Aquat. Living Resour. 21, 373–381 (2008)

DOI: 10.1051/alr:2008060
www.alr-journal.org

Aquatic Living Resources
ICCAT CICTA CICAA

Use of shark fin trade data to estimate historic total shark removals in the Atlantic Ocean

Shelley Clarke[a]

Visiting Researcher, Imperial College London, c/o 1675 Sasama-kami, Kawane-cho, Shimada-shi, Shizuoka-ken, 428-0211 Japan

Received 28 April 2008; Accepted 14 October 2008

Abstract – In order to address critical gaps arising from limited available data on historic shark catches in the Atlantic Ocean, a method was developed to estimate shark removals using shark fin trade data. A characterization of the global fin trade as of 2000, including number and biomass by shark species, was used as the basis of the methodology. A first step involved scaling Hong Kong trade-derived estimates for 2000 to annual global values for 1980-2006 based on the observed quantity of imports to Hong Kong and an approximation of Hong Kong's share of the global trade in each year. The resulting global fin trade figures for each year were then scaled to Atlantic-specific values using three different factors: (1) area of the Atlantic range relative to the global range of pelagic sharks; (2) Atlantic catches of tunas and billfishes relative to global catches of tunas and billfishes; and (3) Atlantic longline effort relative to global longline effort. The strengths and weaknesses of each scaling factor and the assumptions inherent in the methodology are discussed. These estimates are not intended to replace reliable fisheries dependent catch data compiled by ICCAT from submissions of members and cooperators, but can serve as one of a variety of useful cross-validation tools when historic catch data are missing or uncertain.

Key words: Fish catch statistics / Fishery products / Trade / Sharks, *Prionace glauca*, *Isurus oxyrinchus*, *Carcharhinus longimanus*, *Alopias* spp.

Résumé – Utilisation des données commerciales des ailerons de requins pour estimer l'historique des captures de requins dans l'océan Atlantique. Afin de s'attaquer au déficit critique soulevé par le peu de données disponibles sur les captures historiques de requins en océan Atlantique, une méthode est ici développée pour estimer les captures de requins, en utilisant les données commerciales des nageoires. Les caractéristiques du commerce mondial des nageoires en 2000, comprenant le nombre et la biomasse par espèce de requins, ont servi de base à la méthode. Une première étape implique la proportion des estimations du commerce de Hong Kong en 2000 par rapport aux valeurs annuelles mondiales pour 1980-2006, basée sur les quantités observées dans les importations par Hong Kong et une approximation de la part de Hong Kong dans le commerce mondial pour chacune des années. Les données annuelles issues de ces données mondiales sont ensuite rapportées aux valeurs spécifiques de l'Atlantique d'après trois facteurs : (1) la surface de l'Atlantique relative à la répartition des requins pélagiques ; (2) les captures de thons et d'espadons en Atlantique par rapport à celles effectuées au niveau mondial et (3) l'effort de pêche à la palangre développé en Atlantique par rapport à celui des palangres au niveau mondial. Les forces et faiblesses de chaque facteur-échelle et les hypothèses inhérentes à la méthodologie sont discutées. Ces estimations ne sont pas destinées à remplacer les données fiables des pêches dépendantes des données de captures compilées par la Commission internationale pour la conservation des thonidés de l'Atlantique (ICCAT) à partir des informations fournies par les membres et coopérateurs, mais elles peuvent servir en tant qu'un des divers outils utiles de validation croisée, lorsque les données historiques de captures sont absentes ou incertaines.

1 Introduction

The lack of historic catch data has been cited as a serious limitation to assessing the status of shark stocks in the Atlantic (ICCAT 2006), and despite calls for improving the quality of shark catch data, substantial progress has not yet been realized (ICCAT 2007). A portion of the problem lies with some members or cooperators of the International Commission for the Conservation of Atlantic Tuna (ICCAT) who, historically or at present, do not record species-specific shark catches in logbooks and/or do not report such catches to the ICCAT Secretariat. Another portion of the problem stems from the

[a] Corresponding author: shelley.clarke@imperial.ac.uk

Article published by EDP Sciences

fact that catches which are reported do not necessarily reflect dead discards, for example those sharks which were finned and whose carcasses were not landed, and thus do not reflect total fishing mortality. In 2004, the Commission enacted ICCAT Recommendation 04–10 which is designed to curtail shark finning. This recommendation requires that ICCAT members and cooperators ensure their vessels do not have onboard fins that total more than 5% of the weight of sharks onboard, up to the first point of landing. However, even if finning no longer occurs, the dead discards problem remains an issue for historic catch figures as well for sharks which are not finned but still die as a result of being caught.

