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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:

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

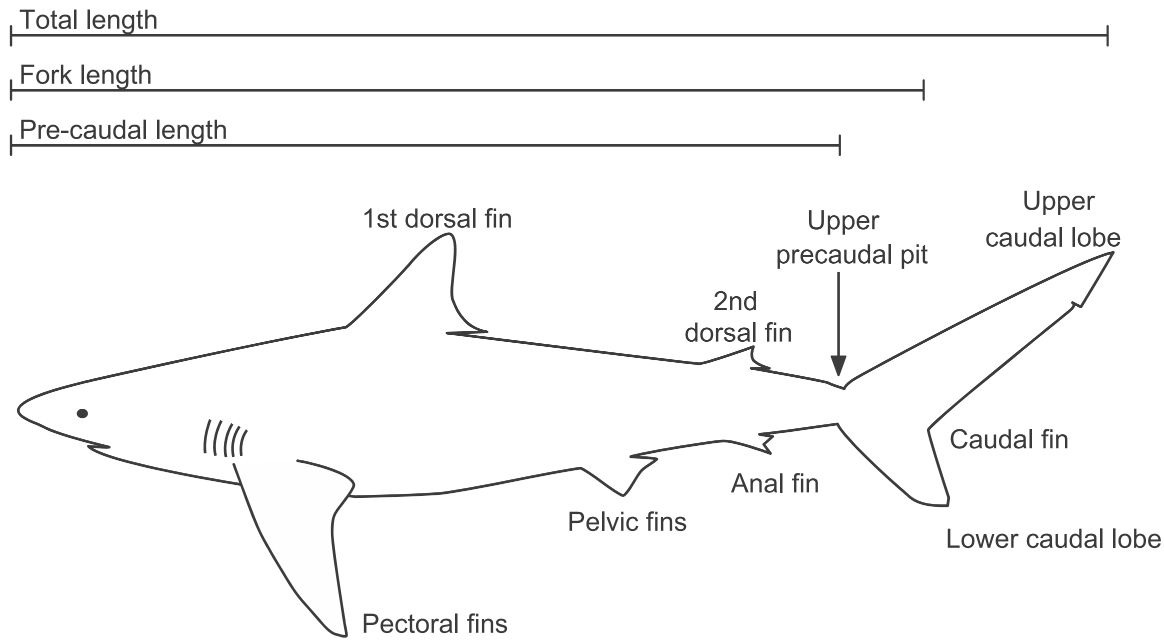

Fig. 1. Length measurements and fin anatomy of sharks.

$\varepsilon_i \sim N(0, \sigma^2)$

where each ratio of the ith sample was modelled as a function of species$_i$, sex$_i$, centred fork length (CFL$_i$), and all two-way interactions. The error term was assumed to follow a normal distribution with a mean of zero and variance of σ^2.

Sampling date was included as a random effect (intercept) in the full model if this was supported by AIC (ΔAIC < 2, Akaike, 1974). If included, a random intercept was assumed to be normally distributed with a mean of zero and variance d^2. The analysis examined whether there was support for residual variances which depended on the levels for the fixed effects (Pinheiro et al., 2014; Zuur et al., 2009). After model selection was performed on the full models, we ensured that the underlying statistical assumptions were met by examining plots of the standardized residuals versus theoretical quartiles (Q–Q plots), plots of the residuals versus fitted values, and checking the variance of the residuals for each level of all predictor variables. Optimal model coefficients were estimated using REML estimation (West et al., 2006). Statistical outputs of the final models were given as the effect sizes (F-statistics) for each model term. The importance of individual terms was given as the likelihood ratio where the full minimal adequate model was compared against a model that excluded the particular term and all of the interaction terms in which it was involved. Statistical analyses were conducted using the 'nlme' package in the R statistical-programming environment (version 2.15.3) (Pinheiro et al., 2014; R Core Development Team, 2014).

3. Results

A total of 347 sharks were sampled during the study, consisting of 289 carcharhinid and 58 hammerhead sharks (Table 1). Bronze whaler (*Carcharhinus brachyurus*) and tiger (*Galeocerdo cuvier*) sharks were removed from the analysis because of their small sample size. All species were caught across similar depth ranges; common black tips (*Carcharhinus limbatus*; 49–84 m), dusky whaler (*Carcharhinus obscurus*; 51–100 m), scalloped hammerhead (*Sphyrna lewini*; 51–100 m), great hammerhead (*Sphyrna mokarran*; 53–84 m), sandbar (*Carcharhinus plumbeus*; 49–95 m), and spinner (*Carcharhinus brevipinna*; 49–100 m). The regression equations calculated for the relationship between CFL and WW had coefficients of determination that ranged from 0.836 (common black tip) to 0.939 (scalloped hammerheads) (Fig. 2). Of the individual sharks whose reproductive status was assessed, the largest proportion of common black tips, dusky, and great hammerhead were classified as sexually mature (C), whereas scalloped hammerhead and spinner sharks were most commonly classified as immature (A) (Table 1).

