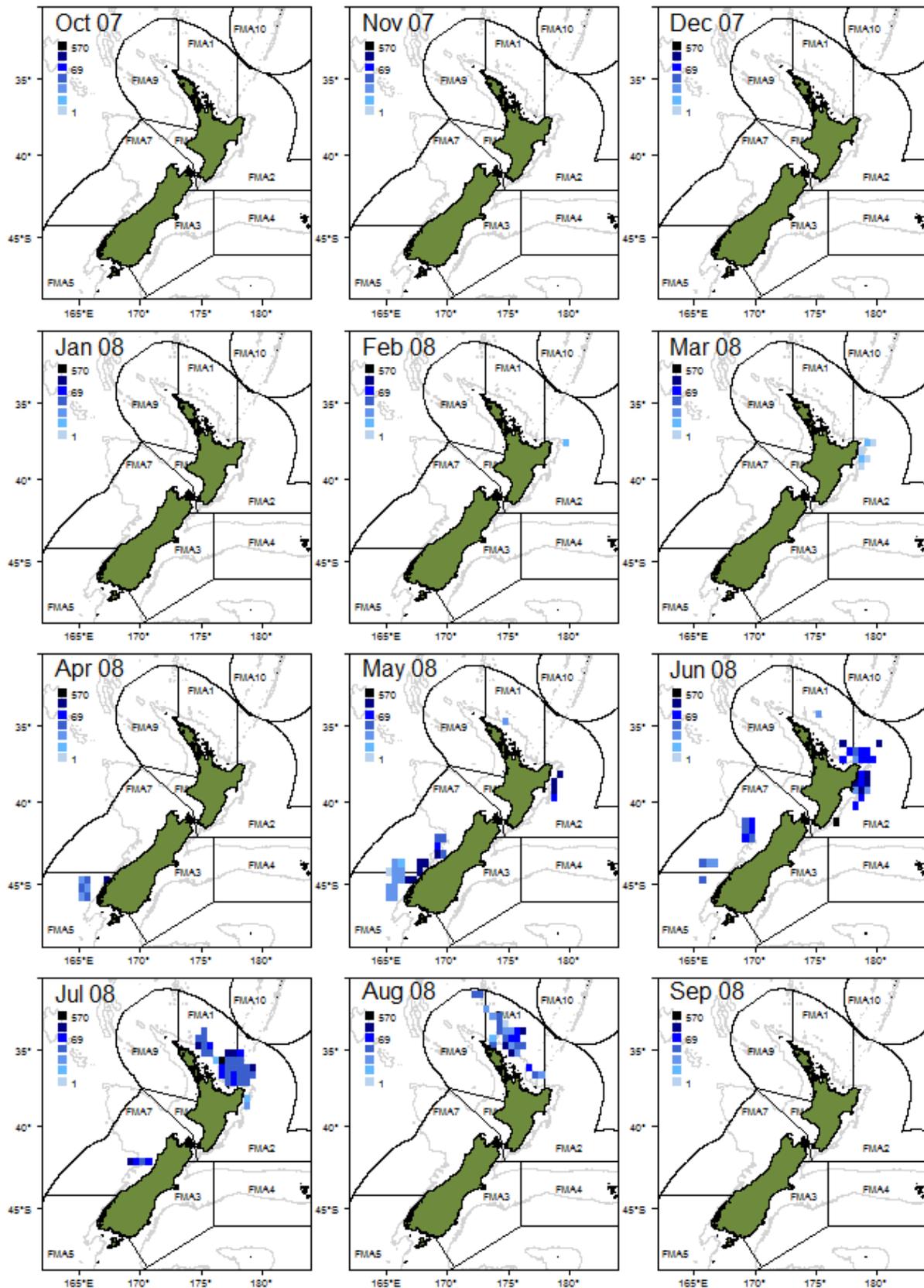
**Appendix 13: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2008. (Log scale used for colour palette. Depth contour at 1000 m.)**



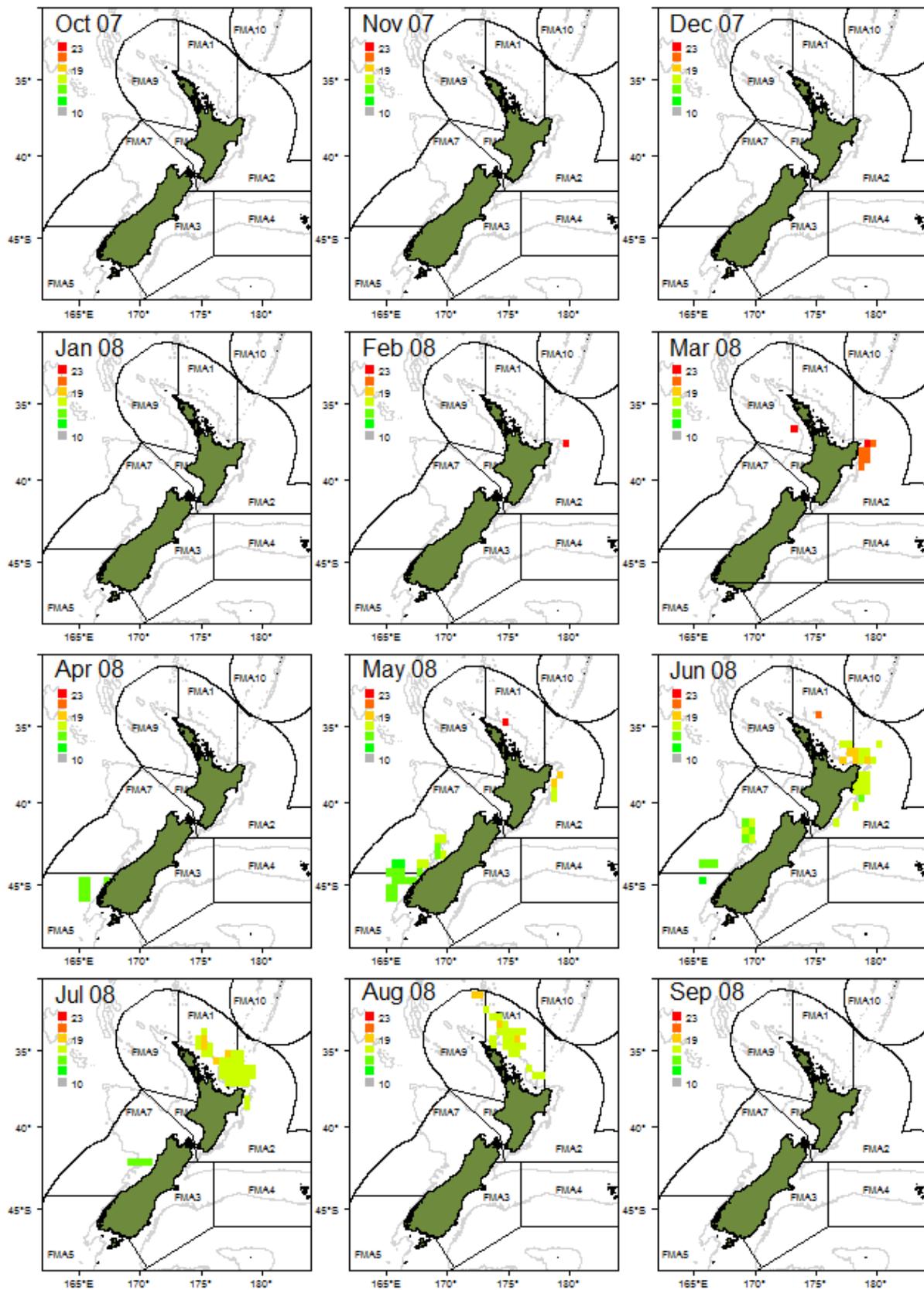
**Appendix 14: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2008. (Log scale used for colour palette. Depth contour at 1000 m.)**



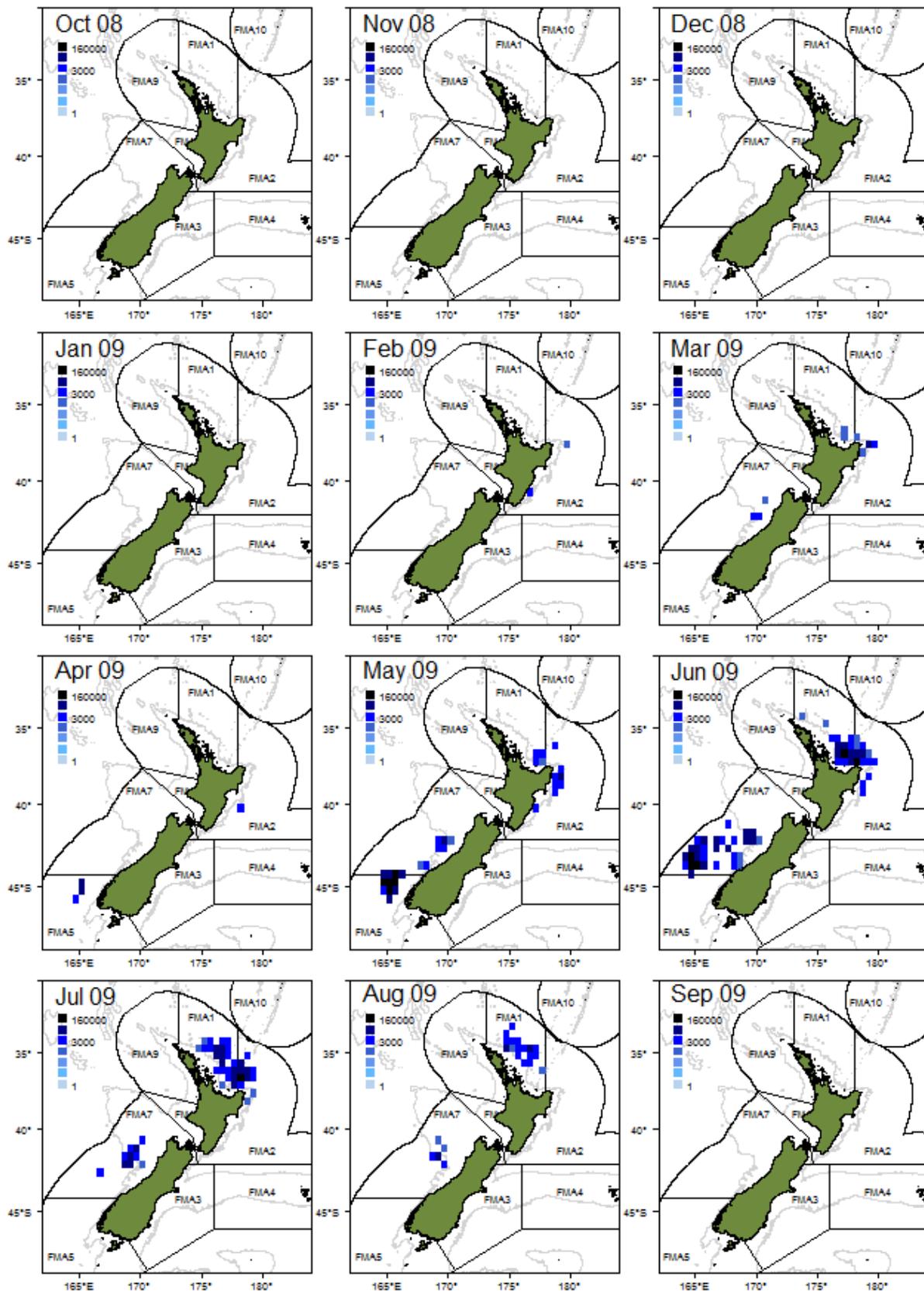
**Appendix 15: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2008. (Log scale used for colour palette. Depth contour at 1000 m.)**



