6 Conclusions

This chapter presents a summary of the new methods and findings of this research, and a discussion of the remaining issues which require further study. Implications of this study for shark resource management and policy are also presented.

6.1 Summary of New Methods and Findings

This thesis has required extensive collection of data on a sensitive topic. Hong Kong shark fin traders were persuaded to provide 148 daily auction records, which necessitated challenging translation and deciphering, as well as hundreds of shark fin tissue samples, which allowed matching of species with trade names used in the auctions. Through interviews and surveys of traders, greater insight into the structure and practices of the trade was gained. Although Hong Kong provided an excellent base for the study, some data were not available there. To support genetic primer development and testing, and conversion factors, voucher tissue samples were gathered under this study in shark landing ports in Taiwan, Japan, and the United Arab Emirates. Compilation of customs and econometric data required on-site gathering of data, some of which was restricted, in Taiwan, Singapore and Mainland China. Meeting these data collection challenges enabled this study to present original findings on a trade that has often rejected attempts to study it in detail.

Working from this foundation of new data, this study developed a framework for compiling and analysing trade data for the purpose of estimating population exploitation rates and comparing them to reference points based on stock assessment. One of the key strengths of the framework is that it accounts for uncertainty at each step and presents estimates in the form of confidence (probability) intervals, therefore it can be applied even in data-poor situations. Application of the framework to the shark fin trade was more strongly supported by the available data in some steps than in others, and those steps which would benefit from further data collection and study are discussed in the following section (Section 6.2). As new and better data become available they can be applied within the context of the framework to refine the estimates. The framework can also be easily modified for application to other fisheries or wildlife species of concern.

The remainder of this section highlights the key contributions of this research in terms of both new findings and new methods:

- Application of Bayesian imputation techniques to fill missing values in trade datasets (Chapter 2);
- Use of conversion factors for parts to whole animals in an algorithm which incorporates uncertainty (Chapter 2);
- Design of a sampling programme for, and testing of, new molecular genetic techniques for identifying shark species from their parts (Chapter 3);
- Estimation of total and species-specific numbers and biomass of sharks represented in the global shark fin trade (Chapter 4);
- Evaluation of the sustainability of current trade-derived harvest levels for blue shark based on fisheries reference points (Chapter 4);
- Quantification of a linkage between disposable income in Mainland China and growth of the shark fin trade (Chapter 5); and,
- Discovery of new information on shark fin products, trade structure, and trader attitudes (several chapters).

6.1.1 Application of Bayesian Imputation to Fill Missing Values in Trade Datasets (Chapter 2)

Missing data, due to blanks, lack of necessary specificity, or data lying outside the acceptable range of values, is a widespread problem in fisheries and wildlife analysis. In the past, investigators simply ignored incomplete records, or employed observed data to fill missing values using the mean or a simple regression model. In recent years, formal methods have been developed to fill missing values and allow analysis of the dataset as if it were complete. One of these methods, multiple imputation, involves iteratively simulating missing observations using a predictive model and then combining the results to provide a single inference about the parameter of interest while factoring in uncertainty due to missing data.

This study applied WinBUGS software, which provides a built-in feature for multiple imputation, to generate data for shark fin trade records which were wholly unavailable, or available but lacking lot weight information. Bayesian multiple imputation methods were used to simulate 313 missing individual lot weights from a total of 2,293 lot weights contained in 148 auction records, and then used the complete set of auction records to predict data for an additional 365 wholly unobserved auctions. By combining multiple imputation features with a hierarchical model structure, which mines the data as well as the data structure for relationships that inform the model estimation, this study illustrated two important methodologies for circumventing problems arising from missing data. These methodologies are straightforward and accessible, and have excellent potential for a wide variety of fisheries and wildlife analyses commonly constrained by incomplete data series.

6.1.2 Use of Conversion Factors for Parts to Whole Animals which Incorporate Uncertainty (Chapter 2)

It is often desirable to convert animal parts to whole animal equivalents in order to evaluate the number of individuals or total biomass present. Such conversions may require several steps to calculate ratios and translate between lengths and weights. In most cases, conversion factors are based on a limited number and range of data points, and calculations are often applied in a deterministic manner. Conversion factors are already important in shark fishery management: many of the current or proposed bans on shark finning allow fins to be removed from carcasses prior to landing, and conversion factors are necessary to check fin weights against whole weights to evaluate whether all carcasses are present.

