SCIENTIFIC COMMITTEE
NINTH REGULAR SESSION

Pohnpei, Federated States of Micronesia

6-14 August 2013

Spatial and temporal distribution of whale sharks in the western and central Pacific Ocean based on observer data and other data sources

WCPFC-SC9-2013/EB-WP-01

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Summary

The purpose of this paper is to examine the spatial and temporal distribution of whale sharks in the western and central Pacific Ocean based on observer data and other data sources. Our focus is primarily on observer data for the equatorial purse seine fishery and a recent synthesis of information on whale shark movements.

We use all observed purse seine sets as the sampling effort to detect whale sharks and a positive record was any instance where either the school association was recorded as whale shark, whale shark was listed on the catch records, or a whale shark interaction was recorded.

Prior to the agreement of 100% observer coverage in 2010, the observer data are not representative of the entire fleet. However, we chose not to include logsheet data in the analyses provided here due to the concern over false zeros (interactions not reported) as there was no requirement to report whale shark interactions and noting that the logsheet data is not fully complete due to the lack of operational data for some fleets.

We found that the occurrence of whale sharks in free schools sets has dropped by about half over the past ten years. While this could be a result of improved identification of whale sharks prior to setting, or other factors that would be included in a formal standardization, the possibility that this reflects a trend in abundance warrants closer examination.

Spatial analysis of observed fishing sets and whale shark records indicated that whale sharks were generally encountered anywhere significant amounts of fishing were observed. While there were some isolated areas where the rate of records per observed set were high, these were generally areas with low observed whale shark records, but even [relatively] lower observed effort. Further statistical modeling is necessary to determine the extent to which whale sharks are informally distributed across the region versus overlapping with the main purse seine fishing grounds.

It is known that the Japanese coastal tuna fisheries interact with whale sharks and historically [at least] details of these interactions were recorded. These data were not available to the present study, nor are records from tuna and non-tuna fisheries in the Philippines, Chinese Taipei and likely other southeast Asian countries where whale shark interactions occur. For this reason we do not believe that it is possible to conduct any sort of stock assessment for whale sharks in the WCPO.

If further work on whale shark distributions is considered useful by the WCPFC, we suggest the following:

- Statistical modeling of the whales shark records from the tropical purse seine fishery using environmental data. This could lead to the development of a relative index of abundance.
- Incorporating any records from other purse seine data sets not currently available to SPC or WCPFC (e.g. from Japan coastal fisheries)
- Electronic tagging of whale sharks to determine the nature and extent of movement within the WCPO
- Observers obtaining more representative size data

1. Background

The whale shark (*Rhincodon typus*) is the world's largest fish and, while there is a paucity of biological studies, it is thought to be one of the latest maturing and longest living animals on earth and are found in all tropical and warm-temperate seas in all the world's oceans – including the WCPO (Compagno 1984, Sequeira et al. 2013). While they have potentially the highest fecundity of all the worlds sharks (Joung et al. 1996) this is countered by estimates of age at maturity around 30 years (Taylor 1994) and size at maturity over 8m (Norman 1999). While these later estimates are uncertain, and in fact there is limited evidence to accurately determine age, growth, and maturity of wild whale sharks (Wintner 2000), it is concluded that they are likely to be a species with low population growth (Colman 1997) and therefore be vulnerable to fishing-related mortality.

There have been recent developments within the WCPFC with respect to protection of whale sharks. The Parties to the Nauru Agreement (PNA), through the Third Implementing Arrangement (3IA; PNA 2010), passed a measure that no purse seine vessel shall engage in fishing or related activity in order to catch tuna associated with whale sharks. At its ninth regular session the WCPFC added whale shark as the 14th species on its list of key shark species (see Rice and Harley 2012) and adopted a Conservation and Management Measure (CMM-2012-04[2]) that prohibits knowingly setting on a whale shark and requires steps be taken to ensure the safe release of any accidentally encircled whale shark and flag state reporting within Part 1 reports to the Commission.

This particular paper responds to the request from SC9 and WCPFC9 to examine the spatial and temporal distribution of whale sharks in the western and central Pacific Ocean based on observer data and other data sources. To achieve this, our focus is primarily on observer data for the equatorial purse seine fishery and a recent synthesis of information on whale shark movements. For the first part, our work builds on previous papers submitted to WCPFC that summarizes available information on purse seine interactions with whale sharks based on observer data (OFP 2012).

2. Data

The observer data used in the analysis comprised all observed purse seine sets held by SPC for the last ten years (2003-2012[3]). Prior to the agreement of 100% observer coverage in 2010, the observer data are not representative of the entire fleet with a strong bias towards US vessels, Pacific Islands fleets (under the FSM Arrangement) and those vessels fishing in the waters of Papua New Guinea.

Nevertheless, they represent over 115,000 observed sets over the past ten years (Table 1). To determine if a set encountered a whale shark in some way we used three criteria 1) was the set labeled as a whale shark associated set as recorded on the observer PS-2 form; 2) whether the set caught a whale shark – from the observer PS-3 form; or 3) was an interaction reported - from the observer GEN-2 form.

