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Contributed Paper

Species composition of the international shark fin trade assessed through a retail-market survey in Hong Kong

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Abstract: *The shark fin trade is a major driver of shark exploitation in fisheries all over the world, most of which are not managed on a species-specific basis. Species-specific trade information highlights taxa of particular concern and can be used to assess the efficacy of management measures and anticipate emerging threats. The species composition of the Hong Kong Special Administrative Region of China, one of the world's largest fin trading hubs, was partially assessed in 1999–2001. We randomly selected and genetically identified fin trimmings (*n = 4800*), produced during fin processing, from the retail market of Hong Kong in 2014–2015 to assess contemporary species composition of the fin trade. We used nonparametric species estimators to determine that at least 76 species of sharks, batoids, and chimaeras supplied the fin trade and a Bayesian model to determine their relative proportion in the market. The diversity of traded species suggests species substitution could mask depletion of vulnerable species; one-third of identified species are threatened with extinction. The Bayesian model suggested that 8 species each comprised >1% of the fin trimmings (34.1–64.2% for blue [*Prionace glauca*], 0.2–1.2% for bull [*Carcharhinus leucas*] and shortfin mako [*Isurus oxyrinchus*]); thus, trade was skewed to a few globally distributed species. Several other coastal sharks, batoids, and chimaeras are in the trade but poorly managed. Fewer than 10 of the species we modeled have sustainably managed fisheries anywhere in their range, and the most common species in trade, the blue shark, was not among them. Our study and approach serve as a baseline to track changes in composition of species in the fin trade over time to better understand patterns of exploitation and assess the effects of emerging management actions for these animals.*

Keywords: Asia, conservation, DNA, fisheries management, forensics, wildlife trade

Composición de Especies del Mercado Internacional de Aleta de Tiburón Evaluada por medio de un Censo de Mercado al Menudeo en Hong Kong

Resumen: *El mercado de aleta de tiburón es un importante conductor de la explotación de tiburones a nivel mundial, la mayoría de los cuales no están manejados a un nivel específico de especie. La información específica de especies en el mercado resalta taxones de preocupación particular y puede usarse para avaluar*

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***Article Impact statement**: One-third of species traded in the Hong Kong shark fin market are threatened with extinction and <10 modeled have sustainably managed fisheries.*

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*la eficiencia de las medidas de manejo y anticipar las amenazas emergentes. La composición de especies en la Región Administrativa Especial de Hong Kong de la República Popular China, uno de los puntos más grandes de venta de aletas, fue evaluada parcialmente entre 1999 y 2001. Seleccionamos al azar e identificamos genéticamente pedazos de aletas (*n = *4800) producidos durante el procesamiento de las aletas, en el mercado al menudeo de Hong Kong entre 2014 y 2015 para evaluar la composición contemporánea de especies dentro del mercado de aletas. Utilizamos estimadores no-paramétricos de especies para determinar que al menos 76 especies de tiburones, batoideos y quimeras suministraban al mercado de aletas y un modelo bayesiano para determinar su proporción relativa dentro del mercado. La diversidad de las especies en el mercado sugiere que la sustitución de especies podría enmascarar la disminución de las especies vulnerables; un tercio de las especies identificadas enfrentan riesgos severos de extinción. El modelo bayesiano sugirió que cada una de ocho especies constituyó >1% de los pedazos de aletas (34.1-64.2% para el tiburón azul [*Prionace glauca*]; 0.2-1.2% para el tiburón toro [*Carcharhinus leucas*] y el tiburón mako [*Isurus oxyrinchus*]); así, el mercado estuvo sesgado a unas cuantas especies con distribución mundial. Muchos otros tiburones costeros, batoideos y quimeras están en el mercado pero con un manejo muy pobre. Menos de diez de las especies que modelamos tienen pesquerías manejadas sustentablemente en cualquier parte de su extensión, incluyendo a la especie más común en el mercado, el tiburón azul. Nuestro estudio y nuestra estrategia sirven como una línea de base para rastrear los cambios en la composición de las especies dentro del mercado de aletas a través del tiempo para entender mejor los patrones de explotación y evaluar los efectos de las acciones de manejo emergentes para estos animales.*

Palabras Clave: ADN, Asia, ciencias forenses, conservación, manejo de pesquerías, mercado de vida silvestre

Introduction

Fisheries-driven declines of many sharks around the world have been linked to trade in their fins, used in shark fin soup (e.g., Vannuccini 1999; Clarke et al. 2006*a*, 2006*b*; Dulvy et al. 2014). Despite the large volume of this global trade, there have been few attempts to monitor it on a species-specific basis (Rose 1996; Vannuccini 1999; Fong & Anderson 2000; Clarke et al. 2006*a*, 2006*b*). Relatively few fishing nations keep accurate species-specific catch data for sharks and their relatives, so it is difficult to assess the effect of fisheries supplying the fin trade on shark populations and species (Dent & Clarke 2015). Trade information can supplement or complement landing information and may improve understanding and regulation of the species composition of fisheries (Eriksson & Clarke 2015).

The trend in the annual import volume of fins in one of the world's largest hubs of the fin trade (Hong Kong Special Administrative Region of China; HK) is similar to the trend in global chondrichthian (sharks, batoids, and chimaeras) landings reported to the UN Food and Agriculture Organization (FAO), which peaked in 2003 and have since declined approximately 20% (Davidson et al. 2015). It is surprising that the fin trade has not declined even more given the inherent vulnerability of this group (Dulvy et al. 2014). This may be explained by geographical shifts in sources, species substitution, or both. The geographic sources of fins have changed somewhat over time (Eriksson & Clark 2015), but there is limited information on possible shifts in species composition. Aggregated trade data are difficult to interpret because they do not capture variation in species-specific trends, which is important for chondrichthians because of their varied life-history traits, ecology, distributions, and conservation statuses (Clarke 2004; Carrier et al. 2012).

Estimates indicate HK imports a substantial fraction of the annual international trade in shark fins; these fins are consumed locally or re-exported (FAO 2016*a*, 2016*b*). This enables multiple avenues for the collection of species-specific information on international patterns of chondrichthian harvest and trade. Clarke et al. (2006*a*, 2006*b*) estimated the total number of individual sharks supplying fins for the trade globally and the proportional contributions of a subset of commonly traded species based on trader records from October 1999 to March 2001. Clarke et al. (2006*a*, 2006*b*) found that importers auctioned about 20% of imported fins after sorting them into approximately 30 trade categories, 11 of which were verified genetically as concordant with a species or species group. The 14 species in these groups comprised about 46% of the auction volume for that year and a half. No one has repeated this work or assessed the species composition of the HK market beyond these species. We sought to assess the contemporary species composition of the HK fin market to assess what percentage of species are threatened with extinction, and how assess have management measures and regional population declines have affected the 14 species previously reported in the market.