Problems with shark catch statistics are not limited to ICCAT and in fact hamper shark stock assessments worldwide. To date, ICCAT is the only Regional Fisheries Management Organization (RFMO) which has released a shark stock assessment for public review (ICCAT 2005). Due to problems of species identification and under- (or non-) reporting in logbook databases, in the 2004 stock assessment (ICCAT 2005), and also in an ICCAT re-assessment of blue (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) sharks planned for 2008, alternative methods for estimating or cross-checking shark catches were suggested. One such method is based on recent studies of the shark fin trade, taking advantage of the fact that since shark fin is a highly valued product, historic levels of the trade are relatively well-documented in customs statistics. An update to this methodology, which was applied in the 2004 assessment (ICCAT 2005), is the subject of this paper.

In many cases shark fin trade data are no more easy to obtain than shark catch data. However, recent studies of the trade in Hong Kong, a major trading center, have provided new insights into the number and biomass of sharks needed to support this trade at current levels. Using commercial data from Hong Kong showing traded weights by fin position, size and Chinese name category, and DNA analysis to match Chinese fin names with sharks' scientific names, the number and biomass of sharks used in the trade in 2000 were estimated (Clarke et al. 2006a; Clarke et al. 2006b). By adjusting these base estimates by a number of factors, it is possible to produce estimates of the number and biomass of sharks from the Atlantic that are used in the fin trade annually. In association with using a novel data source and an innovative methodology several assumptions are necessarily applied and must be carefully considered when interpreting the results. Considerations for the use of the resulting estimates are presented in detail in the discussion.

2 Materials and methods

2.1 Data sources

The algorithm for estimating historical Atlantic shark catches using information from shark fin markets requires 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 Atlantic.

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

	Number (million)	Biomass (thousand t)
Blue shark	10.74 (4.64–15.76)	364 (204–619)
Shortfin mako	0.48 (0.32–0.98)	38 (20–56)
Oceanic whitetip	0.60 (0.22–1.21)	22 (9–47)
Thresher (all species)	0.60 (0.36–3.90)	55 (12–85)

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). Of the eleven categories of species or genera categories presented in that study, this analysis uses the results for blue (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), oceanic whitetip (*Carcharhinus longimanus*) and thresher (*Alopias* spp.) sharks. These estimates are based on the shark fin trade as of 2000 when Hong Kong imported 6788 t of fins and controlled 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, prior to 1998 imports from the Mainland were subtracted from total imports *sensu* 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

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 (1996-2006)).

Year	Quantity	Year	Quantity
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		

for years before (1980-1995), and after (2001-2006) this period are lacking, ranges of values for 1980-1990, 1991-1995 and 2001-2006 were specified based on expert judgment as described below.

There are no empirical data upon which to base an estimate of Hong Kong share of the trade in 1980-1990. This is mainly due to the difficulty in accessing customs statistics, especially for Mainland China, covering 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 2001-2006 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

Three methods were used for proportioning global fin trade-based catch estimates to Atlantic-specific quantities. The first involved a simple ocean basin area proportion for the Atlantic relative to the world ocean. This proportion (0.2506) was taken from Clarke et al. (2006a) as determined through the use of a geographical information system. The area of the ocean basin was considered an acceptable proxy for the area of habitat, and thus for the potential area of catch for wide ranging pelagic sharks such as blue, shortfin mako, and threshers. Its suitability for the oceanic whitetip is less certain; alternative measures of oceanic whitetip habitat in the Atlantic and globally should be considered in future work.

The second method involved scaling against catches of tunas, bonitos and billfishes based on the FAO Capture Production database. The figures for global (all FAO areas) and Atlantic (including Northeast, Northwest, Southeast, Southwest, Eastern Central and Western Central Atlantic, and the Mediterranean and Black Seas) catches and the ratios are given in Table 3.

The final method involved scaling global catches to Atlantic catches using an index of longline effort compiled from RFMO databases. Although it is recognized that other gear types catch sharks, the most important gear type catching the species of interest to this study is longlines (ICCAT 2007). The number of longline hooks (in millions) fished annually were available for the Indian Ocean from the Indian Ocean Tuna Commission (IOTC) database for 1952-2006, for the Eastern and Western Pacific from the Secretariat for the Pacific Community (SPC) database for 1950-2006, and for the Atlantic from the ICCAT database for 1950-2006 (IOTC 2008, SPC 2008, ICCAT 2008). The overall index was started in 1980 to conform to the availability of shark fin trade data and extended to 2006 (Table 4).

2.2 Methods

Due to the extensive computational requirements of the original shark fin trade model in Clarke et al. (2006a) a simplified model was constructed for ease of application in this exercise. The model was implemented in WinBUGS software version 1.4.3 (Imperial College London 2008) using triangular and uniform distributions as well as deterministic calculations (Table S1). The model is comprised of four steps corresponding to the four data sources given above:

- **Step 1**

The probability distributions representing the range of estimates of the four shark species in the global trade by number and biomass (Table 1) were approximated as triangular distributions using the reported lower limit of the 95% probability

Table 3. Global and Atlantic catches of tunas, bonitos and billfishes (in million t), and the ratio of Atlantic to total catch, as reported in FAO's capture production database, 1980-2006 FAO (2008).

