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Bright spots of sustainable shark fishing

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Sharks, rays and chimeras (class Chondrichthyes; herein ‘sharks’) today face possibly the largest crisis of their 420 million year history. Tens of millions of sharks are caught and traded internationally each year, many populations are overfished to the point where global catch peaked in 2003, and a quarter of species have an elevated risk of extinction [1–3]. To some, the solution is to simply stop taking them from our oceans, or prohibit carriage, sale or trade in shark fins [4]. Approaches such as bans and alternative livelihoods for fishers (e.g. ecotourism) may play some role in controlling fishing mortality but will not solve this crisis because sharks are mostly taken as incidental catch and play an important role in food security [5–7]. Here, we show that moving to sustainable fishing is a feasible solution. In fact, approximately 9% of the current global catch of sharks, from at least 33 species with a wide range of life histories, is biologically sustainable, although not necessarily sufficiently managed.

Stock assessments were available for a total of 65 populations (Supplemental information). A subset of 39 populations (of 33 species) met criteria for biological sustainability, including 27 (of 22) sharks, nine (of nine) rays, and three (of two) chimeras, representing a very small fraction (~2.6%) of global shark diversity (*n* = 1,188). Of the populations that met biological sustainability criteria, eight populations of five species did not have science-based management plans. Stocks that met some or all of the sustainability criteria mostly occur in the Exclusive Economic Zones (EEZs) of developed countries that have well-developed fisheries management systems (e.g. USA, Australia, New Zealand and Canada; Figure 1). However, there are some developed nations with good fisheries management capacity (e.g. European Union) that have not yet translated this into sustainable outcomes for shark populations.

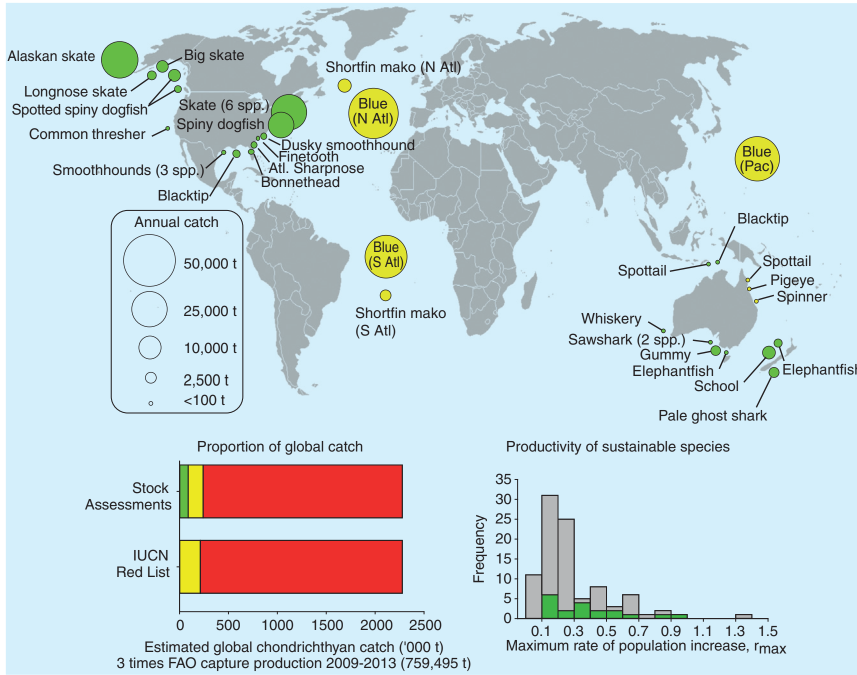

Figure 1. Location and magnitude of sustainable shark, ray and chimaera catches.
Top panel: Location of sustainable and managed (green circles) and sustainable but not managed (yellow circles) shark, ray and chimera populations. Populations assessed as unsustainable or lacking evidence of sustainability (Supplemental information) are not shown. Sustainability is defined as current biomass being greater than that required to achieve Maximum Sustainable Yield ($B_{current} > B_{MSY}$), or current fishing mortality being less than that which will yield MSY ($F_{current} < F_{MSY}$) if current biomass is not available. Managed stocks were those with a science-based management plan in place. Bottom left panel: Proportion of estimated global catch that is sustainable and managed (green), sustainable but not managed (yellow) and lacking evidence for sustainability (red) based on stock assessments and assuming species IUCN-listed as Least Concern and Near Threatened are sustainable but not managed. Bottom right panel: Maximum rate of population increase (r_{max}) of 19 sustainably fished species (green) compared to all other available estimates (*n* = 75; grey).