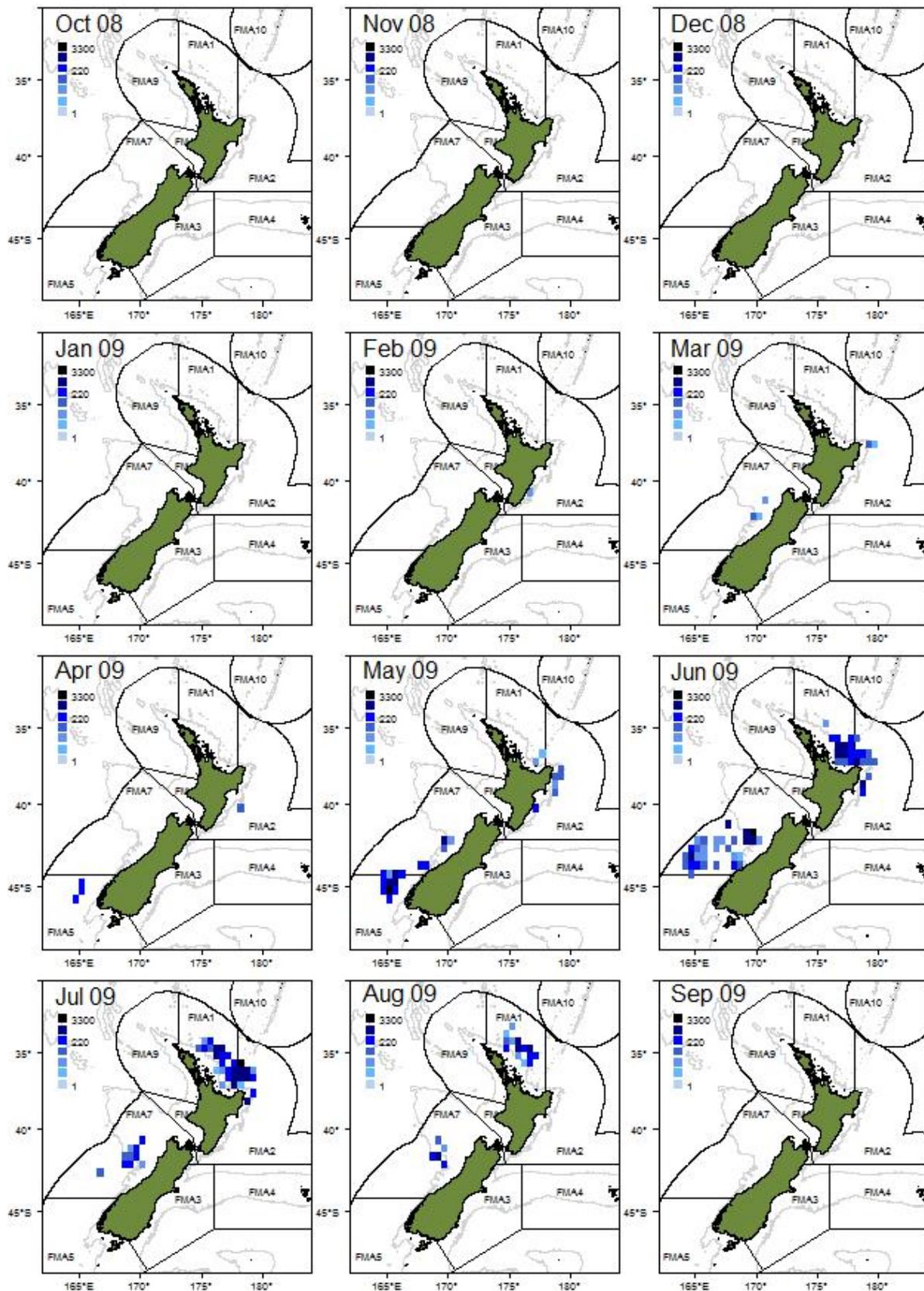
**Appendix 16: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2008.**



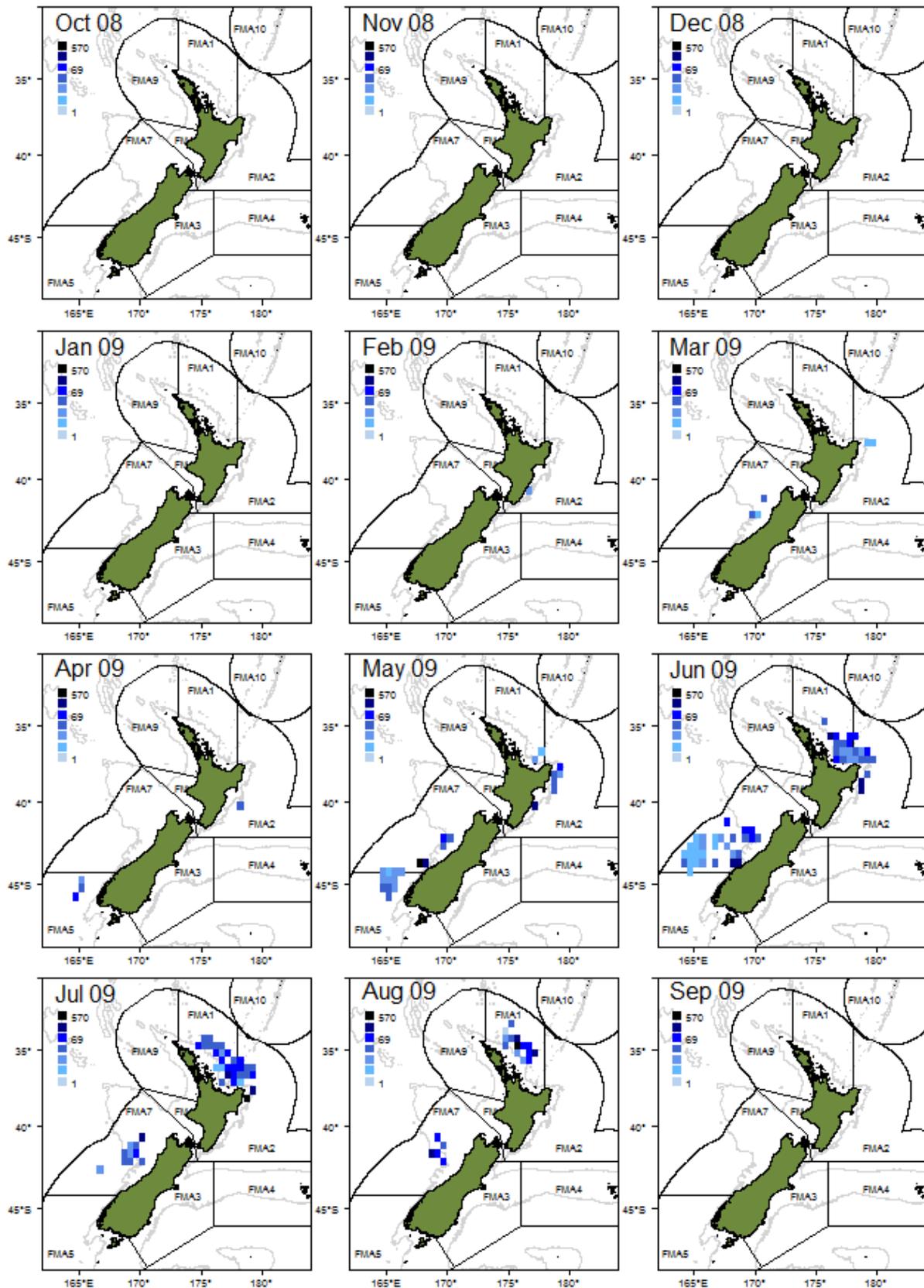
**Appendix 17: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2009. (Log scale used for colour palette. Depth contour at 1000 m.)**