Since the last examination of HK in 1999–2001, its fin trade volume has dropped (likely 30–50% of global trade instead of 44–59% [Clarke 2008]); however, it remains a major importer and trades fins with an average of 83 nations annually (Shea & To 2017). Although the auctions described in Clarke et al. (2006*a*, 2006*b*) remain inaccessible, HK has a large dried seafood district (Sheung Wan and Sai Ying Pun), where imported fins are sold by vendors supplied by local fin traders

Table 1. Estimates of the number of chondrichthian species in trimmings from the Sheung Wan market, Hong Kong.

Model	*Estimate*	*SE*	*95% CI*
Homogeneous model (Chao & Lee 1992)	78.378	2.286	76.014–86.254
Chao1 (Chao 1984)	82.561	5.958	76.936–104.520
Chao1-bc (Chao et al. 2005)	81.110	4.976	76.509–99.728
iChao1 (Chiu et al. 2014)	83.851	4.313	78.581–96.872
ACE[a] (Chao & Lee 1992)	82.608	4.744	77.474–98.393
ACE[a]-1 (Chao & Lee 1992)	84.223	6.153	77.808–105.292

[a] *abundance-based coverage estimator (ACE)*

(i.e., those conducting the auctions). Retail market surveys in HK therefore offer a means to assess the species composition of the international fin trade. Previously, the prohibitively high costs of purchasing dried fins for genetic testing, the unwillingness of retailers to donate fin samples, and the difficulty of visually identifying processed fins to species in the market precluded such surveys. We overcame these obstacles by using trimmings produced when traders remove skin, muscle, and basal cartilage during processing (Supporting Information). Retailers collect and sell these trimmings for relatively low prices, enabling robust sampling through randomized purchasing. We suggest that a modeled species composition of these fin trimmings provides an index of the contemporary shark fin trade in HK, which reflects global trade in shark fins given the size of this market (Shea & To 2017). We estimated the total number of species in the shark fin trade based on a random survey of genetically identified fin trimmings collected over 1 year and characterized traded species in terms of taxonomy, habitat type, body size, and conservation status. We also quantified the relative amount of the most common species in fin trimmings and determined whether the species Clarke et al. (2006*a*) recorded still constitute the majority of traded species.

Methods

Sample Acquisition

We produced a list of all of the dried-seafood retail shops that sell shark fins in the Sheung Wan and Sai Ying Pun Districts of HK from January 2014 through February 2015. We focused on these 2 districts because they are the trading centers for dried seafood in the city and vendors selling shark fin outside these areas yielded few stocked trimmings. The list was initially produced by an exhaustive walking tour of these 2 districts during which shops selling shark fins were identified. This list was modified every 6 months to allow for shops going in and out of business and for shops that began or ceased selling fins during the study. From February 2014 to February 2015, shops were assigned a number, and 75 shops were randomly selected without replacement from the complete shop list every 2 weeks. A resident of HK visited these shops in order of selection and sampled them by purchasing 2 bags of trimmings, which averaged 235 pieces per bag (8–1861). If fin trimmings were not present, the next shop was visited until 10 shops yielded 2 bags of fin trimmings each (i.e., 20 bags collected from 10 shops). All trimmings were individually numbered in each bag, and 10 individual trimmings were randomly selected for genetic analyses.

Genetic Identification of Fin Trimmings

Subsampled fin trimmings were washed with distilled water and DNA was isolated under a laminar flow cabinet with Qiagen DNeasy kits (Qiagen, Valencia, California, U.S.A.). A mini-DNA barcoding approach for identifying shark species from degraded samples (Fields et al. 2015) was used to amplify and sequence approximately 120 base pairs from the 5′ end of the cytochrome oxidase I (COI) gene. We used BLAST in GenBank (www.ncbi.nlm.nih.gov) and BOLD in the Barcode of Life Data Systems (http://boldsystems.org/) to compare our sequences to the databases. We considered the species identifiable with this short COI fragment if BOLD returned a 100% species-level match and the sequence's closest match in BLAST was unambiguous. A sequence was considered unambiguous if it had a high homology (>97%) of base calls of high quality (>Q20) and the next species match was at least 2 base pairs different (about 2%). If BOLD and BLAST searches did not yield a conclusive species-level match, a second mini-barcode located at the 3′ end of the COI barcoding region was obtained via polymerase chain reaction (PCR) with 1 M13-tagged forward primer designed for this study and 2 M13-tagged universal fish barcoding reverse primers (details in Supporting Information). These sequences were concatenated to the original sequence and used in BLAST and BOLD searches with the above criteria.

Data Analyses

We created a rarefaction curve from these data in the R package iNEXT (Chao et al. 2014) and estimated the total number of species based on 3 different methods (Table 1)

(Hortal et al. 2006; Basualdo 2011; Gwinn et al. 2016) in the ChaoSpecies function in the R package SpadeR (Chao et al. 2016). iNext uses the different frequency of species to estimate the Hill numbers (Hill 1973), which are used to estimate the number of species at a given number of samples (rarefaction curve). ChaoSpecies estimates the species richness and its confidence interval through multiple methods, including abundance-based coverage estimator (ACE), Chao1, and iChao1, all of which use the frequencies of rare species in the sample to infer the number of undetected species and confidence intervals.

Traded species were characterized in terms of taxonomy (by family), habitat type, size at maturity, and conservation status. Data used to assign species to categories were obtained from the International Union for the Conservation of Nature (IUCN) Red List (IUCN 2016). Habitat type was where the species completes most of its life cycle: oceanic, off the continental shelf in surface waters; coastal, over the continental shelf; and deep benthic, off the shelf and close to the bottom. Size at maturity was categorized as small, maturing at <100 cm total length (TL), or large, >100 cm TL. Conservation status for each species was drawn from IUCN (2016). We counted the number of sustainable fisheries (i.e., operating under assessment-based catch limits) for each species anywhere in its range (Simpfendorfer & Dulvy 2017).

We used a Poisson multinomial model (Baker 1994; Shelton et al. 2012) to estimate species composition of the fin trimmings and a Bayesian framework with noninformative priors to estimate the parameters:

$$Y_{ijkl} \sim \text{Poisson}(e^{\theta_{ijkl}}), \tag{1}$$

where Y_{ijkl} is the total number of fin trimmings of species i in the sample from week j, shop k and bag l, which is assumed to be Poisson distributed, with a mean equal to $e^{\theta_{ijkl}}$. These factors reflected differences over time (week), supply chain (shop), and diversity within a shop (bag). The mean is an exponent to ensure it is positive, and

$$\theta_{ijkl} = \lambda_{jkl} + \beta_i + \delta_{ij} + \gamma_{ik}, \tag{2}$$

where λ_{jkl} is a scaling term associated with the sample size in samples j, k, l (Baker 1994), β_i is the fixed effect of species, δ_{ij} is the random effect of week, and γ_{ik} is the random effect of shop with respect to species. Both δ_{ij} and γ_{ik} are normally distributed random effects with a value drawn from a normal distribution with mean zero and variances σ_δ^2 and σ_γ^2, respectively. Because the proportion of species in each sample (j, k, l) must sum to 1, the β, γ, and δ parameters are all set to 0 for species 1. The proportion of each species in the trimmings is estimated as the exponent of the species effect over the sum of all the exponents of the species effects:

$$P_i = \frac{e^{\beta_i}}{\sum e^{\beta_i}}, \tag{3}$$

where P_i is the proportion of species i in the trimmings and e^{β_i} is the Poisson mean number of samples of a particular species observed at an average sampling event.