The total annual landed catch of the biologically sustainable populations was approximately 204,945 tonnes live weight, approximately 27.0% of the average annual catch of sharks, rays and chimeras reported to the United Nations Food and Agriculture Organization (FAO) over the past five years (2009–2013) of 759,495 tonnes [7]. However, this figure drops to 12.0% (91,460 t) for populations that are both biologically sustainable and have a science-based management plan in place. FAO capture production statistics underestimate true global take of sharks by a factor of 3 or 4 [1]; hence the proportion of biologically sustainable take is closer to 9 %, and 4% of global shark catch is managed for sustainability (Figure 1).

An alternative method of estimating the current annual catch of sharks that is biologically sustainable is to sum the FAO capture production figures for species that are categorized as ‘Least Concern’ or ‘Near Threatened’ on the IUCN Red List of Threatened Species. Assuming these species meet the biological sustainability criterion, the average FAO capture production over the last five years of Least Concern and Near Threatened species was 212,691 t (~28% of FAO capture production; Figure 1). Again rescaling to account for underreporting of FAO capture production, this figure reduces to ~7% of total shark catch, similar to the results of stock assessments.

The prevalent view has been that only the most productive species with fast life histories can be managed sustainably [4]. We found that some species with relatively low productivity — with the most common

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r_{max} values between 0.1 and 0.2 — can support sustainable fisheries (Figure 1). No species with a maximum rate of population increase (r_{max}< 0.1) were identified as sustainable and species capable of achieving sustainability were proportionally more common at r_{max}> 0.3. These data suggest that with strong science-based management, most shark species have the potential to support sustainable fisheries.

We highlight five lessons that can help progress sustainability across shark fisheries: first, protect those species with the lowest biological productivity. Sustainable outcomes have been achieved only for species with r_{max} > 0.1. Species with very low r_{max} include some deep water species (e.g. gulper sharks) and species with very small litter sizes (e.g. Cownose Ray, Bigeye Thresher Shark) [8].

Second, tuna Regional Fisheries Management Organizations (tRFMOs) should implement precautionary science-based catch limits on the more biologically sustainable high-seas sharks. Some of the largest shark catches come under the remit of tRFMOs. While tRFMOs conduct stock assessments and have some shark-specific rules, they have yet to implement catch limits for blue shark (Atlantic and Pacific Oceans) and shortfin mako shark (Atlantic Ocean) despite repeated scientific advice that catch levels should be capped.

Third, international treaties can contribute to sustainable international fisheries and trade and prompt fisheries management improvements. The Convention on Migratory Species and Convention on International Trade in Endangered Species (CITES) are increasingly being seen as possible drivers of improved shark management [9]. For example, the listing of commercially important shark species on CITES in 2013 and 2016 requires that nations demonstrate that products in international trade do not threaten the survival of the species in the wild. This has required many countries (and tRFMOs) to undertake sustainability assessments (i.e. produce Non-Detriment Findings) and develop product identification and traceability systems that all contribute to improved outcomes for these species.

Fourth, developed countries have a responsibility to support the transition to sustainability in developing countries. Many developed countries import, consume or re-export shark products [6]. Hence, as developed nations bring their fisheries into sustainability and import more fish, they should translate their successes into lessons and capacity building for other nations to ensure that they are able to move towards sustainability.

Finally, responsible, traceable shark fisheries can provide consumers with the ability to choose and purchase sustainable seafood. Traceability has repeatedly and reliably driven sustainability across numerous natural resource supply chains [10]. All products from sustainably caught sharks and rays could be sold as sustainable, including shark fins. At present, the notion of sustainable shark fins is unthinkable to many. Yet, today's sustainable (but not necessarily managed) shark fisheries yield about 4,406 t of dried fins (Supplemental information). This suggests that approximately 8.7% of the fins in the global fin trade are from sustainable sources, but not yet traceable or labeled. Without labeling fins from sustainable sources cannot yet command the price premium that would in-turn feedback to drive sustainability back through supply chains.