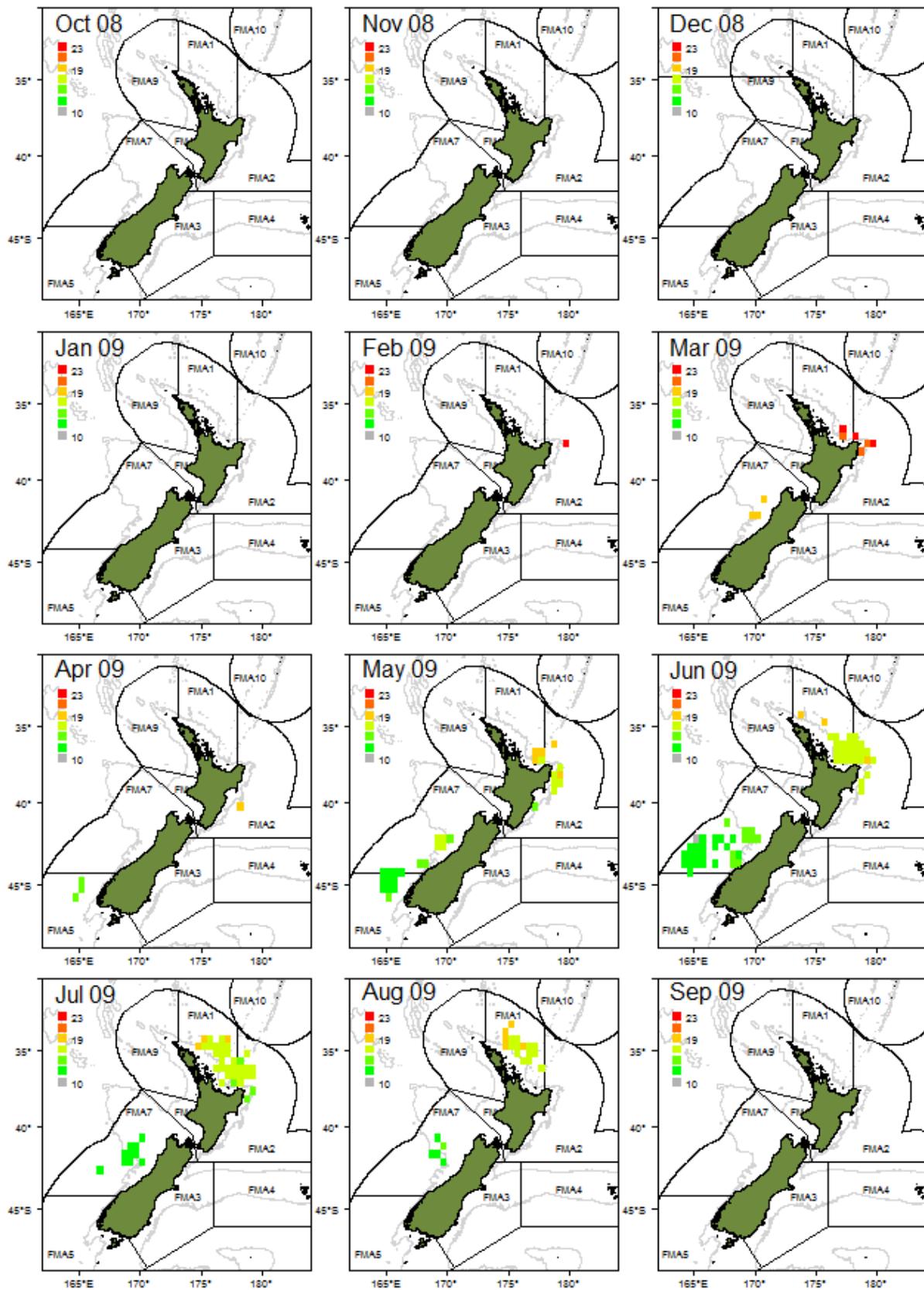
**Appendix 18: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2009. (Log scale used for colour palette. Depth contour at 1000 m.)**



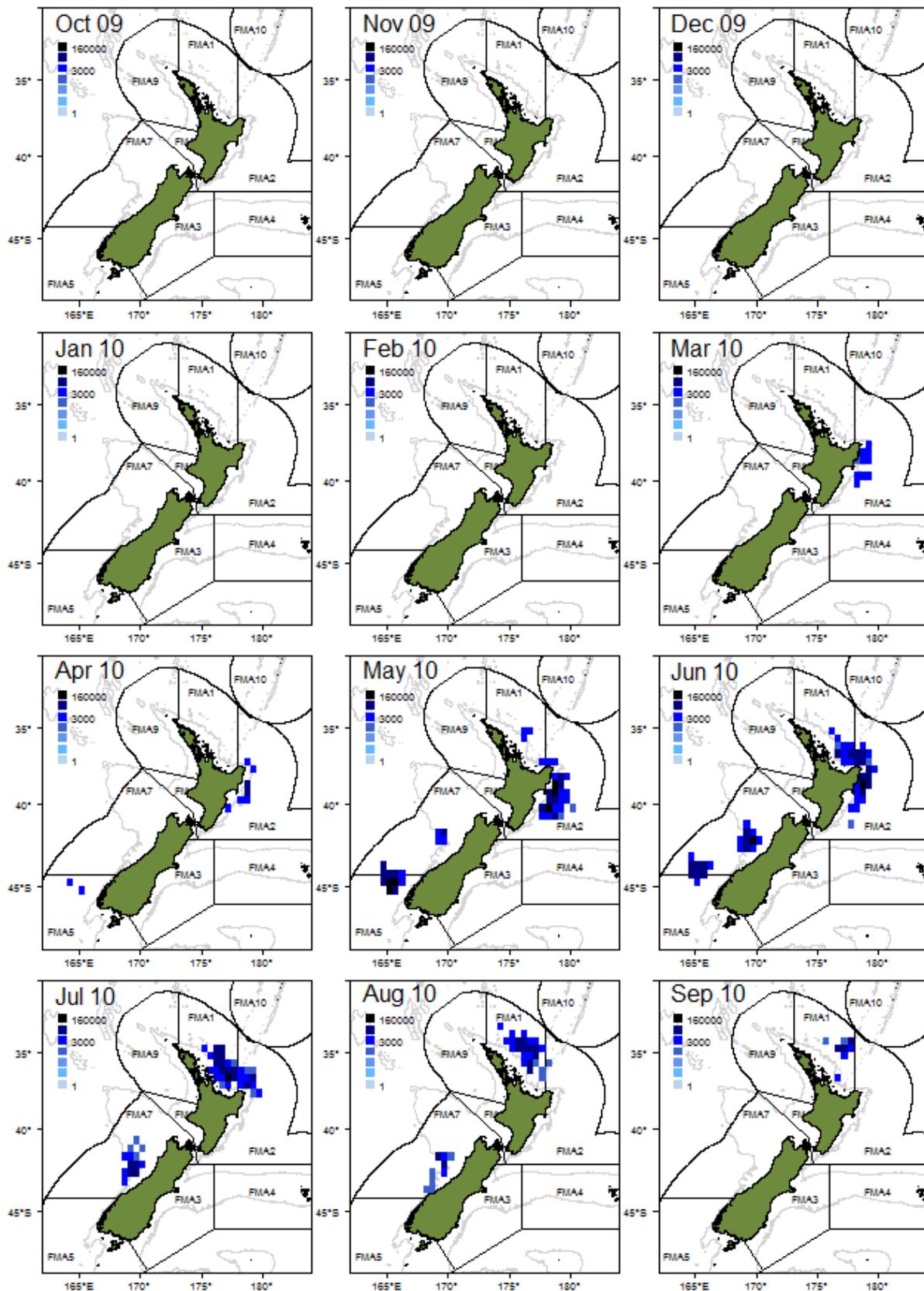
**Appendix 19: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2009. (Log scale used for colour palette. Depth contour at 1000 m.)**



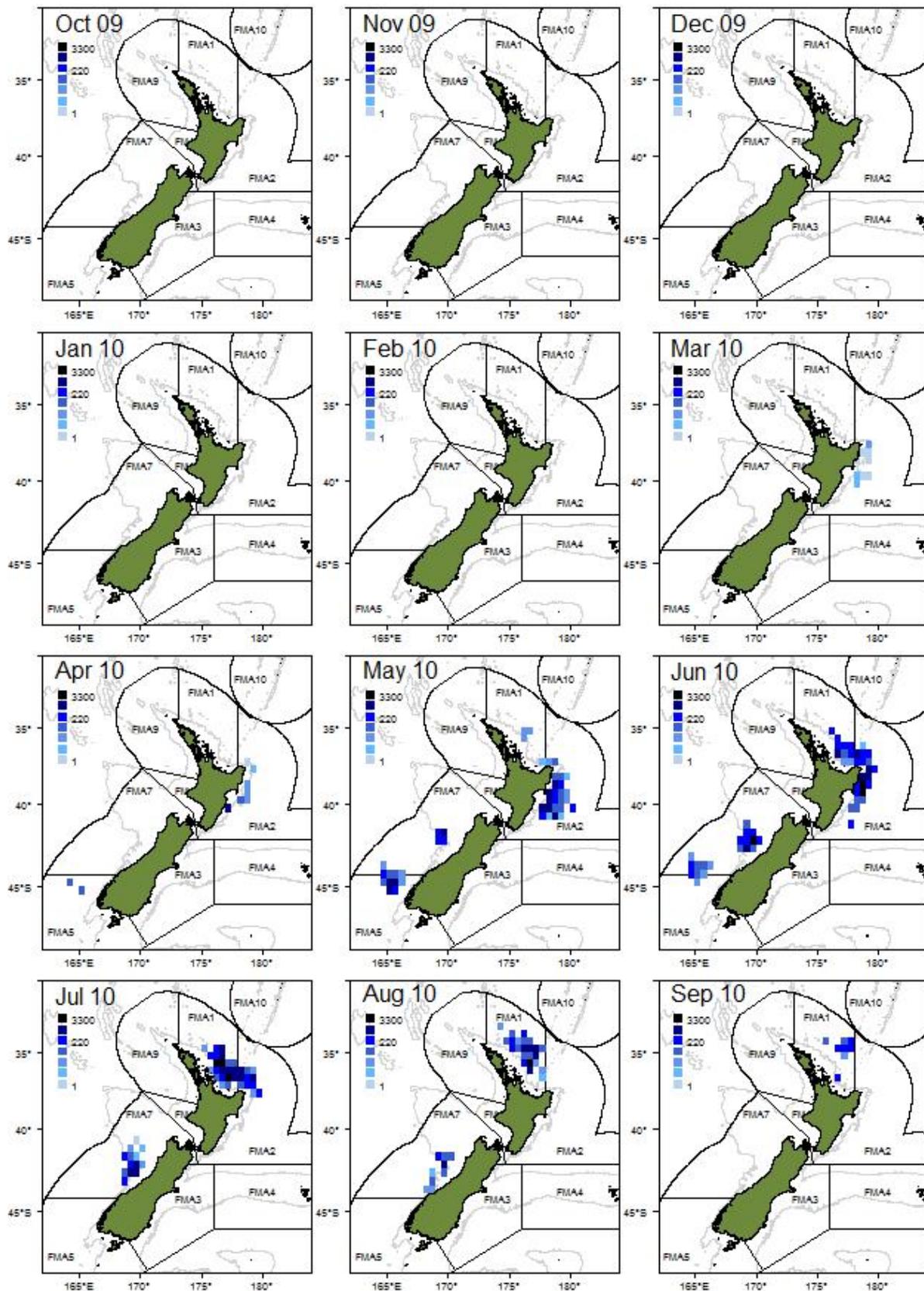
**Appendix 20: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2009.**



