SCIENTIFIC COMMITTEE
FIFTH REGULAR SESSION

10-21 August 2009
Port Vila, Vanuatu

An Alternative Estimate of Catches of Five Species of Sharks in the Western and Central Pacific Ocean based on Shark Fin Trade Data

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WCPFC-SC5-2005/EB-WP-02

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Abstract

Conservation and Management Measure 2008-06 was implemented by the Western and Central Pacific Fisheries Commission in February 2009 and requires the Commission to work toward providing preliminary advice on the stock status of key shark species in 2010. While the need for shark assessments is thus well-recognised, catch data necessary to support such assessments is, in many cases, insufficient. Therefore, methods of assessing species for which no adequate historical catch time series exists should be explored. A method applied to the Atlantic Ocean by ICCAT, and presented here for the Western and Central Pacific Ocean, provides minimum estimates of shark removals using shark fin trade data. Because these estimates capture only a portion of the potential shark mortality, i.e. only those sharks' whose fins are traded, the value of these estimates lies mainly in comparison to other WCPO records of total shark mortality in order to identify potential under-reporting. There is reasonable agreement between SPC catch-based estimates and the trade-based estimates during the period of 1998-2000 but after that time the median trade-based estimates are up to two to three times higher than the catch-based estimates. This result is similar to the result of a catch-based versus trade-based comparison for blue shark at ICCAT. Given that there are important uncertainties in both catch-based and trade-based estimates which cannot be resolved on the basis of existing data, further study of these and other methods is strongly encouraged.

1 Introduction

Although sharks are some of the most commonly caught species in pelagic tuna longline and purse seine fisheries, the quantity and quality of historical shark catch data are often poor (Camhi et al. 2008) This is because sharks have long been considered non-target species and as such are often inaccurately recorded in vessel logbooks. A surge in the shark fin trade in the 1990s, and publicity surrounding the practice of shark finning (i.e. retention of fins while discarding the carcasses at sea), have heightened concerns regarding the potential for over-exploitation of shark species and led to a number of initiatives to improve data collection (Clarke et al. 2007). Since 2001, some countries have committed to improve data collection and to assess and manage sharks and fisheries catching sharks under their jurisdiction in response to the Food and Agriculture Organization's (FAO) International Plan of Action-Sharks by implementing National Plans of Action-Sharks (FAO 1999). On the high seas, Regional Fisheries Management Organizations (RFMOs), beginning with ICCAT in 2004, have agreed a number of conservation and management measures (CMMs) for sharks, most of which were driven by a desire to curb shark finning, but which also confirm the need for further shark data collection and assessment.

In the Western and Central Pacific Ocean (WCPO), a CMM for sharks (CMM 2006-05) was agreed by the Western and Central Pacific Fisheries Commission (WCPFC) in December 2006 and implemented in February 2007. This measure prohibited vessels from retaining shark fins which in total weigh more than 5% of the weight of the shark carcasses on board and called for reporting of shark catches of key species in annual reports to the Commission. This CMM was replaced by CMM 2008-06 in February 2009 which, *inter alia*, defines the key shark species as blue, oceanic whitetip, mako and thresher sharks. The new WCPFC shark CMM also requires the Commission to work toward providing preliminary advice on the stock status of key shark species in 2010.

While the need for shark assessments is thus well-recognised, both in the WCPFC and in other RFMOs, the data necessary to support such assessments is, in many cases, insufficient. As a result, only two RFMOs have produced shark assessments for public review: the ICCAT blue and shortfin mako assessments in 2004 and 2008 (ICCAT 2005, 2008) and a blue shark assessment for the North Pacific conducted under the auspices of the International Scientific Committee (Kleiber et al. 2009). In the case of the 2008 ICCAT assessment, despite strong caveats on the results of the 2004 ICCAT shark stock assessment (ICCAT 2005) and calls for improvements to shark catch data inter-sessionally, substantial progress was not realized prior to the re-assessment (ICCAT 2007). For this reason, alternative methods for estimating or cross-checking shark catches, as well as risk assessment approaches were encouraged for the ICCAT 2008 assessment. For this assessment it was agreed that the higher of the annual values from two alternative methods (i.e. extrapolation using ratios of tuna to shark catches, or estimates based on recent studies of the shark fin trade) would form the base modelling scenario. Discrepancies between annual values from the two series were conspicuous from the mid 1990s onward with greatly increased values for blue shark and slightly increased values for shortfin mako shark based on fin trade data (ICCAT 2008).

The WCPFC faces issues with under-reporting and non species-specific reporting similar to those of ICCAT, and thus must also explore ways of assessing species for which no adequate historical catch time series exists. This study adapts and applies the methodology used by the ICCAT 2008 shark stock assessment working group to produce estimates of the number of sharks from the WCPO utilised in the shark fin trade. These estimates are not intended as direct substitutes for species-specific catch time series, primarily because they capture only a portion of the potential shark mortality, i.e. only those sharks' whose fins are traded. Under these circumstances, figures produced by this study should be considered minimum estimates of shark mortality in the WCPO. The value of these estimates lies in a potential comparison to other WCPO records of total shark mortality. Specifically, these estimates may provide an indication of the extent of under-reporting and/or can be used to gauge the credibility of other alternative catch estimation methods.

2 Materials and Methods

2.1 Data Sources

The algorithm used here for estimating the sharks represented in historical shark fin trade data from the WCPF Convention Area is based on Clarke (2008). The algorithm consists of four data components, each of which is discussed separately below:

1. Estimates, by species, of the number and biomass of sharks used in the global shark fin trade in 2000 (the "anchor point" estimates);

2. A standardized estimate of the quantity of shark fins imported to Hong Kong for each year of interest before and after 2000;

3. An estimate of the Hong Kong market share, relative to the global market, for each year of interest before and after 2000;

4. Estimates of the proportion of the global total of shark fins that are derived from the WCPO.

Only the fourth data component differs from that used in Clarke (2008).

2.1.1 Data Source 1

The "anchor point" estimates of the number and biomass of sharks used in the global shark fin trade are taken from Clarke et al. (2006a). That study used matches of Chinese trade names and taxa from market sampling and genetic testing (Clarke et al. 2006b), in combination with 18 months of Hong Kong auction records to impute missing data and produce an annual estimate of traded fin weights by species and fin size category. These fin weights were then converted to number of sharks and biomass using a series of conversion factors. For each species, three independent estimates based on dorsal, pectoral and caudal fins, respectively, were produced and extrapolated using trade data to represent the global market. A composite estimate for all fin types was then produced using a mixture distribution computed with the density function for each fin position weighted proportional to its precision. Since a Bayesian modelling framework was applied, the results were presented as probability intervals.

Of the eleven categories of species, or groups of species, presented in that study, this analysis uses the results for blue (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), thresher (*Alopias* spp.), oceanic whitetip (*Carcharhinus longimanus*) and silky (*Carcharhinus falciformis*) sharks, which are among the key species identified in CMM 2008-06. These estimates are based on the shark fin trade as of 2000 when Hong Kong imported 6788 t of fins and was estimated to control 44-59% of the global market (Clarke 2004a, Clarke et al. 2006a) An excerpt of the relevant species-specific anchor point estimates from Clarke et al. (2006a) is provided in Table 1.

2.1.2 Data Source 2

Standardized estimates of the quantity of shark fin imported to Hong Kong in each year since 1980 were prepared from unpublished Hong Kong government records (TRAFFIC 1996; HKSARG 2008). Prior to 1998, Hong Kong recorded imports of shark fins in dried or frozen ("salted") categories without distinguishing between processed and unprocessed fins. In order to avoid double-counting fins returning to Hong Kong after processing in Mainland China, imports from the Mainland prior to 1998 were subtracted from total imports based on TRAFFIC (1996). In 1998 Hong Kong established separate customs codes for dried and frozen (i.e. listed as "salted" in commodity coding lists), processed and unprocessed fins. After 1998, only unprocessed dried and frozen fins were included in the annual totals. All frozen fin weights were normalized for water content by multiplying by 0.25 (Clarke 2004a). The adjusted annual imports of shark fin to Hong Kong are shown in Table 2.

2.1.3 Data Source 3

Hong Kong's share of the global shark fin trade was studied in detail for 1996-2000 and was calculated from empirical data to range from 44-59% (Clarke et al. 2006a). Since reliable empirical data for estimating Hong Kong's market share for years before (1980-1995) and after (2001-2007) this period are lacking, ranges of values for 1980-1990, 1991-1995 and 2001-2007 were specified based on expert judgment as described below.

There are no empirical data upon which to base an estimate of Hong Kong's share of the trade for 1980-1990. This is mainly due to the difficulty in accessing customs statistics, especially for Mainland China, in this period. Nevertheless, a general understanding of trade patterns in Hong Kong during the 1980s (Clarke et al. 2007) suggests that Hong Kong's market share was higher in 1980-1990 than during 1996-2000. The earliest accounts of the shark fin trade state that Hong Kong's share of world imports was 50% (Tanaka 1994, based on data through 1990) or 85% (Vannuccini 1999, based on 1992 data). A range of 65-80% was thus selected for the period 1980-1990.

A transitional period for the shark fin trade in Hong Kong occurred in 1991-1995 as demand began to rise appreciably in Mainland China. It is likely that Hong Kong's share began to drop, but not to the extent observed in the period 1996-2000 (i.e. 44-59%), thus a range of 50-65% was selected.

Due to several confounding factors, Hong Kong's market share for 2001-2007 is particularly difficult to specify. Previous analysis has shown that Hong Kong imports of shark fin rose at a rate of 6% per year from 1992-2000 (Clarke 2004a), but afterwards showed a nearly level, slightly declining linear trend (Clarke et al. 2007). Hong Kong shark fin traders attribute this trend to a loss of market share to Mainland China. While this explanation is supported by the well-known liberalization of the Mainland China economy just prior to and as a result of entry to the World Trade Organization in November 2001 (Ferris 2002), Mainland China's shark fin imports do not show a strong trend of increase since 2000. One reason for this lack of trend may be that in 2000 Mainland China began importing frozen shark fin under a category previously used only for frozen shark meat and therefore from 2000 onward frozen fins, which are an important trade component, are no longer distinguishable in the statistics (Clarke 2004b). Complications in trade reporting by Mainland China and their implications for assessing global trade in shark fins are discussed in detail in Clarke et al. (2007). On balance it was considered that even without strong evidence of increasing imports by Mainland China, it was likely that Hong Kong's share of global trade has declined sharply since 2000. A range of 30-50% was thus specified.

2.1.4 Data Source 4

Four methods were used for proportioning global fin trade-based catch estimates to WCPO-specific quantities. All indices were started in 1980 to conform to the availability of shark fin trade data and extended to 2007.