Achieving sustainable outcomes for most or all shark populations will require tailored diagnosis and management depending on species and context, rather than simplified solutions such as outright bans. The successes demonstrated here provide a template to guide the expansion of fisheries sustainability. The benefits of such change, for both biodiversity conservation and human food security, argue for tackling the challenge without further delay.

SUPPLEMENTAL INFORMATION

Supplemental Information including experimental procedures and two tables can be found with this article online at http://dx.doi.org/10.1016/j.cub.2016.12.017.

AUTHOR CONTRIBUTIONS

C.A.S. and N.K.D. devised the study, gathered data and wrote the paper.

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Supplemental Information

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Supplemental Experimental Procedures

Sustainable sources of sharks, rays and chimeras

To identify species and stocks that were sustainable, stock assessments were sourced from the scientific literature, government agencies, known experts, and internet searches. Definitions of “sustainable” with respect to natural resources vary considerably. Probably the most widely used in fisheries is that of the Brundtland Commission: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [S1]. Hilborn et al. [S2] provided an overview of issues around definitions of sustainability for fisheries. Their conclusion was that sustainability is about both the (a) state of the biological system (be it a single stock or the whole ecosystem) and (b) a management process by which sustainability objectives can be achieved and maintained in a changing system. This concept of sustainability for sharks is not new and the biological basis for it has been previously explored [S3]. To meet the criteria for biologically sustainable the stock assessment had to demonstrate that the current biomass was greater than that required to achieve Maximum Sustainable Yield (MSY) ($B_{current} > B_{MSY}$). For species where biomass data was not available, sustainability was indicated by the current level of fishing mortality being less than the level required to yield MSY ($F_{current} < F_{MSY}$). Where stock assessments showed that take was biologically sustainable the mean catch for the most recent five years was calculated. To meet the criteria for having a science-based management plan in place there had to be a publicly available plan that described a mechanism to adjust fishing mortality to ensure sustainable take based on scientific evidence (e.g. a harvest strategy, quota setting mechanism), regular assessments of the population against sustainability criteria, and some form of enforcement to ensure compliance with management measures.

Population increase rates of sustainable sharks and rays

Productivity was measured as the maximum rate of population increase (r_{max}) for 94 species of sharks and rays [S4]. Sustainable species were identified based on data in Table S1 that met the biological criteria.

Proportion of global shark catch that is sustainable

Catches of species that were assessed as biologically sustainable, and biologically sustainable and with science-based management, were summed to provide totals for each category. The FAO capture production of sharks, rays and chimeras for the most recently available five years, from 2009-2013, was sourced from the FAO website (http://www.fao.org/fishery/topic/16140/en). Since shark data reported to FAO underestimates global catch by a factor 3-4 [S5] we multiplied the FAO capture production figure by 3 to provide an estimate of global catch.

Estimate of current weight of sustainable shark fin.

The live weight of sharks that produce fins suitable for use in the shark fin trade was calculated from the mean of the most recent 5-year catches provided in Table S1. A wide range of live weight to wet fin weight are used [S6], so we used a conversion factor of 5% which represents a mid-range value. This was then converted to dry fin weight using a conversion factor of 0.43 [S6]. The average annual volume imported of shark fins was 16, 815 tonnes as reported in official FAO statistics between 2011 and 2014 [S7] and if this is corrected by a factor of 3 for under-reporting [S5] total fin trade volume for the period was 50,445 tonnes.

Author Contributions

Conceptualization, C.S and N.D.; Methodology, C.S. and N.D.; Investigation, C.S. and N.D.; Writing – Original Draft, C.S. and N.D.; Writing – Review & Editing, C.S. and N.D.; Funding Acquisition, C.S. and N.D.; Resources, C.S. and N.D.; Supervision, C.S. and N.D.

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Table S1. Status of shark, ray and chimeran populations. Stock assessment results were taken from published and unpublished (but publically available) sources.