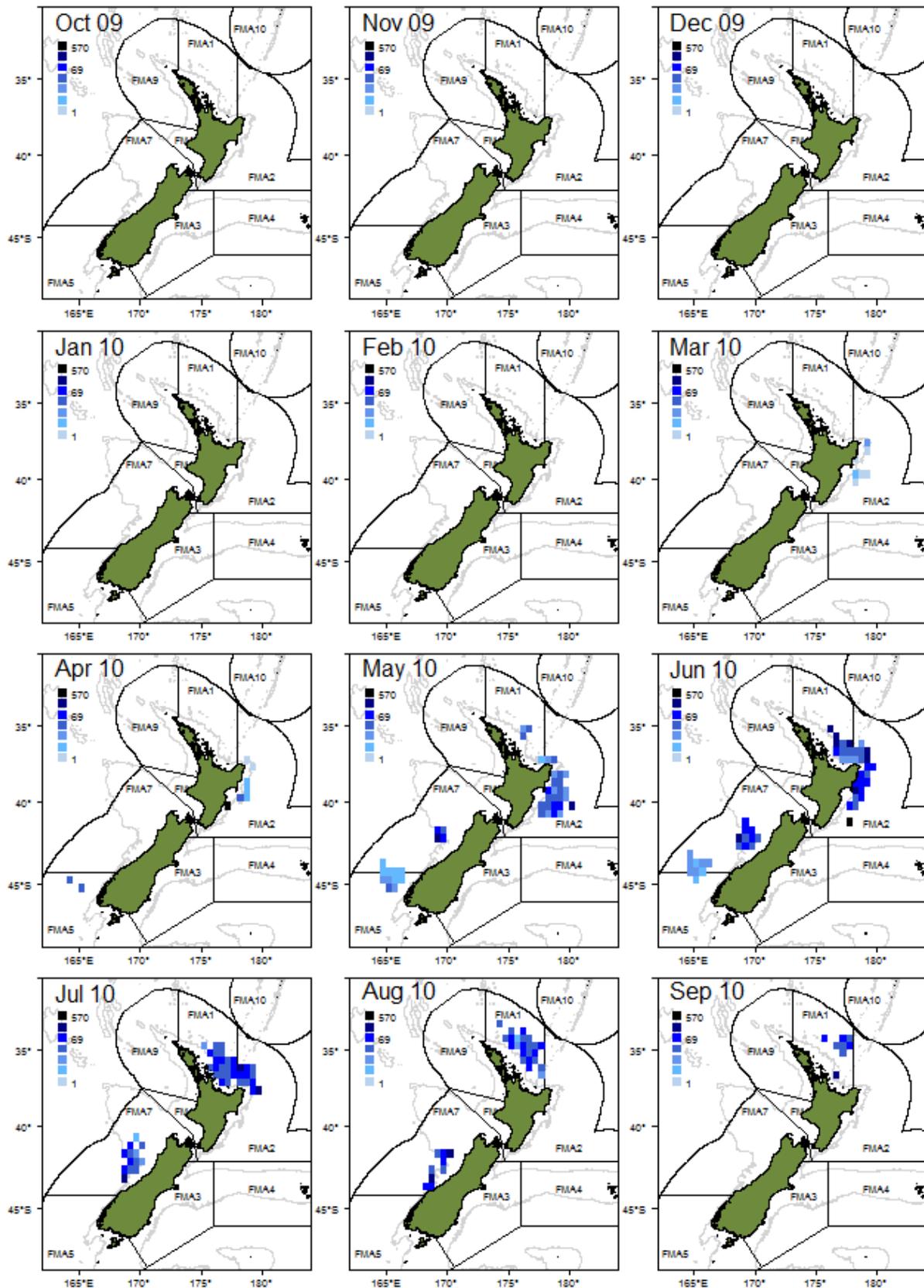
**Appendix 21: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2010. (Log scale used for colour palette. Depth contour at 1000 m.)**



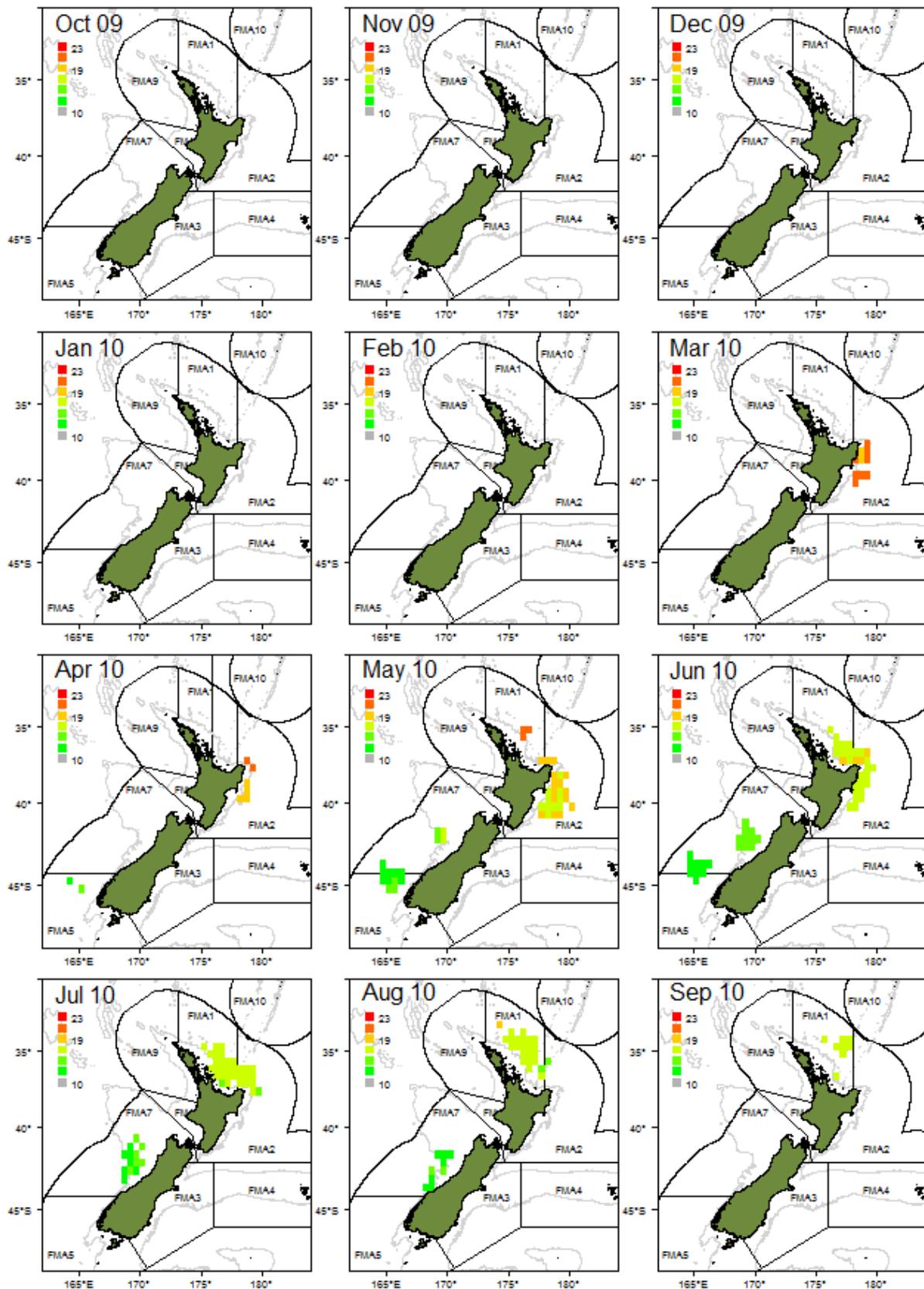
**Appendix 22: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2010. (Log scale used for colour palette. Depth contour at 1000 m.)**



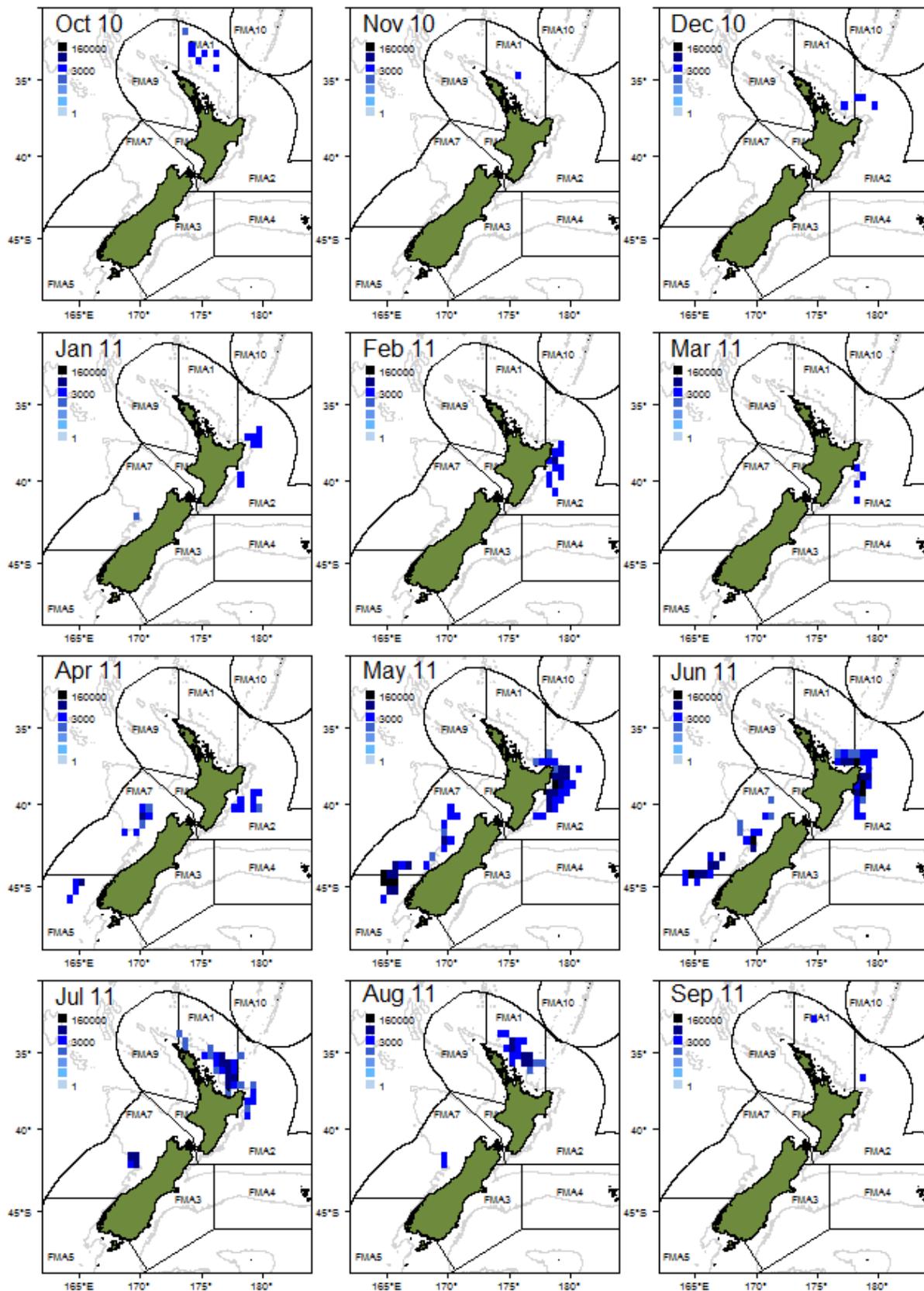
**Appendix 23: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2010. (Log scale used for colour palette. Depth contour at 1000 m.)**