The first involved a simple calculation of the ocean area of the WCPO (assumed for the purposes of this analysis only to coincide with the WCPFC Statistical Area (Figure 1)), relative to the world ocean. This method assumes that each shark species is evenly distributed throughout global waters between the northern-most and southern-most extent of its range. For simplicity, the wide ranging pelagic sharks (blue, shortfin mako and thresher sharks) were considered to be distributed between 50^{o} degrees north and south latitude worldwide, while the oceanic whitetip and silky sharks were considered to be distributed between 30^{o}north and south latitude worldwide based on indicative ranges given in Compagno (1984). The area of habitat for the blue, shortfin mako and thresher sharks (50^{o} N-50^{o} S) was thus calculated as 102.60 million km^2 for the WCPO and 454.10 million km^2 for the global area for a ratio of 0.226 (Figure 2). The area of habitat for the oceanic whitetip and silky sharks (30^{o} N-30^{o} S) was calculated as 75.46 million km^2 for the WCPO and 339.70 million km^2 for the global area for a ratio of 0.222 (Figure 3). Given the assumption of even shark distribution, these ratios imply that 22.2%-22.6 % of the global shark catches occur in the WCPO, therefore these ratios can also serve as scaling factors for the global shark fin trade-based estimates.

The second method involved scaling against a ratio of tuna catches in global waters versus those in the WCPO. The global tuna catches were those reported in the FAO Capture Production database's ISSCAAP "tuna, bonitos and billfishes" group with billfishes excluded (FAO 2009). These figures along with the WCPFC Statistical Area aggregated catches for albacore, bigeye, skipjack and yellowfin (SPC 2009a), and the resulting ratios are shown in Table 3 and Figure 4.

The third method involved scaling estimated global shark catches to WCPO-specific values using an index of longline effort. Although a number of gear types catch sharks, this index was chosen because an estimate of shark catches in the WCPO indicates that most are caught in longline operations (Table 4, Figures 5 and 6). The number of longline hooks (in millions) fished annually were compiled for the Indian Ocean from the Indian Ocean Tuna Commission (IOTC) database (IOTC 2009), for the Eastern and Western Pacific from the WCPFC database maintained by Secretariat of the Pacific Community (SPC) (SPC 2009b), and for the Atlantic from the ICCAT database (ICCAT 2009; Table 5 and Figure 7).

The fourth method considers that silky sharks may be the most common shark caught by purse seine operations (Table 4) and thus the trend in silky shark catches may be determined by changes in effort in the purse seine fishery rather than by changes in effort in longline fisheries (Figures 5 and 6). A purse seine effort index was investigated but could not be constructed due to a lack of standardized measure of effort across fisheries. Instead, purse seine catches of skipjack, bigeye and yellowfin tuna were compiled for all ocean basins (ICCAT 2009, IOTC 2009, SPC 2009b) and the ratio of the WCPO skipjack, bigeye and yellowfin tuna catches by purse seine from the WCPO to the global total was computed (Table 6 and Figure 8). This method was also applied to oceanic whitetip sharks.

2.2 Model and Methods

The model was implemented with the Monte Carlo Markov Chain (MCMC) method using the Gibbs sampler (Gelfand and Smith 1990) via WinBUGS software version 1.4.3 (Imperial College London 2008). Since the original posterior distributions presented in Clarke et al. (2006a) require >24 hours of computing time to replicate, simplified representations of these complex distributions were approximated using triangular distributions (see Step 1). Other uncertain parameters, such as Hong Kong's share of the global fin trade, were specified as uniformly distributed random variables. The indices for proportioning global fin trade-based catch estimates to the WCPO described in Section 2.1.4 above were applied in deterministic equations (Annex 1).

The model was executed in four steps on the basis of the four data sources given above:

Step 1

The probability distributions representing the range of estimates of the five shark species in the global trade by number and biomass (Table 1, the “anchor point” estimates) were approximated as triangular distributions using the reported lower limit of the 95% probability interval as the minimum, the upper limit of the 95% probability interval as the maximum, and the median as the mode. The model drew a random variable from each of the triangular distributions representing each species’ number or biomass in 2000 in each iteration.

Step 2

Each random variable drawn in Step 1 was multiplied by the ratio of the standardized quantity of fins traded through Hong Kong in each year from 1980-1999 and 2001-2007 (Table 2) to the quantity of fins traded through Hong Kong in 2000 (i.e. 6788 t). This step serves to scale the species-specific number or biomass estimates from 2000 to quantities representing trade levels in each of the other 27 years. This step assumes that the species composition in 2000, the only year for which the species composition is known, remains constant over the years 1980-2007.

Step 3

Hong Kong’s share in three alternative periods (S_a), i.e. 1980-1990, 1991-1995 and 2001-2006, relative to its share in 1996-2000 (0.44-0.59, S) was specified as a series of uniformly distributed random variables using endpoints based on expert judgment (Section 2.1.3). The ratio of S and S_a was then computed and multiplied by the result from Step 2. The result of Step 3 is a species-specific number or biomass value representing sharks used in the global trade for each year from 1980-2007.

Step 4

The final step required proportioning the annual values from Step 3 to the WCPO. For the area-based proportioning, constants of 0.226 (for blue, shortfin mako and thresher) and 0.222 (for silky and oceanic whitetip) were applied in all years. In contrast, proportioning by total tuna catch (Table 3 and Figure 4), longline effort (Table 5 and Figure 7), and purse seine tuna catches (Table 6 and Figure 8) applied unique values for each year.

The model was run for 100,000 iterations, and medians and 95% probability interval endpoints were sampled from the final 10,000 iterations.

3 Results

The estimated trends for all species in both number and biomass (Figures 9-12) are of low levels until the early 1990s, followed by a steady increase until 2000, and then a sharper rise until a peak either in 2002 or 2003 . The major influence on these trends is the amount of fins imported by Hong Kong which reached a maximum in 2003 (Table 2). Clarke et al. (2007) concluded that it is reasonable to assume that the trade volumes recorded in Hong Kong accurately reflect globe trade trends for a number of reasons including Hong Kong's duty free status which should present no incentive for under-reporting.

The consistency of the patterns observed for all species, and for both number and biomass, is a result of identical application of the scaling factors in Steps 2, 3 and 4 to each species and for both number and biomass "anchor point" estimates. As a result, while the starting point (i.e. the anchor point estimate based on conditions in 2000 (Clarke et al. (2006a)) differs by species and for number and biomass, for each series (i.e. each proportioning method) the variation from year to year is the same.

In 2003, i.e. the peak year in the tuna catch- and area-proportioned series, and the second highest year for the longline effort-proportioned series, median blue shark estimates for the WCPO in number ranged from 3.2-5.9 million, or in biomass, from about 116-223 thousand t (Figures 9 and 11). In the same year, median values among these three series were estimated for thresher and silky sharks in number at approximately 300-600 thousand for silky, and 450-850 thousand for thresher, and roughly 15-30 thousand t for both species in biomass (Figures 9-12). Shortfin mako and oceanic whitetip sharks median estimates in the peak year (2003) were the lowest of the sharks considered in this study, both of which were approximately 200-400 thousand in number, and 10-20 thousand t in biomass. The additional proportioning method for purse seining, which was applied for silky and oceanic whitetip sharks only, did not result in median values in the peak year which exceeded the ranges given above.

The range of median values for a particular species in a given year, shown in Figures 9-12 and described above, derives from differences in the proportioning of global estimates to the WCPO. For example, in the area- and tuna catch-proportioned series, the highest estimates occur in 2003. In the area-proportioned series, this is because this proportioning method applies a constant for all years, thus the estimates closely follow the fin trade figures which peaked in 2003 (6960 t; Table 2). In the tuna catch-proportioned series, ratios fluctuate around 0.35 without a strong trend and thus in this series also the fin trade figures have a strong influence on the result (Figure 4). In the longline effort-proportioned estimates, the WCPO proportion of global effort was notably higher in 2002 (0.47) relative to 2003 (0.43; Figure 7), and this in combination with a relatively high volume of trade through Hong Kong in 2002 (6513 t), resulted in the maximum estimate in 2002.

In addition to such relatively minor annual variations within each series, major differences in the series are apparent based on the proportioning method applied. In the first 10 years of the time series, all three proportioning methods give generally similar results. In the mid-1990s, however, the tuna catch- and longline effort-proportioned series begin to diverge more widely from the area-proportioned series. From 2000 onward the longline effort-proportioned series is approximately double that of the area-proportioned series with the tuna-catch proportioned values midway between the two. The purse seine-proportioned series estimated for oceanic whitetip and silky sharks only is similar to, though slightly lower than, the longline effort-proportioned series. As described above, the tuna catch-proportioning index (Figure 4) behaves similarly to the constant used as the area-proportioning index and as a result, the increase in the fin trade volume drives the trend. In contrast, the longline effort- and purse seine-proportioned series (Figures 7 and 8) show a stronger slope, particularly in the last ten years of the series, reflecting a proportional increase in effort in the WCPO relative to other fishing areas. This serves to inflate the base estimates in these two series as these base estimates themselves increase in the latter part of the time series. It is noted that the width of the probability intervals is proportional to the magnitude of the median, therefore the longline effort- and purse seine-proportioned estimates have considerably wider probability intervals than the other series.

All series show a decreasing trend since 2003 (since 2002 for the longline effort-proportioning series). This decreasing trend is apparent even if the estimates for 2007, which may be influenced by as yet incomplete reporting of fish catch and effort data, are discarded. Since the trends in the ratio of tuna catch, longline effort and purse seining in the WCPO relative to the global ocean in the last few years of the time series are upward, the decreasing annual estimates are driven by the trends in the fin trade through Hong Kong (Table 2). This decrease in trade volume is substantial enough to determine the trend in spite of the correction for the declining proportion of the Hong Kong trade relative to the global trade in Step 3.

The area-proportioning method is a rough approximation based on the assumption of even distribution of sharks and fishing effort per unit area throughout the world ocean. It is therefore considered to be the coarsest of the four proportioning methods. The tuna catch-proportioning method assumes that when tuna catches in the WCPO are low relative to other oceans, shark catches in the WCPO are also low relative to other oceans. This important assumption may be erroneous, particularly if there have been shifts in targeting between tuna and sharks to differing degrees in different oceans. For these reasons, it is considered that the most reliable proportioning methods are those based on effort, or in the case of the purse seine series, catch as a proxy for effort. In the latter case, as sharks are not targeted by purse seine operations, the purse seine proportioning method is not vulnerable to the potential targeting bias. It is noted that both effort-based methods produced nearly the same results.

4 Discussion

Catch data for most shark species are insufficient to support stock assessment, yet concerns about the status of shark populations continue to grow. Under such circumstances, development of alternative historic shark catch time series and careful evaluation of whether these alternative series can fill some of the existing critical data gaps is a worthwhile exercise. The following discussion first describes special considerations when interpreting trade-based results and then compares these results to available shark catch estimates.

The estimates produced by this study were based on “anchor point” estimates derived from a shark fin trade data set compiled in Hong Kong in 2000 (Clarke et al. 2006a). To date these are the only quantitative, species-specific data on the shark fin trade and represent a snapshot of the centre of the global shark fin trade at that time. Using these data to estimate the number and biomass of sharks used in the fin trade from the WCPO requires a number of assumptions, namely:

1. **The species composition of the sampled portion of the Hong Kong shark fin trade in Clarke et al. (2006a) is representative of global species composition.** As discussed in Clarke et al. (2006b), there is a lack of information to evaluate the strength of this assumption, but there are no other datasets that are considered more representative.