As has been noted previously (OFP 2012) not all whale shark associated sets necessarily result in the encirclement of the whale shark, and many of the whale shark interactions come from sets that were reported by the observer as a free school set because the whale shark was not noticed until after the set was made.

The majority of the analysis in this paper relates to modeling the distribution of sets, whale shark records, and the 'encounter rate' (whale shark records per set) at 1 x 1 degree square resolution. It is

[2] http://www.wcpfc.int/doc/CMM-2012-04/Conservation-and-Management-Measure-protection-whale-sharks-purse-seine-operations

[3] Data are not complete for 2012

important to note here, and we stress this point in the discussion, that the observer data are restricted in its coverage of the WCPO purse seine fishery with no coverage for the domestic purse seine within EEZ fisheries in Indonesia and the Philippines nor the Japanese purse seine fisheries that operate in the North. Any hotspots identified in this paper are not necessarily the areas of highest density of whale sharks in the WCPO or even the equatorial part of the convention area.

3. Results

530 observed sets were recorded as whale shark sets (criteria 1 above) and a further 523 sets met either criteria 2 or 3 (Table 1). This gave 1073 records of whale sharks from just over 115,000 observed sets. The data coverage increased dramatically in 2010 with the introduction of 100% observer coverage so overall the data are biased toward recent years. The percentage of all sets that recorded some form of whale shark interaction has been just under 1% except for the period 2006-2008 when it increased to just under 1.5% (Figure 1).

Noting that many whale shark interactions are from sets where the presence of a whale shark was not noticed until after the set was made, the occurrence of whale sharks in sets recorded as free school or unassociated sets offers a potential data set to investigate trends in relative abundance of whale sharks. Aside from 2006 which had a large spike in the occurrence of whale sharks in free schools sets (2%), there has been a general decline in the occurrence of whale sharks in free school sets with a mean of around 1% for the first six years (ignoring 2006) and just under 0.5% for the last four years.

In general, the distribution of whale shark records is very similar to the distribution of fishing effort (Figure 3). The areas of highest density of whale shark records were in the Bismark and Solomon Seas, but some whale shark records were found across much of the area where observed sets have occurred. In terms of the encounter rate there were some isolated areas where the rate of records per observed set were high but these were generally areas with low observed whale shark records, but even [relatively] lower observed effort. These areas included the southeastern corner of the Papua New Guinea EEZ in the Solomon Sea, the southwest corner of the EEZ of the Federated States of Micronesia, and some small parts of the Gilbert, Phoenix, and Line Islands groups.

In Figure 4 we examine the interannual variability in fishing effort and rates of occurrence of whale shark records. There are some interesting patterns, particularly in years where there are hotspots of observed purse seine fishing further to the east (e.g., see 2010). But such patterns do not provide guidance on whether the whale sharks are always there or are moving to the same areas as the purse seine fleet which attempts to follow the areas of highest abundance of tuna schools.

4. Discussion

In this study we estimated a decline in the occurrence of whale shark interactions from free schools sets of around half over the past ten years. It is not clear if this reflects an increase in identifying whale sharks before the set is made (i.e., more are reported as whale shark sets), a real decline in the abundance of whale sharks, biases in the available data prior to 2010, or simply a result of some other factors that would warrant the inclusion in a standardized analysis of these data. Given the nature of this trend it is strongly recommended that WCPFC consider a standardized analysis of whale shark records to determine if this may reflect a trend in abundance.

We found that the areas of highest numbers of whale shark records were generally the areas of highest observed fishing effort – there were only a few small areas where the occurrence rate was high. Therefore, it is not known if whale sharks are generally quite uniformly distributed across the western equatorial Pacific Ocean, or if instead the whale sharks are in fact aggregated in the areas of highest fishing effort. The question is likely critical to any further directed management of purse seine / whale shark interactions and electronic tagging offers the best way to determine the distribution of whale sharks independent to the fishery.

While over 3000 whale sharks have been tracked globally (Sequeira et al. 2013), little of that data is publically available and what is a) does not cover any of the area covered by the WCPO purse seine fishery, and b) generally the tracks are for very short times. Whale shark tracking programmes have been plagued with premature detachments that are common to many electronic tagging programmes of oceanic fish. If resources are to be directed at electronic tagging then improved techniques for tag attachment will be critical and some of the advances made in the attachment of electronic tags to white sharks (see Domeier and Nasby-Lucas 2013) should be considered.

Since the summary of information presented to SC9 (Rice and Harley 2012) there have been two important pieces of work published on whale sharks by Ana Sequeira and colleagues as part of her PhD research. These were a global review of information on whale shark movements and potentially connectivity across the world's oceans (Sequeira et al. 2013) and a detailed statistical analysis of whale shark interactions with purse seine fishing in the Indian Ocean (Sequeira et al. 2012) which represents a more analytical approach to what we have undertaken here.

Sequeira et al. (2013) considered genetic studies, reports of occurrence (Figure 5), and available tracking studies (Figure 6) and concluded that genetic evidence suggests at least some level of interaction between the oceans, but this has not yet been confirmed through any tracking studies – in concluding this it is important to recognize that the tracking studies to date have not been particularly successful at tracking individuals for any length of time and the levels of mixing do not need to be that high given the long generation time of whale sharks.