A Bayesian framework with noninformative priors was used to estimate the parameters of this model with JAGS (Lunn et al. 2013) in R (R2Jags package [Su & Yajima 2015]) in which a Markov chain Monte Carlo (MCMC) algorithm estimates the posterior distribution of the parameters. The prior for λ_{jkl} was uniform between -100 and 100, as required to make the Poisson likelihood equivalent to the multinomial (Lunn et al. 2013). The prior for β was normal with a mean of 0 (SD = 1000). The prior for the SDs for γ and δ were uniform between 0.0001 and 100. In some model runs, σ_δ^2 and σ_γ^2 were estimated separately for each species and drawn from a lognormal distribution with an estimated mean and variance. The model was also run with no random effects, only a random effect of vendor, and only a random effect of sampling event. The best model structure was chosen based on the deviance information criterion (DIC) (Lunn et al. 2013) (Supporting Information). The MCMC was run with 2 chains for 500,000 iterations with a burn-in of 10,000 and a thin of 100. The Gelman–Rubin diagnostic and effective sample size indicated adequate convergence when the Gelman–Rubin diagnostic was <1.05, and the effective sample size was >400 (Lunn et al. 2013).

Models were fitted to data that included all the species that were at least 1% of the sample with the exception of *Dalatias licha* (species found at 1 vendor and therefore had the potential to not converge well in the model). We used the DIC to determine which model best predicted the species composition. After model selection, the percent cutoff was adjusted downward for as long as the model continued to converge. Species below the cutoff were grouped, and unidentified samples were placed in a separate category. The proportion of each species in the trimmings was conservatively estimated using the final model output; no assumptions were made about the unidentified component.

Evaluation of Survey Design for Quantifying Species Composition

We suggest our estimated species composition of the fin trimmings reflects the broader species composition in the HK fin trade. This is based on the assumption that trimmings from a representative sample of imported fins enter the retail market and processing practices and times are the same for all species. Given the covert nature of the shark fin trade, some of these assumptions are challenging to evaluate directly. Informal conversations with fin traders in HK and Guangzhou indicated fin trimmings sold in HK originate from processing facilities in Hong Kong and Guangzhou. Fins are trimmed of basal muscle, skin, and cartilage, likely just after a fin arrives at a processing center, because these tissues reduce the value of the fin due to their odor (Dent & Clarke 2015). Stockpiling of trimmings is unlikely because they are of relatively low value and perishable. They are used in a cheap version of soup or as a soup base. To determine whether fins from different species are trimmed in a similar way, we measured the length of a subsample of (n = 1787) genetically identified fin trimmings to characterize their size distribution. The size distribution of sampled fin trimmings was wide, so we binned them into 3 categories: small, <41.75 mm ($n = 349$); medium, 41.75–83.5 mm (n = 521), and large >83.5 mm (n = 917). We reran the Bayesian model described previously for all species that were >2% of each size class. A chi-square test was run on a contingency table to test the hypothesis that the size-at-maturity categories (large and small) and the trimming sizes (small, medium, and large) were independent variables.

Results

We visited 334 of 373 retail shops and randomly purchased 480 bags of fin trimmings from 92 retail vendors (24.7% of all retailers). Individual fin trimmings (n = 4800) were randomly selected from these bags, and 82.15% of them were identified to at least the genus level (Table 2). The remaining trimmings failed to amplify after repeated attempts.

We identified 59 species and another 17 groups from 16 families in 8 orders that consisted of sharks, batoids, and chimaeras that were either only identifiable to genus with the barcode available or that consisted of an unresolved species complex (Table 2 & Fig. 1). The rarefaction curve of this sampling reached a plateau (Supporting Information). We used the minimum and maximum confidence intervals from the combined species richness estimates to determine that an additional 0 to 29 taxa occur in the Hong Kong market. Traded species live in a wide variety of habitats, but three-quarters primarily inhabit coastal areas (Fig. 1b). Traded species included a similar proportion of small- and large-bodied taxa (Fig. 1c). Nearly one-third of species recorded in trade were vulnerable (VU) or endangered (EN) (IUCN 2012) (Fig. 1d).

When the Poisson multinomial model was applied to species found in at least 1% of the trimmings sampled, the best model included a fixed effect of species, random effects of shop and week, and variation between species in the variance of the random effects (Supporting Information). This model converged with data for species that were at least 0.4% of the sampled trimmings, including *D. licha*, a category for unidentified samples, and species <0.4% grouped together (Supporting Information). The model with a 0.4% cutoff served as our final model for estimating the species composition of the market. The species composition estimated by the models (Table 3) was sometimes quite different from the raw species com-

