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Variation in whole-, landed- and trimmed-carcass and fin-weight ratios for various sharks captured on demersal set-lines off eastern Australia

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ABSTRACT

Sharks are important apex predators in marine systems but many populations have experienced large declines, which has resulted in adverse effects on marine food webs. Sharks are also economically important, as their fins are valued in Asian markets. In response to concerns about declining shark populations, a number of nations, including Australia, have developed national plans of action for their conservation and management. As part of New South Wales' (NSW) efforts to understand the characteristics of their shark fishery, data were collected on the depth of capture, species, sex, body length and weight, fin weight, and reproductive status of individuals caught in the NSW commercial 'large shark' demersal set-line fishery. We created models of the relationship between fin to body weight and wastage (discarded or low value portions of the carcass) and compared the ratios of whole, landed, trimmed, and fin weight to determine the relationship between fin weight and wastage to length by species. Our results indicate that length, sex, and the interactions between length with species and sex account for differences in the relative fin weight of sharks; whereas species, length, and their interaction account for differences in the proportion of a shark carcass that is wasted. The data reveal that catching smaller sharks will increase relative fin weight and decrease wastage. Given these results, we recommend that managers consider weight ratio data information in their decision making to promote a sustainable and profitable shark fishery.

1. Introduction

As apex predators, sharks are important members of many marine food webs (Heithaus et al., 2008). Sharks are also economically important, and although their meat is generally low value (Vannuccini, 1999), the fins (especially in the ceratotrichia) are a valuable commodity as the Chinese middle class grows and the demand for shark-fin soup increases (Cook, 1990). Many shark populations around the globe have declined more than 50% since the early 1980s (Baum et al., 2003; Ferretti et al., 2010), and this global decline has been to the detriment of marine food webs and seafood-based economies (Walker, 1998; Stevens et al., 2000; Heithaus et al., 2008). According to the fisheries data reported to the Food and Agriculture Organisation of the United Nations (FAO), shark landings increased between 1950 and 1997 from 121,000 metric tonnes to 414,000 tonnes; whereas reported landings decreased since the 1997 high (FAO, 2012 in Worm et al., 2013). However, the reported trade volume of shark fins has continued to grow steadily, suggesting that there is a discrepancy between catch and trade data (Worm et al., 2013). This discrepancy may be attributed to illegal, unregulated, and unreported (IUU) landings of sharks. Indeed, Worm et al. (2013) estimated that 22% of the global shark catch is IUU. If global shark populations are to be managed sustainably, there must be more rigorous reporting of catches and less IUU fishing.

In response to growing awareness and concern about the status of shark populations, the FAO devised the International Plan of Action for the Conservation and Management of Sharks (IPOA Sharks) in 1999 (FAO, 1999). The aim of IPOA Sharks is to promote conservation and sustainable management via improved data

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collection, monitoring, and management of shark fisheries. As of 2012, 17 of the 26 countries with the largest shark fisheries had adopted a national plan of action for sharks (NPOA Sharks), and five other countries were in the process of adopting a plan (FAO-COFI, 2012). Commonly adopted management measures include restrictions on finning, technical measures, protected species, Total Allowable Catches, and quotas, licences and permits, reporting and research activities, monitoring measures, capacity building, and public awareness. Despite progress in developing and implementing NPOA Sharks, there are a number of challenges facing FAO member countries, including a lack of shark-specific fisheries management regimes, a lack of funds, staff, and institutional practices, and the low political priority for shark conservation (Fischer et al., 2012).

Sharks are often caught as bycatch and discarded (Molina and Cooke, 2012) or only the fins are retained (Bonfil, 1994). As such, they are rarely recorded by fishers or identified to the species level. Further, many shark species are highly mobile (Hammerschlag et al., 2011), crossing the management boundaries of countries and international organizations (e.g. Barnett et al., 2011), making comprehensive stock assessment and management difficult (Bonfil, 1994). For these reasons, baseline population numbers and global catch statistics are largely unknown. In addition, most shark species have slow growth, late sexual maturity, and low fecundity, a suite of life history traits that confer a low intrinsic rate of population increase such that sharks are extremely vulnerable to fishing mortality (Dulvy et al., 2008). In response to these challenges, many of the countries involved in IPOA Sharks have taken steps towards improved shark fishery management (Fischer et al., 2012). Whereas shark fisheries have the potential to affect marine ecosystems by removing top predators, carefully managed shark fisheries can avoid detrimental effects (Walker, 1998).