Common Name	Scientific name	Location	Overfished ($B<B_{MSY}$)	Overfishing ($F>F_{MSY}$)	Management mechanism	Mean catch last 5 yr (t)[1]	Source
Biologically sustainable, management process							
Alaska Skate	*Bathyraja parmifera*	Bering Sea and Aleutian Islands	N	N	Y	27,698	[S8]
Atlantic Sharpnose Shark	*Rhizoprionodon terraenovae*	NW Atlantic & Gulf of Mexico	N	N	Y	1,855	[S9]
Australian Blacktip Shark	*Carcharhinus tilstoni*	N Australia	N	N	Y	56	[S10, S11]
Barndoor Skate	*Dipturus laevis*	NE USA	N	N	Y	26,932[2]	[S12, S13];
Big Skate	*Beringraja binoculata*	Gulf of Alaska	?	N	Y	2,919	[S14]
Blacktip Shark	*Carcharhinus limbatus*	Gulf of Mexico	N	N	Y	989	[S15]
Bonnethead Shark	*Sphyrna tiburo*	NW Atlantic & Gulf of Mexico	N	N	Y	507	[S16]
Clearnose Skate	*Raja eglanteria*	NE USA	N	N	Y	26,932[2]	[S12, S13];
Common Thresher Shark	*Alopias vulpinus*	NE Pacific	N	N	Y	165	[S17]
Dusky smoothhound	*Mustelus canis*	NW Atlantic	N	N	Y	1,559	[S18]
Elephantfish	*Callorhinchus milli*	SE Australia	N	N	Y	83	[S19]
Elephantfish	*Callorhinchus milli*	New Zealand	N	N	Y	1,391	[S20]
Finetooth Shark	*Carcharhinus isodon*	NW Atlantic	N	N	Y	?[3]	[S21]
Gummy Shark	*Mustelus antarcticus*	S Australia	N	N	Y	1,922	[S22]
Little Skate	*Leucoraja erinacea*	NE USA	N	N	Y	26,932[2]	[S12, S13]
Longnose skate	*Raja rhina*	Gulf of Alaska	?	N	Y	1,721	[S14]
Pale Ghost Shark	*Hydrolagus bemisi*	New Zealand	N	N	Y	2,094	[S20]

Rosette Skate	*Leucoraja garmani*	NE USA	N	N	Y	26,932[2]	[S12, S13]
Sawshark	*Pristiophorus* spp.	SE Australia	N	N	Y	248	[S19]
School Shark	*Galeorhinus galeus*	New Zealand	N	?	Y	3,331	[S20]
Smoothhounds	*Mustelus* spp.	Gulf of Mexico	N	N	Y	?[3]	[S18]
Smooth Skate	*Malacoraja senta*	NE USA	N	N	Y	26,932[2]	[S12, S13];
Spottail Shark	*Carcharhinus sorrah*	N Australia	N	N	Y	55	[S10, S11]
Spiny Dogfish	*Squalus acanthias*	NW Atlantic	N	N	Y	13,778	[S23, S24];
Spotted Spiny Dogfish	*Squalus suckleyi*	British Columbia	N	N	Y	1,000	[S25, S26]
Spotted Spiny Dogfish	*Squalus suckleyi*	Gulf of Alaska	?	N	Y	3,038	[S27]
Whiskery Shark	*Furgaleus macki*	Western Australia	N	N	Y	119	[S28]
Winter Skate	*Leucoraja ocellata*	NE USA	N	N	Y	26,932[2]	[S12, S13]
Biologically sustainable, insufficient management							
Blue Shark	*Prionace glauca*	N Atlantic	N	N	N	37,333	[S29]
Blue Shark	*Prionace glauca*	S Atlantic	N	N	N	28,923	[S29]
Blue Shark	*Prionace glauca*	N Pacific	N	N	N	41,000	[S30]
Pigeye Shark	*Carcharhinus amboinensis*	Queensland	?	N	N	?[3]	[S31]
Shortfin Mako	*Isurus oxyrinchus*	N Atlantic	N	N	N	3,762	[S32]
Shortfin Mako	*Isurus oxyrinchus*	S Atlantic	N	N	N	2,467	[S32]
Spinner Shark	*Carcharhinus brevipinna*	Queensland	?	N	N	?[3]	[S31]
Spottail Shark	*Carcharhinus sorrah*	Queensland	?	N	N	?[3]	[S31]
Rebuilding (not sustainable, but fishing mortality $<F_{MSY}$)							
Dusky Shark	*Carcharhinus obscurus*	Western Australia	Y	N	Y		[S33]
Porbeagle	*Lamna nasus*	NW Atlantic	Y	N	Y		[S34, S35]
Sandbar Shark	*Carcharhinus plumbeus*	Western Australia	Y	N	Y		[S36]
Sandbar Shark	*Carcharhinus plumbeus*	NW Atlantic	Y	N	Y		[S37]