The work of Sequeira et al. (2012) was pertinent due to its use of fishery data similar to that described here. They examined chlorophyll and sea surface temperature as potential drivers of whale shark habitat preferences within a generalized linear mixed modeling framework. We think that the application of this approach to WCPO data, while not a trivial exercise, could lead to a better understanding of the potential overlap of the WCPO purse seine fishery and whale sharks in the region. This will be important, when combined with observer reports of whale shark mortality, to determine the level of risk that purse seining provides to whale sharks in the WCPO. The trend of occurrence in free school sets found in the current study raises the importance of undertaking such investigations.

Finally we reinforce the important message about the nature of the observer data to identify the spatial extent of whale sharks in the WCPO. The historical presence of directed whale shark fisheries throughout southeast Asia is well known (Chen et al. 1997, Uchida 1984) and there are domestic purse seine fisheries operating in the waters of Indonesia, Philippines, and likely Vietnam that are encountering / interacting with whale sharks. Further it is known that the Japanese coastal tuna fisheries interact with whale sharks and historically [at least] details of these interactions were recorded (Iwasaki 1970). These data were not available to the present study. For this reason we do not believe that it is possible to conduct any sort of stock assessment for whale sharks in the WCPO.

If further work whale shark distributions is considered useful by the WCPFC, we suggest the following:

- Detailed statistical modeling of the whales shark records from the tropical purse seine fishery using environmental data as a predictor (after Sequeira et al. 2012). Such analysis could lead to the development of some form of relative index of abundance.
- Incorporating any records from other purse seine data sets not currently available to SPC or WCPFC (e.g. from Japan coastal fisheries)

- Electronic tagging of whale sharks to determine the nature and extent of movement within the WCPO
- Observers obtaining more representative size data

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Table 1: Summary of observer data included in this analysis. Whale shark sets are those recorded as such prior to the set being made while the whale shark records include sets where either whale shark was noted as school association, whale shark was listed on the catch records, or a whale shark interaction was reported (some sets may have all three met).

	All sets	Whale shark sets	Whale shark records
2003	3,638	18	36
2004	5,317	17	39
2005	6,230	29	54
2006	6,117	37	91
2007	6,028	43	80
2008	6,322	40	84
2009	10,737	42	89
2010	31,383	112	259
2011	27,688	140	234
2012	11,954	52	107

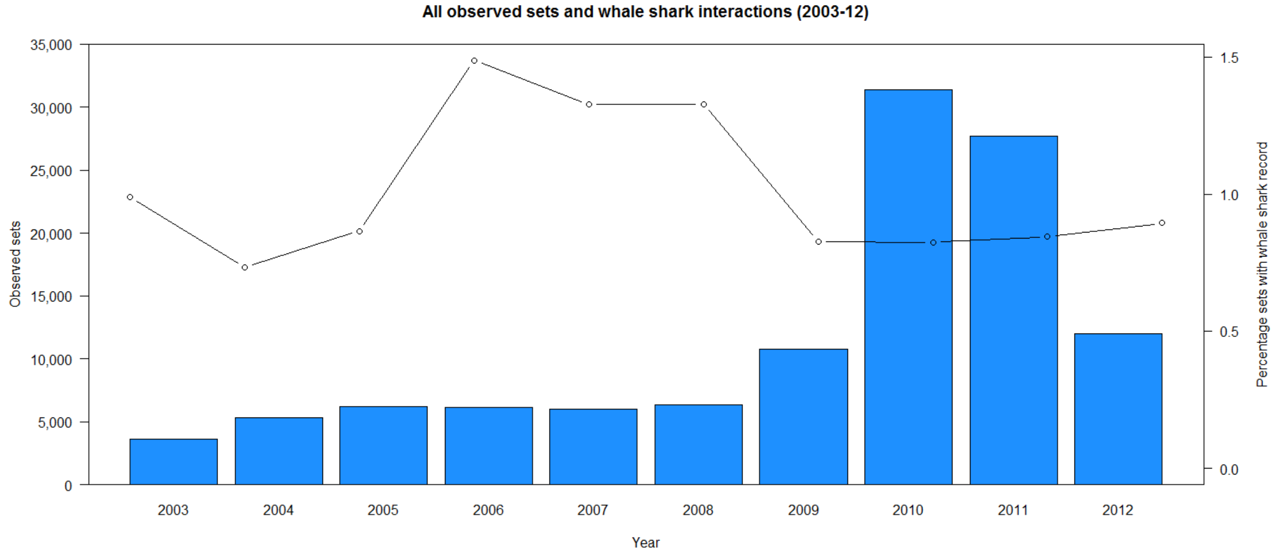


Figure 1: Annual number of <u>observed sets</u> (bars) and proportion of sets with some form of whale shark interaction (see text for criteria).