Year	Global Catch (million t)	Atlantic Catch (million t)	Ratio (Atlantic: Global)
1980	2.681	0.537	0.200
1981	2.688	0.584	0.217
1982	2.799	0.667	0.238
1983	2.963	0.630	0.213
1984	3.139	0.555	0.177
1985	3.224	0.603	0.187
1986	3.536	0.578	0.163
1987	3.665	0.579	0.158
1988	4.082	0.632	0.155
1989	4.103	0.654	0.159
1990	4.375	0.696	0.159
1991	4.474	0.691	0.154
1992	4.504	0.673	0.149
1993	4.622	0.722	0.156
1994	4.747	0.720	0.152
1995	4.888	0.681	0.139
1996	4.872	0.702	0.144
1997	5.177	0.645	0.125
1998	5.766	0.703	0.122
1999	5.976	0.697	0.117
2000	5.852	0.649	0.111
2001	5.788	0.671	0.116
2002	6.173	0.590	0.096
2003	6.315	0.593	0.094
2004	6.274	0.581	0.093
2005	6.414	0.634	0.099
2006	6.480	0.569	0.088

interval as the minimum, the upper limit of the 95% probability interval as the maximum, and the median as the mode. In each iteration of the model a random variable was drawn from each of the triangular distributions representing each species' number or biomass in 2000.

• 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 2001-2006 (Table 2) to the quantity of fins traded through Hong Kong in 2000 (i.e. 6788 t). The purpose of this step is to scale the species-specific number or biomass estimates from 2000 to quantities representing global trade levels in each of the other 26 years. For this step only it is assumed that variation in the global quantities of traded fins is represented by imports into Hong Kong.

• Step 3

To allow for the Hong Kong market share of global trade to shift over time, Hong Kong's share in the 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 calculated. Values of S and S_a were specified as uniformly distributed random variables defined using the endpoints of the range of the share specified for each period by expert judgment. The ratio was then calculated as $\frac{S}{S_a}$ 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 1980-2006.

• Step 4

The final step required proportioning the annual values from Step 3 to the Atlantic Ocean. For the area-based proportioning, a constant (0.2506) was applied in all years. For the catch-based proportioning, the observed ratio of Atlantic:global tuna, bonito and billfish catches in each year was applied (Table 3). The effort-based proportioning used the ratio of longline effort in the Atlantic to the sum of the Atlantic, Pacific and Indian Oceans as shown in Table 4.

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 algorithm outlined above applied the same Steps 2, 3 and 4 scaling factors to all species in both number and biomass. Therefore it is as expected that all of the results in number of sharks (Fig. 1, Table S2) and in biomass (Fig. 2, Table S3) show the same patterns of increase and decrease. The general trends shown for all species in both number and biomass are of low levels until the early 1990s followed by a steady increase through the 1990s. In each series a decline is observed after either 2001 or 2003. The major influence on these trends is the amount of fins imported by Hong Kong which peaked in 2003.

Differences in estimates by species in each year derive from the original "anchor point" estimates produced by Clarke et al. (2006a). In 2003, i.e. the peak year for the area- and effort-proportioned series and the second highest year for the tuna catch-proportioned series, median blue shark estimates for the Atlantic ranged from 1.3–3.4 million, or in biomass, from about 50–130 thousand t. In the same year, shortfin mako and oceanic whitetip shark were both estimated at approximately 80–210 thousand in number but differed in biomass with estimates of 5–12 thousand t for shortfin mako and 3–8 thousand t for oceanic whitetip. Thresher shark estimates for the Atlantic in 2003 ranged from 200–500 thousand in number and from 6–17 thousand t in biomass (Figs. 1 and 2).

The range of median values for a particular species in a given year, derives from differences in the proportioning of global estimates to the Atlantic (Figs. 1 and 2). For example, in the area- and effort-proportioned series, the highest estimates occur in 2003. In the area-proportioned series, this is because these proportioning methods apply a constant for all years, thus the estimates closely follow the fin trade figures which peaked in 2003. In the effort-proportioned series, ratios fluctuate around 0.25 without a strong trend and thus in this series also the fin trade figures have a strong influence on the result. In the tuna catch-proportioned estimates, the Atlantic proportion of global tuna, bonito and billfish catches was notably higher in 2001 relative to other years, resulting in a peak value in 2001.

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

Table 4. Atlantic, Pacific and Indian Ocean fishing effort (in million hooks) compiled from RFMO databases, and the ratio of Atlantic to total effort, 1980-2006.