Spiny Dogfish	*Squalus acanthias*	NE Atlantic	Y	N	Y	[S38]
No evidence of sustainability						
Austalian Blacktip Shark	*Carcharhinus tilstoni*	Queensland	?	Y	N	[S31]
Blacknose Shark	*Carcharhinus acronotus*	NW Atlantic	Y	Y	Y	[S39]
Blacktip Shark	*Carcharhinus limbatus*	NW Atlantic	?	?	Y	[S40]
Blacktip Shark	*Carcharhinus limbatus*	India	Y	Y	N	
Dark Ghost Shark	*Hydrolagus novaezealandiae*	New Zealand	?	?	Y	[S20]
Dusky Shark	*Carcharhinus obscurus*	NW Atlantic	Y	Y	Y	[S41]
Kitefin Shark	*Dalatias licha*	Azores	Y	?	N	[S38]
Rig	*Mustelus lenticulatus*	New Zealand	?	?	Y	[S20]
Oceanic Whitetip Shark	*Carcharhinus longimanus*	W Pacific	Y	Y	Y	[S42]
Rough Skate	*Zearaja nasuta*	New Zealand	?	?	Y	[S20]
Scalloped Hammerhead	*Sphyrna lewini*	NW Atlantic	Y	Y	Y	[S43]
School Shark	*Galeorhinus galeus*	SE Australia	Y	?	Y	[S44]
Silky Shark	*Carcharhinus falciformis*	E Pacific	?	?	N	[S45]
Silky Shark	*Carcharhinus falciformis*	W Pacific	Y	Y	Y	[S46]
Shortfin Mako	*Isurus oxyrinchus*	Taiwan	Y	Y	N	[S47]
Smooth Hammerhead	*Sphyrna zygaena*	New Zealand	?	?	Y	[S48]
Smooth Skate	*Dipturus innominata*	New Zealand	?	?	Y	[S20]
Smooth Skate	*Malacoraja senta*	Atlantic Canada	Y	?	Y	[S49]
Spiny Dogfish	*Squalus acanthias*	New Zealand	?	?	Y	[S20]
Thorny Skate	*Amblyraja radiata*	N Atlantic	?	?	Y	[S50]
Thorny Skate	*Amblyraja radiata*	NE USA	Y	N	Y	[S12, S13]

[1] Catches were the mean of the most recent 5 years of available data

[2] Catch is for a suite of species for which individual catches are unavailable; however catches are dominated by Winter and Little skates. Indicated catch is counted only once in overall total of sustainable catches

[3] Assessments completed in numbers of individuals not weights. As such total sustainable take will be under-estimated by summing all of the sustainable catches.

Table S2. Shark, ray and chimera species listed by the IUCN Red List of Threatened Species as Least Concern or Near Threatened that are listed as captured in FAO capture production statistics. Note that recent and upcoming changes in the taxonomy, especially of the rays, are not be reflected in FAO's list of scientific names. The abbreviation "nei" refers to not elsewhere identified.

Scientific name	FAO Common name
Bathyraja brachyurops	Broadnose skate
Bathyraja eatonii	Eaton's skate
Bathyraja irrasa	Kerguelen sandpaper skate
Bathyraja maccaini	McCain's skate
Bathyraja macloviana	Patagonian skate
Bathyraja murrayi	Murray's skate
Bathyraja spp	Bathyraja rays nei
Callorhinchus callorynchus	Plownose chimaera
Callorhinchus capensis	Cape elephantfish
Callorhinchus milii	Ghost shark
Carcharhinus acronotus	Blacknose shark
Carcharhinus brachyurus	Copper shark
Carcharhinus brevipinna	Spinner shark
Carcharhinus dussumieri	Whitecheek shark
Carcharhinus falciformis	Silky shark
Carcharhinus isodon	Finetooth shark
Carcharhinus leucas	Bull shark
Carcharhinus limbatus	Blacktip shark
Carcharhinus sorrah	Spot-tail shark
Centrophorus squamosus	Leafscale gulper shark
Centroscyllium fabricii	Black dogfish
Centroscymnus coelolepis	Portuguese dogfish
Centroscymnus crepidater	Longnose velvet dogfish
Centroscymnus owstoni	Roughskin dogfish
Cephaloscyllium isabellum	Draughtsboard shark
Chimaera monstrosa	Rabbit fish
Chimaera phantasma	Silver chimaera
Dalatias licha	Kitefin shark
Dasyatis akajei	Whip stingray
Dasyatis americana	Southern stingray
Dasyatis longa	Longtail stingray
Dasyatis violacea	Pelagic stingray
Deania calcea	Birdbeak dogfish
Deania profundorum	Arrowhead dogfish
Dipturus chilensis	Yellownose skate
Dipturus innominatus	New Zealand smooth skate
Etmopterus princeps	Great lanternshark
Etmopterus spinax	Velvet belly
Etmopterus spp	Lanternsharks nei
Galeocerdo cuvier	Tiger shark
Galeus melastomus	Blackmouth catshark

