SCIENTIFIC COMMITTEE
THIRTEENTH REGULAR SESSION
Rarotonga, Cook Islands
9-17 August 2017

Summary of progress on data preparation for an updated, Pacific-wide silky shark (*Carcharhinus falciformis*) assessment

WCPFC-SC13-2017/SA-IP-12

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1 Introduction

Under the Common Oceans (Areas Beyond National Jurisdiction (ABNJ)) Tuna Project, the Western and Central Pacific Fisheries Commission (WCPFC), with support from the United Nations Food and Agriculture Organization (FAO), is executing a programme of shark and bycatch work. One of the components of this work involves shark assessment and management and funding has been provided to conduct four shark stock assessments on the condition that they be pan-Pacific in nature. Two of these stock status assessments (Pacific-wide bigeye thresher shark (Common Oceans (ABNJ) Tuna Project 2017a) and Southern Hemisphere porbeagle shark (Common Oceans (ABNJ) Tuna Project 2017b)) are being presented to SC13 in August 2017.

It was agreed at SC12 in August 2016 that the third ABNJ Pacific-wide shark stock status assessment would be for the silky shark (*Carcharhinus falciformis*) (see SC12 Summary Report, Attachment H). This species has been identified by both WCPFC and the Inter-American Tropical Tuna Commission (IATTC) as being depleted and in need of management, and was recently listed on the Convention on International Trade in Endangered Species (CITES). By updating the previous assessment (Rice & Harley 2013, which used data through 2009), this study will provide useful information on Western and Central Pacific Ocean (WCPO) stock status and help evaluate the WCPFC no-retention measure for this species (CMM 2013-08). By expanding the scope to the entire Pacific, the study also addresses a priority shark research topic for the IATTC (Resolution C-16-05) in the Eastern Pacific Ocean (EPO) and has the potential to elucidate basin-wide patterns for this highly migratory stock.

2 Scoping and Data Access Arrangements

Cooperation between the WCPFC and IATTC Secretariats was initiated through an exchange of letters in February 2017 proposing to share purse seine observer data between the two Secretariats' nominated staff for the purpose of the silky shark assessment only. This type of arrangement is provided for under a 2009 Memorandum of Cooperation on Exchange and Release of Data between WCPFC and IATTC (WCPFC 2009). WCPFC Circular 2017/20, issued on 21 March 2017, finalized the data sharing arrangement and specified that WCPFC would only make available to IATTC staff purse seine observer data from the regional observer programme (ROP). WCPO non-ROP data will not be used in the study due to data unavailability. Available WCPO longline data will be used in the study, subject to data confidentiality arrangements agreed with the data holders, but will not be shared with IATTC staff.

There is little existing information on stock structure that can serve as a basis for organizing the data preparation work according to biological boundaries. The silky shark inhabits both coastal and offshore waters and is one of the world's most abundant and widely distributed sharks (Bonfil 2008). Based on life history data through 2001, Bonfil (2008) suggested that there are distinct populations of silky shark in the Eastern Pacific versus the Western Central Pacific. This hypothesis rests on observations of smaller sizes at maturity for both males and females in the Eastern Pacific, but it was noted that sample sizes were limited and length measurements may differ between studies. In parallel, Bonfil (2008) stated that the Pacific population structure is unknown and that Pacific islands may serve as a link between the two edges of the ocean basin. More recently, research by the United States National Oceanic and Atmospheric Administration (NOAA) has suggested a Pacific stock boundary running eastward through the WCPO at the equator until it approaches the South American coast where it dips southward to 20^{o}S (Aires-da-Silva et al. 2013).

WCPFC and IATTC agreed to initiate work by preparing (or updating) their own datasets and then to explore the appropriateness of combining datasets or data products for integrated analysis. This work plan reflects the importance of understanding and accounting for differences in the fisheries as well as the observer programmes in the EPO and WCPO before combining data for analysis. In the EPO, IATTC attempted a stock assessment for silky shark several years ago (Aires-da-Silva et al. 2013) and has updated an index of abundance based on the purse seine fishery in every year since then (Aires-da-Silva et al. 2014, 2015; Lennert-Cody et al. 2016, 2017). While a stock assessment (Rice & Harley 2013) and indicators (Clarke et al. 2013, Rice et al. 2015) analyses have been prepared for the WCPO, these have primarily focused on the longline fishery.

This paper provides a status report on the data preparation activities for the WCPO data only. Data confidentiality arrangements necessary to obtain access to the WCPO data required for this study preclude the provision of much of the data to outside consultants. As a result, the WCPFC's ABNJ Technical Coordinator-Sharks and Bycatch (TCSB) is acting as the data manager for the WCPFC data and is undertaking the data preparation. The time required to prepare the WCPO observer datasets was longer than anticipated, mainly due to the need for multiple extracts to redress structural issues in the data and the desire to formulate new explanatory variables (e.g. net dimensions, duration of the encirclement phase and proximal fish aggregation device (FAD) density) to match the modelling approach developed by IATTC. Data preparation work began in February 2017 and continued until May 2017, and this paper reflects the work that could be accomplished during that period.

3 Description of Key Data Sets

The silky shark is the most frequently encountered shark in the tropical WCPO purse seine fishery and the second most frequently encountered in the tropical and sub-tropical WCPO longline fishery (Lawson 2009). It also the most common shark caught in both the EPO purse seine and longline fisheries (IATTC 2017, Siu et al. 2017). Given the important contribution of both fisheries to the expected impact of fishing mortality on the silky shark stock, unlike other Pacific shark stock assessments which have been based primarily on data from longline fisheries, data from both purse seine and longline fisheries must be compiled for this study.

A number of non-public domain datasets which are exclusively or mainly focused on WCPO fisheries are available to this study. These include:

- Longline observer data maintained by SPC as part of the WCPFC Regional Observer Programme accessible to the TCSB via the WCPFC Secretariat, as well as non-public domain longline observer data maintained by SPC on behalf of Australia, the Cook Islands, the Federated States of Micronesia, Fiji, French Polynesia, the Republic of the Marshall Islands, New Caledonia, New Zealand, Samoa, Solomon Islands, Tonga and Vanuatu and accessible to the TCSB through data confidentiality agreements with each country for use in the ABNJ Tuna Project ("SPC LL observer data");
- United States longline observer data provided directly to the TCSB for use in the ABNJ Tuna Project under a data confidentiality agreement ("US LL observer data");
- Japan longline observer data provided to the TCSB under a data confidentiality agreement specific to this assessment ("Japan LL observer data");
- Purse seine observer data maintained by SPC as part of the WCPFC Regional Observer Programme accessible to the TCSB via the WCPFC Secretariat ("SPC ROP PS observer data").

Each of these datasets is described and explored separately below.

3.1 SPC LL Observer Data

3.1.1 Data Description

These data were provided by SPC to the TCSB on 29 March 2017. They consist of two files: one file contains set-level information with one row per set ("Set Header", Table 1) and one file contains catch records for individual fish with one row per fish caught ("Catch", Table 2). The catch dataset contains all species in order to explore potential explanatory variables associated with the catch of target species. The field names for the data in each file are shown in Table 3; explanations of the fields and how they are collected can be found in SPC (2017a).

To link each catch record to its set characteristics, a unique identifier was created by combining set identifiers and trip identifiers in the set database. At this step there were 202 set records which shared a unique identifier with another set. As it was impossible to know which, if any, of these set records were correct, all 202 were removed. From the remaining number of sets (n=78,354), containing 23,824 silky sharks (FAL), the following number of sets (and FAL records) were removed sequentially:

- Removed due to missing lat/long information (2,464 sets and 70 FAL);
- Removed due to not being within the year range of sufficient observer coverage (10,902 sets and 3,564 FAL);
- Removed due to missing hooks fished values (3,420 sets and 43 FAL);
- Removed due to missing hooks between floats (70 sets and 3 FAL);
- Removed due to too many or too few hooks per set (720 sets and 285 FAL);
- Removed due to too many or too few hooks between baskets (344 sets and 27 FAL);
- Removed due to being outside the spatial boundaries of the assessment (3,734 sets and 8 FAL); and
- Removed due to originating from the Hawaii or American Samoa longline observer programme (11,048 sets and 778 FAL).

Removals related to missing values (hooks between floats, latitude, longitude and number of hooks fished) were necessary because these values are likely to be very important in the catch rate standardizations and missing values may interfere with coefficient estimation. Extreme values of hooks fished (i.e. <500 or >4500) were considered to represent abnormal fishing operations and were also thus removed. Similarly, sets recording fewer than four, or more than 45 hooks between baskets were considered dubious and were removed. Sets before 2002 and sets after 2016 were removed to avoid biases associated with poor observer coverage (prior to 2002) or incomplete reporting (2017). The spatial boundaries were defined based on the Pacific-wide tropical/semi-tropical distribution of the species as not extending more than 40° north and south of the equator; the longitudinal distribution was based on the range within which there was observer coverage over most of the time series (130°-230°E longitude). Finally, sets from the Hawaii and American Samoa longline fisheries were removed because they are likely to be duplicated in the US longline observer dataset described below in Section 3.2.

A number of other filters applied or discussed in Rice et al. (2015) were considered but not applied as follows:

- sets from fisheries known to be targeting sharks (e.g. Papua New Guinea) and those sets for which the set header field target_shk_yn=yes (Table 3), were not removed *a priori* as it was considered that any shark targeting effect could be addressed through the catch rate standardization;
- removing sets from small national observer programs with < 100 sets each was not considered necessary as this analysis will not be using the observer program identifier in lieu of actual (lat/long) location (as Rice et al. 2015 did);
- removing records considered to be outside the sea surface temperature (SST) range of species was not done due to doubts about the certainty of silky shark's SST range and a preference to address habitat issues through a lat/long exclusion criterion and explanatory variables in the standardization model;
- removing records where the catch rate of FAL is greater than the 97.5th percentile of nominal mean CPUE for the dataset as a whole was not done because FAL may exhibit schooling behaviour and thus we might expect to see rare large catches.

In total 32,702 sets were removed from the analysis, containing 4,778 FAL, leaving 45,643 sets and 19,046 FAL. Nearly 86% of the sets recorded no catch of silky sharks. All catch and effort data were screened before plotting in accordance with the three-vessel rule (WCPFC 2007).

Table 1. Number of observed sets by flag and year extracted for this study (before filtering) from the SPC LL observer dataset. Year-flag combinations without any observations are shaded in blue.

SET	AS	AU	CK	CN	FJ	FM	GU	JP	KI	KR	MH	NC	NZ	PF	PG	PW	SB	TO	TW	US	VU	WS	TOTAL
1980	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	17
1981	-	17	-	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	35
1982	-	10	-	-	-	-	-	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	27
1984	-	10	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	19
1985	-	-	-	-	-	-	-	18	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18
1986	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
1987	-	4	-	-	-	-	-	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-	40
1988	-	19	-	-	-	-	-	79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	98
1989	-	60	-	-	-	-	-	106	-	-	-	-	-	-	-	-	-	-	-	-	-	-	166
1990	-	32	-	-	-	-	-	314	-	-	-	-	-	-	-	-	-	-	-	-	-	-	346
1991	-	43	-	-	-	-	-	877	-	7	-	-	-	-	-	-	-	-	-	-	-	-	927
1992	-	9	-	-	-	-	-	1,011	-	8	-	-	16	-	-	-	-	-	-	-	-	-	1,044
1993	-	-	-	18	-	-	-	1,459	-	5	-	-	-	-	-	-	-	-	35	-	-	-	1,517
1994	-	-	-	29	-	7	-	963	-	-	-	-	13	-	-	-	-	-	95	-	-	-	1,107
1995	-	-	-	28	-	2	23	644	-	-	-	-	80	-	-	-	-	-	39	-	2	-	818
1996	-	-	-	69	-	12	13	470	-	-	-	-	144	-	-	-	5	-	-	-	-	-	713
1997	-	13	-	67	-	27	8	653	-	-	-	-	136	-	-	-	-	-	57	-	-	-	961
1998	-	-	-	82	-	42	9	371	-	-	-	-	143	-	-	-	14	-	162	-	-	-	823
1999	-	10	-	65	-	20	-	358	-	25	-	-	74	-	-	-	41	-	138	-	-	-	731
2000	-	-	-	73	-	54	5	334	-	-	-	-	41	-	-	12	50	-	154	-	-	-	723
2001	-	115	6	122	-	27	-	265	-	-	-	12	276	-	-	-	65	-	53	-	-	14	955
2002	84	697	7	6	49	28	-	292	-	175	-	56	126	72	-	-	419	-	191	-	-	2	2,204
2003	-	644	40	35	195	23	-	257	-	39	-	81	268	172	-	-	283	-	126	-	-	2	2,165
2004	-	798	59	209	133	67	-	20	-	1	-	84	451	180	-	-	174	83	101	-	-	-	2,360
2005	-	944	60	191	443	61	-	366	-	106	-	37	138	136	-	-	-	11	-	-	-	9	2,502
2006	-	930	18	553	437	131	-	219	-	240	-	48	107	291	-	-	-	145	8	-	-	15	3,142
2007	-	455	12	576	339	62	-	275	-	107	-	61	160	93	-	-	-	56	9	-	-	-	2,205
2008	-	575	32	125	355	39	-	83	-	-	23	86	158	186	-	-	-	108	48	-	-	-	1,818
2009	-	402	54	80	236	-	-	244	-	-	8	211	174	434	-	-	-	33	71	-	59	-	2,006
2010	-	224	52	-	176	-	-	109	17	-	-	227	175	445	-	-	-	10	1	-	129	-	1,565
2011	-	317	58	-	334	-	-	80	-	145	-	172	160	351	-	-	63	-	23	-	260	7	1,970
2012	-	282	-	175	174	-	-	82	-	589	-	127	109	399	52	-	137	8	3,311	3,374	6	-	8,825
2013	-	277	159	272	963	61	-	129	-	877	11	102	98	453	-	-	54	-	7,371	3,957	515	16	15,315
2014	-	128	85	465	1,375	311	-	136	-	427	-	150	133	437	1	-	-	22	4,810	3,981	143	-	12,604
2015	-	66	129	330	1,991	151	-	133	50	550	-	103	141	342	-	-	-	51	1,071	-	211	20	5,339
2016	-	-	14	128	1,984	94	-	16	8	171	-	144	-	186	-	-	-	8	340	-	116	-	3,209
2017	-	-	-	8	18	-	-	-	-	-	-	13	-	-	-	-	-	-	-	-	-	-	39
TOTAL	84	7,098	785	3,706	9,202	1,219	58	10,444	75	3,472	42	1,714	3,321	4,177	53	12	1,305	535	18,214	11,312	1,441	85	78,354

Table 2. Number of FAL catch records (each record is one shark) by flag and year extracted for this study (before filtering) from the SPC LL observer dataset. Year-flag combinations without any observations are shaded in blue. Year-flag combinations with zero silky sharks recorded are shaded in red.

SET	AS	AU	CK	CN	FJ	FM	GU	JP	KI	KR	MH	NC	NZ	PF	PG	PW	SB	TO	TW	US	VU	WS	TOTAL
1980	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1981	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1982	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1984	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1985	NA	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1986	NA	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1987	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1988	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1989	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1990	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1991	NA	-	NA	NA	NA	NA	NA	-	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1992	NA	-	NA	NA	NA	NA	NA	-	NA	-	NA	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	NA	-
1993	NA	NA	NA	-	NA	NA	NA	-	NA	-	NA	NA	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	-
1994	NA	NA	NA	-	NA	-	NA	-	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	-	NA	NA	NA	-
1995	NA	NA	NA	57	NA	-	24	28	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	100	NA	-	NA	209
1996	NA	NA	NA	81	NA	-	43	-	NA	NA	NA	NA	-	NA	NA	NA	-	NA	NA	NA	NA	NA	124
1997	NA	-	NA	21	NA	4	6	55	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	118	NA	NA	NA	204
1998	NA	NA	NA	96	NA	2	2	28	NA	NA	NA	NA	-	NA	NA	NA	6	NA	470	NA	NA	NA	604
1999	NA	-	NA	128	NA	11	NA	33	NA	2	NA	NA	-	NA	NA	NA	30	NA	1,151	NA	NA	NA	1,355
2000	NA	NA	NA	160	NA	20	-	30	NA	NA	NA	NA	-	NA	NA	3	31	NA	374	NA	NA	NA	618
2001	NA	2	-	273	NA	8	NA	27	NA	NA	NA	1	-	NA	NA	NA	18	NA	119	NA	NA	9	457
2002	11	8	-	-	5	6	NA	4	NA	12	NA	7	-	2	NA	NA	146	NA	126	NA	NA	-	327
2003	NA	-	-	16	44	4	NA	11	NA	14	NA	12	-	2	NA	NA	136	NA	65	NA	NA	-	304
2004	NA	18	-	366	31	137	NA	4	NA	-	NA	16	1	53	NA	NA	43	50	223	NA	NA	NA	942
2005	NA	41	-	204	163	101	NA	47	NA	16	NA	7	-	22	NA	NA	NA	2	NA	NA	NA	-	603
2006	NA	19	-	658	213	102	NA	14	NA	243	NA	-	-	15	NA	NA	NA	75	33	NA	NA	-	1,372
2007	NA	33	3	1,436	130	228	NA	13	NA	32	NA	-	1	35	NA	NA	NA	34	11	NA	NA	NA	1,956
2008	NA	27	4	182	118	61	NA	-	NA	NA	39	3	-	2	NA	NA	NA	11	391	NA	NA	NA	838
2009	NA	8	13	48	150	NA	NA	3	NA	NA	2	35	-	4	NA	NA	NA	19	133	NA	43	NA	458
2010	NA	9	2	NA	60	NA	NA	-	-	NA	NA	29	-	27	NA	NA	NA	-	-	NA	170	NA	297
2011	NA	11	13	NA	106	NA	NA	-	NA	83	NA	38	-	3	NA	NA	-	NA	77	NA	429	-	760
2012	NA	15	NA	60	63	NA	NA	-	NA	283	NA	8	-	5	1,711	NA	438	1	2,009	231	-	NA	4,824
2013	NA	27	96	37	148	19	NA	-	NA	413	-	5	-	6	NA	NA	13	NA	1,662	317	222	-	2,965
2014	NA	11	53	94	173	246	NA	-	NA	537	NA	5	-	19	-	NA	NA	2	266	230	64	NA	1,700
2015	NA	10	67	54	365	22	NA	-	1	989	NA	6	-	31	NA	NA	NA	1	81	NA	408	-	2,035
2016	NA	NA	-	4	318	16	NA	23	-	137	NA	61	NA	105	NA	NA	NA	-	14	NA	187	NA	865
2017	NA	NA	NA	-	-	NA	NA	NA	NA	NA	NA	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7
TOTAL	11	239	251	3,975	2,087	987	75	320	1	2,761	41	240	2	331	1,711	3	861	195	7,423	778	1,523	9	23,824

Table 3. Data types extracted for the SPC LL observer set and catch datasets.

Data Set	Fields Available
SPC LL Observer Dataset (Set Header)	year, obstrip_id, program_code, flag, vessel_id, vessel_name, l_set_id, set_start_date, set_start_time, set_end_time, haul_start_date, haul_start_time, soak_time, lat1d, lon1d, eez_code, tar_sp_code, target_tun_yn, target_swo_yn, target_shk_yn, hk_bt_flt, hook_set, hook_est, lightsticks, bask_set, bask_observed, nbshark_lines, bait1_sp_code, bait2_sp_code, bait3_sp_code, bait4_sp_code, bait5_sp_code, wire_trace, hook_type, sharktarget, sharkbait, moonfrac, sst
SPC LL Observer Dataset (Catch)	year, obstrip_id, l_set_id, catch_time, sp_code, sp_category, hk_bt_flt, hook_no, condition_land, condition_release, fate_code, length, len_code, sex_code

3.1.2 Data Exploration

The SPC longline observer dataset, after cleaning and filtering, is distributed with low coverage over a wide area as illustrated by a sample of plots of annual observed effort and annual total effort from 2004, 2009 and 2014 (Figure 1). Although the distribution and amount of effort fished remains remarkably constant throughout the 15-year period, the observed effort increased considerably between 2009 and 2014 both in quantity and range of areas covered. This is a positive development but it suggests that the observer dataset, in its nominal form, may be unbalanced over the time series as well as still unrepresentative of the total fishing effort on the stock. In addition to representing much less than 1% of the total effort, until recently much of the observed effort is concentrated in the Southern Hemisphere at or below 20°S and thus potentially outside much of the WCPO core habitat area for FAL. It should also be noted that Figure 1 does not include observer data provided for this study by the US and Japan, and thus there is better coverage for the North Pacific than this figure suggests. Some data are available for analysis but are not plotted in the figure due to the three vessel rule, in particular coverage north of Hawaii from the Chinese Taipei observer programme which has been providing data since 2012.

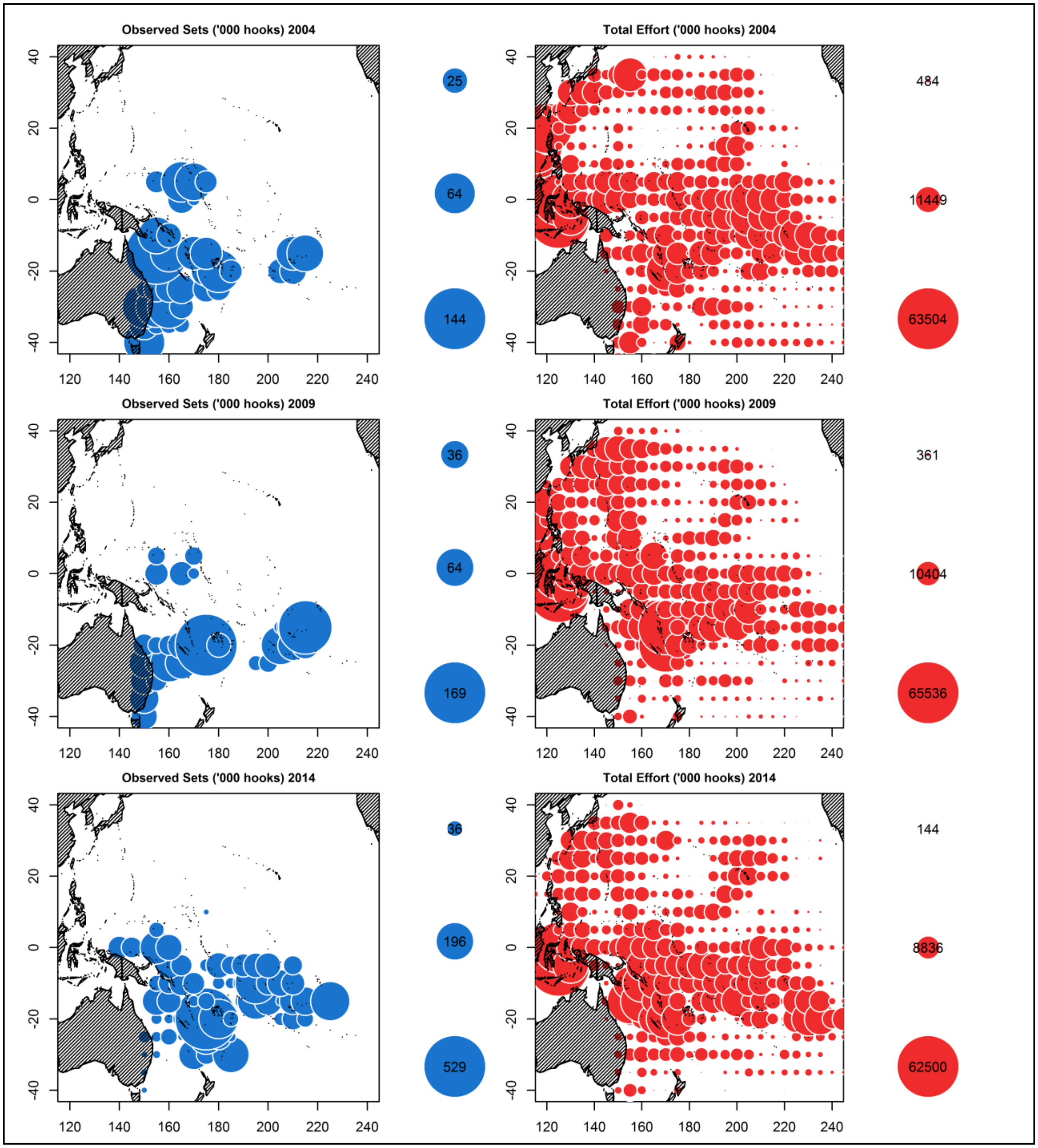

Figure 1. Distribution of observed effort relative to total effort (in thousand hooks) in the Pacific longline fishery (for comparison) for a sample of years (2004, 2009 and 2014) within the extracted SPC LL observer and CES effort datasets. The size of the circles is proportional to the number of hooks fished in each 5ºx5º cell in thousands of hooks (10th, 50th and 90th percentiles given as a legend). Actual set locations are rounded southward and westward to the nearest 5ºx5º grid point and may be plotted over land as a result.

Silky shark catch per unit effort (CPUE) by year and 5ºx5º grid in the SPC LL observer dataset are shown in Figure 2. These nominal catch rate plots suggest that within the observed sets shown here the main centres of FAL abundance lie in near-equatorial waters between 20º N and 20º S. Within this dataset, areas of high CPUE are often found in or just east of the Papua New Guinea and Solomon Island exclusive economic zones (EEZs).

