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Indicators of the spatial distribution of blue shark (Prionace glauca) in the North Pacific

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1. ABSTRACT

The Western and Central Pacific Fisheries Commission at its 14th Annual Session (paragraph 378, WCPFC14 Summary Report) requested the Scientific Committee to provide advice as to whether blue shark in the North Pacific should be designated as a “northern stock”, defined as those stocks “which occur mostly in the area north of the 20° north parallel”.

Blue shark comprise a single stock in the North Pacific, and occur widely from the Equator to at least 57°N. They mate in subtropical and tropical waters during the summer, after which females migrate northwards, giving birth in the following year between 30-40°N. The area south of 20°N is an important part of the blue shark distribution in the North Pacific, particularly for adults. Furthermore, the area may be part of the breeding ground, and/or post-breeding area for pregnant females.

Catch and CPUE data from several fisheries and research cruises were examined for indications of relative distribution of blue shark north and south of 20°N. Japanese research cruise data indicated that blue shark CPUE is higher in the northern area. Other data sets examined – Chinese Taipei large-scale tuna longline and Hawaii-based deep-set longline – indicated similar levels of CPUE in both northern and southern areas. It is acknowledged that such spatial comparisons may be confounded by possibly different depth distributions that blue shark occupy in the northern temperate and southern tropical regions of the North Pacific, and the depths that longline gear fish in these regions. Nevertheless, it is clear from the available data that the tropical region of the North Pacific south of 20°N is an important component of the blue shark distribution. This is also supported by conventional and electronic tagging data.

The question: *do blue shark occur mostly north of 20îN?* – is difficult to answer scientifically because of the qualitative nature of the question. Based on nominal CPUE spatial comparisons, we would judge that blue shark has a tropical component at 0-20°N similar to some already-designated northern stocks. Comparisons of swordfish, albacore and blue shark nominal CPUE in the Hawaii-based deep-set longline fishery show similar ratios north and south of 20°N for all three species, indicating that, at least in the area of this fishery, swordfish, albacore and blue shark all have significant parts of their distributions south of 20°N.

In order to provide more specific advice, the Commission needs to clarify, and ideally quantify, what is meant by *mostly north of 20îN*. If this can be done, indicators of the spatial distribution of candidate northern stocks, or indeed existing northern stocks, could be more objectively evaluated.

Recommendations for further research that could improve the indicators of spatial distribution of blue shark include:

- The further collection and analysis of observer data for longliners fishing in the North Pacific;
- The development of spatially-structured population models;
- The collection and analysis of electronic tagging data to estimate patterns of vertical habitat use in the North Pacific and;

- Analyses to estimate effective effort and standardised CPUE that simultaneously take into account patterns of blue shark habitat use, and the fishing depth and other characteristics of longline gear.

SC14 is invited to note the information currently available to evaluate blue shark spatial distribution in the North Pacific, and to provide relevant advice to WCPFC14 on the question of its potential designation as a northern stock.

INTRODUCTION

Blue shark (*Prionace glauca*) has a circumglobal distribution and is the most widely distributed and most abundant species of oceanic pelagic shark (Figure 1; ISC website: http://isc.fra.go.jp/working_groups/shark_blue_shark.html). Abundance is thought to increase from equatorial waters to the higher latitudes; however, there is little quantitative information to inform the scale of abundance change. They are present close to the surface in all regions, particularly at night, and at greater depths (in cooler waters and following the distribution of the deep scattering layer) in tropical and sub-tropical waters (Nakano 1994).

Life history information, in particular separate breeding grounds in both the North and South Pacific, has led to a generally accepted assumption that blue shark comprises two separate stocks for assessment and management purposes in the Pacific Ocean, separated at the Equator. Genetic analysis of blue shark in the North Pacific indicates little genetic structuring in this region, supporting the current practice of treating blue shark as a single stock in the North Pacific (King *et al*. 2015).

Since 2014, and most recently in 2017, the Western and Central Pacific Fisheries Commission (WCPFC) has requested the Scientific Committee (SC) to provide advice as to whether blue shark in the North Pacific should be designated as a "northern stock" (paragraph 378, WCPFC14 Report). The definition of "northern stock", according to the WCPFC Convention (Art. 11, paragraph 7) and the Rules of Procedure of the Northern Committee (Paragraph 2) is that northern stocks are those stocks "which occur mostly in the area north of the 20° north parallel". There is no specific guidance given as to the definition of "mostly". There are three stocks currently recognised as "northern stocks" by WCPFC – North Pacific albacore, North Pacific swordfish and Pacific bluefin. Longline catch and CPUE plots (averaged over 2013-2017) are shown in Figure 2. These plots might serve as a useful reference for interpreting "mostly".

The approach taken in this paper is to compile information that might provide a useful indication of blue shark distribution in the North Pacific. Three categories of information have been compiled – life history information, catch and CPUE distributions from various fisheries and tagging information. These are discussed in the next section of the paper below.

2. INDICATORS OF SPATIAL DISTRIBUTION

Life-history information

Blue shark are distributed throughout the North Pacific Ocean, from the Equator to at least 57°N (Nakano and Seki 2003). They are reported to have an ambient temperature preference of around 12-20°C (ISC website: http://isc.fra.go.jp/working_groups/shark_blue_shark.html); however electronic tagging data indicate a range in the Pacific from 10.8°C to 29.8C across a wide depth range, with 20% of time during the day occupying waters cooler than 12°C (H. Dewar, *pers. comm.*). As with many other large pelagics, blue sharks move closer to the surface during the night and to greater depths during the day, likely foraging on squid and other species in the deep scattering layer (Heard *et al.* 2017). They are generally found near the surface in temperate waters around 40°N, but over a wide depth range elsewhere. Figure 3 shows the depth distribution of the 12°C and 20°C isotherms by latitude at 150°E and 150°W in the North Pacific to give an approximate indication of their potential depth distribution.

Blue sharks are viviparous, with an average litter size of around 26 pups per pregnancy (Nakano 1994; Fujinami *et al.* 2017). Based on the size composition of embryos, Nakano (1994) concluded that blue sharks mate in the area 20-30°N in the northern summer. After mating, females migrate northwards, giving birth in the following year between 30-40°N. The gestation period has been estimated to be 11 months and females can reproduce annually (Fujinami *et al.* 2017). The distribution of pregnant blue sharks obtained from Japanese research surveys shows a wide distribution spanning north and south of 20°N (Figure 4, Nakano 1994), with observations of sharks that were still in, or to the south of the breeding grounds, as well as those that had undergone their northwards migration at the time of sampling.

Nakano (1994) proposed a schematic migration model for blue shark based on CPUE by size and sex obtained from Japanese research cruises in the North Pacific (Figure 5). To quote Nakano (1994):

"Parturition occurs in early summer on the nursery ground located at 30-40°N. Age 2 to 5 year old females generally move northward, while 2 to 4 year old males generally move southward. Adults mainly occur from equatorial water to the south of the nursey area at 40°N. Mating occurs in early summer at the 20° to 30°N area, and pregnant females migrate to parturition grounds by the summer. The reason for sexual segregation of sub adult sharks is thought to be an adaptation for sub adult females to avoid danger associated with male mating behaviour (biting at females). Separation of the nursery ground from the adults habitat avoids predation on pups by adult sharks. Also, it is reasonable that the parturition and nursery grounds are located in the subarctic boundary where there is a large prey biomass for young sharks."

Based on the above, it appears that the area south of 20°N is an important part of the blue shark distribution in the North Pacific, particularly for adults. Furthermore, the area may be part of the breeding ground, and/or post-breeding area for pregnant females. The area north of 20°N is important for parturition and as a nursery ground, with high abundance of both adults and juveniles.

Catch and Catch-per-unit-effort data

Blue shark are caught in the North Pacific by both target fisheries and as bycatch in tuna and swordfish longline fisheries. Historically, catches have not been consistently reported by many fishing fleets, and catch history has been estimated by the ISC Shark Working Group based on the application of a variety of statistical methods, including more recently the use of observer data.

The highest catches are typically made by longliners targeting blue shark or other shark species (e.g. parts of the Japanese and Chinese Taipei fleets at certain times of the year) and by longliners targeting swordfish that set their gear relatively shallow (e.g. parts of the Japan coastal and offshore longline fleet, Chinese Taipei small-scale tuna longline fleet and the Hawaii shallow-set swordfish longline fleet). These fleets, which fish mostly north of 20°N, have relatively high CPUE because, apart from any possible effects of higher abundance and aggregation, shallow setting at these latitudes results in most hooks fishing in the depth range likely to be utilised by blue shark. Most of these fisheries also soak their gear predominantly at night, when blue sharks tend to occupy shallower depths.