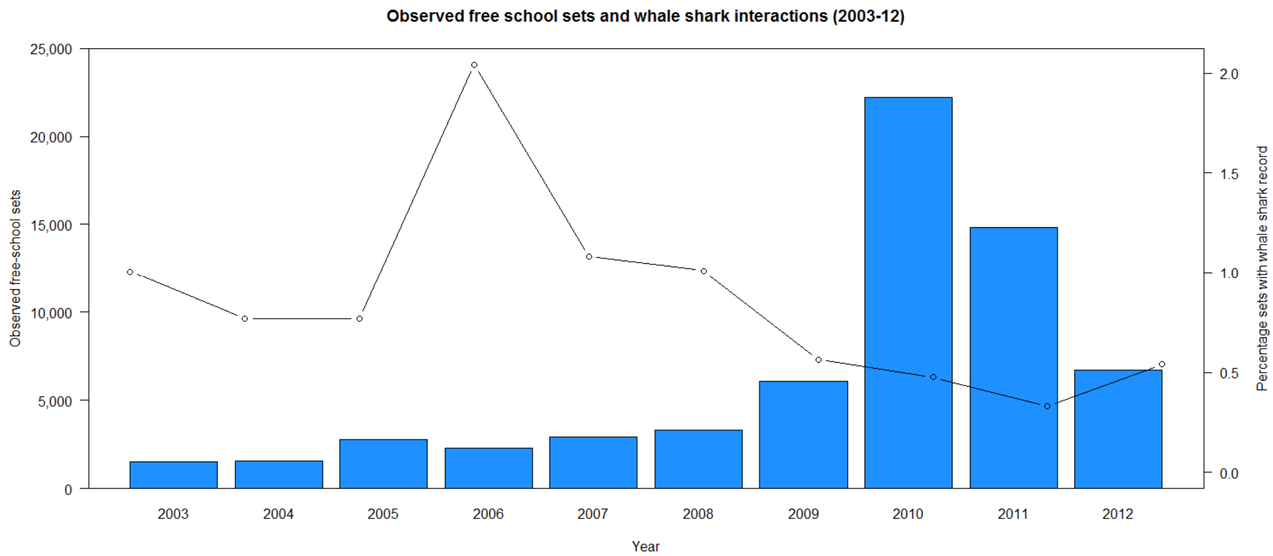


Figure 2: Annual number of <u>observed free school sets</u> (bars) and proportion of sets with some form of whale shark interaction (see text for criteria).