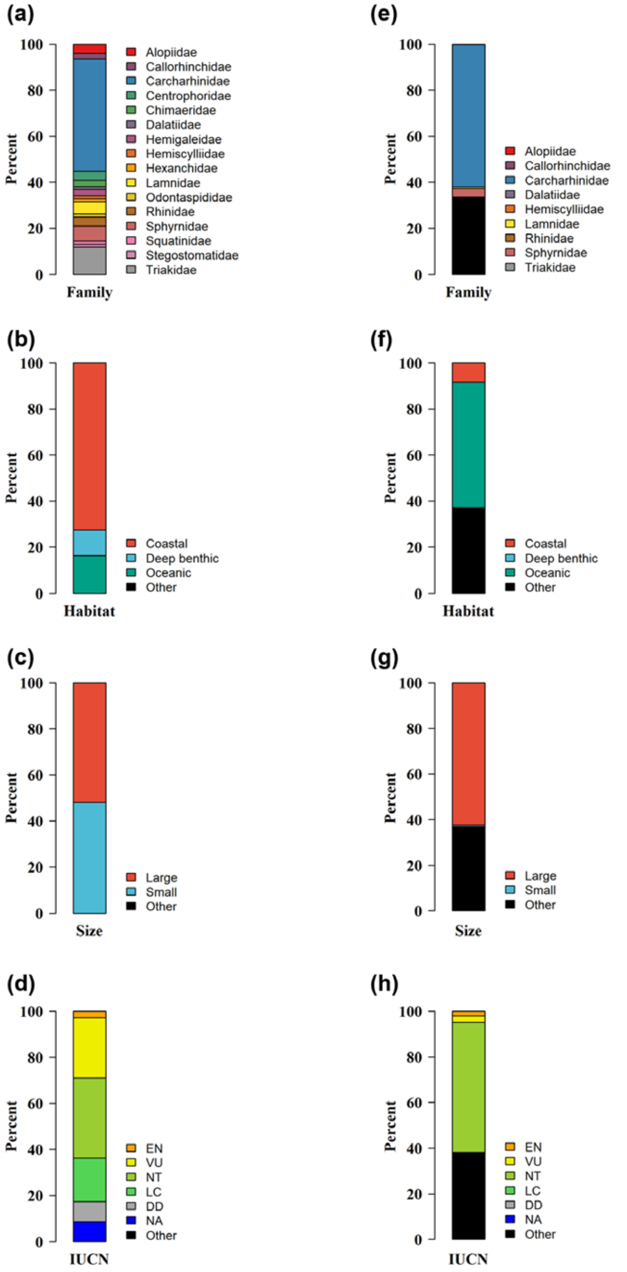

Figure 1. Composition of the identified species by (a and e) family, (b and f) primary habitat type, (c and g) relative size at maturity, and (d, h) conservation status (DD, data deficient; LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered [IUCN 2012]) for both the (a–d) fin trimmings by species groups (n=76) from the Sheung Wan market, and the (e–h) modeled fin trimmings by frequency (other, groups of species that come from more than 1 threat category, including the unidentified group in the model). Species categorized as VU, EN, or CR are considered at risk of extinction (IUCN 2012). Small bodied means species that mature at 100 cm total length or less. See text for habitat definitions.

Table 2. Species or species groups sampled from the Sheung Wan and Sai Ying Pun fin market, Hong Kong; fin trimmings identified to species; and the conservation status of each species.

Order	*Scientific name*	*Common name*	*IUCN*[a]	*CITES status*[b]	*Size*[c]	*Group*[d]	*Habitat*[e]	*Count*	*Percentage of samples*
Carcharhiniformes	*Prionace glauca*	Blue Shark	NT		large	S	oceanic	1632	34.00
Carcharhiniformes	*Carcharhinus falciformis*	Silky Shark	NT		large	S	oceanic	483	10.06
Carcharhiniformes	*C. limbatus, C. amblyrhynchoides, C. leiodon, C. tilstoni*	Blacktip, Graceful, Smoothtooth blacktip, Australian blacktip Sharks	NT		large	S	coastal	198	4.13
Carcharhiniformes	*Sphyrna lewini*	Scalloped hammerhead Shark	EN	II	large	S	coastal	196	4.08
Carcharhiniformes	*Sphyrna zygaena*	Smooth hammerhead Shark	VU	II	large	S	coastal	165	3.44
Lamniformes	*Isurus oxyrinchus*	Shortfin mako Shark	VU		large	S	oceanic	133	2.77
Carcharhiniformes	*Carcharhinus* spp.	Requiem Sharks				S		114	2.35
Carcharhiniformes	*Carcharhinus leucas*	Bull Shark	NT		large	S	coastal	87	1.81
Carcharhiniformes	*Rhizoprionodon acutus*	Milk Shark	LC		small	S	coastal	66	1.38
Carcharhiniformes	*Carcharhinus brevipinna*	Spinner Shark	NT		large	S	coastal	55	1.15
Carcharhiniformes	*Carcharhinus amboinensis*	Pigeye Shark	DD		large	S	coastal	54	1.13
Squaliformes	*Dalatias licha*	Kitefin Shark	NT		large	S	deep benthic	53	1.10
Carcharhiniformes	*Carcharhinus sorrah*	Spot-tail Shark	NT		large	S	coastal	50	1.04
Carcharhiniformes	*Carcharhinus longimanus*	Oceanic whitetip Shark	VU	II	large	S	oceanic	48	1.00
Carcharhiniformes	*Carcharhinus obscurus/galapagensis*	Dusky/Galapagos Shark	VU/NT		large	S	coastal	42	0.88
Carcharhiniformes	*Sphyrna mokarran*	Great hammerhead Shark	EN	II	large	S	coastal	41	0.85
Lamniformes	*Alopias superciliosus*	Bigeye thresher Shark	VU	II	large	S	oceanic	37	0.77
Carcharhiniformes	*Negaprion acutidens*	Sicklefin lemon Shark	VU		large	S	coastal	29	0.60
Chimaeriformes	*Callorhinchus* spp.	Plough-nose Chimaeras	NA		small	C		27	0.56
Rajiformes	*Rhynchobatus australiae complex*	White-spotted guitarfish complex	VU		large	B	coastal	26	0.54
Carcharhiniformes	*Rhizoprionodon taylori*	Australian sharpnose Shark	LC		small	S	coastal	24	0.50
Carcharhiniformes	*Carcharhinus limbatus*	Blacktip Shark	NT		large	S	coastal	21	0.44
Orectolobiformes	*Chiloscyllium* spp.	Bamboo Sharks			small	S	coastal	20	0.42
Lamniformes	*Alopias pelagicus*	Pelagic thresher Shark	VU	II	large	S	oceanic	19	0.40
Squaliformes	*Centrophorus* spp.	Gulper Sharks			small	S	deep benthic	19	0.40
Carcharhiniformes	*Galeorhinus galeus*	Soupfin Shark	VU		large	S	oceanic	19	0.40
Lamniformes	*Lamna ditropis*	Salmon Shark	LC		large	S	oceanic	17	0.35

Continued

Table 2. Continued.