2. **The species composition of the fin trade observed in 2000, and the relationships between fin sizes/weights and whole shark weights observed at that time, are constant throughout the time series.** While some stock composition shifting would be expected over time, there are no existing data with which to explore alternative assumptions. The range of variability resulting from these factors is therefore assumed to be reflected in the specification of the probability intervals within the model.

3. **Each of the five species assessed is equally likely to be found in the WCPO as in any other ocean.** This appears to be a reasonable assumption given what is known regarding the distribution of these sharks.

Trade-based estimates reflect only the portion of shark mortality relating to fins and are thus fundamentally different from reported catches or catch estimates. For at least two reasons it would be expected that trade-based estimates would be lower than the true figures of sharks caught. First, the original "anchor point" estimates are in themselves conservative because they are based only on those fins which could be confirmed to derive from the species of interest. More than half (54%) of the fins observed by Clarke et al. (2006a) could not be characterized by species and could have contained additional quantities of the species of interest (Clarke et al. 2006b). Second, only those sharks whose fins are taken for use in the international shark fin trade are enumerated. This is because there is no means in this study of accounting for mortality associated with sharks which are a) discarded dead with their fins attached; b) released with their fins attached but subsequently die due to injury or stress; or c) are retained but whose fins are either not used or used within the country of landing. These two reasons emphasize that actual shark mortality may in fact be greater than the trade-based estimates but it is highly unlikely to be lower.

This point is also relevant to interpretation of the increasing estimates of sharks used in the fin trade over time (Figures 9-12). Since it is not known whether the underlying factor causing the rise is increased catches, increased utilization of fins, or both (see Dulvy et al., 2008), it cannot be confirmed that the trend is reliable over the entire time series. In other words, the low estimates in the early portion of the time series may be due to lower utilisation of shark fins even though actual shark mortality may have been similar throughout the time series. As a result, it is not recommended to interpret these estimates as a record of catches. Nevertheless, as the annual trade-based estimates represent minimum levels of fishing mortality in each year, any estimates which are substantially lower than these levels should be suspect. If as expected, fin utilisation in recent years is high and mortality to sharks released with their fins intact is low, trade-based estimates for this period may provide a reasonable proxy for catch figures.

The trade-based estimates produced by this study can be compared to fishery-based catch estimates from several sources. The primary source of shark catch information in the WCPO is catch estimates produced from a generalised linear model of CPUE fitted to observer data (SPC 2008). Estimates were produced separately for longline for blue, mako, oceanic whitetip and silky sharks in 1994-2006 and for purse seine for silky shark in 1995-2007, in addition to other target species. The SPC (2008) longline catch estimates for blue, mako and oceanic whitetip sharks are shown in Figure 13 along with the median estimates for all four proportioning series (this study). Figure 13 also shows the medians for all four proportioning series for silky shark (this study) contrasted with the sum of the SPC (2008) longline and purse seine catch estimates for that species. It should be noted that the SPC (2008) estimates do not account for catches by the domestic fleets of Indonesia, the Philippines and Chinese Taipei.

The most obvious result of the comparison is the divergence of the catch-based and trade-based estimates in the past 10 years. While the trade-based estimates continued to increase since the mid 1990s until the early 2000s, the WCPO catch-based estimates for all species have steadily declined since 1998-1999 (with the exception of silky shark for which estimates peaked in 1995). The cause of the decreasing estimates of shark catches in the WCPO is unknown. It is noted, however, that the SPC (2008) analysis is limited in its reliability by the lack of observer data covering the distant water longline fleets and the decreases may be related to discontinuities in the time series of observer data covering the other sectors of the longline fishery on which the models are based. The sensitivity of the estimates to these discontinuities is currently being examined by SPC (T. Lawson, pers. comm.) It is also possible that the trend in SPC (2008) reflects an actual decrease in shark catches (e.g. due to declining shark populations or to changes in fishing practices).

If the shark catches in the WCPO, and thus shark fin production from the region, did actually decrease, it is interesting to consider how this could occur at the same time as very strong growth in the global shark fin trade. One possibility is that the unaccounted domestic shark catches of Indonesia, Philippines and Chinese Taipei in the WCPO began contributing proportionally more shark fins to the trade in the last ten years. Another explanation could be that the increase in the shark fin trade was driven by higher catch rates in other oceans. In ICCAT, one of the few other areas where shark catches have been estimated, the trend of blue shark catches over the period 1980-2006 hovered around 50,000 t (+/- 15,000 t) per annum with no strong trend over time (ICCAT 2008). Catch estimates for shortfin mako by ICCAT (2008) showed an increasing trend since the late 1990s, similar to that estimated based on trade data. The difference in the ICCAT blue and shortfin mako shark reported catches could be explained by more accurate landings records for shortfin mako due to their relatively higher value as meat (Clarke 2008). A recent North Pacific blue shark stock assessment provides longline catch data through 2002 and indicates that in contrast to the SPC (2008) estimates, blue shark catches increased steadily at a rate of 8% per year from 1998-2002 (Kleiber et al. 2009).

In addition to the divergence in trends between the catch-based and trade-based estimates, the magnitude of the estimates differs considerably in the latter portion of the time series. It is interesting to note that there is reasonable agreement between most of the catch-based and trade-based estimates during the period of 1998-2000 which is the period during which the trade-based "anchor point" estimates were compiled. After that time, however, the catch-based estimates generally lie below the area-, tuna catch-, longline effort-, and purse seine-proportioned medians for all species (with the exception of oceanic whitetip shark until 2003). For most of this period the median trade-based estimates are two to three times higher than the catch-based estimates. This result is similar to the result of the catch-based versus trade-based comparison for blue shark at ICCAT (Clarke 2008).

Other than the SPC (2008) shark catch estimates there are only a few other studies which have attempted to quantify shark catches in the Pacific. The recent north Pacific blue shark stock assessment estimated that as of 2002 approximately 3 million blue sharks were caught each year in the North Pacific (Kleiber et al. 2009). It is not possible to directly compare this Kleiber et al. (2009) figure to the SPC (2008) figure due to different units (north Pacific versus WCPO, as well as number versus biomass). However, it is noted that even though the Kleiber et al. (2009) estimate is for the North Pacific alone (defined as equator to 60^{o}N, and 140^{o}E to 130^{o}W), it is still slightly above the median area-proportioned estimate for the WCPO based on trade data (Figure 9). The median area-proportioned trade-based estimate in biomass (Figure 11) in 2002 is more than double the SPC (2008) estimate of blue shark catch (both estimates for the WCPO).

Oshitani (2000) estimated total catches of silky shark by longline in the Pacific Ocean from 1992-1998 at approximately 400,000-600,000 sharks with an additional catch of approximately 40,000 silky sharks by purse seine. These figures generally exceed the upper 95th percentile probability interval for all of the trade-based estimates prior to 1998, but are similar to the median tuna catch-, longline effort- and purse seine effort-proportioned estimates for 2000-2006. Oshitani (2008) also produced estimates for 1998 in biomass of 13,000-20,000 t for longline and approximately 550 t for purse seine for a total of approximately 13,500-21,000 t over the 1992-1998 period. This figure is similar to the trade-based medians for 1992-1998 which range from 6,000 to 18,000 t (Figure 13). It is possible to compare the Oshitani (2000) estimates to the SPC (2008) estimates but the latter show no data for 1992-1993 and widely varying estimates in 1994-2007 (Figure 13). It should be noted that that the Oshitani (2000) estimates are for the entire Pacific Ocean whereas the other estimates are for the WCPO only.

Another estimate of Pacific shark catches was made by Senba (2003) for shortfin mako sharks. This estimate is provided in number only and is based solely on longline catches. The estimate ranges from 15,000 to 30,000 sharks per annum for the entire Pacific for the period 1994-1999. In contrast to the Oshitani (2000) estimates, the Senba (2003) estimates are well below the upper 95th percentile probability interval for all of the trade-based estimates during this period (Figure 9). It would be expected that rather than being lower than the trade-based estimates, the Senba (2003) estimates would be higher as they cover the entire Pacific Ocean. The Senba (2003) estimates cannot be compared to the SPC (2008) estimates due to differences in units (number versus biomass).

This discussion illustrates that while both trade-based and catch-based methods have merit, there are also some important uncertainties in both types of estimates which cannot be resolved on the basis of existing data. Although the trade-based estimates are in almost all cases higher than the SPC (2008) catch estimates, even so they may not reflect all fishing-related mortality since not all sharks caught have had their fins traded internationally between 1980 and 2006. Therefore, despite the fact that the trade-based estimates are higher, they are probably best considered as minimum values of actual shark mortality. Given the urgent need for improvement in historic catch data to support shark stock assessment, further study of these and other methods is strongly encouraged.

5 Acknowledgements

The author would like to thank T. Lawson of the Secretariat of the Pacific Community for his assistance with data compilation and for peer reviewing a draft version of this paper. C. Palma of ICCAT also kindly assisted with data provision. Funding support for this work was provided by the Secretariat of the Pacific Community, Nouméa, New Caledonia.

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Table 1. Number and biomass of blue, shortfin mako, thresher, oceanic whitetip and silky sharks (median and 95% probability interval) used in the global shark fin trade in 2000 (Clarke *et al*. 2006a).

Shark Species	**Number (million)**	**Biomass ('000 t)**
Blue	10.74 (4.64 – 15.76)	364 (204 – 619)
Shortfin mako	0.48 (0.32 – 0.98)	38 (20 – 56)
Thresher	0.60 (0.36 – 3.90)	55 (12 – 85)
Oceanic Whitetip	0.60 (0.22 – 1.21)	22 (9 – 47)
Silky	0.80 (0.37 – 2.01)	45 (30 – 74)

Table 2. Adjusted total imports of shark fin (t) to Hong Kong, 1980-2006 (see text for adjustment methods). (Source: TRAFFIC 1996 (1980-1995), HKSARG 2008 (1996-2007))

Year	Quantity (t)	Year	Quantity (t)
1980	2739	1994	4144
1981	2741	1995	4706
1982	2704	1996	4513
1983	2512	1997	4868
1984	2748	1998	5196
1985	2613	1999	5824
1986	2788	2000	6788
1987	3317	2001	6435
1988	3272	2002	6513
1989	3003	2003	6960
1990	3018	2004	6142
1991	3526	2005	5887
1992	4265	2006	5337
1993	3856	2007	2896

Table 3. Global (FAO 2009), and Western and Central Pacific catches of tunas and bonitos (SPC 2009a), and the ratio of these species caught in the Western and Central Pacific Ocean.