Lower catches and CPUEs for blue shark are recorded by longliners targeting tuna. These vessels generally set their gear deeper and fish mainly during the day. Fishing effort, while higher in the tropical Pacific south of 20°N, also occurs for some fleets (Japan, Chinese Taipei and US) in sub-tropical waters north of 20°N.

The distribution of reported retained North Pacific blue shark longline catch for 2014-2017, based on data provided by fishing nations to WCPFC, is shown in Figure 6. Reported catch is strongly concentrated in the area north of 20°N.

The spatial distribution of longline CPUE needs to be interpreted with some care, because of the interaction of blue shark vertical habitat utilisation and the fishing depths of various longline fisheries. We have considered several different published data sets, in order to obtain an indication of relative abundance of blue shark north and south of 20°N. Commercial fisheries either targeting blue shark or conducting shallow sets targeting swordfish have been excluded from consideration, because while these fisheries generally record high blue shark CPUE, they occur only north of 20°N and therefore cannot be used as a basis for comparing relative abundance north and south of 20°N.

Japan Research Longline Data

Nakano (1994) published a voluminous amount of data from Japanese research cruises in his seminal blue shark publication, including CPUE by various size classes throughout the North Pacific. A summary of these data, which originate from shark and tuna research longline cruises, is shown in Figure 7. These research cruises (targeting both tuna and shark) generally used a common gear configuration of 5-7 hooks between floats, therefore fishing at relatively shallow depths (Nakano, pers. comm.). Blue shark CPUE is substantially higher north of 20°N than to the south of 20°N, which may at least partly have resulted from better catching efficiency of shallow longline gear in areas where blue shark vertical distribution is relatively shallow, in particular 35-40°N. Nevertheless, it is apparent even from these data that blue shark still occur in considerable numbers between 20°N and the Equator.

Chinese Taipei Large-Scale Tuna Longline Fishery

Blue shark CPUE from this fishery was reported in Tsai and Liu (2016). The data reported in this paper are particularly useful because:

- The distribution of fishing covers both the areas north and south of 20°N (Figure 8);
- Blue shark catches are based on observer records, and should therefore represent full and accurate reporting; and
- The analysis of blue shark CPUE includes standardisation for the number of hooks per basket as a categorical variable (HPB$\leq$15 and HPB>15) in both the binomial and lognormal parts of the model.

The CPUE standardisation also includes area as a categorical variable. Unfortunately, the areas chosen are north and south of 25°N and so do not match exactly our areas of interest. However, the distribution of nominal CPUE (Figure 8) suggests that this slight mis-match should not overly bias the comparison.

Estimates of nominal and standardised CPUE for the northern and southern sub-areas are given in Table 1. The average CPUE over years is only slightly higher in the northern area (ratio of average northern to southern standardised CPUE =1.10, ratio of average nominal CPUE = 1.14), but CPUE is higher in the southern area in five of the eleven years for which comparison is possible.

Note that this work is based on a relatively small amount of observer data, covering an average of only 251 longline sets per year (range 69-407; see Table 1 of Tsai and Liu 2016). These results should therefore be re-examined as more observer data become available in the coming years.

Hawaii-based deep-set longline fishery

The Hawaii-based longline fishery targets swordfish in shallow longline sets and tuna in deep longline sets. The shallow-set fishery occurs primarily to the north of 20°N, while the deep-set fishery occurs to both the north and south of 20°N (Carvalho 2016). Therefore, the deep-set fishery is the more useful for examining the spatial distribution of blue shark CPUE.

Blue shark nominal CPUE, based on logsheet data provided to WCPFC, are similar either side of 20°N (Figure 9). The overall average CPUE north of 20°N is 1.37 fish per 1,000 hooks, and to the south of 20°N is almost identical at 1.38 fish per 1,000 hooks.

Carvalho (2016) undertook a standardised CPUE analysis of blue shark data collected by fisheries observers in the Hawaii-based longline fishery in 2002-2015. The analysis focused on estimating time-series trends in CPUE to support the 2017 stock assessment of North Pacific blue shark (ISC SHARKWG 2017). However, the structure of the analysis is suitable for spatial comparison of standardised CPUE also. Separate analyses were undertaken for the shallow-set and deep-set components of the fishery, but we focus on the deep-set component for the reasons noted above. The analysis consisted of a GLM using the delta-lognormal approach. Candidate factors considered in the analysis included year, quarter, eight spatial regions (four to the north of 20°N and four to the south of 20°N, see Carvalho 2016 Figure 1) and six bait types. Sea-surface temperature, vessel length, hooks-per-float and begin-set time were considered as continuous variables. Year-quarter and region-quarter interactions were also considered. The final model selected (based on AIC) retained year, quarter, region, bait type and both interactions in both the binomial and lognormal components of the model.

The model was used to estimate standardised blue shark CPUE in the deep-set fishery north and south of 20°N (Table 2). Over the 2000-2015 period of the analysis, CPUE was somewhat higher in the northern area (average 2.10) compared to the southern area (average 1.86) and was higher in the north in ten of the sixteen individual years considered. The ratio of average standardised CPUE in the north to the south was 1.13, very similar to value obtained for the Chinese Taipei deep-set fishery.

Tagging data

Blue shark has been the subject of both conventional and electronic tagging in the North Pacific. Sippel *et al.* (2011) summarised available conventional tagging data for both blue and shortfin mako sharks, concluding, "the maximum range of movements suggests at least northern and southern sub-populations of both species, demarked by the equator". Figure 10 indicates substantial north-south and east-west movements of blue shark, with a substantial number of movements crossing the 20°N line.

Most electronically tagged blue sharks in the Pacific have been tagged close to the west coast of the United States and Mexico and mostly north of 20°N (Figure 11). However many tracks show that both males and females spent considerable time south of 20°N over the tracking duration, and more generally indicate that blue sharks are capable of utilising the entire North Pacific, from close to the Equator to at least 50°N.

3. Conclusions

The available life history, fishery and tagging information on blue shark distribution indicate that they may occupy, at various times, most areas of the North Pacific, from the Equator north. It is clear from the well-studied reproductive biology that tropical waters are an important part of the breeding area, with many observations of females in the early stages of pregnancy in particular occurring in these waters (Figure 4).

Despite their wide distribution, the reported catch of blue shark is dominated by shallow-set fisheries targeting swordfish and/or blue shark in waters north of 20°N (Figure 6). However, this catch distribution is unlikely to accurately represent the relative distribution of blue shark north and south of 20°N. This is because blue shark are likely more susceptible to capture by the shallow-set longline gear that occurs mainly in the north, than to the tuna-targeting, deep-set longline gear occurring mainly in the tropics, because of different overlap of longline fishing depth and blue shark vertical habitat use in these areas.

Nominal CPUE from Japanese research cruises (using a common gear configuration of 5-7 hooks between floats) with wide coverage of the blue shark distribution indicates that blue shark CPUE is substantially higher north of 20°N than to the south of 20°N. However, nominal and standardised CPUE distributions from deep-set Chinese Taipei and Hawaii-based longliners show a consistent pattern of only slightly higher CPUE north of 20°N compared to the area south of 20°N. While GLMs used to analyse both sets of data considered longline gear configuration, it should be acknowledged that standardised CPUE from these fisheries, and nominal CPUE from Japanese research cruises, might not accurately represent relative abundance because of the different depth distributions that blue shark occupy in the northern temperate and southern tropical regions of the North Pacific.

The question: *do blue shark occur mostly north of 20ȋN?* – is difficult to answer scientifically because of the qualitative nature of the question. It is clear that a biologically significant parts of the distribution occur both north (parturition, nursery, feeding) and south (mating, post-mating) of 20°N, but the information available to quantify it is imperfect. On the basis of nominal CPUE spatial comparisons for those stocks already designated as northern stocks (Figure 2), we would judge that blue shark has a tropical component at 0-20°N at least as significant as the already-designated northern stocks. Some specific comparisons of swordfish, albacore and blue shark in the Hawaii-based deep-set longline fishery show similar ratios of nominal CPUE north and south of 20°N for all three species (Table 3, Figure 9 and Figure 12). This indicates that, at least in the area of this fishery, swordfish, albacore and blue shark all have significant parts of their distributions south of 20°N.

In order to provide more specific advice, the Commission needs to clarify, and ideally quantify, what is meant by *mostly north of 20îN*. If this can be done, indicators of the spatial distribution of candidate northern stocks, or indeed existing northern stocks, could be more objectively evaluated.