The full model for TW/WW was not improved by allowing the residual variance to depend on species (L-ratio = 3.47, d.f. = 5, P = 0.63) nor did it appear necessary when examining residuals plotted against the categorical predictors. Based on AIC, a random effect did not improve the full model (AIC$_{\text{full model + random effect}}$ = 996.6; AIC$_{\text{full model}}$ = 932.8). Therefore, the optimal model included species, centred fork length, and its interaction (McFadden's Pseudo R^2 = 0.579; Table 2; Supp. Table 1). TW/WW decreased with body length for all species except scalloped hammerhead (Fig. 3). For example, TW/WW in relatively small to large (195–295 cm) dusky shark was predicted to decrease by 18.4% (195 cm CFL: mean fit$_{\text{TW/WW}}$ = 0.467, 0.452–0.483, 95% CI; 295 cm mean CFL: fit$_{\text{TW/WW}}$ = 0.381, 0.366–0.397, 95% CI) whereas TW/WW from small to large (87 cm CFL to 187 cm CFL) scalloped hammerhead was predicted to increase by 5.1% (87 cm CFL: mean fit$_{\text{TW/WW}}$ = 0.554, 0.524–0.584, 95% CI; 187 cm CFL: mean fit$_{\text{TW/WW}}$ = 0.582, 0.552–0.612, 95% CI).

Supplementary Table 1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2015.02.008.

The full model for TW/LW was not improved by including a variance structure on species (L-ratio = 9.91, d.f. = 5, P = 0.08). The full random-effects model was not competitive with the full fixed-effects model (AIC$_{\text{full model + random effect}}$ = 907.6; AIC$_{\text{full model}}$ = 852.2). The optimal TW/LW model therefore contained species, centred fork length, and their interaction (McFadden's Pseudo R^2 = 0.435; Table 2; Supp. Table 1). Similar to the model for TW/WW, the model for TW/LW indicated that TW/LW decreased with increasing body length for all shark species except scalloped hammerhead. TW/LW rapidly declined with increasing body length in both dusky and spinner shark whereas scalloped