Order	*Scientific name*	*Common name*	*IUCN*[a]	*CITES status*[b]	*Size*[c]	*Group*[d]	*Habitat*[e]	*Count*	*Percentage of samples*
Carcharhiniformes	*Mustelus* spp.	Smoothhound Shark			small	S		17	0.35
Carcharhiniformes	*Rhizoprionodon porosus/terraenovae*	Caribbean/Atlantic sharpnose Shark	LC		small	S	coastal	17	0.35
Carcharhiniformes	*Galeocerdo cuvier*	Tiger Shark	NT		large	S	oceanic	16	0.33
Carcharhiniformes	*Carcharhinus amblyrhynchos*	Grey reef Shark	NT		large	S	coastal	15	0.31
Carcharhiniformes	*Carcharhinus* cf. *dussumieri/dussumieri*	Whitecheek Shark	NT		small	S	coastal	15	0.31
Carcharhiniformes	*Mustelus punctulatus*	Blackspotted smoothhound Shark	DD		small	S	coastal	14	0.29
Carcharhiniformes	*Carcharhinus brachyurus*	Bronze whaler Shark	NT		large	S	coastal	13	0.27
Carcharhiniformes	*Mustelus mosis*	Arabian smoothhound Shark	DD		small	S	coastal	12	0.25
Carcharhiniformes	*Carcharhinus altimus/plumbeus*	Bignose/Sandbar Shark	DD/VU		large	S	coastal	11	0.23
Carcharhiniformes	*Mustelus mustelus*	Common smoothhound Shark	VU		small	S	coastal	10	0.21
Carcharhiniformes	*Carcharhinus acronotus*	Blacknose Shark	NT		small	S	coastal	9	0.19
Carcharhiniformes	*Rhizoprionodon* spp.	Sharpnose Sharks			small	S	coastal	9	0.19
Chimaeriformes	*Hydrolagus novaezealandiae*	Dark ghostshark	LC		small	C	deep benthic	7	0.15
Chimaeriformes	*Hydrolagus* spp.	Other Chimaeras			small	C	deep benthic	7	0.15
Carcharhiniformes	*Rhizoprionodon longurio*	Pacific sharpnose Shark	DD		small	S	coastal	7	0.15
Carcharhiniformes	*Carcharhinus amblyrhynchoides*	Graceful Shark	NT		large	S	coastal	0	0.13
Carcharhiniformes	*Carcharhinus isodon*	Finetooth Shark	LC		small	S	coastal	6	0.13
Carcharhiniformes	*Carcharhinus macloti*	Hardnose Shark	NT		small	S	coastal	6	0.13
Lamniformes	*Lamna nasus*	Porbeagle	VU	II	large	S	oceanic	6	0.13
Carcharhiniformes	*Carcharhinus albimarginatus*	Silvertip Shark	NT		large	S	coastal	5	0.10
Carcharhiniformes	*Hemipristis elongata*	Snaggletooth Shark	VU		small	S	coastal	5	0.10
Carcharhiniformes	*Negaprion brevirostris*	Lemon Shark	NT		large	S	coastal	5	0.10
Squaliformes	*Deania profundorum*	Arrowhead dogfish Shark	LC		small	S	deep benthic	4	0.08
Lamniformes	*Isurus paucus*	Longfin mako Shark	VU		large	S	oceanic	4	0.08
Carcharhiniformes	*Lamiopsis temminckii*	Broadfin Shark	EN		small	S	coastal	4	0.08

Continued

Table 2. Continued.

Order	*Scientific name*	*Common name*	*IUCN*[a]	*CITES status*[b]	*Size*[c]	*Group*[d]	*Habitat*[e]	*Count*	*Percentage of samples*
Rajiformes	*Rhynchobatus* cf. *laevis*		VU		large	B	coastal	4	0.08
Carcharhiniformes	*Scoliodon laticaudus*	Spadenose Shark	NT		small	S	coastal	4	0.08
Carcharhiniformes	*Loxodon* spp.				small	S	coastal	3	0.06
Carcharhiniformes	*Mustelus canis*	Smooth dogfish	NT		small	S	coastal	3	0.06
Carcharhiniformes	*Sphyrna tiburo*	Bonnethead Shark	LC		small	S	coastal	3	0.06
Lamniformes	*Alopias vulpinus*	Common thresher Shark	VU	II	large	S	oceanic	2	0.04
Carcharhiniformes	*Carcharhinus brevipinna/brachyurus*	Spinner Shark/Bronze whaler Shark			large	S	coastal	2	0.04
Carcharhiniformes	*Carcharhinus melanopterus*	Blacktip reef Shark	NT		small	S	coastal	2	0.04
Carcharhiniformes	*Carcharhinus porosus*	Smalltail Shark	DD		small	S	coastal	2	0.04
Carcharhiniformes	*Glyphis* spp.	River Shark	EN		large	S	riverine/ coastal	2	0.04
Carcharhiniformes	*Hemigaleus australiensis*	Australian weasel Shark	LC		small	S	coastal	2	0.04
Carcharhiniformes	*Loxodon macrorhinus*	Sliteye Shark	LC		small	S	coastal	2	0.04
Rajiformes	*Rhynchobatus djiddensis*	Giant guitarfish	VU		large	B	coastal	2	0.04
Chimaeriformes	*Callorhinchus callorynchus*	Elephantfish	NA		small	C	deep benthic	1	0.02
Lamniformes	*Carcharias taurus*	Sand tiger Shark	VU		large	S	coastal	1	0.02
Squaliformes	*Deania* spp.	Deepwater dogfish Sharks			small	S	deep benthic	1	0.02
Carcharhiniformes	*Eusphyra blochii*	Winghead Shark	EN		large	S	coastal	1	0.02
Hexanchiformes	*Hexanchus griseus*	Bluntnose sixgill Shark	NT		large	S	deep benthic	1	0.02
Carcharhiniformes	*Mustelus californicus*	Grey smoothound Shark	LC		small	S	coastal	1	0.02
Carcharhiniformes	*Mustelus henlei*	Brown smoothhound Shark	LC		small	S	coastal	1	0.02
Carcharhiniformes	*Mustelus lunulatus*	Sicklefin smoothound Shark	LC		small	S	coastal	1	0.02
Squatiniformes	*Squatina californica*	Pacific angel shark	NT		small	S	coastal	1	0.02
Orectolobiformes	*Stegostoma fasciatum*	Zebra Shark	EN		large	S	coastal	1	0.02
Carcharhiniformes	*Triaenodon obesus*	Whitetip reef shark	NT		small	S	coastal	1	0.02

[a] *International Union for Conservation of Nature status: DD, data deficient; LC, least concern; NT, near threatened; VU, vulnerable; EN, endangered. Species categorized as VU, EN, or critically endangered (CR) are considered at risk of extinction (IUCN 2012).*

[b] *Convention on International Trade in Endangered Species Appendix.*

[c] *Small bodied defined as species that mature at 100 cm total length or less.*

[d] *Taxonomic classification group: S, shark; B, batoid; C, chimaera.*

[e] *Habitat where species complete most of their life cycle: oceanic, off the continental shelf in surface waters; coastal, over the continental shelf; deep benthic, off the shelf and close to the bottom.*

Table 3. **Estimated mean and 95% CI of the number of fin trimmings in the 2014–2015 Hong Kong market by species from the deviance information criterion best Poisson multinomial model and the rank order of species by abundance from 1999 to 2001 and 2014 to 2015 for species occurring in both this study and Clarke et al. (2006*a*).**