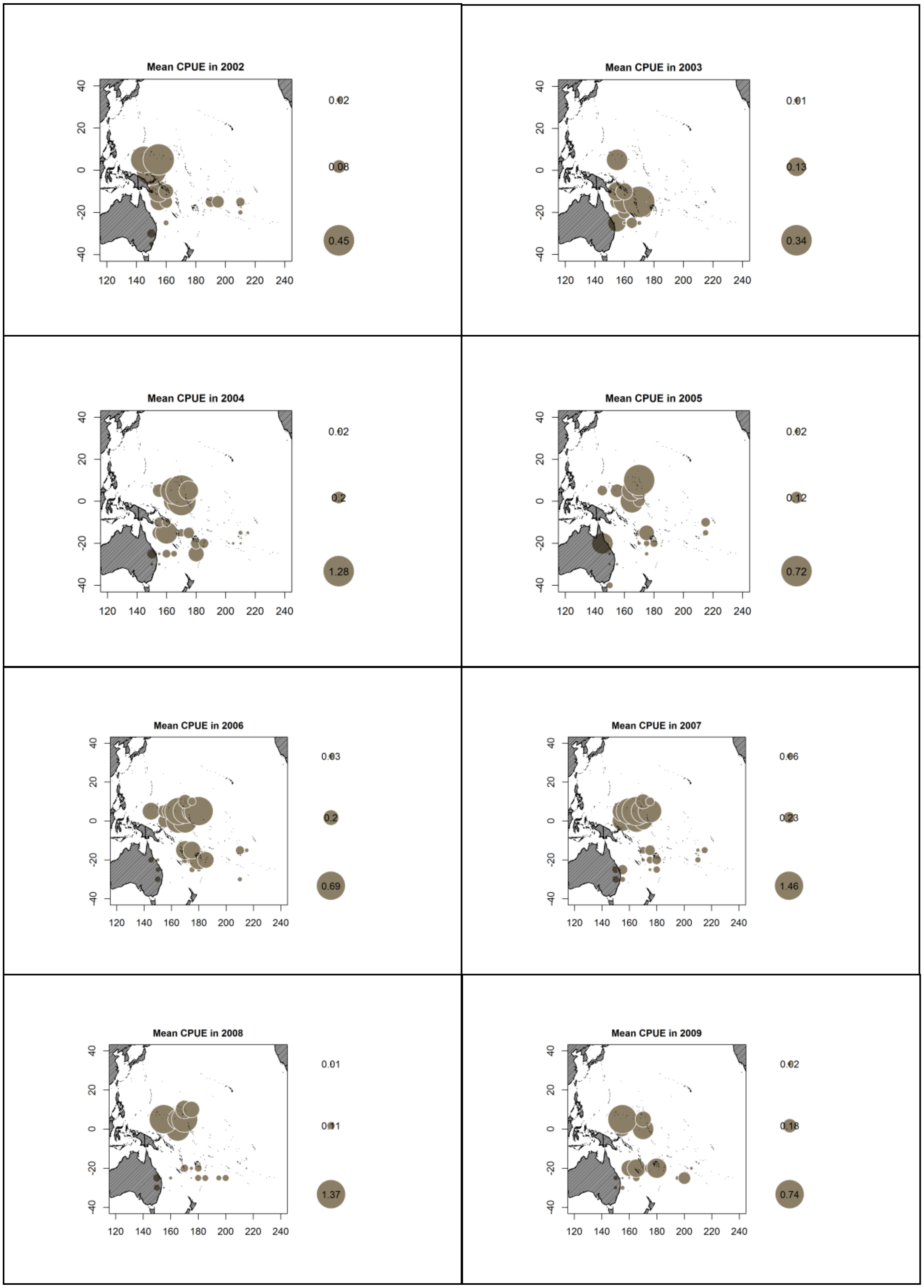

Figure 2a. Annual mean CPUE for silky shark in the SPC LL observer dataset, 2002-2009. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). Actual set locations are rounded southward and westward to the nearest 5^{o}x5^{o} grid point and may be plotted over land as a result.

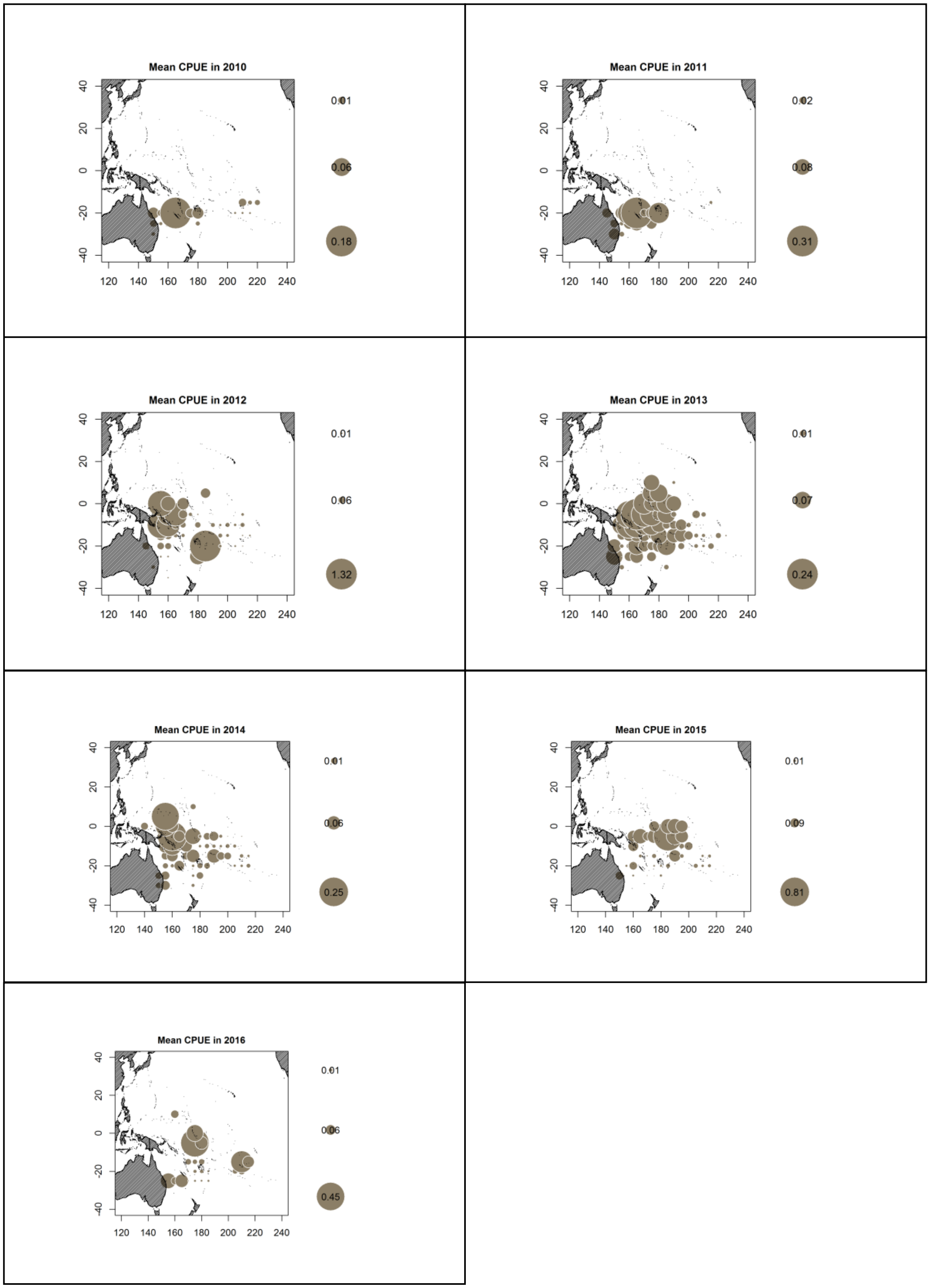

Figure 2b. Annual mean CPUE for silky shark in the SPC LL observer dataset, 2010-2016. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). Actual set locations are rounded southward and westward to the nearest 5°x5° grid point and may be plotted over land as a result.

In order to explore some of the potential explanatory variables that might be useful in standardizing the catch rate data to derive an abundance index, boxplots for latitude, longitude, year, month, hooks between floats and program code were constructed (Figure 3). Of these factors, the spatial, program code and hooks between floats variables appear to be the most promising.

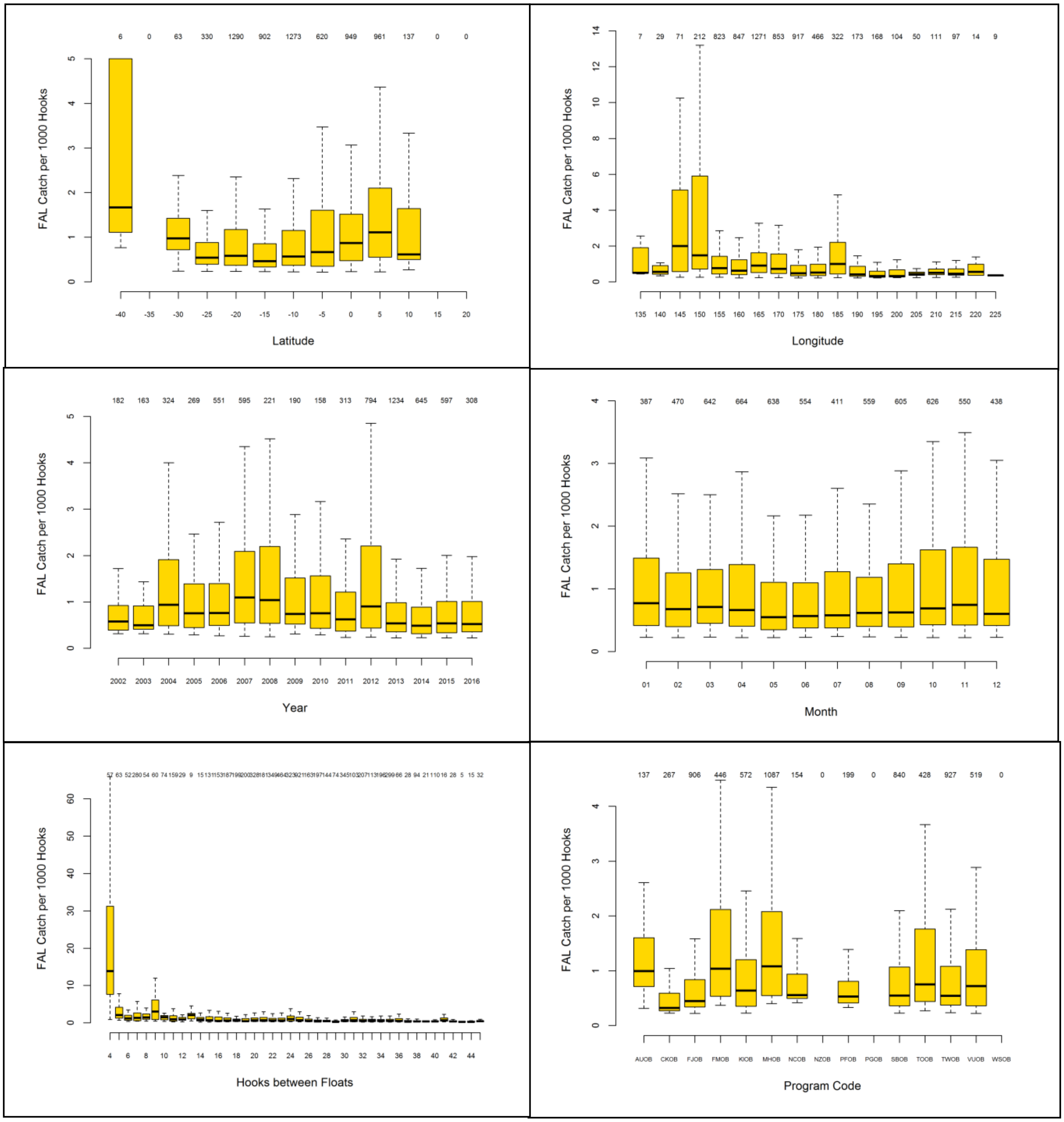

Figure 3. Box and whisker plots of potential explanatory variables in silky shark catch rates for sets with non-zero catch rates in the SPC LL observer dataset. The gold box shows the range between the 25th and 75th percentile (the interquartile range). The black line is the median. The whiskers are plotted at the most extreme data point which is no more than 1.5 times the interquartile range from the box (i.e. extreme outliers are not plotted). The sample size is annotated at the top of each column.

Using the same dataset, nominal CPUE was plotted as the mean of set-by-set catch rates (i.e. catch of FAL divided by hooks fished for each set) by year (Figure 4). It should be noted that this abundance trend will differ from the boxplot by year in Figure 3 as Figure 3 only shows non-zero catches whereas zero and non-zero catches are shown here. There are many reasons why, in general, it should not be expected that the nominal CPUE trend is not an accurate reflection of the true abundance trend of the population (Hoyle et al. 2014). This caveat is particularly important for this dataset as shown by the uneven distribution of observed effort in space and time (Figure 1), in particular, the large increase in observer data from the Chinese Taipei observer programme from 2012 onward (Table 1). The effects of the adoption and implementation of CMM2013-08 prohibiting retention of silky sharks in 2013 and 2014, respectively, also remain to be addressed.

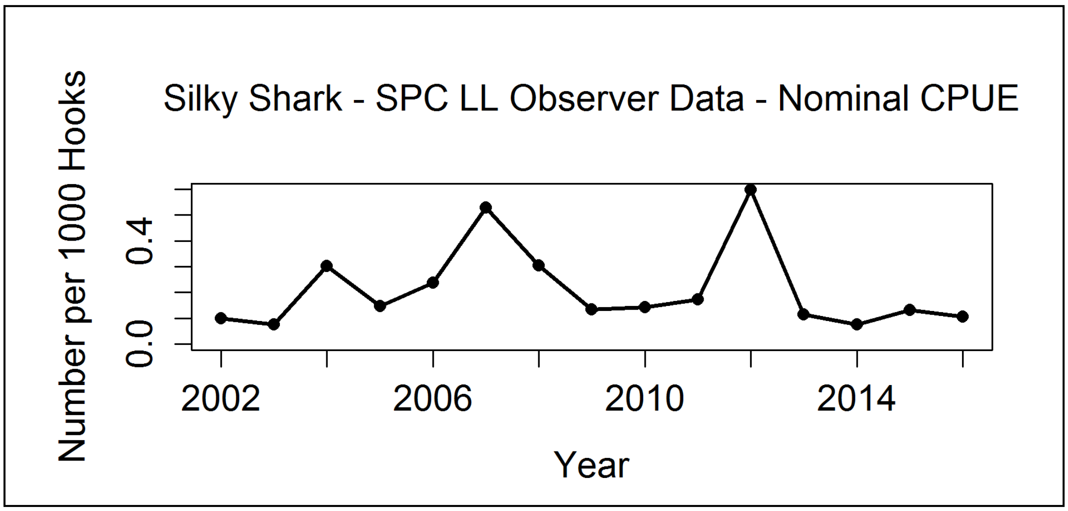

Figure 4. Nominal annual mean CPUE (i.e. mean of individual set catch rates) in the SPC LL observer dataset, 2002-2009.

As the plan is to revisit the 2013 SS3 stock assessment (Rice & Harley 2013) with updated data, in addition to compiling catch and effort data, biological data in the form of length frequencies by sex must also be prepared. In the SPC LL observer data available to this study, there are length and sex data available for 8,548 female silky shark and 7,487 male silky sharks between 1995 and 2016. The majority of these (87%) were measured in fork length (FL); the remaining lengths in total length (TL) were converted to fork length using the following equation from Joung et al. 2008 (cited in Clarke et al. 2015): FL=(TL-2.36)/1.21. Lengths were screened to exclude observations below a nominal size at birth of 50 cm FL and a nominal maximum size of 271 cm FL based on the review in Clarke et al. (2015). Spatial representations of length frequencies, shaded on a relative scale, across the WCPO for female and male silky sharks (Figure 5) suggest larger individuals in the southwest for both sexes. Such a pattern may also be present in the southeast but obscured by low or no sampling. There is also a suggestion of large individuals to the east in equatorial waters, although sample sizes in that area are also low.

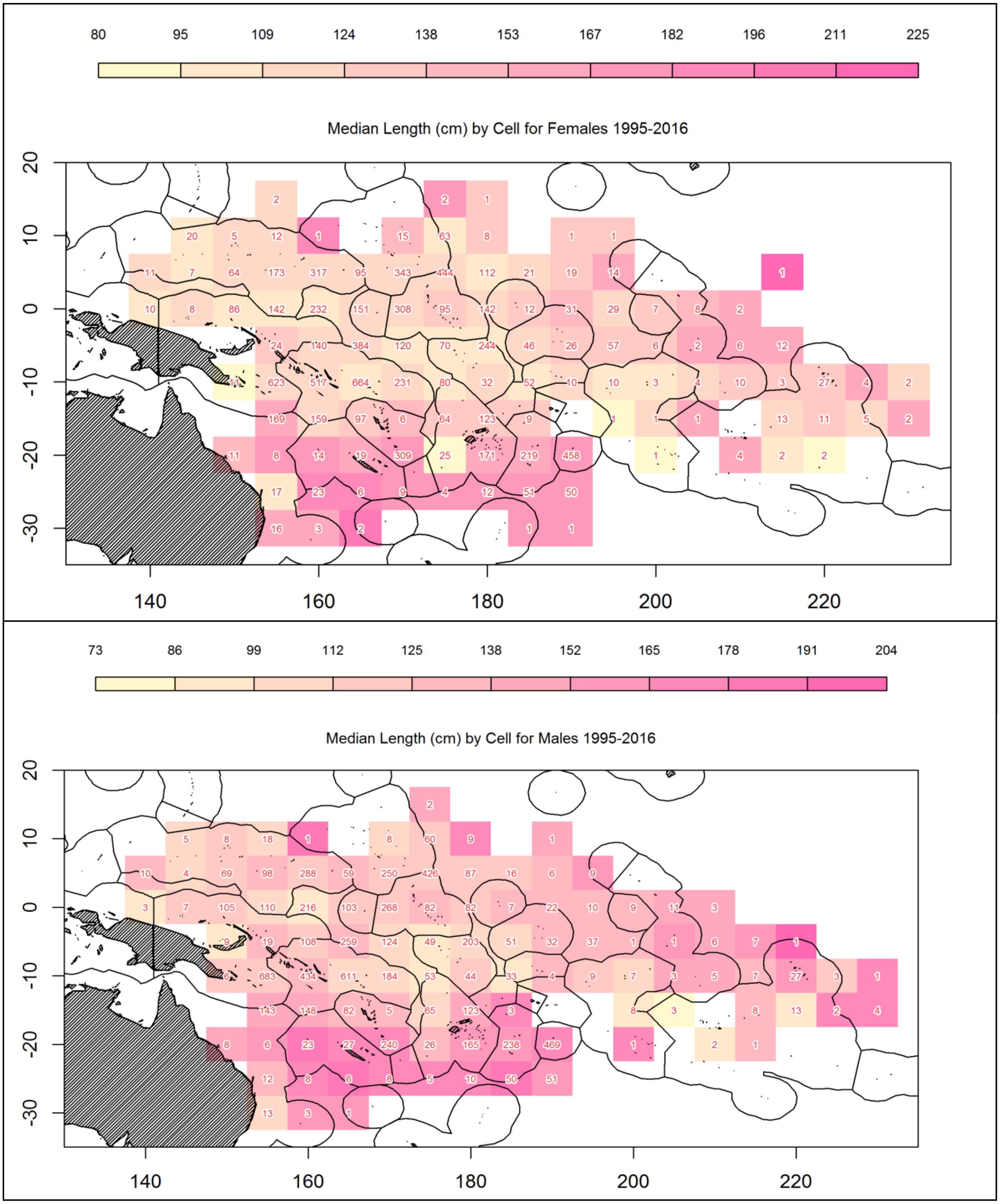

Figure 5. Mapping of median length on a relative scale for female and male silky sharks in the SPC LL observer database, 1995-2016. All lengths shown are in cm fork length (see text for conversion factors). The number annotated in each 5x5 degree cell is the number of measured sharks.

3.2 United States LL Observer Data

3.2.1 Data Description

These data were authorized for use by the TCSB in this study by the National Oceanic and Atmospheric Administration's Pacific Islands Fisheries Science Center on 24 February 2017. Unlike the SPC LL observer data, the Hawaii and American Samoa longline observer data files contain set header information for each species-specific catch record and so did not need to be joined. Data for all species recorded by observers were provided. In total the dataset contained 70,331 sets with 7,626 silky sharks (FAL) caught (Table 4).

Table 4. Number of observed sets and number of silky shark catch records in the US Hawaii and American Samoa longline observer data set provided for this study. Year-flag combinations without any observations are shaded in blue.

	Number of Sets		**Number of FAL catch records**	
Year	**Hawaii**	**American Samoa**	**Hawaii**	**American Samoa**
1995	538	0	27	NA
1996	638	0	24	NA
1997	497	0	22	NA
1998	579	0	59	NA
1999	454	0	97	NA
2000	1,396	0	257	NA
2001	2,713	0	638	NA
2002	3,307	0	847	NA
2003	3,081	0	180	NA
2004	3,927	0	329	NA
2005	5,928	0	194	NA
2006	4,162	235	582	90
2007	4,830	327	279	260
2008	5,055	269	171	88
2009	4,746	237	335	72
2010	5,036	890	190	403
2011	4,721	1,017	197	613
2012	4,696	592	251	208
2013	4,447	584	237	291
2014	4,914	515	259	426
Total	**65,665**	**4,666**	**5,175**	**2,451**

The field names in the US longline observer dataset are shown in Table 5. It was assumed that 17 values of longitude which were in the range of 530°-540°E were actually in the range of 230°-240°E and were changed accordingly.

Table 5. Data types extracted for the Hawaii and American Samoa longline observer set and catch datasets. (* indicates that the field was available in the Hawaii longline observer dataset only).

Data Set	**Fields Available**
Hawaiian and American Samoa Longline Observer (set header)	TRIP_NUM, VESSEL_FLAG, PERMIT_NUM, SET_NUM, SET_BEGIN_DATETIME, SET_END_DATETIME, HAUL_BEGIN_DATETIME, SET_BEGIN_LAT, SET_BEGIN_LON, HKS_PER_FLT, NUM_HKS_SET, LITE_DEVICE_TYPE_CODE_VAL, NUM_LITE_DEVICES, NUM_FLTS, NUM_FLTS_OBSRVD*, BAIT_CODE, BAIT_CODE_VAL, LDR_MAT_CODE, LDR_MAT_CODE_VAL, HOOK_TYPE_CODE_VALUE_1, HOOK_TYPE_CODE_VALUE_2, HOOK_TYPE_CODE_VALUE_3, HOOK_TYPE_CODE_VALUE_4, SPECIES_CODE, SPECIES_COMMON_NAME, HK_NUM, CAUGHT_COND_CODE_VAL, KEPT_RETURN_CODE_VAL

From the initial number of records shown in Table 4, the following number of sets (and FAL records) were removed sequentially:

- Removed due to missing lat/long information (9 sets and 2 FAL);
- Removed due to missing hooks fished values (6 sets and no FAL);
- Removed due to missing hooks between floats (22 sets and 7 FAL);
- Removed due to too many or too few hooks per set (280 sets and 4 FAL);
- Removed due to too many or too few hooks between baskets (186 sets and 4 FAL);
- Removed due to being outside the spatial boundaries of the assessment (387 sets and no FAL).

The rationale for applying these filters and for not applying other filters is given in Section 3.1.1 above. In total 890 sets contained 17 FAL were removed from the analysis, leaving 69,441 sets and 7,609 FAL. Over 94% of the sets recorded no catch of silky sharks. All catch and effort data were screened before plotting in accordance with the three-vessel rule (WCPFC 2007).

3.2.2 Data Exploration

US LL observer coverage is concentrated around Hawaii until 2006 when the American Samoa longline observer programme began (Table 4 and Figure 6). Although the number of observed sets in the US longline observer programme data is similar to that in the SPC longline observer dataset (compare Tables 1 and 4), the US observer coverage is focused on areas which have a relatively low amount of fishing effort compared to other areas in the Pacific (Figure 6). Another important distinction between the US and SPC LL observer datasets is the number of silky shark catch records. Despite the fact that a substantial proportion of the US observed effort lies within areas expected to be core habitat for the silky shark, i.e. 20° north and south of the equator, the number of catch records in the US LL dataset is only one-third of that in the SPC LL dataset. One advantage of the US LL observer dataset is that it appears to be relatively evenly distributed over consistent areas through time. Therefore, while the catch rates of silky shark are relatively low, the dataset may prove easier to standardize to obtain a relative abundance index.