In attempting to calculate whole shark numbers and biomass from individual fin measurements, this study faced difficulties in locating or generating appropriate conversion factor datasets (i.e. most existing factors operate on the weight of all fins combined). While the data used in this study are not ideal (see Section 6.2.2), the estimates of fin weights, and whole shark lengths and weights, were usually within ranges of empirical values observed in the field, and are believed to represent the best existing algorithms for these conversions. Furthermore, the methodology for applying these data to Bayesian linear models explicitly incorporates both parameter and observation uncertainty and thus maximizes the utility of the data without ignoring the variability that characterizes many of the calculated relationships. These analyses can be updated as better datasets become available to produce improved versions of the conversion factors used in this study. The methods developed are also recommended for application to other conversion algorithms such as those being developed in support of shark finning bans.

6.1.3 Design of a Sampling Programme for Applying and Testing New Molecular Genetic Techniques Capable of Identifying Shark Species from their Parts (Chapter 3)

Molecular genetic methods for identifying shark species from DNA using polymerase chain reaction (PCR) primers were developed in parallel with this study by scientists at the Guy Harvey Research Institute of Nova Southeastern University, and were first tested on dried fins collected for this research. The initial aim of applying these primers to the Hong Kong shark fin market was to characterize species composition, but this proved unworkable due to access constraints, and therefore this study focused instead on matching trade names with taxonomic classifications. Practical sampling targets were defined by limiting the scope of the study to 11 common market categories which were believed to contain species for which species-specific genetic primers were available. The survey was then designed to sample those categories across as broad a range of traders and source countries as possible. The achieved sample size (n=596) and distribution provided robust estimates of the probability that a given sample from a particular market category would correspond to the expected species or genus. These results were then paired with trade records that describe shark fins by trade name, to estimate the species composition of the trade.

Blue shark (*Prionace glauca*) were estimated to comprise approximately 18% of traded fins by weight, whereas hammerheads (*Sphyrna* spp.) and silky (*Carcharhinus falciformis*) sharks constituted approximately 6% and 4% by weight, respectively. All of the other identified species in the shark fin market were found to comprise less than 3% by weight. These figures are considered minimum estimates since it is possible that additional numbers of studied species are traded in unidentified market categories and are thus not included in these percentages.

This study has integrated molecular genetic testing with sampling design and existing trade information, establishing a methodology for monitoring the Hong Kong shark fin trade. This methodology may also prove suitable for similar wildlife trade studies operating under budgetary and sample access constraints.

6.1.4 Estimation of Total and Species-specific Numbers and Biomass of Sharks Represented in the World Shark Fin Trade (Chapter 4)

Obtaining a sizeable set of daily auction records from the world's largest shark fin entrepôt provided this study with a unique opportunity to estimate the number and biomass of sharks represented in the world trade. A Bayesian hierarchical model was first applied to estimate the traded weight over an 18 month period for each of eleven common market categories and an extra category for all other fins, and in each of three distinct fin position categories. Size class distributions for fins provided on the auction sheets were used in combination with conversion factors (described above) to calculate the weight of a single fin of each shark type-fin type combination in an iterative, probabilistic manner. The quotient resulting from division of the total traded weight by the estimate of the weight of a single fin gave the number of sharks represented for dorsal and caudal fin positions, and half the number of sharks represented for pectoral fins. Further conversion factors were applied to probabilistically translate the length of a single fin to the corresponding length and weight of the whole shark.

Once customs statistics had been used to extrapolate figures to represent the entire world trade, the number of sharks was estimated at 17-89 million per year, and the shark biomass was estimated at 0.5-4.5 million metric tonnes. FAO capture production statistics indicate that approximately 350,000 mt shark are caught each year, but the FAO figures may underestimate the true amount of catches due to under- or non-specific reporting of shark landings, and/or reported landings of fins only. This analysis offers the first quantitatively rigorous estimates of the scope of the global shark fin trade and provides a benchmark for future monitoring and assessment.