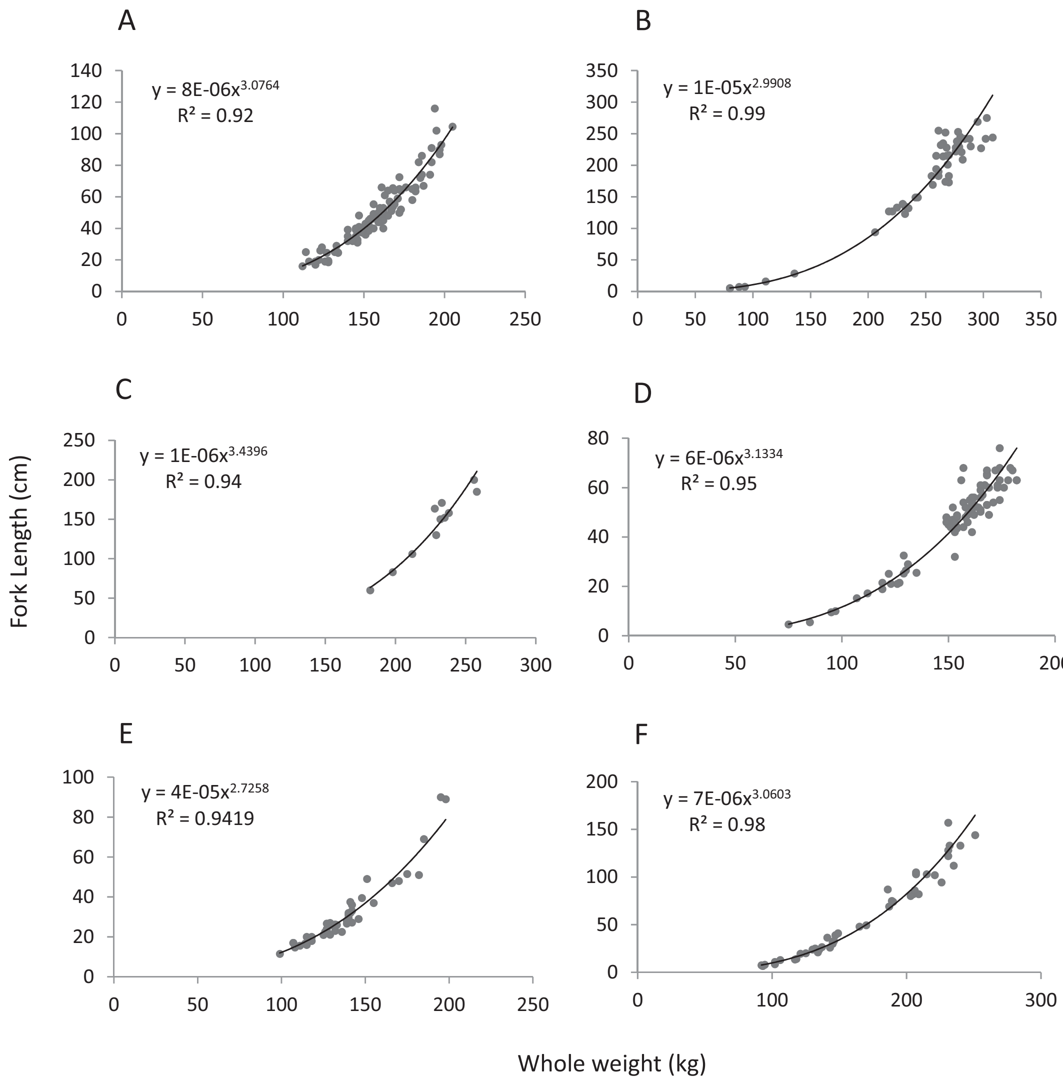

Fig. 2. Length-weight relationships for (A) common black tip, (B) dusky whaler, (C) great hammerhead, (D) sandbar, (E) scalloped hammerhead, and (F) spinner sharks caught by commercial vessels off northern NSW, Australia.

hammerhead TM/LM showed a slight increase with body length (Fig. 4).

The full model for FW/WW was improved by allowing the residual variance to depend on species (L-ratio = 32.9, d.f. = 5, P < 0.0001). A random effect was not included in the optimal model ($AIC_{full\ model + random\ effect}$ = 2298; $AIC_{full\ model}$ = 2335). The form of the optimal model for FW/WW was species, sex, centred fork length and the interaction between species and sex, species and centred fork length, and a variance structure for species (McFadden's Pseudo R^2 = 0.530; Table 2; Supp. Table 1). On average, females had a higher ratio of FW/WW. For example, based on confidence limit overlap, an average sized (233 mm CFL ± 2.64 SE) female great hammerhead had a significantly higher ratio of FW/WW than an average sized (220 mm CFL ± 3.57 SE) male great hammerhead (♀: mean $fit_{FW/WW}$ = 0.050, 0.043–0.059, 95% CI; ♂: mean $fit_{FW/WW}$ = 0.037, 0.032–0.041, 95% CI). The model further indicated that FW/WW declined with fork length for all species but spinner shark (Supp. Table 1).

As with FW/WW, the full model for FW/LW was significantly improved by allowing the residual variance to depend on species (L-ratio = 32.1, d.f. = 5, P < 0.0001). A random effect was not included in the optimal model ($AIC_{full\ model + random\ effect}$ = 2102; $AIC_{full\ model}$ = 2050). The optimal FW/LW model contained species, sex, centred fork length, the species × centred fork length interaction, and a variance factor on species (McFadden's Pseudo R^2 = 0.538; Table 2; Supp. Table 1). On average, females exhibited significantly higher FW/LW compared to males ($F_{1,319}$ = 5.74, P = 0.017). FW/LW decreased with fork length in only dusky and sandbar shark. The highest ratio of FW to LW was predicted in small dusky and sandbar sharks, however in both species this ratio decreased significantly with body length (Supp. Table 1).

Finally, the FW/TW full model was significantly improved by allowing the residual variance to depend on species (L-ratio = 41.5, d.f. = 5, P < 0.0001). Again, a random effect was not included in the optimal model ($AIC_{full\ model + random\ effect}$ = 1928; $AIC_{full\ model}$ = 1861). This model contained species, sex and the interaction between species and centred fork length interaction, and a variance structure for species (McFadden's Pseudo R^2 = 0.630; Table 2; Supp. Table 1). Females showed greater FW/TW ratios than males for all except scalloped hammerhead. However, the differences between males and females were only significant for averaged sized male and female great hammerhead (Fig. 5). As with FW/LW, the species × fork length interaction showed FW/TW decreased for dusky, great hammerhead, sandbar, and scalloped hammerhead and increased for common black tip and spinner shark (Table 3; Fig. 4). Despite the significant interaction

Table 1
Summary data of shark species caught by commercial fishing vessels in northern NSW, Australia. To define reproductive status, male claspers were categorized as (A) flaccid, (B) semi-rigid or (C) fully rigid whereas female uteruses were 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.