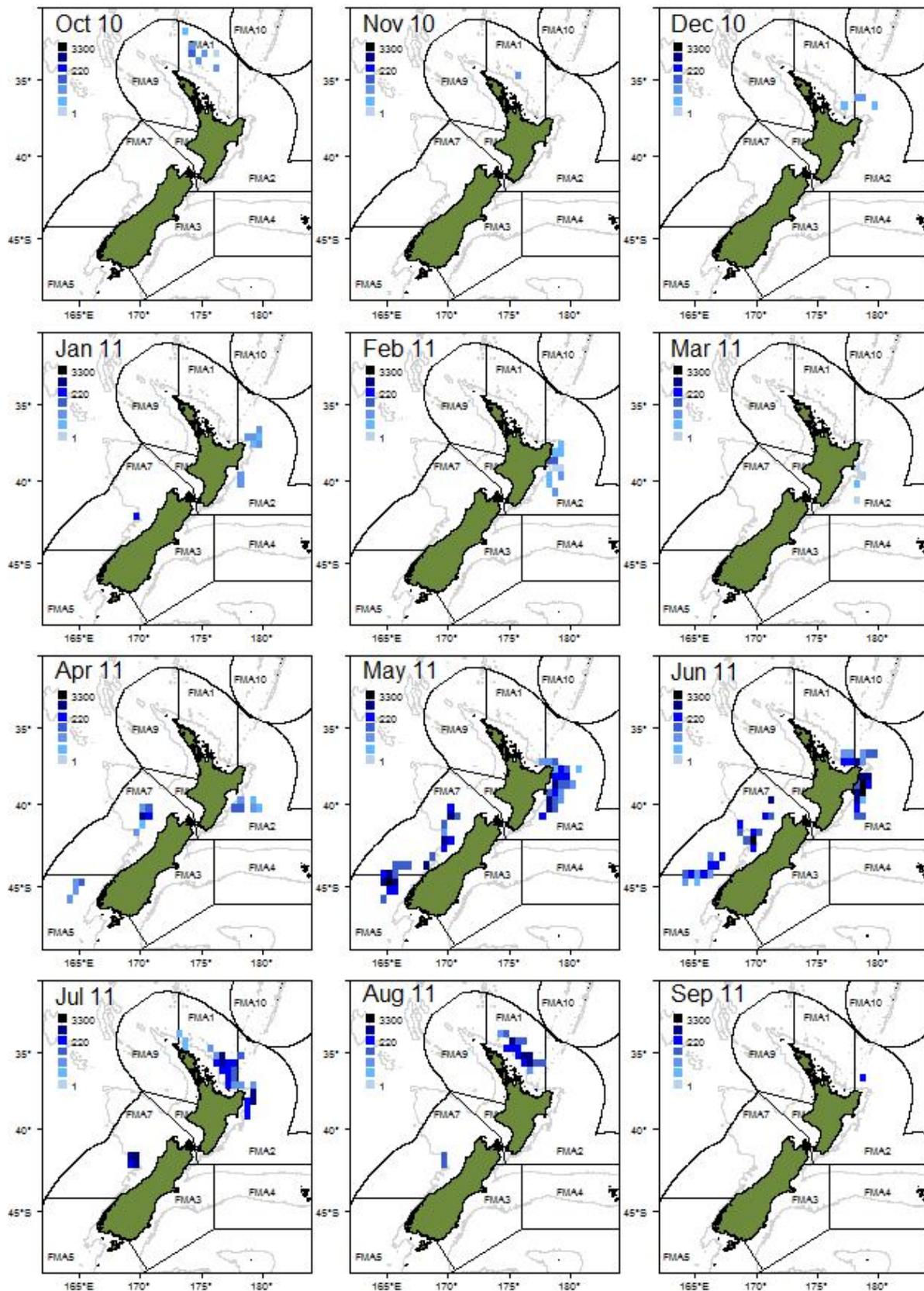
**Appendix 24: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2010.**



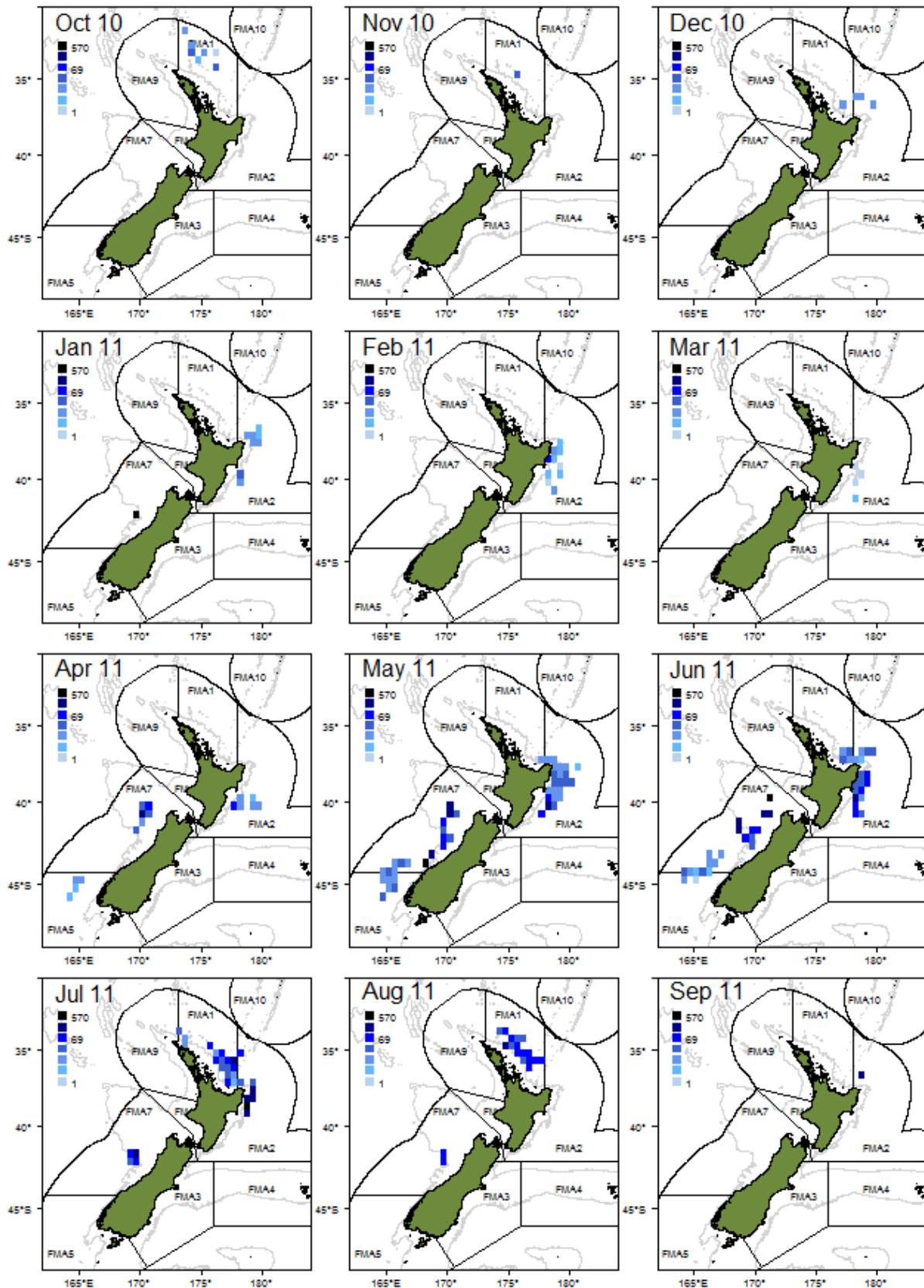
**Appendix 25: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2011. (Log scale used for colour palette. Depth contour at 1000 m.)**