Year	Atlantic Ocean Longline Effort (ICCAT 2008)	Pacific Ocean Longline Effort (SPC 2008)	Indian Ocean Longline Effort (IOTC 2008)	Total	Ratio (Atlantic : Total)
1980	212	596	207	1015	0.209
1981	224	660	187	1071	0.209
1982	270	590	224	1084	0.249
1983	234	488	257	980	0.239
1984	250	509	240	998	0.250
1985	287	555	226	1069	0.269
1986	306	526	254	1086	0.282
1987	291	634	255	1180	0.246
1988	282	666	268	1216	0.232
1989	307	589	269	1166	0.264
1990	346	631	221	1198	0.289
1991	361	671	353	1386	0.261
1992	340	642	310	1292	0.263
1993	411	619	424	1455	0.283
1994	444	658	320	1422	0.312
1995	430	658	366	1454	0.295
1996	459	572	356	1388	0.331
1997	436	594	366	1396	0.312
1998	443	607	506	1556	0.285
1999	494	707	448	1648	0.300
2000	494	727	443	1665	0.297
2001	464	945	418	1826	0.254
2002	381	928	391	1700	0.224
2003	434	957	402	1793	0.242
2004	399	989	435	1822	0.219
2005	357	893	435	1685	0.212
2006	340	836	181	1356	0.251

of the time series, all three proportioning methods give generally similar results. In mid-1990s, however, the area- and effort-proportioned series begin to diverge more widely from the tuna catch-proportioned series and by 2000 the former are approximately twice as large as the latter. As described above, the effort-proportioning index (Table 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 tuna catch proportioning index (Table 3) shows a stronger, and negative, slope over time which serves to depress the trade figures. It is noted that the width of the probability intervals is proportional to the magnitude of the median, therefore both the area- and effort-proportioned estimates have wider probability intervals than the tuna-catch proportioned estimates.

All series show a decreasing trend since 2003. This is particularly apparent in the effort-proportioned series. This may be expected given that higher fuel prices are reportedly causing some vessels to exit the fishery (Miyake 2007). The slope of the ratio of Atlantic to global effort suggests that longline effort in the Atlantic has decreased disproportionately faster than in other oceans. The data in Table 4 indicates that while effort in the Atlantic has contracted, Pacific effort has actually increased since 2000 and Indian Ocean effort data showed a clear reduction in effort only beginning in 2006.

4 Discussion

Most RFMOs rely on stock assessment as the first step in determining whether conservation and management measures are warranted. In turn, though, stock assessment requires reliable estimates of historic catches. In the case of sharks, the most straightforward means of obtaining such catch estimates is for countries to require fishermen to record shark catches by species in logbooks and for these logbooks to be periodically collected, analyzed and reported to the appropriate RFMO. Despite calling for better shark catch data as early as 2001 (ICCAT 2002), ICCAT records are still incomplete and due to lack of past reporting requirements the prospects of obtaining actual historic catch records are slim. At the same time concerns regarding high and often unrestricted levels of mortality to pelagic sharks are growing (Camhi et al. 2008; Dulvy et al. 2008). Under these circumstances, it is therefore imperative to develop alternative historic shark catch time series and to carefully evaluate whether