Species	*n*	Average CFL in mm (SD)	Sex			Reproductive status									
			% Male (*n*)	% Female (*n*)	% Not reported (*n*)	%A (*n*) male	%A (*n*) female	%B (*n*) male	%B (*n*) female	%C (*n*) male	%C (*n*) female	%D (*n*)	%E (*n*)	%F (*n*)	% Not reported (*n*)
Bronze Whaler	3	218.7 (±16)	66.7 (2)	33.3 (1)	0.0	0.0	0.0	0.0	0.0	66.7 (2)	0.0	0.0	0.0	33.3 (1)	0.0
Common Blacktip	102	158.1 (±21)	86.3 (88)	12.7 (13)	1.0 (1)	15.7 (16)	1.0 (1)	21.6 (22)	0.0	43.1 (44)	1.0 (1)	0.0	0.0	2.0 (2)	11.8 (12)
Dusky	51	245.1 (±59)	54.9 (28)	43.1 (22)	2.0 (1)	3.9 (2)	3.9 (2)	5.9 (3)	0.0	37.3 (19)	0.0	2.0 (1)	0.0	9.8 (5)	37.3 (19)
Great Hammerhead	11	227.4 (±23)	63.6 (7)	27.3 (3)	9.1 (1)	9.1 (1)	9.1 (1)	9.1 (1)	0.0	45.5 (5)	0.0	0.0	0.0	9.1 (1)	18.2 (2)
Sandbar	82	152.9 (±22)	57.3 (47)	42.7 (35)	0.0	7.3 (6)	2.4 (2)	2.4 (2)	0.0	39.0 (32)	2.4 (2)	2.4 (2)	2.4 (2)	6.1 (5)	34.1 (28)
Scalloped Hammerhead	47	137.2 (±23)	42.6 (20)	55.3 (26)	2.1 (1)	6.4 (3)	23.4 (11)	10.6 (5)	0.0	23.4 (11)	0.0	0.0	0.0	0.0	36.2 (17)
Spinner	44	168.0 (±48)	50.0 (22)	47.7 (21)	2.3 (1)	18.2 (8)	9.1 (4)	9.1 (4)	0.0	15.9 (7)	0.0	2.3 (1)	0.0	11.4 (5)	34.1 (15)
Tiger	7	178.7 (±81)	57.1 (4)	42.9 (3)	0.0	57.1 (4)	0.0	0.0	0.0	0.0	0.0	0.0	14.3 (1)	0.0	28.6 (2)
Total	347														

Source: adopted from Walker (2007).

between species and fork length, confidence limits overlapped for all but the smallest and largest sandbar (e.g., 107 cm CFL ♀: mean $fit_{FW/TW}$ = 0.071, 0.064–0.078, 95% CI; 207 cm CFL ♀: mean $fit_{FW/TW}$ = 0.052, 0.044–0.059, 95% CI) and spinner sharks (e.g., 135 cm CFL ♀: mean $fit_{FW/TW}$ = 0.028, 0.024–0.031, 95% CI; 235 cm CFL ♀: mean fit $_{FW/TW}$ = 0.04, 0.035–0.045, 95% CI).

4. Discussion

The results indicate that fin-to-weight-ratios and wastage vary among size classes, sexes, and species. Optimal statistical models indicated that centred fork length, sex and the interactions of centred fork length with sex and species were all important factors in explaining the ratio of fin weight to body weight (Table 2; Supp. Table 1). With the exception of spinner sharks, relative fin weight decreased as whole weight increased (Supp. Table 1). Female sharks tended to have a greater proportion of fin weight to whole weight, fin weight to landed weight, and fin weight to trimmed weight as compared to males. Shark species, centred fork length, and their interaction were important factors for predicting the proportion of the carcass that is wasted (Table 2; Supp. Table 1). For all six shark species sampled, except scalloped hammerheads, relatively more of the carcass is wasted as whole weight and landed weight increase (Figs. 3 and 4). Given that fins are the most valuable portion of a shark carcass, these data have important implications for management of the NSW shark fishery as smaller sharks, female sharks, and dusky and sandbar sharks (the two primary target species), have relatively greater fin weight to body weight ratios. For example, it may be worthwhile to encourage shorter deployment times for gears to improve ‘at-vessel’ survival rates (P. Butcher, Fisheries NSW, *pers. comm.*) to target higher value species and promote the survival of discarded bycatch.