6.1.5 Evaluation of Current Trade Derived Harvest Levels for Blue Shark against Fisheries Reference Points (Chapter 4)

The estimates of numbers and biomass presented above, though interesting, do not provide any insight into whether the utilization of sharks by the shark fin trade is sustainable. This insight can be gained from comparison to fisheries reference points, such as maximum sustainable yield (MSY), but despite concerns regarding the potential overexploitation of sharks (FAO 1999), very few shark stock assessments have been performed. Stock-specific or regional reference points would be the preferred basis for comparison but since the trade-based estimates in this study could not be partitioned by stock or even ocean basin, global reference points were applicable.

Two studies of blue shark (*Prionace glauca*) were identified and used to construct and contrast estimates of maximum sustainable yield (MSY) for this species in the North Pacific and the world ocean, based on a simple two-dimensional area extrapolation. One study (Kleiber et al. 2001) provided a value for MSY based on a comprehensive age-structured stock assessment. The other study was used only as a cross-check and consisted of population and catch estimates for 1988 (Nakano and Watanabe 1991) and was used in a surplus production model under scenarios comprising a range of values for the intrinsic rate of increase and natural mortality to estimate the carrying capacity and MSY. After extrapolation, the global estimate of MSY in number of sharks ranged from 7 to 13 million blue sharks per year based on the Kleiber et al. (2001) study and as high as 21 million based on the cross-check calculations. This range encompassed the range of trade-based median estimates (11 to 16 million blue sharks per year) but lay below the highest trade-based estimate (75 million blue sharks per year).

These findings do not support a conclusion that blue sharks are being unsustainably harvested for the fin trade on a global level. However, if any regional populations of blue shark have considerably lower values for MSY per unit area or are being fished more intensively than indicated in the global assessment, these populations could be overexploited. Blue shark is one of the most productive and resilient of shark species, and therefore this assessment cannot be used to make any inferences about trade-derived harvest rates for other shark species. Conclusions regarding the sustainable or unsustainable use of other species, and thus of the shark fin trade as a whole, cannot be drawn until a broader suite of appropriate fishery reference points has been developed.

6.1.6 Quantification of a Linkage between Disposable Income in Mainland China and Growth in the Shark Fin Trade (Chapter 5)

The relationship between economic development in China and the expansion of the global trade in shark fins has long been suspected, but never quantitatively evaluated. This study has modelled the market demand for shark fins as a function of price, income, substitute price and exchange rates for Hong Kong and Mainland China and found that the only significant variables are those reflecting income and consumer spending. A demand model based on disposable income in Mainland China, a measure of consumer spending in Hong Kong, and a seasonal effect accounts for over 80% of the variance in the dependent variable. A simple projection based on this model suggests that the shark fin trade will grow by 5.7% per annum. However, several factors, including predicted declines in expenditures on luxury goods, price increases if supplies become limited, and potential heightened consumer awareness based on shark conservation campaigns, may act to reduce demand. Given the currently limited understanding of the impact of the shark fin trade on shark populations, any increase in demand for shark fins will only serve to exacerbate existing concerns for vulnerable species and underscore the need for appropriate shark fisheries management.

6.1.7 Discovery of New Information on Shark Fin Products, Trade Structure and Trader Attitudes

Gathering data in the shark fin market of Hong Kong resulted not only in the findings described above, but also a large amount of qualitative information concerning the trade itself. By providing details of how traders name, sort, size and market shark fin products, this study facilitates the design of future monitoring programmes. This study also provides an improved understanding of product flows from source countries through Hong Kong to Mainland China. This type of knowledge is important in deriving and applying accurate adjustment factors for customs data and understanding the full magnitude of the trade. Finally, this study provides insights into trader attitudes toward their business, the sustainability of shark populations and the actions of the conservation community. Understanding traders' sensitivities provides a basis for improved communication on trade monitoring and/or resource management issues in the future.

6.2 Remaining issues for Further Research

This section describes the limitations of the present study and highlights areas, in order of priority, for further research. Suggestions for improving ongoing monitoring programmes and implementing new ones are also provided.