Species or species group	*2014 Mean % (95% CI)*	*Rank order 2014–2015*	*Rank order 1999–2000*	*IUCN category*[a]	*CITES Appendix*[b]	*Retention bans*[c]	*Number of sustainably managed fisheries*[d]	*Range*	*Habitat*
Blue shark, *Prionace glauca*	49.0 (34.1–64.2)	1	1	NT			none	global	oceanic
Silky shark, *Carcharhinus falciformis*[e]	4.6 (2.1–8.7)	2	3	NT	II	IATTC, ICCAT, WCPFC, U.S.A. (Atlantic)	none	global	oceanic
Scalloped hammerhead shark, *Sphyrna lewini*[f],[g]	2.0 (0.9–3.8)	3	2	EN	II	ICCAT	none	global	coastal
Smooth hammerhead shark, *Sphyrna zygaena*[f],[g]	1.7 (0.7–3.3)	4	2	VU	II	ICCAT	none	global	coastal
Shortfin mako shark, *Isurus oxyrinchus*	0.6 (0.2–1.2)	5	4	VU			none	global	oceanic
Bull shark, *Carcharhinus leucas*	0.6 (0.2–1.2)	5	7	NT			none	global	coastal
Oceanic whitetip shark, *Carcharhinus longimanus*[f]	0.3 (0.1–0.6)	7	8	VU	II	IATTC, ICCAT, IOTC, WCPFC	none	global	oceanic
Great hammerhead shark, *Sphyrna mokarran*[f]	0.3 (0.1–0.7)	7	9	EN	II	ICCAT	none	global	coastal
Dusky shark, *Carcharhinus obscurus*	0.3 (0.1–0.7)[h]	7	10	VU		U.S.A. (Atlantic)	none	global	coastal
Thresher sharks, *Alopias vulpinus* & *A. pelagicus*[e]	0.1 (0.0–0.2)	10	6	VU	II	IOTC	one (U.S.A.)	global/regional	oceanic
Bigeye Thresher shark, *Alopias superciliosus*[e]	0.1 (0.0–0.3)	10	6	VU	II	ICCAT, IOTC, U.S.A. (Atlantic)	none	global	oceanic
Tiger shark, *Galeocerdo cuvier*	0.3[h]	NR	11	NT			none	global	oceanic
Sandbar shark, *Carcharhinus plumbeus*	0.3[i]	NR	5	VU		U.S.A. (Atlantic)	none	global	coastal
Blacktip shark complex[j]	2.4 (1.1–4.6)			NT			2 (U.S.A., Australia)	regional	coastal
Spinner shark, *Carcharhinus brevipinna*	0.6 (0.3–1.2)			NT			One (Australia)	global	coastal
Java shark, *Carcharhinus amboinensis*	0.4 (0.1–0.8)			DD			1 (Australia)	regional	coastal
Spot-tail shark, *Carcharhinus sorrah*	0.3 (0.1–0.6)			NT			2 (Australia)	regional	coastal
Smoothhound sharks, *Mustelus* spp.	0.3 (0.1–0.6)						4 (U.S.A.)	regional	coastal
Sharpnose sharks, *Rhizoprionodon* spp.	0.1 (0.0–0.3)						1	regional	coastal
Milk shark, *Rhizoprionodon acutus*	0.3 (0.1–0.6)			LC			0	regional	coastal
Wedgefish, *Rhynchobatus* spp.	0.1 (0.0–0.2)			VU		India, Philippines (one species)	0	regional	coastal

Continued

Table 3. Continued.

Species or species group	2014 Mean % (95% CI)	Rank order 2014–2015	Rank order 1999–2000	IUCN category[a]	CITES Appendix[b]	Retention bans[c]	Number of sustainably managed fisheries[d]	Range	Habitat
Porbeagle[f] and Salmon sharks, *Lamna* spp.	0.1 (0.0–0.2)			VU/LC	II	ICCAT	0	global/regional	oceanic
Sicklefin Lemon shark, *Negaprion acutidens*	0.0 (0.0–0.1)			VU			0	regional	coastal
Plough-nose chimaeras, *Callorhinchus* spp.	0.0 (0.0–0.1)			LC			2 (Australia, New Zealand)	regional	coastal
Kitefin shark, *Dalatias licha*	0.0 (0.0–0.1)			NT			0	deep benthic	coastal
Australian sharpnose shark, *Rhizoprionodon taylori*	0.0 (0.0–0.1)			LC			0	regional	coastal

[a] *The International Union for Conservation of Nature Red List status.*
[b] *Convention on International Trade in Endangered Species Appendix.*
[c] *Regions with retention bans in regional fisheries management organizations or by individual nations.*
[d] *Number of sustainably managed fisheries documented for the species by Simpfendorfer and Dulvy (2017).*
[e] *Species listed on CITES in October 2017.*
[f] *Species listed on CITES in September 2014.*
[g] *Species combined in Clarke et al. (2006a).*
[h] *Includes* Carcharhinus altimus *within* C. plumbeus *and* C. galapagensis *within* C. obscurus *because these species cannot be differentiated with our methods.*
[i] *This is the nonmodeled percentage of 2014–2015 sample; it was too infrequent to add to our model.*
[j] *Includes* Carcharhinus limbatus, C. tilstoni, C. leiodon, *and* C. amblyrhynchoides.
NR, not reported in the model output.

position (Table 2) because the model estimated a typical species composition after accounting for random variation between vendors and sampling periods. This tended to increase the importance of species found in a higher fraction of samples and vendors relative to those that were found rarely.

Although three-quarters of the traded species live in coastal areas, >50% of the trade was from oceanic species (Figs. 1b & 1f). A small number of species comprised the majority of modeled fin trimmings (Fig. 2), particularly the blue shark (*Prionace glauca*) (33.9–64.1%) and silky shark (*Carcharhinus falciformis*) (2.1–8.7%). With 1 exception (sandbar shark [*Carcharhinus plumbeus*]), the 14 species identified in the HK trade approximately 15 years earlier were among the most common species in the modeled trimmings in 2014–2015 (Tables 2 & 3). We found these globally distributed, large-bodied species are now nearly all subject to management measures (Table 3), and that only 1 species of the 14 (the common thresher [*Alopias vulpinus*]) has a fishery that is managed sustainably anywhere (Simpfendorfer & Dulvy 2017). The taxa not previously reported in the market were primarily range-restricted coastal species and a small number of deep benthic taxa, most of which have relatively little management (Table 3). Several of these taxa support fisheries that are managed sustainably, but only in the United States, Australia, and New Zealand (Simpfendorfer & Dulvy 2017).

The Bayesian models for the fin trimmings we binned into 3 categories converged adequately (Supporting Information). The estimated species composition of the modeled trimmings was not generally sensitive to the sampled trimming size in that the estimated credible intervals overlapped for every species. The rank order of the most abundant large species was generally the same regardless of whether the modeled trimmings were small, medium, or large (Table 4). Nevertheless, there was a significant relationship between the size of the shark and the size of the sampled trimmings; small species (e.g., sharpnose [*Rhizoprionodon* spp.], smooth hounds [*Mustelus* spp.]) were more frequent in small trimmings ($\chi^2 = 12.4$, df $= 2$, $p = 0.002$) (Supporting Information). Trimmings from small species were not frequent in medium and large categories (Table 4), but a similar number of species and species groups were found in each size group (large, 27; medium, 31; small, 30), although the trajectory of the species richness curves varied (Supporting Information).