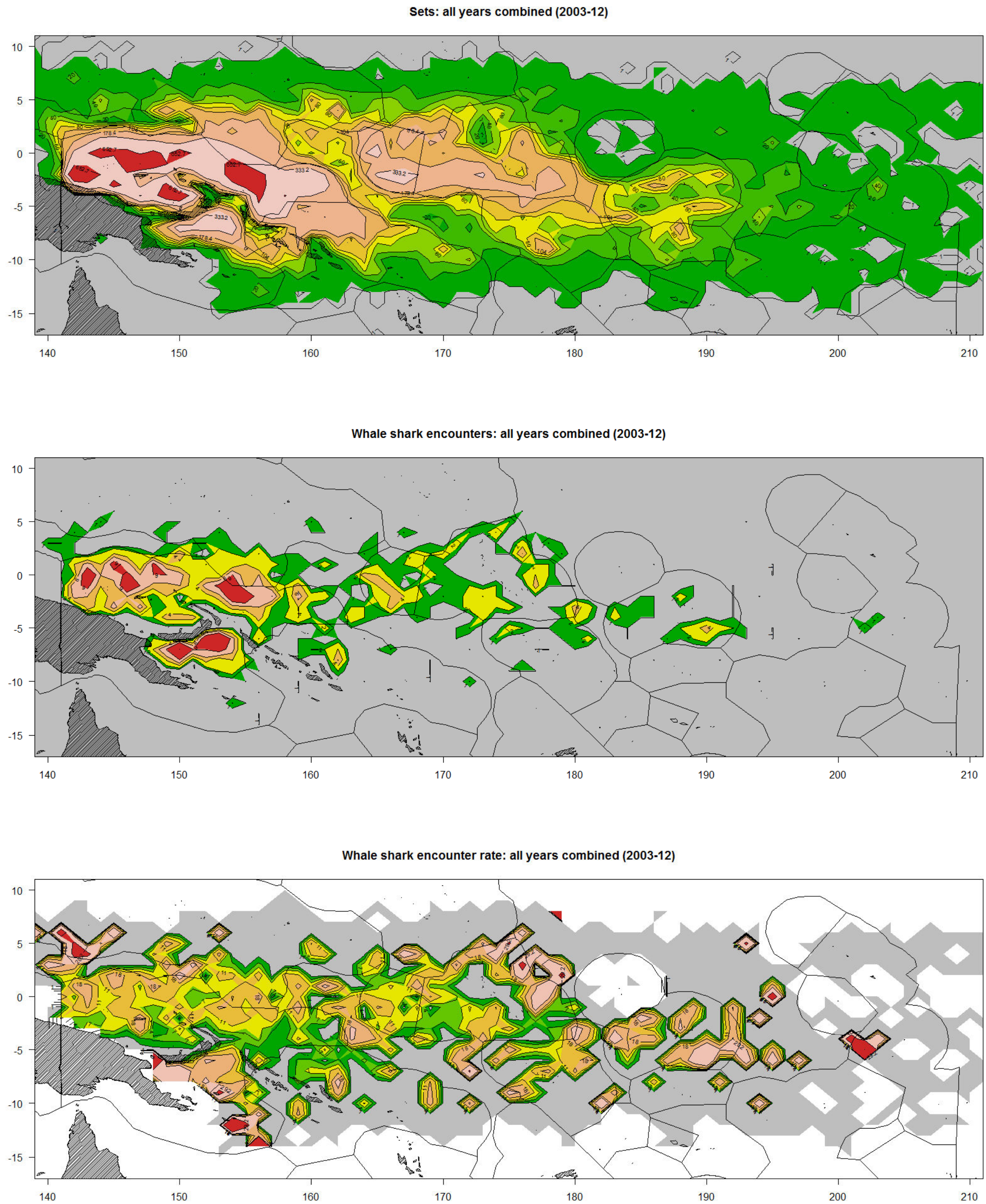
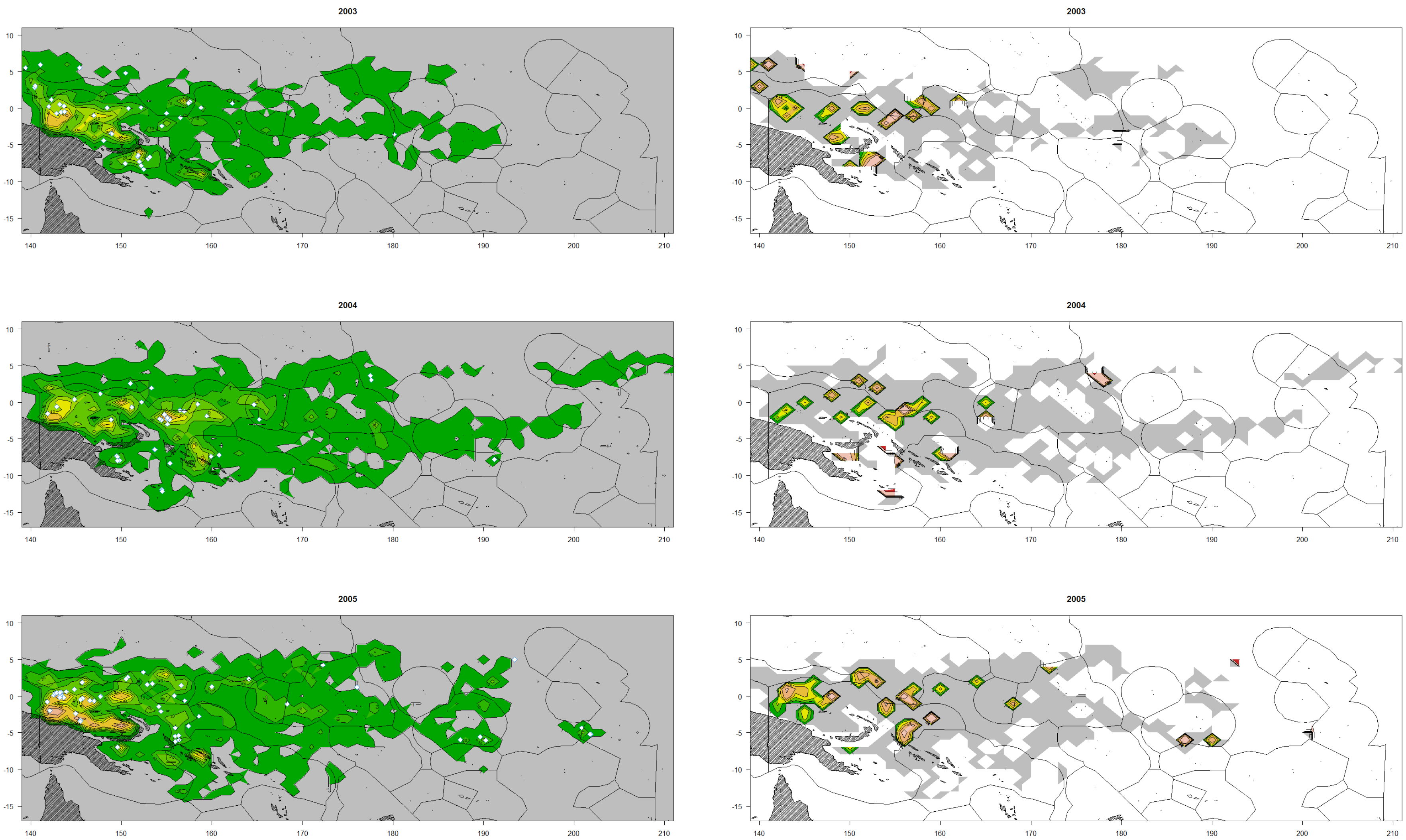