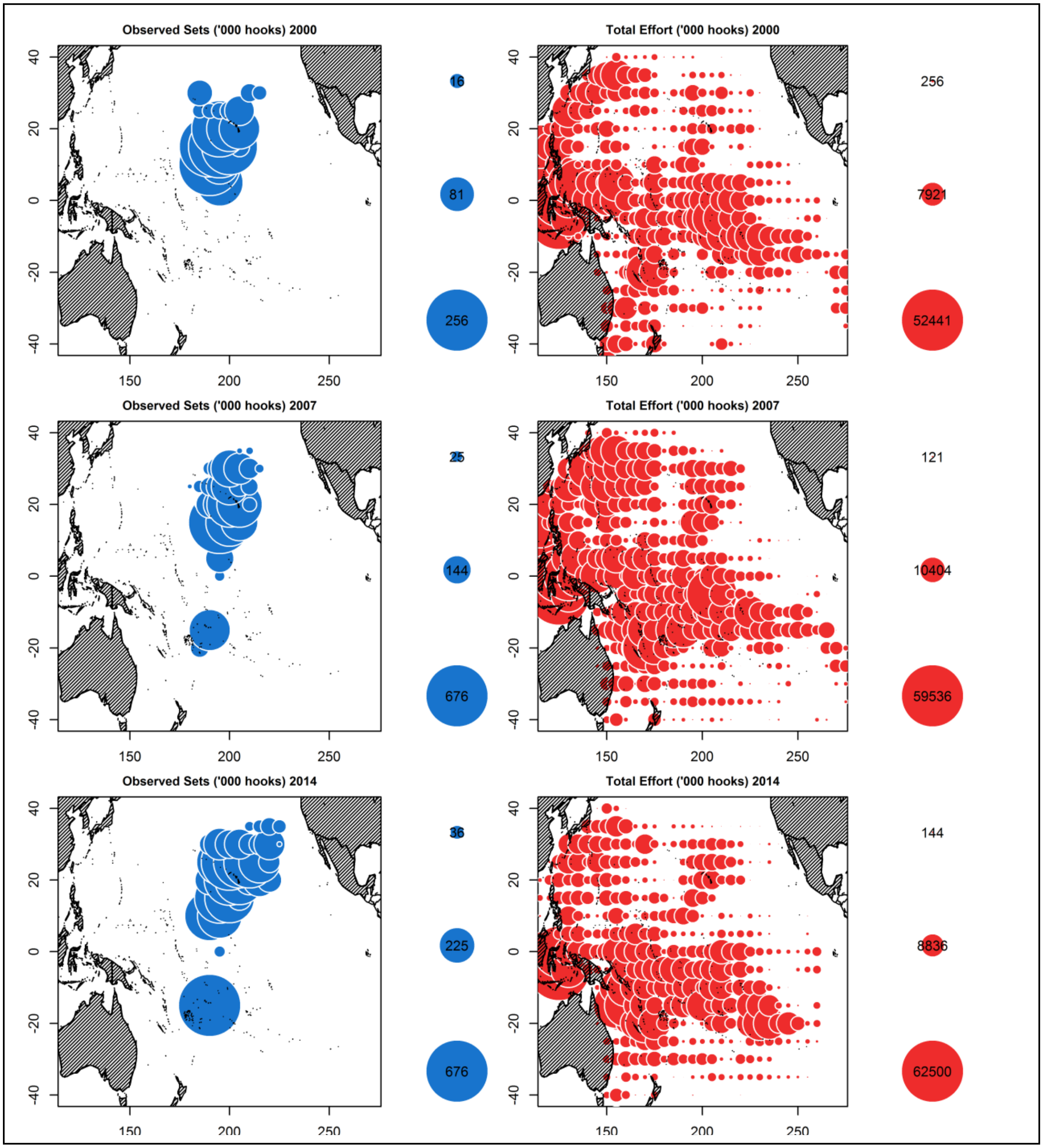

Figure 6. Distribution of observed effort relative to total effort (in thousand hooks) in the Pacific longline fishery (for comparison) for a sample of years (2000, 2007 and 2014) within the extracted US Hawaii and American Samoa LL observer and CES effort datasets. The size of the circles is proportional to the number of hooks fished in each 5°x5° cell (10th, 50th and 90th percentiles given as a legend). Actual set locations are rounded southward and westward to the nearest 5°x5° grid point and may be plotted over land as a result.

Silky shark catch per unit effort (CPUE) within the US Hawaii fishery by year and 5°x5° grid (Figure 7) show the pattern identified in Walsh & Clarke (2011) of the highest catch rates for silky sharks occurring at latitudes within 10° of the equator. Catch rates in the American Samoan fishery are often, but not always, lower than the southerly sets in the Hawaii fishery. Catch rates in the northern region of the Hawaii longline fishery are generally the lowest in this dataset.

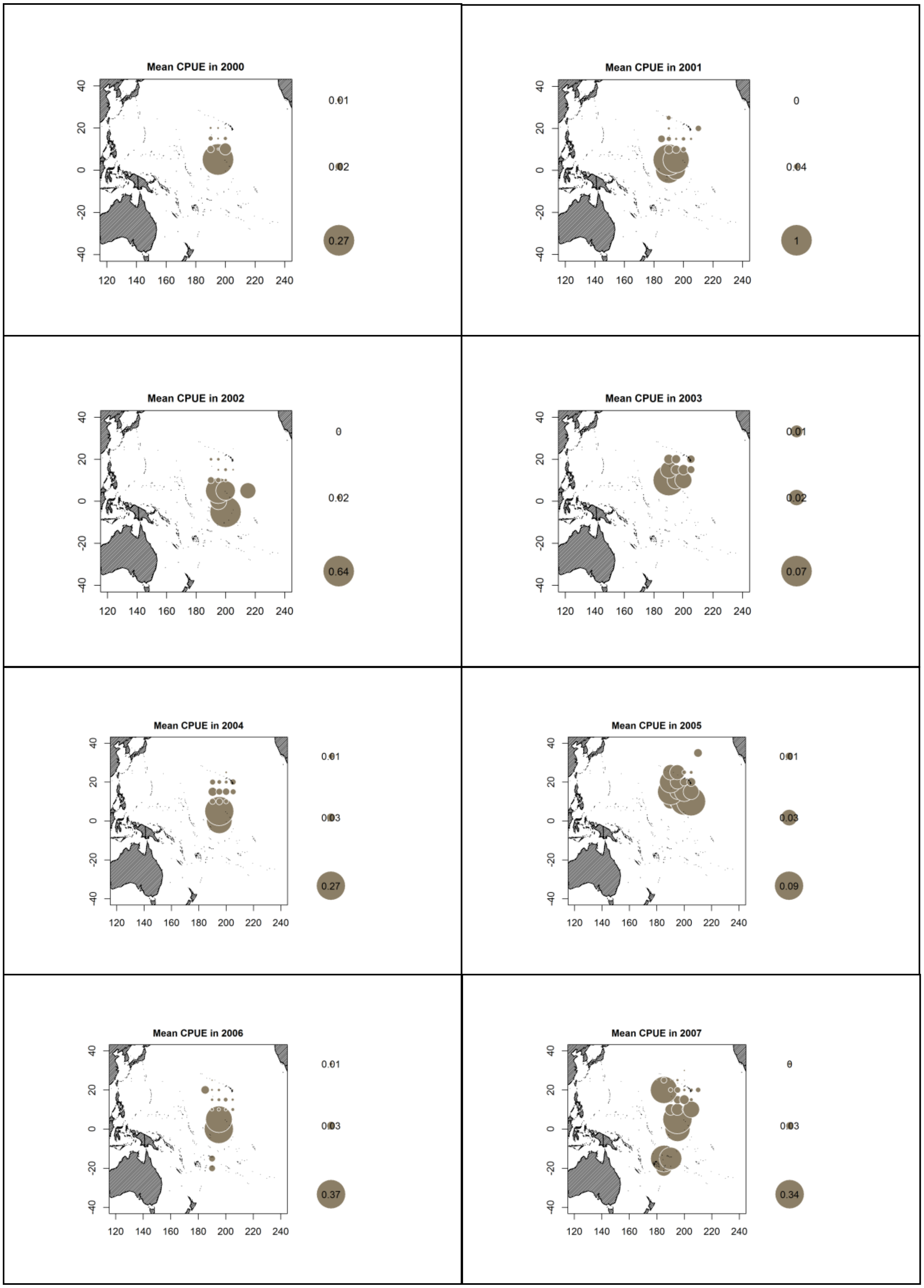

Figure 7a. Annual mean CPUE for silky shark in the US Hawaii and American Samoa LL observer dataset, 2000-2007. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). The legend is rounded to two significant figures.

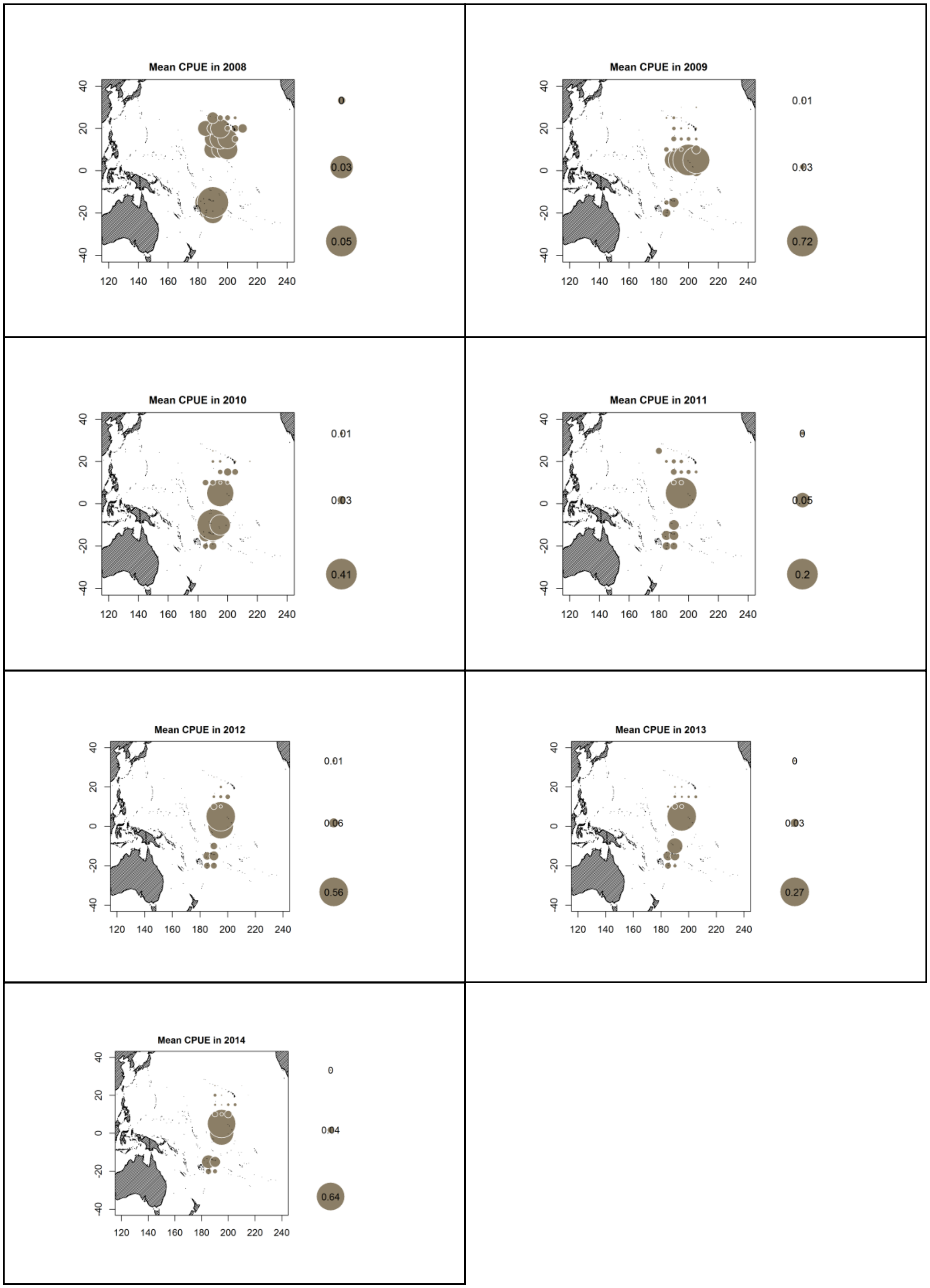

Figure 7b. Annual mean CPUE for silky shark in the US Hawaii and American Samoa longline observer dataset, 2008-2014. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). The legend is rounded to two significant figures.

In order to explore some of the potential explanatory variables that might be useful in standardizing the catch rate data to derive an abundance index, boxplots for latitude, longitude, year, month, hooks between floats and program code were constructed (Figure 8). Catch rates appear higher for shallow sets, the Hawaii fishery and in the latitudinal bands immediately adjacent to the equator.

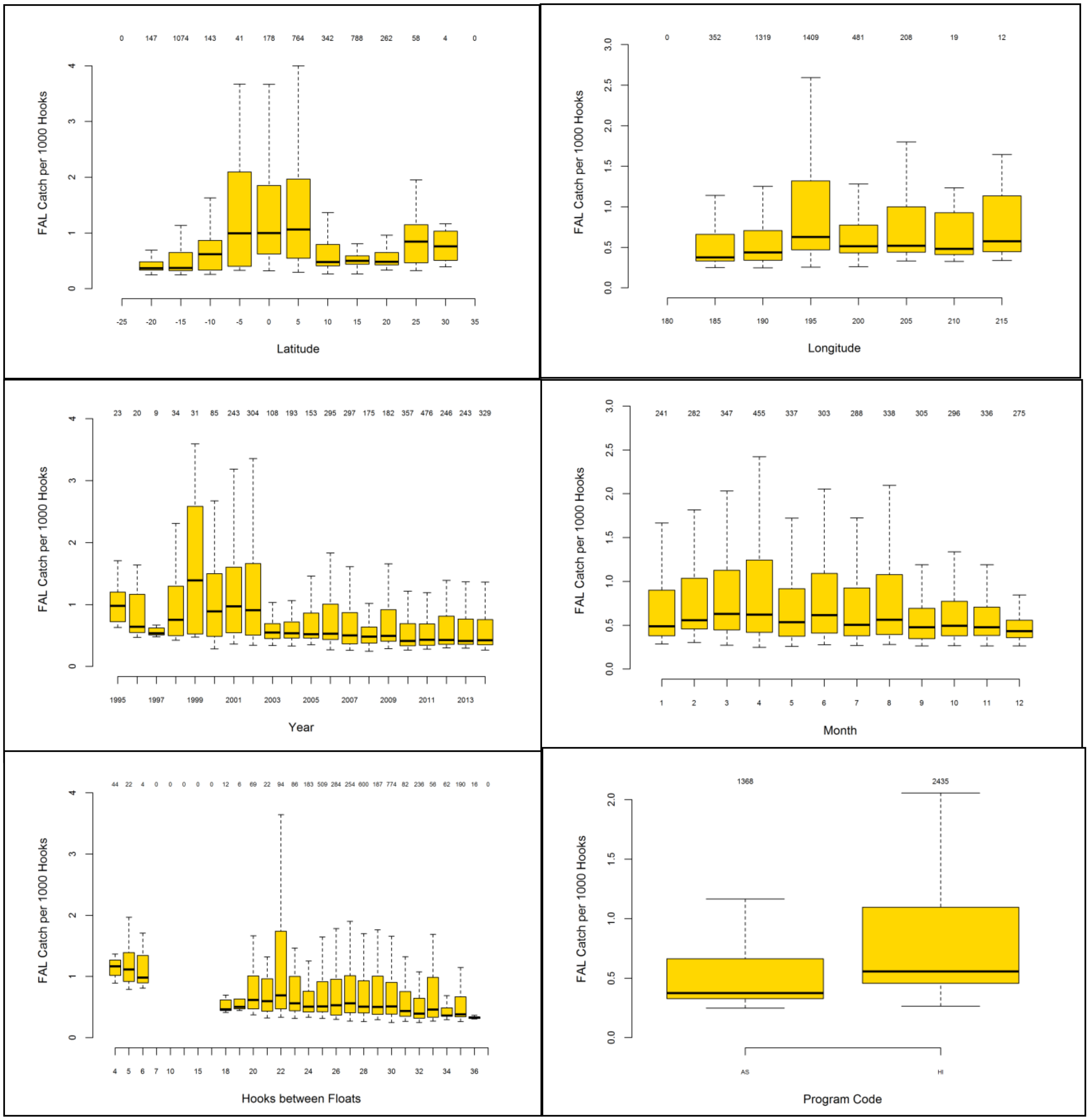

Figure 8. Box and whisker plots of potential explanatory variables in silky shark catch rates for sets with non-zero catch rates in the US LL observer dataset. The gold box shows the range between the 25th and 75th percentile (the interquartile range). The black line is the median. The whiskers are plotted at the most extreme data point which is no more than 1.5 times the interquartile range from the box (i.e. extreme outliers are not plotted). The sample size is annotated at the top of each column.

Nominal CPUE was plotted as the mean of set-by-set catch rates (i.e. catch of FAL divided by hooks fished for each set) by year for the Hawaii and American Samoa fisheries separately (Figure 9). As noted above, as this plot includes all catch records, rather than just the positive catches as shown above, differences between it and the boxplot for year shown in Figure 8 should be expected. The extreme fluctuations in relative abundance observed by Walsh & Clarke (2011) for the US longline fishery through 2010 are not apparent in recent years. Such fluctuations are not uncommon in catch rate indices but nevertheless are biologically improbable given the slow growth and reproductive rates of elasmobranchs. Although the previous study did not find that standardization appreciably changed the nominal index, standardization of the updated nominal times series must be attempted before there can be any confidence in its reliability as an index of abundance.

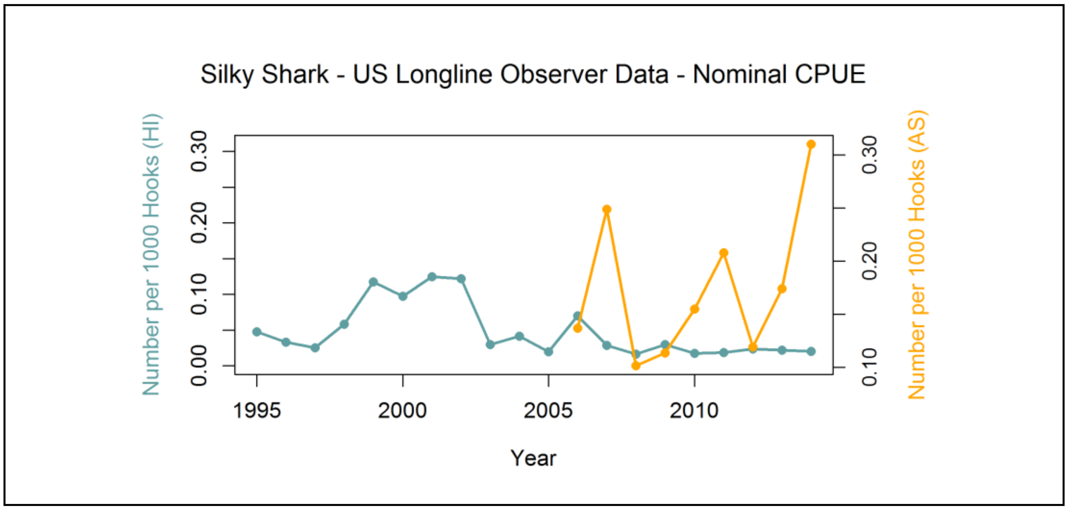

Figure 9. Nominal annual mean CPUE (i.e. mean of individual set catch rates) in the US LL observer dataset, 1995-2014 for Hawaii (HI) and American Samoa (AS) fisheries.

Biological data on silky shark length and sex was requested from the PIFSC in March 2017 and provided in April 2017. A total of 183 length records were provided for 2003-2017 with an average of 13 silky shark lengths measured each year (maximum n=55, minimum n=1). PIFSC staff report that the lengths are estimated to the nearest foot (30.5 cm). The sex of the shark was not recorded (or not provided). Given the low information content of the US longline observer length data for silky shark, no further data exploration was undertaken.

3.3 Japan Longline Observer Data

3.3.1 Data Description

Japan agreed to provide data from its Pacific longline observer programme for use in this study on 15 February 2017. Catch data for silky shark only were provided on 16 March 2017 (revised on 21 April 2017) and biological data for silky shark only were provided on 21 April 2017. In comparison to the SPC and US LL observer programmes, the Japan programme has been operating for a much shorter period but it is valuable because it provides coverage of geographic areas not covered by the other two datasets. In total the Japan dataset contained 9,775 sets with 1,579 silky sharks (FAL) caught (Table 6). However, there were 322 sets which did not record any date information, therefore these sets are not shown in the table and were removed from the dataset. They contained 7 silky sharks.

Table 6. Number of observed sets and number of silky shark catch records in the Japan longline observer data set provided for this study (after initial filtering). Years with zero silky sharks recorded are shaded in red.

Year	Sets	Silky Shark Catch
2007	12	0
2008	144	0
2009	93	0
2010	151	12
2011	397	10
2012	975	86
2013	1,804	211
2014	2,297	670
2015	2,999	510
2016	903	80
Total	**9,775**	**1,579**

The field names in the Japan longline observer dataset are shown in Table 7.

Table 7. Data types extracted for the Japan longline observer set and catch dataset.

Key Data Set	Fields Available
Japanese Longline Observer Dataset	CallSign, SetID, SST, SetStart, LatSetStart, LonSetStart, SetEnd, LatEnd, LonEnd, HaulStart, LatHaulStart, LonHaulStart, HaulEnd, LatHaulEnd, LonHaulEnd, hpb, Hooks, ObsHooks, Bait1, Bait2, Bait3, Bait4, Bait5, Target, HookType1, HookType1Ratio, HookType2, HookType2Ratio, MainLineMaterial, BranchLineMaterial, WireLeader, HookswithWireLeader, FAL

From the initial number of records shown in Table 6, the following number of sets (and FAL records) were removed sequentially:

- Removed due to missing lat/long information (1 set and no FAL);
- Removed due to missing hooks fished values (286 sets and 2 FAL);
- Removed due to missing hooks between floats (no sets and no FAL);
- Removed due to too many or too few hooks per set (7 sets and no FAL);
- Removed due to too many or too few hooks between baskets (142 sets and 5 FAL);
- Removed due to being outside the spatial boundaries of the assessment (850 sets and 35 FAL).

The rationale for applying these filters and for not applying other filters is given in Section 3.1.1 above. The spatial filter was relaxed slightly to the east from 230°E to 280°E to account for Japan's longline fishery in the Eastern Pacific Ocean which would likely encounter silky shark. Most of the removed sets were south of 40°S. In total 1,286 sets were removed from the analysis, containing 42 FAL, leaving 8,489 sets and 1,537 FAL. Nearly 93% of the sets recorded no catch of silky sharks.

3.3.2 Data Exploration

Japan's longline observer data is distributed in three distinct areas: the southern bluefin tuna fishery below 30°S, the Eastern Pacific fishery at or just south of the equator, and the Western Pacific fishery west of 160°E in tropical and subtropical waters (Figure 10). Although it represents only a short time series it provides a useful complement to the SPC LL observer dataset which is concentrated in the southern hemisphere of the Western and Central Pacific, and the Hawaii LL observer dataset in the north Central and Eastern Pacific. It should also be noted that the total number of hooks observed is lower than the other datasets.

Silky shark catch per unit effort (CPUE) for the last five years of the Japan LL observer dataset are plotted by year and 5°x5° grid in Figure 11. Even though these data provide useful 'snapshot' information for the offshore Eastern Pacific, and may thus help link to data being compiled by IATTC, their temporal coverage will not provide a sufficient basis for any indices of abundance. It appears that within the Japan LL observer dataset catch rates are lower in the Eastern and Central Pacific than in the Western Pacific. This pattern is similar to that shown in the SPC longline dataset (compare to Figure 2).

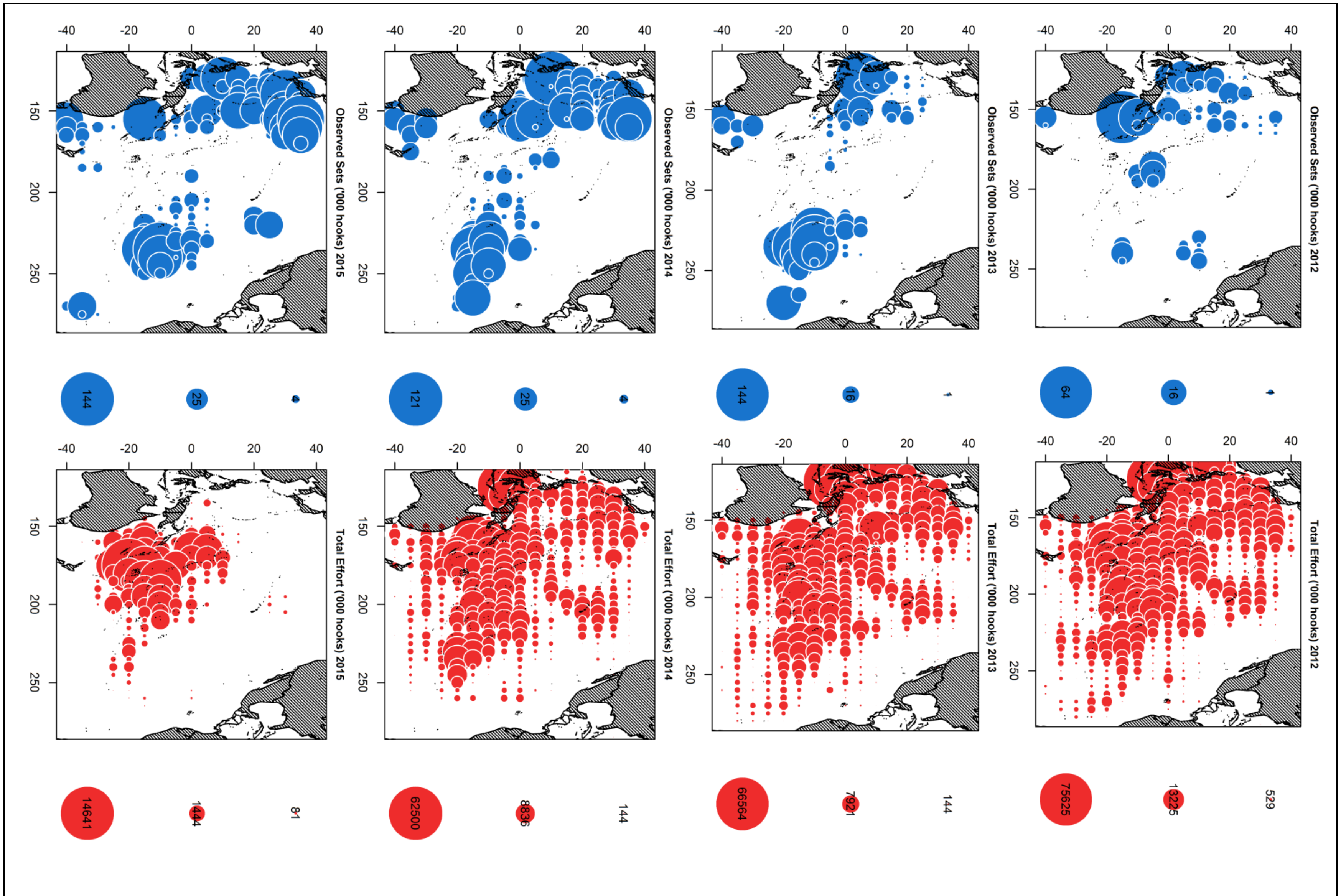

Figure 10. Distribution of observed effort relative to total effort (in thousand hooks) in the Pacific longline fishery (for comparison) for a sample of years (2012-2015) within the Japan longline observer and CES effort datasets (CES effort for 2015 appears to be incomplete and will be updated). The size of the circles is proportional to the number of hooks fished in each 5ox5o cell in thousands of hooks (10th, 50th and 90th percentiles given as a legend). Actual set locations are rounded southward and westward to the nearest 5°x5° grid point and may be plotted over land as a result.