Year	Global Catch (million t)	Western and Central Pacific Catch (million t)	Ratio (Western and Central Pacific : Global)
1980	2.572	0.840	0.327
1981	2.588	0.809	0.312
1982	2.701	0.859	0.318
1983	2.856	1.069	0.374
1984	3.029	1.160	0.383
1985	3.108	1.015	0.327
1986	3.410	1.147	0.336
1987	3.536	1.143	0.323
1988	3.944	1.269	0.322
1989	3.964	1.308	0.330
1990	4.236	1.420	0.335
1991	4.353	1.654	0.380
1992	4.367	1.597	0.366
1993	4.472	1.470	0.329
1994	4.595	1.617	0.352
1995	4.715	1.620	0.344
1996	4.706	1.529	0.325
1997	4.968	1.641	0.330
1998	5.505	2.008	0.365
1999	5.709	1.832	0.321
2000	5.597	1.894	0.338
2001	5.568	1.795	0.322
2002	5.916	1.998	0.338
2003	6.042	2.000	0.331
2004	6.015	2.059	0.342
2005	6.174	2.203	0.357
2006	6.214	2.275	0.366
2007	6.107	2.391	0.392

Table 4. Shark catches estimated based on observer data by the Secretariat of the Pacific Community on behalf of the Western and Central Pacific Fisheries Commission, 1994-2007 (SPC 2008). These figures do not account for shark catches by the domestic fleets of Indonesia, the Philippines and Chinese Taipei. na=not estimated; *=total based on longline only; **=total based on purse seine only

	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Longline														
Blue	46,854	73,096	69,325	83,112	96,438	110,459	93,076	67,975	53,903	47,346	51,920	41,336	39,556	na
Makos	5,640	6,505	6,493	7,391	8,951	10,664	10,374	9,706	9,081	8,106	6,773	5,257	5,454	na
Oceanic Whitetip	10,364	13,999	13,651	11,776	15,338	13,860	12,268	9,054	9,035	6,551	6,124	4,627	3,586	na
Silky	1,080	13,940	11,111	7,603	8,266	10,579	10,487	8,887	8,352	6,863	7,268	6,062	4,993	na
Other	12,654	12,839	8,341	6,120	8,583	10,689	10,633	9,350	8,370	5,929	5,579	7,218	7,308	na
SUBTOTAL	76,592	120,379	108,921	116,002	137,576	156,251	136,838	104,972	88,741	74,795	77,664	64,500	60,897	na
Purse Seine														
Silky	na	145	236	427	455	786	685	753	941	944	1366	1087	1060	889
Whale	na	166	157	252	285	248	214	272	411	510	636	694	694	781
Other	na	1,361	1,361	1,901	1,115	1,114	734	589	561	404	467	383	274	192
SUBTOTAL	na	1,672	1,754	2,580	1,855	2,148	1,633	1,614	1,913	1,858	2,469	2,164	2,028	1,862
TOTAL	76,592*	122,051	110,675	118,582	139,431	158,399	138,471	106,586	90,654	76,653	80,133	66,664	62,925	1,862**

Table 5. Atlantic, Indian, and Pacific and WCPO longline fishing effort (in million hooks) compiled from RFMO databases, and the ratio of WCPO to total effort, 1980-2007. Data for 2007 may be incomplete.

Year	Atlantic Ocean Longline Effort (ICCAT 2009)	Indian Ocean Longline Effort (IOTC 2009)	Pacific Longline Effort (SPC 2009b)	Total	WCPO Longline Effort (SPC 2009b)	Ratio (WCPO : Total)
1980	212	207	596	1015	467	0.460
1981	224	187	660	1071	522	0.487
1982	270	224	590	1084	463	0.427
1983	234	257	488	980	357	0.365
1984	250	240	509	998	402	0.402
1985	287	226	555	1069	461	0.431
1986	306	254	526	1086	362	0.333
1987	291	255	634	1180	429	0.363
1988	282	217	666	1165	505	0.433
1989	307	216	589	1113	438	0.393
1990	346	179	631	1155	457	0.395
1991	361	333	671	1365	447	0.327
1992	340	310	642	1292	437	0.339
1993	411	424	619	1455	454	0.312
1994	444	319	658	1422	513	0.361
1995	430	366	658	1454	520	0.358
1996	459	356	572	1387	459	0.331
1997	436	366	594	1396	476	0.341
1998	443	418	607	1467	516	0.352
1999	494	463	707	1663	623	0.375
2000	494	453	727	1674	637	0.381
2001	464	431	945	1839	818	0.445
2002	381	410	928	1720	810	0.471
2003	434	460	971	1865	810	0.434
2004	399	454	989	1841	884	0.480
2005	357	448	894	1699	772	0.454
2006	340	397	842	1579	751	0.476
2007	na	193	584	777	555	na

Table 6. Atlantic, Indian, and Pacific and WCPO purse seine catches of skipjack, bigeye and yellowfin tunas (in million t) compiled from RFMO databases, and the ratio of WCPO to total catch, 1980-2007. Data for 2007 may be incomplete.

Year	Atlantic Ocean Catch (ICCAT 2009)	Indian Ocean Catch (IOTC 2009)	Pacific Catch (SPC 2009b)	Total	WCPO Catch (SPC 2009b)	Ratio (WCPO : Total)
1980	0.171	0.395	0.137	0.703	0.099	0.141
1981	0.207	0.452	0.138	0.796	0.150	0.188
1982	0.225	0.476	0.160	0.861	0.254	0.295
1983	0.225	0.575	0.187	0.986	0.429	0.435
1984	0.171	0.665	0.265	1.101	0.461	0.418
1985	0.175	0.665	0.319	1.159	0.396	0.342
1986	0.169	0.786	0.354	1.309	0.457	0.349
1987	0.161	0.845	0.397	1.403	0.518	0.369
1988	0.162	0.942	0.490	1.595	0.576	0.361
1989	0.175	1.003	0.521	1.700	0.629	0.370
1990	0.229	1.112	0.546	1.886	0.768	0.407
1991	0.281	1.268	0.558	2.107	0.970	0.460
1992	0.245	1.271	0.674	2.191	0.952	0.434
1993	0.296	1.152	0.806	2.253	0.839	0.372
1994	0.267	1.283	0.778	2.328	0.969	0.416
1995	0.234	1.319	0.786	2.340	0.932	0.399
1996	0.225	1.296	0.788	2.310	0.895	0.387
1997	0.192	1.447	0.829	2.468	0.988	0.400
1998	0.194	1.727	0.793	2.714	1.293	0.476
1999	0.210	1.723	0.933	2.866	1.130	0.394
2000	0.191	1.738	0.890	2.819	1.187	0.421
2001	0.213	1.746	0.873	2.832	1.162	0.410
2002	0.187	1.936	0.969	3.092	1.316	0.426
2003	0.197	2.023	1.051	3.271	1.319	0.403
2004	0.174	1.922	1.107	3.202	1.389	0.434
2005	0.170	2.178	1.139	3.486	1.581	0.454
2006	0.150	2.173	1.126	3.450	1.629	0.472
2007	0.152	2.170	0.901	3.223	1.730	0.537

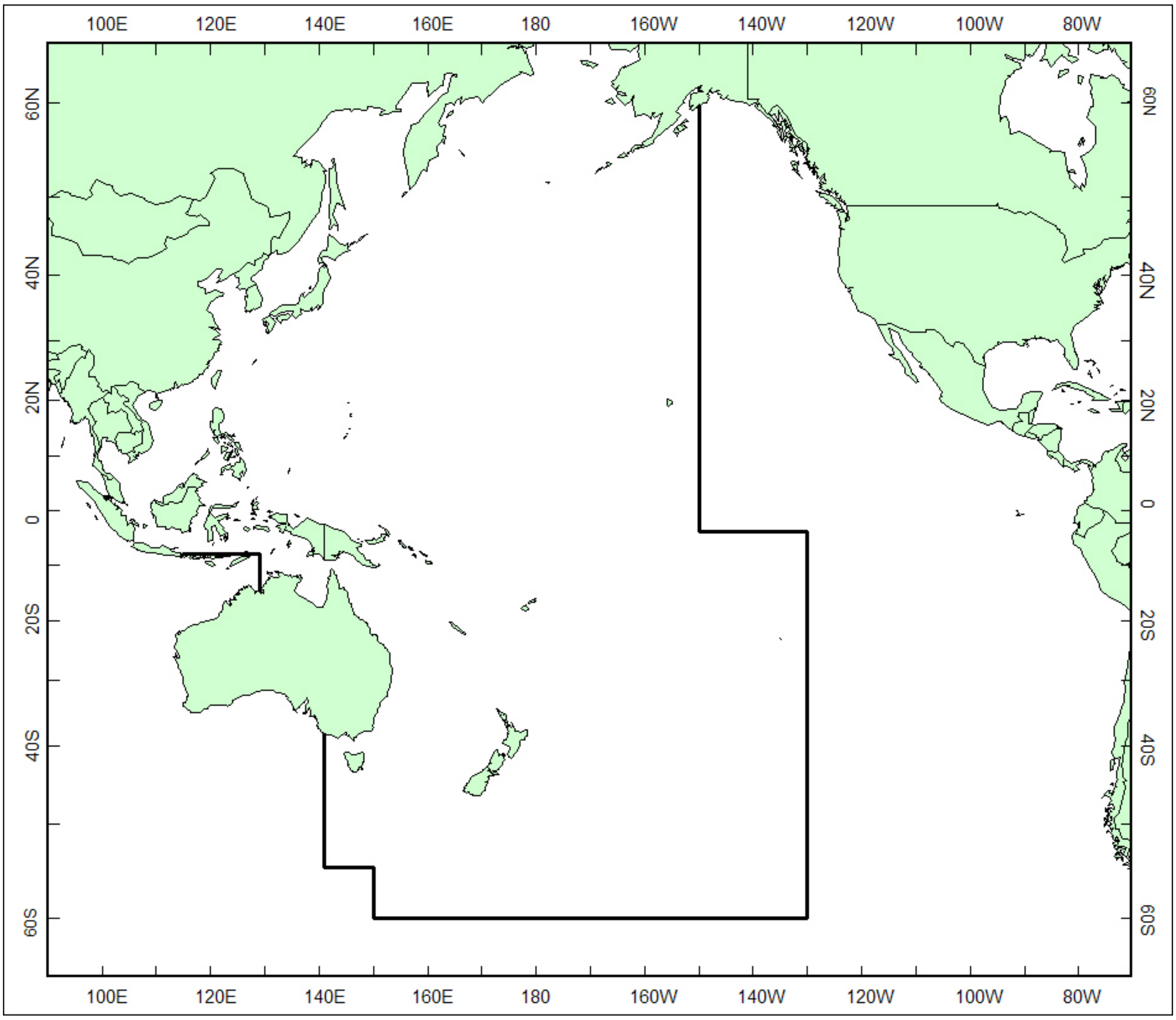

Figure 1. The Western and Central Pacific Ocean Statistical Area boundaries (WCPFC 2007).