Figure 3: Contour plots based on 1 x 1 degree square data for all years combined of purse seine sets (top), whale shark records (middle – see text for criteria), and encounter rates (bottom – simply whale shark records divided by total sets for each 1 x1 degree square). Grey represents zeros, white are NA's (e.g. zero whale sharks divided by zero sets), and the scale increases from green to yellow to orange to pink to red.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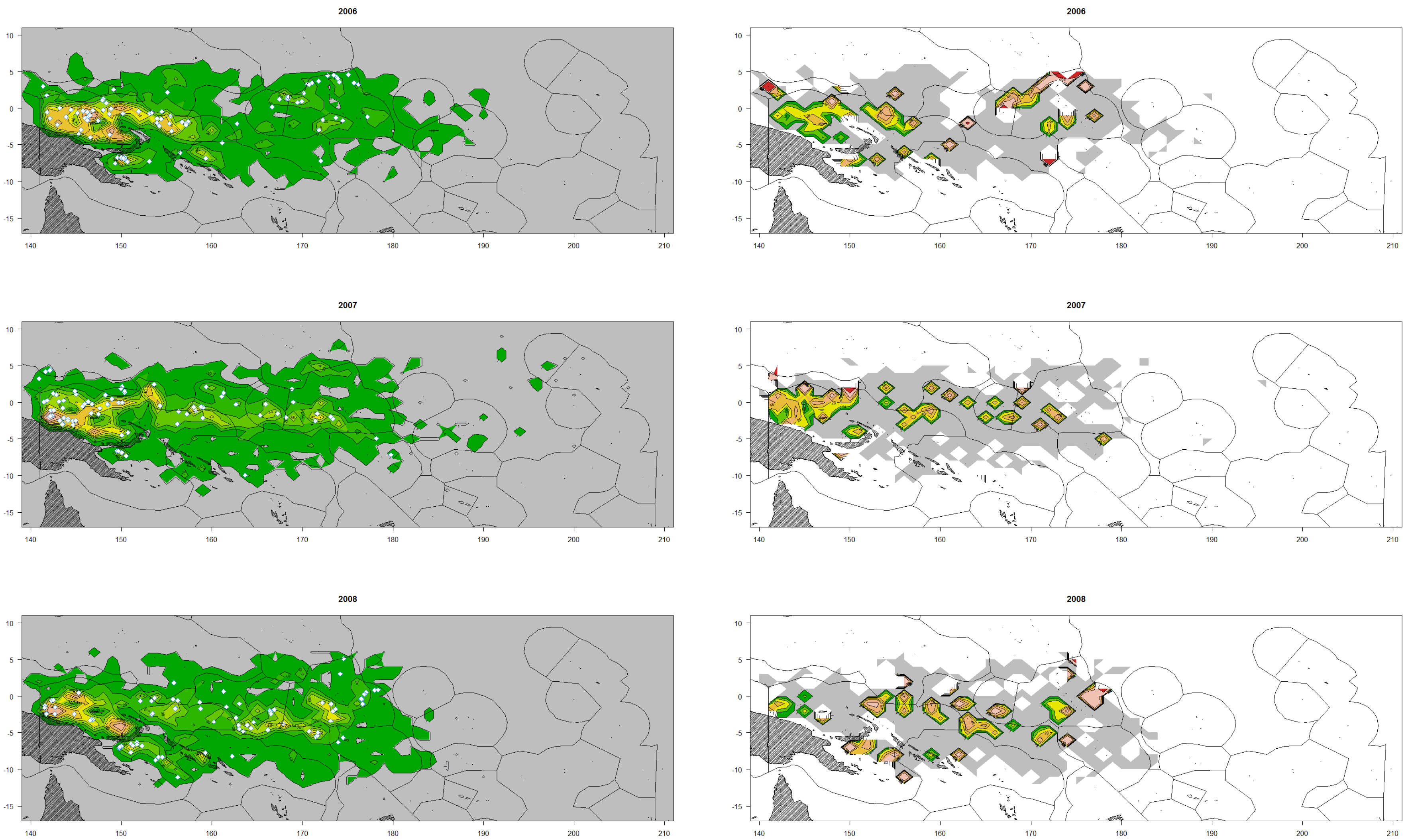
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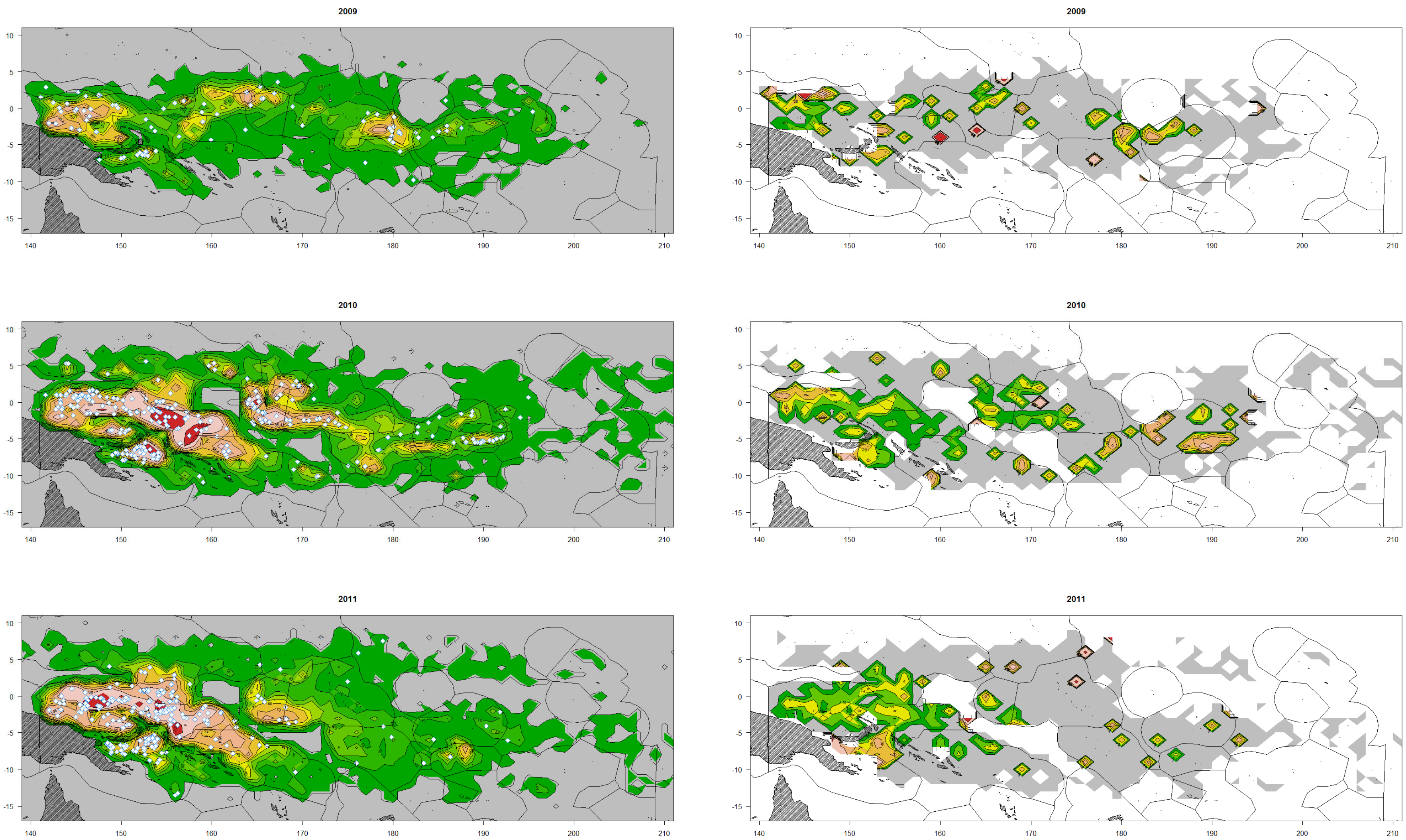
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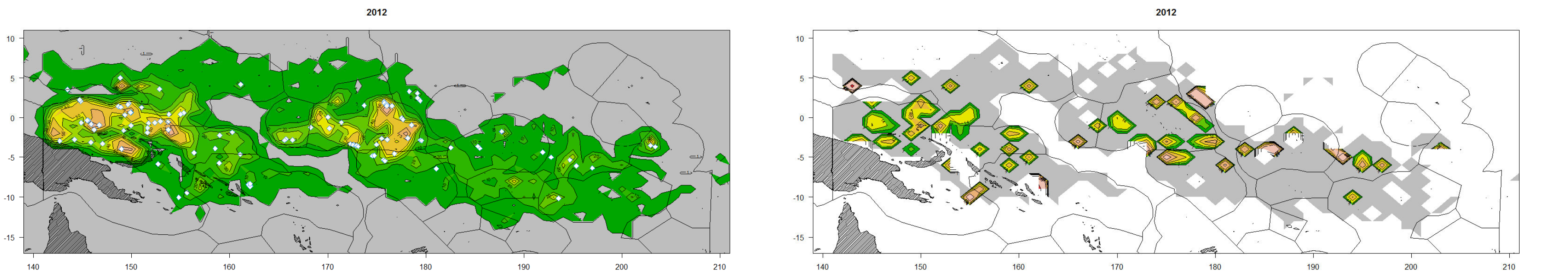