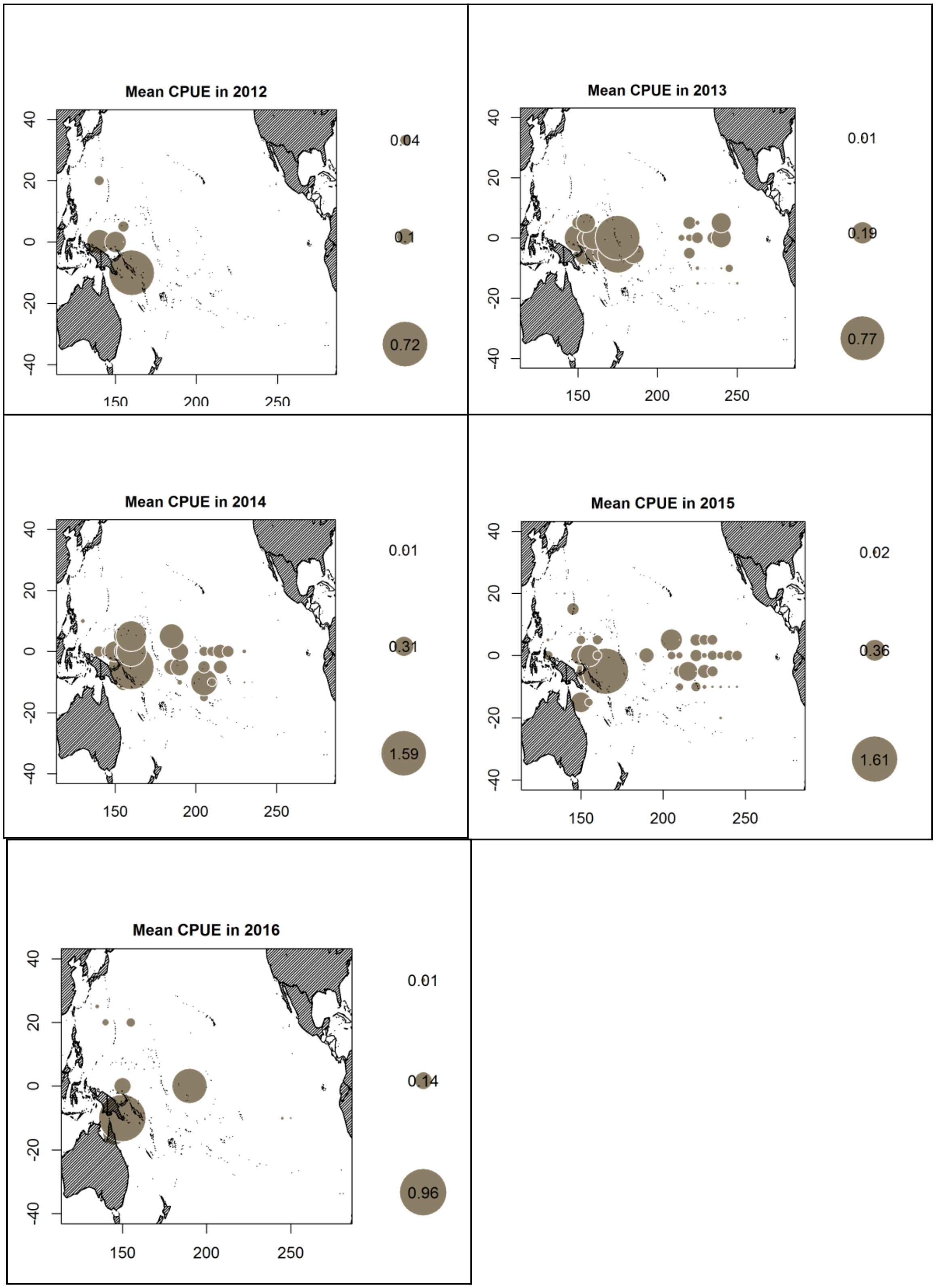

Figure 11. Annual mean CPUE for silky shark in the Japan longline observer dataset, 2012-2016. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). The legend is rounded to two significant figures.

Exploration of the Japan LL observer dataset highlights its small sample size and focus on specific areas (Figure 12). Only a small range of latitudes and longitudes are sampled with reasonable statistical power, and as shown in Figure 11, areas to the west tend to have higher catch rates. Despite the potential information in the dataset, the sample sizes are too small to allow any conclusions to be drawn regarding hooks between floats (almost all > 16) and the use of wire leaders.

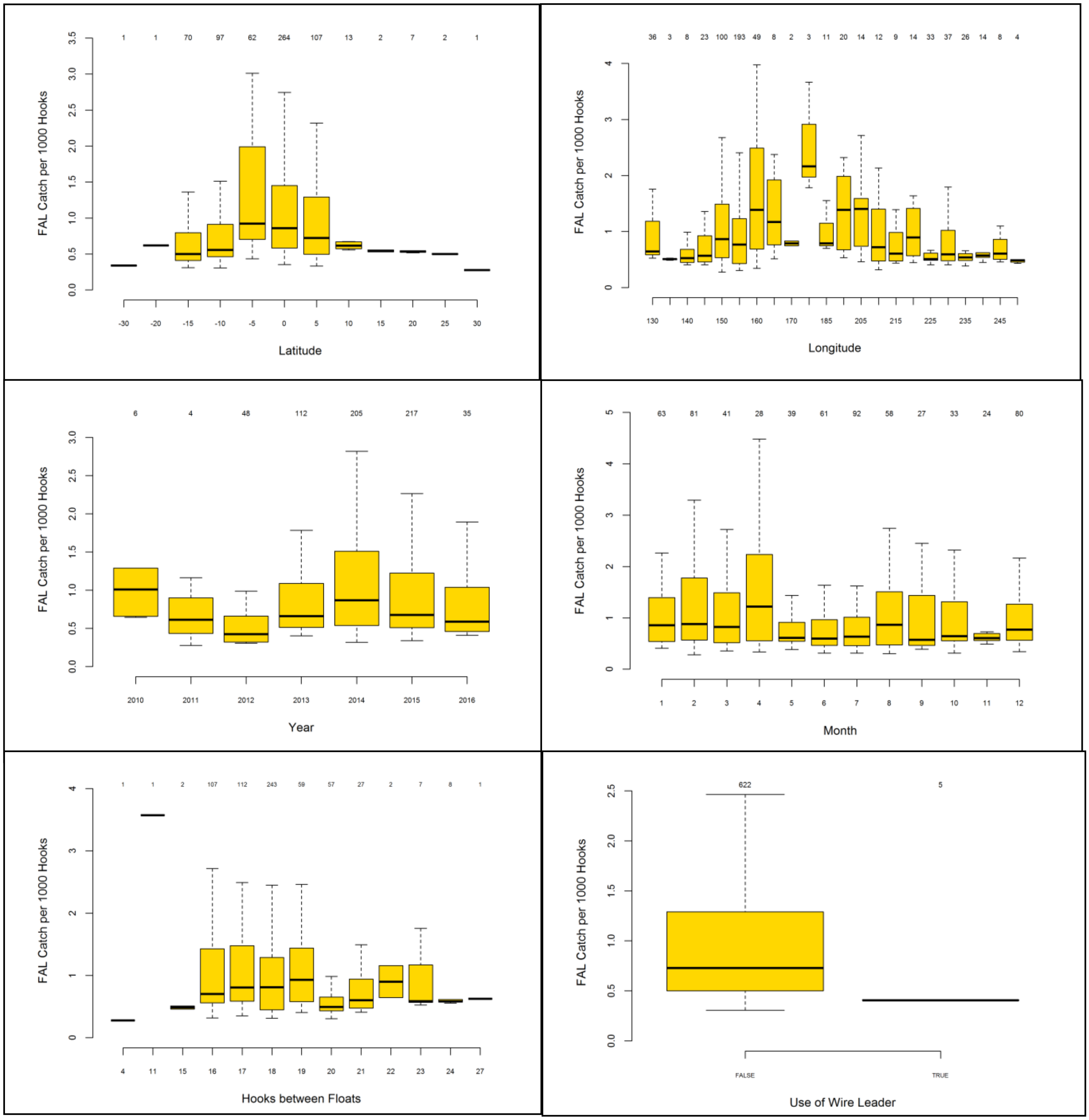

Figure 12. Box and whisker plots of potential explanatory variables in silky shark catch rates for sets with non-zero catch rates in the Japan observer dataset. The gold box shows the range between the 25th and 75th percentile (the interquartile range). The black line is the median. The whiskers are plotted at the most extreme data point which is no more than 1.5 times the interquartile range from the box (i.e. extreme outliers are not plotted). The sample size is annotated at the top of each column.

Nominal CPUE for the Japan LL observer dataset is not particularly interesting as the time series is very short and the observations prior to 2012 are very few in number (Figure 13). All of the caveats expressed above regarding unstandardized catch rate indices apply even more strongly to this time series.

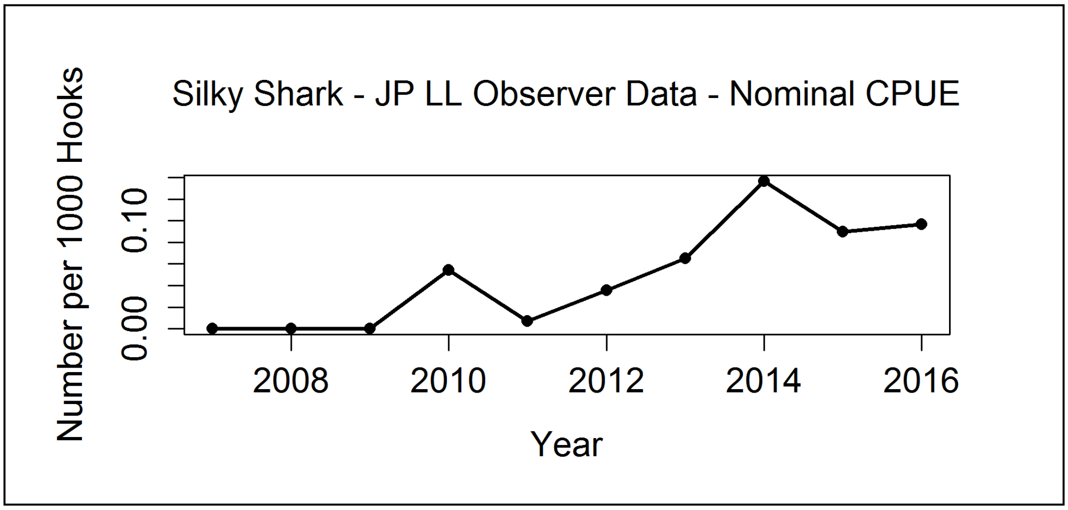

Figure 13. Nominal annual mean CPUE (i.e. mean of individual set catch rates) in the Japan LL observer dataset, 2007-2016.

Biological data on silky shark length and sex was provided in a separate dataset consisting of 1,217 records. Sex was recorded for most records with n=533 females and n=519 males measured; records without sex were removed (n=157). The unit of length was given as either fork length (n=4) or pre-caudal length (n=1022); records without the unit recorded were removed (n=26). To be consistent with the SPC dataset (both longline and purse seine), pre-caudal lengths (PCL) were converted to fork lengths (FL) using the conversion factor equation FL=(PCL*1.09)+1.10 from Joung et al. (2008) as reviewed in Clarke et al. (2015). Sample sizes are small but it is interesting to note larger sizes in the Central and Eastern Pacific as compared to the Western Pacific off Papua New Guinea (Figure 14). This pattern was also noted in the SPC LL observer dataset (compare to Figure 5).

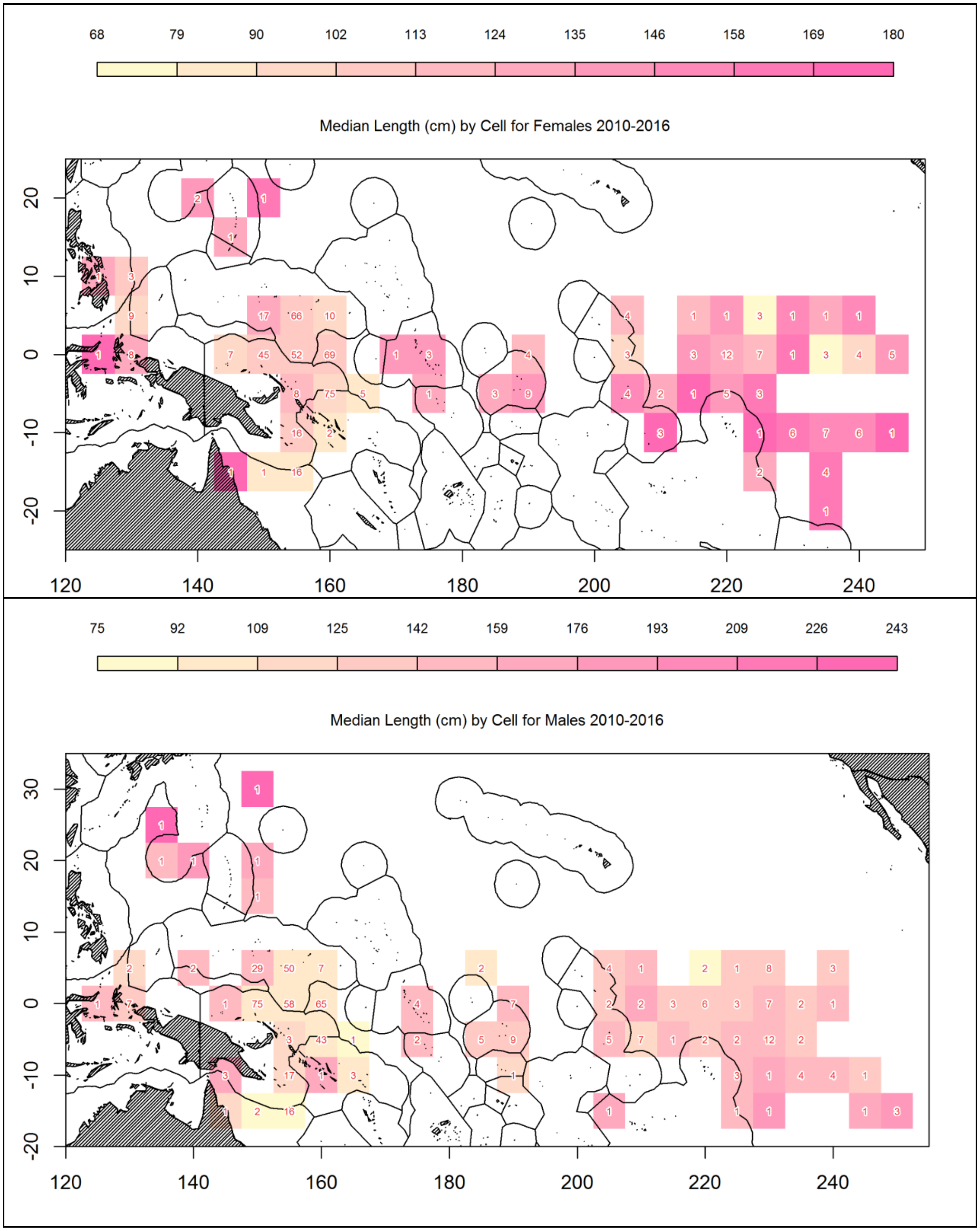

Figure 14. Mapping of median length on a relative scale for female and male silky sharks in the Japan LL observer database, 2010-2016. All lengths shown are in cm fork length (see text for conversion factors). The number annotated in each 5ºx5º degree cell is the number of measured sharks.

3.4 Regional Observer Programme PS Observer Data

3.4.1 Data Description

The Regional Observer Programme (ROP) purse seine observer data are a WCPFC dataset and thus accessible to the WCPFC Secretariat, however, they are maintained by the Scientific Services Provider and must be extracted from the more comprehensive purse seine observer dataset maintained by SPC. The ROP PS observer data were extracted several times, most recently on 31 March 2017. As for the SPC LL observer data there are two files: one file contains set-level information with one row per set ("Set Header", Table 8) and one file contains catch records for individual fish with one row per fish caught ("Catch", Table 9). The catch dataset contains all species in order to explore potential explanatory variables associated with the catch of target species. Two other datasets on net characteristics and FAD characteristics were obtained and linked to the set header to provide additional potential explanatory variables for catch rate standardization. The field names for the data in each file are shown in Table 10; explanations of the fields and how they are collected can be found in SPC (2017b).

To link each catch record to its set characteristics, a unique identifier was created by combining set identifiers and trip identifiers in the set database. From the joined dataset containing 239,975 sets and 375,706 silky sharks (FAL), the following number of sets (and FAL records) were removed sequentially:

- Removed due to missing lat/long information (7 sets and 1 FAL);
- Removed due to being outside the spatial boundaries of the assessment (38 sets and 43 FAL); and
- Removed due to missing information on the set type (associated or unassociated) (8,539 sets and 16,614 FAL);
- Removed an extreme value of silky shark count in one set (1 set and 14,285 FAL); and
- Removed due to not being within the year range of sufficient observer coverage and reliable species identification (16,589 sets and 17,362 FAL).

Missing and extreme values (latitude, longitude, set type, silky shark counts) were removed due to the potential bias they could impart to catch rate standardizations. The spatial filter was relaxed slightly to the east from 230°E to 280°E to allow for potential cross-endorsed observer trips in recent years and to provide additional biological information for the tropical Eastern Pacific for comparison to other data sets. Data from 2017 were incomplete and thus excluded. The beginning of the year range (2004) was selected on the basis of discussion in Rice (2013) which illustrates that until the early 2000s silky sharks are likely to have been recorded as unidentified sharks. While the trend toward better species identifications was a gradual one, 2004 was selected as a conservative assumption and as a year in which the number of observed sets increased considerably over previous years. In total 25,174 sets, containing 48,305 FAL, were removed from the analysis, leaving 214,801 sets and 327,401 FAL. Over 95% of the unassociated sets recorded no catch of silky sharks; in contrast, only 60% of the associated sets recorded no catch of silky sharks. All catch and effort data were screened before plotting in accordance with the three-vessel rule (WCPFC 2007).

Table 8. Number of observed sets by flag and year extracted for this study (before filtering) from the ROP PS observer dataset. Year-flag combinations without any observations are shaded in blue.

SET	CN	EC	ES	FM	JP	KI	KR	MH	NZ	PG	PH	SB	SV	TV	TW	US	VU	TOTAL
1993	-	-	-	33	152	-	57	-	-	-	-	-	-	-	68	-	-	310
1994	-	-	-	66	99	-	275	-	33	-	-	-	-	-	182	580	-	1,235
1995	-	-	-	46	115	57	30	-	-	71	-	-	-	-	152	743	19	1,233
1996	-	-	-	9	118	35	64	-	45	-	-	-	-	-	-	1,282	-	1,553
1997	-	-	-	-	48	44	80	-	35	82	-	-	-	-	121	1,482	-	1,892
1998	-	-	-	78	57	60	298	-	-	13	-	14	-	-	797	1,006	38	2,361
1999	-	-	-	27	29	19	321	-	-	19	-	86	-	-	305	573	20	1,399
2000	-	-	-	82	117	13	257	-	25	85	-	45	-	-	382	800	-	1,806
2001	-	-	-	72	123	10	138	28	29	60	-	31	-	-	186	1,095	-	1,772
2002	-	-	-	163	94	112	40	78	-	110	-	156	-	-	188	1,138	-	2,079
2003	-	-	-	157	132	72	161	158	17	549	-	116	-	-	65	661	9	2,097
2004	-	-	-	219	139	24	429	256	26	984	-	160	-	-	353	807	138	3,535
2005	-	-	-	183	100	25	358	313	43	751	61	74	-	-	503	528	257	3,196
2006	7	-	-	106	106	75	266	522	26	1,255	-	-	-	-	126	485	29	3,003
2007	-	-	-	87	112	35	270	573	4	1,473	-	67	-	-	300	397	282	3,600
2008	-	-	28	147	98	54	411	450	34	532	-	131	-	-	124	1,503	39	3,551
2009	347	-	4	193	593	140	698	603	77	1,309	510	-	53	25	770	2,894	214	8,430
2010	1,767	372	266	587	3,616	527	4,213	1,211	165	3,419	81	39	145	345	3,989	7,803	662	29,207
2011	1,279	464	137	918	4,284	637	3,735	1,071	189	2,970	493	112	143	228	3,726	5,744	710	26,840
2012	1,152	222	271	807	4,708	1,215	3,554	1,551	343	3,622	422	283	37	271	4,265	7,735	582	31,040
2013	2,667	434	685	115	4,950	1,173	5,009	2,046	215	3,999	755	136	175	205	5,944	7,450	556	36,514
2014	1,882	391	468	736	3,582	1,479	2,881	1,938	165	3,276	823	384	313	92	5,315	8,831	355	32,911
2015	2,121	87	153	1,463	2,209	1,615	1,566	2,085	99	4,591	928	443	83	141	3,890	6,445	166	28,085
2016	936	-	44	1,051	1,941	1,038	337	833	152	2,023	660	122	35	48	1,946	1,029	69	12,264
2017	-	-	-	-	52	-	-	-	-	4	-	-	-	-	2	-	-	58
TOTAL	12,158	1,970	2,056	7,345	27,574	8,459	25,448	13,716	1,722	31,197	4,733	2,399	984	1,355	33,699	61,011	4,145	239,971

Table 9. Number of FAL catch records (each record is one shark) by flag and year extracted for this study (before filtering) from the ROP PS observer dataset. Year-flag combinations without any observations are shaded in blue. Year-flag combinations with zero silky sharks recorded are shaded in red.

CATCH	CN	EC	ES	FM	JP	KI	KR	MH	NZ	PG	PH	SB	SV	TV	TW	US	VU	TOTAL
1993	NA	NA	NA	-	-	NA	-	NA	NA	NA	NA	NA	NA	NA	-	NA	NA	-
1994	NA	NA	NA	-	-	NA	-	NA	-	NA	NA	NA	NA	NA	173	-	NA	173
1995	NA	NA	NA	87	192	-	-	NA	NA	183	NA	NA	NA	NA	3	-	-	465
1996	NA	NA	NA	170	108	-	32	NA	-	NA	NA	NA	NA	NA	NA	-	NA	310
1997	NA	NA	NA	NA	164	-	95	NA	-	11	NA	NA	NA	NA	27	-	NA	297
1998	NA	NA	NA	-	31	30	29	NA	NA	-	NA	-	NA	NA	598	419	-	1,107
1999	NA	NA	NA	-	-	-	63	NA	NA	-	NA	356	NA	NA	360	679	-	1,458
2000	NA	NA	NA	52	150	-	110	NA	-	136	NA	7	NA	NA	59	928	NA	1,442
2001	NA	NA	NA	139	256	7	92	51	-	93	NA	-	NA	NA	519	3,986	NA	5,143
2002	NA	NA	NA	216	339	261	1	18	NA	15	NA	1,043	NA	NA	114	522	NA	2,529
2003	NA	NA	NA	324	113	78	58	312	-	859	NA	847	NA	NA	67	2,485	15	5,158
2004	NA	NA	NA	716	353	58	375	348	5,866	2,169	NA	3,178	NA	NA	750	2,779	220	16,812
2005	NA	NA	NA	1,257	474	-	1,156	324	-	705	956	284	NA	NA	850	1,332	93	7,431
2006	6	NA	NA	124	232	291	381	1,267	107	2,866	NA	NA	NA	NA	173	1,790	41	7,278
2007	NA	NA	NA	343	115	61	535	426	14	2,206	NA	144	NA	NA	429	750	129	5,152
2008	NA	NA	127	225	128	71	166	246	96	313	NA	993	NA	NA	112	1,264	241	3,982
2009	1,219	NA	2	307	2,294	159	127	581	51	2,051	327	NA	762	1	3,183	2,566	70	13,700
2010	777	911	3,824	731	2,690	352	2,562	2,498	959	4,459	101	127	863	155	4,825	13,592	378	39,804
2011	1,860	1,600	394	3,065	15,771	2,333	3,215	17,323	600	5,022	599	211	1,247	60	5,817	33,012	460	92,589
2012	962	203	668	1,451	4,097	2,089	1,478	1,025	113	2,459	201	728	1,680	10	3,288	6,122	214	26,788
2013	2,435	1,002	15,857	66	6,033	1,025	2,867	1,463	114	3,728	466	555	215	10	5,691	6,774	361	48,662
2014	2,086	2,455	2,410	1,567	6,758	1,326	1,156	2,419	136	3,788	860	1,325	856	62	5,375	7,306	418	40,303
2015	1,672	464	981	2,532	1,857	599	3,947	1,760	28	4,215	999	1,048	237	44	6,125	5,590	243	32,341
2016	991	NA	251	2,519	3,527	1,066	570	1,109	9	3,063	1,491	131	12	79	4,719	3,151	49	22,737
2017	NA	NA	NA	NA	45	NA	NA	NA	NA	-	NA	NA	NA	NA	-	NA	NA	45
TOTAL	12,008	6,635	24,514	15,891	45,727	9,806	19,015	31,170	8,093	38,341	6,000	10,977	5,872	421	43,257	95,047	2,932	375,706

Table 10. Data types extracted for the SPC longline observer set and catch datasets.