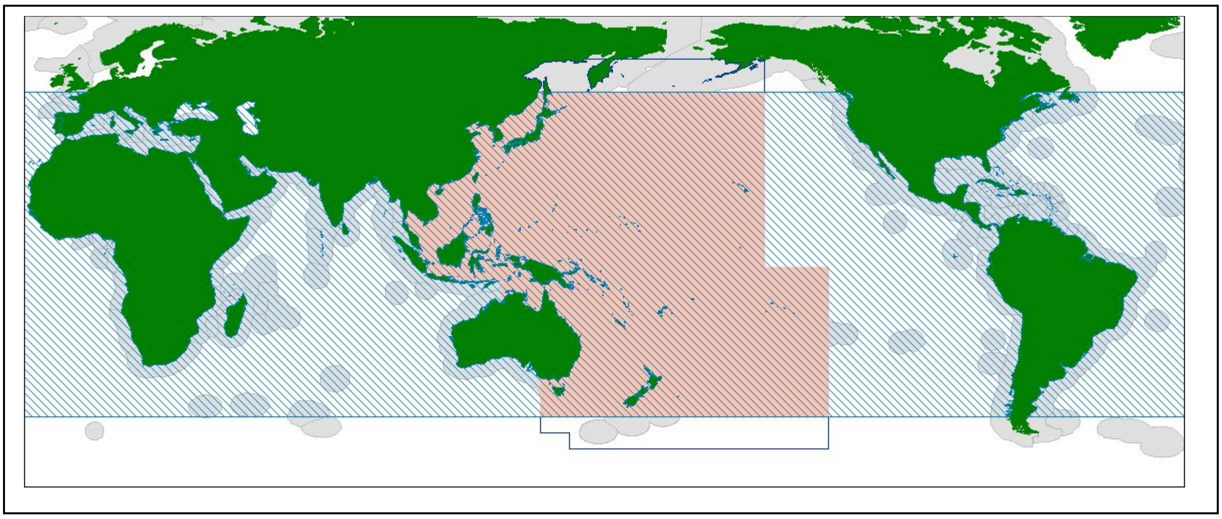

Figure 2. Calculation of the ratio (0.226) of WCPFC ocean area (102.60 million km^2, pink shading) : Global ocean area (454.10 million km^2 hatched lines) between 50^{o}N and 50^{o}S (prepared by the Secretariat of the Pacific Community using Mapinfo GIS).

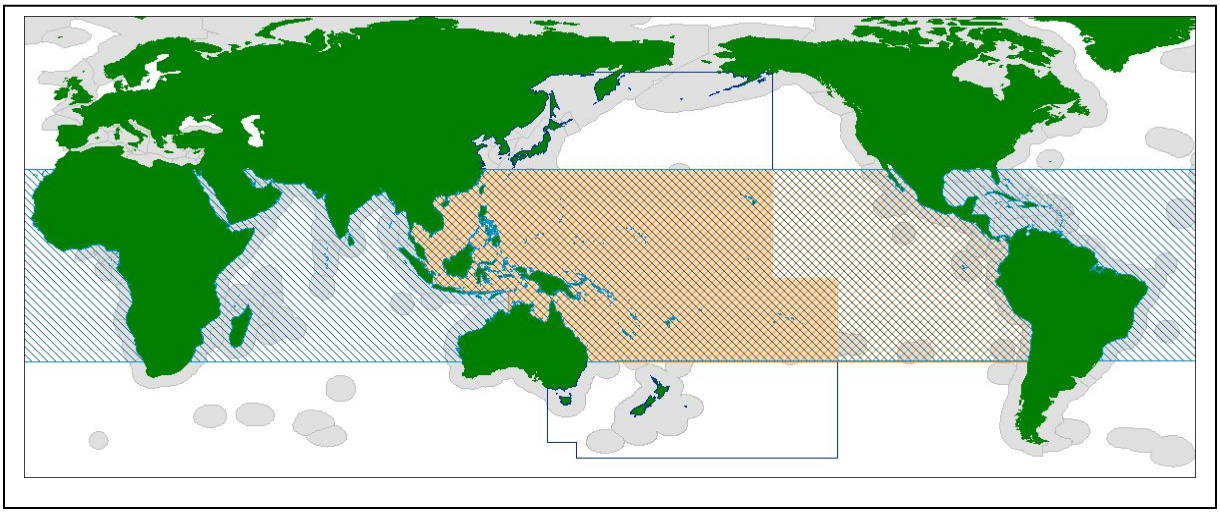

Figure 3. Calculation of the ratio (0.222) of WCPFC ocean area (75.46 million km^2, pink shading) : Global ocean area (339.70 million km^2, hatched lines) between 30^{o}N and 30^{o}S (prepared by the Secretariat of the Pacific Community using Mapinfo GIS).

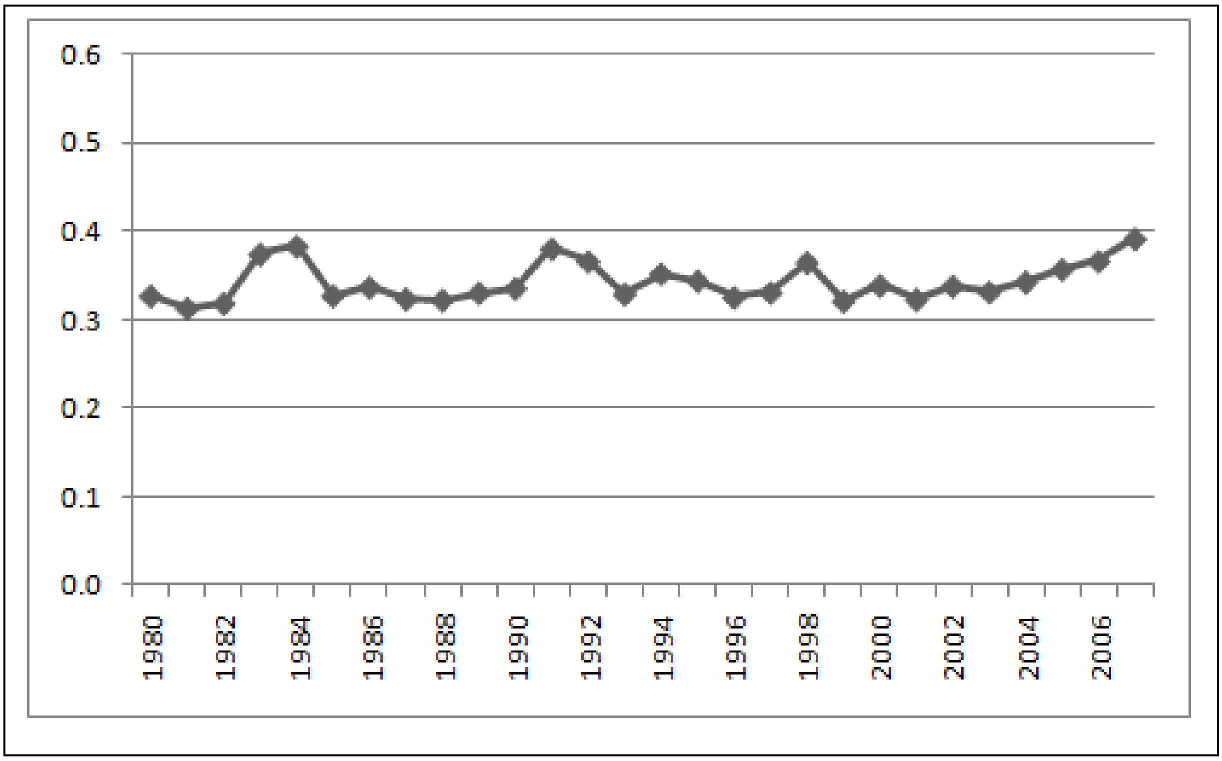

Figure 4. Annual ratios of albacore, bigeye, skipjack and yellowfin tuna catch in the WCPO to the global catch of these species, 1980-2007 (data given in Table 3).

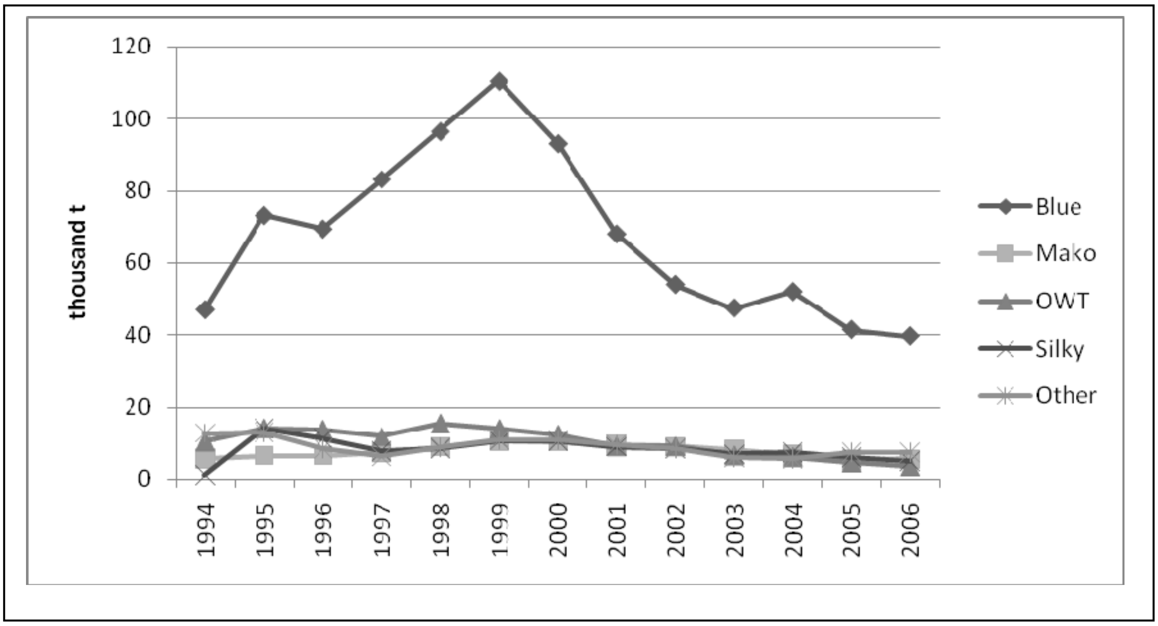

Figure 5. Estimated catches of sharks by longliners 1994-2006 (SPC 2008; data given in Table 4).