This analysis could be improved by additional research, most importantly:

Possible in the short-medium term

1. The collection and analysis of data on blue shark catches and associated data by observers on longliners fishing in all areas of the Pacific north of the Equator, would provide a better understanding of the size- and sex-specific spatial distribution of blue sharks in the North Pacific Ocean in relation to 20°N latitude;
2. The development of a spatially structured population model for North Pacific blue shark, with an area boundary at 20°N, would assist by providing explicit estimates of population abundance by area. This could be a variant of the current Stock Synthesis assessment model;

Possible in the longer term

3. The collection and analysis of electronic tagging data to estimate spatial patterns of vertical habitat use in the North Pacific;
4. Other more spatially flexible models, such as SEAPODYM, could be used to capture more explicitly aspects of blue shark biology and how that interacts with the environment to determine spatial distribution. This would offer the added insight of variability in distribution over time in response to environmental variability; and
5. Given the likely interaction of blue shark habitat use, its spatial variability and longline fishing depth and other factors in determining observed CPUE in longline fisheries, it might be useful to develop estimates of effective effort and standardised CPUE that take these factors simultaneously into account. The habitat-based model described by Bigelow *et al.* (2002) could be a useful starting point for such an analysis. The CPUE estimates so obtained could then be used as stand-alone information, or as the basis of abundance indices for population models such as described in 2 and 4 above.

4. Acknowledgements

I am grateful to Mikihiko Kai, Chair of the ISC Shark Working Group, Keith Bigelow, Felipe Carvalho, Eric Chang, Heidi Dewar, Kwang-Ming Liu and Hideki Nakano for valuable comments and advice on the preparation of this paper.

5. References

Bigelow, K.A., J. Hampton and N. Miyabe. 2002. Application of a habitat-based model to estimated effective longline fishing effort and relative abundance of Pacific bigeye tuna (*Thunnus obesus*). *Fish. Oceanogr.* 11: 143-155.

Carvalho, F. 2016. Standardized CPUE for blue shark (*Prionace glauca*) caught by the longline fisheries based in Hawaii (1995-2015). Working document submitted to the ISC Shark

Working Group Workshop, 14-21 November 2016, Busan, Korea. ISC/16/SHARKWG-1/16. http://isc.fra.go.jp/pdf/SHARK/ISC16_SHARK_1/ISC2016-SHARKWG-1-16_Carvalho_HI_LL_CPUE.pdf

Fujinami, Y., Y. Semba, H. Okamoto, S. Ohshimo and S. Tanaka. 2017. Reproductive biology of blue shark (*Prionace glauca*) in the western North Pacific Ocean. *Mar. Freshw. Res.* 68: 2018-2027.

Heard, M., P.J. Rogers, B.D. Bruce, N.E. Humphries and C. Huveneers. 2017. Plasticity in the diel vertical movement of two pelagic predators (*Prionace glauca* and *Alopias vulpinus*) in the southeastern Iandian Ocean. *Fish. Oceanogr*. 2017:1-13.

ISC SHARKWG. 2017. Stock assessment and future projections of blue shark in the North Pacific Ocean through 2015. WCPFC-SC13-2017/SA-WP-10. https://www.wcpfc.int/system/files/SC13-SA-WP-10%20Stock%20Assessment%20and%20Projections%20Blue%20Shark.pdf

King, J.R., M. Wetklo, J. Supernault, M. Taguchi, K. Yokawa, O. Sosa-Nishizaki and R.E. Withler. 2015. Genetic analysis of stock structure of blue shark (*Prionace glauca*) in the North Pacific Ocean. *Fish. Res.* 172: 181-189.

Nakano, H. 1994. Age, reproduction and migration of blue shark in the North Pacific Ocean. *Bull. Nat. Res. Inst. Far Seas Fish.* 31: 141-256.

Nakano, H. and M. Seki. 2003. Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus. *Bull. Fish. Res. Agen.* 6: 18-55.

Sippel, T., J. Wraith, S. Kohin, V. Taylor, J. Holdsworth, M. Taguchi, H. Matsunaga and K. Yokawa. 2011. A summary of blue shark (*Prionace glauca*) and shortfin mako shark (*Isurus oxyrinchus*) tagging data available from the North and Southwest Pacific Ocean. Working document submitted to the ISC Shark Working Group Workshop, 28 November – 3 December 2011, NOAA Southwest Fisheries Science Center, La Jolla, California, USA. ISC/11/SHARKWG-2/04. http://isc.fra.go.jp/pdf/SHARK/ISC11_SHARK_2/04-Sippel_et_al._conventional_tagging.pdf

Tsai, W-P and K-M Liu. 2016. Catch estimate and CPUE standardization of the blue shark based on observers' records of Taiwanese large-scale tuna longline fisheries in the North Pacific Ocean. Working document submitted to the ISC Shark Working Group Workshop, 14-21 November 2016, Busan, Korea. ISC/16/SHARKWG-1/22. http://isc.fra.go.jp/pdf/SHARK/ISC16_SHARK_1/ISC2016-SHARKWG-1-22-Tsai_Taiwanese_LTLL_catch_and_cpue.pdf

Table 1. Nominal and standardised CPUE by the Chinese Taipei large-scale tuna longline fleet for northern and southern areas of the North Pacific Ocean (after Tsai and Liu 2016).

Year	Area A – North of 25°N		Area B – South of 25°N	
	Nominal CPUE	Standardised CPUE	Nominal CPUE	Standardised CPUE
2004	0.0038	0.0054	0.3523	0.3017
2005	0.9523	0.8433	0.8945	1.1268
2006	0.5932	0.4906	0.6337	0.5095
2007	0.4815	0.4327	0.1657	0.1602
2008	0.5918	0.4955	0.4359	0.3617
2009	0.4698	0.4102	0.0987	0.0966
2010			0.7776	0.5076
2011	0.6838	0.6813	0.5867	0.5451
2012	0.0438	0.0475	0.8155	0.7262
2013	0.3912	0.3309	1.2570	1.0740
2014	0.4977	0.4346	0.3527	0.3969
2015	2.7198	2.3137	0.7567	0.6001
Average	**0.6753**	**0.5896**	**0.5939**	**0.5339**

Table 2. Estimates of standardised CPUE for blue shark in the Hawaii-based deep-set longline fishery, based on the model of Carvalho (2016).

Year	Standardised CPUE	
	North of 20°N	South of 20°N
2000	3.83	3.64
2001	3.76	1.67
2002	3.86	1.54
2003	2.67	2.10
2004	2.50	2.13
2005	1.92	1.98
2006	1.61	1.25
2007	1.73	1.44
2008	1.21	1.15
2009	1.04	1.62
2010	1.14	2.72
2011	1.48	1.45
2012	1.46	1.50
2013	1.75	1.85
2014	1.97	1.78
2015	1.69	1.87
Average	**2.10**	**1.86**

Table 3. Nominal CPUE of blue shark, swordfish and albacore in the Hawaii-based deep-set longline fishery. Source: logsheet data 2007-2017 submitted to WCPFC. CPUE is total reported catch divided by total reported effort in the two areas.

Area	Blue shark CPUE (no per 1,000 hooks)	Swordfish CPUE (no per 1,000 hooks)	Albacore (no per 1,000 hooks)
North of 20°N	1.37	0.097	0.303
South of 20°N	1.38	0.087	0.477