Australia participates in IPOA Sharks and, following a review of the 2004 Australian NPOA Sharks, prepared a second National Plan of Action for the Conservation and Management of Sharks (Shark-plan 2) in 2012 (http://www.daff.gov.au/fisheries/environment/sharks/sharkplan2; October, 2014). The country's fishing resources are managed both by the Commonwealth and the individual states/territories. This plan has promoted significant improvements in the collection of catch and effort data from commercial fisheries though logbook and observer programmes, improved identification of species caught via the development and distribution of identification guides to fishers, the implementation of management practices such as restrictions on fishing areas and gears, trip limits, and specific management programmes for species of concern (Bensley et al., 2010). In addition, fishers are prohibited from landing fins that are not attached to shark carcasses in order to prevent finning (Fischer et al., 2012). To promote the appropriate management of regional shark populations, the Department of Primary Industries in New South Wales, Australia, has conducted research on shark assemblage structure, their biology, fishing gear details, survival, and spatio-temporal catch information for the ocean trap and line fishery, which is the primary harvester of large sharks (Macbeth et al., 2009; Geraghty et al., 2014; Broadhurst et al., 2014). Shark catch monitoring in NSW has relied on measures of processed weight and whole weight to compare the catch of different fisheries. This likely leads to inaccuracies in catch estimates and may significantly over- or under-estimate the catches of some species. For example, processed weight and whole weight do not describe the relative value of fins or flesh among the different species and size classes of sharks.

The objective of this study was to determine the relationships between body weight and fin weight, as well as body weight and wastage for some of the most common shark species captured in the NSW 'large' shark fishery, with body size and sex as factors. We consider the discarded head, guts, body fat, belly flaps, and unwanted fins (pelvic, second dorsal, anal, and upper caudal lobe; Fig. 1) as wastage, although the belly flaps and unwanted fins have a small value as bait. To achieve this objective, we sampled sharks on board commercial fishing vessels and compared the ratios of whole, landed, trimmed, and fin weight to determine proportion of fin weight or wastage for each species by length and sex. The optimal models for each relevant weight ratio were selected based on the biological data to determine whether variation in value and wastage was related to biological factors.

2. Materials and methods

Sharks were targeted from two commercial fishing vessels that worked offshore between Nambucca Heads (30°34′ S 153°13′ E) and Wooli (29°56′ S 153°26′ E) in northern NSW, Australia over 17 days between January and June 2013. The crew and fishing gear were the same on each vessel. On each fishing day, a demersal set-line was deployed from the vessel in 49–100 m of water after sunset for 7–22 h. Four hundred and eighty gangions (each set 20 m apart) were connected to the anchored mainline (3.2 mm nylon monofilament) via a stainless steel clip rigged with 3.6 m of 400-kg monofilament line and a 16/0 non-offset circle hook baited with approximately 0.3 kg of sea mullet (*Mugil cephalus*) or eastern Australian salmon (*Arripis trutta*).

At sunrise each day, the line was retrieved via a hydraulic winch. Immediately after capture, each shark was hauled onboard and measured (pre-caudal length – PCL, centred fork length – CFL, and total length – TL – to the nearest mm with a tape measure; Fig. 1), weighed (whole weight – to the nearest kg with 'Nagata' electronic scales), sexed and tagged (with numbered anchor tags for later identification). All live sharks considered likely to survive (based on their vigour) were then released. To classify their reproductive status, where appropriate, each male had their claspers categorized as (A) flaccid, (B) semi-rigid or (C) fully rigid, whereas each female had their uterus categorized as (A) thin and empty, (B) thick at posterior, (C) entirely thick, (D) contains yolky eggs, (E) contains embryos or (F) very thick and flaccid (adopted from Walker, 2007) following necropsy. All carcasses were then stored in wet ice for 6–48 h before the (a) landed (headed and gutted), (b) trimmed (landed weight minus fins and belly flap) and (c) fin (first dorsal, right and left pectorals, and bottom caudal fin) weight (to the nearest 0.1 kg) were weighed using electronic scales (Mettler Toledo and Nagata) at the dock (all as per normal commercial operations).

2.1. Data analysis

Data were first explored using Cleveland dot plots, boxplots, and scatterplots to identify patterns and influential observations. To facilitate analyses with interactions, missing values and shark species with small sample sizes (<10) were removed from the analyses. Trimmed to whole weight (TW/WW), trimmed to landed weight (TW/LW), fin weight to whole weight (FW/WW), fin weight to landed weight (FW/LW), and fin weight to trimmed weight (FW/TW) were modelled using generalized least squares models and a backwards model-selection single-term deletion procedure using log-ratio tests at $\alpha = 0.05$ (drop1 command in R; Chambers, 1992). Full models included the predictors: shark species, sex, centred fork length (cm), and all two-way interactions. Our full fixed-effects models took the form:

$$\begin{aligned}\text{Ratio}_i = {} & \propto_i + \beta_1 \times \text{Species}_i + \beta_2 \times \text{Sex}_i + \beta_3 \times \text{CFL}_i + \beta_4 \\ & \times \text{Species}_i : \text{Sex}_i + \beta_5 \times \text{Species}_i : \text{CFL}_i + \beta_6 \\ & \times \text{Species}_i : \text{CFL}_i + \varepsilon_i\end{aligned}$$