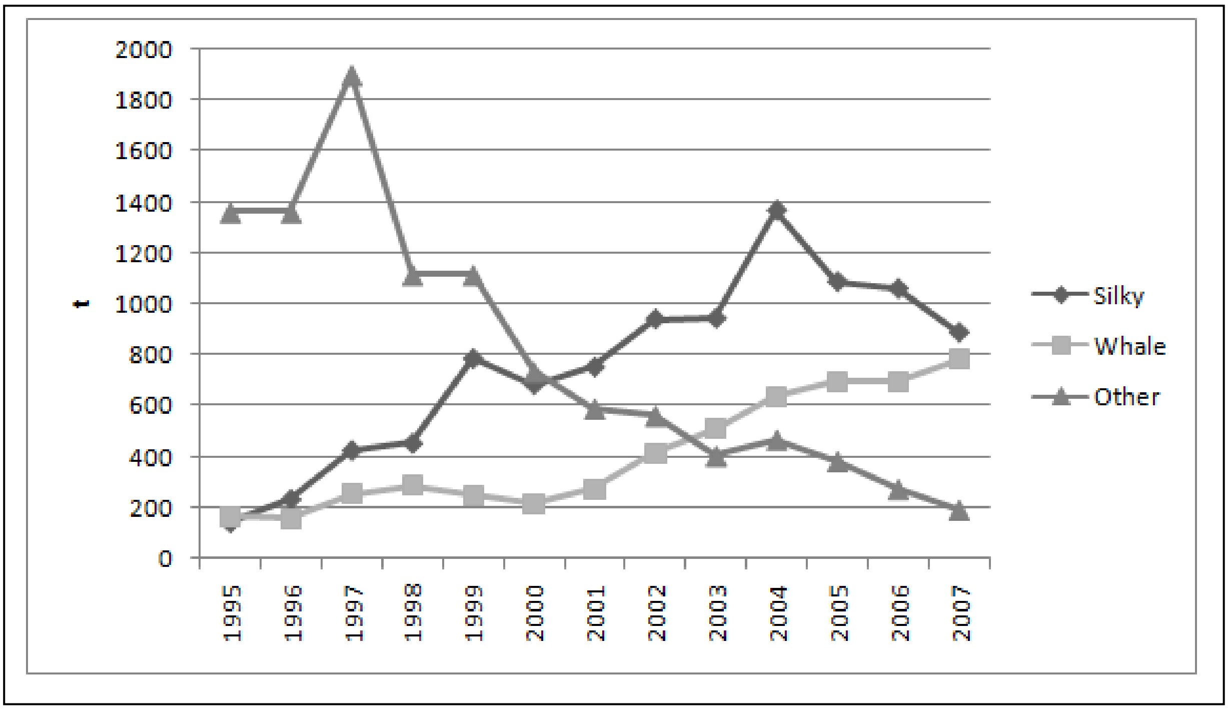

Figure 6. Estimated catches of silky, whale and other sharks by purse seiners 1995-2007 (SPC 2008; data given in Table 4).

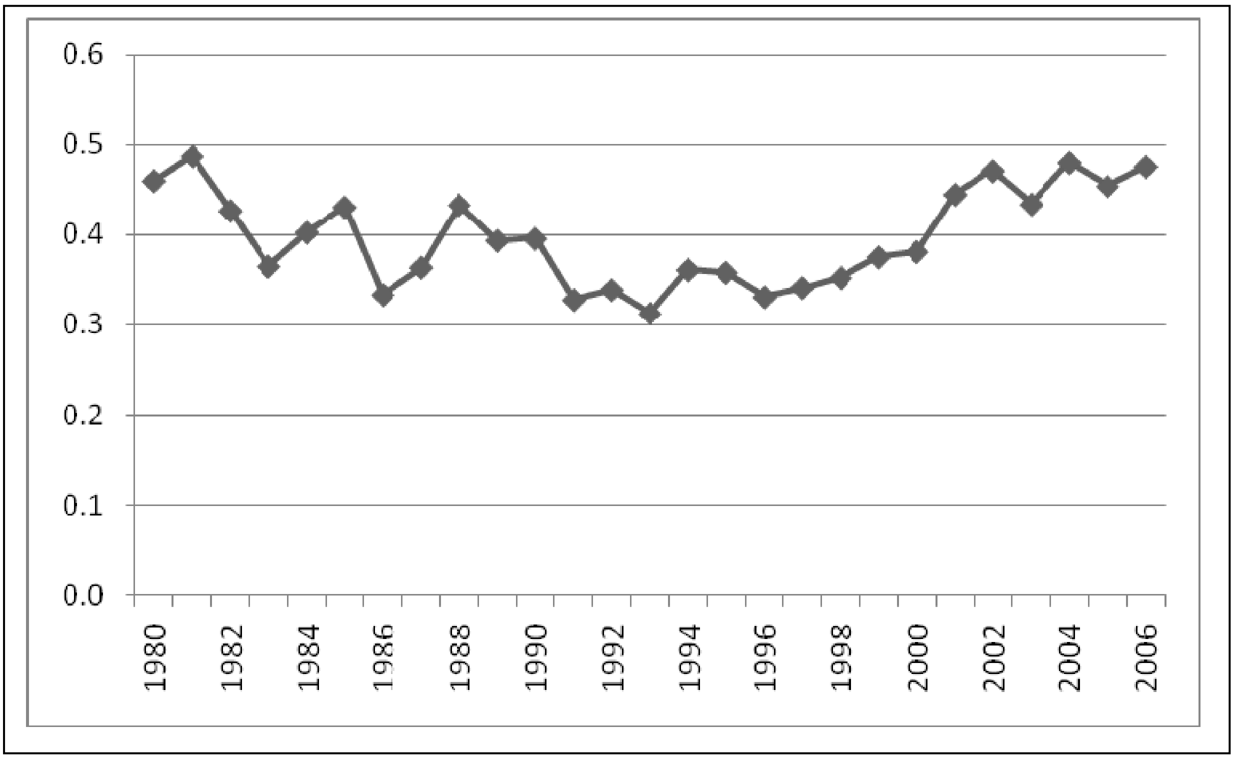

Figure 7. Annual ratios of longline effort in the WCPO to global longline effort, 1980-2006 (data given in Table 5).

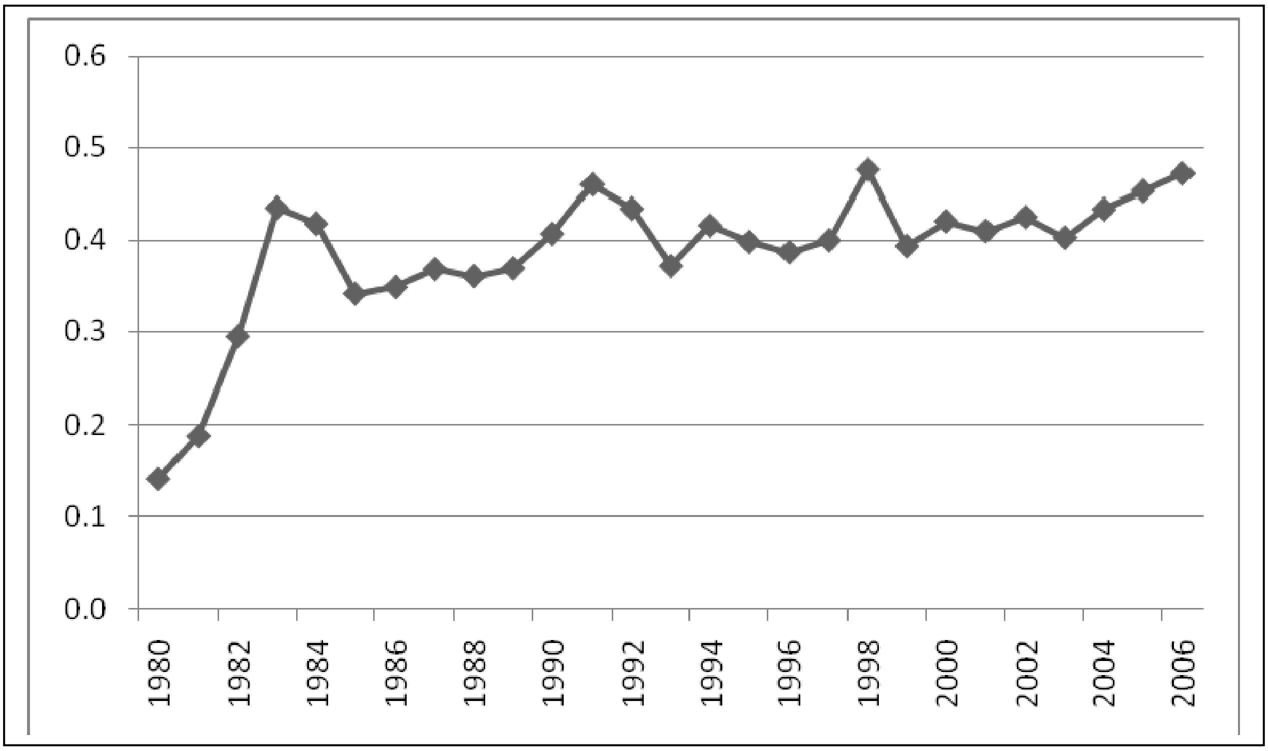

Figure 8. Annual ratios of purse seine catches of skipjack, bigeye and yellowfin in the WCPO to global purse seine catch of these species, 1980-2006 (data given in Table 6).

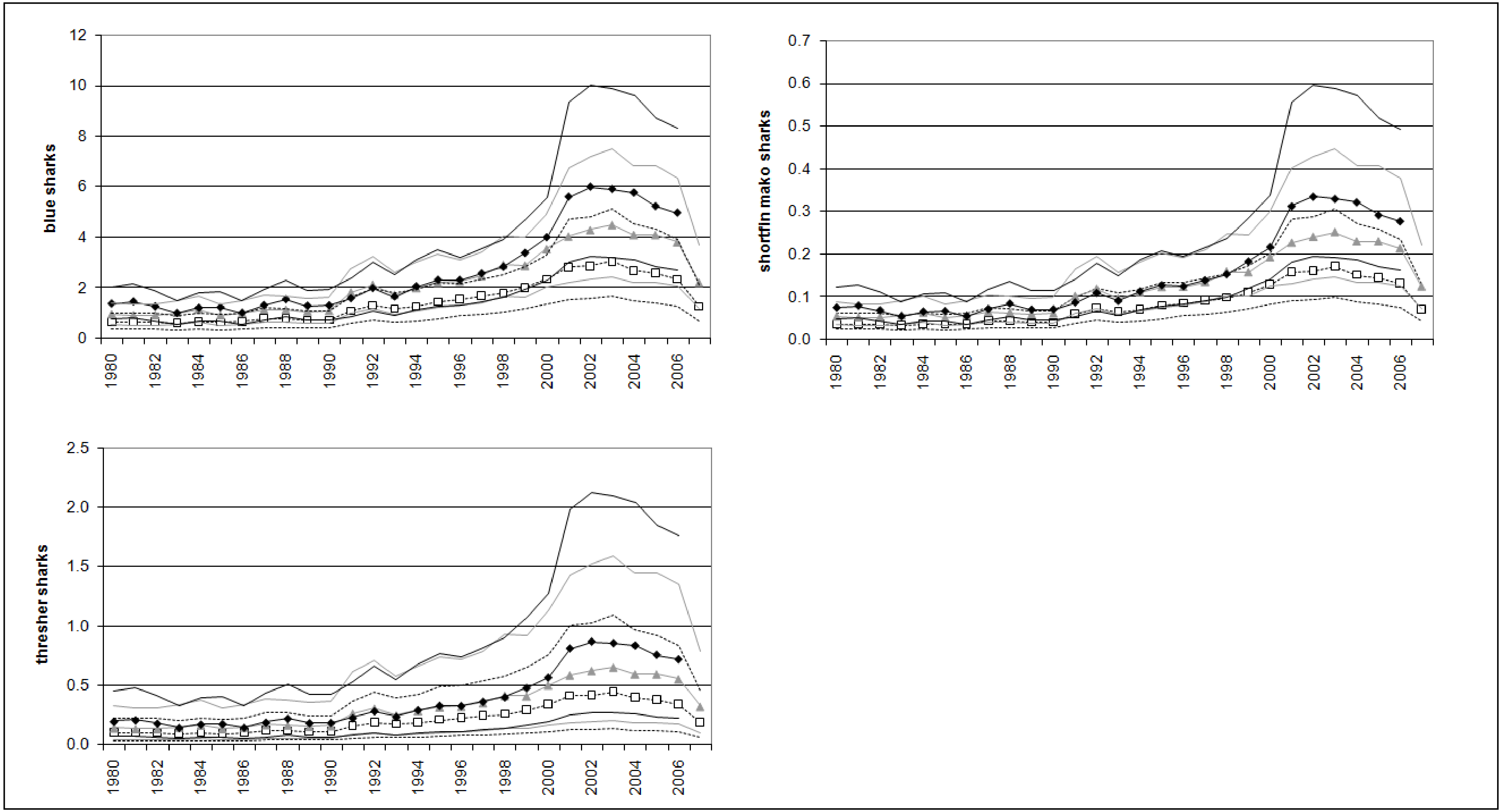

Figure 9. Median and 95% confidence interval estimates for blue, shortfin mako and thresher sharks (in million sharks), using area- (□ and black dashed lines), tuna catch- (△ and gray solid lines) and longline effort- (♦ and black solid lines) proportioning methods to scale global estimates to the WCPO.