The species with the highest fin to landed weight ratios were also those that are caught most frequently in the NSW shark fishery. Sandbar sharks are the primary catch of the NSW shark fishery (Macbeth et al., 2009) and have the highest fin to landed weight ratio based on our findings. Dusky sharks are the second most frequent catch of the NSW shark fishery (Macbeth et al., 2009) and have the second highest fin to landed weight ratio. Although many species of sharks are landed in the NSW shark fishery and the flesh is sold locally, catch data from Macbeth et al. (2009) and our ratio data suggest that the fishery is targeting species with the more valuable fins, which are mostly exported to Asia (Clarke et al., 2006).

Our data suggest that using TW, LW, and WW measurements interchangeably when determining fin to body weight ratios should be done with caution given that in our study they produced different results when regressed against important predictor variables; FW/WW declined with fork length for all shark species sampled except spinner sharks (Supp. Table 1), whereas FW/LW declined with fork length only in dusky and sandbar sharks (Supp. Table 1), and FW/TW declined with fork length for all shark species sampled except spinner and common black tip sharks (Fig. 5). Variation in the relative sizes of the body parts removed (head, gut, and belly flaps) between species may be an important source of this variability in fin to body weight ratios. Further, different fisheries and even different boat crews may gut and trim their catch differently (Biery and Pauly, 2012), which would also introduce variability in fin to body weight ratios between TW, LW, and WW measurement. Our data suggest that variation in trimming methods contributes little to the variability in fin to body weight ratios between TW, LW, and WW measurements when the fishing crew and gear are kept consistent. For these reasons we recommend that studies reporting shark catch weight examine whether variation in trimming methods contributes to variability in fin to body weight ratios within and between the catch samples of interest.

Table 2
Summary of the importance of individual terms, including variance structures (var), degrees of freedom (df), and the effect sizes of the optimal models to predict TW/WW, TW/LW, FW/WW, FW/LW, and FW/TW. Model coefficients are provided in the supplementary Table 1. TW – trimmed weight, WW – whole weight, LW – landed weight, FW – fin weight, and CFL – centred fork length.

Response	Model term	*L*-ratio	Numerator df	*F*-value	*P*-value
TW/WW	Intercept		1	43,745	<.0001
	Species	231.1 (df = 5, *P* < 0.0001)	5	67.94	<.0001
	CFL	48.5 (df = 1, *P* < 0.0001)	1	81.31	<.0001
	Species × CFL	18.9 (df = 5, *P* = 0.002)	5	3.94	0.0017
			denominator df: 320		
TW/LW	Intercept		1	71,168	<.0001
	Species	101.8 (df = 5, *P* < 0.0001)	5	25.51	<.0001
	CFL	54.7 (df = 1, *P* < 0.0001)	1	63.61	<.0001
	Species × CFL	46.7 (df = 5, *P* < 0.0001)	5	9.34	<.0001
			denominator df: 320		
FW/WW	Intercept		1	7926	<.0001
	Species	185.5 (df = 5, *P* < 0.0001)	5	90.15	<.0001
	Sex	7.04 (df = 1, *P* = 0.008)	1	9.16	0.003
	Species × Sex	13.2 (df = 5, *P* = 0.021)	5	2.27	0.048
	Species × CFL	48.2 (df = 5, *P* < 0.0001)	6	6.10	<.0001
	Species (var)	32.9, (df = 5, *P* < 0.0001)	5		<.0001
			denominator df: 314		
FW/LW	Intercept		1	7219	<.0001
	Species	217.7 (df = 5, *P* < 0.0001)	5	64.17	<.0001
	Sex	10.6 (df = 1, *P* = 0.001)	1	5.74	0.0171
	Species × CFL	28.0 (df = 5, *P* < 0.001)	6	5.09	<.0001
	Species (var)	32.1 (df = 5, *P* < 0.0001)	5		<.0001
			denominator df: 319		
FW/TW	Intercept		1	7926	<.0001
	Species	217.4 (df = 5, *P* < 0.0001)	5	90.15	<.0001
	Sex	6.8 (df = 1, *P* = 0.009)	1	9.16	0.003
	Species × Sex	15.5 (df = 5, *P* = 0.008)	5	2.27	0.047
	Species × CFL	33.8 (df = 5, *P* < 0.0001)	6	6.10	<.0001
	Species (var)	41.5 (df = 5, *P* < 0.0001)	5		<.0001
			denominator df: 314		