Galeus murinus	Mouse catshark
Gollum attenuatus	Slender smooth-hound
Gymnura altavela	Spiny butterfly ray
Gymnura marmorata	California butterfly ray
Hemitriakis japanica	Japanese topeshark
Heptranchias perlo	Sharpnose sevengill shark
Hexanchus griseus	Bluntnose sixgill shark
Himantura gerrardi	Sharpnose stingray
Hydrolagus colliei	Spotted ratfish
Hydrolagus novaezealandiae	Dark ghost shark
Hydrolagus spp	Ratfishes nei
Isurus oxyrinchus	Shortfin mako
Leptocharias smithii	Barbeled houndshark
Mustelus antarcticus	Gummy shark
Mustelus asterias	Starry smooth-hound
Mustelus canis	Dusky smooth-hound
Mustelus henlei	Brown smooth-hound
Mustelus lenticulatus	Spotted estuary smooth-hound
Mustelus spp	Smooth-hounds nei
Myliobatis aquila	Common eagle ray
Negaprion brevirostris	Lemon shark
Oxynotus paradoxus	Sailfin roughshark
Prionace glauca	Blue shark
Pristiophorus spp	Sawsharks nei
Pseudocarcharias kamoharai	Crocodile shark
Raja alba	White skate
Raja asterias	Mediterranean starry ray
Raja batis	Blue skate
Raja brachyura	Blonde ray
Raja castelnaui	Spotback skate
Raja circularis	Sandy ray
Raja clavata	Thornback ray
Raja cyclophora	Eyespot skate
Raja erinacea	Little skate
Raja fullonica	Shagreen ray
Raja fyllae	Round ray
Raja georgiana	Antarctic starry skate
Raja hyperborea	Arctic skate
Raja lintea	Sailray
Raja microocellata	Small-eyed ray
Raja miraletus	Brown ray
Raja montagui	Spotted ray
Raja naevus	Cuckoo ray
Raja nidarosiensis	Norwegian skate
Raja oxyrinchus	Longnosed skate
Raja radiata	Starry ray

Raja spp	Raja rays nei
Raja taaf	Whiteleg skate
Raja undulata	Undulate ray
Rhinobatos cemiculus	Blackchin guitarfish
Rhinobatos percellens	Chola guitarfish
Rhinobatos planiceps	Pacific guitarfish
Rhinobatos rhinobatos	Common guitarfish
Rhinochimaera atlantica	Straightnose rabbitfish
Rhinoptera bonasus	Cownose ray
Rhinoptera marginata	Lusitanian cownose ray
Rhizoprionodon acutus	Milk shark
Rhizoprionodon terraenovae	Atlantic sharpnose shark
Rhynchobatus australiae	Whitespotted wedgefish
Rioraja agassizi	Rio skate
Scyliorhinus canicula	Small-spotted catshark
Scyliorhinus spp	Catsharks, nursehounds nei
Scyliorhinus stellaris	Nursehound
Scymnodon ringens	Knifetooth dogfish
Somniosus microcephalus	Greenland shark
Somniosus rostratus	Little sleeper shark
Sphyrna tiburo	Bonnethead
Squalus blainville	Longnose spurdog
Squatina californica	Pacific angelshark
Sympterygia acuta	Bignose fanskate
Torpedo spp	Torpedo rays
Triakis megalopterus	Sharptooth houndshark
Zearaja nasuta	New Zealand rough skate