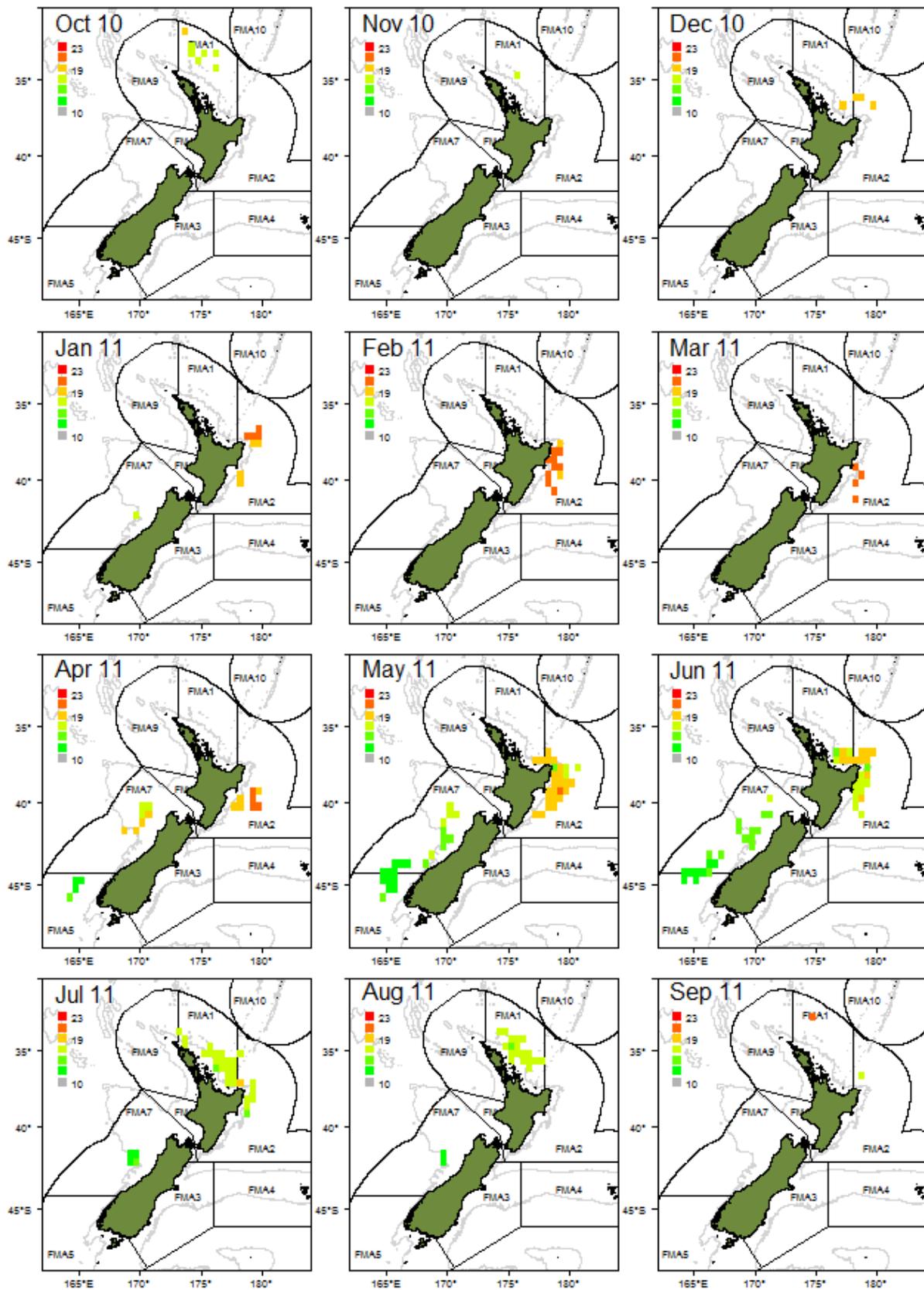
**Appendix 26: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2011. (Log scale used for colour palette. Depth contour at 1000 m.)**



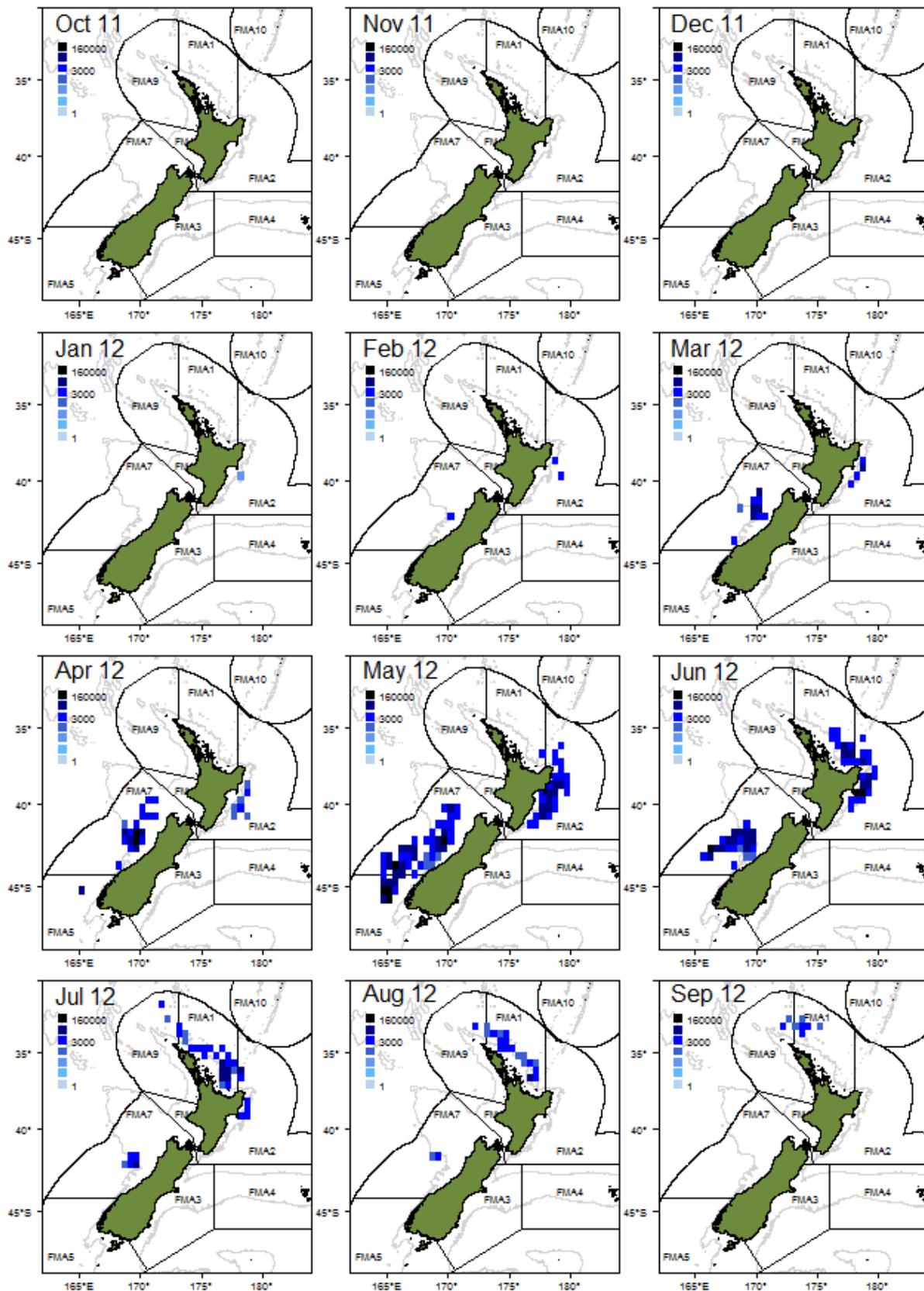
**Appendix 27: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2011. (Log scale used for colour palette. Depth contour at 1000 m.)**



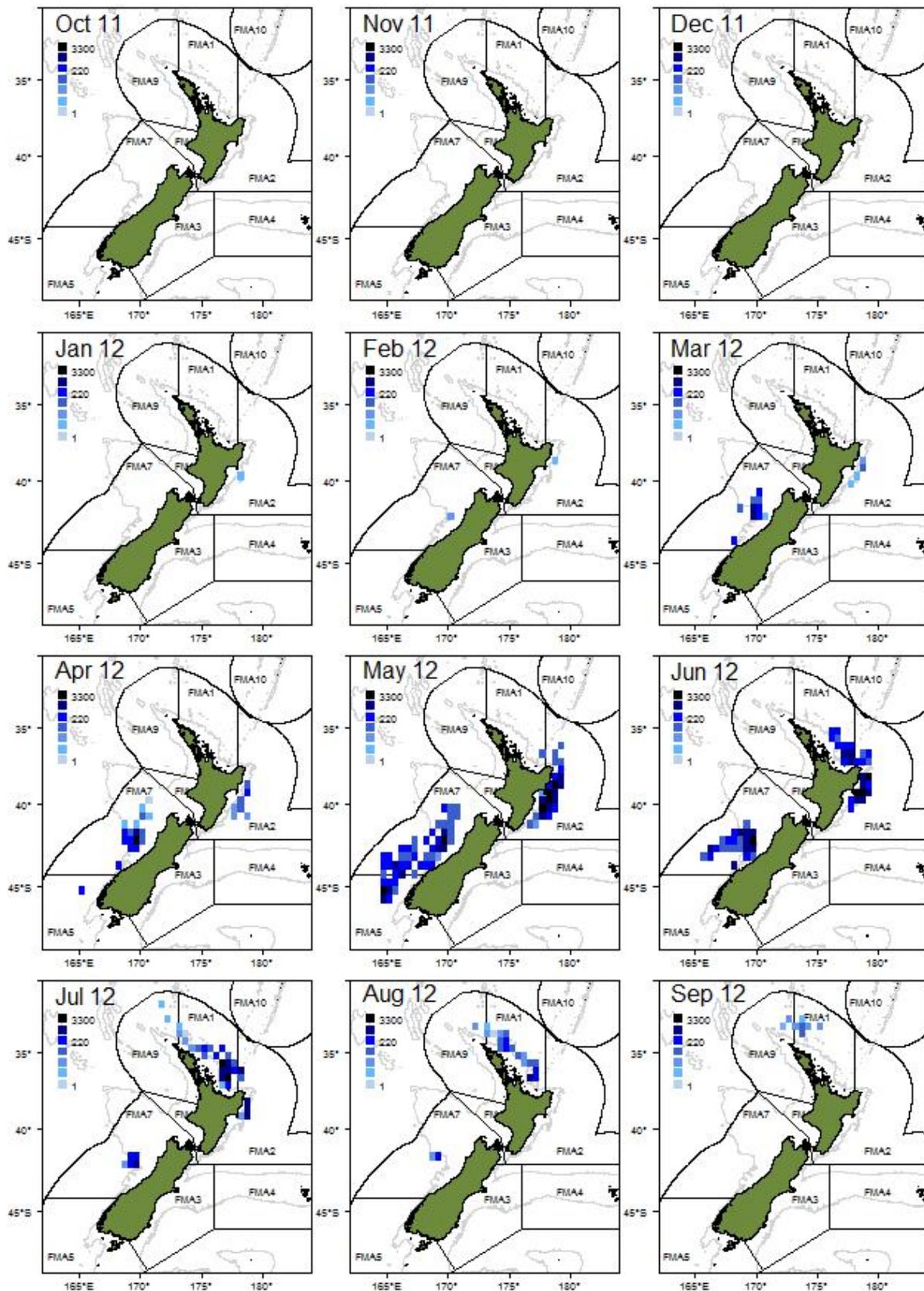
**Appendix 28: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2011.**