Figure 4: Contour plots based on 1 x 1 degree square data by year of purse seine sets (left; with whale shark records as small white diamonds), and encounter rates (right – simply whale shark records divided by total sets for each 1 x1 degree square). Grey represents zeros, white are NA's (e.g. zero whale sharks divided by zero sets), and the scale increases from green to yellow to orange to pink to red.

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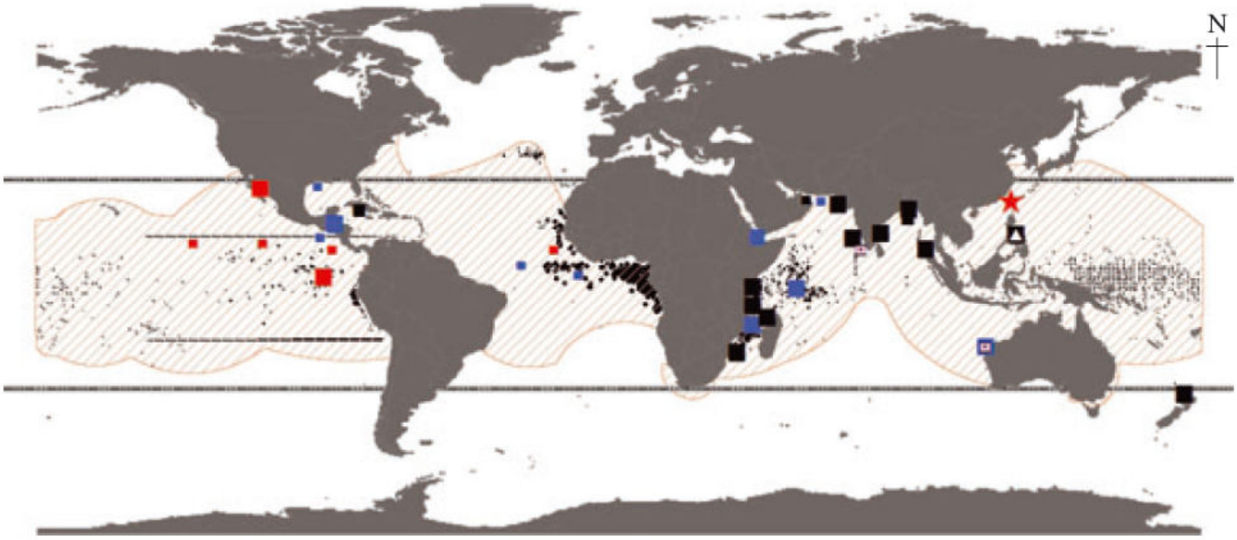

FIG. 2. Compilation of worldwide *Rhincodon typus* occurrences from Compagno (2001), Martin (2007), Stacey *et al*. (2008) and Rowat (2007) showing latitudinal range (▬) overlaid with the IUCN (Norman, 2012) distribution (▨). ■, <1 m total length (L_T) sex not specified; ■, <1 m L_T males; ■, 1 m L_T females; ■, 1–3 m L_T sex not specified; ■, *c*. 5 m L_T males (Djibouti); ■, *c*. 7 m L_T sex not specified; ■, *c*. 7 m L_T males; ■, *c*. 7 m L_T females (mostly; square size increases with increase in L_T); ◭, 46 cm L_T (smallest *R. typus*); ▣, groups of juveniles (≥ 10 individuals); ★, the sighting of pregnant female >10 m L_T with 300 embryos (Joung *et al*., 1996); •, long-term (1980–2010) *R. typus* sightings from tuna fisheries.

Figure 5: Global whale shark occurrences taken from Sequeira et al. (2013).

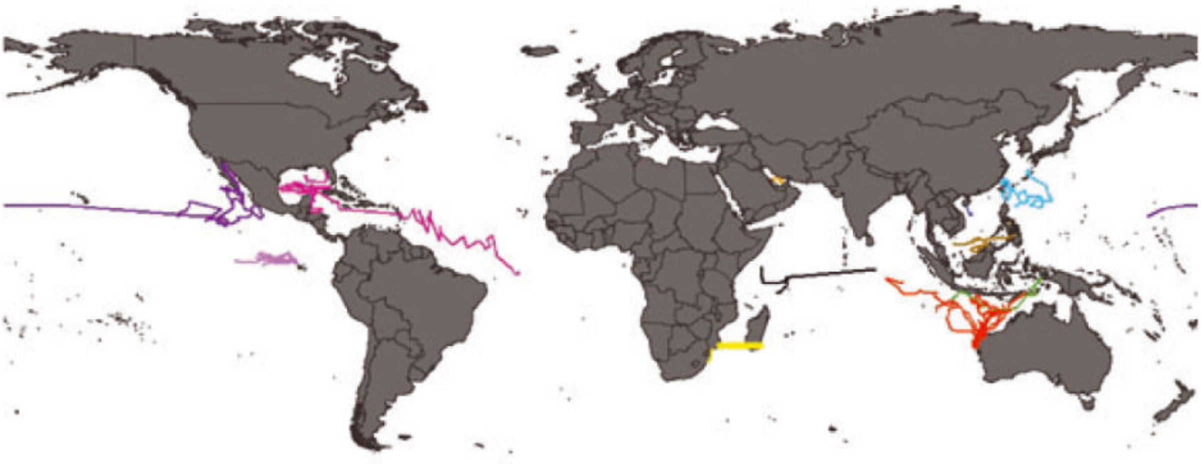

FIG. 3. Global overview of published *Rhincodon typus* tracks (—, Gulf of California; —, Galapagos; —, Gulf of Mexico; —, The Arabian Gulf; —, Seychelles; —, South Africa–Mozambique; —, Ningaloo (Western Australia); —, Christmas Island; —, Hainan (China); —, Taiwan; —, Philippines–Malaysia). Colour code indicates area of tag deployment. Tracks adapted from original sources as detailed in Tables II–IV.

Figure 6: Global whale shark tagging tracks taken from Sequeira et al. (2013).