Data Set	Fields Available
Set Header	obstrip_id, obsprg_code, flag, vessel_id, set_id, Set_number, Start_of_set, Skiff_off, Winch_on, Rings_up, Begin_brailing, End_of_brailing, End_of_set, lat, lon, schtype_id, eez_code
Catch Data	obstrip_id, obsprg_code, flag, vessel_id, set_id, act_date, act_time, lat, lon, schtype_id, eez_code, sp_code, fate_code, sp_c_est, sp_n_est, cond_code
Net Characteristics	obstrip_id, tripno, vessel_id, trip_year, net_depth, net_depth_unit, net_depth_m, net_length, net_length_unit, net_length_m, net_strips, net_hang_ratio, mesh_main, mesh_main_unit, mesh_main_cm, brail_size1, brail_size2, brail_type
FAD Characteristics	obstrip_id, tripno, internal_FAD_ID, object_number, origin, date, lat, lon, latd, lond, how_detected, as_found, as_left, max_depth_m, length_m, width_m, comments, main_net_size, attach_net_size, ssi_seen, fad_lifted, material_code, is_attachment

3.4.2 Data Exploration

Unlike the SPC LL observer dataset, the ROP observer dataset, after cleaning and filtering, overlaps most of the core area of the fishery in the equatorial WCPO (Figure 15). Nevertheless, there is limited or no coverage in other areas, some of which have non-negligible purse seine effort, e.g. primarily the area between Indonesia, the Philippines and Papua New Guinea, but also off Japan and in the East China Sea. While the latter area is not core habitat for silky shark, the former area is likely to encounter this species in substantial numbers and is not accounted for in this, or any other known available, observer dataset. While observer coverage does not appear to have spatially shifted over time, the progression of years in Figure 15 illustrates the increasing percent coverage gained through the implementation of the requirement for 100% observer coverage in the tropical (20^{o}N-20^{o}S) purse seine fishery since January 2010. Some data are available for analysis but are not plotted in the figure due to the three vessel rule, but for the ROP PS observer dataset these filtered data points are very few in number.

Silky shark catch per unit effort (CPUE) by year and 5^{o}x5^{o} grid in the ROP PS observer dataset are shown in Figure 16. In recent years, i.e. when observer coverage rates are higher and the purse seine fishery has expanded to the east due to climatic conditions, catch rates appear to be as high or higher in the Central Pacific than they are in the traditional core area of the fishery off Papua New Guinea. It is important to note that sample sizes in the central Pacific are quite small and may thus be unrepresentative of overall stock conditions. Nevertheless, the presence of high catch rates in the Central Pacific suggests the utility of further exploration of the population connectivity between silky sharks found in western and eastern areas of the Pacific basin.

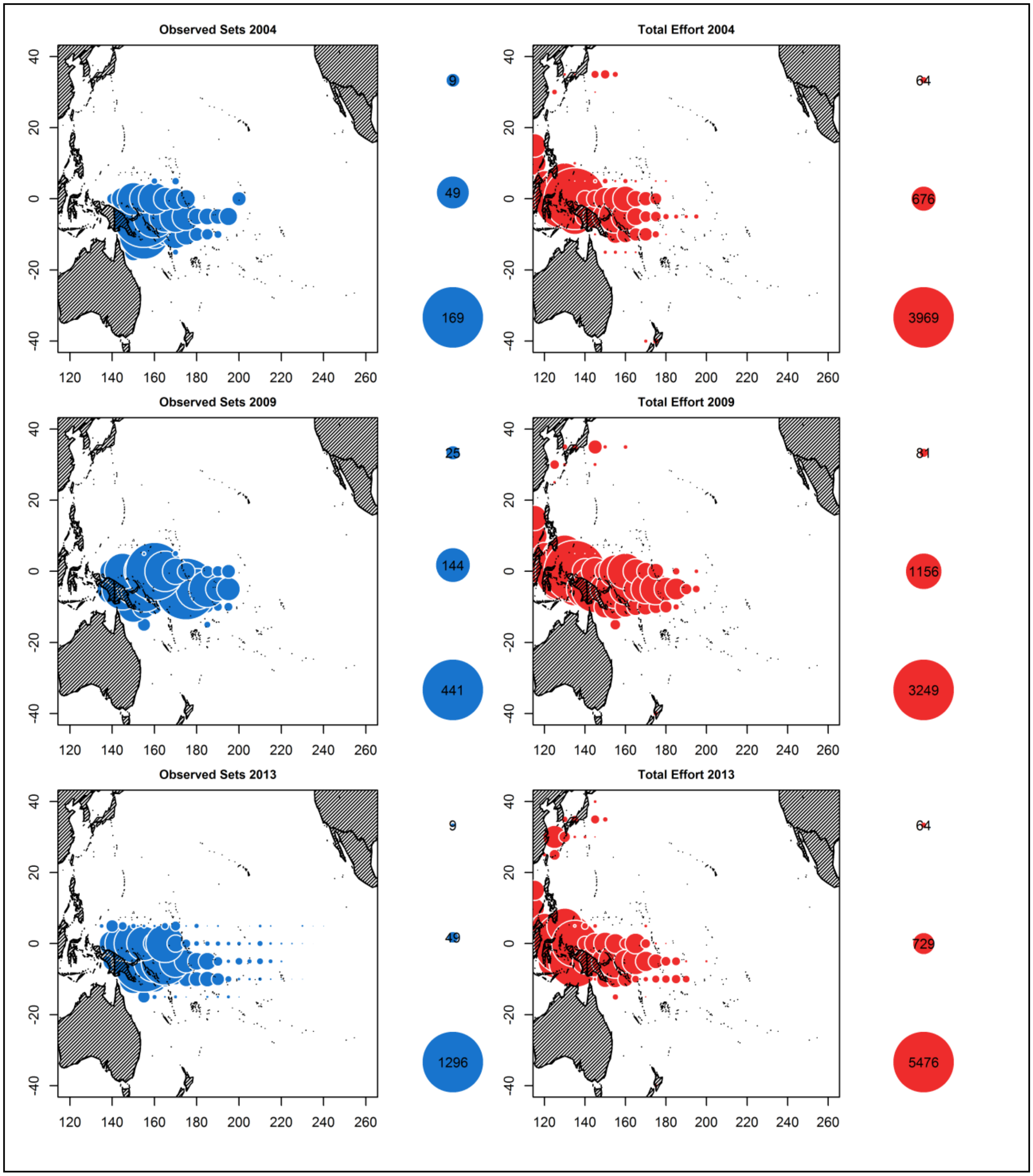

Figure 15. Distribution of observed effort (in number of sets) relative to total effort (in standardized days fished) in the Western and Central Pacific purse seine fishery (for comparison) for a sample of years (2004, 2009 and 2013) within the extracted ROP PS observer and CES effort datasets. The size of the circles is proportional to the amount of effort in each 5°x5° cell (10th, 50th and 90th percentiles given as a legend). Actual set locations are rounded southward and westward to the nearest 5°x5° grid point and may be plotted over land as a result.

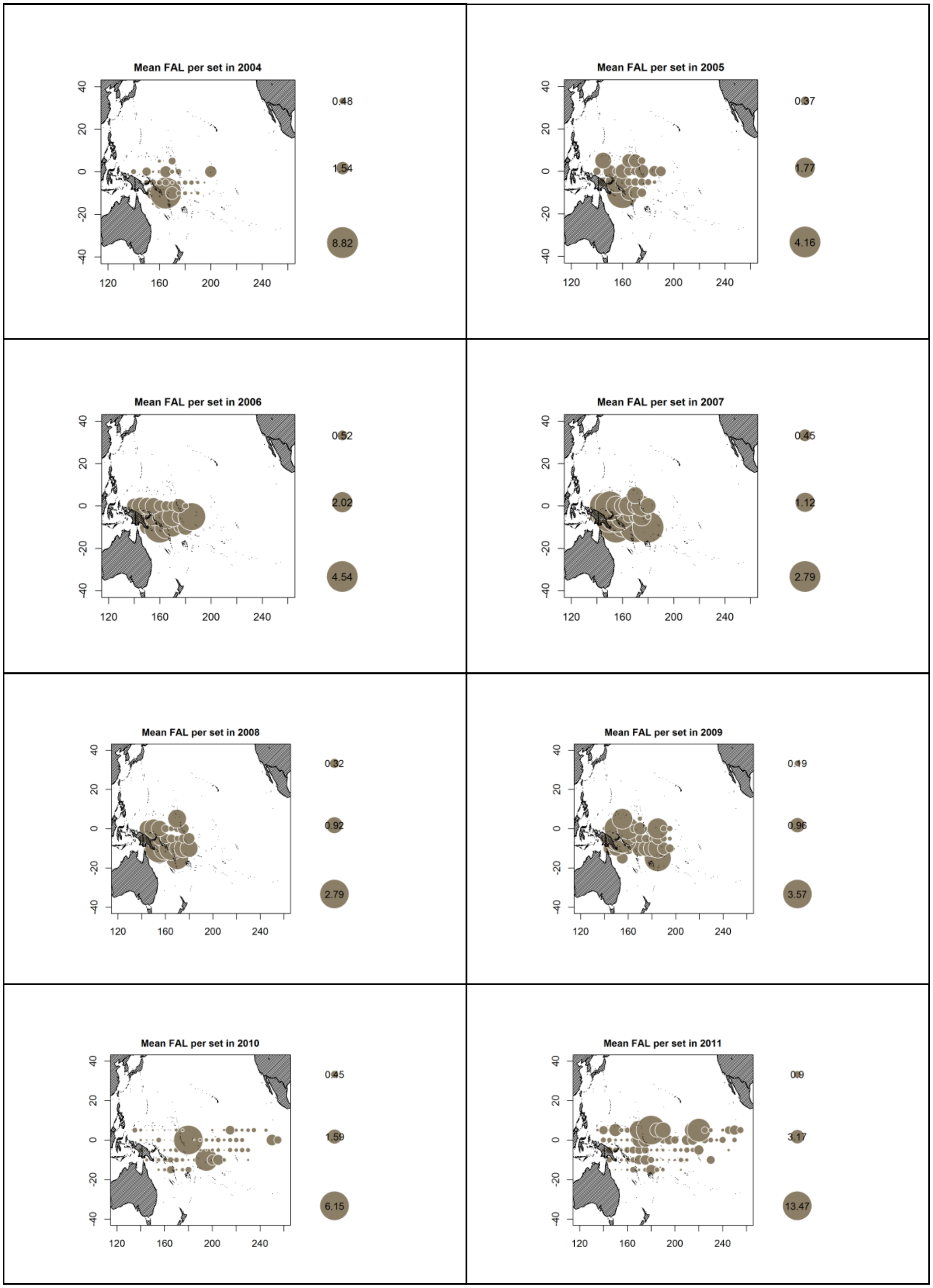

Figure 16a. Annual mean CPUE for silky shark in the ROP PS observer dataset, 2004-2011. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). Actual set locations are rounded southward and westward to the nearest 5°x5° grid point and may be plotted over land as a result.

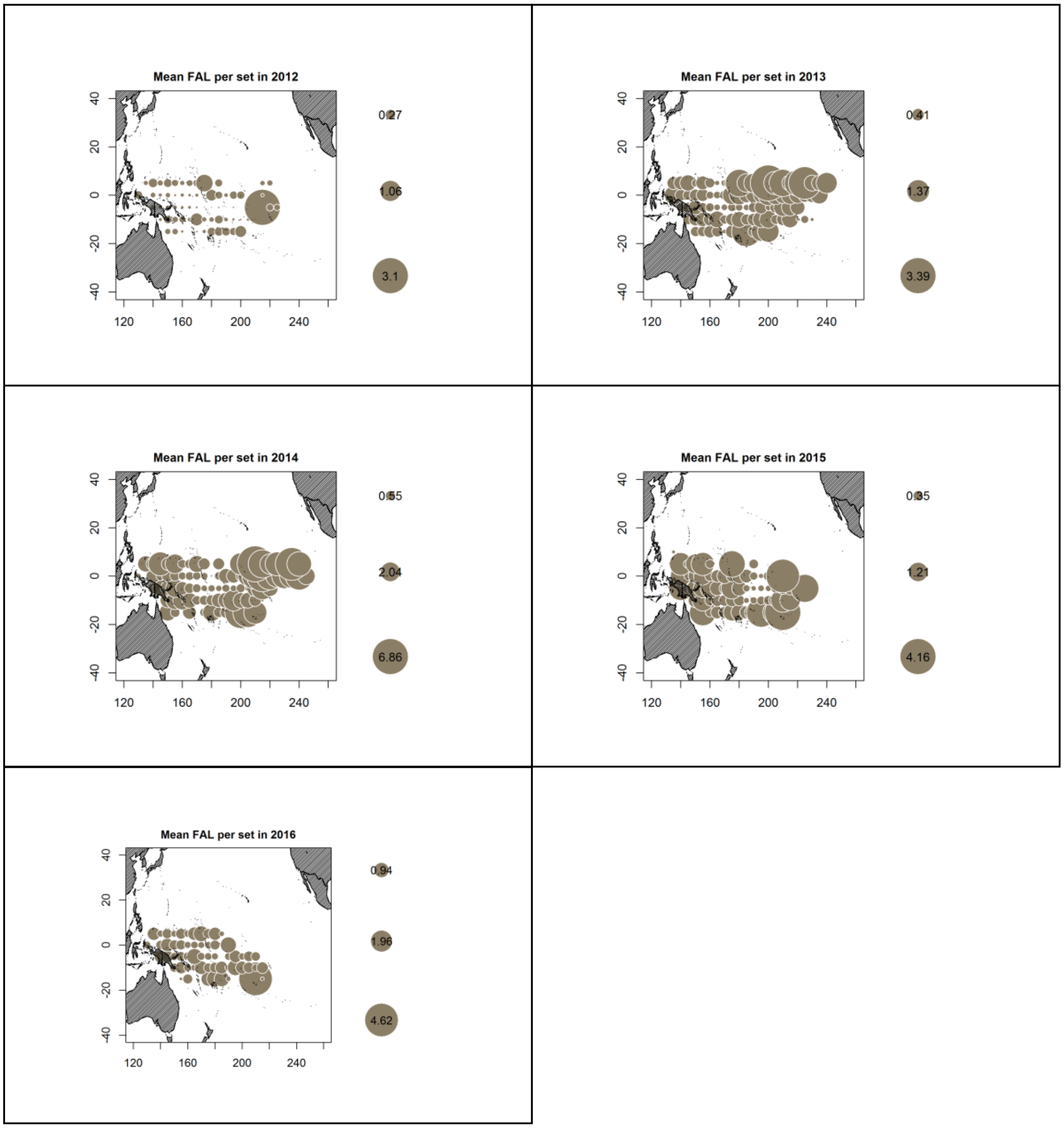

Figure 16b. Annual mean CPUE for silky shark in the ROP PS observer dataset, 2012-2016. The size of the circle is proportional to the CPUE as shown in the legend (10th, 50th and 90th percentiles). Actual set locations are rounded southward and westward to the nearest 5ºx5º grid point and may be plotted over land as a result.

A selection of potential explanatory variables for catch rate standardization in purse seine fisheries are presented in Figure 17. The only clear difference in the plots is between the catch rates for associated (ASS) and unassociated (UNA) set types. There are remarkably few visible differences in the temporal or spatial variables, but certain specific areas (250°E longitude and 5°N latitude) demonstrate high catch rates in relatively small samples sizes.

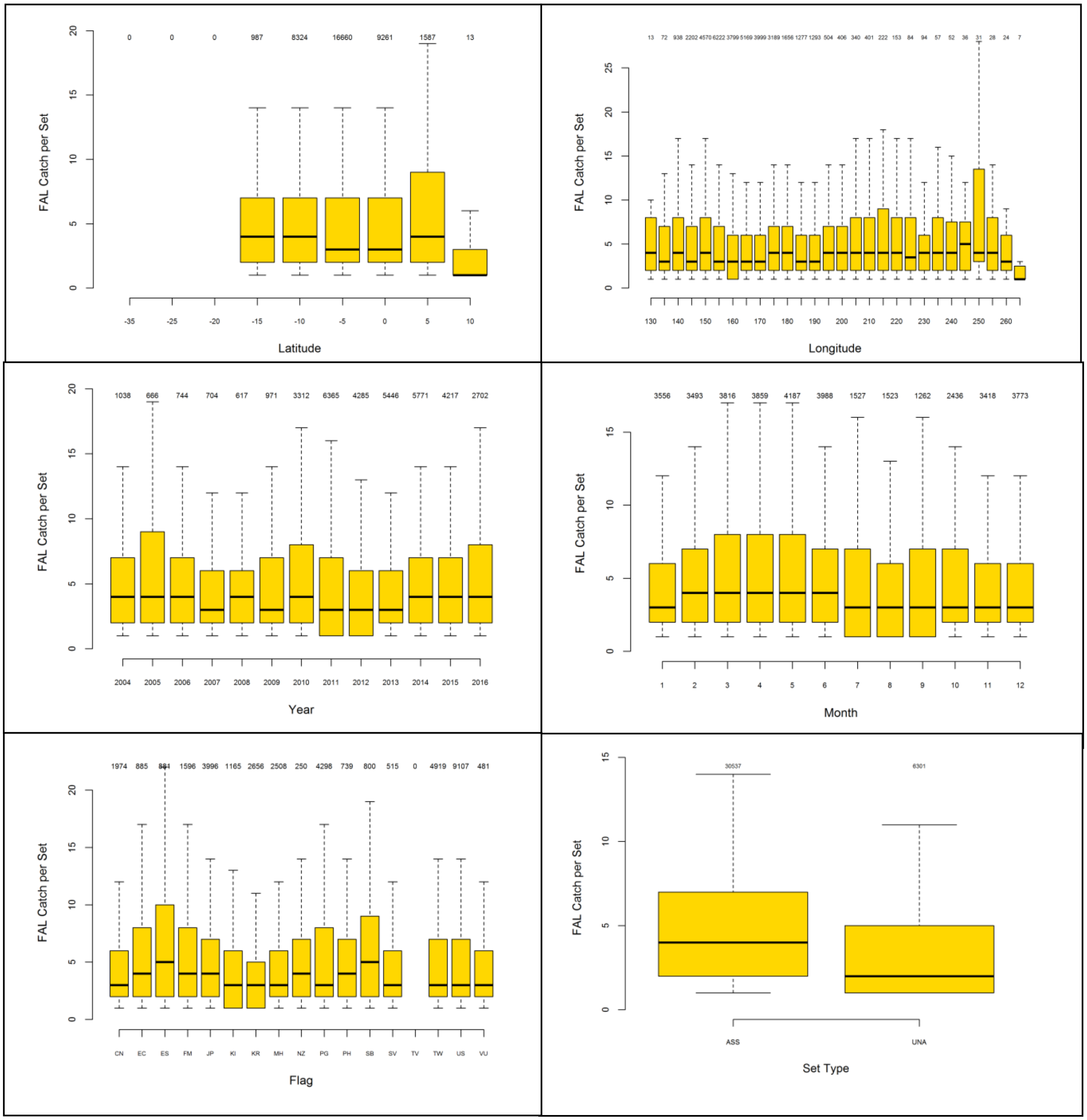

Figure 17. Box and whisker plots of potential explanatory variables in silky shark catch rates for purse seine sets with non-zero catch rates. The gold box shows the range between the 25th and 75th percentile (the interquartile range). The black line is the median. The whiskers are plotted at the most extreme data point which is no more than 1.5 times the interquartile range from the box (i.e. extreme outliers are not plotted). The sample size is annotated at the top of each column.

For purse seine data catch rate per unit effort can simply be taken as catch per set. This catch rate was computed for associated and unassociated sets by year as shown in Figure 18. Again, this abundance trend will differ from the boxplot by year in Figure 17 as Figure 17 only shows non-zero catches whereas zero as well as non-zero catches are shown here. It is interesting to note the SPC LL observer data since 2010 shows a sharp increase in 2012 and relative constant catch rates in other years (Figure 4). A similar trend appears in the ROP PS observer dataset since 2010, although the sharp increase occurs in 2011. This pattern is visible in both associated and unassociated set types except in 2016 (which may be influenced by as yet incomplete data reporting).

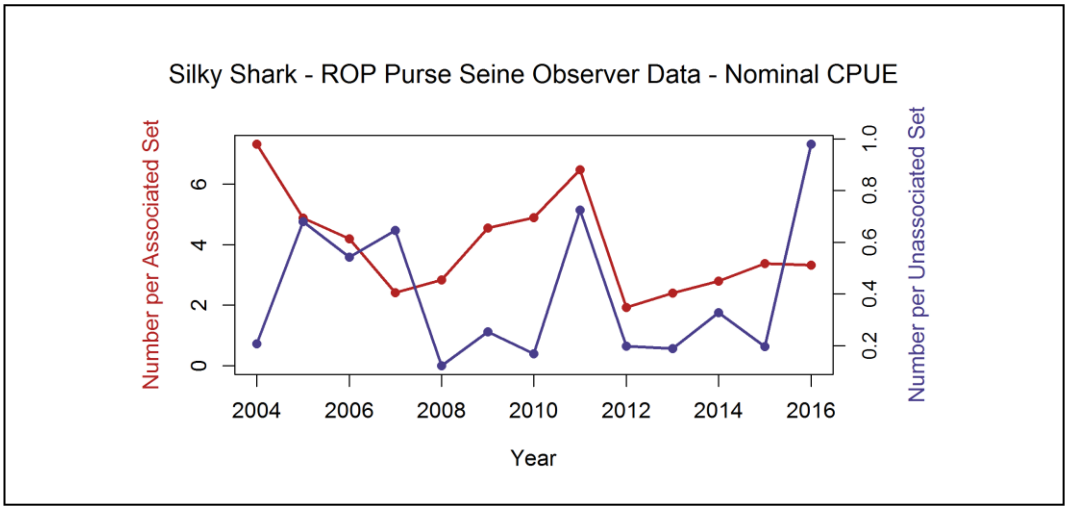

Figure 18. Nominal annual mean CPUE (i.e. mean of individual set catch rates) in the SPC PS observer dataset, 2004-2016.

Length data are available for 30,485 silky sharks caught in the associated set fishery and another 4,339 silky sharks caught in the unassociated set fishery for a total of 34,824 silky sharks measured. However, purse seine observers did not begin collecting information on the sex of measured sharks until 2016 (P. Williams, SPC, pers. comm., 7 March 2017) so fine-scale analysis is somewhat comprised by differences in growth rates between the sexes. All measurements are assumed to be in fork length as that is the convention applied in the ROP LL and PS observer programmes. Lengths were screened to exclude observations below a nominal size at birth of 50 cm FL and a nominal maximum size of 271 cm FL based on the review in Clarke et al. (2015) (n=559 excluded). Only associated sets extend into the Central and Eastern Pacific and sample sizes are low in these areas (Figure 19). Even so, the same pattern of larger individuals to the east is visible in this dataset as in the Japan longline dataset in the Central and Eastern Pacific (Figure 14). There is no strong trend apparent in the purse seine data for larger individuals to be found in the southwest Pacific as in the SPC LL observer data (see Figure 5).

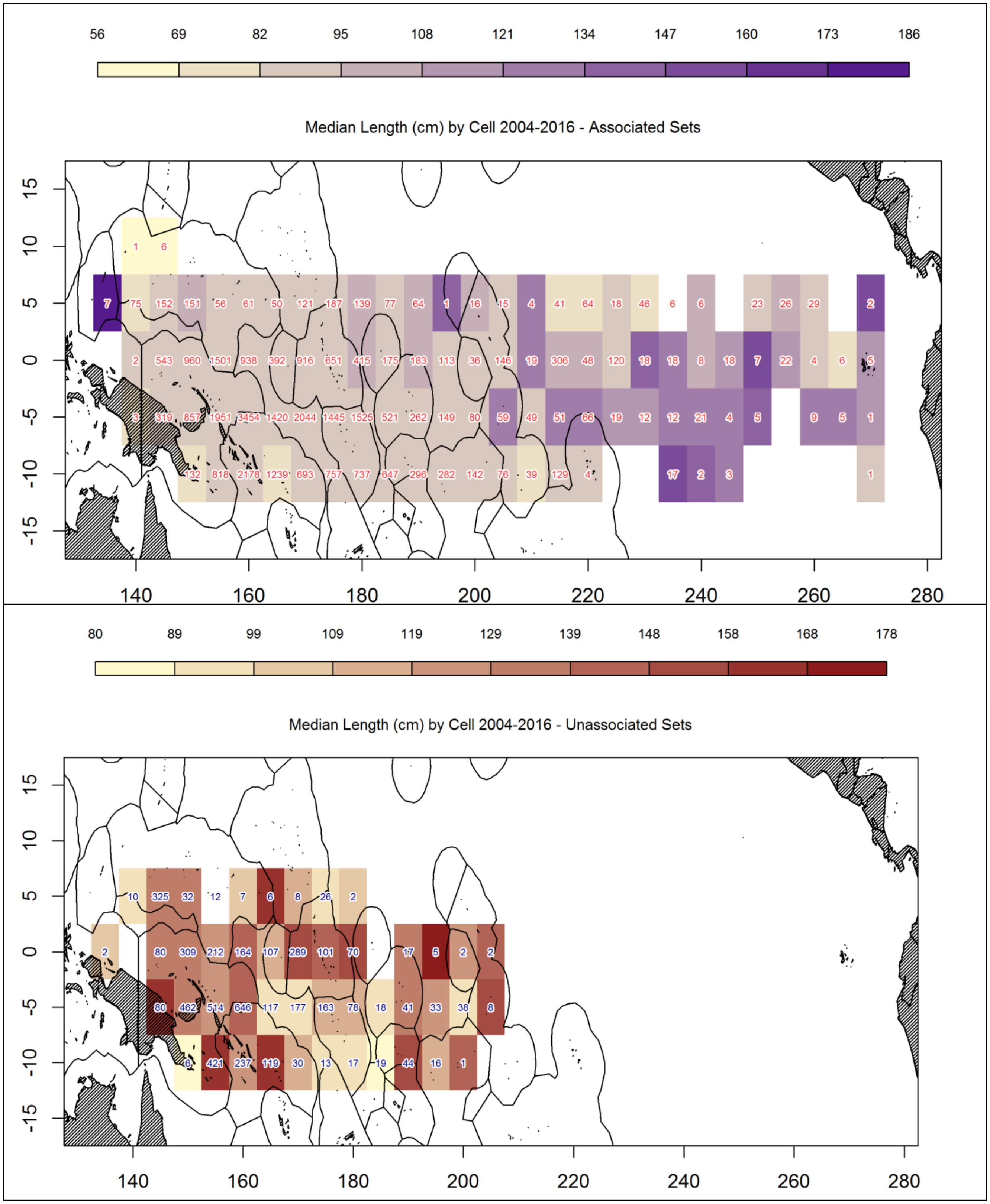

Figure 19. Mapping of median length on a relative scale for silky sharks caught in associated and unassociated sets in the ROP PS observer database, 2004-2016. All lengths shown are in cm fork length (see text for conversion factors). The number annotated in each 5°x5° degree cell is the number of measured sharks. All points were moved southward and eastward to the closest 5°x5° grid point in preparation for merging with the IATTC PS observer dataset.