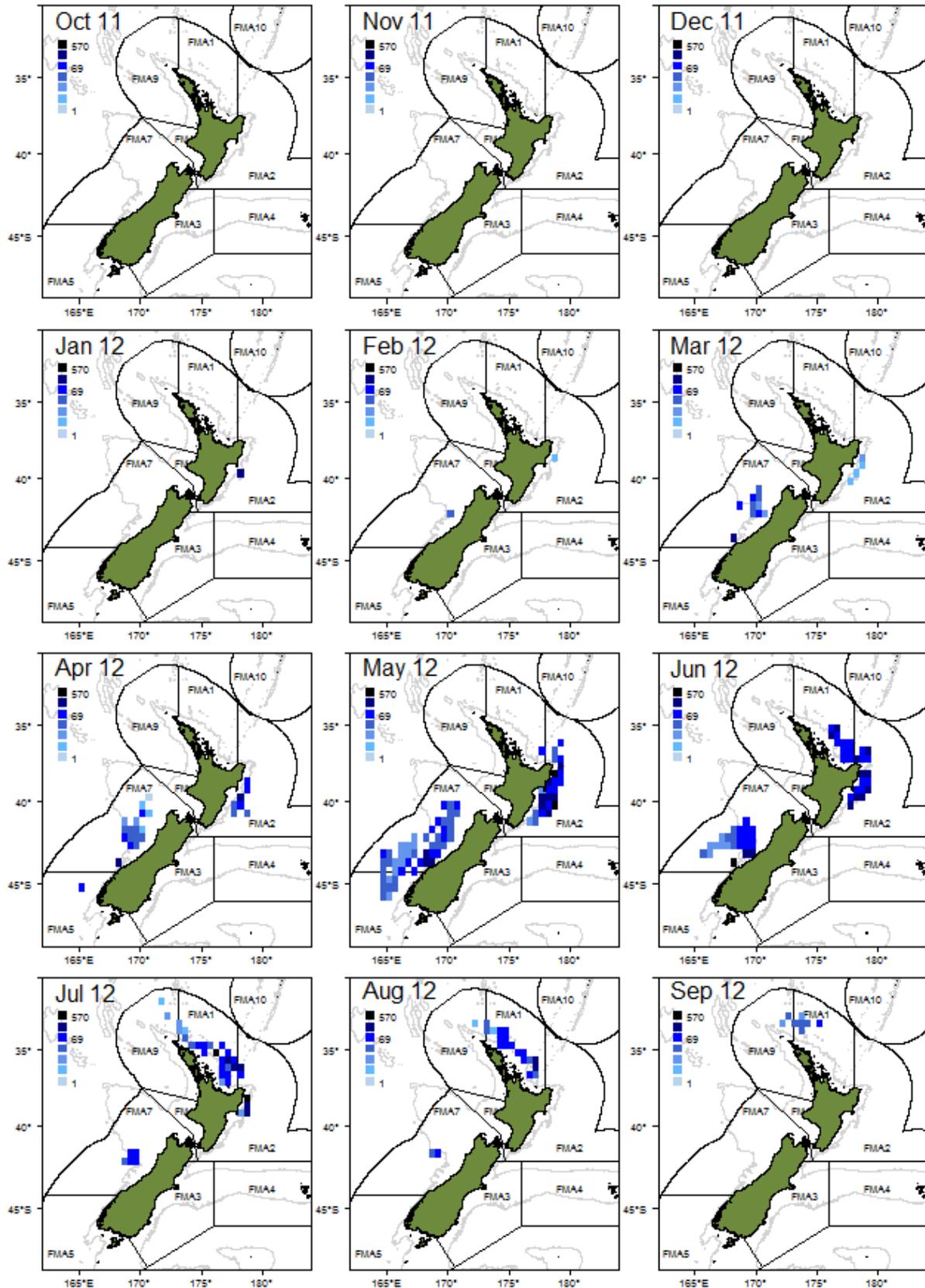
**Appendix 29: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2012. (Log scale used for colour palette. Depth contour at 1000 m.)**



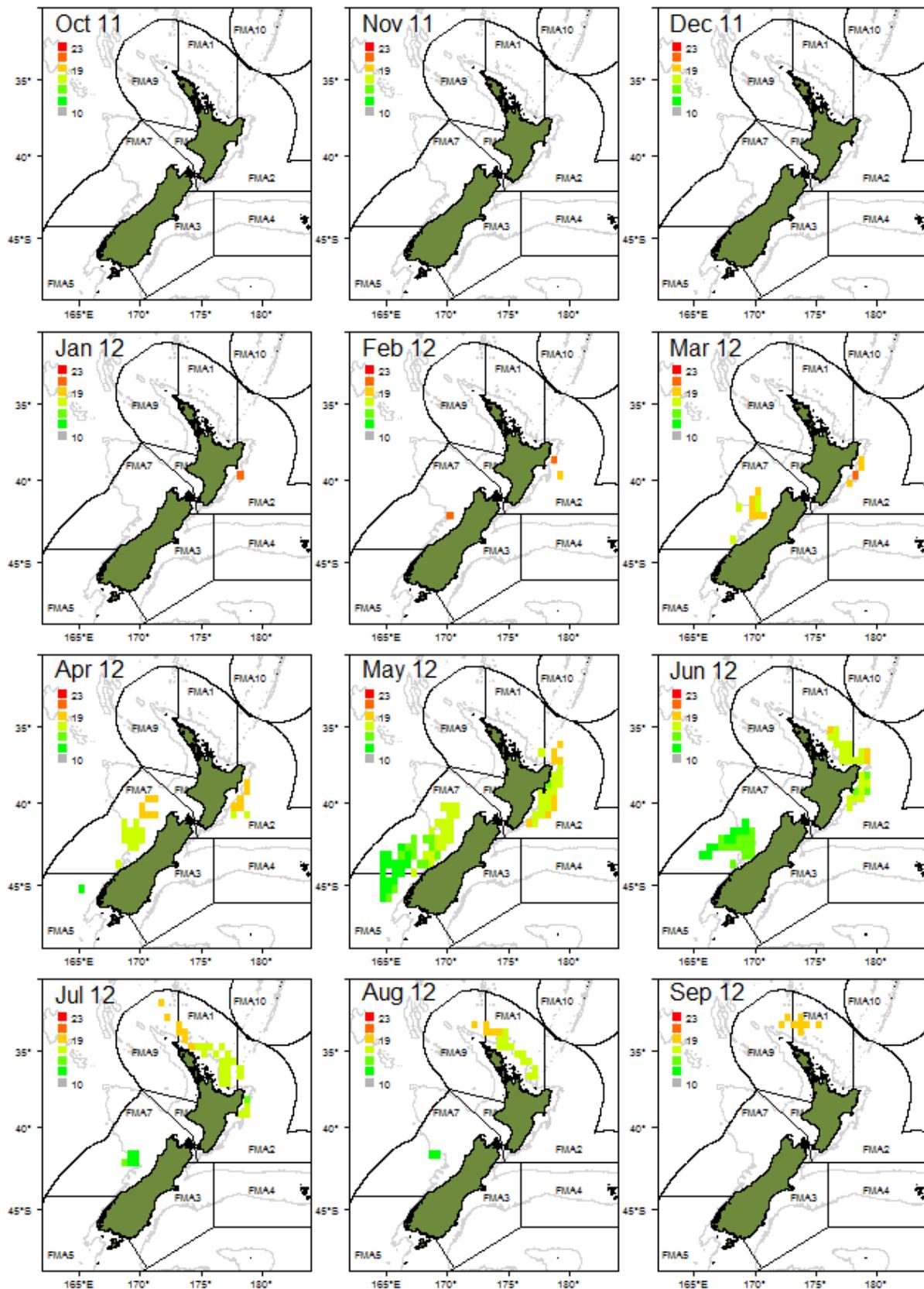
**Appendix 30: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2012. (Log scale used for colour palette. Depth contour at 1000 m.)**



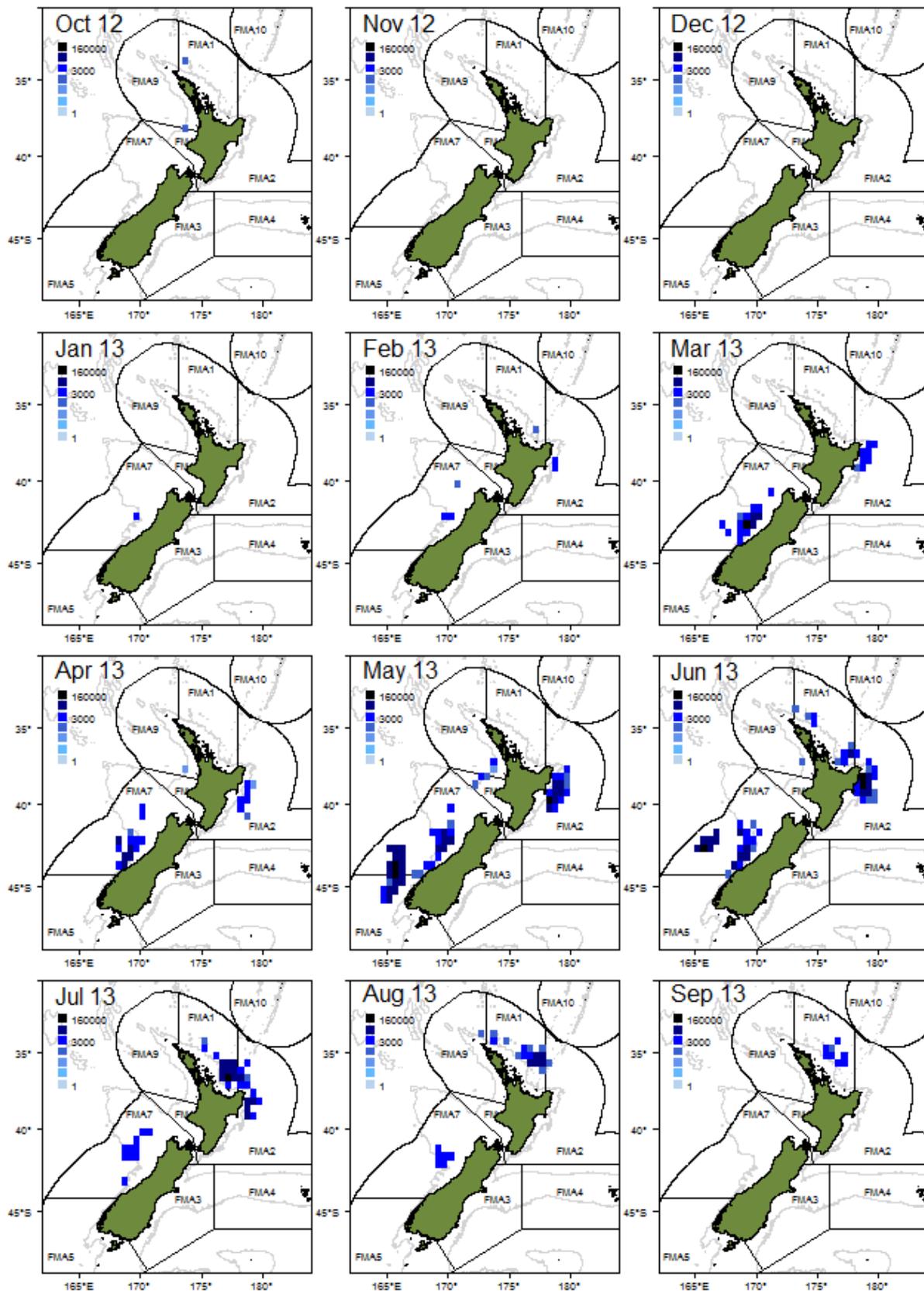
**Appendix 31: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2012. (Log scale used for colour palette. Depth contour at 1000 m.)**