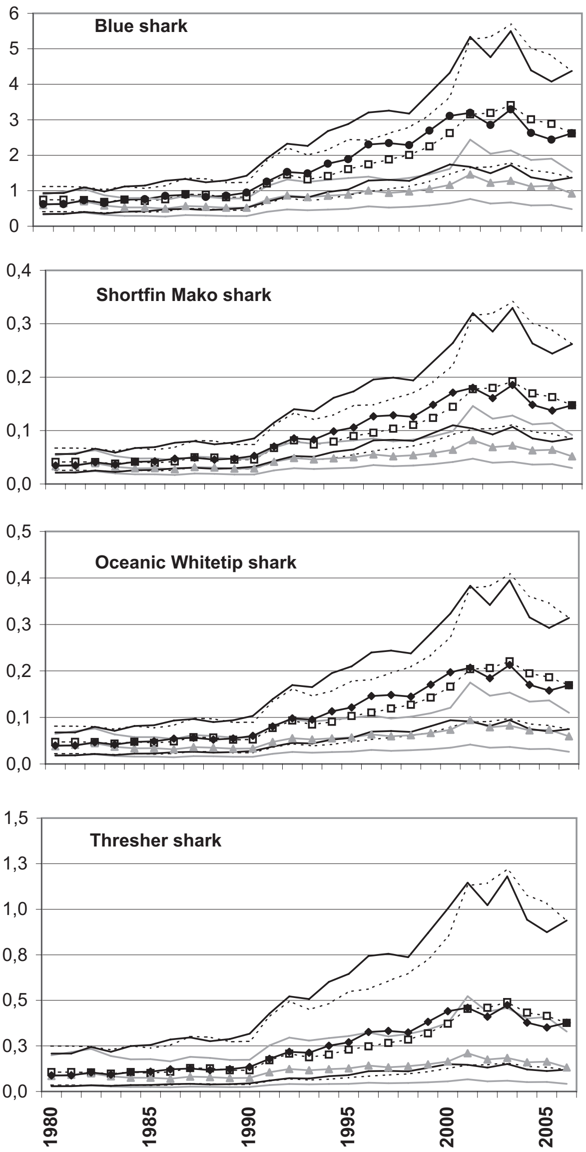

Fig. 1. Estimates of historic shark catches by species (in million sharks), using area- (□), tuna catch- (▲) and effort- (♦) proportioning methods to scale global estimates to the Atlantic.

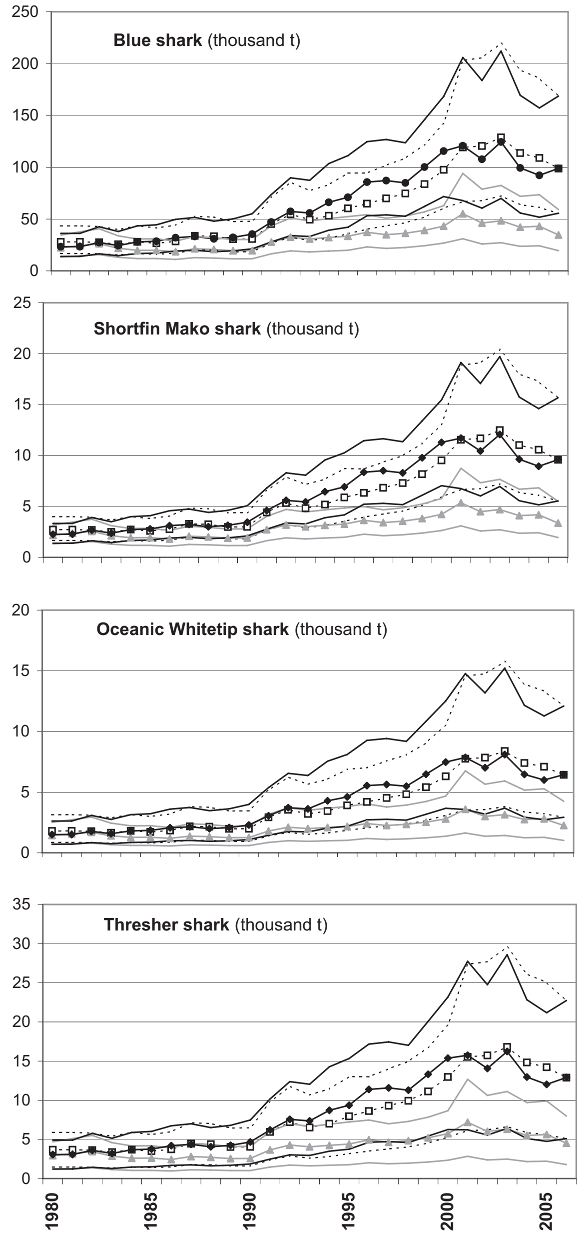

Fig. 2. Estimates of historic shark catches by species (in thousand t), using area- (□), tuna catch- (▲) and effort- (♦) proportioned methods to scale global estimates to the Atlantic. Blue and shortfin mako catches estimated using ratios between catches of sharks and tunas/billfishes in the ICCAT database by gear type, fleet and area; applying these ratios to gear-fleet-area strata which did not report their catches to ICCAT; and adding the calculated (unreported) catches to the reported catches (ICCAT 2007) are shown with a solid black line (▬).

these alternative series can fill some of the existing, critical data gaps.

In this study an existing shark fin trade data set was used opportunistically to produce species-specific estimates of the number and biomass of sharks used in the fin trade from the Atlantic. This dataset was sourced from Hong Kong in 2000 and it currently represents the most comprehensive information available regarding the global shark fin trade. It is not likely that a study of similar depth will be undertaken in the near future because the shark fin trade is becoming increasingly less concentrated in Hong Kong and thus harder to study. Working with the 2000 dataset implies a number of assumptions which must be considered when interpreting the results. First, it is necessary to adopt the assumption in Clarke et al. (2006a) that the species composition of the sampled portion of the Hong Kong shark fin trade is representative of global species composition. Second, additional assumptions are required in order to extrapolate these data over the entire time span of interest. Specifically, use of the Clarke et al. (2006a) dataset to estimate values for other years assumes that 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 these assumptions are problematic in that some stock composition shifting would be expected over time, there are no existing data with which to explore alternative assumptions. Therefore, of necessity, it is assumed that the range of variability resulting from these factors is reflected in the specification of the probability intervals within the model. Finally, it is assumed that each of the four species assessed is equally likely to be found in the Atlantic as in any other ocean. This appears to be a reasonable assumption given what is known regarding pelagic shark habitat.