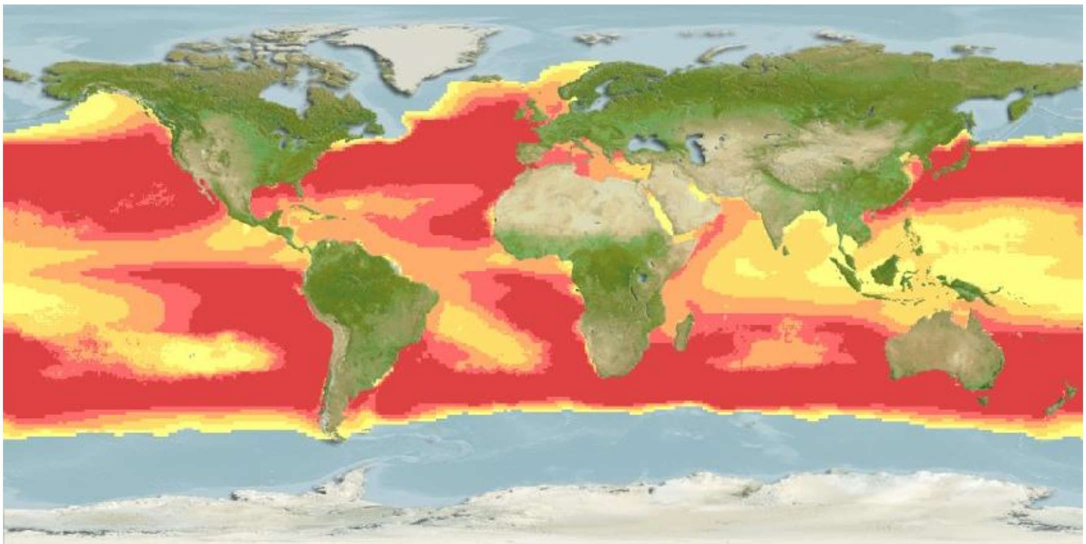
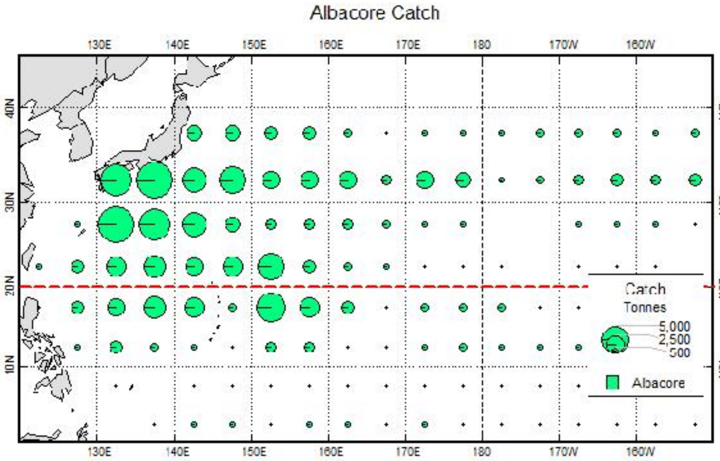


Figure 1. Global distribution of blue shark habitat (from https://www.aquamaps.org/).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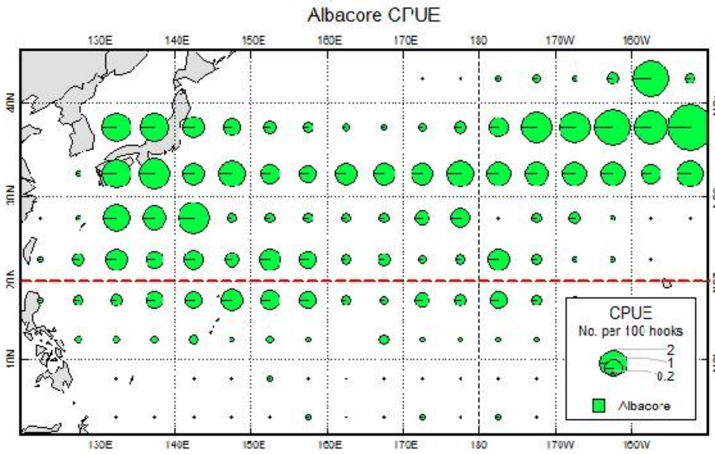
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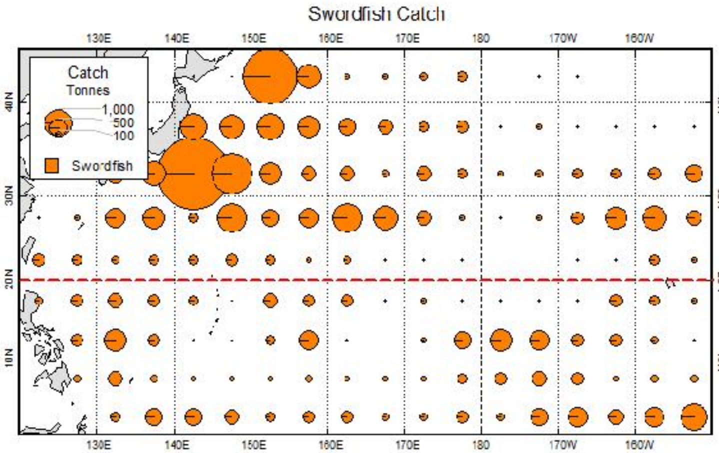
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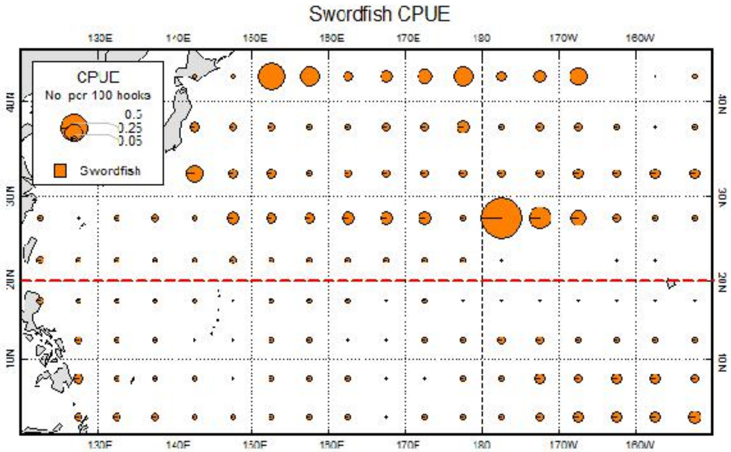
Swordfish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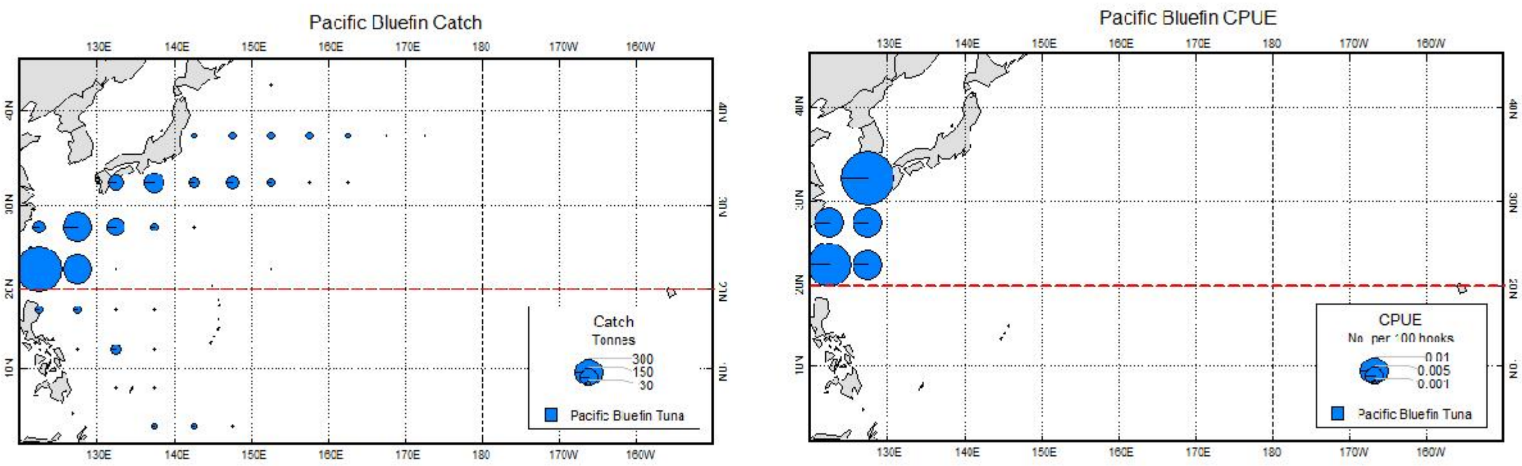


Figure 2. Catch and CPUE distributions (2013-2017) for currently designated northern stocks (source: 5-degree square aggregated data submitted to WCPFC by CCMs).