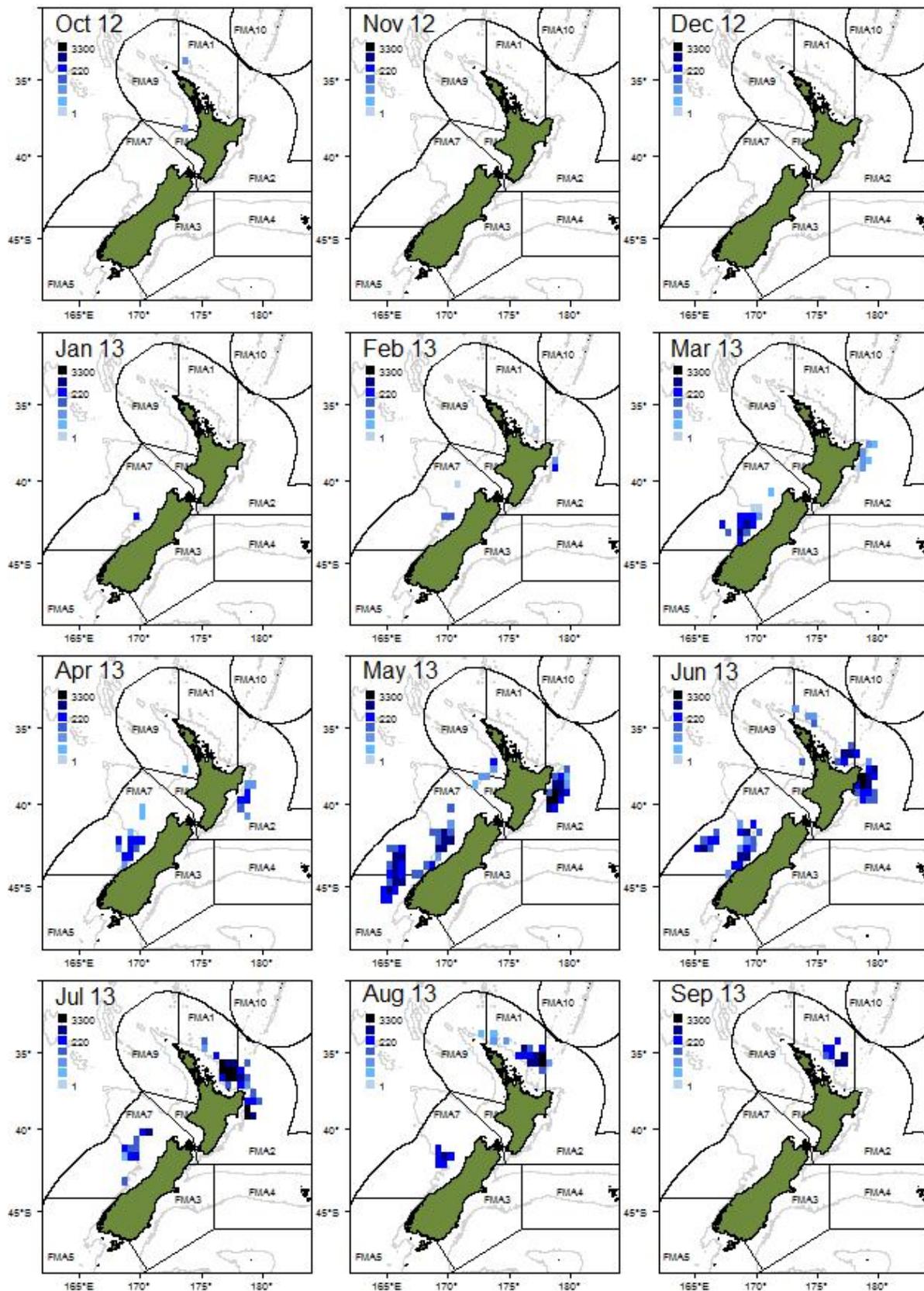
**Appendix 32: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2012.**



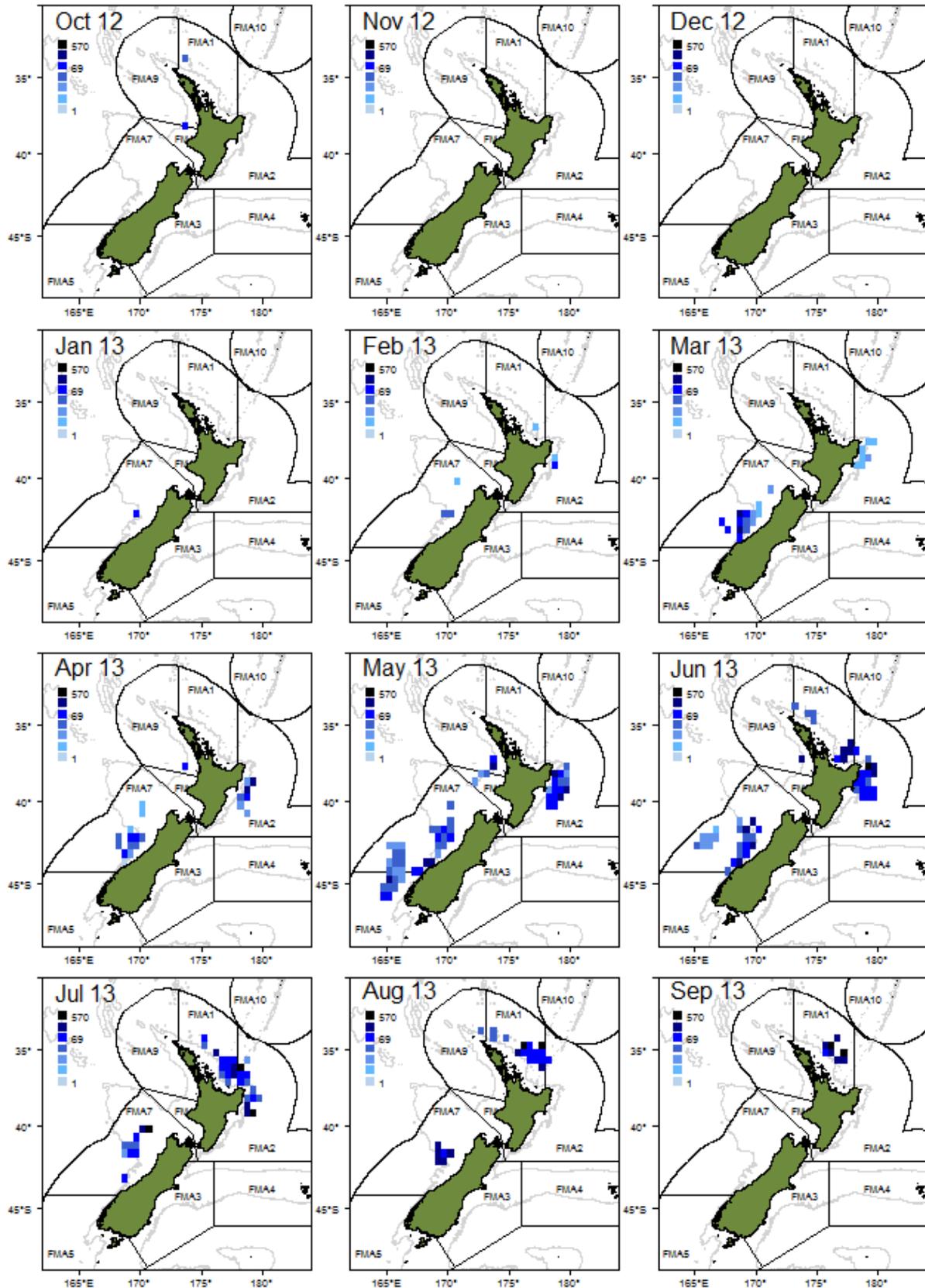
**Appendix 33: Number of hooks set by surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2013. (Log scale used for colour palette. Depth contour at 1000 m.)**



**Appendix 34: BWS catches (number) by the surface longline fishery targeting STN in 0.5 degree rectangles for the fishing year 2013. (Log scale used for colour palette. Depth contour at 1000 m.)**



**Appendix 35: BWS catch rates (number per 1000 hooks) by the surface longline fishery targeting STN (total catch/total effort) in 0.5 degree rectangles for the fishing year 2013. (Log scale used for colour palette. Depth contour at 1000 m.)**



**Appendix 36: Mean sea surface temperature (degrees C) for sets targeting STN in the surface longline fishery in 0.5 degree rectangles for the fishing year 2013.**