There are several reasons why the trade-based estimates are likely to be conservative. 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. 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; b) released but subsequently die due to injury or stress; or c) are retained but whose fins are either not used at all or used within the country of landing.

These two points emphasize that trade-based estimates reflect minimum estimates of sharks used in the trade and are thus fundamentally different from reported catches or catch estimates. Actual catches may in fact be higher than the trade-based estimates but they are very unlikely to be lower (i.e. unless there are major errors in the trade-based estimates). This point is also relevant to interpretation of the increasing estimates of sharks used in the fin trade over time (Figs. 1 and 2). Since it is not known whether the cause of the rise is increased catches, increased utilization of fins, or both (Dulvy et al. 2008), it cannot be confirmed that the trend is reliable over the entire time series. However, as the annual trade-based estimates represent confirmed minimum levels of fishing mortality in each year, any estimates which are substantially lower than these levels should be suspect. It is less certain, but still worth considering, that if as expected, fin utilization in recent years is high and mortality to sharks released with their fins intact is low, trade-based estimates in recent years may provide a reasonable proxy for catch figures.

Having argued that despite some limitations, trade-based estimates may approximate minimum catch estimates, it is now necessary to consider how the different trade-based estimates compare to available catch data. In the previous ICCAT shark stock assessment (ICCAT 2005) in order to compensate for the fact that reported catches were known to represent only a portion of total removals an alternative method for estimating catches was applied. This method involved calculating ratios between catches of sharks and tunas/billfishes in the ICCAT database by gear type, fleet and area; applying these ratios to gear-fleet-area strata which did not report their catches to ICCAT; and adding the calculated (unreported) catches to the reported catches (ICCAT 2005, ICCAT 2007). This type of annual alternative catch estimates calculated by ICCAT for blue shark from 1980-2005 ranges from 34–67 thousand t and suggests a gradual decline since 1995; annual alternative catch estimates for shortfin mako for the same time period range from 4–11 thousand t and show an increasing trend since 1997 (Fig. 2).

One of the major differences between blue shark and shortfin mako shark logbook recording practices is that in the past the large difference between the price of the two species' meat (Vannuccini 1999) is believed to have resulted in a greater retention rate and recording rate for shortfin makos (Nakano and Clarke 2006). Nevertheless, catch recording for shortfin makos is unlikely to be perfect. Therefore, while the trend in reported catches may be reliable, the actual catch levels may not be, e.g. if only a portion of fishermen are logging their catches accurately. Since the alternative catch estimates for shortfin mako lie above the trade-based estimates from 1980-1995 and from 2004-2005, there is no reason to doubt that the alternative catch estimates in these years represent the best available estimate of shortfin mako catches. Since the alternative catch estimates lie slightly below both the area- and effort-proportioned trade-based estimates in 1996-2003, they may be slightly under-reporting catches during this period, but the overall agreement between these three types of estimates remains generally good. In summary, after comparison with trade-based estimates, the ICCAT alternative catch estimates for shortfin mako appear reasonable.

It is noted that in recent years the tuna-catch proportioned trade-based estimates are considered less credible than the other two trade-based estimates. This is because this proportioning method assumes that when tuna catches in the Atlantic are low, shark catches in the Atlantic are also low, even though it is known that some fisheries switch to targeting sharks when tunas are scarce (i.e. an inverse relationship). In particular, a major shift in longline target species by Spain in the Atlantic was observed beginning in 1997 (Clarke and Mosqueira 2002) which coincided with declines in reported tuna catches and increases in reported shark catches (FAO 2008). In this way, the assumption that shark catches are proportional to tuna catches, particularly in the Atlantic, is tenuous in recent years, and by applying this assumption the tuna-catch trade-based estimates for shortfin makos since 1997 are likely to be under-estimates.

Comparison of the various estimates for blue shark shows a similar pattern to those for the shortfin mako until the mid-1990s. For blue shark the alternative catch estimates lie above all of the trade-based estimates until 1994. Afterward, rather than showing increased catches as might be expected from the information presented above, alternative estimates of blue shark catches gradually decline. In the last few years of the time series, the alternative catch estimates are very similar to the tuna-catch proportioned trade-based estimates which, as discussed above, are believed to be under-estimates. From 2000-2005 the alternative catch estimates and tuna catch-proportioned trade-based estimates are generally less than half of those estimated using the area- and effort-proportioning methods. It is thus considered that alternative catch estimates for blue shark since 2000 may be under-estimated by at least 100%. It may not be appropriate, for reasons discussed above, to treat the area- or effort-proportioned trade-based estimates for blue shark as catch estimates for years beginning in the mid-1990s when the ICCAT alternative catch estimates and the area- and effort-proportioned estimates diverge. However,

Table 5. Shark catches reported to ICCAT and alternative catch estimates (in thousand t) for 1980-2006 as described in ICCAT (2007). Annotations: "na" indicates no data reported. Asterisk (*) indicates that reporting may not have been complete at the time these data were presented.