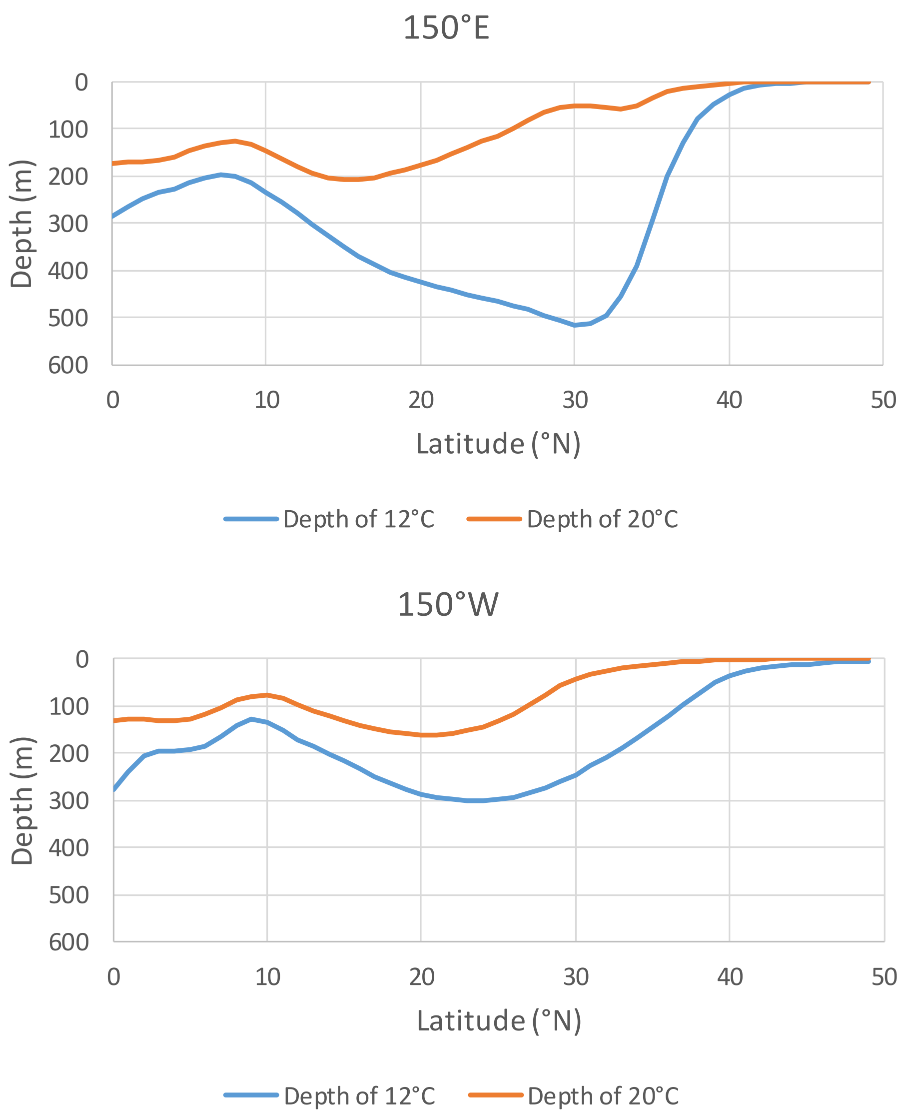


Figure 3. Average (1980-2017) depth of the 12îC and 20îC isotherms in the North Pacific Ocean by latitude, compiled for two transects at 150îE and 150îW. Source: GODAS data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/. Temperature-at-depth data were transformed to isotherms by depth using linear interpolation.

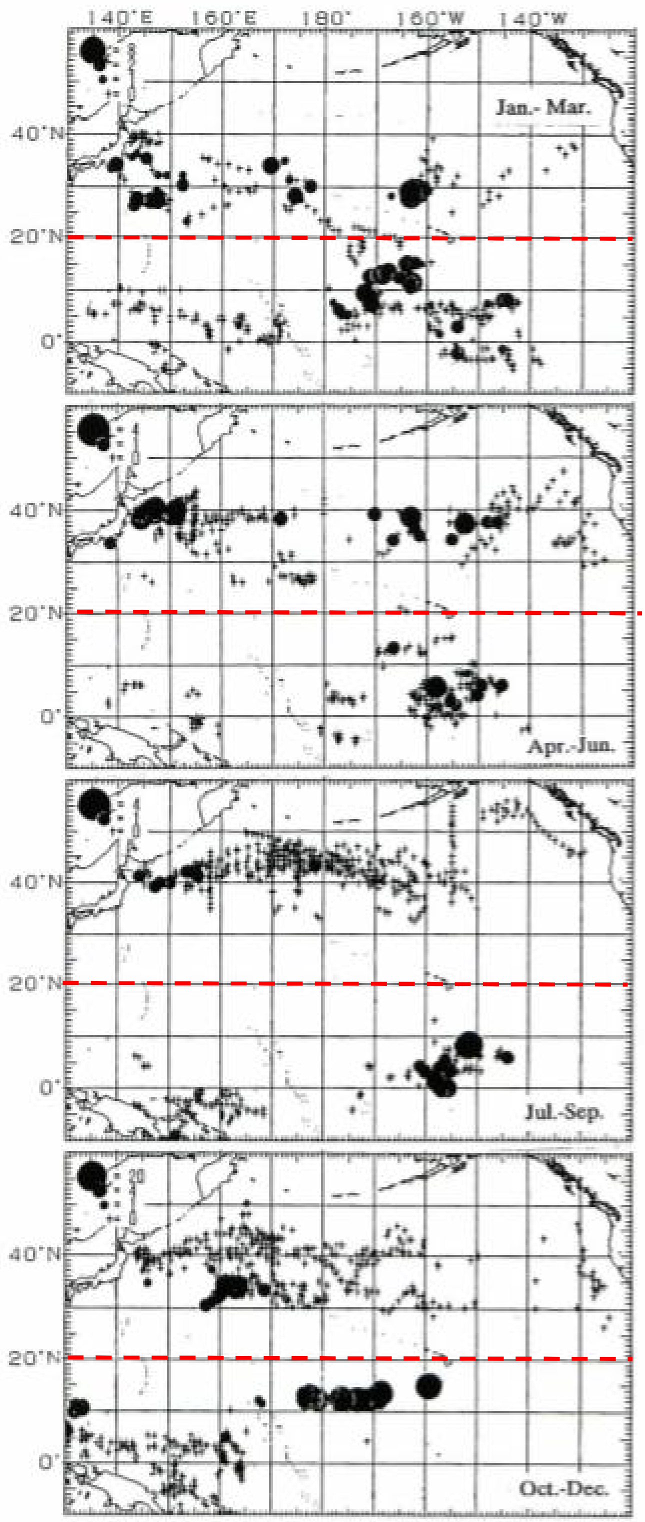


Figure 4. The quarterly distribution of pregnant blue sharks from Japanese research surveys (after Nakano 1994, Fig. 5-13, p. 209). Red dashed line at 20îN added.