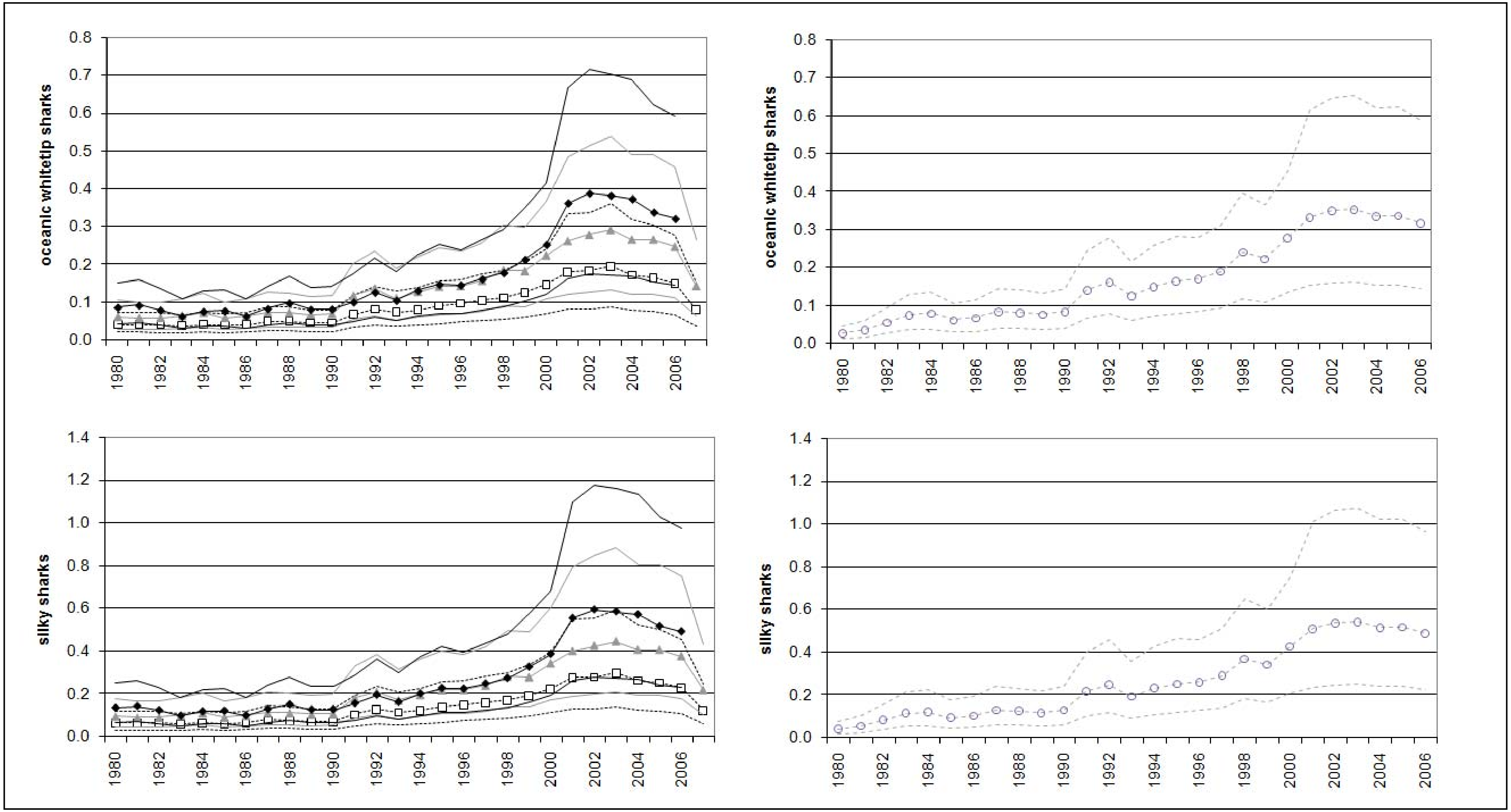

Figure 10. Median and 95% confidence interval estimates for oceanic whitetip and silky sharks (in million sharks), using area- (□ and black dashed lines), tuna catch- (△ and gray solid lines), longline effort- (♦ and black solid lines) and purse seine effort- (right panel, ○ and gray dashed lines) proportioning methods to scale global estimates to the WCPO.

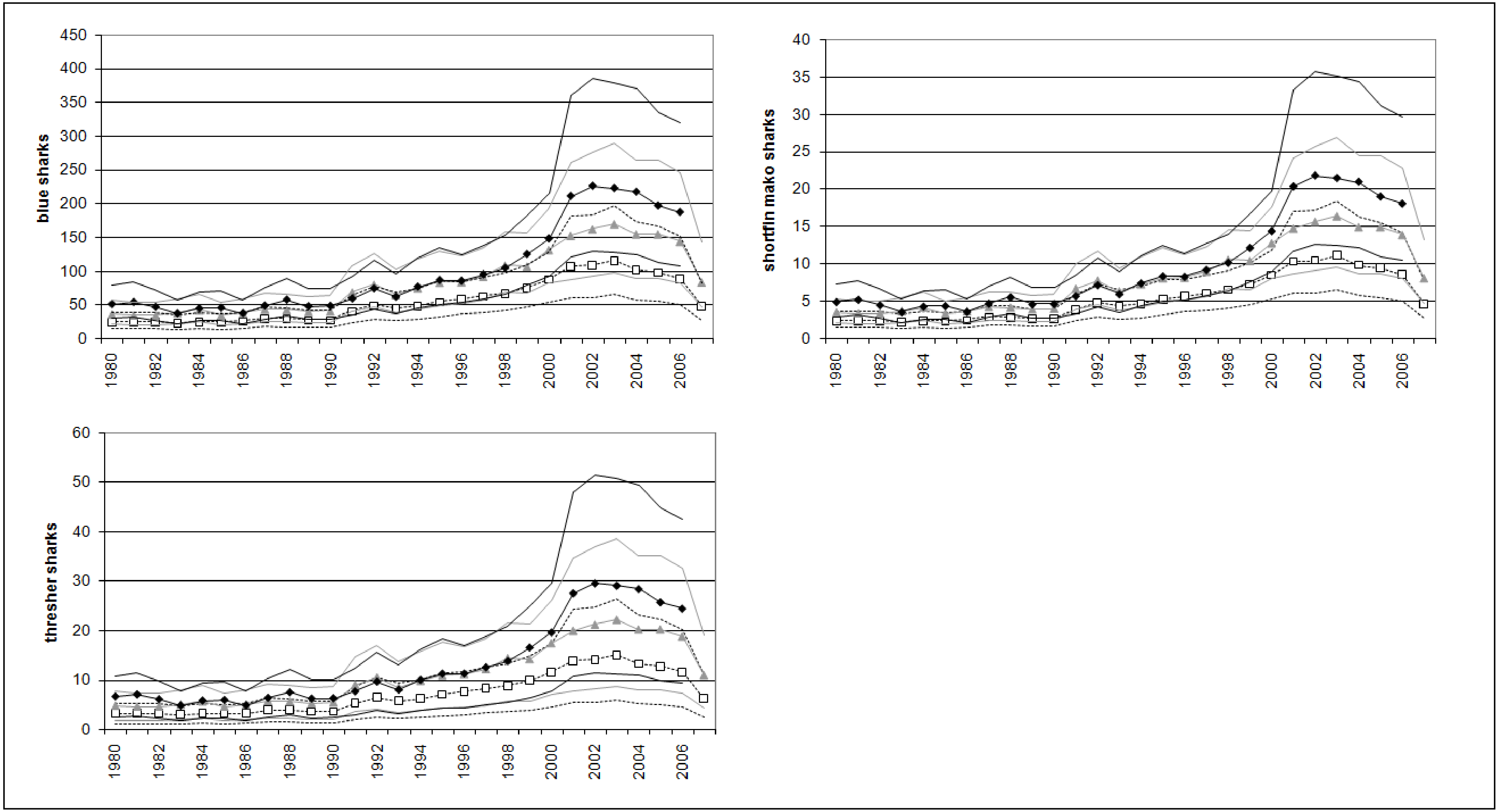

Figure 11. Median and 95% confidence interval estimates for blue, shortfin mako and thresher sharks (in thousand t), using area- (□ and black dashed lines), tuna catch- (△ and gray solid lines) and longline effort- (♦ and black solid lines) proportioning methods to scale global estimates to the WCPO.