Year	Blue Shark		Shortfin Mako Shark	
	Reported to ICCAT	Alternative catch estimate	Reported to ICCAT	Alternative catch estimate
1980	na	34.3	0.5	4.3
1981	0.2	37.9	1.0	4.1
1982	<0.1	50.7	1.7	5.6
1983	0.6	47.8	0.9	5.1
1984	0.1	47.3	1.8	5.6
1985	0.4	58.7	3.8	8.9
1986	1.2	65.8	2.0	7.7
1987	1.5	66.7	1.0	7.3
1988	0.9	64.6	1.6	7.7
1989	0.8	51.8	1.6	6.4
1990	2.3	53.5	1.3	5.9
1991	3.5	58.0	1.3	6.3
1992	2.3	54.4	1.4	5.8
1993	7.9	63.7	3.0	7.6
1994	8.3	64.1	3.0	7.6
1995	8.4	66.3	4.9	10.3
1996	9.0	63.2	2.8	7.6
1997	36.9	56.1	5.6	6.1
1998	33.2	50.9	5.5	6.4
1999	34.2	53.0	4.1	5.8
2000	38.5	53.0	5.0	6.2
2001	34.3	50.2	4.7	8.7
2002	31.4	44.0	5.4	8.3
2003	35.3	38.6	7.4	9.4
2004	35.4	36.7	7.5	11.0
2005*	20.6	39.3	4.0	10.8
2006*	2.6	na	0.2	na

if further alternative estimates are lacking and if it can reasonably be assumed that fin utilization is high and unaccounted for mortality is low, this may be the best currently-available option.

This discussion has shown that neither the trade-based estimates nor the alternative catch-based estimates are ideal, but both are preferable to relying on existing reported catches alone (Table 5). The main issue with the trade-based estimates is that they may not reflect all fishing-related mortality since not all sharks caught in Atlantic fisheries have had their fins traded internationally from 1980-2006. In this sense, it is advisable to treat the trade-based estimates primarily as minimum values for comparison. If the trade-based estimates are to be used as proxy values for catch, a number of the assumptions outlined above need to be carefully considered. In lieu of either trade-based estimates or catch figures, a number of different methods for calculating alternative catch estimates are possible, including the method used by ICCAT (2007). The key concern with the ICCAT (2007) method is that it only accounts for unreported catches and does not attempt to compensate for catches which may be under-reported (i.e. including reports of zero catch). The ICCAT method also needs to assume accurate reporting of shark catches in at least some strata (fleet, gear type, area) in order to develop the ratios between tuna and shark catches. Unless these ratios are careful specified and/or allowed to vary over time, this method may suffer from bias as targeting strategies shift within fleets. Given the urgent need for improvement in historic catch data for sharks, further study of these and other methods is strongly encouraged.

Supplementary Materials (only available in electronic form)

Table S1. Shark fin trade model implemented in WinBUGS software version 1.4.3 (Imperial College London 2008) using triangular and uniform distributions as well as deterministic calculations.
Table S2. Estimates in number of shark catches in the Atlantic Ocean, 1980-2006 (all figures in millions of sharks).
Table S3. Estimates in biomass of shark catches in the Atlantic Ocean, 1980-2006 (all figures in thousand t).

Acknowledgements. An earlier version of this paper was first submitted to the ICCAT Shark Data Preparatory meeting held in Punta del Este, Uruguay in June 2007. The author wishes to thank the United States government for providing travel funding to support attendance at this meeting and the Brazilian government for allowing participation in the meeting as a member of the Brazilian delegation. This paper was revised in preparation for the ICCAT Shark Stock Assessment held in Madrid, Spain in September 2008. The author's participation in this meeting, as a member of the United States delegation, was supported by funding provided by the University of Miami. T. Lawson of the Secretariat of the Pacific Community (SPC) generously assisted with data provision for the Pacific. Two anonymous peer reviewers are thanked for providing comments which improved the methodology and clarified the findings.

References

Camhi M., Pikitch E., Babcock E. (Eds.), 2008, Sharks of the Open Ocean: biology, fisheries and conservation. Blackwell, Oxford.

Clarke S., 2004a, Understanding pressures on fishery resources through trade statistics: a pilot study of four products in the Chinese dried seafood market. Fish Fish. 5, 53–74.

Clarke S., 2004b, Shark product trade in Hong Kong and Mainland China, and implementation of the shark CITES listings. TRAFFIC East Asia, Hong Kong.