6.2.1 Validation and Expansion of Molecular Genetic Primer Library

In this research, selection of shark fin market categories for study was based largely on the availability of polymerase chain reaction primers to identify the species expected to be found in these categories. Optimally, when targeting any one market category, validated primers should be available for the all of the taxa expected to be present in that category. Furthermore, for a primer to be considered fully validated, it must be shown to amplify samples of the target species from all potential subpopulations, and not amplify any other species or their subpopulations.

The primer development and testing undertaken in parallel with this study has made rapid progress in providing tools for shark species identification, but additional validation testing must continue until the unlikely possibility of multiple species amplification (false positives) or differential amplification within a species (false negatives) is eliminated. Much of this work is constrained by acquiring voucher tissue samples from rare sharks, but once obtained, these specimens will allow for validation testing of existing primers and development of new primers for rare species.

In addition to the ongoing development of new primers for species recently listed on CITES Appendix II such as basking (*Cetorhinus maximus*) and whale (*Rhincodon typus*) sharks, other species of conservation concern such as guitarfish and sawfishes (Rhinobatidae and Pristidae, believed to be traded as ‘Qun’) should be a priority. Better primer coverage of the numerous species of Carcharhinidae identified by traders simply as ‘Qing’ (translated as blacktip, potentially *Carcharhinus limbatus*, *C. tilstoni*, *C. melanopterus*, and others) would aid in defining a large proportion of the trade that could not be differentiated in this study.

6.2.2 Additional Data to Support Conversion Factors

In contrast to the detailed and extensive auction datasets obtained for this study, the data available to support conversions from traded fin weights to numbers and biomass of sharks were very limited. Data on the relationship between fins' market size category and actual length (n=179) were, due to trader sensitivities, compiled in Hong Kong through observing others' measurements, visual calibration and interviews. Fin length to fin weight conversions were based on measurements obtained from 397 fins, representing a range of market categories, fin positions and sizes, provided by a cooperative Hong Kong trader. Fin wet-to-dry weight ratios were based on 28 data points from a previous study (Fong 1999). Individual fin length to whole shark length measurements were taken from 124 sharks representing seven species at a fishing port in Taiwan.

The final step in the algorithm, i.e. converting from shark length to shark weight, was the only step for which ample data existed. Even so, the length-weight relationships in the literature varied in using total length, fork length or pre-caudal length, and most did not include any measure of the variance in the dependent variable given the independent variable. Parameter estimates differed, sometimes widely, between studies, highlighting the importance of methodology and the potential for discrepancies to be introduced if parameters are drawn from different studies.

While the datasets assembled for this study represent an adequate starting point for conversion algorithms, resulting estimates vary by up to an order of magnitude by fin position and can undoubtedly be improved. Data collection on a species-specific basis to refine the conversion steps defined by this study and allow improved future estimates could be easily incorporated into fisheries sampling programmes and should be prioritized. This effort could be undertaken in parallel with other studies to improve datasets and estimation algorithms necessary to support existing and proposed shark finning bans. Any such conversion factors should always be reported with an associated margin of error so that the compounded variance of estimates resulting from more than one conversion step can be fully appreciated.

6.2.3 Determination of Confidence Intervals for Customs Datasets through Monitoring

Extrapolation factors based on the volume of the global shark fin trade and Hong Kong's proportional share were formulated based on national customs datasets and compounded uncertainties associated with the fin-based conversion factors discussed above. The range of customs-based extrapolation factors used in this study caused the estimates of shark numbers and biomass to vary by considerably less than the order of magnitude observed in the conversion factors above. However, the precision of these extrapolation factors is based only on a relative comparison of national customs datasets as published, without any means of quantifying how accurately these figures represent the true traded quantities. Therefore, the uncertainty in these extrapolation factors can be only partially quantified on the basis of existing information.

Like many traded goods, shark fin quantities are often difficult to compare between customs jurisdictions due to discrepancies in commodity codes. Numerous systems exist worldwide to harmonize such codes, yet even the most subtle of differences can prevent meaningful tracking. The utility of customs data currently being collected could be considerably improved by encouraging all national customs authorities to distinguish between raw and processed shark fins and between frozen and dried raw fins.