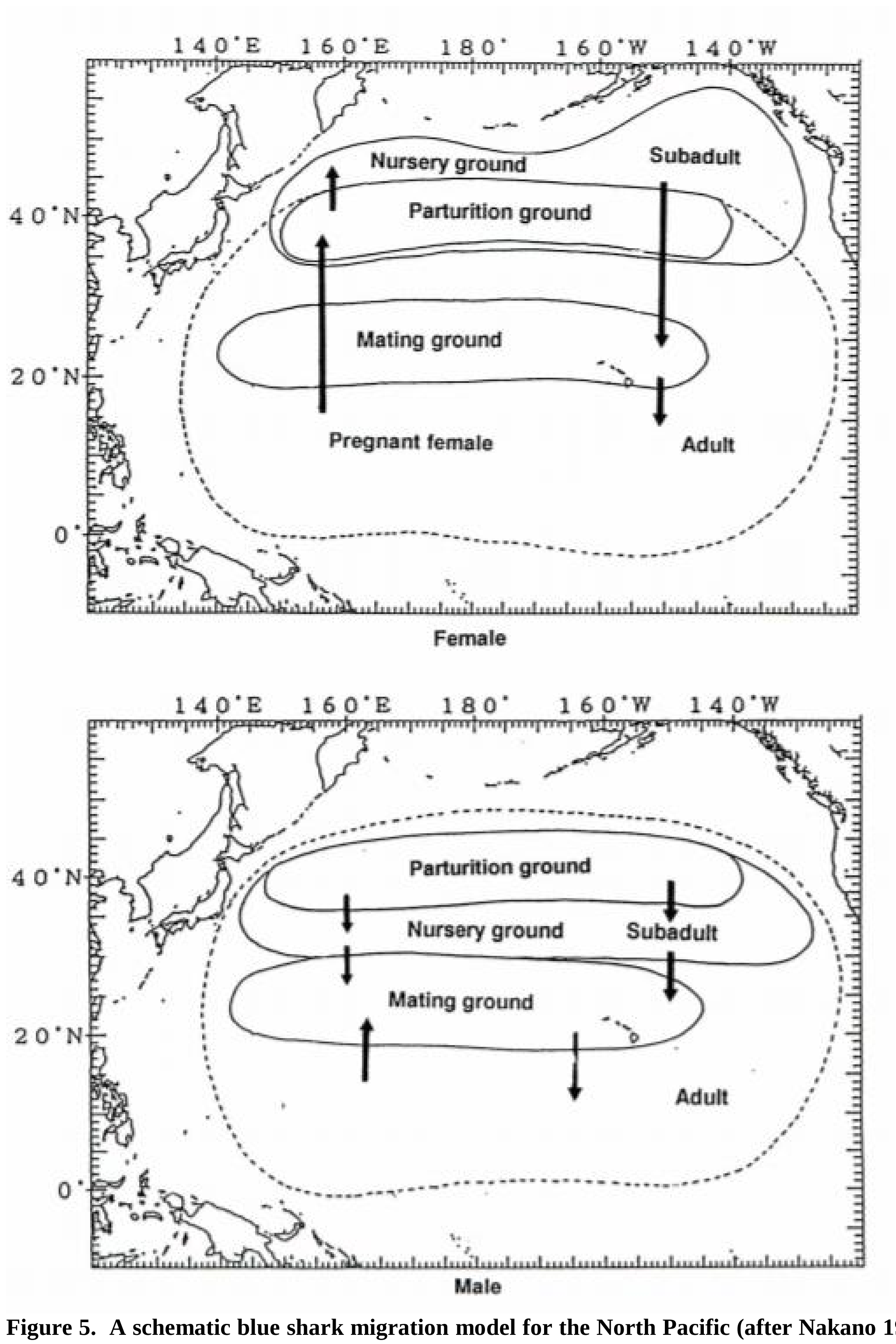


Figure 5. A schematic blue shark migration model for the North Pacific (after Nakano 1994, Fig. 5-14, p. 211).

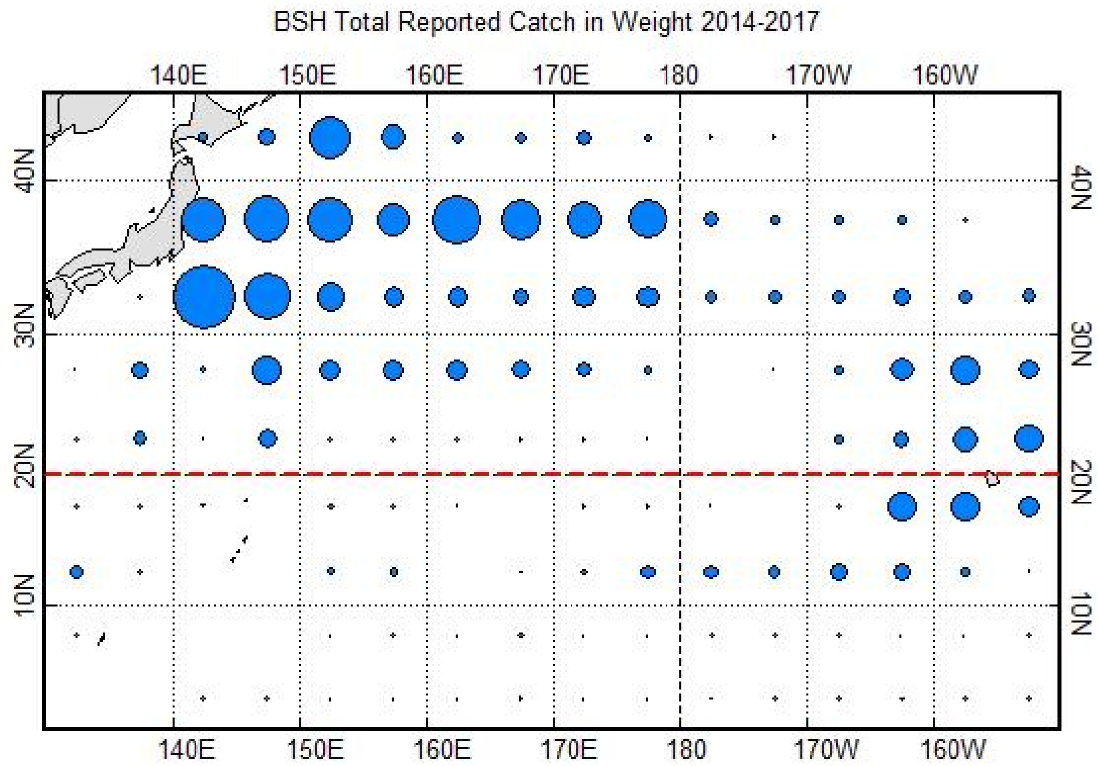


Figure 6. Blue shark longline retained catch for 2014-2017, based on data submitted to WCPFC. The maximum circle size represents are catch of 7,135 tonnes over the 2014-2017 period.

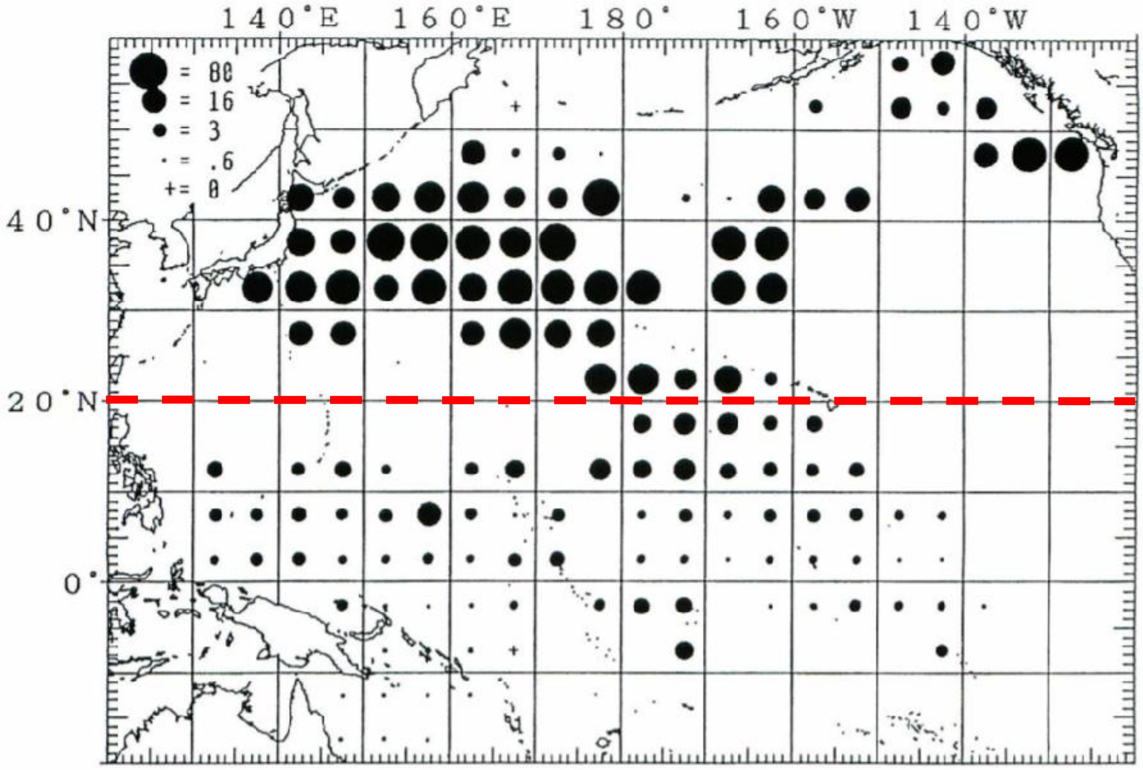


Figure 7. Overall distribution of blue shark CPUE (catch in numbers / 1000 hooks) caught by shark and tuna longline research vessels combined, by 5-degree area (after Nakano 1994, Fig. 1-9, p. 160). Red dashed line at 20îN added.