4 Ongoing and Future Work

A considerable number of weeks have been expended to access, format, filter, describe and explore the four datasets presented above, but there is also substantial work remaining to prepare other WCPO data products for use in the assessment. Updated logsheet effort will be obtained from available datasets including not only the SPC-based CES (Catch Effort Query System) but also any available data from the West Pacific East Asia project (or other sources) on effort by Indonesia, the Philippines or Vietnam in Southeast Asia. These potential sources of data may also be useful for producing an estimate of total removals of silky sharks. Although reported catches are available from the WCPFC data catalogue (WCPFC 2016), and estimated catches from Lawson (2011) and Clarke (2009), it is anticipated that further, and potentially considerable, work will be required to produce a robust estimate of total removals.

Following on from the initial exploration of catch rates in this paper, standardization work will be required to produce indices of abundance for the stock assessment model. An initial standardization of the WCPO ROP purse seine data for associated sets was presented in Lennert-Cody et al. (2017; see Annex A). That study suggests a coherence between the abundance trends for associated sets for small sharks in the northern Eastern Pacific, the abundance trends for associated sets in the WCPO, and the Indo-Pacific tri-pole oceanographic index (see Lennert-Cody et al. (2017), Figures 8 and 10). This in turn may indicate that catch rate trends, particularly for juvenile silky sharks, may reflect oceanographic conditions at a basin-wide scale that influence catchability and/or movement rather than abundance. To support a Pacific-wide collaborative stock assessment, Lennert-Cody et al. (2017) recommends further analysis to explore, and perhaps filter out, the influence of oceanography to produce more representative abundance indices. They also knitted together silky shark length data across the Pacific for the first time and postulated a coherence between the WCPO and northern EPO silky shark population structures (see Lennert-Cody et al. (2017), Figure 7). Observations of larger individuals in the southern EPO are especially interesting in light of similar observations for the Southern Hemisphere Central Pacific in the WCPFC ROP purse seine and Japan longline observer datasets as presented in this paper.

In all of this work it will be important to consider the effect of recently adopted prohibitions on retaining silky sharks by both WCPFC (CMM 2013-08) and IATTC (C-16-06). These measures undoubtedly influence logbook-reported catches but may also affect observer datasets, particularly for longline fisheries. This may occur because silky sharks are cut free before observers have the opportunity to identify them to species, or because it may change fleet targeting practices, and thus change catch rate patterns. In any case, this issue presents a major issue for analysis and one which cannot easily be overcome.

WCPO data preparation and analysis will continue through 2017-2018 as other assignments permit. IATTC will be working over the same timeframe to further explore some of the findings of Lennert-Cody et al. (2017) and potentially collaborate on other data preparation to support a Pacific-wide exploratory stock assessment. WCPFC has a contract in place with Adam Langley to run the SS3 stock assessment model using the data products provided by WCPFC and IATTC with the aim of presenting an assessment to SC14 in August 2018.

5 Acknowledgements

The author would like to thank G. Compeán, A. Aires-da-Silva, C. Lennert-Cody, M. Maunder, C. Minte-Vera, M. Román-Verdesoto and N. Vogel of IATTC for their generous support to this project.

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INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

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DOCUMENT SAC-08-08a(i)

UPDATED STOCK STATUS INDICATORS FOR SILKY SHARKS IN THE EASTERN PACIFIC OCEAN (1994-2016), WITH OCEANOGRAPHIC CONSIDERATIONS

Cleridy E. Lennert-Cody, Shelley C. Clarke, Alexandre Aires-da-Silva, Mark N. Maunder, Marlon H. Román

CONTENTS

1. SUMMARY

Indices of relative abundance for the silky shark in the eastern Pacific Ocean (EPO), developed from purse-seine catch-per-set, were updated with data from 2016. The index for all silky sharks north of the equator (north EPO) shows a large decrease in 2016 relative to 2015. In contrast, the index for all silky sharks south of the equator (south EPO) remains at about the 2014-2015 level. Some recent strong increasing trends in the indicators for silky sharks have been identified in previous reports, but they are not biologically plausible. To help further the understanding of potential processes driving the recent trends in the north EPO indices, silky shark indices by sub-region within the north EPO, and by shark size category, were compared to an index of variability in oceanographic conditions, and to a preliminary silky shark index for the Western and Central Pacific Ocean (WCPO) associated-set purse-seine fishery. Based on the preliminary results of these comparisons, it is hypothesized that the recent changes in the silky shark indices for the north EPO, particularly for small silky sharks, may be influenced by changing oceanographic conditions (*e.g.*, El Niño and La Niña events), and thus the north EPO indices are potentially biased. Further analysis will be necessary to evaluate the magnitude of this bias quantitatively and, if the indices for large silky sharks are found to be less susceptible to bias caused by changing oceanographic conditions, they may be used exclusively as stock status indicators in the future. The IATTC staff reiterates its previous recommendation (SAC-07-06b(i), SAC-07-06b(iii)) that improving shark fishery data collection in the EPO is critical. This will facilitate the development of other stock status indicators and/or conventional stock assessments to better inform the management of the silky shark and other co-occuring shark species. Spatio-temporal models that

combine data from multiple gear types to improve spatial coverage should also be explored in the future, to facilitate modeling efforts once data from other sources become available.

2. BACKGROUND

An attempt by the IATTC staff in 2013 to assess the status of the silky shark (*Carcharhinus falciformis*) in the EPO, using conventional stock assessment models, was severely hindered by major uncertainties in the fishery data, primarily total annual catch in the early years for all fisheries that caught silky sharks in the EPO (SAC-05 INF-F). Although the stock assessment attempt produced a substantial amount of new information about the silky shark in the EPO (*e.g.*, absolute and relative magnitude of the catch by different fisheries, and their selectivities), the absolute scale of population trends and the derived management quantities were compromised. Since a conventional stock assessment was not possible, in 2014 the staff proposed a suite of possible stock status indicators (SSIs) that could be considered for managing the silky shark in the EPO (SAC-05-11a), including standardized catch-per-set (CPS) indices from the purse-seine fishery. This document updates the purse-seine CPS indices with data for 2016, hypothesizes possible drivers underlying observed trends, and discusses future research directions with respect to purse-seine indicators for the silky shark.

3. DATA AND METHODS

Data collected by IATTC observers aboard Class-6[1] purse-seine vessels were used to generate CPS-based indices of relative abundance for the silky shark. Observers record bycatches of silky sharks, which occur predominantly in floating-object (OBJ) sets (SAC-07-07b), by size category: small (< 90 cm total length (TL), medium (90-150 cm TL), and large (>150 cm TL)). Annual summaries of spatial data on bycatches (in numbers) of silky sharks in floating-object sets, by size category and for all sizes combined, are shown in Figure 1.

CPS trends for floating-object sets (CPS-OBJ) were estimated using generalized additive models (GAMs). A zero-inflated negative binomial (ZINB) GAM was used to model the bycatch data from OBJ sets because of the presence of many sets with zero bycatch, and also sets with large bycatches. Predictors used in this model were: year (factor); smooth terms for latitude, longitude, time of set, and day of the year (to capture seasonal patterns); and linear terms for depth of the purse-seine net, depth of the floating object, sea-surface temperature, natural logarithm of non-silky bycatch, natural logarithm of tuna catch, and two proxies for local floating-object density. Trends were computed by shark size category and for all sizes combined, using the method of partial dependence, which produces a data-weighted index. Approximate 95% pointwise confidence intervals were computed for the trends for all shark sizes combined by resampling from the multivariate normal distribution of the estimated GAM coefficients, assuming known smoothing and scale parameters. As in previous years, trends were computed for the EPO north and south of the equator, and for four smaller areas within the north EPO:

Area	Latitude	Longitude	No. of OBJ sets
1	North of 8°N	Coast-150°W	2,007
2	0°-8°N	120°W-150°W	6,353
3	0°-8°N	95°W-120°W	17,953
4	0°-8°N	Coast-95°W	7,444

It has been suggested that recent trends in the north EPO silky shark indices integrate immigration and/or recruitment processes with a linkage to the WCPO (SAC-07-06b(i)). To investigate this hypothesis, two exploratory analyses were conducted to develop a better understanding of processes potentially affecting the indices.

[1] Carrying capacity > 363 t

First, through a collaboration with the Western and Central Pacific Fisheries Commission (WCPFC) that was initiated to support a forthcoming ABNJ Tuna Project-funded Pacific-wide assessment for the silky shark[2], it was possible to compute a preliminary standardized trend for the silky shark from observer data collected in associated sets in the purse-seine fishery from 2004-2015 in the WPO between 145°E-180°E and 10°S-5°N. This area was selected because it was fished consistently across the 12-year time period. The trend was estimated using the same ZINB GAM methods used for the EPO, with the following predictors: year (factor), smooth terms for latitude, longitude, time of set and month (month was specified as a cyclic cubic spline), linear terms for the natural logarithm of tuna catch and the natural logarithm of a proxy for local object density, and vessel flag and association type as factors. This preliminary trend was compared to the north EPO CPS-OBJ trends for both small and medium silky sharks, following on a preliminary comparison of the size composition of the sampled catch in the WCPO with that of EPO OBJ sets during 2005-2015 (see Results).

Second, it has been noted previously that silky trends differed spatially within the north EPO (SAC-07-06b(i)). Therefore, a second analysis compared the north EPO silky shark trends, by area, and the WCPO trend, with an indicator of variability in oceanographic conditions, the Indo-Pacific Tripole (TPI) (Henley *et al*. 2015). The TPI is a measure of variability in sea-surface temperature anomalies that captures low and high-frequency links between ocean basins, which influence tropical Pacific oceanographic conditions (Lian *et al*. 2014 and references therein). The TPI shows similarities to the better-known Multivariate El Niño-Southern Oscillation (ENSO) Index (MEI) (Figure 2) (Wolter and Timlin 1993; 1998; 2011;), which is based on sea-level pressure, surface winds, sea-surface temperature, surface air temperature, and cloud cover.

4. RESULTS

4.1. Updated trends in the EPO

For the north EPO, the CPS-OBJ index shows an initial sharp decline during 1994-1998, followed by a period of relative stability at a low level (1999-2009), then a sharp increase from 2009 to 2010, a sharp decrease from 2010 through 2012, a sharp increase from 2012 through 2015 and another sharp decrease in 2016 (Figure 3). As noted in previous documents (*e.g*., SAC-07-06b(i)), the CPS-OBJ trend in the north EPO shows general agreement with standardized presence/absence indices for all silky sharks in the north EPO (obtained using logistic GAMs) for dolphin sets and unassociated sets (Figure 4).

In the north EPO, the trends for the three size categories of silky sharks (Figure 5a) are generally similar to the trend for all silky sharks. However, year-to-year changes in the index for small sharks have not always been the same as those of the indices for medium and large sharks (Figure 5b). This might be expected if the small shark category is a proxy for recruitment (ages 0+ and 1+ years) and the trends in the larger sizes are more reflective of changes in overall stock abundance. Since about 2009, however, the year-to-year changes in the small shark index more closely follow the trends for medium and large sharks (Figure 5b). This suggests that the mechanisms acting on the different size classes may be more complex.

Trends computed by sub-area within the northern EPO suggest that the recent changes in the north EPO index for all silky sharks are most consistent with the trends for the more offshore equatorial regions (Areas 2-3, Figure 6). Updated indices show contrasting trends by sub-area for the most recent year. There was only a small decrease in 2016 in the indices in the far northern area (Area 1, Figure 6) and an increase in 2016 in the indices in the coastal area (Area 4, Figure 6). However, in the more offshore equatorial areas

[2] Led by Dr. Shelley Clarke, Technical Coordinator-Sharks and Bycatch, Western and Central Pacific Fisheries Commission

(Areas 2-3, Figure 6) there was a decrease for all size categories in 2016, with the most pronounced decreases for the indices of small- and medium-sized sharks. Because the EPO indices are data-weighted, the trends are influenced by areas with more sets in the analysis data set. Of the four northern sub-regions, Areas 2 and 3 represent 19% and 53%, respectively, of the sets in the analysis data set for the north EPO (see Data and Methods above).

For the south EPO, the CPS-OBJ indicator for all sharks shows a sharp decline during 1994-2004, followed by a period of stability at much lower levels until 2013, and then a small increase in 2014, with little change through 2016 (Figure 3). In general, the trend for medium sharks is similar to the trend for all sharks, although it does not show as great an increase from 2013 to 2014 as the trend for all sharks. This greater increase in the trend for all silky sharks may be the result of an increased presence of small sharks along the western boundary of the southern EPO in recent years (Figure 1a), and will be investigated further in the future. The trend for large sharks, however, differs from the trend for all sharks in recent years in that it continued to decrease slightly in 2016 (Figure 5b). Trends by sub-area, and for other set types, were not computed for the southern area because of the low levels of silky shark bycatch (Figure 1). In particular, very few small silky sharks are generally caught in the southern area (Figure 1a), which may be due to a lack of recruitment, or possibly a lower selectivity for small sharks by the southern fishery.

4.2. Trends in the WCPO

The size-composition data for silky sharks caught in associated sets in the WCPO between 145°E and180°E from 10°S to 5°N are skewed towards smaller-sized individuals, as are samples from OBJ sets in the north EPO (Figure 7). The modes of the distributions of fork length (FL) from the WCPO, by 5° area, ranged from 67cm to 110cm, with the median at 83 cm, about 10 cm above the upper limit of the EPO 'small' category of 72 cm FL (90 cm TL). For 90% of sharks sampled in the WCPO, fork length was below the upper limit of the EPO 'medium' category of 122cm FL (150cm TL). The range of sampled fork lengths in the WCPO data thus largely overlaps with the 'small' and 'medium' categories of the EPO data, and so the WCPO trend was compared to the trends for both small and medium sharks for OBJ sets for the north EPO, by sub-area, (Areas 1-4 of Figure 6).

The level of agreement between the WCPO and north EPO trends depends on which region within the north EPO is chosen for comparison. In the equatorial region (Areas 2-4, Figure 6), the WCPO trend shows the greatest agreement with the EPO trend for small and medium sharks in the offshore areas (Areas 2-3) and the least agreement with the small shark trend in the coastal area (Area 4) (Figure 8). There is even less agreement between the WCPO trend (Figure 8) and the small shark trend in the region north of 8°N (Area 1 of Figure 6). Thus, the level of agreement between the WCPO trend and the north EPO small and medium trends appears to decrease closer to the coast, as well as north of the equatorial area. To some extent this might be expected, given the difference in oceanographic conditions between the coastal and offshore equatorial areas of the EPO (*e.g.*, Martinez *et al*. 2015). Although the WCPO trend is relatively short (12 years), and comparisons of short time series can be problematic because apparent correlations are more likely to be spurious, the peak in the WCPO trend in 2011 appears to lag one year behind the peak in the EPO trend in 2010 (Figure 8, Areas 2-3). Since the 2009-2010 period included an El Niño event, it may be that this one-year lag is related to the evolution of El Niño conditions across the Pacific.

4.3. Comparison of trends with the TPI

Environmentally-driven population growth (via increased recruitment), movement, and availability to fishing gear are processes that might lead to similar trends in the indices for the WCPO and EPO (Figure 8), and among purse-seine set types within the EPO (Figure 4). However, the increases in the OBJ indices for all sharks in consecutive years, especially in the north EPO, are generally too large to attribute to population growth alone. Specifically, in several years there is no overlap of the upper confidence limit on the estimated finite rate of population increase for a virgin population and the lower confidence limit on the proportional change in the OBJ index from one year to the next (Figure 9).

Although a formal time series analysis will be undertaken in future (see below), the coherence between the OBJ trends for small sharks in the north EPO, the WCPO silky shark trend, and the TPI (Figure 10) suggests that the EPO trend may be biased by changes in oceanographic conditions that influence catchability and/or movement. For the north EPO, the level of agreement of the small shark index and the TPI differs between coastal and offshore areas: in the offshore equatorial area (Area 2) there is considerable agreement between the longer-period fluctuations of the TPI and the small shark index. It is noteworthy that, for both of the strongest El Niño events between 1995 and -2016 (1997-1998 and 2015-2016), the small shark index in Area 2 increased about one year prior to the peak in the TPI. In the coastal equatorial area (Area 4), however, there appears to be less overall agreement between the small shark index and the TPI, and there is about a 1-year lag between the peak in the TPI in 1997-1998 and the peak in the small shark index in about 1998-1999. For the large shark indices, there appears to be less agreement with the TPI, even in the offshore equatorial area (Area 2 of Figure 10). This would be expected if large silky sharks are less sensitive to habitat fluctuations caused by oscillations in the oceanographic environment and/or the abundance of an adult population is inherently less influenced by recent, oceanographically-driven recruitment events.

5. FUTURE WORK

Given the apparent oceanographic influence on the EPO silky shark indices, especially for small sharks in the equatorial north EPO, it is essential that data from other sources be collected to develop additional indicators. Although further analysis may show that the indices for large silky sharks might be better stock status indicators than indices based on all silky sharks, purse-seine fishery indices alone are not sufficient to determine stock status for a species that may be impacted by different oceanographic factors and fisheries in different regions within the EPO. Obtaining reliable catch data for all fisheries catching silky sharks in the EPO, indices of relative abundance for other fisheries (especially longline fisheries, which take the majority of the catch), and composition data, by length/age and sex, is vital. In addition, given the apparent similarities between the WCPO index and the EPO index for small sharks in the western north EPO, Pacific-wide collaborative stock assessment work between WCPFC and IATTC should be pursued to better understand the population dynamics and stock status at the biological stock level, rather than within the confines of RFMO boundaries.

To evaluate the relationship between silky shark indices and environmental forcing quantitatively, future work will focus on using multiple applications of linear autoregressive models to obtain filtered oceanographic indicators (Di Lorenzo and Ohman 2013) on time scales biologically relevant for the silky shark life stages of interest. This filtering process removes variability in an environmental index on scales that are too short to be biologically meaningful for the species and life stages under consideration, while enhancing environmental variability at lower frequencies. The correlation of the filtered environmental indicators with silky shark indices can be computed to quantify the level of agreement between the indices and environmental forcing on specific time scales. Furthermore, changes in the degree of correlation with different amounts of filtering of the environmental indices can be investigated. Indices of oceanographic forcing that will be considered in the analysis include the TPI, the MEI, the North Pacific Gyre Oscillation index, and the Pacific Decadal Oscillation.

ACKNOWLEDGEMENTS

We thank the WCPFC for purse-seine data on silky shark bycatch from the WCPO, Nickolas Vogel for database assistance with the EPO data, and Shane Griffiths for helpful discussions and comments on this document.

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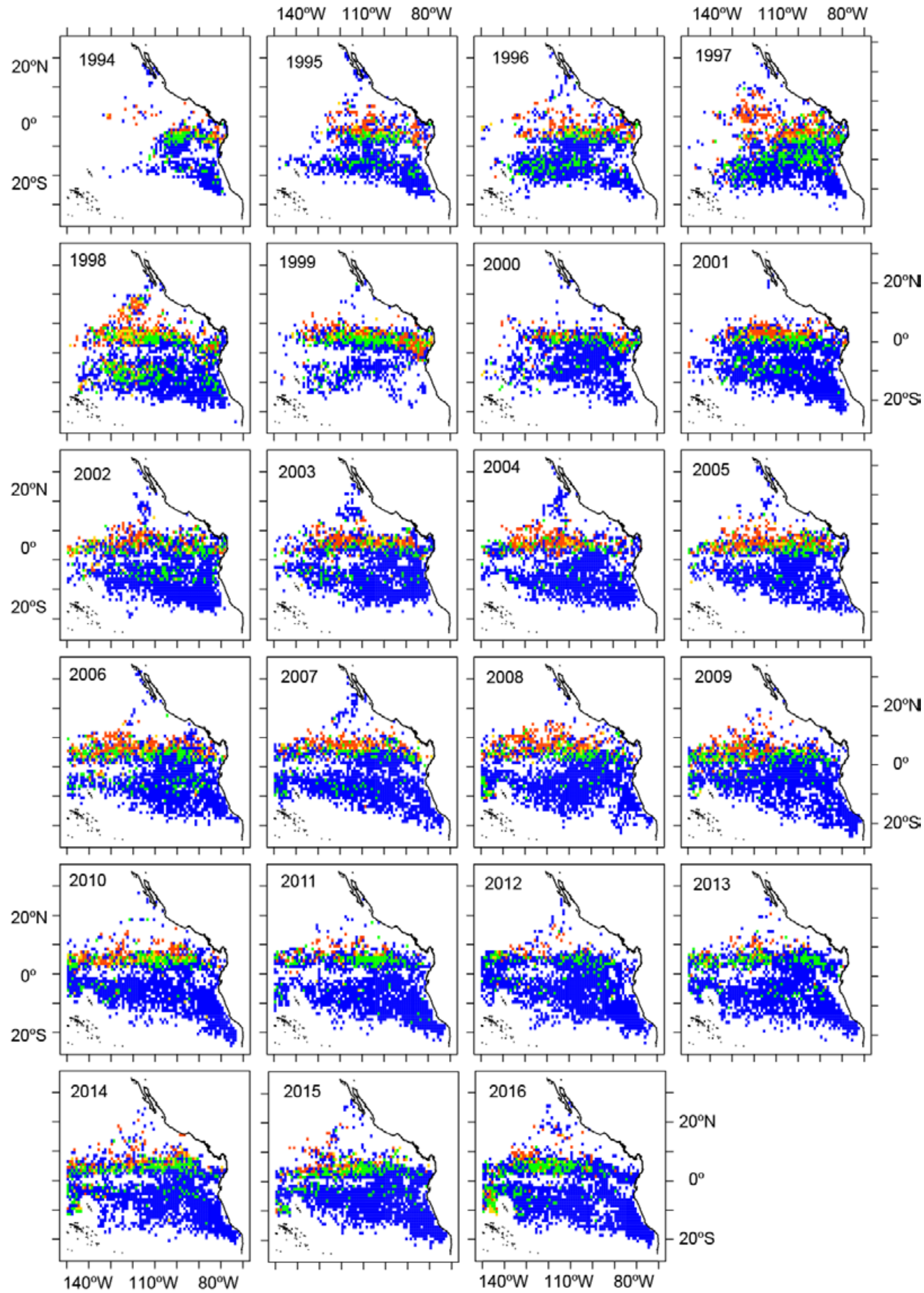

FIGURE 1a. Average bycatch per set in floating-object sets, in numbers, of small (< 90 cm total length) silky sharks, 1994-2016. Blue: 0 sharks per set, green: ≤ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1a. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos pequeños (< 90 cm de talla total), 1994-2016. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