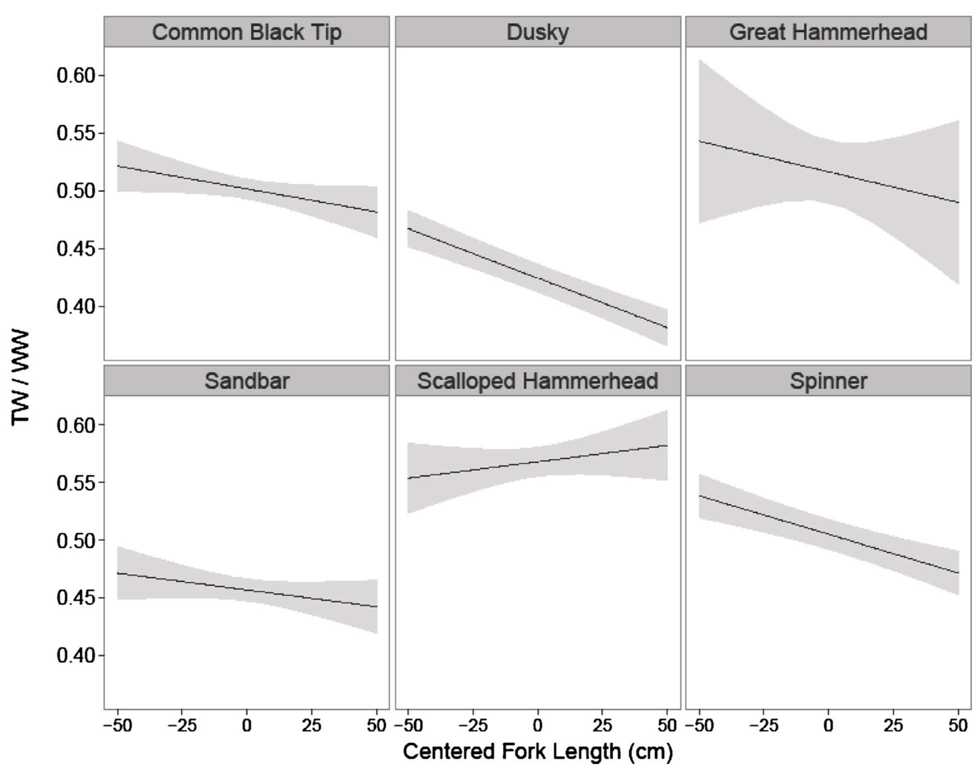

Fig. 3. Model predictions for TW/WW (±95% CI) for six shark species caught by commercial vessels off northern NSW, Australia.