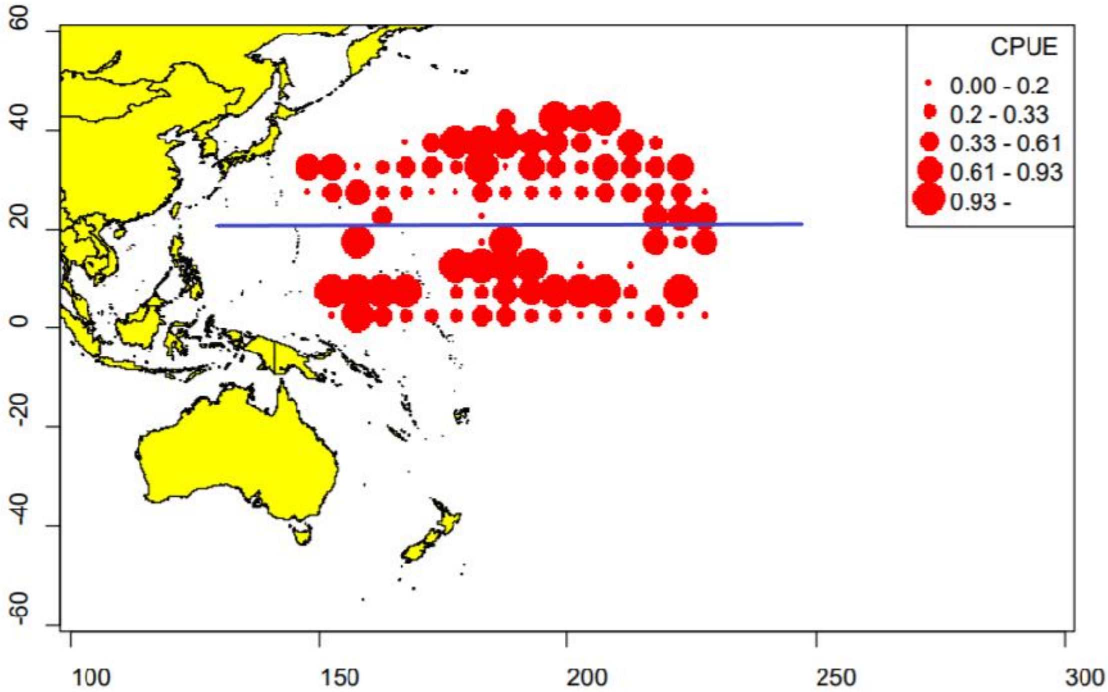


Figure 8. Distribution of blue shark nominal CPUE from Chinese Taipei large-scale longliners, 2004-2015 (after Tsai and Liu 2016). The blue line at 20îN has been added to the original figure.

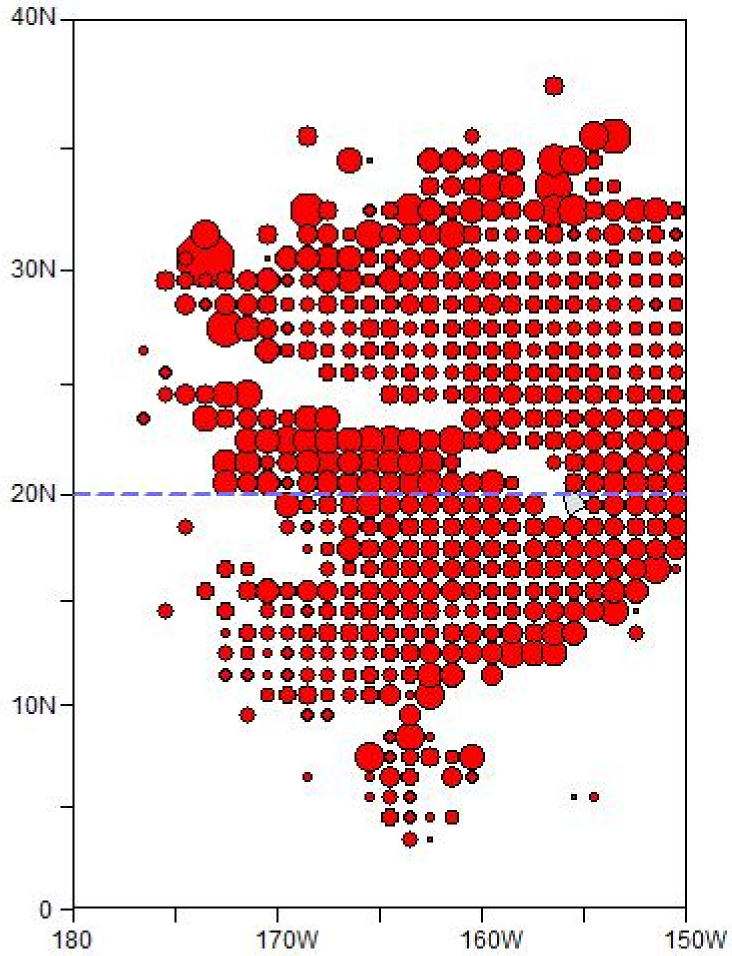


Figure 9. Blue shark nominal CPUE for the Hawaii-based tuna-targeting deep-set longline fishery. Source: logsheet data 2007-2017 submitted to WCPFC. The maximum circle size shown represents a CPUE of 10.3 blue shark per 1,000 hooks.

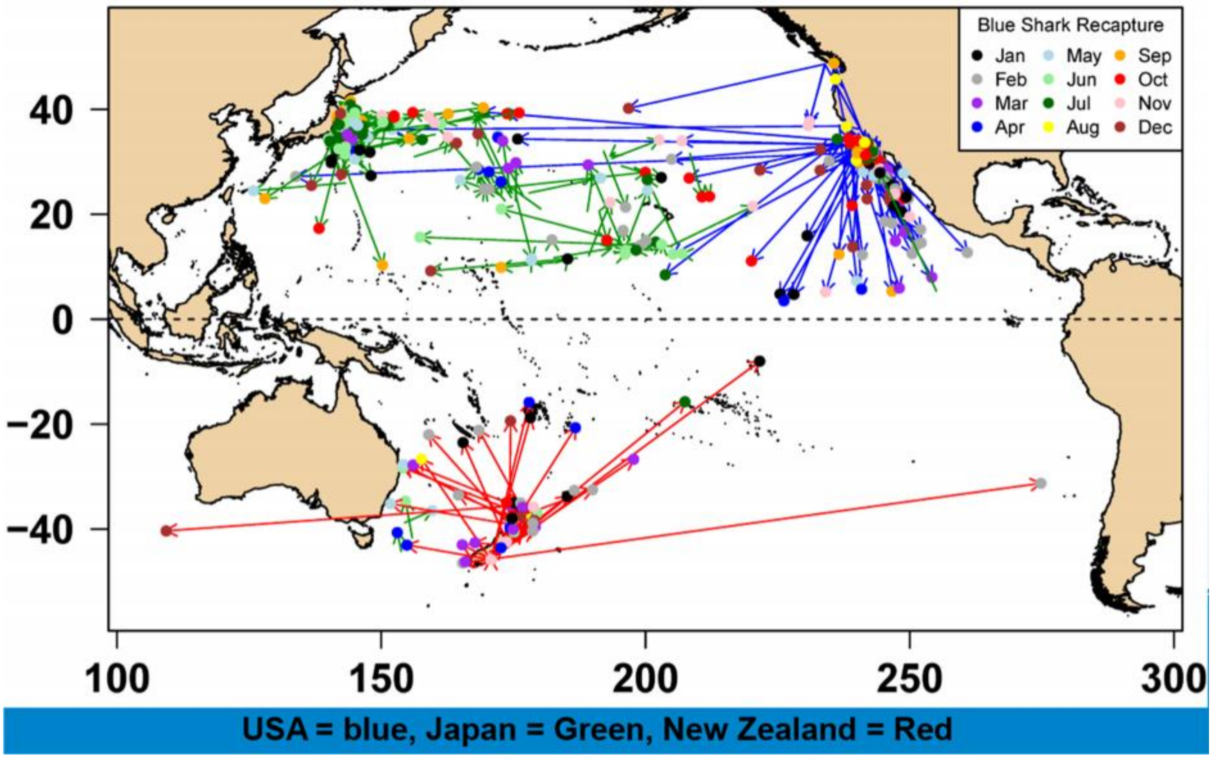
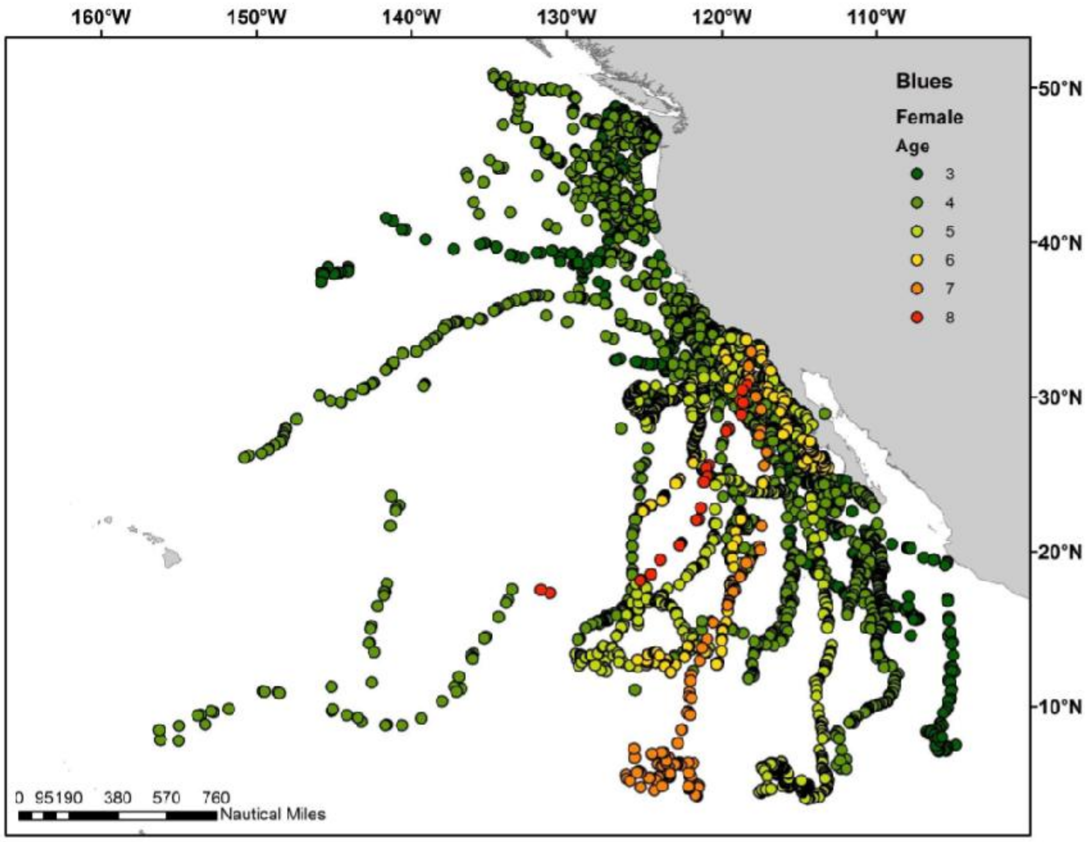