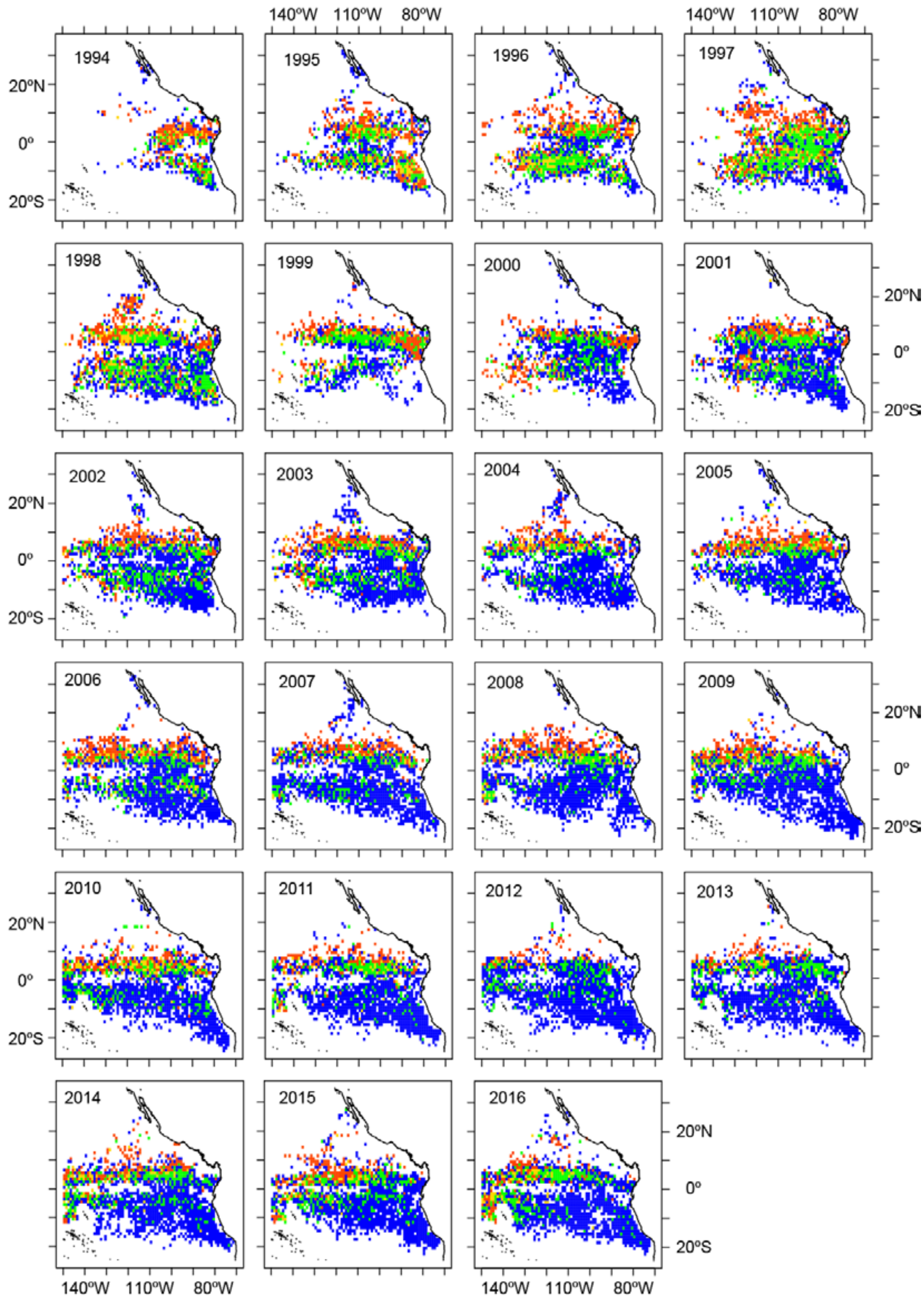

FIGURE 1b. Average bycatch per set in floating-object sets, in numbers, of medium (90-150 cm total length) silky sharks, 1994-2016. Blue: 0 sharks per set, green: ≤ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1b. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos medianos (90-150 cm de talla total), 1994-2016. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

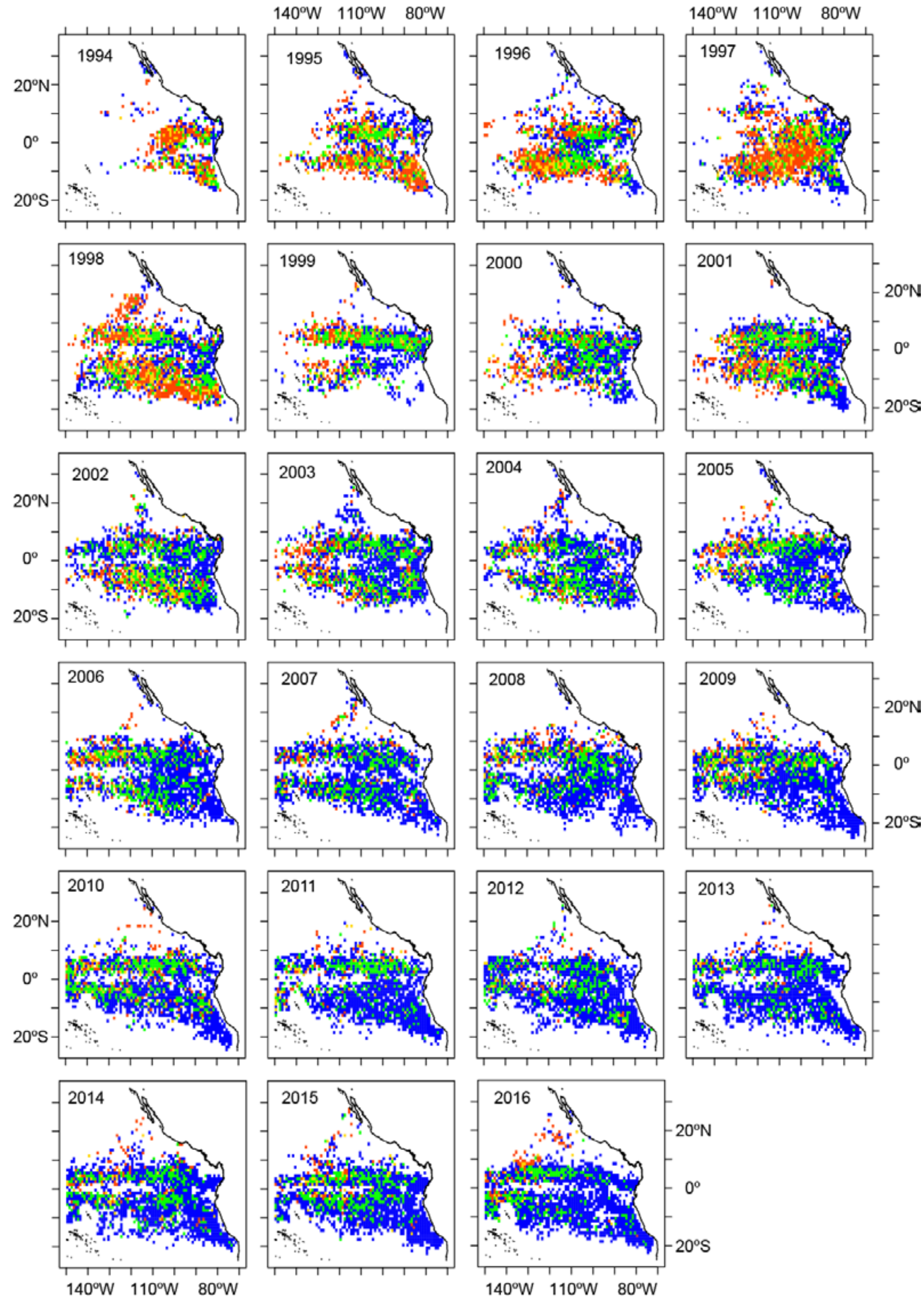

FIGURE 1c. Average bycatch per set in floating-object sets, in numbers, of large (> 150 cm total length) silky sharks, 1994-2016. Blue: 0 sharks per set, green: ≤ 1 shark per set; yellow: 1-2 sharks per set; red: > 2 sharks per set.

FIGURA 1c. Captura incidental media por lance en lances sobre objetos flotantes, en número, de tiburones sedosos grandes (> 150 cm de talla total), 1994-2016. Azul: 0 tiburones por lance, verde: ≤ 1 tiburones por lance; amarillo: 1-2 tiburones por lance; rojo: > 2 tiburones por lance.

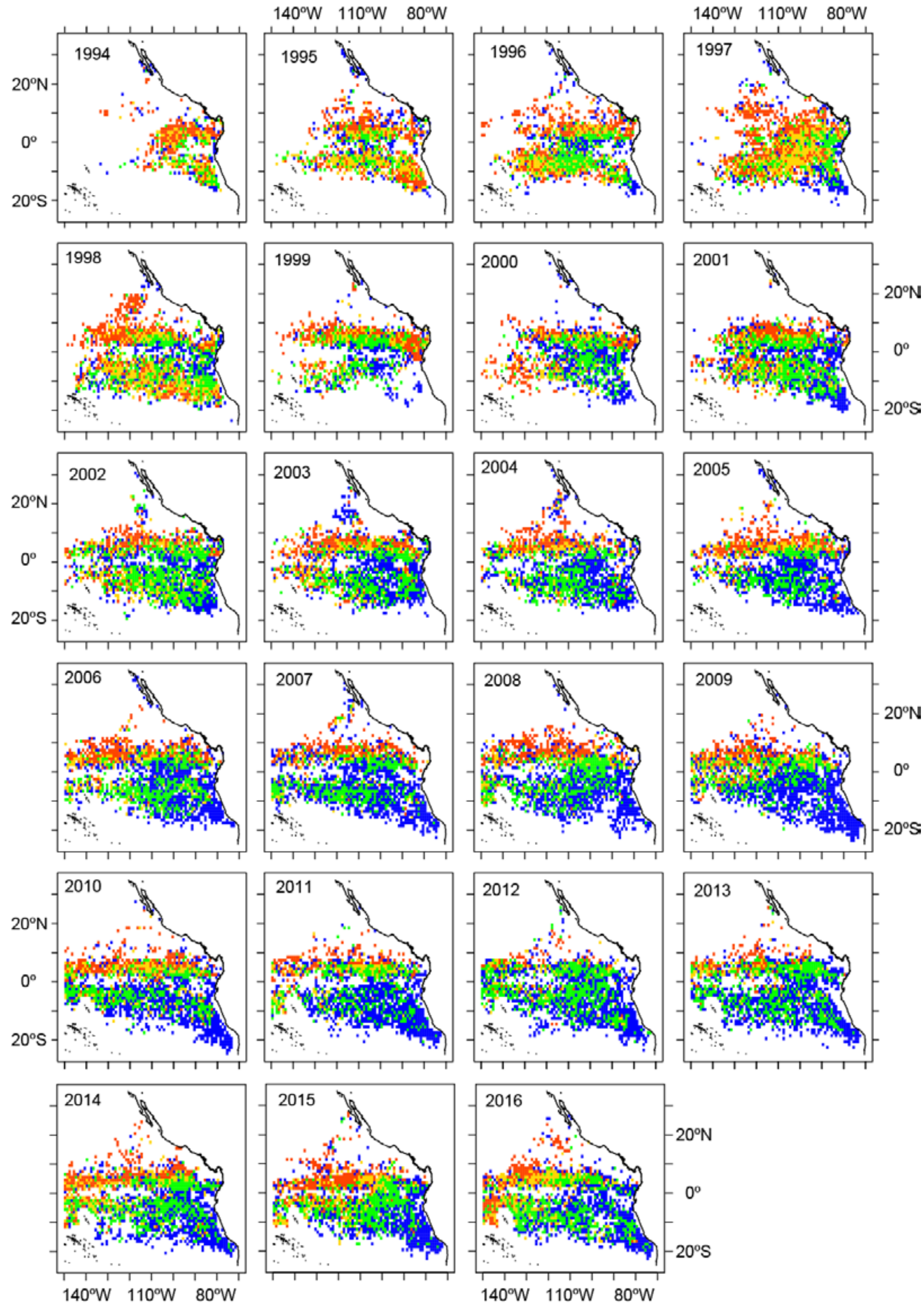

FIGURE 1d. Average bycatch per set in floating-object sets, in numbers, of all silky sharks, 1994-2016. Blue: 0 sharks per set, green: ≤2 shark per set; yellow: 2-5 sharks per set; red: >5 sharks per set.

FIGURA 1d. Captura incidental media por lance en lances sobre objetos flotantes, en número, de todos tiburones sedosos, 1994-2016. Azul: 0 tiburones por lance, verde: ≤ 2 tiburones por lance; amarillo: 2-5 tiburones por lance; rojo: > 5 tiburones por lance.

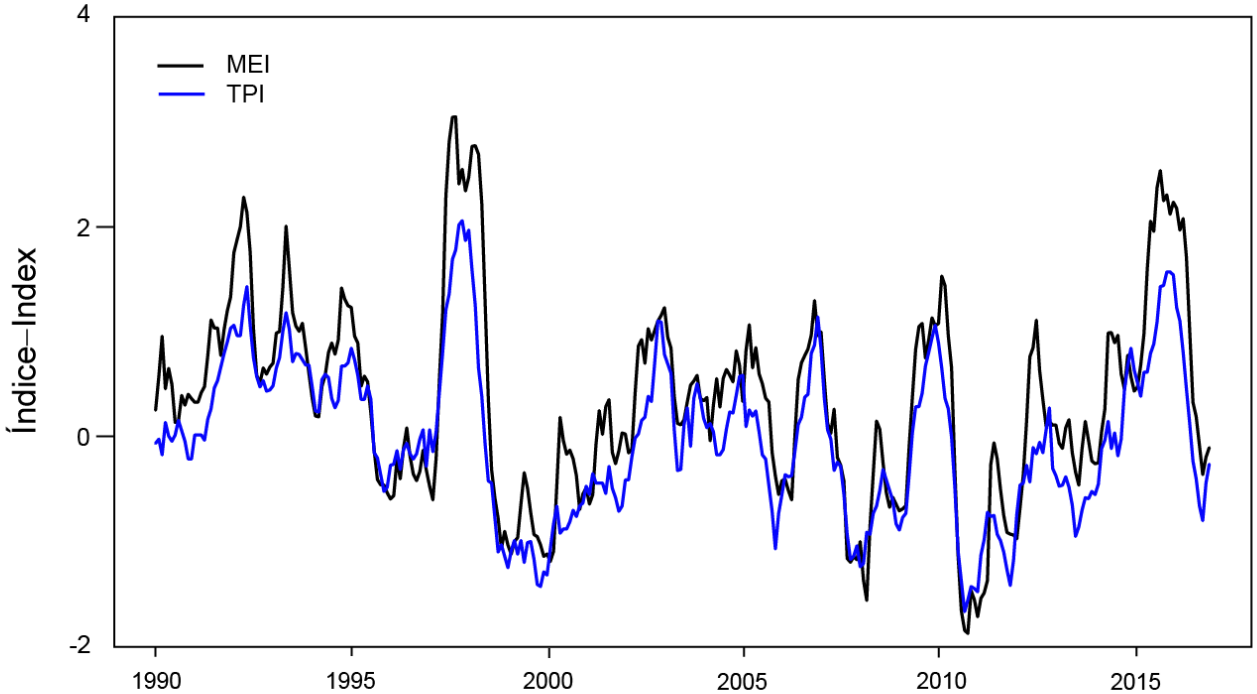

FIGURE 2. Multivariate ENSO Index (MEI; https://www.esrl.noaa.gov/psd/enso/mei/index.html) and Indo-Pacific Tripole Index (TPI; https://www.esrl.noaa.gov/psd/data/timeseries/IPOTPI/), 1990-2016.
FIGURA 2. Índice ENOS multivariable (MEI; https://www.esrl.noaa.gov/psd/enso/mei/index.html) e índice tripolar indopacífico (TPI; https://www.esrl.noaa.gov/psd/data/timeseries/IPOTPI/), 1990-2016.

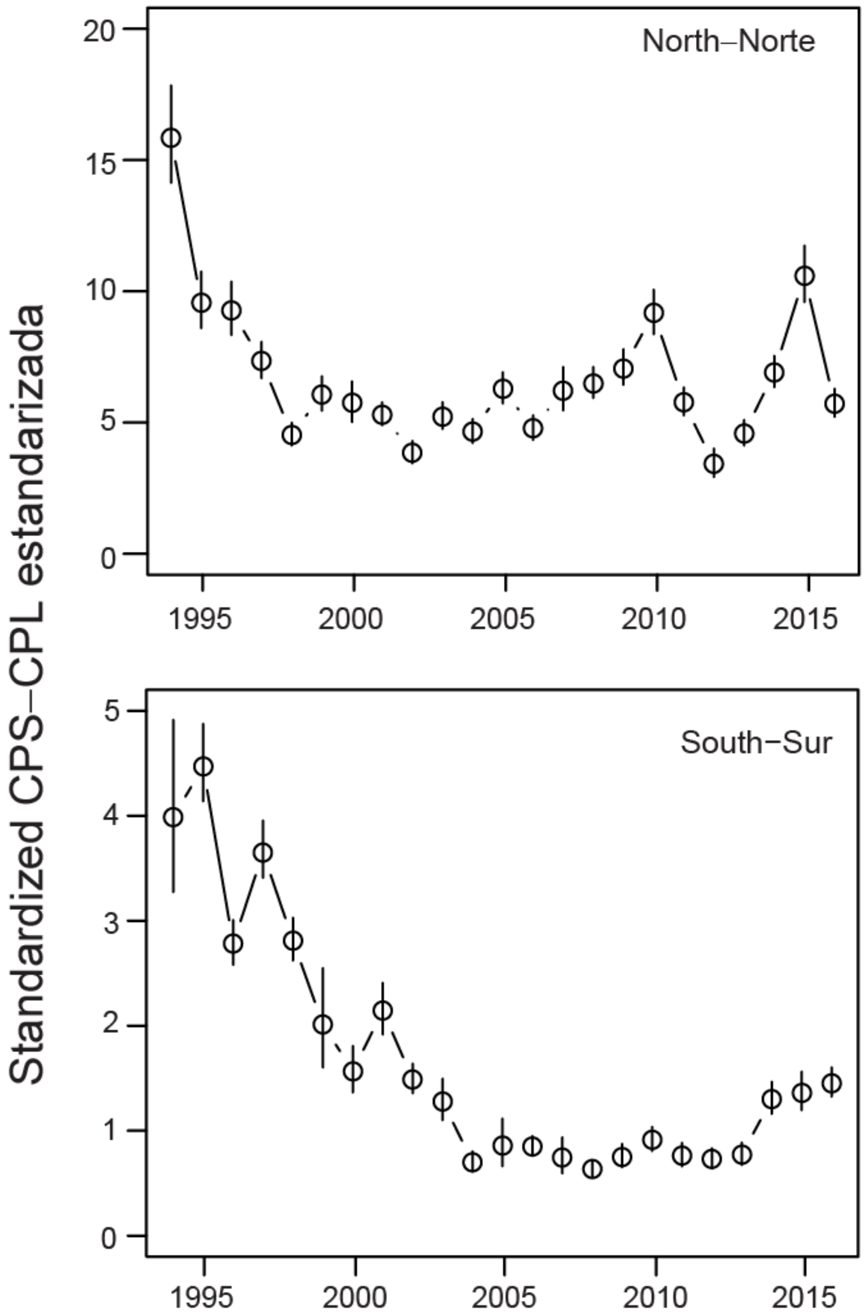

FIGURE 3. Standardized catch-per-set (CPS, in number of sharks per set) of silky sharks (all size classes combined) in floating-object sets in the north (top) and south (bottom) EPO.

FIGURA 3. Captura por lance (CPL, en número de tiburones por lance) estandarizada de todos los tiburones en lances sobre objetos flotantes en el OPO norte (arriba) y sur (abajo).

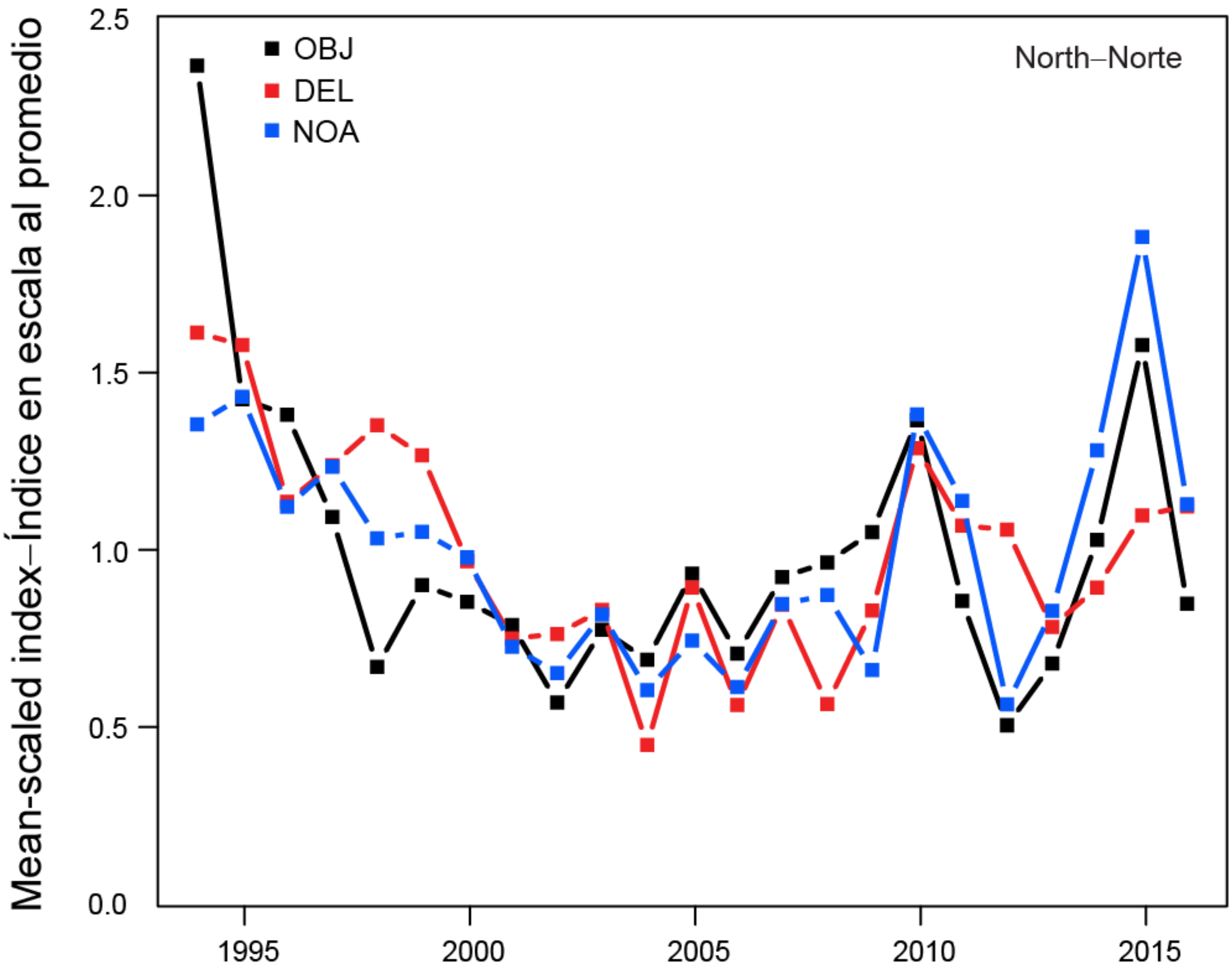

FIGURE 4. Mean-scaled indices for the silky shark in the north EPO for different purse-seine set types (floating-object (OBJ), dolphin (DEL), unassociated (NOA)).
FIGURA 4. Índices en escala al promedio para el tiburón sedoso en el OPO norte en distintos tipos de lance cerquero (objeto flotante (OBJ), delfín (DEL), no asociado (NOA)).

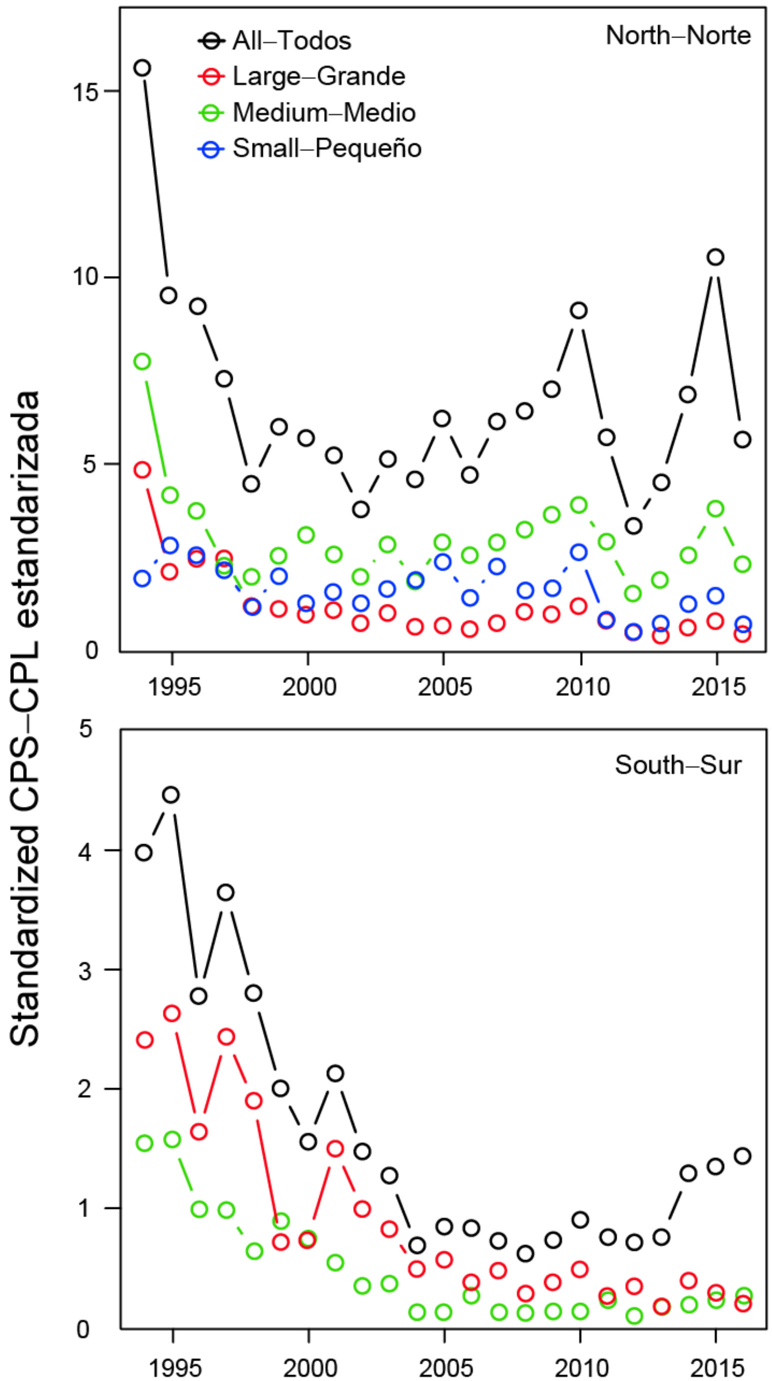

FIGURE 5a. Standardized catch-per-set (CPS; in numbers of sharks per set) in sets on floating objects of silky sharks of three size classes (small, medium, large) and all sizes combined in the north (top) and south (bottom) EPO. No index was computed for small silky sharks in the south EPO due to model instability caused by the low levels of bycatch in recent years; see Figure 1a.