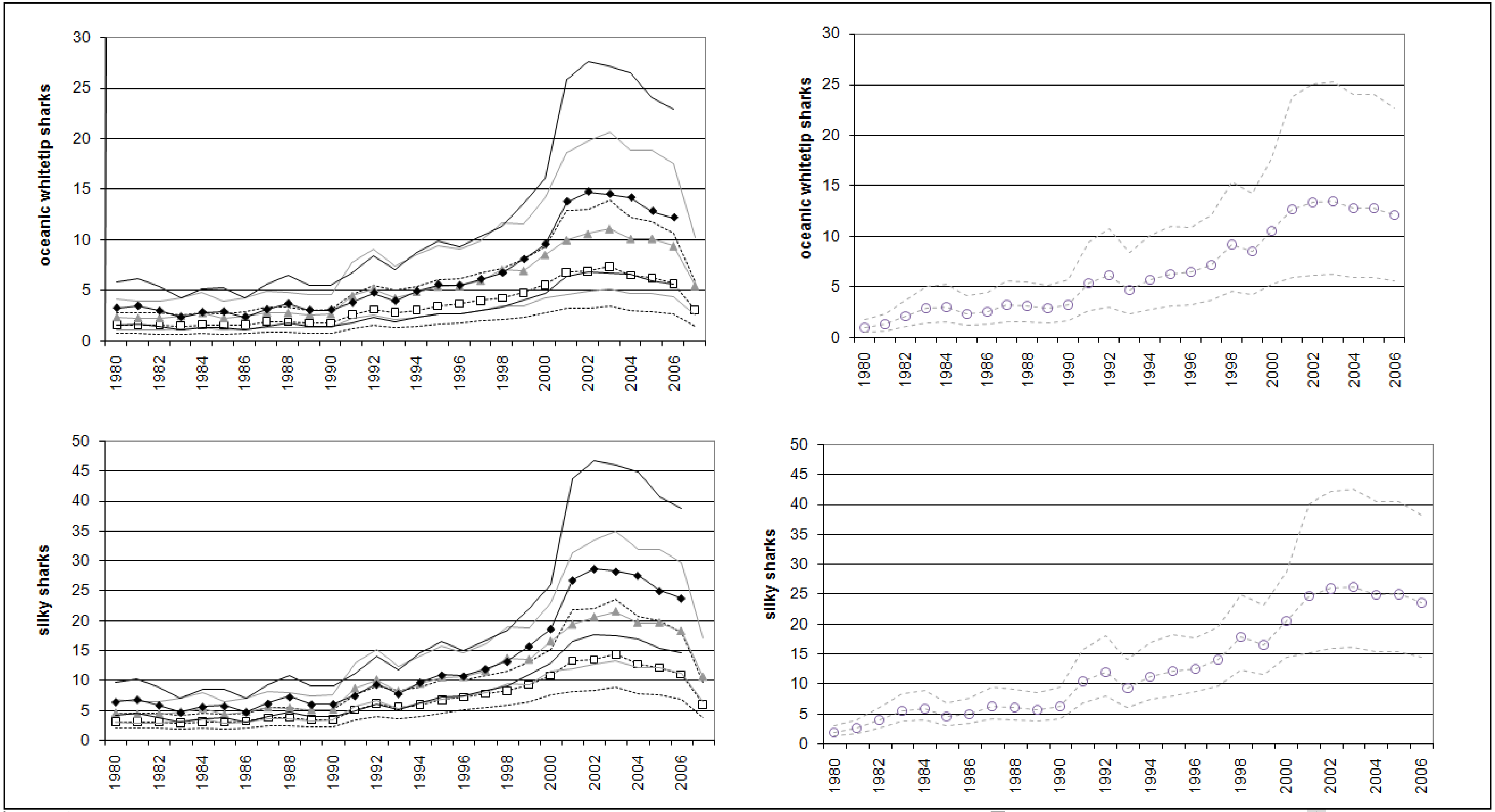

Figure 12. Median and 95% confidence interval estimates for oceanic whitetip and silky sharks (in thousand t), using area- (□ and black dashed lines), tuna catch- (△ and gray solid lines), longline effort- (♦ and black solid lines) and purse seine effort- (right panel, ○ and gray dashed lines) proportioning methods to scale global estimates to the WCPO.

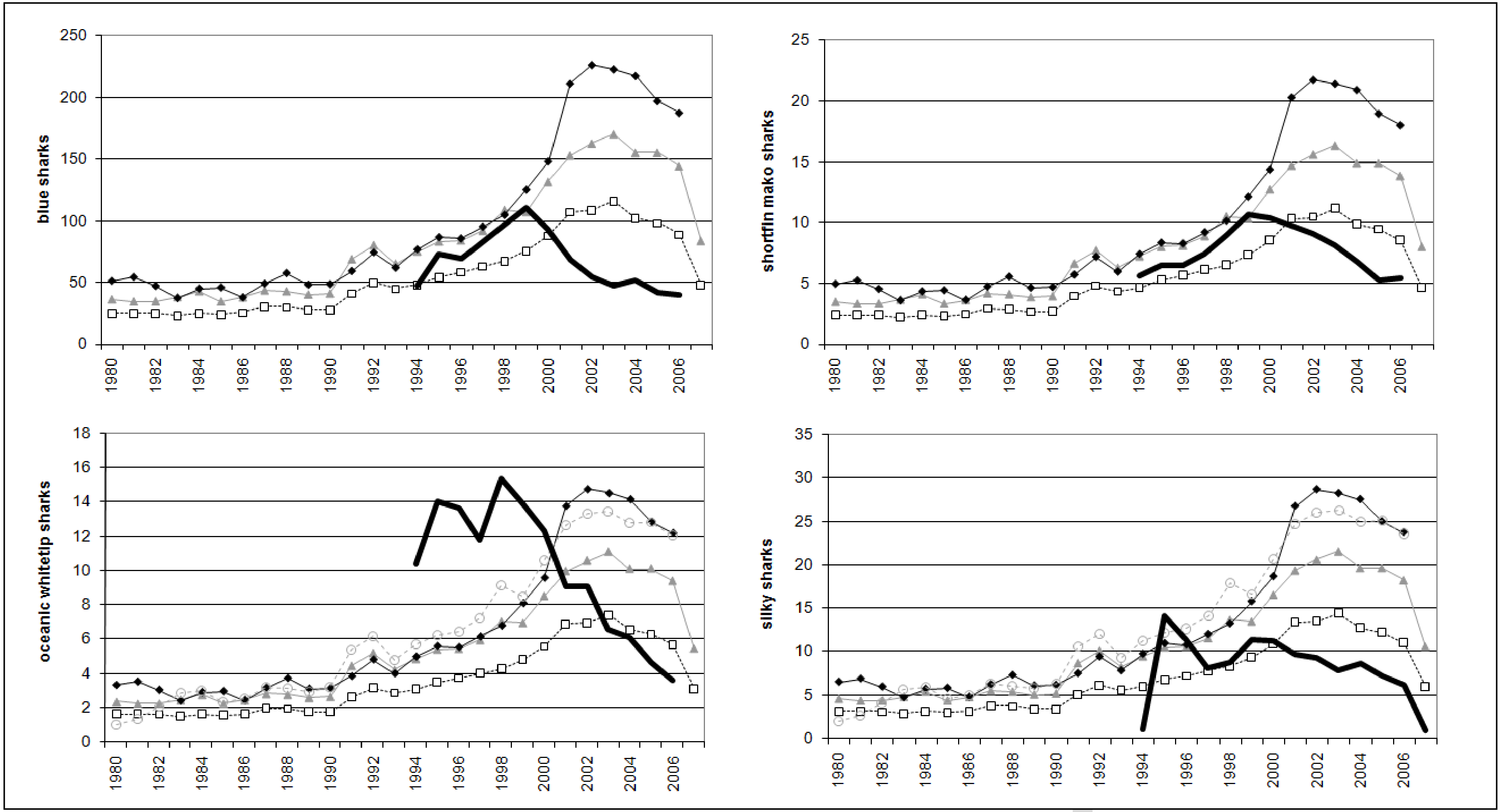

Figure 13. Median estimates for blue, shortfin mako, oceanic whitetip and silky sharks (in thousand t), using area- (□), tuna catch- (△), longline effort- (♦) and purse seine effort- (○) proportioning methods to scale global estimates to the WCPO. Shark catch estimates (sum of longline + purse seine) from SPC (2008) are shown with thick black lines. Data for silky sharks in 2007 is based on purse seine catch estimates only.

Annex 1. WinBUGS code

```
model
{
	shar8090~dunif(0.65,0.80)
	shar9195~dunif(0.50,0.65)
	shar9600~dunif(0.44,0.59)
	shar0007~dunif(0.30,0.50)
for (z in 1:11) {						#first 11 years:  1980-1990
	ratio[z] <- shar9600/shar8090
	}
for (z in 12:16){
	ratio[z] <-  shar9600/shar9195				#next 5 years:  1991-1995
	}
for (z in 17:21){					#next 5 years:  1996-2000 (this is the base period)
	ratio[z] <- 1
	}
for (z in 22:28){					#last 7 years:  2001-2007
	ratio[z] <- shar9600/shar0007
	}

for (g in 1:5) {

	rv[g]~dunif(0,1000)
	x[g]<-rv[g]/1000

	gate[g]<-((trimode[g]-trimin[g]) / (trimax[g]-trimin[g]))
	A[g]<-min(x[g],gate[g])				# find out whether x is higher or lower than criterion
	B[g]<-equals(x[g],A[g])		# if x IS lower then B will be 1, if x>calculation then B will be 0
	C[g]<-equals(B[g],0)# sets C to zero if B=1 or sets C to 1 if b=0; so B and C are binary and opposite

	draw[g]<-(B[g]*(trimin[g]+sqrt(x[g]*(trimode[g]-trimin[g])*(trimax[g]-trimin[g]))))+
		(C[g]*(trimax[g]-sqrt((1-x[g])*(trimax[g]-trimode[g])*(trimax[g]-trimin[g]))))

	for (h in 1:28) {
		scaled[g,h] <- draw[g] * (HKimport[h]/HKimport[21])
		share[g,h] <- scaled[g,h] * ratio[h]
		areaprop[g,h] <- share[g,h] * GIS[g]
		tunaprop[g,h] <- share[g,h] * tunaPac[h]
		hookprop[g,h] <- share[g,h] * LLratio[h]
		PSprop[g,h] <-  share[g,h] * PSratio[h]
			}
}

}
#DATA
list(

trimin=c(4.640, 0.320, 0.358,0.218, 0.368),		#species order is blue, mako, thresher, owt, silky
trimode=c(10.741,0.485,0.597,0.604,0.795),		# these are inputs for shark numbers
trimax=c(15.762,0.978,3.896,1.209,2.008),

#trimin=c( 203.63,19.71,12.13,8.8, 29.94),		#species order is blue, mako, thresher, owt, silky
#trimode=c(364.26,38.07,55.00,21.95,45.46),		# these are inputs for shark biomass
#trimax=c(619.29,56.02,85.18,46.89,74.05),

HKimport=c(2739,2741,2704,2512,2748,2613,2788,3317,3272,3003,	#Hong Kong Imports in 1980-1989 (mt)
3018,3526,4265,3856,4144,4706,4513,4868,5196,5824,		#Hong Kong imports in 1990-1999 (mt)
6788,6435,6513,6960,6142,5887,5337,2896),			#Hong Kong imports in 2000-2007 (mt)

GIS=c(0.226,0.226,0.226,0.222,0.222),

tunaPac=c(0.327,0.312,0.318,0.374,0.383,0.327,0.336,0.323,0.322,0.330,
0.335,0.380,0.366,0.329,0.352,0.344,0.325,0.330,0.365,0.321,
0.338,0.322,0.338,0.331,0.342,0.357,0.366, 0.392),
LLratio=c(
0.460,0.487,0.427,0.365,0.402,0.431,0.333,0.363,0.433,0.393,
0.395,0.327,0.339,0.312,0.361,0.358,0.331,0.341,0.352,0.375,
0.381,0.445,0.471,0.434,0.480,0.454,0.476, 0.5),				#last value is a dummy
PSratio = c(
0.141,0.188,0.295,0.435,0.418,0.342,0.349,0.369,0.361,0.370,
0.407,0.460,0.434,0.372,0.416,0.399,0.387,0.400,0.476,0.394,

0.421,0.410,0.426,0.403,0.434,0.454,0.472,0.537))			#last two values are dubious
```