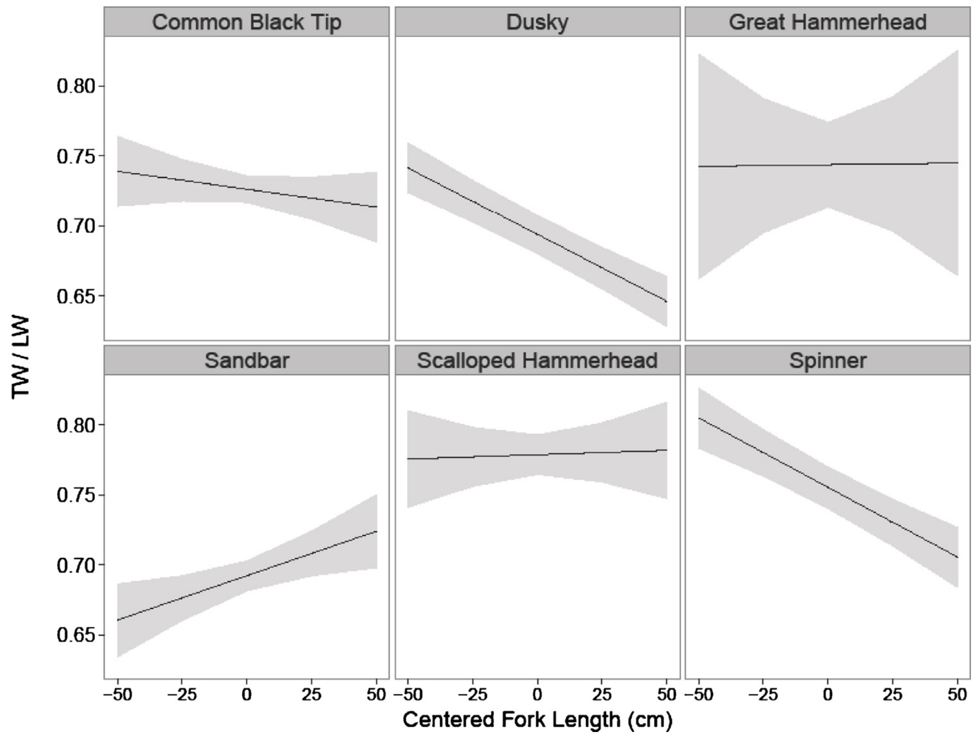

Fig. 4. Model predictions for TW/LW (±95% CI) for six shark species caught by commercial vessels off northern NSW, Australia.

A limited number of studies address the fin to body weight ratios for sharks. For example, most countries, and all regional fisheries management organizations, impose a 5% fin to dressed carcass weight-limit to prevent shark finning (Fowler and Séret, 2010) and studies have been performed to validate this limit (Cortés and Neer, 2006). Fin to body weight ratios have also been characterized to estimate shark catch biomass from fin trade data (Clarke et al., 2006). To the best of our knowledge, this is the first study in which body weights have been used to characterize the relationship between body size, species, sex, and wastage in a commercial shark catch, and the first study to rigorously model shark fin to body weight measurements while including sex as a factor. The

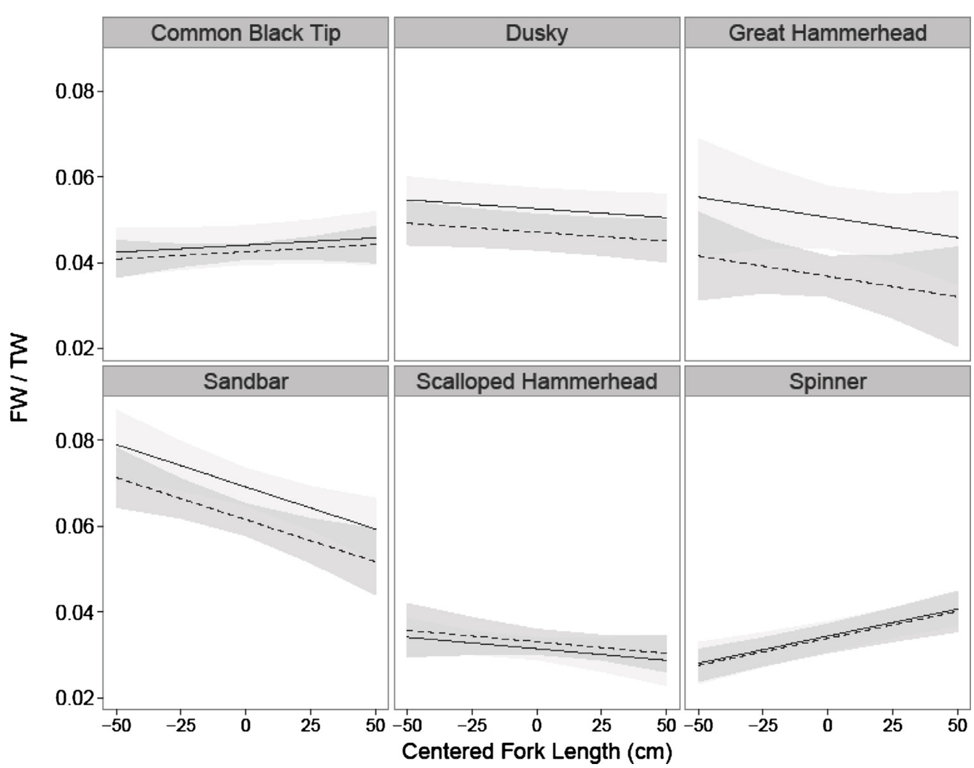

Fig. 5. Model predictions for FW/TW (±95% CI) for male (dotted line, dark grey confidence bands) and female (solid line, light grey confidence bands) shark species caught by commercial vessels off northern NSW, Australia.

Table 3
Sex proportions and mean size (cm ± SD) of the sharks sampled in this study and Macbeth et al. (2009) and the relationship between centred fork length (CFL) and wastage.