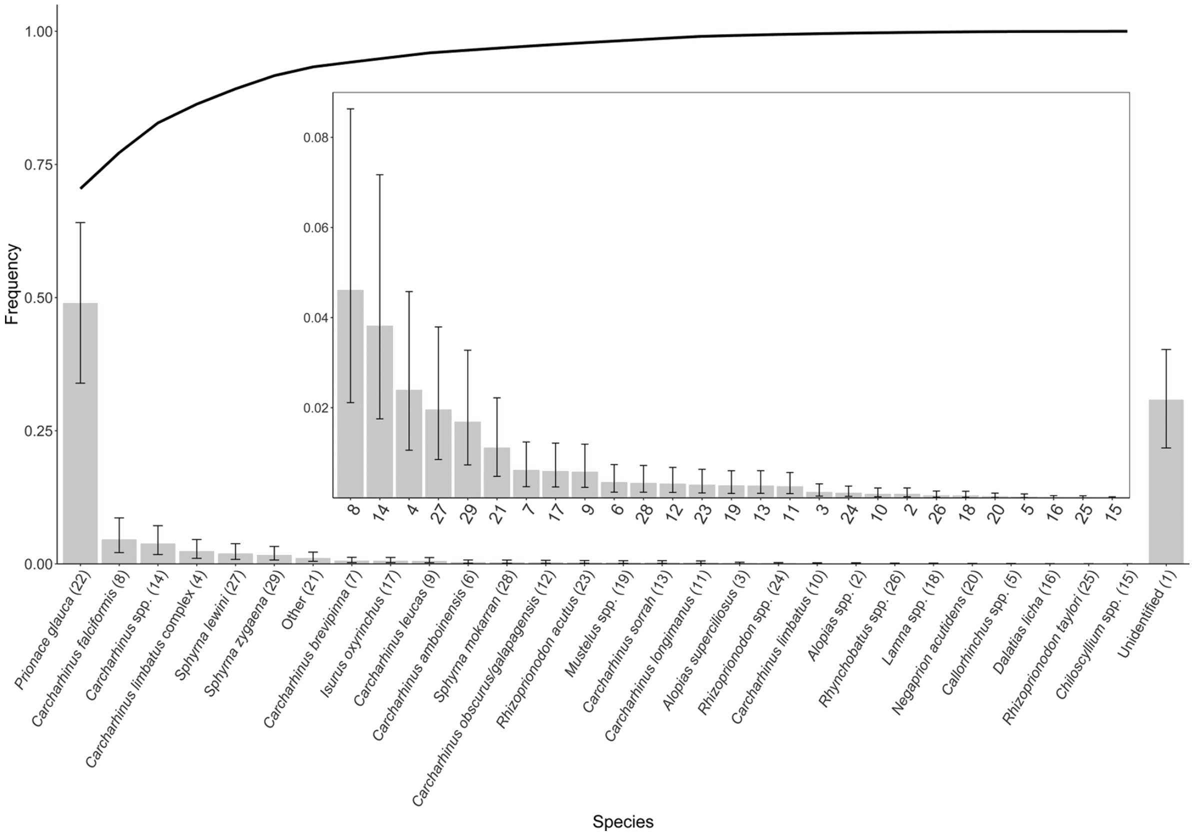

Figure 2. Estimated total contribution to fin trimmings of all species modeled and the cumulative curve of the mean of samples identified (unidentified, samples failed to amplify after repeated attempts; other species, all species or genera that make up <0.4% of the total sample; error bars, 95% CI; numbers in parentheses, species i *value from the model (Eq.* (1)*), which provides an association with the model output [Supporting Information]). The cumulative curve is based on the assumption that the unidentified portion was not identified because of degraded DNA and therefore the proportion from each species was recalculated after removing the unidentified category. The insert zooms in on the less common species that are differentiated by the* i *value from the model.*

Table 4. Mean estimated[a] contribution to fin trimmings in the Sheung Wan market and the rank order of those point estimates within a fin-trimming size.

	Rank order				*Contribution (%)*			
Species or group	*all*	*large*	*medium*	*small*	*all*	*large*	*medium*	*small*
Prionace glauca	1	1	1	1	35.07 (19.3–54)	47.87 (28.4–67.5)	36.69 (20.7–55.5)	27.3 (11.3–49.7)
Carcharhinus falciformis	2	2	2	3	5.43 (2.1–11.4)	4.45 (1.4–10.1)	7.53 (2.8–15.4)	4.75 (1.1–12.1)
Carcharhinus spp.	3	4	3	2	3.95 (1.5–8.4)	1.99 (0.6–4.9)	2.56 (0.8–5.9)	6.93 (1.9–16.4)
Sphyrna zygaena	4	5	4	5	2.41 (0.8–5.3)	1.8 (0.5–4.4)	2.55 (0.8–5.9)	2.91 (0.6–7.9)
C. limbatus, C. amblyrhynchoides, C. leiodon, C. tilstoni	5	3	7	7	2.06 (0.7–4.6)	2.25 (0.7–5.4)	1.12 (0.3–2.9)	1.69 (0.3–5)
Sphyrna lewini	6	6	5	4	1.83 (0.6–4.1)	1.29 (0.3–3.3)	1.77 (0.5–4.3)	3.49 (0.8–9.2)
Mustelus spp.	7	NR	8	6	0.87 (0.3–2.1)	–	0.68 (0.1–1.9)	1.93 (0.3–5.6)
Isurus oxyrinchus	8	7	NR	10	0.42 (0.1–1.1)	0.65 (0.1–1.8)	–	0.37 (0–1.4)
Dalatias licha	9	NR	9	NR	0.07 (0–0.2)	–	0.18 (0–0.7)	–
Carcharhinus sorrah	NR	NR	6	8	–	–	1.15 (0.3–2.9)	0.76 (0.1–2.6)
Rhizoprionodon spp.	NR	NR	NR	9	–	–	–	0.6 (0.1–2.1)
Unidentified	–	–	–	–	33.42 (23.1–44.1)	30.39 (18.7–43.7)	31.59 (21.2–43.2)	30.5 (18.8–44.5)
Other	–	–	–	–	14.48 (6.3–26.9)	9.3 (3.3–19.6)	14.18 (6.1–26.5)	18.77 (6.8–37.4)

[a] *Estimated with the Poisson multinomial applied to the counts of trimmings in each size category (95% CI is in parentheses).*
NR, not reported in the model output.

Discussion

Overall Species Diversity and Characteristics of the Contemporary Fin Trade

From the identified fin trimmings sampled, we estimated there were at least 76 species in the fin trade, indicating a high potential for species substitution (Eriksson & Clarke 2015). The trade focused on sharks, and the majority of identified species (80% of the species) were from just 2 of 8 orders (Carcharhiniformes and Lamniformes). Almost 50% of species were from 1 family (Carcharhinidae) (Fig. 1a). Although it is possible our primers failed to amplify some more distantly related species, trials show that they amplify species from at least 7 of the 8 extant orders of sharks (Fields et al. 2015). These primers also amplified the more distantly related batoids (at least 3 species) and chimaeras (at least 2 species) that are also present in the fin trade.