In addition to improving the consistency of reported quantities worldwide, a programme for auditing shark fin import declarations in key trade entrepôts should be developed.

Although Hong Kong's under-reporting bias has been shown by this study to be relatively less than that of other shark fin trading countries, the true degree of under-reporting remains unknown. Even a very small scale auditing programme in Hong Kong would provide quantification of biases in declared versus actual quantities. With such data reflecting the absolute bias, and pair-wise comparisons similar to those conducted in this study to identify relative biases, the Hong Kong trade data could be used to form an estimate of globally traded quantities. Pursuing this type of quantification is particularly important given that the FAO Commodities Production and Trade dataset suffers from several problems including non-reporting, mismatching of commodity codes and double-counting of trans-shipped goods, and cannot be relied upon to provide an accurate quantification of the world trade.

6.2.4 Benchmarking and Sustainability Studies for Informing Fisheries Policy

One of the purposes of this study was to provide a quantitative 'snapshot' characterization of the shark fin trade for the first time. The benchmarks established in this study, for example species composition, numbers and biomass of sharks represented, will be most useful if they can be contrasted to similar future calculations. Therefore, ongoing studies of the shark trade should be initiated to allow tracking of trade levels and changes in species composition. Changes in the shark fin trade may mirror changes in shark fisheries and in this way monitoring the trade can communicate important trends to shark fishery managers.

In addition, comparison of trade-based estimates to fisheries reference points should be expanded to include a greater range of species. There is considerable scope for expansion within the set of species studied in this research, but this will require that species-specific stock assessments be conducted. An ability to determine the proportion of traded fins by both species and stock or ocean basin, perhaps through more advanced molecular genetic techniques such as microsatellites, could enable future trade-based estimates to be directly linked to particular fisheries and their reference points, and avoid the complications associated with conducting comparisons at the global level.

Finally, although this was a study of the shark fin trade, it is concerned with the number of sharks killed for the trade, rather than the means and motivation of the killing, for example whether sharks were finned. Trade monitoring focuses on the opposite end of the supply chain from finning, and since it is difficult to link shark fin trade figures to particular regions or shark populations, it is even more difficult to determine whether those sharks were finned or retained whole. As long as finning continues in some fisheries, trade monitoring as conducted in this study possesses an important advantage over fishery monitoring as it is insensitive to discrepancies in landings data arising from reporting whole sharks, carcasses plus separated fins, or fins only. Trade monitoring cannot address the issues of cruelty (i.e. how many sharks are finned alive), wastage (i.e. what is the disposition of the carcass), or the incentive to catch more sharks (i.e. how many sharks will be released alive under various scenarios). However, it provides a practical, scientifically-based method for estimating the number of sharks killed, a key resource sustainability issue.

6.3 The Importance of Trade Monitoring for Sharks

Analysis of catch data will always be preferred over analysis of trade data for establishing the status and sustainability of fisheries populations. Unlike trade data, catch databases generally report whole organisms in numbers or biomass, and often include information on species, size, sex and location of capture. However, there may be cases in which the quality and quantity of catch data is so poor that trade data provide equal or better opportunities for understanding whether populations are threatened by exploitation.

Sharks may be one of the best examples of the need for trade studies. Shark species are generally ignored or given a low priority in most fisheries management systems due to their characterization as bycatch and their low value per unit weight. The resulting lack of catch or landings data severely inhibits the types of assessments conducted for more data-rich fishery species. At the same time, shark fins are being sourced globally through special market channels to supply consumer demand concentrated in a handful of Asian trading centres. Although it may not address all the issues of concern at the required level of detail, monitoring the markets for shark fin in Asia may be the only viable option for determining shark exploitation rates and population pressures worldwide.

The use of trade data presents a unique set of challenges because, unlike fisheries stock assessment, there are few if any standardized methodologies and models which can be applied. This study has demonstrated that technical, access and funding difficulties associated with studying the shark fin trade can be overcome with only a limited staff, budget and study timeframe. Given the small investment and large potential information returns, and the inability of most existing fisheries management systems to address real concerns about shark over exploitation, shark fin trade studies both can and should play a role in shark resource management.