Species	Sex			Mean total CFL harvested (SD)[a]	CFL and wastage relationship[b]
	% Male (n)[a]	% Female (n)[a]	% Not reported (n)[a]		
Common Black Tip	75.7 (156)	23.3 (48)	1.0 (2)	203 (±30)	Positive
Dusky	52.7 (158)	43.7 (131)	3.7 (11)	294 (±66)	Positive
Great Hammerhead	63.6 (7)	27.3 (3)	9.1 (1)	288 (±45)	Positive
Sandbar	58.8 (383)	39.8 (259)	1.4 (9)	184 (±30)	Positive
Scalloped Hammerhead	46.0 (46)	48.0 (48)	6.0 (6)	187 (±38)	Negative
Spinner	38.5 (84)	59.2 (129)	2.3 (5)	211 (±59)	Positive

[a] Combined data from this study and Macbeth et al. (2009).
[b] Data from this study.

comparison of weight values to those in other shark fisheries may be of limited value because fin cutting and carcass trimming procedures are likely to vary between fisheries (Biery and Pauly, 2012). Nevertheless, regionally derived data can be useful in developing fisheries management strategies within the region that such data are collected.

Both our data and the data from an observer study by Macbeth et al. (2009) suggest that the NSW Ocean Trap and Line fishery generally captures large, mature sharks (Table 3). Specifically, Macbeth et al. (2009) reported that the majority of sandbar sharks and dusky sharks and a large portion of the spinner and common blacktip sharks caught were large, sexually mature individuals. However, the majority of the small samples of smooth and scalloped hammerhead sharks ($n = 71$ and $n = 53$, respectively) were immature. Harvest data indicate that males were caught in similar or greater numbers than females for sandbar, dusky, common blacktip, and scalloped hammerhead shark species, whereas proportionally more female spinner sharks were caught than males (Table 3). In our study, the majority of common black tip, dusky, great hammerhead, and sandbar sharks whose sexual maturity was assessed were sexually mature. The majority of scalloped hammerhead and spinner sharks assessed were immature. Both the data from Macbeth et al. (2009) and our study indicate that fishers in NSW may not be targeting the sharks with less wastage and greater relative fin weight (Table 3) but rather, those with larger, more valuable fins.

Sharks that have less wastage are more valuable, because they have a greater proportion of flesh that can be sold for consumption. Also, ethical concerns exist around wasting shark carcasses (Bruce, 2010). Given that some of the shark species sampled have proportionally less wastage as size decreases, it may be more appropriate to target smaller sharks. Our data also reveal that smaller sharks have relatively greater fin weight, the most valuable portion of the carcass. However, the fins of larger sharks are considerably more valuable per unit of weight than those of smaller sharks (Anderson and Hudha, 1993). In NSW, anecdotal information from two commercial fishers suggest that fins <23 cm and >60 cm long are sold for A$6–40 per kg and A$100–125 per kg, respectively, at point of first sale, (P. Butcher, Fisheries NSW, *pers. comm.*). To maximize returns, fishers could use body size, wastage, and fin weight relationships for each species together with fin size-value and flesh-value relationships to estimate and target the most valuable sharks. We recommend that managers use life history information in combination with our weight ratio data to develop management schemes that continue to promote both the sustainability and the profitability of the shark fishery in NSW. This may include modelling the potential impact of removing sharks of various sizes on the reproductive rates of those populations.

Despite the inherent challenges, there are promising examples of sustainably managed shark fisheries. On the western and southwestern coasts of Australia, fisheries managers have used controls such as transferable time/gear effort units, catch length limits, restrictions on mesh and hook sizes, net height, and maximum net length, a time-area closure, penalties for catches by non-target fisheries, and fishery monitoring to promote the maintenance or recovery of shark populations (Braccini et al., 2013). In response to management efforts, gummy (*Mustelus antarcticus*), whiskery (*Furgaleus macki*), dusky, and sandbar shark population sizes are slowly increasing following fishery-caused depletions (Braccini et al., 2013). Although rates of increase for these shark stocks are expected to be low, appropriate fishery controls, regular stock assessments with relevant biological reference points, and continued refinement of management schemes have effectively supported the maintenance or recovery of these western and southwestern Australia shark populations while sustaining an active fishery.

Our results suggest that, for some species, catching smaller sharks can increase the value of the catch and reduce wastage. Fin weight and wastage data, together with size at maturity data, could be used by fishery managers to design optimal catch length limits that promote the survival of mature sharks, increase the value of the catch, and reduce wastage. However, this is reliant on the majority of the catch being alive on retrieval so that selective harvesting could take place. Further data on the distribution of species by size and maturity could be used to create gear restrictions, closed seasons, or marine reserves to target sharks within, for example, a particular size limit. Our data suggests that, as in western and southwestern Australia, the NSW fishery could be managed to maintain a sustainable and profitable shark fishery that serves as a model for other shark fisheries.

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