FIGURA 5a. Captura por lance (CPL, en número de tiburones por lance) estandarizada en lances sobre objetos flotantes de tiburones sedosos de tres clases de talla (pequeño, mediano, grande) y todas las tallas combinadas, en el OPO norte (arriba) y sur (abajo). No se calculó un índice para los tiburones sedosos pequeños en el OPO sur debido a la inestabilidad del modelo causada por los bajos niveles de captura incidental en los años recientes (Figura 1a).

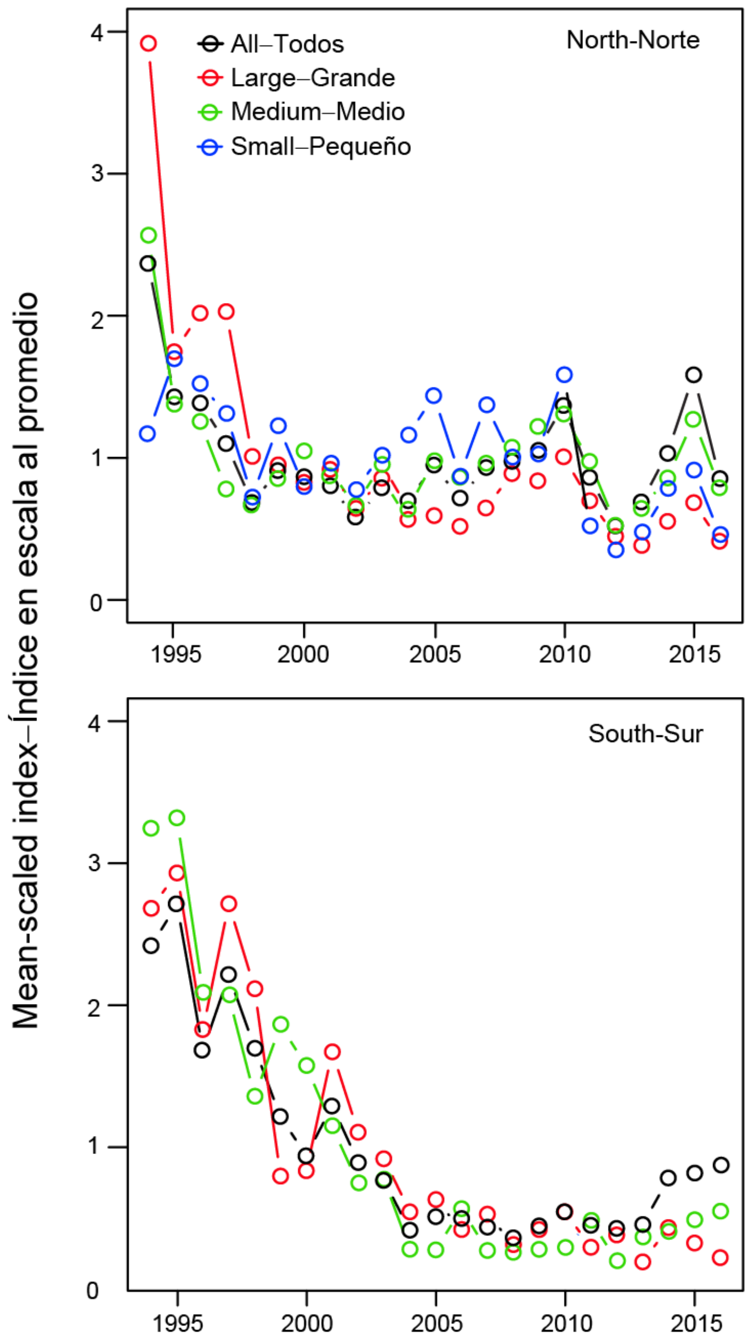

FIGURE 5b. Mean-scaled standardized catch-per-set in floating-object sets (from Figure 3a) for silky sharks of three size classes (small, medium, large) and all sizes combined for the north (top) and south (bottom) EPO. No index was computed for small silky sharks in the south EPO due to model instability caused by the low levels of bycatch in recent years (Figure 1a).

FIGURA 5b. Captura por lance estandarizada en escala as promedio en lances sobre objetos flotantes (de la Figura 3a) de tiburones sedosos de tres clases de talla (pequeño, mediano, grande) y de todas tallas combinadas, en el OPO norte (arriba) y sur (abajo). No se calculó un índice para los tiburones sedosos pequeños en el OPO sur debido a la inestabilidad del modelo causada por los bajos niveles de captura incidental en los años recientes (Figura 1a).

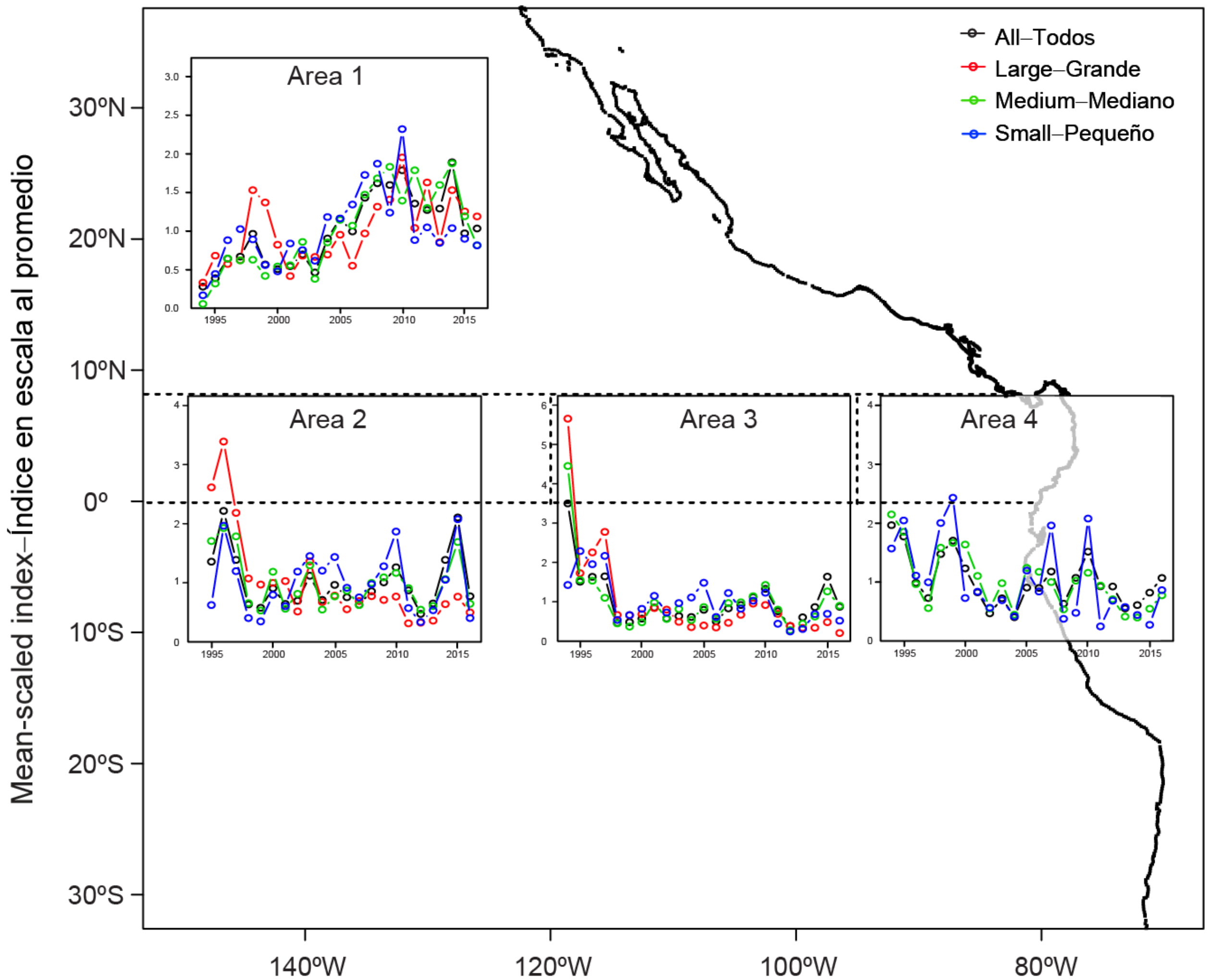

FIGURE 6. Mean-scaled standardized CPS for silky sharks in the north EPO, by sub-area. The black horizontal dashed lines show the locations of the four sub-areas: Area 1 (north of 8°N); Area 2 (0°-8°N and 120°-150°W); Area 3 (0°-8°N and 95°-130°W), and Area 4 (0°-8°N, from the coast to 95°W). No trend was computed for large sharks in Area 4 because of model instability identified in previous analyses.

FIGURA 6. Captura por lance estandarizada en escala al promedio de tiburones sedosos en el OPO norte, por subárea. Las líneas de trazos negras horizontales indican la posición de las cuatro subáreas: Área 1 (al norte de 8°N); Área 2 (0°-8°N y 120°-150°O); Área 3 (0°-8°N 95°-130°O), y Área 4 (0°-8°N, desde la costa hasta 95°O). No se calculó una tendencia para los tiburones grandes en el Área 4 debido a inestabilidad en el modelo identificado en análisis previos.

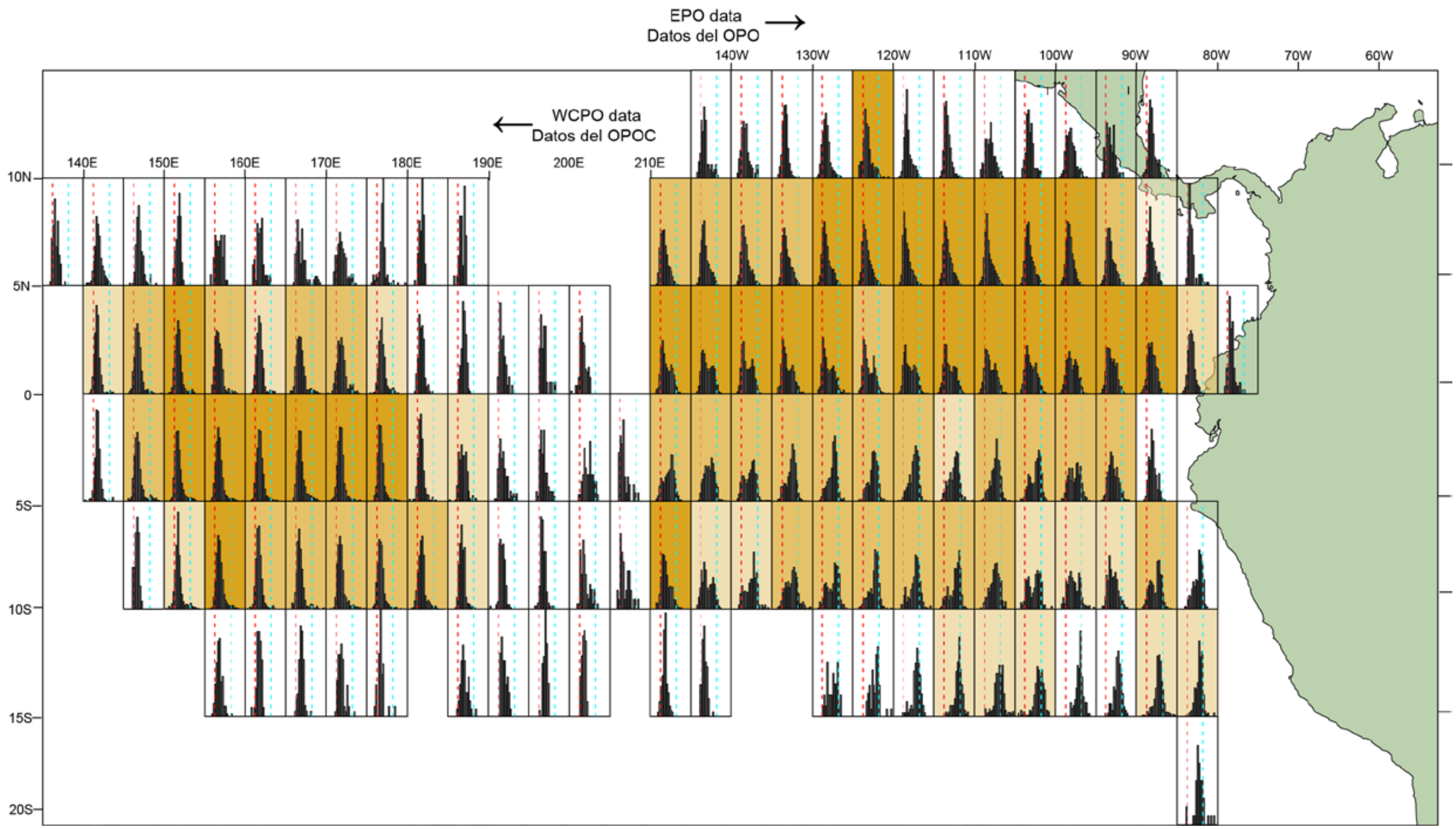

FIGURE 7. Length-frequency histograms (fork length, in cm; FL) for silky sharks sampled from purse-seine sets on floating-objects in the EPO and from associated sets in the WCPO, 2005-2015. The red and blue dashed lines are provided for visual reference and are located at 55cm FL and 165cm FL, respectively. Shading of the histogram panels indicates number of sets in which sharks were measured (white: ≤ 75 sets; light gold: 76-150 sets; gold: 151-300 sets; dark gold: > 300 sets).

FIGURA 7. Histogramas de la frecuencia de talla (talla furcal, en cm; TF) de tiburones sedosos muestreados en lances cerqueros sobre objetos flotantes en el OPO y en lances asociados en el OPOC, 2005-2015. Las líneas de trazos roja y azul representan TF de 55 cm y 165 cm, respectivamente. El color de las casillas indica el número de lances con tiburones medidos (blanco: < 75 lances; amarillo claro: 76-150 lances; amarillo: 151-300 lances; amarillo oscuro: > 300 lances).

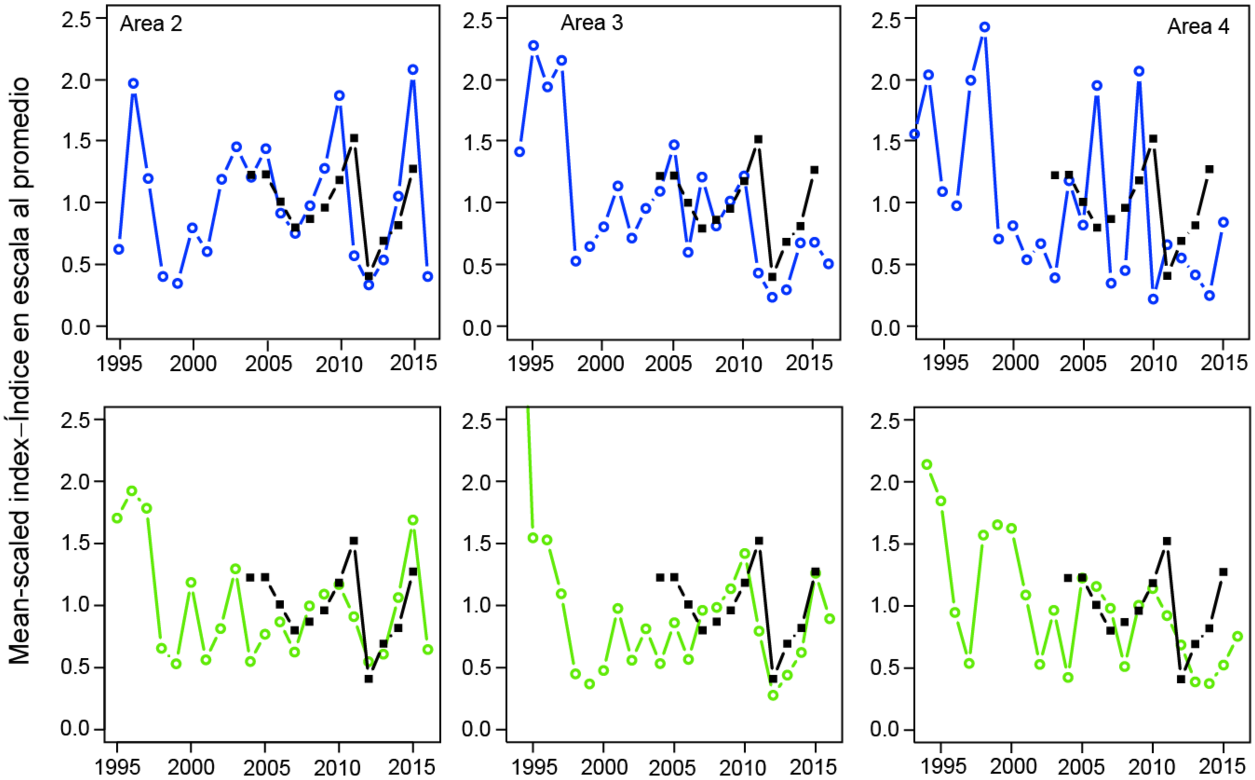

FIGURE 8. Mean-scaled standardized catch-per-set for small (blue) and medium (green) silky sharks in subareas 2-4 in the north EPO (Figure 6) and the preliminary index for the WCPO (black) (145°E-180°E, 10°S-5°N).

FIGURA 8. Captura por lance estandarizada en escala al promedia poro de tiburones sedosos pequeños (azul) y medianos (verde) en las subáreas 2-4 del OPO norte (Figura 6) y el índice preliminar del OPOC (negro) (145°E-180°E, 10°S-5°N).

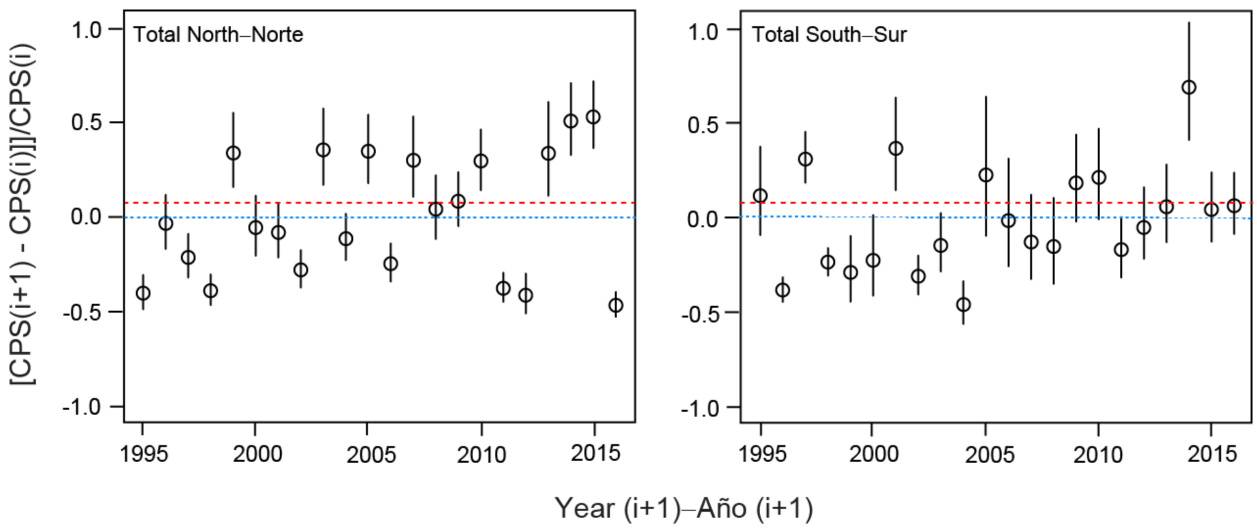

FIGURE 9. Proportional change in the indices for all silky sharks (Figure 2). The proportional change was computed as the difference in CPS from year *i*+1 to year *i*, divided by the CPS in year *i*. The blue dashed line denotes no change. The red dashed line is at the value 0.0745, which is the upper 95% confidence limit on the finite population growth rate for a virgin population, estimated by Román *et al*. (in prep.).

FIGURA 9. Cambio proporcional en los índices de todo tiburón sedoso (Figura 2). Se calculó el cambio proporcional como la diferencia en CPL del año *i* +1 al año *i*, dividido por la CPL en el año *i*. La línea de trazos azul indica ningún cambio. La línea de trazos roja señala el valor de 0.0745, el límite de confianza de 95% superior de la tasa de crecimiento de población finita para una población virgen, estimada por Román *et al*. (en prep.).

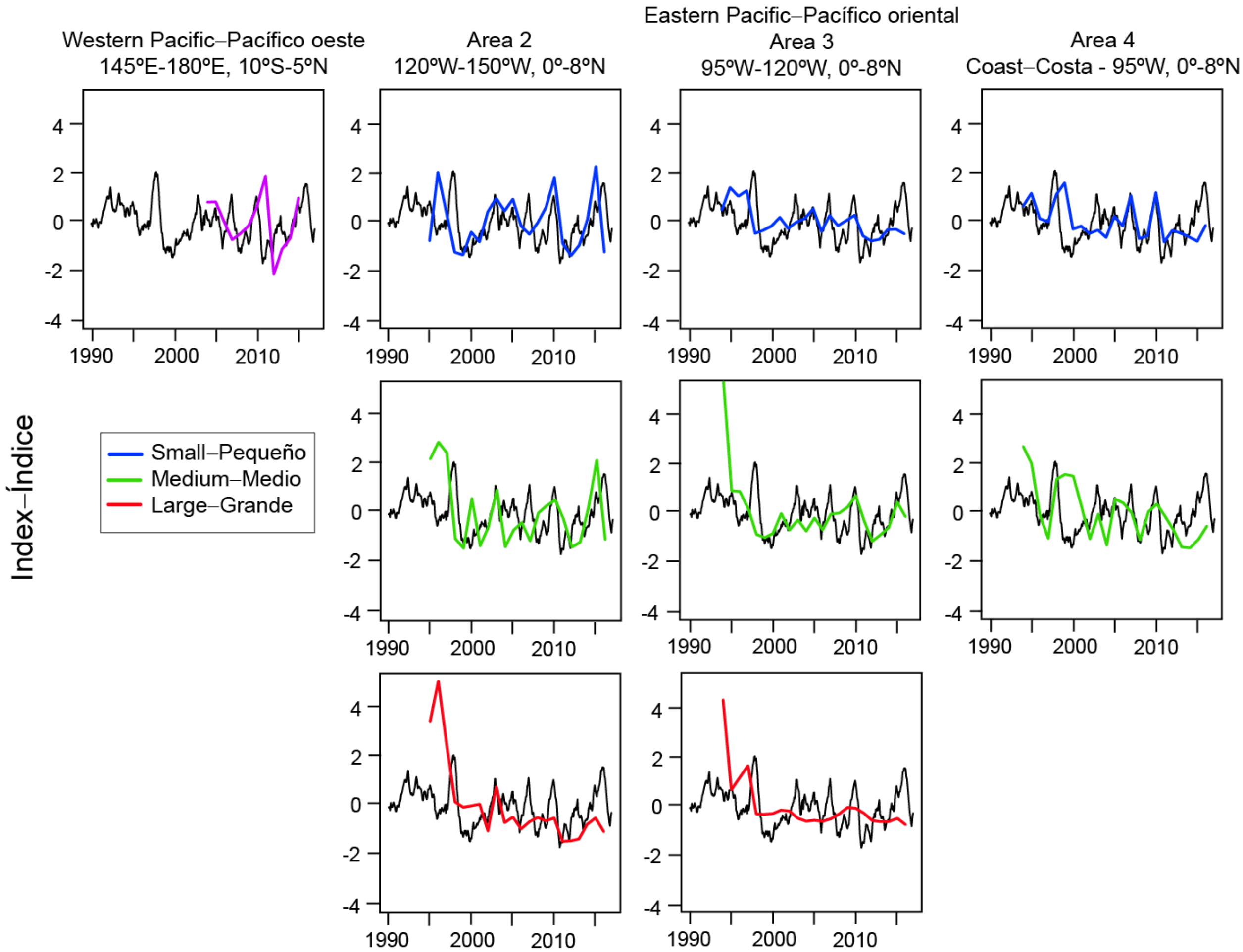

FIGURE 10. Silky shark indices by size for Areas 2-4 of the north EPO (Figure 6) and the WCPO (Figure 8) *versus* the TPI (Figure 2). The black lines correspond to the TPI, the blue, green, and red lines to the EPO indices for small, medium, and large sharks, respectively. And the gray line to the WCPO index. For comparison to the TPI, the shark indices are shown as anomalies (*i.e.*, index – mean(index)).

FIGURA 10. Índices de tiburón sedoso por talla en las áreas 2-4 del OPO norte (Figura 6) y el OPOC (Figura 8) graficados contra el TPI (Figure 2). Las líneas negras corresponden al TPI, las líneas azules, verdes, y rojas a los índices de tiburón sedoso pequeño, mediano, y grande, respectivamente, en el OPO, y la línea gris al índice del OPOC. Para compararlos con el TPI, se ilustran los índices de tiburón sedoso como anomalías (o sea, índice - promedio(índice))