It is commonly assumed overexploitation could cause a collapse in the fin trade (Clarke 2014). Although fin value tends to increase with fin size (Vannuccini 1999), small-bodied sharks and chimaeras made up almost half of the species in the HK trade (48%). This indicates that consumers are willing to pay for diverse fin sizes and morphologies. This willingness could facilitate substitution if supplies of particular species decline and enable robust trade despite depletion of the most vulnerable groups (Eriksson & Clarke 2015). One-third of the species present in the HK trade were listed in threatened categories by IUCN.

Species Composition

Fin trimmings for a given species were not of uniform size, and small species were more abundant in small trimmings. This size and species composition suggests processers make a variable number of cuts per fin; thus, our Bayesian estimates of species composition of the trimmings is most likely to be proportional to the number of individual sharks in the trade or a combination of this and fin mass. Clarke et al.'s (2006*a*) survey of the Hong Kong fin trade in 1999–2001 produced an estimate of the partial species composition of the trade relative to the traded weight of each species in the HK market. The species-specific proportions we and Clarke et al. (2006*a*) estimated are not directly comparable, and our estimates should not be expressed as a direct proportion of a species in trade. Instead, our metrics represent an index of relative abundance. Comparisons of the rank order of species between the periods 1999–2001 and 2014–2015 are likely valid because both studies enabled an assessment of the relative importance of an overlapping suite of common species to the global fin trade that passes through HK.

Despite the high species diversity we found, our results suggest the contemporary fin trade is dominated by a small number of species. Only 8 species or complexes likely comprise >1% of the modeled trimmings each: blue, silky, blacktip complex, scalloped hammerhead, smooth hammerhead, shortfin mako, bull and spinner sharks. Their contributions ranged from 34.1–64.2% (blue) to 0.2–1.2% (bull and shortfin mako). Skewed species composition is concordant with fin exports from Indonesia, United Arab Emirates, and Taiwan, which are important suppliers of HK, albeit each with its own unique set of dominant species (Jabado et al. 2015; Sembiring et al. 2015; Chuang et al. 2016). It is also concordant with the 1999–2001 HK trade (Clarke et al. 2006*a*, 2006*b*). It is remarkable given the sustained harvest over the last 15 years that large hammerheads, dusky, threshers, and oceanic whitetip sharks all contributed substantially to both surveys in HK (i.e., 1999–2001 and 2014–2015), despite being globally or regionally listed as endangered or vulnerable for over a decade (IUCN 2016); there is evidence of large regional declines for at least some of them (Hayes et al. 2009; Walsh & Clarke 2011; Clarke et al. 2013; Grubbs et al. 2016). Many of these species have a global distribution, so it is possible that shifts in geographic sources of fins or expansion of fishing areas have enabled a relatively high-volume trade to continue (Eriksson & Clarke 2015). The exception was the sandbar shark, which was rarely encountered in the 2014–2015 trimmings sampled but common in auctioned fins in 1999–2001 (Table 2). Two fisheries supplying large volumes of sandbar shark existed along the Atlantic coast of the United States and the coast of Western Australia in 1999–2001, but they were subsequently subject to large reductions in catch limits in response to population declines (SEDAR 2010; McAuley & Rowland 2012). These declines and regulatory measures may explain the reduced abundance of this species in the contemporary HK fin trade.

The blue shark was the most abundant species in both surveys, consistent with very high landings of this species between 1999–2001 and 2014–2015 (Davidson et al. 2015; Eriksson & Clarke 2015). Clarke et al. (2006*b*) suggested global blue shark landings were at or close to maximum sustainable yield in 1999–2001, yet the global proportion of shark landings identified as blue shark and reported to the FAO nearly tripled from 2000 to 2013 (Davidson et al. 2015; Eriksson & Clarke 2015). Although this increase could in part reflect improvements in species-specific reporting over this period, it is also plausible that the market contribution of this productive species has increased (Davidson et al. 2015; Eriksson & Clarke 2015). Blue sharks are not currently classified as overfished, but the quality of the data used in assessments is generally poor, and none of the regional fisheries management organizations (RMFOs) have imposed catch limits for this species (Simpfendorfer & Dulvy 2017). Given the importance of this species in the fin trade, it is critical that RMFOs develop assessment-based catch limits that are closely monitored and enforced.

We identified additional species and species groups as relatively common in trade that were outside of the scope of Clarke et al.'s (2006*b*) 1999–2001 survey. We categorized most of them as oceanic; large or small coastal sharks; coastal batoids; or chimaeras. Except for the chimaeras and oceanic species, most are poorly studied and not managed for sustainability anywhere outside of the United States, Australia, or New Zealand (Table 3) (Simpfendorfer & Dulvy 2017). The oceanic species (porbeagle and salmon shark) are very different. The porbeagle is listed on CITES Appendix II and considered vulnerable to extinction, and the salmon shark is at low risk of extinction but is largely unmanaged in much of its North Pacific distribution (Stevens et al. 2006; Goldman et al. 2009). The relatively commonly traded, large coastal (including the blacktip shark species complex, spinner, Java, and sicklefin lemon), and small coastal sharks (spot-tail, sharpnoses, and smoothhounds) often have restricted ranges (Musick et al. 2004) and highly structured populations that make them vulnerable to localized overexploitation and possibly regional extirpation due to limited immigration (Chapman et al. 2015). Many of the small species are relatively productive (Cortés 2016) and generally considered of least concern (IUCN 2016). A few of the large and small coastal species support sustainably managed fisheries (Simpfendorfer & Dulvy 2017), and more potentially could, given their productivity, if basic investments in fisheries management were made. The coastal chimaeras tend to support sustainably managed fisheries (Didier et al. 2012; IUCN 2016), whereas the coastal batoids in trade primarily originate from Rhinidae (wedgefishes), which are listed as at high risk of extinction (IUCN 2016). Overall, the near absence of sustainably managed fisheries for many of the coastal sharks and batoids highlights the need for a new focus on domestic coastal fisheries management in many of the nations that supply fins to HK and more stringent protection and trade regulation for some highly vulnerable species (e.g., wedgefish).

Future Monitoring

Our results indicate species-aggregated data from the fin trade kept by HK and FAO potentially mask key species-specific trends that urgently need monitoring. The majority of species in trade are not as yet known to support sustainably managed fisheries outside the developed world, and around one-third of the species we identified are at serious risk of extinction (IUCN 2016). We suggest monitoring fin trimmings in HK over time would reveal trends in the relative abundance of species in trade. This could enable robust testing of the hypothesis that the contribution of more productive species (e.g., blue) is increasing and obscuring declines in other species. Continued monitoring could also enable an assessment of the effect of new species-specific management measures, including CITES listings and RMFO zero-retention policies, on the trade of threatened chondrichthian species.

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Supporting Information

Additional methods (Appendix S1), images of fin trimming and rarefaction curves (Appendix S2), and additional tables reporting model parameters and the contingency table (Appendix S3) are available as part of the on-line article. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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