Clarke S., Mosqueira I., 2002, A preliminary assessment of European participation in the shark fin trade. Proc. 4th Eur. Elasmobranch Assoc. Meeting, Livorno, Italy, 2000. ICRAM, ARPAT-GEA & Soc. Fr. Ichtyologie, pp. 65–72.

Clarke S.C., McAllister M.K., Milner-Gulland E.J., Kirkwood G.P., Michielsens C.G.J., Agnew D.J., Pikitch E.K., Nakano H., Shivji M.S., 2006a, Global estimates of shark catches using trade records from commercial markets. Ecol. Lett. 9, 1115–1126.

Clarke S.C., Magnussen J.E., Abercrombie D.L., McAllister M.K., Shivji M.S., 2006b, Identification of shark species composition and proportion in the Hong Kong shark fin market based on molecular genetics and trade records. Conserv. Biol. 20, 201–211.

Clarke S., Milner-Gulland E.J., Bjørndal T., 2007, Social, economic and regulatory drivers of the shark fin trade. Mar. Resour. Econ. 22, 305–327.

Dulvy N.K., Baum J.K., Clarke S., Compagno L.J.V., Cortés E., Domingo A., Fordham S, Fowler S., Francis M.P., Gibson C., Martínez J., Musick J.A., Soldo A., Stevens J.S., Valenti S., 2008, You can swim but you can't hide: the global status and conservation of oceanic pelagic sharks and rays. Aquat. Conserv. Mar. Freshw. Ecosyst. 18, 459–482.

FAO (Food and Agriculture Organization), 2008, FishSTAT Capture Production (1950-2006) Database. Accessed online at http://www.fao.org

Ferris, G.D. 2002, What Change in China Means for Trade in Hong Kong. AgExporter, March 2002. Accessed online at http://findarticles.com/p/articles/mi_m3723/is_3_14/ai_84879836.

HKSARG (Hong Kong Special Administrative Region Government), 2008, Census and Statistics Department, unpublished data, 1996-2006.

ICCAT (International Commission for the Conservation of Atlantic Tunas), 2002, ICCAT Data Preparatory Meeting for Atlantic Shark Stock Assessment. Col. Vol. Sci. Pap. ICCAT 54, N°4, 1064–1106.

ICCAT (International Commission for the Conservation of Atlantic Tunas), 2005, Report of the 2004 Inter-sessional meeting of the ICCAT Subcommittee on by-catches: shark stock assessment. Col. Vol. Sci. Pap. ICCAT 58, N°3, 799–890.

ICCAT (International Commission for the Conservation of Atlantic Tunas), 2006, Report of the Standing Committee on Research and Statistics, Oct. 2006. ICCAT, Madrid.

ICCAT (International Commission for the Conservation of Atlantic Tunas), 2007, Report of the 2007 Data Preparatory Meeting of the Shark Species Group, Punta del Este, Uruguay June 25 to 29, 2007.

ICCAT (International Commission for the Conservation of Atlantic Tunas), 2008, Task II Catch/Effort Catalogues (T2CE), 1950-2006. Available online at http://www.iccat.int/accesingdb.htm

Imperial College London, 2008, WinBUGS software (version 1.4.3). Available online at http://www.mrc-bsu.cam.ac.uk/bugs/

IOTC (Indian Ocean Tuna Commission), 2008, Catch and effort database for longlines, 1950-2006. Available online at http://www.iotc.org/English/data/databases.php

Miyake M.P., 2007, Factors affecting recent developments in tuna longline fishing capacity and possible options for management of longline capacity. In: Miyake M.P., Bayliff W.H., Majkowski J. (Eds.).Methodological Workshop on the Management of Tuna Fishing Capacity: stock status, data envelopment analysis, industry surveys and management options. La Jolla CA, 8–12 May 2006, FAO Fish. Proc. 8, 1813–3940.

Nakano H., Clarke S., 2006, Filtering method for obtaining stock indices by shark species from species-combined logbook data in tuna longline fisheries. Fish. Sci. 72, 322–332.

SPC (Secretariat for the Pacific Community), 2008, Tuna Fishery Catch and Effort Query System, 1950-2003, Available online at http://www.spc.int/oceanfish/Html/Statistics/Ces/index.htm and data for 2004-2006 via personal communication with T. Lawson, Secretariat of the Pacific Community, August 2008.

Tanaka S., 1994, East Asian fin trade. Shark News 2, 6.

TRAFFIC 1996, The World Trade in Sharks: A Compendium of TRAFFIC's Regional Studies (Vol. 1 and 2). TRAFFIC International, Cambridge, UK.

Vannuccini S., 1999, Shark utilization, marketing and trade. Food and Agriculture Organization, Rome. FAO Fish. Techn. Pap. 389.