Figure 10. Blue shark tag recaptures. Blue lines are from NOAA - Southwest Fisheries Science Center databases, green lines are from Japanese National Research Institute of Far Seas Fisheries databases, red lines are from the New Zealand Ministry of Fisheries database. Recapture months are depicted by coloured circles. After Sippel *et al*. (2011), Figure 1.



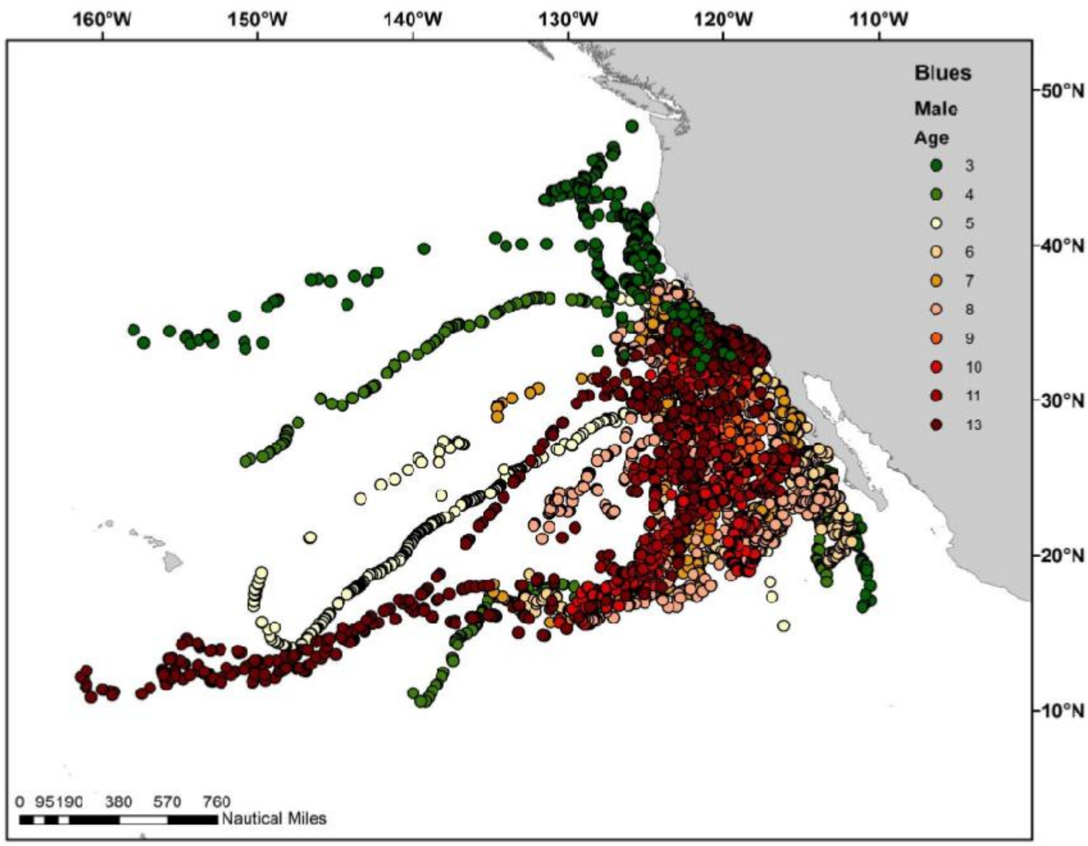


Figure 11. Popup-archival tag tracks of blue shark females (top) and males (bottom). Figures kindly provided by Dr Heidi Dewar, NOAA Southwest Fisheries Science Center, La Jolla.

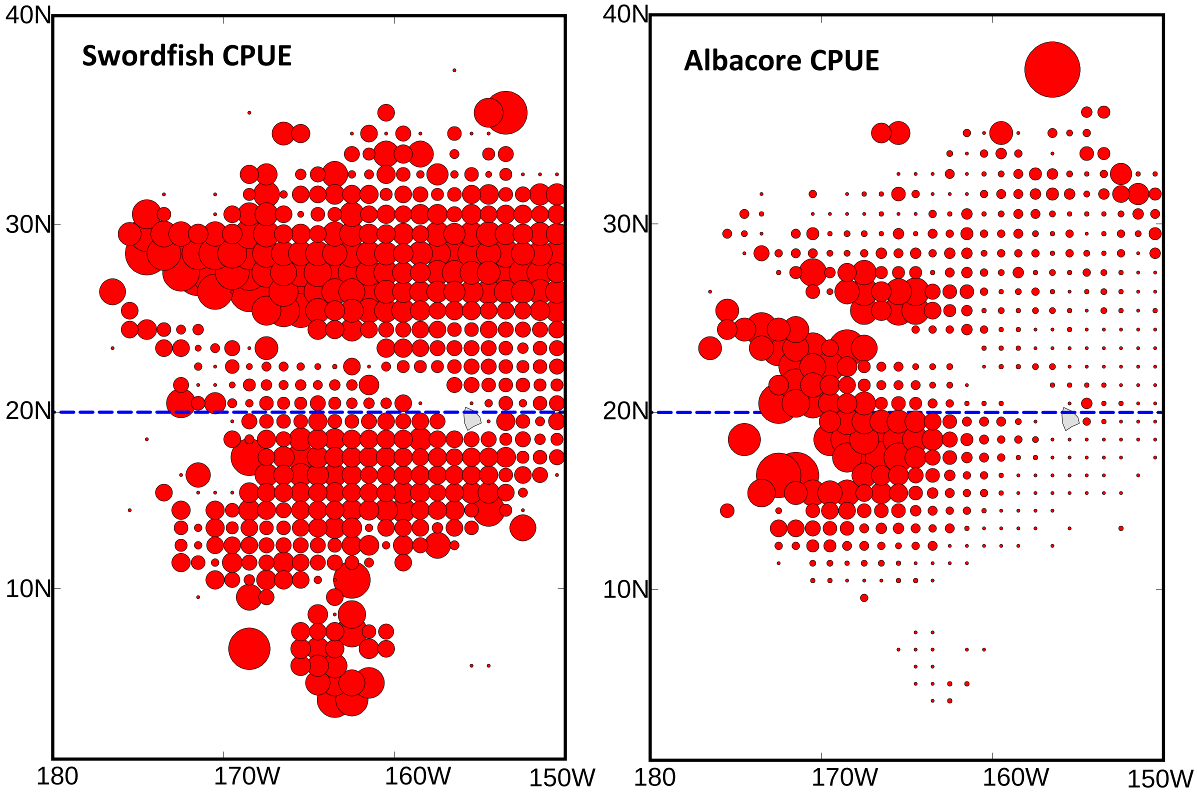


Figure 12. Swordfish and albacore nominal CPUE for the Hawaii-based tuna-targeting deep-set longline fishery. Source: logsheet data 2007-2017 submitted to WCPFC. The dashed line is at 20îN. The maximum circle size for swordfish represents a CPUE of 0.6 fish per 1,000 hooks, and for albacore 9.9 fish per 1,000 hooks.